



Climate change in Viet Nam, impacts and adaptation: a COP26 assessment report of the GEMMES Viet Nam project

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Climate change in Viet Nam Impacts and adaptation

A COP26 assessment report
of the GEMMES Viet Nam project

PREFACE

On the occasion of COP26, this report is proposing an assessment of the socio-economic impacts of climate change in Viet Nam by 2050, based on the intermediary results of the GEMMES Viet Nam research project. MONRE and AFD have undertaken this ambitious collaboration around the GEMMES Viet Nam project with the general objective to support Viet Nam in the implementation of the Paris Climate Agreement. Financed by the Facility 2050, in collaboration with IRD and IMHEN, this report materializes our common wish to develop a long-term vision of the economic, social and territorial issues of a resilient development strategy for Viet Nam.

The work presented in this report is also the result of an exceptional scientific cooperation, involving a large team of Vietnamese, French and international researchers and experts. From downscaled climate scenarios to final macroeconomic damages, all the way through diverse sectoral impact assessments, it offers a unique prospective exercise on the climate challenges for Viet Nam by 2050. In this way, it assesses how global warming levels of 1.5°C or 2°C and even more, compared to the pre-industrial period, translate to the Vietnamese society and economy.

As Viet Nam is often presented as one of the countries that are most vulnerable to climate change, this report confirms the difficulties ahead for Viet Nam in terms of potential impacts and the need for adaptation. At the same time, it also emphasizes some crucial adaptation leverages in adjusting local development strategies as well as some opportunities arising from local adaptation dynamics. It also integrates this analysis within an original empirical macro-financial stock-flow coherent model of the Vietnamese economy.

Climate change often produces discordances in the ways we understand our place in nature. Scientific assessments such as those of the Intergovernmental Panel on Climate Change are certainly helpful in establishing climate change as a global phenomenon, but sometimes struggle in giving meaningful insights to national stakeholders. This report contributes to break through this detachment of knowledge from meaning by putting scientific results directly at the politically meaningful level. In that way, it will certainly nourish in the months ahead further policy-relevant scientific debates on how best to adapt to climate impacts and more local anthropic disturbances, both in Viet Nam and France.

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SUMMARY
TÓM TẮT
RÉSUMÉ

SUMMARY

Viet Nam is often presented as one of the countries that are most vulnerable to climate change

1] Annual temperatures increased over the whole country with the nationwide average increase of 0.89°C between 1958 and 2018 (~0.15°C/decade). The highest increase was experienced in the last decade. Over the same period, the annual rainfall slightly increased by 5.5% on average, but with contrasting trends depending on regions. In addition, sea level is rising, with an average trend of 3.6 mm/year over 1993–2018.

2] Future climate change depends on the collective capacity of nations to radically reduce their respective greenhouse gases (GHG) emissions, in line with the Paris Agreement.

- In Viet Nam, the average temperature increase projected in the middle of the XX^{1st} century (compared to 1986–2005) is $1.13 \pm 0.87^\circ\text{C}$ under a scenario of strong reduction of global emissions, in agreement with the Paris Agreement (RCP2.6). If strong GHG emissions continue (scenario RCP8.5), the increase could reach $1.9 \pm 0.81^\circ\text{C}$. Temperature projections by the end of the century highly depend on the GHG scenario, with an increase limited to $1.34 \pm 1.14^\circ\text{C}$ under RCP2.6 but as high as $4.18 \pm 1.57^\circ\text{C}$ under RCP8.5.
- In any scenario, temperature is expected to increase faster in the North of Viet Nam than in the South, while annual rainfall is projected to increase in most parts of the country, but with a different seasonal distribution.
- Projections of the likely average sea level rise along the Viet Nam's coastlines range from 0.13 m to 0.36 m by mid-century and from 0.27 m to 1.03 m by the end of the century, depending on the GHG scenario. It is worth noting that, due to large uncertainties in the future behavior of polar ice sheets, higher values cannot be ruled out.

3] Another way to see this is to project the changes of temperature, rainfall, and several extreme events in Viet Nam with global warming levels ranging from 1.5°C, 2°C, 3°C and up to 4°C compared to the pre-industrial period (1850–1900). However, when using climate change scenarios for the purpose of an impact assessment, it is essential to consider and analyze carefully the uncertainty range associated with these future climates.

Uncertainties regarding future climate change impacts are often increased by local anthropogenic drivers of change

4] The Vietnamese Mekong Delta (VMD) is for example subject to a combination of drivers of change, of which anthropogenic drivers — namely hydropower dams, sand mining and groundwater extractions — pose the greatest threats in this first half of the century, while climate change will probably to dominate in the second half of the century.

- Indeed the VMD has an extremely low-lying delta plain, with an average elevation of ~80 cm. Therefore, it is extremely vulnerable to even small changes in relative sea level, which arise from the cumulative effect of global sea level change and local vertical land movements (e.g. land subsidence). The VMD currently faces high levels of land subsidence, up to 5 cm/year in some places, mainly driven by groundwater extractions (currently $\sim 2.5 \cdot 10^6$ m³/day, with an annual increase of 4%/year). Should the rate of extraction remain at present-day level, the cumulative subsidence combined with sea level rise could cause the majority of the delta to fall below sea level by the end of this century.
- In addition, sediment starvation from upstream dams and excessive sand mining, has led to important incision rates of the riverbed levels over the past 20 years (10–20 cm/year), driving tidal amplification and thus increasing saline water intrusions. Anthropogenic riverbed level incision will remain the main driver of salinization of the delta up to 2050.

5] Hence, the VMD is already under pressure, which leaves a limited window of opportunity for adaptation, since climate change effects will then most probably dominate the threats in the second half of the century. Reducing sand mining and groundwater extractions appear as important mitigation measures to reduce subsidence and saline water intrusions and reduce the threats to the livelihoods and the agricultural and aquacultural sectors in the delta.

6] Furthermore, the Delta is strongly influenced by the water governance of the whole Mekong basin, or the lack thereof, with a scattered institutional architecture that still needs to be fully aligned with the mitigation and adaptation objectives of the Paris Agreement, while acknowledging the full scope of local anthropogenic environmental dynamics.

7] In that respect, the Basin Development Strategy 2021–2030 of the Mekong River Commission recently called for “proactive regional planning”, which could play an integrative role, via joint mitigation investment projects and adaptation measures between countries, actors, and sectors under the general principle that water is a basic need and right of every Mekong inhabitant.

Projected macroeconomic impacts of climate change plead for scaling-up adaptation finance while mainstreaming climate change within development planning

8] Climate change could give rise to significant impacts on a variety of sectors as different as health (mortality increase, higher incidence of infectious diseases), agriculture, energy, total factor productivity or labour productivity. Putting aside the multiple socio-economic non-linearities that could arise in the face of a changing climate, the cumulative direct economic impact on these sectors represents an average of 1.8% of annual GDP losses in the case of a temperature increase of 1°C relative to the pre-industrial period 1851–1900. This loss becomes 4.5% for a 1.5°C increase, 6.7% for a 2°C increase, and up to 10.8% for a 3°C increase.

- The cross-sectoral and macroeconomic effects of these sectoral impacts by 2050 lead to average losses which are larger than direct damages by around 30%.
- In addition, the annual GDP losses due to typhoons in the period 1993–2013 is 2.4%. If uncertainties remain about the future impacts of typhoons combined with climate change scenarios, this figure should remain a floor value.
- Finally, evidence is given that climate change through international damage spillovers is expected to reduce Viet Nam's long-term growth rate over the next decades and should be investigated carefully.

9] Despite significant effort in responding to climate change has been made in the last 10 years, the lack of technical and financial resources for adaptation, the need for capacity-building actions at the local level, the necessary focus on the structural drivers of vulnerability as well as the integration of climate change into a holistic institutional scheme remain crucial challenges. In the short run, adaptation policies would require development in at least three directions:

- Strengthening data gathering and availability. Weather forecasts and early warning systems, and raising awareness on adaptation is still needed to improve preventive and proactive actions. The availability of good statistical data is also crucial to understand the role of climate finance. To date, there is a lack of operational tools and comprehensive systems to consistently monitor and assess adaptation finance. Therefore, measuring the effectiveness of adaptation policies and the impact of adaptation finance is not always straightforward. In addition, the lack of consistency in reporting systems, and of a clear definition of adaptation finance makes it difficult to assess whether funding for a development project contributes to adaptation, and to assess the immaterial resources mobilised for adaptation, especially at the community level.
- Encouraging local resilience. The ability of local actors to mobilize various resources to restore and implement everyday pragmatic adjustments, and to develop multiple options (e.g. multiple sources of income) to cope with shocks, reveals a high degree of flexibility at the local level that can foster adaptive capacity and reinforce resilience. It could be favored through specific stakeholder engagement policies.
- Mainstreaming adaptation into development planning. However, while these actions are efficient in the short-term and should be supported, they are not sufficient to face and absorb the potential impacts of climate change in the long term. They need to be accompanied by forms of external support that encourage more planned adaptation strategies, and should be integrated into the broader master plans (Master plan 2021–2030 and vision to 2050).

TÓM TẮT

Việt Nam thường được xem như là một trong các quốc gia dễ bị tổn thương nhất do Biến đổi Khí hậu

1] Nhiệt độ trung bình năm đã tăng trên toàn Việt Nam với mức tăng trung bình khoảng $0,89^{\circ}\text{C}$ cho thời kỳ từ 1958 đến 2018 ($\sim 0,15^{\circ}\text{C}$ /thập kỷ). Thập kỷ vừa qua chứng kiến mức tăng cao nhất. Trong cùng thời kỳ, lượng mưa năm tăng nhẹ với mức tăng trung bình khoảng 5,5%, tuy nhiên có sự trái ngược về xu thế tùy thuộc vào khu vực cụ thể. Hơn nữa, mực nước biển cũng tăng lên, với mức tăng trung bình là 3,6 mm/năm cho giai đoạn 1993–2018.

2] Sự biến đổi khí hậu trong tương lai phụ thuộc vào nỗ lực chung của các quốc gia trong việc cắt giảm triệt để lượng phát thải khí nhà kính, phù hợp với Thỏa thuận Paris.

- Tại Việt Nam, nhiệt độ trung bình được dự tính tăng khoảng $1,13 \pm 0,87^{\circ}\text{C}$ vào giữa thế kỷ 21 (so sánh với thời kỳ 1986–2005) theo kịch bản có sự cắt giảm mạnh mẽ khí nhà kính phù hợp với Thỏa thuận Paris (RCP2.6). Nếu lượng phát thải khí nhà kính tiếp tục cao (kịch bản RCP8.5), mức tăng có thể đạt tới $1,9 \pm 0,81^{\circ}\text{C}$. Kết quả dự tính nhiệt độ vào cuối thế kỷ phụ thuộc mạnh vào các kịch bản khí nhà kính, với mức tăng được giới hạn ở mức $1,34 \pm 1,14^{\circ}\text{C}$ theo kịch bản RCP2.6 nhưng có thể đạt tới $4,18 \pm 1,57^{\circ}\text{C}$ theo kịch bản RCP8.5.
- Với các kịch bản, nhiệt độ được dự tính sẽ tăng nhanh hơn ở miền Bắc Việt Nam so với miền Nam, trong khi tổng lượng mưa năm được dự tính sẽ tăng trên hầu khắp đất nước, nhưng xu thế theo từng mùa có sự khác biệt.
- Kết quả dự tính mức tăng của mực nước biển dọc bờ biển Việt Nam đa số trong khoảng từ 0,13 m đến 0,36 m vào giữa thế kỷ, và từ 0,27 m đến 1,03 m vào cuối thế kỷ, phụ thuộc vào kịch bản khí nhà kính. Cần lưu ý rằng do tính bất định lớn trong việc xác định sự biến đổi của các tảng băng ở vùng cực trong tương lai, cũng không thể loại trừ khả năng mực nước biển sẽ có thể tăng cao hơn nữa.

3] Một cách phân tích khác là thực hiện dự tính mức độ biến đổi của nhiệt độ, lượng mưa và các hiện tượng cực đoan tại Việt Nam theo các mức nóng lên toàn cầu khác nhau, thay đổi từ $1,5^{\circ}\text{C}$, 2°C , 3°C lên tới 4°C so với thời kỳ tiền công nghiệp (1850–1900). Tuy nhiên, khi sử dụng các kịch bản biến đổi khí hậu cho các bài toán đánh giá tác động, điều cần thiết là phải xem xét và phân tích cẩn thận các khoảng bất định gắn với các kết quả dự tính khí hậu tương lai này.

Sự không chắc chắn về tác động của biến đổi khí hậu trong tương lai tăng lên do các hoạt động của con người tại cấp địa phương

4] Đồng bằng sông Cửu Long (ĐBSCL) là một ví dụ về sự tác động tổng hợp bởi nhiều yếu tố tạo nên sự thay đổi. Trong đó tác động của con người cụ thể là các đập thủy điện, khai

thác cát và khai thác nước ngầm là những mối đe dọa lớn nhất trong nửa đầu thế kỷ này, trong khi biến đổi khí hậu sẽ là vấn đề mấu chốt trong nửa sau thế kỷ.

- Thật vậy, ĐBSCL là vùng châu thổ cực thấp với độ cao trung bình khoảng 80 cm. Do đó vùng này rất dễ bị tổn thương bởi những thay đổi (thậm chí rất nhỏ) của mực nước biển dâng phát sinh từ tác động thay đổi tích lũy của mực nước biển toàn cầu và sự sụt lún đất. ĐBSCL hiện đang phải đối mặt với mức độ sụt lún đất cao, có nơi lên tới 5 cm/năm, chủ yếu do khai thác nước ngầm (hiện tại là $\sim 2,5.10^6 \text{ m}^3/\text{ngày}$, với mức tăng hàng năm là 4%/năm). Nếu tốc độ khai thác nước ngầm duy trì ở mức hiện tại, sự sụt lún tích lũy cùng với nước biển dâng có thể khiến phần lớn Đồng bằng chìm xuống dưới mực nước biển vào cuối thế kỷ này.
- Ngoài ra, tình trạng thiếu hụt phù sa bồi đắp do các đập ở thượng nguồn và việc khai thác cát quá mức dẫn đến sự bào mòn lòng sông một cách trầm trọng trong 20 năm qua (vào khoảng 10–20 cm/năm), điều này dẫn đến sự xâm nhập của thủy triều và gia tăng mức độ xâm nhập mặn. Vấn đề bào mòn đáy sông do con người gây ra vẫn sẽ là nguyên nhân chính dẫn đến quá trình nhiễm mặn tại Đồng bằng đến năm 2050.

5] Do ĐBSCL đã chịu nhiều áp lực nên cơ hội thích ứng bị hạn chế khi đối mặt với các tác động của biến đổi khí hậu điều mà sẽ chiếm ưu thế lớn nhất trong số các mối đe dọa trong nửa sau của thế kỷ này. Giảm khai thác cát và khai thác nước ngầm được coi là các biện pháp quan trọng để giảm sụt lún đất, xâm nhập mặn, giảm thiểu các mối đe dọa đối với sinh kế, các ngành nông nghiệp và nuôi trồng thủy sản ở Đồng bằng.

6] Xa hơn nữa, ĐBSCL chịu ảnh hưởng lớn của việc quản lý nước của toàn bộ lưu vực sông Mê Kông, hoặc sự thiếu vắng của một cơ chế quản lý tổng thể, hoặc sự phức tạp với thể chế riêng biệt của các quốc gia, vùng. Việc quản lý vẫn cần chú ý đến sự phù hợp với các mục tiêu giảm nhẹ và thích ứng của Thỏa thuận Paris, đồng thời ghi nhận sự tác động của con người gây ra đối với môi trường ở từng khu vực địa phương.

7] Từ những khía cạnh đã phân tích, chiến lược phát triển lưu vực giai đoạn 2021–2030 của Ủy hội sông Mê Kông gần đây đã kêu gọi thực hiện “quy hoạch vùng chủ động”. Quy hoạch này có thể đóng vai trò tích hợp các dự án đầu tư về giảm thiểu các vấn đề và các biện pháp thích ứng giữa các quốc gia, các bên liên quan và các ngành nói chung; tất cả dựa trên nguyên tắc chung rằng nước là nhu cầu và quyền cơ bản của mọi người dân sông Mê Kông.

Dự báo các tác động kinh tế vĩ mô của biến đổi khí hậu cho thấy cần tăng nguồn tài chính cho thích ứng khi lòng ghép biến đổi khí hậu vào công tác quy hoạch phát triển

8] Biến đổi khí hậu có thể gây ra những tác động đáng kể đến nhiều lĩnh vực khác nhau như sức khỏe (tỷ lệ tử vong tăng, tỷ lệ mắc bệnh truyền nhiễm cao hơn), nông nghiệp, năng lượng, năng suất nhân tố tổng hợp hoặc năng suất lao động. Bỏ qua những yếu tố phi tuyến tính về kinh tế – xã hội có thể nảy sinh khi khí hậu thay đổi, thiệt hại kinh tế trực tiếp tích lũy

trung bình hàng năm khoảng 1,8% GDP khi nhiệt độ tăng lên 1°C so với nhiệt độ của thời kỳ tiền công nghiệp 1851–1900. Thiệt hại sẽ là 4,5% khi nhiệt độ tăng 1,5°C, 6,7% khi nhiệt độ tăng 2°C và lên đến 10,8% khi nhiệt độ tăng 3°C.

- Đến năm 2050, thiệt hại kinh tế vĩ mô và liên ngành trung bình có thể lớn hơn thiệt hại trực tiếp khoảng 30%.
- Ngoài ra, thiệt hại GDP hàng năm do bão trong giai đoạn 1993–2013 được ước tính là 2,4%. Trong trường hợp không chắc chắn về tác động trong tương lai của bão kết hợp với các kịch bản biến đổi khí hậu, thiệt hại tối thiểu do bão có thể tương đương con số này.
- Cuối cùng, nghiên cứu cho thấy, biến đổi khí hậu, thông qua tác động từ quốc tế dự kiến sẽ làm giảm tốc độ tăng trưởng dài hạn của Việt Nam trong những thập kỷ tới và cần được nghiên cứu cẩn trọng hơn.

9] Mặc dù đã có những nỗ lực đáng kể trong việc ứng phó với biến đổi khí hậu trong 10 năm qua, việc thiếu nguồn lực kỹ thuật và tài chính cho thích ứng, nhu cầu tăng cường các hỗ trợ nhằm nâng cao năng lực cho các địa phương, sự cần thiết phải tập trung giải quyết những nguyên nhân sâu xa của tình trạng dễ bị tổn thương và việc lồng ghép biến đổi khí hậu vào hệ thống thể chế một cách toàn diện vẫn là những thách thức quan trọng. Trong ngắn hạn, các chính sách thích ứng nên được phát triển theo ít nhất ba định hướng sau:

- Tăng cường thu thập dữ liệu và đảm bảo tính sẵn có về dữ liệu. Các hệ thống dự báo thời tiết và cảnh báo sớm, và nâng cao nhận thức về thích ứng vẫn cần thiết để cải thiện các hành động phòng ngừa và thích ứng chủ động. Sự sẵn có các dữ liệu thống kê có chất lượng cũng rất quan trọng để hiểu được vai trò của tài chính khí hậu. Cho đến nay, các công cụ hiệu quả và hệ thống toàn diện để giám sát và đánh giá một cách nhất quán vấn đề tài chính cho thích ứng vẫn còn thiếu. Do đó, việc đo lường hiệu quả của các chính sách thích ứng và tác động của tài chính cho thích ứng còn gặp nhiều khó khăn. Ngoài ra, sự thiếu nhất quán trong các hệ thống báo cáo và việc không có một định nghĩa rõ ràng về tài chính cho thích ứng khiến cho việc đánh giá liệu ngân sách dành cho một dự án phát triển có đóng góp cho thích ứng hay không, và việc đánh giá các nguồn lực phi vật chất được huy động cho thích ứng, đặc biệt là ở cấp cộng đồng gặp nhiều khó khăn.
- Khuyến khích tăng cường khả năng chống chịu ở các địa phương. Khả năng của các bên liên quan ở địa phương trong việc huy động các nguồn lực khác nhau để phục hồi và thực hiện các điều chỉnh hàng ngày, và phát triển nhiều giải pháp khác (ví dụ như nhiều nguồn thu nhập) để đối phó với các cú sốc cho thấy mức độ linh hoạt cao ở cấp địa phương có thể thúc đẩy năng lực thích ứng và củng cố khả năng chống chịu. Điều này có thể được tăng cường thông qua các chính sách cụ thể nhằm đảm bảo sự tham gia của các bên liên quan.
- Lồng ghép thích ứng vào công tác quy hoạch phát triển. Tuy nhiên, trong khi các hành động này có hiệu quả trong ngắn hạn và cần được hỗ trợ, chúng không đủ để ứng phó với và giảm thiểu các tác động tiềm tàng của biến đổi khí hậu trong dài hạn. Những giải pháp này cần những hỗ trợ từ bên ngoài nhằm khuyến khích và tăng cường các chiến lược thích ứng được lên kế hoạch và cần được lồng ghép vào các quy hoạch tổng thể quy mô lớn (Quy hoạch tổng thể giai đoạn 2021–2030 và tầm nhìn đến 2050).

RÉSUMÉ

Le Viet Nam est souvent présenté comme l'un des pays les plus vulnérables au changement climatique

1] Les températures annuelles ont augmenté sur l'ensemble du pays, avec une augmentation moyenne de 0,89°C entre 1958 et 2018 (~0,15°C/décennie). La plus forte augmentation a été enregistrée au cours de la dernière décennie. Sur la même période, les précipitations annuelles ont légèrement augmenté de 5,5% en moyenne, mais avec des évolutions contrastées selon les régions. Par ailleurs, le niveau de la mer augmente, avec une tendance moyenne de 3,6 mm/an sur 1993–2018.

2] L'évolution future du climat dépend de la capacité collective des nations à réduire radicalement leurs émissions respectives de gaz à effet de serre (GES), conformément à l'Accord de Paris.

- Au Viet Nam, l'augmentation moyenne de la température prévue au milieu du XXI^e siècle (par rapport à la période 1986–2005) est de 1,13±0,87°C dans un scénario de forte réduction des émissions mondiales, conformément à l'accord de Paris (RCP2.6). Si les fortes émissions de GES se poursuivent (scénario RCP8.5), l'augmentation pourrait atteindre 1,9±0,81°C. Les projections de température d'ici la fin du siècle dépendent fortement du scénario de GES, avec une augmentation limitée à 1,34±1,14°C sous RCP2.6 mais pouvant atteindre 4,18±1,57°C sous RCP8.5.
- Quel que soit le scénario, la température devrait augmenter plus rapidement dans le nord du Viet Nam que dans le sud, tandis que les précipitations annuelles devraient augmenter dans la plupart des régions du pays, mais avec une répartition saisonnière différente.
- Les projections de l'élévation moyenne probable du niveau de la mer le long des côtes vietnamiennes vont de 0,13 m à 0,36 m d'ici le milieu du siècle et de 0,27 m à 1,03 m d'ici la fin du siècle, selon le scénario d'émissions de GES. Il convient de noter qu'en raison des grandes incertitudes qui pèsent sur le comportement futur des calottes glaciaires polaires, des valeurs plus élevées ne peuvent être exclues.

3] Une autre façon de le voir est de projeter les changements de température, de précipitations et de plusieurs événements extrêmes au Viet Nam avec des niveaux de réchauffement global allant de 1,5°C, 2°C, 3°C et jusqu'à 4°C par rapport à la période préindustrielle (1850–1900). Toutefois, lorsqu'on utilise des scénarios de changement climatique aux fins d'une évaluation d'impact, il est essentiel de considérer et d'analyser soigneusement la plage d'incertitude associée à ces climats futurs.

Les incertitudes concernant les impacts futurs du changement climatique sont souvent accrues par les facteurs de changement anthropiques locaux

4] Le delta du Mékong vietnamien (DMV) est par exemple soumis à une combinaison de facteurs de changement, dont les facteurs anthropiques — à savoir les barrages hydroélectriques, l'extraction de sable et l'extraction d'eau souterraine — représentent les plus grandes menaces dans la première moitié du siècle, tandis que le changement climatique sera probablement dominant dans la seconde moitié du siècle.

- En effet, le DMV possède une plaine deltaïque extrêmement basse, avec une élévation moyenne de ~80 cm. Elle est donc extrêmement vulnérable aux changements, même minimes, du niveau relatif de la mer, qui résultent de l'effet cumulé du changement global du niveau de la mer et des mouvements verticaux locaux des terres (par exemple, la subsidence, ou affaissement des terres). Le DMV est actuellement confronté à des niveaux élevés d'affaissement du sol, jusqu'à 5 cm/an à certains endroits, principalement en raison des extractions d'eau souterraine (actuellement ~2,5 10⁶ m³/jour, avec une augmentation annuelle de 4%/an). Si le taux d'extraction reste au niveau actuel, la subsidence cumulée combinée à l'élévation du niveau de la mer pourrait faire tomber la majorité du delta sous le niveau de la mer d'ici la fin du siècle.
- En outre, la pénurie de sédiments due aux barrages en amont et à l'extraction excessive de sable a entraîné des taux d'incision importants des niveaux du lit du fleuve au cours des 20 dernières années (10–20 cm/an), ce qui a entraîné une amplification des marées et donc une augmentation des intrusions d'eau salée. L'incision anthropique du lit du fleuve restera le principal facteur de salinisation du delta jusqu'en 2050.

5] Par conséquent, le DMV est déjà sous pression, ce qui laisse une fenêtre d'opportunité limitée pour l'adaptation, puisque les effets du changement climatique domineront très probablement les menaces dans la seconde moitié du siècle. La réduction de l'exploitation du sable et des extractions d'eau souterraine apparaît comme une mesure d'atténuation importante pour réduire la subsidence et les intrusions d'eau salée et réduire les menaces qui pèsent sur les moyens de subsistance et les secteurs agricoles et aquacoles dans le delta.

6] En outre, le delta est fortement influencé par la gouvernance de l'eau de l'ensemble du bassin du Mékong, ou plutôt par son absence, avec une architecture institutionnelle dispersée qui doit encore être pleinement alignée sur les objectifs d'atténuation et d'adaptation de l'Accord de Paris, tout en reconnaissant toute la portée des dynamiques environnementales anthropiques locales.

7] À cet égard, la stratégie de développement du bassin 2021–2030 de la Commission du Mékong a récemment appelé à une “planification régionale proactive”, qui pourrait jouer un

rôle intégrateur, via des projets d'investissement conjoints en matière d'atténuation et des mesures d'adaptation entre pays, acteurs et secteurs, en vertu du principe général selon lequel l'eau est un besoin et un droit fondamental de chaque habitant du Mékong.

Les impacts macroéconomiques prévus du changement climatique plaident pour une augmentation du financement de l'adaptation tout en intégrant le changement climatique dans la planification du développement

8] Le changement climatique pourrait avoir des impacts significatifs sur une variété de secteurs aussi différents que la santé (augmentation de la mortalité, incidence accrue des maladies infectieuses), l'agriculture, l'énergie, la productivité totale des facteurs ou la productivité du travail. Si l'on met de côté les multiples non-linéarités socio-économiques qui pourraient survenir face à un climat changeant, l'impact économique direct cumulé sur ces secteurs représente en moyenne annuelle 1,8 % du PIB en cas d'augmentation de température de 1°C par rapport à la période pré-industrielle 1851–1900. Cette perte devient de 4,5% pour une augmentation de 1,5°C, de 6,7% pour une augmentation de 2°C et jusqu'à 10,8% pour une augmentation de 3°C.

- Les effets transsectoriels et macroéconomiques de ces impacts sectoriels à l'horizon 2050 conduisent à des pertes macroéconomiques moyennes supérieures aux dommages directs d'environ 30%.
- En outre, les pertes annuelles de PIB dues aux typhons au cours de la période 1993–2013 sont de 2,4%. Si des incertitudes subsistent quant aux impacts futurs des typhons combinés aux scénarios de changement climatique, ce chiffre devrait rester une valeur plancher.
- Enfin, il est prouvé que le changement climatique, par le biais des retombées internationales des dommages climatiques affectant les autres pays, devrait réduire le taux de croissance à long terme du Viet Nam au cours des prochaines décennies. Cet effet commercial devrait être étudié avec soin.

9] Malgré les efforts considérables déployés ces dix dernières années pour faire face au changement climatique, le manque de ressources techniques et financières pour l'adaptation, la nécessité d'actions de renforcement des capacités au niveau local, l'accent nécessaire sur les facteurs structurels de vulnérabilité ainsi que l'intégration du changement climatique dans un schéma institutionnel global restent des défis cruciaux. À court terme, les politiques d'adaptation devraient évoluer dans au moins trois directions :

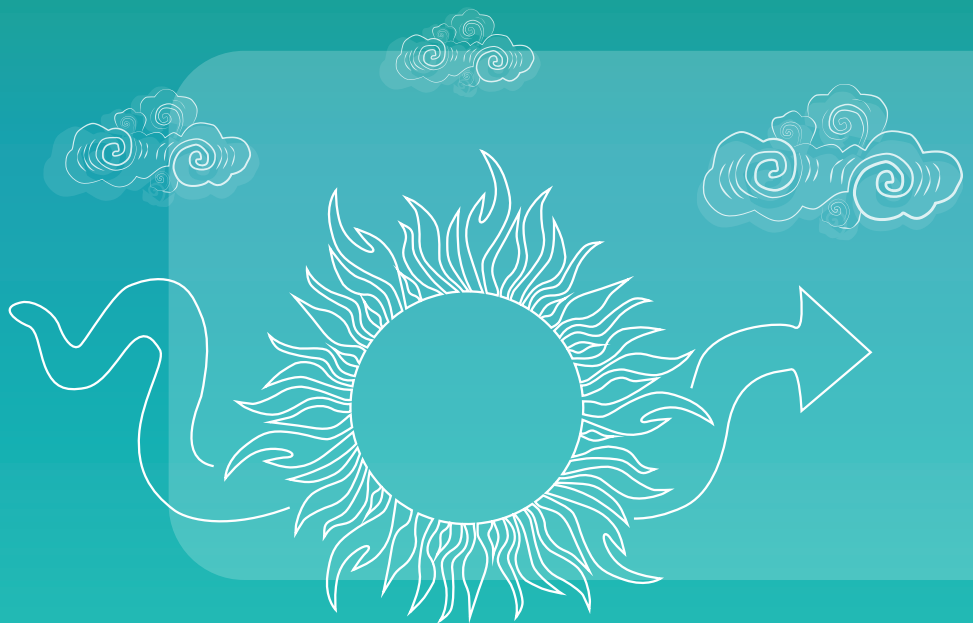
- Renforcer la collecte et la disponibilité des données. Les prévisions météorologiques et les systèmes d'alerte précoce, ainsi que la sensibilisation à l'adaptation sont encore nécessaires pour améliorer les actions préventives et proactives. La disponibilité de bonnes données statistiques est également cruciale pour comprendre le rôle du financement climatique. À ce jour, on manque d'outils opérationnels et de systèmes complets pour suivre et évaluer de manière cohérente le financement de l'adaptation. Il n'est donc pas

toujours facile de mesurer l'efficacité des politiques d'adaptation et l'impact du financement de l'adaptation. En outre, le manque de cohérence des systèmes de notification et l'absence d'une définition claire du financement de l'adaptation font qu'il est difficile de déterminer si le financement d'un projet de développement contribue à l'adaptation et d'évaluer les ressources immatérielles mobilisées pour l'adaptation, en particulier au niveau communautaire.

- Encourager la résilience locale. La capacité des acteurs locaux à mobiliser diverses ressources pour restaurer et mettre en œuvre des ajustements pragmatiques quotidiens, et à développer de multiples options (par exemple, de multiples sources de revenus) pour faire face aux chocs, révèle un haut degré de flexibilité au niveau local qui peut favoriser la capacité d'adaptation et renforcer la résilience. Elle pourrait être favorisée par des politiques spécifiques d'engagement des parties prenantes.
- Intégrer l'adaptation dans la planification du développement. Cependant, si ces actions locales sont efficaces à court terme et doivent être soutenues, elles ne sont pas suffisantes pour faire face et absorber les impacts potentiels du changement climatique à long terme. Elles doivent être accompagnées de formes de soutien externe qui encouragent des stratégies d'adaptation plus planifiées, et doivent être intégrées dans les plans directeurs plus larges (plan directeur 2021–2030 et vision à l'horizon 2050).

Part 1

Climate in Viet Nam: past, present and future



SUMMARY | CLIMATE CHANGE IN VIETNAM: RECENT TRENDS AND FUTURE PROJECTIONS

Viet Nam is often presented as one of the countries that are being most severely impacted by climate change. In recent years, several reports on climate change and sea level rise scenarios for Viet Nam have been published notably by the Ministry of Natural Resources and Environment (MoNRE). Based on recent past observations and future projections, these reports provide the latest information on trends of climate change and sea level rise in Viet Nam, offering an important scientific basis for ministries, sectors and localities in assessing impacts, vulnerability and risks due to climate change, and thus developing and updating their action plans to respond to climate change. The information from these scenarios is an essential input for climate change impact assessment in its various socio-economic aspects.

The first part of this report presents a synthesis of this latest knowledge regarding past, present and future trends of climate change in Viet Nam, and notably some updated results from the latest technical report on climate change and sea level rise scenarios for Viet Nam. At the same time, it also implements a new statistical downscaling approach to future climate simulations, using the Bias Correction Spatial Disaggregation (BCSD) method, applied to 31 global climate models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) over all four Representative Concentration Pathways (RCPs). Finally, it emphasizes the importance of building a time series of climate events and trends from different sources throughout Viet Nam's long-term history. It also shows that adaptation to violent and recurrent climatic events has been a constant in Vietnamese national history.

The following parts of the report rely directly on climate data and simulation results generated and obtained from the work presented here, in order to develop socio-economic assessments of climate impacts as well as adjusted adaptation strategies.

The contemporary period in Viet Nam

For the period 1958–2018, annual temperatures increased over the whole country with a nationwide average increase of 0.89°C ($\sim 0.146^{\circ}\text{C}/\text{decade}$). The rates of increase vary by regions and seasons. Over the whole country, these rates were 0.205°C and 0.231°C per decade for the period 1981–2018, and 1986–2018, respectively. For the period 1958–2018, annual temperatures increased throughout the country, with a nationwide average increase of 0.89°C ($\sim 0.146^{\circ}\text{C}/\text{decade}$). The rates of increase vary by region and by season. For the country as a whole, these rates were 0.205°C and 0.231°C per decade for the periods 1981–2018, and 1986–2018, respectively. This indicates an acceleration in the temperature increase dynamics, with the highest increase experienced in the last decade. As a consequence, the numbers of hot days and very hot days also increased, while the numbers of cold days and very cold days in the North decreased.

During the same period, annual rainfall over the whole country increased slightly by 5.5%, but with contrasting trends depending on the region. Rainfall decreased at several stations in the North of Viet Nam, and increased at many stations in the North East, North Delta, South Central and Central Highlands. Rainfall extremes tended to vary differently across the climatic sub-regions: rainfall declined in stations in the coastal areas of North Central and increased in many stations in the North East, North West and South Central.

Both station and satellite altimetry data show an increasing sea level trend in the coastal areas of Viet Nam. The trend was about 3.6 mm/year for the period 1993–2018 with the highest rate of 4.2–5.8 mm/year from Quang Ngai to Binh Thuan and a lower rate of 2.2–2.5 mm/year in the Southern region.

Viet Nam's climate: a long-term approach

By adopting a long-term perspective on the climate history of Viet Nam, it is possible to extend empirical knowledge of climate change well beyond the contemporary period, using a broad diversity of sources, from dendrochronology (dating and identifying climatic variations using the annual growth rings of trees or from the Palmer Drought Severity Index - PDSI) to imperial archives or meteorological bulletins from the colonial period.

All the primary sources show that the history of Viet Nam has constantly undergone violent climatic events, and that far from being exceptional, the alternation of droughts, floods and typhoons is the “normal” climatic regime of Viet Nam due to its geographic position (Inter-tropical and East coastal region of a continent). In the classical Confucian cosmology of imperial period, meteorological calamities were interpreted as signals of disturbances in the cosmos and therefore as a sign of a challenge to the mandate of Heaven (天命) which the sovereign was entrusted with to ensure harmony on Earth. As a result of this concern, climatic events were meticulously calculated and carefully reported in official paperwork practically since the XIIIth century. Court reports and dynastic chronicles are among major sources of climatic information. Most important among them are the Complete Book of the Historical Records of the Dai Viet. Descriptions of climate increase after the beginning of the XVIIth century, in voluminous historical works produced by scholars of the Le and Nguyen dynasties. Using this climatic information from early-modern Vietnamese history to reconstruct the climates of the past calls for close cooperation between historians and climate scientists.

During the French colonial period, meteorological and climatological services were first established in Cochinchina, where the Agricultural chamber and the Agricultural and Industrial Committee published some meteorological information in their Bulletin between 1865 and 1883. But no real meteorological service existed during the XIXth century. The first weather stations were established in 1897, and it was only in 1900, under the impetus

of Governor General Paul Doumer, that the first unified Meteorological Service was set up. Around 10 principal stations and 20 secondary ones composed the network for the whole of Indochina. From this date onwards and throughout the period of colonisation, the *Bulletin Économique de l'Indochine* published the monthly observations of the entire network. This network of stations was completed in 1902 by the creation of the Central Meteorological Observatory in Phu-Liên (9 km from Haiphong), in the typhoon activity zone. An exhaustive examination of the archives of these stations and of this service would undoubtedly make it possible to produce new thermometric series in order to extend the knowledge of climate in Viet Nam during the colonial period.

In 1945, just after setting up the interim government of the Democratic Republic of Viet Nam, President Ho Chi Minh signed a Resolution to establish a Meteorological Agency, given the importance of the role of meteorological services. Throughout the decades of war, the attention paid by the Socialist Republic of Viet Nam to climate was thus constant. In 1956, the Meteorological Department was renamed Hydro-Meteorological Administration and attached to the Ministry of Communications and Public Works. In 1958, the Prime Minister transferred it to the Ministry of Water Resources, and in 2002 to the Ministry of Natural Resources and Environment. For the management of surface water and climatic hazards, the “Dyke Management and Flood Control Department” is attached to Ministry of Agriculture and Rural Development (MARD). This underlines on the one hand the importance of precise knowledge of the climate, and on the other its specific importance for Vietnamese agriculture.

Projections for the XXIst century

Building prospective climate change scenarios for Viet Nam involves downscaling global scenarios for various greenhouse gas (GHG) emission scenarios. Two methods are used in this report: statistical downscaling and dynamical downscaling. The statistical downscaling method has the advantage of being simple and not requiring huge computer resources. Meanwhile, the dynamical downscaling method, which implies the use of regional climate models, has the advantage of being able to provide coherent information among climate variables. However the main disadvantage of the dynamical method is its high demand for computing power and storage.

The GHG scenarios used in the latest MoNRE reports are two of the four Representative Concentration Pathways. The RCPs have been used in the Fifth Assessment Report of Intergovernmental Panel on Climate Change (IPCC). According to the different scenarios published by MoNRE, the average annual temperature in Viet Nam at the end of the XXIst century would increase by 1.5–4.2°C, average annual rainfall would increase by 10–40%, and extreme rainfall by 20–40% relative to the baseline period (1980–1999 or 1986–2005 depending on the used GHG scenarios).

Average temperature in Viet Nam in the middle of the XXIst century is projected to increase from $1.13 \pm 0.87^{\circ}\text{C}$ under RCP2.6 to $1.9 \pm 0.81^{\circ}\text{C}$ under RCP8.5 relative to the baseline period 1986–2005. At the end of the century temperature is projected to increase from $1.34 \pm 1.14^{\circ}\text{C}$ under RCP2.6 to $4.18 \pm 1.57^{\circ}\text{C}$ under RCP8.5. Temperature is expected to increase faster in the North than in the South. Annual rainfall is projected to increase in most parts of Viet Nam in the future, but with a different seasonal distribution, according to the results obtained from the dynamical downscaling experiments.

Sea level rise in the coastal areas of Viet Nam is projected to increase from 0.24 m ($0.13 \div 0.32$) under RCP2.6 to 0.27 m ($0.19 \div 0.36$) under RCP8.5 in the mid-century period. At the end of the century, the projected increase is 0.44 m ($0.27 \div 0.66$) and 0.73 m ($0.49 \div 1.03$) under RCP2.6 and RCP8.5, respectively. It is worth noting that, due to large uncertainties in the future behavior of polar ice sheets, much higher values, up to more than 2 m in 2100 cannot be ruled out. In the remainder of this report, only three scenarios of sea level rise in 2050 will be taken into account, independently of the different RCPs: 0.30 m, 0.60 m and 0.90 m.

Identifying the magnitude of climate change in each region for various global warming levels (GWLs) is invaluable for the study of impact assessment and climate change response in every nation. In that context, one of the essential policy take-aways of this part is to project the changes of temperature, rainfall, and several extreme events in Viet Nam with the GWLs from 1.5°C , 2°C , 3°C and up to 4°C . With these different GWLs, temperature in Viet Nam is projected to increase with the highest rate in the North and the lowest one in the coastal Southern Central region and Southern Viet Nam. Annual rainfall is projected to generally increase, especially in Central Viet Nam and Central Highlands with the global warming levels.

TÓM TẮT | BIẾN ĐỔI KHÍ HẬU Ở VIỆT NAM: QUÁ KHỨ, HIỆN TẠI VÀ TƯƠNG LAI

Việt Nam là một trong những quốc gia bị ảnh hưởng nặng nề nhất của biến đổi khí hậu (BĐKH). Trong những năm qua kịch bản BĐKH và nước biển dâng cho Việt Nam đã được Bộ Tài nguyên và Môi trường (TNMT) xây dựng, cập nhật và công bố nhằm cung cấp những thông tin mới nhất về xu thế BĐKH trong quá khứ và những dự tính BĐKH và nước biển dâng trong thế kỷ XXI ở Việt Nam. Các thông tin này là cơ sở khoa học quan trọng cho các Bộ, ngành, địa phương sử dụng trong đánh giá tác động, mức độ dễ bị tổn thương và rủi ro do BĐKH, từ đó xây dựng, cập nhật Kế hoạch hành động ứng phó với BĐKH. Các thông tin nhận được từ những kịch bản BĐKH là dữ liệu đầu vào quan trọng để từ đó có thể đưa ra đánh giá tác động của BĐKH đến các mặt của đời sống kinh tế – xã hội.

Phần đầu của báo cáo này tổng hợp kết quả mới nhất về xu thế BĐKH trong quá khứ, hiện tại và tương lai tại Việt Nam, đặc biệt là một số kết quả mới nhất được cập nhật từ kịch bản BĐKH và nước biển dâng cho Việt Nam. Bên cạnh đó chúng tôi cũng đưa ra các tính toán mới dựa trên phương pháp chi tiết hoá thống kê Hiệu chỉnh sai số và Phân rã không gian BCSD (Bias Correction Spatial Disaggregation) cho bộ 31 mô hình khí hậu toàn cầu (GCM) thuộc Dự án so sánh đa mô hình kết hợp pha 5 CMIP5 (Coupled Model Intercomparison Project Phase 5) theo cả 4 kịch bản đường nồng độ khí nhà kính đại diện (RCPs). Cuối cùng, báo cáo nhấn mạnh tầm quan trọng của việc xây dựng mô hình theo thời gian các hiện tượng và xu thế khí hậu dọc theo chiều dài lịch sử Việt Nam dựa trên các nguồn dữ liệu khác nhau trong quá khứ. Báo cáo cũng chỉ ra sự thích ứng với các hiện tượng khí hậu khắc nghiệt, có tính chu kỳ vốn diễn ra thường xuyên trong lịch sử đất nước Việt Nam.

Các phần tiếp theo của báo cáo trực tiếp sử dụng dữ liệu khí hậu và các kết quả mô phỏng được trình bày ở đây để xây dựng đánh giá tác động kinh tế, xã hội của BĐKH, cũng như các chiến lược thích ứng phù hợp.

Việt Nam thời kỳ hiện đại

Đối với giai đoạn 1958–2018, nhiệt độ hàng năm đã tăng ở mức trung bình toàn quốc là $0,89^{\circ}\text{C}$ ($\sim 0,146^{\circ}\text{C}/\text{thập kỷ}$). Tốc độ gia tăng thay đổi theo khu vực và mùa. Trên cả nước, tỉ lệ này là $0,205^{\circ}\text{C}$ và $0,231^{\circ}\text{C}/\text{thập kỷ}$ lần lượt cho các thời kỳ 1981–2018 và 1986–2018. Điều này cho thấy sự gia tăng nhanh của nhiệt độ với kết quả tăng nhanh nhất ở thập kỷ gần đây. Hệ quả là số ngày nắng nóng và nắng nóng gay gắt cũng đã tăng lên trong khi số ngày rét đậm, rét hại ở miền Bắc đã giảm xuống.

Trong thời kỳ 1981–2018, lượng mưa hàng năm trên cả nước tăng nhẹ 5,5% nhưng với các xu hướng đối lập theo vùng. Lượng mưa giảm ở một số trạm phía Bắc, tăng ở nhiều trạm Đông Bắc, đồng bằng Bắc Bộ, Nam Trung Bộ và Tây Nguyên. Lượng mưa cực trị có xu

hướng thay đổi khác nhau theo các tiểu vùng khí hậu, giảm tại các trạm khu vực duyên hải Bắc Trung Bộ và tăng tại nhiều trạm Đông Bắc, Tây Bắc và Nam Trung Bộ.

Cả dữ liệu trạm và vệ tinh đo cao đều cho thấy xu hướng mực nước biển dâng tại các khu vực ven biển Việt Nam. Mức tăng khoảng 3,6 mm/năm cho thời kỳ 1993–2018; mức tăng cao nhất đạt 4,2–5,8 mm/năm từ Quảng Ngãi đến Bình Thuận và mức tăng thấp hơn đạt 2,2–2,5 mm/năm ở khu vực phía Nam.

Khí hậu Việt Nam trong lịch sử dài hạn

Không chỉ giới hạn ở thời kỳ hiện đại, cách tiếp cận từ khung cảnh dài hạn của lịch sử khí hậu Việt Nam có khả năng mở rộng tri thức về BĐKH bằng cách sử dụng các nguồn dữ liệu đa dạng từ nghiên cứu tuổi thọ cây (định niên đại và tri nhận các hình thái khí hậu dựa trên vòng tăng trưởng hàng năm của cây hoặc từ Chỉ số hạn hán Palmer (PDSI)) cho đến các kho lưu trữ hoàng gia và bản tin khí tượng của thời kỳ thuộc địa.

Tất cả các tài liệu gốc đều chỉ ra rằng lịch sử Việt Nam liên tục phải đối mặt với các sự kiện khí hậu cực đoan, và không hiếm gặp là việc hạn hán, lũ lụt, mưa bão liên miên là hình thái khí hậu “bình thường” xuất phát từ vị trí địa lý của Việt Nam (khu vực liên chí tuyến và ở duyên hải phía đông của một lục địa). Trong vũ trụ quan Nho giáo cổ điển của thời kỳ vương triều, tai ương tự nhiên được cho là tín hiệu của sự xáo trộn trong vũ trụ, do đó được xem như dấu hiệu thách thức Thiên mệnh (天命) mà vị hoàng đế được giao phó để đảm bảo sự hòa hợp trên Trái đất. Kết quả là các hiện tượng khí hậu đã được tính toán tỉ mỉ và báo cáo chi tiết trong các văn bản của nhà nước từ khoảng từ thế kỷ XIII. Các báo cáo của triều đình và biên niên sử triều đại là những nguồn chủ yếu về thông tin khí hậu. Quan trọng nhất trong số đó là Đại Việt Sử ký Toàn thư (1697). Những ghi chép về khí hậu đã tăng lên từ đầu thế kỷ XVII trong các tác phẩm lịch sử đồ sộ do các học giả triều Lê và Nguyễn thực hiện. Việc sử dụng các thông tin khí hậu này từ lịch sử Việt Nam sơ kỳ hiện đại để phác thảo lại khí hậu trong quá khứ đòi hỏi sự hợp tác chặt chẽ giữa các nhà sử học và các nhà khoa học khí hậu.

Trong thời Pháp thuộc, hoạt động theo dõi khí tượng và thời tiết lần đầu tiên xuất hiện ở Nam Kỳ, tại đó Phòng Nông nghiệp và Ủy ban Công Nông nghiệp đã xuất bản các thông tin khí tượng trong Bản tin của họ từ năm 1865 đến năm 1883, nhưng không có một cơ quan khí tượng nào thực sự được xác lập ở thế kỷ XIX. Các trạm thời tiết đầu tiên được thiết lập vào năm 1897, và chỉ đến năm 1900, dưới sự thúc đẩy của Toàn quyền Paul Doumer, Cơ quan Khí tượng thống nhất đầu tiên được thiết lập. Khoảng 10 trạm chính và 20 trạm phụ đã hình thành mạng lưới cho toàn Đông Dương [Annales de Géographie, 1900]. Kể từ thời điểm này trở đi và trong suốt thời kỳ thuộc địa, Bản tin Kinh tế Đông Dương đã xuất bản các kết quả quan trắc hàng tháng của toàn bộ mạng lưới. Mạng lưới các trạm quan trắc được hoàn thành vào năm 1902 thông qua sự ra đời của Đài quan sát Khí tượng Trung ương ở Phù Liễn (cách Hải Phòng 9 km), nằm trong vùng hoạt động của bão. Việc nghiên cứu toàn diện các tài liệu

lưu trữ của các trạm này chắc chắn có thể giúp xây dựng được chuỗi số liệu nhiệt độ mới, nhằm mở rộng tri thức về khí hậu ở Việt Nam trong thời kỳ thuộc địa.

Năm 1945, ngay sau khi thành lập Chính phủ Lâm thời nước Việt Nam Dân chủ Cộng hòa, Chủ tịch Hồ Chí Minh đã ký Nghị quyết thành lập Cơ quan Khí tượng, cho thấy tầm quan trọng của của ngành khí tượng. Trong suốt nhiều thập kỷ chiến tranh, Nước Cộng hòa Xã hội Chủ nghĩa Việt Nam luôn thể hiện sự quan tâm đối với lĩnh vực khí hậu. Năm 1956, Cục Khí tượng được đổi tên thành Cục Khí tượng Thủy văn và trực thuộc Bộ Truyền thông và Công cộng. Năm 1958, Thủ tướng Chính phủ chuyển giao cho Bộ Tài nguyên Nước và năm 2002 chuyển cho Bộ Tài nguyên và Môi trường. Đối với việc quản lý nước mặt và rủi ro khí hậu, “Cục Quản lý đê điều và Phòng chống lụt bão” được giao cho Bộ NN & PTNT. Điều này nhấn mạnh tầm quan trọng của tri thức khí hậu và vai trò của khí hậu đối với nông nghiệp Việt Nam.

Dự tính cho thế kỷ XXI

Việc xây dựng các kịch bản BĐKH tương lai cho Việt Nam liên quan đến việc chi tiết hoá các kịch bản toàn cầu với các kịch bản phát thải khí nhà kính (KNK) khác nhau. Hai phương pháp được sử dụng trong báo cáo này bao gồm: chi tiết hoá thống kê và chi tiết hoá động lực. Phương pháp chi tiết hoá thống kê có ưu điểm là đơn giản và không yêu cầu tài nguyên máy tính lớn. Trong khi đó, phương pháp chi tiết hoá động lực, sử dụng các mô hình khí hậu khu vực, có lợi thế có thể cung cấp thông tin nhất quán giữa các biến khí hậu. Tuy nhiên, nhược điểm chính của phương pháp chi tiết hoá động lực là yêu cầu cao về nguồn lực máy tính và lưu trữ.

Các kịch bản KNK được sử dụng trong các báo cáo mới nhất của Bộ TNMT là hai trong bốn kịch bản đường nồng độ KNK đại diện. Các RCPs này đã được sử dụng trong Báo cáo Đánh giá lần thứ Năm của IPCC. Theo các kịch bản khác nhau do Bộ TNMT công bố, nhiệt độ trung bình hàng năm ở Việt Nam vào cuối thế kỷ 21 sẽ tăng 1,5–4,2°C, lượng mưa trung bình hàng năm tăng 10–40% và lượng mưa cực trị tăng 20–40% so với thời kỳ cơ sở (1980–1999 hoặc 1986–2005 tùy thuộc vào các kịch bản KNK được sử dụng).

Nhiệt độ trung bình ở Việt Nam vào giữa thế kỷ XXI được dự tính sẽ tăng từ $1,13 \pm 0,87^\circ\text{C}$ theo RCP2.6 lên $1,9 \pm 0,81^\circ\text{C}$ theo RCP8.5 so với thời kỳ cơ sở 1986–2005. Vào cuối thế kỷ, nhiệt độ dự tính sẽ tăng từ $1,34 \pm 1,14^\circ\text{C}$ theo RCP2.6 lên $4,18 \pm 1,57^\circ\text{C}$ theo RCP8.5. Nhiệt độ được dự tính sẽ tăng nhanh hơn ở miền Bắc so với miền Nam. Theo kết quả từ các thí nghiệm chi tiết hoá động lực, lượng mưa hàng năm được dự tính sẽ tăng ở hầu hết các vùng của Việt Nam trong tương lai, nhưng với sự phân bố theo mùa khác nhau dựa theo các kết quả thu được từ các thí nghiệm chi tiết hóa động lực.

Mức nước biển dâng ở các vùng ven biển của Việt Nam được dự tính sẽ tăng từ 0,24 m ($0,13 \div 0,32$) theo RCP2.6 lên 0,27 m ($0,19 \div 0,36$) theo RCP8.5 vào giữa thế kỷ này. Vào cuối thế kỷ này, mức tăng dự tính lần lượt là 0,44 m ($0,27 \div 0,66$) và 0,73 m ($0,49 \div 1,03$) theo RCP2.6 và RCP8.5. Cần lưu ý rằng, do tính bất định lớn khi xét đến các tảng băng ở vùng cực trong tương lai, không thể loại trừ các giá trị cao hơn nhiều, lên tới hơn 2 m vào năm 2100. Trong phần còn lại của báo cáo này, chỉ có ba kịch bản nước biển dâng vào năm 2050 được xem xét độc lập với các RCPs khác nhau: 0,30 m, 0,60 m và 0,90 m.

Việc xác định mức độ BĐKH ở mỗi khu vực đối với các mức độ nóng lên toàn cầu khác nhau (GWLs) có ý nghĩa thực tế rất lớn đối với các nghiên cứu đánh giá tác động và ứng phó với BĐKH ở mỗi quốc gia. Trong bối cảnh đó, một trong những nội dung quan trọng về chính sách của phần này là dự tính sự thay đổi của nhiệt độ, lượng mưa và các hiện tượng cực đoan ở Việt Nam với GWLs từ 1,5°C, 2°C, 3°C và lên đến 4°C. Với các GWLs khác nhau này, nhiệt độ ở Việt Nam được dự tính sẽ tăng với tốc độ cao nhất ở miền Bắc và thấp nhất ở vùng duyên hải Nam Trung Bộ và Nam Bộ. Lượng mưa hàng năm được dự tính sẽ tăng lên, đặc biệt là ở miền Trung Việt Nam và Tây Nguyên cùng với các mức độ nóng lên toàn cầu.

RÉSUMÉ | LE CHANGEMENT CLIMATIQUE AU VIET NAM : PASSÉ, PRÉSENT ET FUTUR

Le Viet Nam est souvent présenté comme l'un des pays les plus gravement touchés par le changement climatique. Ces dernières années, plusieurs rapports sur les scénarios de changement climatique et d'élévation du niveau de la mer au Viet Nam ont été publiés, notamment par le ministère des ressources naturelles et de l'environnement (MoNRE). Ces rapports fournissent les informations les plus récentes sur les tendances passées et futures du climat et de l'élévation du niveau de la mer au Viet Nam, qui constituent une base scientifique importante pour les ministères, les secteurs et les localités dans l'évaluation des impacts, de la vulnérabilité et des risques dus au changement climatique, et donc dans le développement et la mise à jour de leur plan d'action pour répondre au changement climatique. Les informations tirées de ces scénarios constituent un apport essentiel pour l'évaluation de l'impact du changement climatique sur divers aspects socio-économiques.

La première partie de ce rapport présente une synthèse de ces dernières connaissances concernant les tendances passées, présentes et futures du changement climatique au Viet Nam, notamment certains résultats actualisés du dernier rapport technique sur les scénarios de changement climatique et d'élévation du niveau de la mer pour le Viet Nam. Parallèlement, il met en œuvre une nouvelle approche de réduction d'échelle statistique des simulations climatiques futures, en utilisant la méthode de désagrégation spatiale avec correction des biais (BCSD), appliquée à 31 modèles climatiques globaux (GCM) de la phase 5 du projet d'intercomparaison des modèles couplés (CMIP5) sur les quatre scénarios RCP (Representative Concentration Pathway). Enfin, elle souligne l'importance de construire des séries chronologiques d'événements et de tendances climatiques à partir de différentes sources historiques sur la longue durée de l'histoire du Viet Nam. Elle montre également que l'adaptation aux événements climatiques violents et récurrents a été une constante de l'histoire nationale vietnamienne.

Les parties suivantes du rapport s'appuient directement sur les données climatiques et les résultats de simulation générés afin de développer des évaluations socio-économiques des impacts climatiques ainsi que des stratégies d'adaptation.

La période du Viet Nam contemporain

Pour la période 1958–2018, les températures annuelles ont augmenté sur l'ensemble du pays avec une moyenne de 0,89°C (~0,146°C/décennie). Les taux d'augmentation varient selon les régions et les saisons. Sur l'ensemble du pays, ces taux étaient de 0,205°C et 0,231°C par décennie pour la période 1981–2018, et 1986–2018, respectivement. Cela indique une accélération de la dynamique d'augmentation de la température, la plus forte augmentation ayant été enregistrée au cours de la dernière décennie. En conséquence, le nombre de jours chauds et de jours très chauds a également augmenté, tandis que le nombre de jours froids et de jours très froids dans le nord a diminué.

Sur la même période, les précipitations annuelles sur l'ensemble du pays ont légèrement augmenté de 5,5% pour la période 1981–2018 mais avec des tendances contrastées selon les régions. Les précipitations ont diminué dans plusieurs stations du nord du Viet Nam, et augmenté dans de nombreuses stations du nord-est, du delta du nord, du centre-sud et des hauts plateaux centraux. Les extrêmes pluviométriques ont eu tendance à varier différemment selon les sous-régions climatiques : ils ont diminué dans les stations des zones côtières du centre-nord et augmenté dans de nombreuses stations du nord-est, du nord-ouest et du centre-sud.

Les données altimétriques des stations et des satellites montrent une tendance à l'augmentation du niveau de la mer dans les zones côtières du Viet Nam. La tendance était d'environ 3,6 mm/an pour la période 1993–2018, avec un taux le plus élevé de 4,2–5,8 mm/an de Quang Ngai à Binh Thuan et un taux plus faible de 2,2–2,5 mm/an dans la région du Sud.

Le climat du Viet Nam en longue durée

En adoptant une perspective de longue durée de l'histoire climatique du Viet Nam, il est possible d'étendre les connaissances empiriques sur les changements climatiques bien au-delà de la période contemporaine, en utilisant une plus grande diversité de sources, de la dendrochronologie (datation et identification des variations climatiques à partir des anneaux de croissance annuels des arbres ou du *Palmer Drought Severity Index* - PDSI) aux archives impériales ou aux bulletins météorologiques de la période coloniale.

Toutes les sources primaires montrent que l'histoire du Viet Nam est constamment frappée par des événements climatiques violents, et que loin d'être exceptionnelle, l'alternance de sécheresses, d'inondations et de typhons est le régime climatique "normal" du Viet Nam en raison de sa position géographique (région intertropicale et côtière orientale d'un continent). Dans la cosmologie confucéenne classique de l'époque impériale, les calamités météorologiques étaient interprétées comme des signaux de perturbations dans le cosmos et donc comme le signe d'un défi au mandat du Ciel (天命) dont le souverain était chargé pour assurer l'harmonie sur Terre. En raison de cette préoccupation, les événements climatiques ont été méticuleusement calculés et soigneusement rapportés dans les documents officiels presque depuis le XIII^e siècle. Les rapports de cour et les chroniques dynastiques sont parmi les principales sources d'informations climatiques de cette période. Les plus importantes d'entre elles sont le Livre complet des archives historiques du Dai Viet. Les descriptions du climat augmentent après le début du XVII^e siècle, dans les volumineux ouvrages historiques produits par les lettrés des dynasties Le et Nguyen. L'utilisation de ces informations climatiques du début de l'histoire du Viet Nam moderne pour reconstruire les climats du passé nécessite une forte coopération entre les historiens et les climatologues.

Pendant la période coloniale française, des services météorologiques et climatologiques ont été établis pour la première fois en Cochinchine où la chambre d'agriculture et le comité d'agriculture et d'industrie ont publié quelques informations météorologiques dans leur bulletin entre 1865 et 1883, mais aucun véritable service météorologique n'a existé au cours du XIX^e siècle. Les premières stations météorologiques sont établies en 1897, et ce n'est qu'en 1900, sous l'impulsion du gouverneur général Paul Doumer, que le premier service météorologique unifié est mis en place. Une dizaine de stations principales et une vingtaine de stations secondaires composent le réseau pour toute l'Indochine. A partir de cette date et pendant toute la période de la colonisation, le Bulletin Économique de l'Indochine publie les observations mensuelles de l'ensemble du réseau. Ce réseau de stations est complété en 1902 par la création de l'Observatoire central météorologique à Phu-liên (9 km de Haïphong), dans la zone d'action des typhons. Un dépouillement exhaustif des archives de ces stations et de ce service permettrait sans doute de produire de nouvelles séries thermométriques afin d'étendre la connaissance du climat au Viet Nam à l'époque coloniale.

En 1945, juste après avoir mis en place le gouvernement provisoire de la République démocratique du Viet Nam, le président Ho Chi Minh a signé la résolution visant à créer une agence météorologique, étant donné l'importance du rôle des services météorologiques. Tout au long des décennies de guerre, l'attention portée par la République socialiste du Viet Nam au climat a donc été constante. En 1956, le Service météorologique est rebaptisé Administration hydro-météorologique et rattaché au ministère des Communications et des Travaux publics. En 1958, le Premier ministre l'a transféré au ministère des ressources en eau, puis en 2002 au ministère des ressources naturelles et de l'environnement. Pour la gestion des eaux de surface et des risques climatiques, le "Département de gestion des digues et de lutte contre les inondations" est rattaché au ministère de l'agriculture et du développement rural (MARD). Ceci souligne d'une part l'importance d'une connaissance précise du climat et son importance spécifique pour l'agriculture vietnamienne.

Projections pour le XX^e siècle

L'élaboration de scénarios prospectifs de changement climatique pour le Viet Nam implique une réduction d'échelle des scénarios mondiaux pour divers scénarios d'émission de gaz à effet de serre (GES). Deux méthodes sont utilisées dans ce rapport : la réduction d'échelle statistique et la réduction d'échelle dynamique. La méthode de réduction d'échelle statistique a l'avantage d'être simple et de ne pas nécessiter d'énormes ressources informatiques. Quant à la méthode de réduction d'échelle dynamique, qui implique l'utilisation de modèles climatiques régionaux, elle présente l'avantage de fournir des informations cohérentes entre les variables climatiques. Cependant, le principal inconvénient de la méthode dynamique est la forte demande en puissance de calcul et en stockage.

Les scénarios d'émission utilisés dans les derniers rapports du MoNRE sont deux des quatre scénarios RCP utilisés dans le cinquième rapport d'évaluation du GIEC. Selon les différents scénarios publiés par le MoNRE, la température annuelle moyenne au Viet Nam à la fin du XX^e siècle augmenterait de 1,5 à 4,2°C, les précipitations annuelles moyennes augmenteraient de 10 à 40% et les précipitations extrêmes de 20 à 40% par rapport à la période de référence (1980–1999 ou 1986–2005 selon les scénarios GES utilisés).

Au milieu du XXI^e siècle, la température moyenne au Viet Nam devrait augmenter de 1,13±0,87°C selon le scénario RCP2.6 à 1,9±0,81°C selon le scénario RCP8.5 par rapport à la période de référence 1986–2005. À la fin du siècle, la température devrait augmenter de 1,34±1,14°C selon le scénario RCP2.6 à 4,18±1,57°C selon le scénario RCP8.5. L'augmentation de la température devrait être plus rapide dans le nord que dans le sud. Les précipitations annuelles devraient augmenter dans la plupart des régions du Viet Nam à l'avenir, mais avec une distribution saisonnière différente, selon les résultats obtenus à partir des expériences de réduction d'échelle dynamique.

L'élévation du niveau de la mer dans les zones côtières du Viet Nam devrait passer de 0,24 m (0,13÷0,32) avec le RCP2.6 à 0,27 m (0,19÷0,36) avec le RCP8.5 au milieu du siècle. À la fin du siècle, l'augmentation prévue est de 0,44 m (0,27÷0,66) et de 0,73 m (0,49÷1,03) sous RCP2.6 et RCP8.5, respectivement. Il convient de noter qu'en raison des grandes incertitudes qui pèsent sur le comportement futur des calottes polaires, on ne peut exclure des valeurs beaucoup plus élevées, jusqu'à plus de 2 m en 2100. Dans le reste de ce rapport, seuls trois scénarios d'élévation du niveau de la mer en 2050 seront pris en compte, indépendamment des différents RCP : 0,30 m, 0,60 m et 0,90 m.

L'identification de l'ampleur du changement climatique dans chaque région pour différents niveaux de réchauffement global (GWL) est pratiquement inestimable pour l'étude de l'évaluation de l'impact et de la réponse au changement climatique au sein de chaque pays. Dans ce contexte, l'une des principales utilités en termes de politique publique de cette partie est de projeter les changements de température, de précipitations et de plusieurs événements extrêmes au Viet Nam pour des niveaux de réchauffement global de 1,5°C, 2°C, 3°C et jusqu'à 4°C. Avec ces différents niveaux, la température au Viet Nam devrait augmenter avec le taux le plus élevé dans le Nord et le plus faible dans la région côtière du Centre-Sud et le Sud du Viet Nam. Les précipitations annuelles devraient augmenter dans l'ensemble, en particulier dans le centre du Viet Nam et les hauts plateaux centraux.

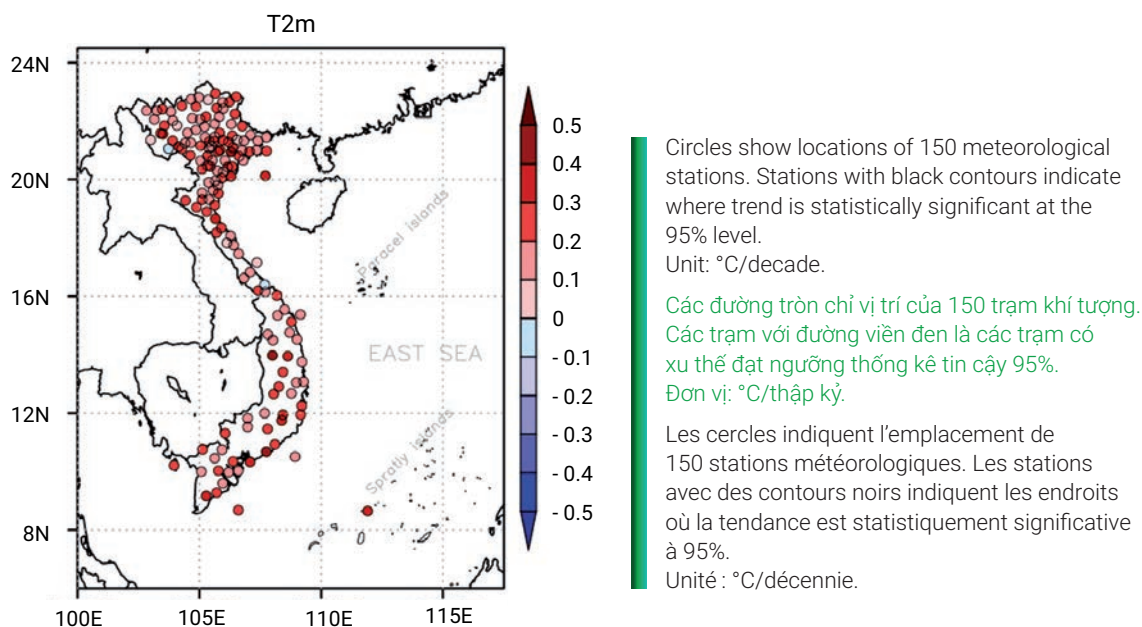
FIGURES | HÌNH

[Figure 1 | Hình 1]

Average annual T2m increase in Viet Nam for the period 1981–2018

Mức tăng trung bình của nhiệt độ T2m trên Việt Nam giai đoạn 1981–2018

Augmentation annuelle moyenne de T2m au Viet Nam pour la période 1981–2018

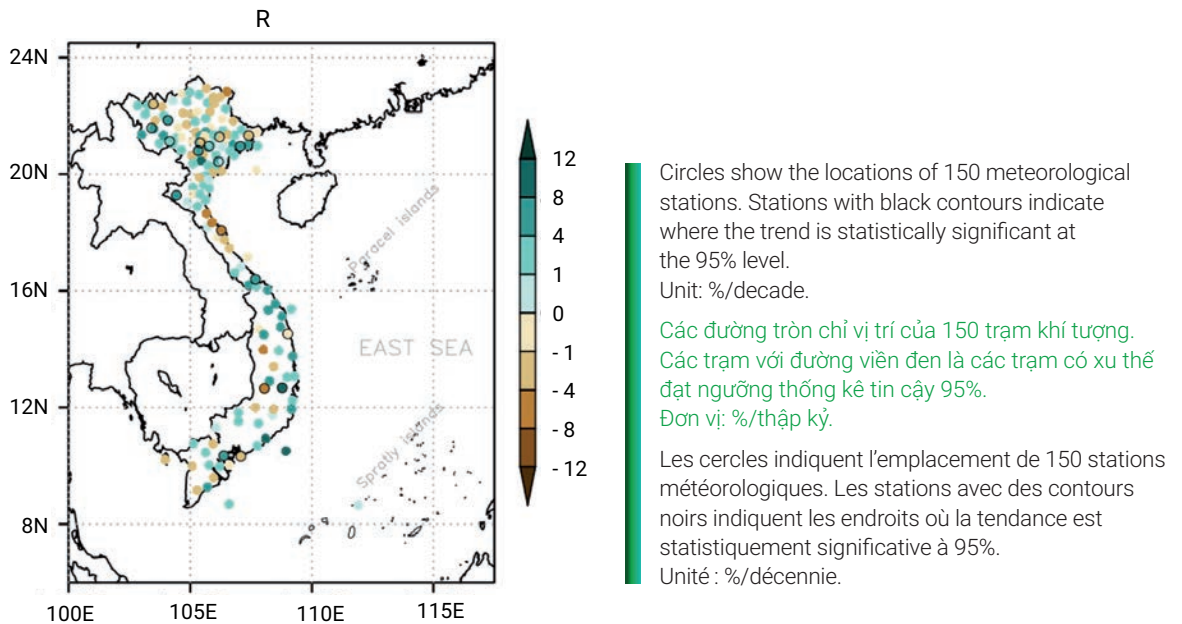


[Figure 2 | Hình 2]

Annual rainfall changes in Viet Nam for the period 1981–2018

Biến đổi của lượng mưa năm trên Việt Nam giai đoạn 1981–2018

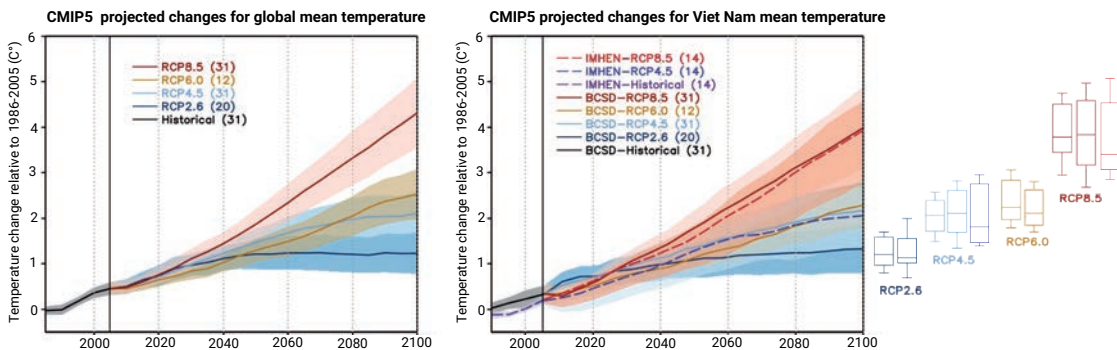
Évolution des précipitations annuelles au Viet Nam pour la période 1981–2018



[Figure 3 | Hình 3]

Global (left) and Viet Nam (right) temperature increase shown with 5-year moving average
 Mức tăng của nhiệt độ toàn cầu (bên trái) và Việt Nam (bên phải) biểu diễn bởi trung bình trượt 5 năm

Augmentation de la température mondiale (à gauche) et vietnamienne (à droite)
 représentée par une moyenne mobile sur 5 ans



Global temperature data were obtained from the CMIP5 GCMs while those of Viet Nam were obtained from the dynamical downscaling experiments provided by IMHEN and from the BCSD statistical downscaling results. Box plots on the right display the occurrence statistics (quartile, median, 10th and 90th percentile) for warming levels on global scale and in Viet Nam at the end of the century 2080–2099, relative to the baseline period 1986–2005. For each RCP, two or three box plots display global values from GCMs (left boxes), values for Viet Nam from BCSD (middle boxes) and from IMHEN (for RCP4.5 and RCP8.5, right boxes) at the end of the century.

Số liệu nhiệt độ toàn cầu nhận được từ các mô hình khí hậu toàn cầu tham gia vào CMIP5, trong khi số liệu nhiệt độ Việt Nam nhận được từ các thí nghiệm chi tiết hoá động lực cung cấp bởi IMHEN và từ các kết quả chi tiết hoá thống kê BCSD. Các biểu đồ hộp bên tay phải hiển thị các thông số thống kê (từ phân vị, trung vị, phân vị thứ 10 và thứ 90) cho các mức nóng lên ở quy mô toàn cầu và ở Việt Nam vào cuối thế kỷ 2080–2099 so với thời kỳ cơ sở 1986–2005. Với mỗi kịch bản RCP, hai hoặc ba biểu đồ hộp hiển thị các giá trị toàn cầu từ các GCMs (hộp bên trái), các giá trị cho Việt Nam từ BCSD (hộp ở giữa), và từ IMHEN (cho kịch bản RCP4.5 và RCP8.5, hộp bên phải).

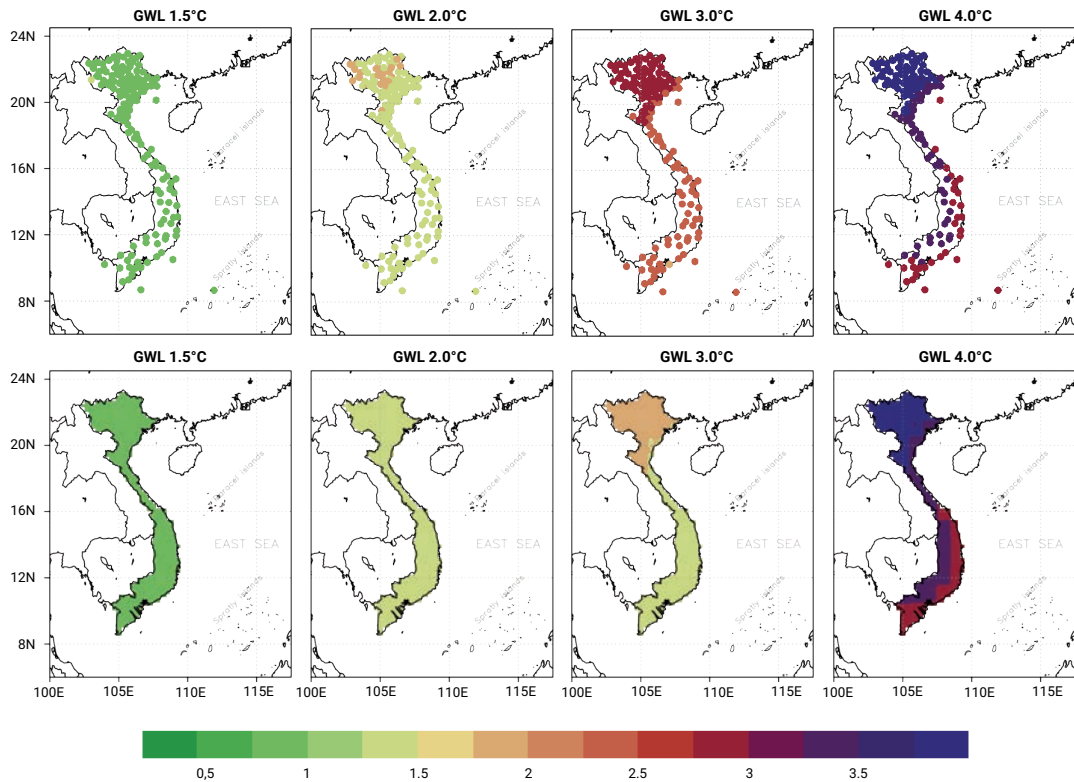
Les données de température mondiale ont été obtenues à partir des GCMs du CMIP5, tandis que celles du Viet Nam ont été obtenues à partir des expériences de réduction d'échelle dynamique fournies par l'IMHEN et des résultats de réduction d'échelle statistique par la méthode BCSD. Les diagrammes de droite présentent les statistiques d'occurrence (quartile, médiane, 10^e et 90^e percentile) des niveaux de réchauffement à l'échelle mondiale et au Viet Nam à la fin du siècle 2080–2099, par rapport à la période de référence 1986–2005. Pour chaque RCP, deux ou trois diagrammes en boîte affichent les valeurs mondiales des GCM (cases de gauche), les valeurs pour le Viet Nam du BCSD (cases du milieu) et de l'IMHEN (pour les RCP4.5 et RCP8.5, cases de droite).

[Figure 4 | Hình 4]

Temperature changes in Viet Nam for different global warming levels

Biến đổi của nhiệt độ trên Việt Nam cho các mức nóng lên toàn cầu khác nhau

Changements de température au Viet Nam pour différents niveaux de réchauffement climatique global



Temperature changes in Viet Nam at the times when the GWLs are reached, relative to the baseline 1986–2005. Results obtained from all the dynamical downscaling experiments (upper panel) and from that of the BCSD statistical downscaling (lower panel). Unit: °C.

Biến đổi nhiệt độ trên Việt Nam tại các thời điểm đạt mức GWL khác nhau so với thời kỳ cơ sở 1986–2005 đối với kết quả tổng hợp từ phương pháp chi tiết hoá động lực (trên) và từ phương pháp chi tiết hoá thống kê BCSD (dưới). Đơn vị: °C.

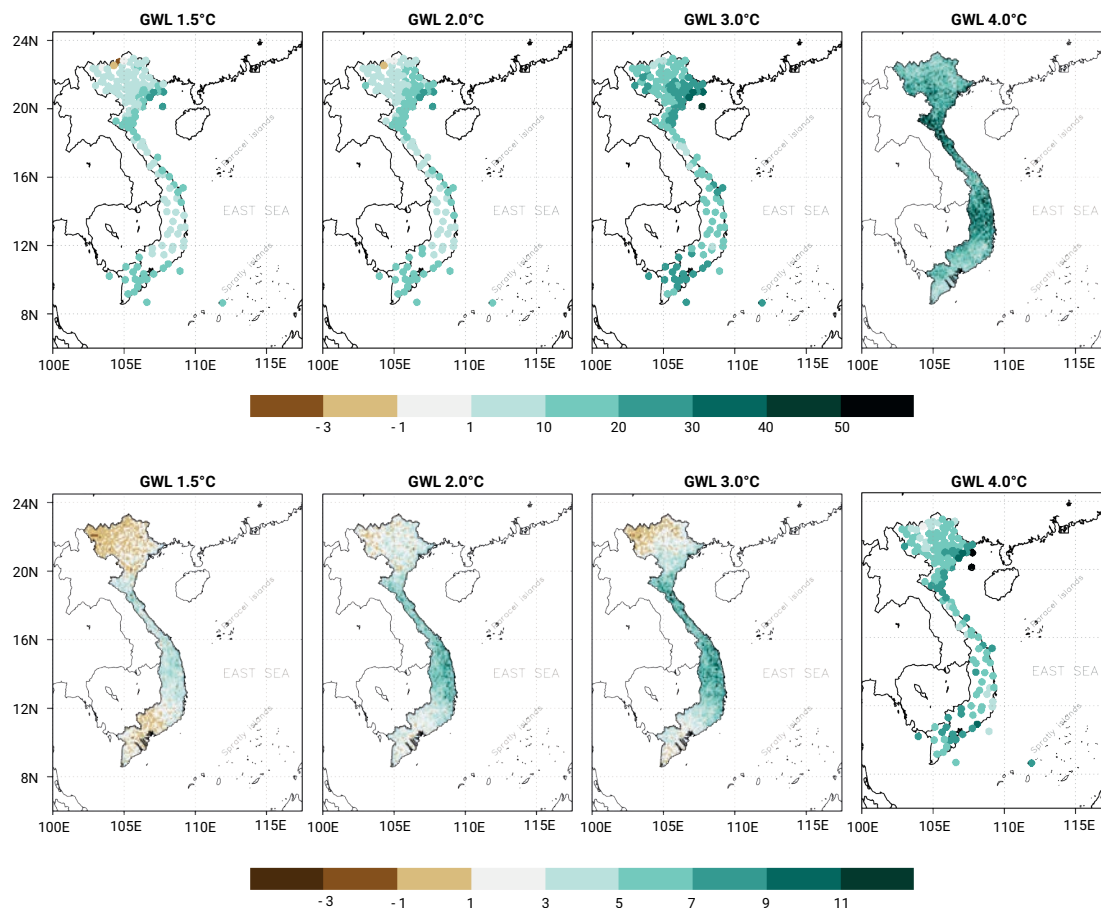
Changements de température au Viet Nam aux moments où les différents niveaux de réchauffement global sont atteints, par rapport à la référence 1986–2005. Résultats obtenus à partir de toutes les expériences de réduction d'échelle dynamique (panneau supérieur) et de celle de la réduction d'échelle statistique du BCSD (panneau inférieur). Unité : °C.

[Figure 5 | Hình 5]

Rainfall changes in Viet Nam for different global warming levels

Biến đổi của lượng mưa trên Việt Nam cho các mức nóng lên toàn cầu khác nhau

Changements dans les précipitations au Viet Nam pour différents niveaux de réchauffement climatique global



Rainfall changes in Viet Nam at the times when the GWLs are reached, relative to the baseline 1986–2005. Results obtained from all the dynamical downscaling experiments (upper panel) and from that of the BCSD statistical downscaling (lower panel). Note the difference of scale between the two panels. Unit: °C

Biến đổi lượng mưa trên Việt Nam tại các thời điểm đạt mức GWL khác nhau so với thời kỳ cơ sở 1986–2005 đối với kết quả tổ hợp từ phương pháp chi tiết hoá động lực (trên) và từ phương pháp chi tiết hoá thống kê BCSD (dưới). Đơn vị: °C.

Changements de précipitations au Viet Nam aux moments où les différents niveaux de réchauffement global sont atteints, par rapport à la référence 1986–2005. Résultats obtenus à partir de toutes les expériences de réduction d'échelle dynamique (panneau supérieur) et de celle de la réduction d'échelle statistique du BCSD (panneau inférieur). Unité: °C.

RECOMMENDATIONS

For policy makers

1] Uncertainty over climate simulations: although there is a high consensus in the results on projected temperature by the dynamical downscaling and the statistical methods, the results on rainfall are significantly different due to the high uncertainty characteristics of modeled rainfall. It is noteworthy to recall that climate change scenarios always include uncertain factors that are associated with GHG scenarios, limited perception in global and regional climate systems, scenario building methods and climate models, etc. Therefore, when using climate change scenarios for the purpose of an impact assessment, it is essential to consider and analyze carefully the uncertainty range of future climate.

2] Updating of global climate models and downscaling over Viet Nam: regarding the climate downscaling efforts in Viet Nam to date, the projections were generally still bounded by the driving GCMs CMIP5 results. More attention and efforts should be paid to update/upgrade information with the latest CMIP6 data and associated upcoming downscaling products.

3] Building empirical historical climate knowledge: the combination of human archival sources and natural sources (palynology, dendrochronology, etc.) would allow to extend the understanding of Viet Nam's past climate well beyond the modern period and characterize the role of climate events and trends in Viet Nam's society and institutional history.

4] Valuing traditional knowledge of climate: climate historians of Viet Nam could uncover the past experiences of the Vietnamese people in dealing with natural and climatic disasters, which would be informative in designing contemporary climate policies at the national and international levels.

For researchers

1] The uncertainty in rainfall projection over Viet Nam is an issue that needs further careful study in the future, particularly when updating the scenarios with the recent available CMIP6 outputs.

2] The downscaled results from CMIP5 GCMs might not cover all probabilities that may occur in the future. A study that applies the probabilistic method could be envisaged to build a new high-resolution climate change scenario set for Viet Nam. This new approach is expected to better depict the tails of the probability distribution, and thus could better take into account the extreme risks that might occur in the future.

3] The high-resolution (10 km) climate scenario set for Viet Nam built by the BCSD method under the framework of this study can be freely downloaded and used via the following address:

https://remosat.usth.edu.vn/Download/dat_GEMMES_WP1/WP1_MODEL_OUTPUT/

We recommend the potential use of this dataset for studies on climate change assessment as well as climate change impacts on socio-economic activities in Viet Nam.

4] A collaborative online database for climate historians of Viet Nam should be built to deposit all archival data that can be used for climate history in Viet Nam and to make it available (in open access or in a form of a commons) to climate scientists. Such an initiative would lay the foundation for interdisciplinary collaboration between historians and climate scientists.

5] Climate science and traditional perceptions of climate should be valued in climate related policies and adaptation strategies together. Firstly, the theories on which traditional knowledge is based favor empirical observation (like modern science does), even though climate change and biodiversity losses tend to modify the value of this knowledge. Secondly, this traditional knowledge still strongly influences Vietnamese society, and enables a better understanding of social behaviors in the face of climate change. Climate adaptation policies could look for the “best of the two worlds” of modern climate science and traditional perceptions of climate by valuing the additional information in community-level knowledge-based forecasts.

CÁC KHUYẾN NGHỊ

Đối với các nhà hoạch định chính sách

1] Tính bất định đối với các mô phỏng khí hậu: mặc dù có sự thống nhất cao trong kết quả dự tính nhiệt độ từ phương pháp chi tiết hoá động lực và chi tiết hoá thống kê, tuy nhiên kết quả nhận được về lượng mưa có sự khác biệt đáng kể do tính bất định cao của bài toán mô phỏng và dự tính lượng mưa. Cần nhắc lại rằng các kịch bản BĐKH luôn bao gồm các yếu tố bất định liên quan đến các kịch bản KNK, nhận thức hạn chế về các hệ thống khí hậu toàn cầu và khu vực, các phương pháp xây dựng kịch bản và mô hình khí hậu, v.v. Do đó, khi sử dụng các kịch bản BĐKH để đánh giá tác động, cần phải xem xét và phân tích cẩn thận khoảng bất định của khí hậu trong tương lai.

2] Cập nhật các mô hình khí hậu toàn cầu và chi tiết hoá tại Việt Nam: liên quan đến các nỗ lực chi tiết hoá khí hậu ở Việt Nam cho đến nay, các dự tính nhìn chung vẫn bị ràng buộc bởi các mô hình khí hậu toàn cầu thuộc dự án CMIP5. Cần chú ý và nỗ lực hơn để cập nhật/nâng cấp thông tin với dữ liệu CMIP6 mới nhất và các sản phẩm chi tiết hoá sắp tới có liên quan.

3] Xây dựng tri thức thực tiễn về lịch sử khí hậu: kết hợp giữa các nguồn dữ liệu lưu trữ nhân tạo và tự nhiên (ngành nghiên cứu phấn hoa, nghiên cứu tuổi thọ cây, v.v.) sẽ cho phép mở rộng tri thức về khí hậu trong quá khứ của Việt Nam vượt khỏi giới hạn của thời kỳ hiện đại và xác định vai trò của các hiện tượng và xu thế khí hậu trong lịch sử thiết chế và lịch sử xã hội Việt Nam.

4] Coi trọng tri thức truyền thống về khí hậu: các nhà sử học về khí hậu của Việt Nam có thể khám phá những kinh nghiệm quá khứ của người Việt Nam trong việc đối phó với thiên tai, điều này giúp cung cấp tài liệu trong việc định hình các chính sách khí hậu hiện tại cấp quốc gia và quốc tế.

Đối với các nhà nghiên cứu

1] Tính bất định trong dự tính lượng mưa ở Việt Nam là một vấn đề cần được nghiên cứu sâu hơn trong tương lai, đặc biệt khi cập nhật các kịch bản với các kết quả CMIP6 hiện có gần đây.

2] Kết quả chi tiết hoá từ các mô hình khí hậu toàn cầu thuộc CMIP5 có thể không bao gồm tất cả các xác suất có thể xảy ra trong tương lai. Việc nghiên cứu áp dụng phương pháp xác suất đề xuất bởi Rasmussen *et al.* (2016) và Hsiang *et al.* (2017) có thể được xem xét áp dụng trong việc xây dựng các bộ kịch bản BĐKH phân giải cao tiếp theo cho Việt Nam, từ đó có thể tính đến tốt hơn các rủi ro cực trị có thể xảy ra trong tương lai.

3] Bộ kịch bản khí hậu phân giải cao (10 km) thiết lập cho Việt Nam được xây dựng bằng phương pháp BCSD trong khuôn khổ nghiên cứu này có thể được tải và sử dụng miễn phí từ địa chỉ:

https://remosat.usth.edu.vn/Download/dat_GEMMES_WP1/WP1_MODEL_OUTPUT/

Bộ số liệu là một nguồn tham khảo hữu ích, được khuyến nghị có thể sử dụng cho các nghiên cứu đánh giá BĐKH cũng như các tác động của BĐKH đến các hoạt động kinh tế – xã hội ở Việt Nam.

4] Một cơ sở dữ liệu trực tuyến hợp tác dành cho các nhà lịch sử khí hậu Việt Nam cần được xây dựng để lưu trữ tất cả các dữ liệu có thể được sử dụng cho lịch sử khí hậu ở Việt Nam và cung cấp cho các nhà khoa học khí hậu (truy cập mở hoặc dưới hình thức dùng chung). Một sáng kiến như vậy sẽ đặt nền tảng cho hợp tác liên ngành giữa các sử gia và nhà khoa học khí hậu.

5] Khoa học khí hậu và những nhận thức truyền thống về khí hậu cần được coi trọng trong các chính sách và chiến lược thích ứng liên quan đến khí hậu. Thứ nhất, các lý thuyết dựa trên kiến thức truyền thống thiên về quan sát thực nghiệm (giống như khoa học hiện đại), mặc dù tồn tại đa dạng sinh học và BĐKH có xu hướng làm thay đổi giá trị của kiến thức này. Thứ hai, kiến thức truyền thống này vẫn còn ảnh hưởng mạnh mẽ đến xã hội Việt Nam, và giúp hiểu rõ hơn về các hành vi xã hội khi đương đầu với biến đổi khí hậu. Các chính sách thích ứng với BĐKH có thể tìm kiếm “điều tốt nhất của hai thế giới” của khoa học khí hậu hiện đại và nhận thức truyền thống về khí hậu bằng cách coi trọng các thông tin được bổ sung từ những dự báo dựa trên tri thức cộng đồng.

RECOMMANDATIONS

A l'intention des décideurs politiques

1] Incertitude sur les simulations climatiques : bien qu'il y ait un consensus élevé dans les résultats sur la température projetée par la réduction d'échelle dynamique et les méthodes statistiques, les résultats sur les précipitations sont significativement différents en raison des grandes incertitudes sur les façons de modéliser les précipitations. Il convient de rappeler que les scénarios de changement climatique comprennent toujours des facteurs incertains qui sont associés aux scénarios d'émissions, à la perception limitée des systèmes climatiques mondiaux et régionaux, aux méthodes d'élaboration des scénarios et aux modèles climatiques, etc. Par conséquent, lors de l'utilisation de scénarios de changement climatique à des fins d'évaluation d'impact, il est essentiel de prendre en compte et d'analyser soigneusement la gamme d'incertitude associée.

2] Mise à jour des modèles climatiques mondiaux et réduction d'échelle au Viet Nam : en ce qui concerne les efforts de réduction d'échelle du climat au Viet Nam jusqu'à présent, les projections étaient généralement encore limitées par les résultats du CMIP5 des GCMs. Il convient d'accorder plus d'attention et d'efforts à l'actualisation et à la mise à niveau des informations à l'aide des dernières données CMIP6.

3] Construire une connaissance empirique du climat historique : la combinaison de sources d'archives humaines et de sources naturelles (palynologie, dendrochronologie, etc.) permettrait d'étendre la compréhension du climat passé du Viet Nam bien au-delà de la période moderne et de caractériser le rôle des événements et des tendances climatiques dans l'histoire de la société et des institutions vietnamiennes.

4] Valoriser les connaissances traditionnelles en matière de climat : les historiens du climat du Viet Nam pourraient redécouvrir les expériences passées du peuple vietnamien en matière de gestion des catastrophes naturelles et climatiques, ce qui serait instructif pour la conception des politiques climatiques contemporaines aux niveaux national et international.

A l'intention des chercheurs

1] L'incertitude dans la projection des précipitations sur le Viet Nam est une question qui doit être étudiée plus attentivement à l'avenir, en particulier lors de la mise à jour des scénarios avec les résultats récents disponibles de CMIP6.

2] Les résultats de la réduction d'échelle des modèles du CMIP5 pourraient ne pas couvrir toutes les probabilités susceptibles de se produire à l'avenir. Une étude probabiliste suggé-

rée pourrait être envisagée pour élaborer un nouvel ensemble de scénarios de changement climatique à haute résolution pour le Viet Nam. Cette nouvelle approche devrait mieux représenter les queues de la distribution de probabilité, et pourrait donc mieux prendre en compte les risques extrêmes qui pourraient survenir à l'avenir.

3] L'ensemble des scénarios climatiques à haute résolution (10 km) pour le Viet Nam, élaboré par la méthode BCSD dans le cadre de cette étude, peut être téléchargé et utilisé gratuitement à l'adresse suivante :

https://remosat.usth.edu.vn/Download/dat_GEMMES_WP1/WP1_MODEL_OUTPUT/.

Nous recommandons l'utilisation potentielle de cet ensemble de données pour des études sur l'évaluation du changement climatique ainsi que sur les impacts du changement climatique sur les activités socio-économiques au Viet Nam.

4] Une base de données en ligne collaborative pour les historiens du climat du Viet Nam devrait être construite pour déposer toutes les données d'archives qui peuvent être utilisées pour l'histoire du climat au Viet Nam et pour les mettre à la disposition (en accès libre ou sous forme de biens communs) des climatologues. Une telle initiative jetterait les bases d'une collaboration interdisciplinaire entre historiens et climatologues.

5] La science du climat et les perceptions traditionnelles du climat devraient être valorisées ensemble dans les politiques liées au climat et les stratégies d'adaptation. D'abord parce que les théories sur lesquelles se fondent les connaissances traditionnelles privilégient l'observation empirique (comme le fait la science moderne), même si le changement climatique et les pertes de biodiversité tendent à modifier la valeur de ces connaissances. Ensuite parce que ces connaissances traditionnelles influencent encore fortement la société vietnamienne, et permettent de mieux comprendre les comportements sociaux face au changement climatique. Les politiques d'adaptation au climat pourraient rechercher le "meilleur des deux mondes" de la science climatique moderne et des perceptions traditionnelles du climat en valorisant les informations supplémentaires dans les prévisions basées sur les connaissances communautaires.

Chapter 1

Climate change in Vietnam: recent trends and future projections

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Abstract

This chapter provides the latest information on observed and projected trends for climate and sea level rise in Viet Nam. Over the period 1981–2018, annual temperatures increased by the nationwide average of 0.21°C per decade, while annual rainfall increased slightly by 5.5% for the country as a whole, with contrasting trends depending on the region. The trend for sea level rise was ~ 3.6 mm/year during the period 1993–2018. For the future projections, two downscaling approaches – dynamical and statistical – are applied. The statistical one is used to downscale 31 global models under four Representative Concentration Pathways (RCPs) scenarios, while 14 (5) experiments are used to dynamically project temperature (rainfall). According to the results, average temperature in Viet Nam in the middle (at the end) of the XXIst century is projected to increase by between $1.13\pm 0.87^{\circ}\text{C}$ ($1.34\pm 1.14^{\circ}\text{C}$) under RCP2.6 and $1.9\pm 0.81^{\circ}\text{C}$ ($4.18\pm 1.57^{\circ}\text{C}$) under RCP8.5, relative to the baseline period 1986–2005. Annual rainfall obtained with the dynamical approach is projected to increase in most parts of Viet Nam in the future, but with a different seasonal distribution. Sea level rise in the coastal areas is projected to increase by between 0.24 m ($0.13\div 0.32$) under RCP2.6 and 0.27 m ($0.19\div 0.36$) under RCP8.5 in the mid-century period, and between 0.44 m ($0.27\div 0.66$) under RCP2.6 and 0.73 m ($0.49\div 1.03$) under RCP8.5 at the end of the century. Last but not least, the chapter also assesses changes in temperature, rainfall and some extreme events in Viet Nam when global warming levels reach 1.5°C , 2°C , 3°C and 4°C .

Tóm tắt

Chương này cung cấp các thông tin cập nhật về xu thế quan trắc trong quá khứ và dự tính tương lai cho một số yếu tố khí hậu và mực nước biển dâng ở Việt Nam. Trong giai đoạn 1981–2018, nhiệt độ trung bình năm tăng trung bình khoảng $0,21^{\circ}\text{C}$ /thập kỷ trên toàn quốc trong khi lượng mưa năm tăng nhẹ khoảng 5,5% nhưng với xu thế có thể là đối nghịch phụ thuộc vào khu vực xem xét. Mức dâng mực nước biển là $\sim 3,6$ mm/năm cho giai đoạn 1993–2018. Để dự tính cho tương lai, hai phương pháp chi tiết hoá là động lực và thống kê được sử dụng. Phương pháp thống kê đã thực hiện việc chi tiết hoá 31 mô hình toàn cầu theo 4 kịch bản đường nồng độ đại diện (RCPs), trong khi 14 (5) thí nghiệm đã được sử dụng việc chi tiết hoá động lực nhiệt độ (mưa). Kết quả chỉ ra rằng nhiệt độ tại Việt Nam vào thời kỳ giữa (cuối) thế kỷ 21 được dự tính tăng từ $1,13\pm 0,87^{\circ}\text{C}$ ($1,34\pm 1,14^{\circ}\text{C}$) theo RCP2.6 đến $1,9\pm 0,81^{\circ}\text{C}$ ($4,18\pm 1,57^{\circ}\text{C}$) theo RCP8.5 so với thời kỳ cơ sở 1986–2005. Lượng mưa năm nhận được với phương pháp động lực cho xu thế tăng trên hầu hết các khu vực của Việt Nam trong tương lai, nhưng với sự phân bố khác biệt theo mùa. Mực nước biển dâng ở các vùng ven biển được dự tính tăng từ 0,24 m ($0,13\div 0,32$) theo RCP2.6 đến 0,27 m ($0,19\div 0,36$) theo RCP8.5 vào giữa thế kỷ; và từ 0,44 m ($0,27\div 0,66$) theo RCP2.6 đến 0,73 m ($0,49\div 1,03$) theo RCP8.5 vào cuối thế kỷ.

theo RCP8.5 vào cuối thế kỷ. Cuối cùng, chương này cũng đánh giá sự biến đổi của nhiệt độ, mưa và một số hiện tượng cực đoan ở Việt Nam theo các mức nóng lên toàn cầu là 1,5°C, 2°C, 3°C và 4°C.

Résumé

Ce chapitre fournit les dernières informations sur les tendances observées et à venir en matière de changement climatique et d'élévation du niveau de la mer au Viet Nam. Sur la période 1981–2018, les températures annuelles ont augmenté en moyenne de 0,21°C par décennie à l'échelle nationale, tandis que les précipitations annuelles ont légèrement augmenté de 5,5% pour l'ensemble du pays, avec des tendances contrastées selon les régions. La tendance de l'élévation du niveau de la mer a été de ~3,6 mm/an au cours de la période 1993–2018. Pour les projections futures, deux approches de réduction d'échelle (*downscaling*) – dynamique et statistique – sont appliquées. L'approche statistique est utilisée pour réduire l'échelle de 31 modèles mondiaux selon quatre scénarios RCP (*Representative Concentration Pathways*), tandis que 14 (respectivement 5) exercices sont menés pour projeter dynamiquement la température (les précipitations). Selon les résultats, la température moyenne au Viet Nam au milieu (à la fin) du XXI^e siècle devrait augmenter de 1,13±0,87°C (1,34±1,14°C) dans le scénario RCP2.6 et de 1,9±0,81°C (4,18±1,57°C) dans le scénario RCP8.5, par rapport à la période de référence 1986–2005. Les précipitations annuelles obtenues avec l'approche dynamique devraient augmenter dans la plupart des régions du Viet Nam à l'avenir, mais avec une distribution saisonnière différente. L'élévation du niveau de la mer dans les zones côtières devrait augmenter de 0,24 m (0,13÷0,32) dans le scénario RCP2.6 et de 0,27 m (0,19÷0,36) dans le scénario RCP8.5 au milieu du siècle, et de 0,44 m (0,27÷0,66) et 0,73 m (0,49÷1,03) dans les scénarios RCP2.6 et RCP8.5 respectivement à la fin du siècle. Enfin, le chapitre évalue également les changements de température, de précipitations ainsi que la fréquence de certains événements extrêmes au Viet Nam lorsque les niveaux de réchauffement planétaire atteignent 1,5°C, 2°C, 3°C et 4°C.

1. Introduction

Viet Nam is among the countries that have been severely impacted by climate change [MoNRE, 2016]. In recent years, the Ministry of Natural Resources and Environment has published several reports on climate change and sea level rise scenarios for Viet Nam [MoNRE, 2009; 2012; 2016; IMHEN, 2021]. These reports provide the latest information on observed and projected trends for climate and sea level rise in Viet Nam; they offer an important scientific basis for ministries, sectors and localities in assessing impacts, vulnerability and risks due to climate change, enabling them to develop and update their action plans as necessary. Building climate change scenarios for Viet Nam involves downscaling global scenarios for various global greenhouse gas (GHG) scenarios. Two methods have been used: statistical downscaling [MoNRE, 2009; 2012] and dynamical downscaling [MoNRE, 2012; 2016; IMHEN, 2021]. The statistical downscaling method has the advantages of being simple and not requiring huge computer resources. Meanwhile, the dynamical downscaling method, which implies the use of regional climate models, has the advantage of being able to provide coherent information among climate variables. Yet the main disadvantage of the dynamical method in the high computing storage capacity it requires. The MoNRE reports published in 2009 and 2012 applied the Special Report on Emission scenarios (SRES) [Nakicenovic *et al.*, 2000], which were used in the Third and the Fourth Assessment Reports of the Intergovernmental Panel on Climate Change [IPCC, 2001; 2007]. Meanwhile, the greenhouse gas (GHG) scenarios used in the latest MoNRE reports [MoNRE, 2016; IMHEN, 2021] are the Representative Concentration Pathways [RCPs; van Vuuren, 2011]. The RCPs were used in the

Fifth Assessment Report of IPCC [IPCC, 2013]. According to the various scenarios published by MoNRE, average annual temperatures in Viet Nam at the end of the XXIst century will increase by 1.5–4.2°C, average annual rainfall will increase by 10–40%, and extreme rainfall by 20–40% relative to the baseline period (1980–1999 or 1986–2005 depending on the used GHG scenarios).

The information sourced from these climate change scenarios is an essential input for climate change impact assessment in various socio-economic aspects. Part of this assessment is being implemented within the framework of the GEMMES Viet Nam project sponsored by the French Development Agency (AFD). This chapter summarizes some updated results from the latest technical report on climate change and sea level rise scenarios for Viet Nam [IMHEN, 2021] and developed in parts 2, 3 and 4 of this report. In addition, we implement a new statistical downscaling approach using the Bias Correction Spatial Disaggregation (BCSD) method, applied for 31 global climate models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5). In this new approach, four RCPs (RCP2.6, 4.5, 6.0 and 8.5) were used. It should be noted that only two RCPs (RCP4.5 and RCP8.5) were used in the 2016 and 2021 reports of MoNRE and IMHEN, respectively. The reason is that because these reports used the dynamical downscaling method, the number of models and GHG scenarios needed to be limited as a result of associated computation times.

In 2015, many countries around the world adopted the Paris Agreement – which aims to limit global warming at the end of XXIst century to well below 2°C in relation to the pre-industrial era – and endeavoured to limit the increase

to 1.5°C. Scientists warn that if global warming extends beyond 2°C, it will cause devastating impacts on human beings and ecosystems [IPCC, 2018]. Identifying the magnitude of climate change in each region via different global warming levels (GWLs) is an invaluable practical tool to study impact assessment and climate change response in every nation. In that context, one of the essential policy take-aways of this chapter is to project changes of temperature and rainfall, and various extreme events in Viet Nam, with the GWLs ranging from 1.5°C, 2°C and 3°C up to 4°C.

2. Climate change in the past

The report of the World Meteorology Organization [WMO, 2020] shows that global average temperature has increased rapidly in recent years. The decade 2010–2019 is the warmest decade since the pre-industrial period, and the

last five years have seen the highest temperatures for the last 140 years. In 2019 specifically, the average global temperature was 1.1°C higher than that of the pre-industrial period (~1850s).

This section provides some up-to-date information on historical climate changes in Viet Nam. Recent trends in annual and seasonal values for temperature, rainfall and some extreme variables are presented in Section 2.1 and 2.2. Section 2.3 discusses past sea level rise. [Chapter 2](#) of this report will propose avenues of research to build even longer time series of climate changes over Viet Nam using a wider range of historical sources. Based on daily data for the period 1981–2018 from 150 stations belonging to the meteorological and hydrological station network of the Viet Nam Meteorological and Hydrological Administration, trends in the following variables were estimated: 1) daily average temperature (T2m), 2) daily minimum temperature (Tn), 3) daily maximum temperature (Tx), 4) daily

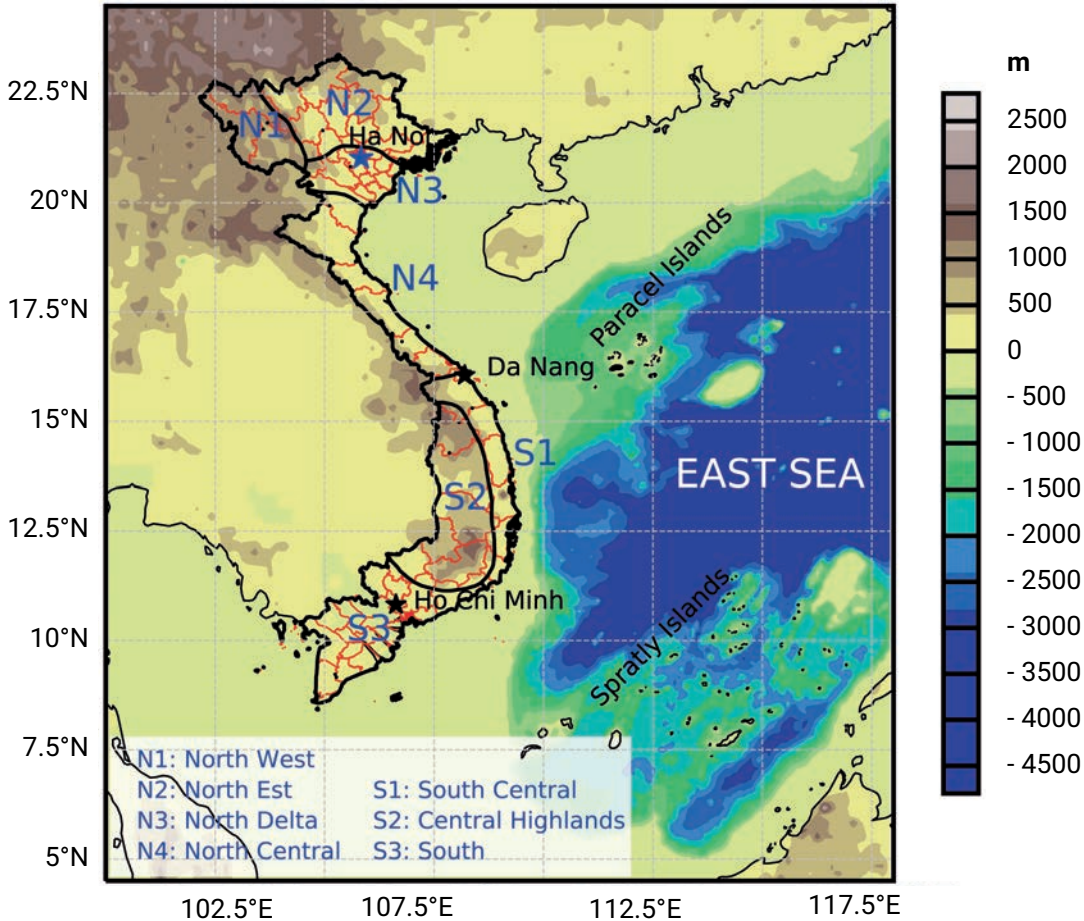
[Table 1.1]

Main temperature and rainfall-related variables used and analysed throughout the chapter

	Variable name	Definition (unit)
1	T2m	Daily average temperature at 2m (°C)
2	Tn	Daily minimum temperature at 2m (°C)
3	Tx	Daily maximum temperature at 2m (°C)
4	R	Daily precipitation (mm)
5	Su35	Annual number of hot days, <i>i.e.</i> the day where $Tx \geq 35^{\circ}\text{C}$ (days)
6	Su37	Annual number of very hot days, <i>i.e.</i> the day where $Tx \geq 37^{\circ}\text{C}$ (days)
7	Fd15	Annual number of cold days, <i>i.e.</i> the day where $T2m \leq 15^{\circ}\text{C}$ (days)
8	Fd13	Annual number of very cold days, <i>i.e.</i> the day where $T2m \leq 13^{\circ}\text{C}$ (days)
9	Rx1day	Annual maximum 1-day rainfall (mm)
10	Rx5day	Annual maximum 5-day consecutive rainfall (mm)

[Figure 1.1]

Topography of Viet Nam and surrounding areas



■ The seven climatic regions as well as the administrative provincial boundaries of Viet Nam are also displayed.

precipitation (R), and 5) some extreme indexes such as number of hot and very hot days, number of cold and very cold days, annual maximum 1-day rainfall (Rx1day), annual maximum 5-day consecutive rainfall (Rx5day) [Table 1.1].

With the aim of updating and assessing climate change information in Viet Nam, in this Chapter we present the changes in annual climatic factors on a nationwide scale, and over 7 climatic sub-regions [Nguyen-Duc

and Nguyen-Trong, 2004] [Figure 1.1]. The changes in regional or national values were estimated using the linear regression method. The trends in climate factors were estimated at each station and displayed as changes detected over the entire observation period. The confidence assessment of the trends was carried out by applying a T-test with a significance level of 95%. Note that in the latest Report on Climate Change and Sea Level Rise scenarios for Viet Nam [IMHEN, 2021], monthly data

and daily data from 150 stations for the maximum periods of 1958–2018 and 1961–2018 were used, respectively; but the periods of data availability are not homogenous for all stations. No statistical significance test has been done in IMHEN (2021).

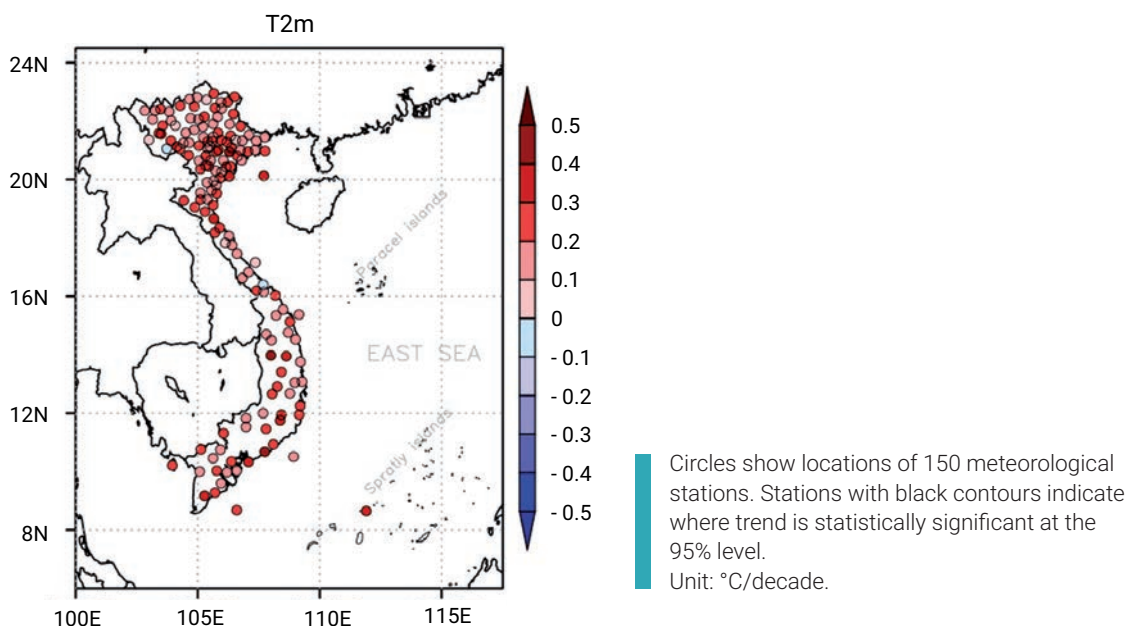
2.1 Average temperature and extremes

Trend assessment shows a temperature increase in nearly all stations. The increases vary between regions and seasons [Figure 1.2, Table 1.2]. The speed of change has increased gradually over time and was highest in recent years (2011–2018). The average annual temperature on a nationwide scale increased by

0.78°C for the period 1981–2018 ($\sim 0.205^\circ\text{C}/\text{decade}$). The highest increase of $0.34^\circ\text{C}/\text{decade}$ took place in the Central Highlands in autumn and in the North Delta in spring. The lowest increment of $0.08^\circ\text{C}/\text{decade}$ was in summer in the North East and North Central regions. According to the latest Report on Climate Change and Sea Level Rise scenarios for Viet Nam [IMHEN, 2021], annual temperature in Viet Nam increased by 0.89°C for the period 1958–2018 ($\sim 0.146^\circ\text{C}/\text{decade}$), with an increase of 0.74°C for 1986–2018 ($\sim 0.231^\circ\text{C}/\text{decade}$). It may thus be concluded that the rate of temperature increase has been faster in recent decades; climate change is happening faster and more intensely, not only on a global scale but also at the scale of a country like Viet Nam.

[Figure 1.2]

Average annual T2m increase in Viet Nam for the period 1981–2018



[Table 1.2]
Average temperature increase (T2m, °C) in 38 years (1981–2018) in 7 climatic sub-regions

Climatic sub-regions	Winter	Spring	Summer	Autumn
North West	0.11	0.18	0.16	0.26
North East	0.18	0.26	0.08	0.24
North Delta	0.24	0.34	0.11	0.32
North Central	0.13	0.24	0.08	0.29
South Central	0.18	0.11	0.16	0.24
Central Highlands	0.32	0.16	0.26	0.34
Southern Viet Nam	0.29	0.18	0.21	0.29

■ Units: °C/decade.

Extreme temperatures also increased in nearly all regions [Figure 1.3]. Like average temperature, maximum daily temperature increased more in autumn than in winter and summer, although the rate of increase was not uniform over different regions in different seasons. Records on T2m and Tx are frequently set year by year.

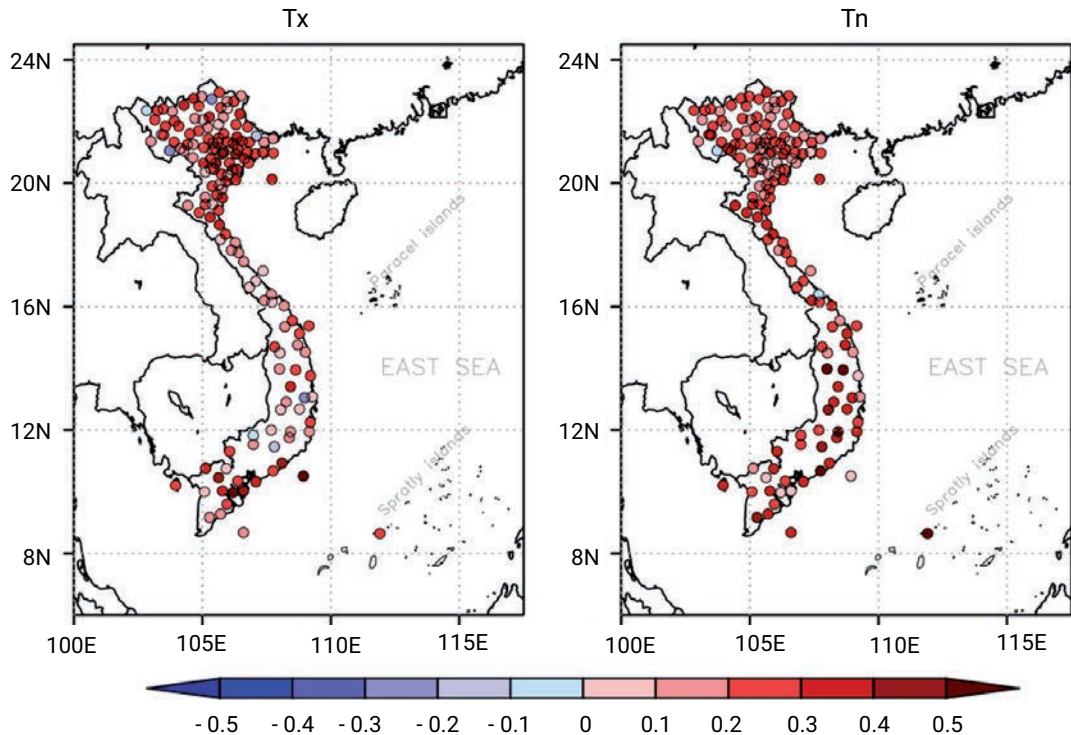
Tx increased in the whole country for the period 1981–2018 [Figure 1.3]. High records were set mainly in El Niño years (1987, 1997, 2010, 2017). The general incremental levels were from 0.11 to 0.32°C/decade in almost all regions, except for several stations in the Northwest, North East and Central Highlands where Tx decreased within the range of -0.05 to -0.21°C/decade. While Tx increased relatively faster in the North Delta, southern North East, northern North Central, and eastern Southern Viet Nam – with some areas reaching a rise of over 0.5°C/decade – Tx increased relatively slower in the South Central and western Central Highlands.

In parallel, Tn for the period 1981–2018 also increased nationwide: the highest rise was 0.5°C/decade in Central Highlands, followed by 0.45°C/decade in North West, 0.29°C/decade in the South, and ~0.24–0.26°C/decade in the remaining regions. Overall, the average rise of Tn was higher than that of Tx in Viet Nam [Figure 1.3].

The number of hot days ($T_x \geq 35^\circ\text{C}$) and very hot days ($T_x \geq 37^\circ\text{C}$) increased or decreased depending on the region; in contrast, the number of cold days ($T_{2m} \leq 15^\circ\text{C}$) and very cold days ($T_{2m} \leq 13^\circ\text{C}$) decreased [Figure 1.4]. For the period 1981–2018, the number of hot days increased or decreased unevenly among the climatic sub-regions. The increase was higher in the southern North East, North Delta, North Central, and South Central regions, with values of 10–40 days over the 38-year period (~2.6–10.5 days/decade). Meanwhile, the number of hot days decreased by 10–20 days (2.6–5.3 days/decade) in some areas of the North West and Central Highlands, and in the eastern part of South Viet Nam. The number

[Figure 1.3]

Average daily maximum temperature (Tx) and daily minimum temperature (Tn) changes for the period 1981–2018



Circles show locations of 150 meteorological stations. Stations with black contours indicate where trend is statistically significant at the 95% level.

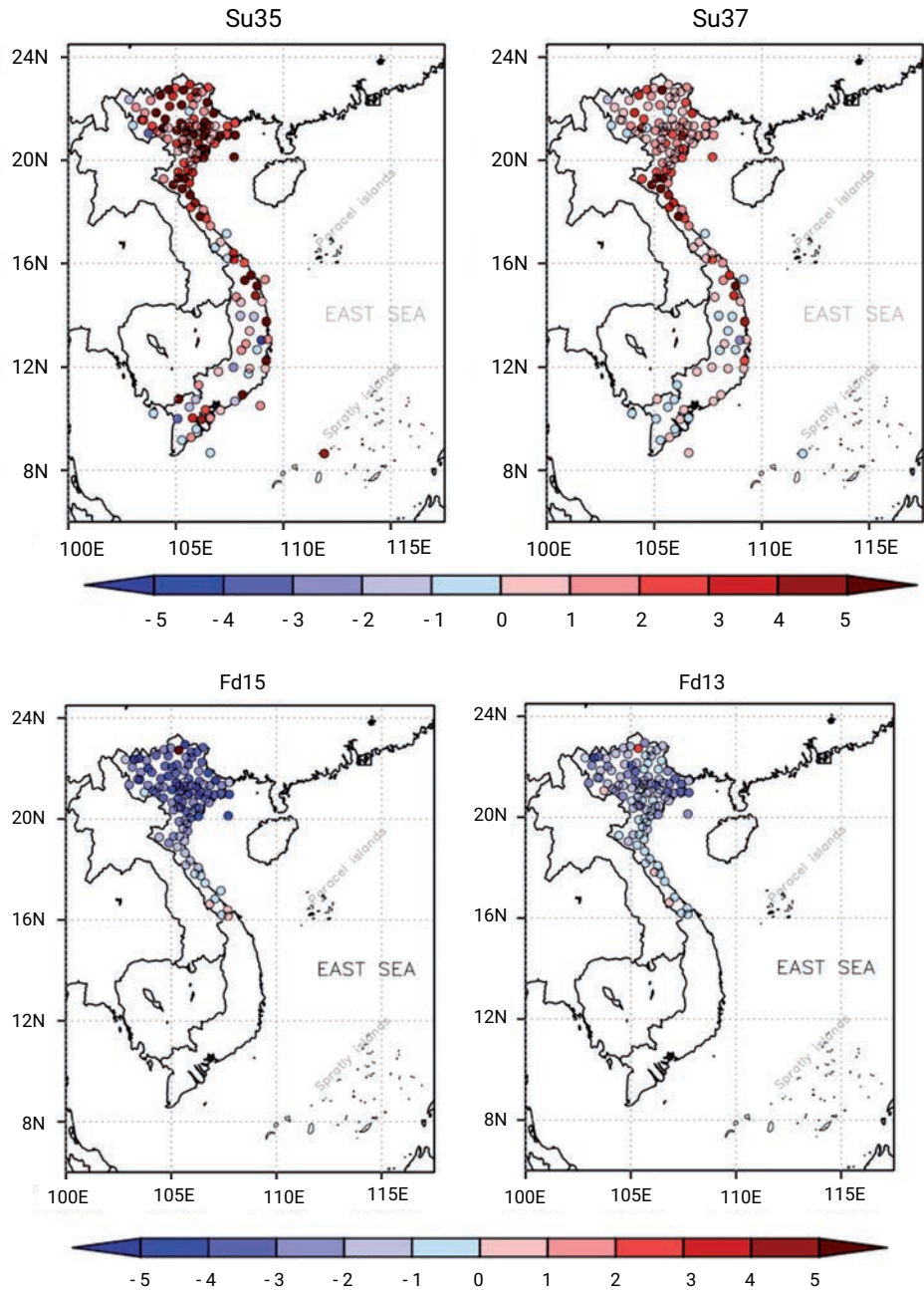
Unit: °C/decade.

of very hot days also increased, but at a lower rate than the number of hot days, with trends of about 2.6–5.3 days/decade. The North Central region experienced the country's highest increases in the number of very hot days.

The number of cold days ($T_{2m} \leq 15^{\circ}\text{C}$) declined markedly, generally from 5 to 25 days over the whole 38-year period (1.3–6.6 days/decade) in the northern parts of Viet Nam. The most obvious reductions took place in the North West and North East regions, with several areas experiencing a 35-day decline. The number of very cold days ($T_{2m} \leq 13^{\circ}\text{C}$) tended

to decrease in northern areas, generally from 5 to 20 days/38 years (1.3–5.3 days/decade), mainly in the North West and North East regions. It should be noted that in the Southern climatic domain south of 16°N – where there are typically no cold events – we have not taken the change in the number of cold and very cold days into account.

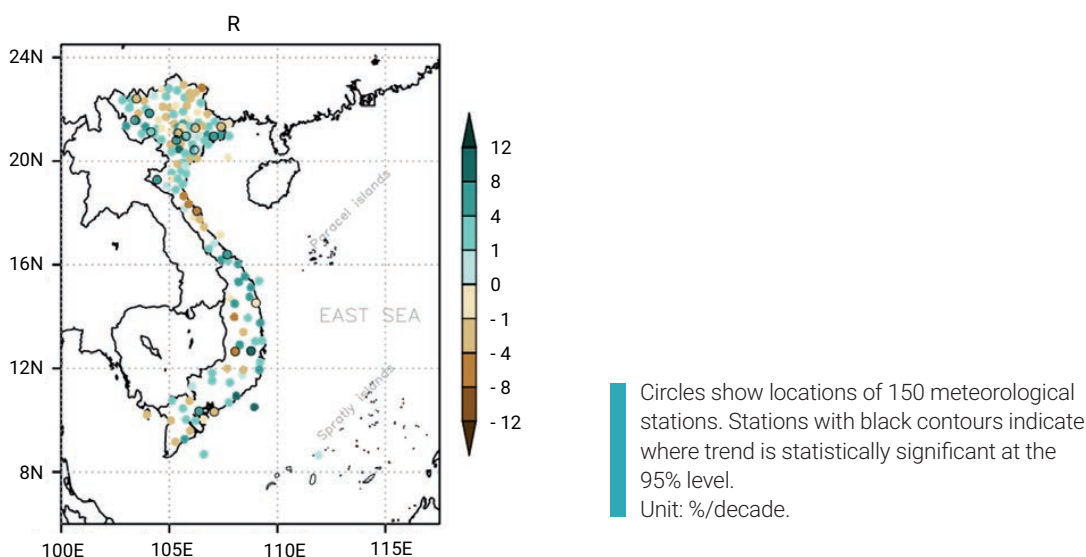
[Figure 1.4]
Changes in the annual number of hot days (Su35), very hot days (Su37), cold days (Fd15), and very cold days (Fd13) for the period 1981–2018



Circles show locations of 150 meteorological stations. Stations with black contours indicate where trend is statistically significant at the 95% level.
Unit: day(s)/decade.

[Figure 1.5]

Annual rainfall changes in Viet Nam for the period 1981–2018



2.2 Average rainfall and extremes

Average annual precipitation for the whole country increased slightly by 5.5% for the period 1981–2018, with contrasting trends depending on the specific region. Annual precipitation declined at several stations in the North and North Central regions, and increased at many stations in the North East,

North Delta, South Central and Central Highlands [Figure 1.5]. However unlike temperature, the rainfall trend is only statistically significant at very few stations. For every climatic sub-region, seasonal rainfall had the highest increase in autumn, with the level rising from 2.5% per decade in North Central to 28.9% per decade in Southern Viet Nam, while rainfall declined from 3.0% to 7.4% per decade in summer in the North [Table 1.3].

[Table 1.3]

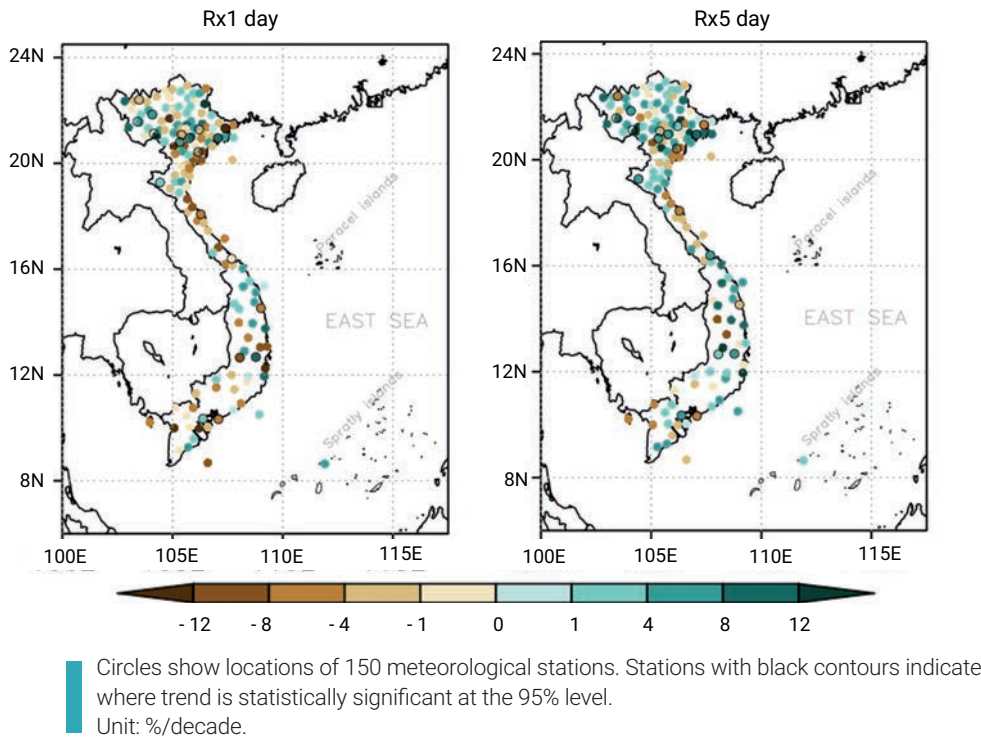
Average rainfall changes in the 7 climatic sub-regions for the period 1981–2018

Climatic sub-regions	Winter	Spring	Summer	Autumn
North West	0,1	3,4	-3,0	16,9
North East	-3,9	4,7	-4,5	8,7
North Delta	-2,6	5,9	-7,4	4,2
North Central	0,7	4,8	-3,8	2,5
South Central	4,7	3,6	0,8	21,9
Central Highlands	4,3	-0,6	-0,1	12,1
Southern Viet Nam	1,1	-0,6	-0,6	28,9

Unit: %/decade.

[Figure 1.6]

Rx1day and Rx5day changes in Viet Nam for the period 1981–2018



Rainfall extremes tended to vary differently over the climatic sub-regions; they declined in stations in the coastal areas of the North Central region, and increased in many stations in the North East, North West and South Central regions [Table 1.7]. Heavy rainfall occurred abnormally in terms of time, place, frequency and intensity in recent years [IMHEN, 2021]. It took place in not only rainy seasons, but also dry ones.

Over the past 38 years, Rx1day had an increasing tendency in the centre of the North East region, some areas in the North, and the northern part of the South Central region, with an increase from 5 to 30% (i.e. 1.3%–7.9% per decade). In contrast, Rx1day declined in a few provinces in the coastal areas of the North Central region and in most of the

Southwest region. The highest increase in Rx1day is 19.4% per decade at Co Noi station (Son La), and the highest decrease is 16.8% per decade at Tuy Hoa station (Phu Yen). Rx5day increased more than Rx1day, with typical increases from 1.3 to 15.8% per decade: the highest increases were in some areas in the North and South Central regions, while 0.5 to 5.3% decreases in Rx5day were found in parts of the North East, North Central, and Southwest regions.

2.3 Past sea level rise

According to the latest estimates from the IPCC's Special Report on the Ocean and Cryosphere in a Changing Climate [IPCC, 2019], the global mean sea level (GMSL) rose

by 0.16 m (likely range 0.12–0.21 m) between 1902 and 2015, due to ocean thermal expansion and ice loss from glaciers and the Greenland and Antarctic ice sheets. Land ice loss is now estimated to be the dominant source of GMSL rise, accounting for about 1.8 mm/year over 2006–2015 compared with 1.4 mm/year for thermal expansion. Because of land ice loss and regional variations in ocean warming and circulation, this rise is not uniform across the globe, and regional variations can reach 30% of the global mean.

The global rate has clearly accelerated over the last decades to reach 3.6 mm/year for 2006–2015, *i.e.* about 2.5 times the rate observed for 1901–1990, due to the increasing contribution from the polar ice sheets.

For Viet Nam, IMHEN (2021) indicated that the sea level at 13/15 observed stations has been increasing over past decades, but the trend is not uniform along the coastline. For example the rate of increase was 1.8 mm/year at Bai Chay station (North East region) during 1962–2018, 4.9 mm/year at Phu Quy station (South Central region) during 1986–2018, and 3.2 mm/year at Phu Quoc station (South region) during 1986–2018. Satellite altimetry data for the period 1993–2018 show an increasing sea level trend of about 3.6 mm/year in the coastal areas of Viet Nam. sea level from Quang Ngai to Binh Thuan rose the highest by 4.2–5.8 mm/year, while a lower increase of 2.2–2.5 mm/year was observed in the Southern region from Ho Chi Minh city to Tra Vinh [IMHEN, 2021].

3. Climate change projection in Viet Nam

3.1 Climate projection methods used in the report

Future global climate change scenarios are generally based on global climate model (GCM) simulations for different GHG scenarios. Results in the Assessment Reports (AR) by IPCC mostly rely on GCM outputs. However, because of limited computation and storage capacities, current GCMs have relatively coarse spatial resolutions, generally around 100 km or coarser. Thus, climate change projection for small areas — such as the provinces in Viet Nam — necessitates some downscaling techniques to provide projections at a higher spatial resolution. In this section, a brief intro-

duction to two downscaling methods is given. The first method is called dynamical downscaling and uses regional climate models (RCMs) integrated (for the historical and future periods) with initial and boundary conditions from GCMs. This method has already been applied within the national climate change scenarios [MoNRE, 2016; IMHEN, 2021]. The second is called bias correction and spatial disaggregation (BCSD) [Wood *et al.*, 2004]. It is implemented within the framework of the GEMMES project.

Global input data for both methods originate from CMIP5 GCMs [Taylor *et al.*, 2012]. It should be noted that CMIP5 experiments were designed with RCP scenarios [van Vuuren *et al.*, 2011; MoNRE, 2016]. Each RCP is designated by a number (2.6, 4.5, 6.0, and 8.5), which corresponds to the level of radiative forcing (unit, Wm^{-2}) in the year 2100 compared to the pre-industrial period. It should be noted

that radiative forcing is defined as the difference between solar irradiance received by the Earth at the top of the troposphere (10–16 km high) and energy radiated back to space. The CMIP5 experiments have greatly contributed to global and local climate change projections, which were synthesized in the AR4 [IPCC, 2013] and the IPCC AR6, whose publication is expected for the end of 2021.

Dynamical downscaling methods

Dynamical downscaling is the main method used to build the recent climate change sce-

narios in Viet Nam [MoNRE, 2016; IMHEN, 2021]. The RCMs or the high-resolution atmospheric GCM used in both 2016 and 2021 reports include: 1) PRECIS [Jones *et al.*, 2004], 2) cIWRf [Fita and Fernández 2010], 3) CCAM [McGregor and Dix, 2008], 4) RegCM [Giorgi *et al.*, 2012], 5) AGCM/MRI [Murakami *et al.*, 2012], and 6) RCA3 [Samuelsson *et al.*, 2011].

Each dynamical downscaling experiment used initial and boundary conditions from CMIP5 GCM outputs [IPCC, 2013]. In the case of CCAM, sea surface temperature data sourced

[Table 1.4]

List of the GCM-RCM couples used in this report and in IMHEN (2021)

No.	RCM	GCM	Period			Resolution
			Baseline	RCP4.5	RCP8.5	
1	PRECIS	HadGEM2-ES*	1960–2005	2006–2099	2006–2099	25 km
2		GFDL-CM3*				
3		CNRM-CM5*				
4	CCAM	CCSM4	1970–2005	2006–2099	2006–2099	30 km
5		CNRM-CM5				
6		GFDL-CM3				
7		NorESM1-M				
8	RegCM4	CNRM-CM5	1980–2000	2046–2065 2080–2099	2046–2065 2080–2099	20 km
9		HadGEM2-AO	1980–2005	2046–2065 2080–2099	2046–2065 2080–2099	
10		MPI-ESM-MR*				
11		EC-Earth				
12		CSIRO MK3.6*				
13		GFDL-ESM2M				
14	cIWRf	NorESM1-M	1970–2005	2006–2099	2006–2099	30 km

■ To simulate and project temperature and rainfall (indicated by the symbol *).

from GCMs were bias-corrected with observed data [Katzfey *et al.*, 2016]. In total, 19 numerical experiments were chosen: 14 experiments for temperature and 5 for rainfall [Table 1.4]. These experiments were also used to build the latest scenario of MoNRE (2021), and provided by the Viet Nam Institute of Meteorology, Hydrology and Climate Change (IMHEN).

The dynamical downscaling method has the advantage of capturing the physical and chemical processes of the atmosphere. The results of this method thus ensure the physical relationships among climate variables. However, each GCM and RCM has certain systematic biases. Therefore, in this report along with IMHEN (2021), the gridded outputs of the dynamical downscaling experiment were extracted for each of 150 stations' locations, and then corrected based on observed station data. The steps for correcting the systematic biases of daily temperature and daily precipitation at every station for the baseline period 1986–2005 and at the end of the XXIst century were implemented as follows: (1) for precipitation: the cumulative distribution functions transform (CDFt) method [Vrac and Friederichs, 2015; Vrac, 2018] was applied; (2) for temperature: the correction based on percentile levels according to Amengual *et al.*, (2012) was applied.

The temperature and precipitation values simulated for the baseline and projected for the future periods, after being bias-corrected, were used to construct the climate change scenario presented in Section 3.2.

Bias correction and spatial disaggregation (BCSD) method

The statistical downscaling method used here is called Bias Correction Spatial Disaggregation

[BCSD; Wood *et al.*, 2004]. The BCSD method includes two separate steps: bias correction (BC) and spatial disaggregation (SD) [Figure 1.7]. The description of the steps is as follows:

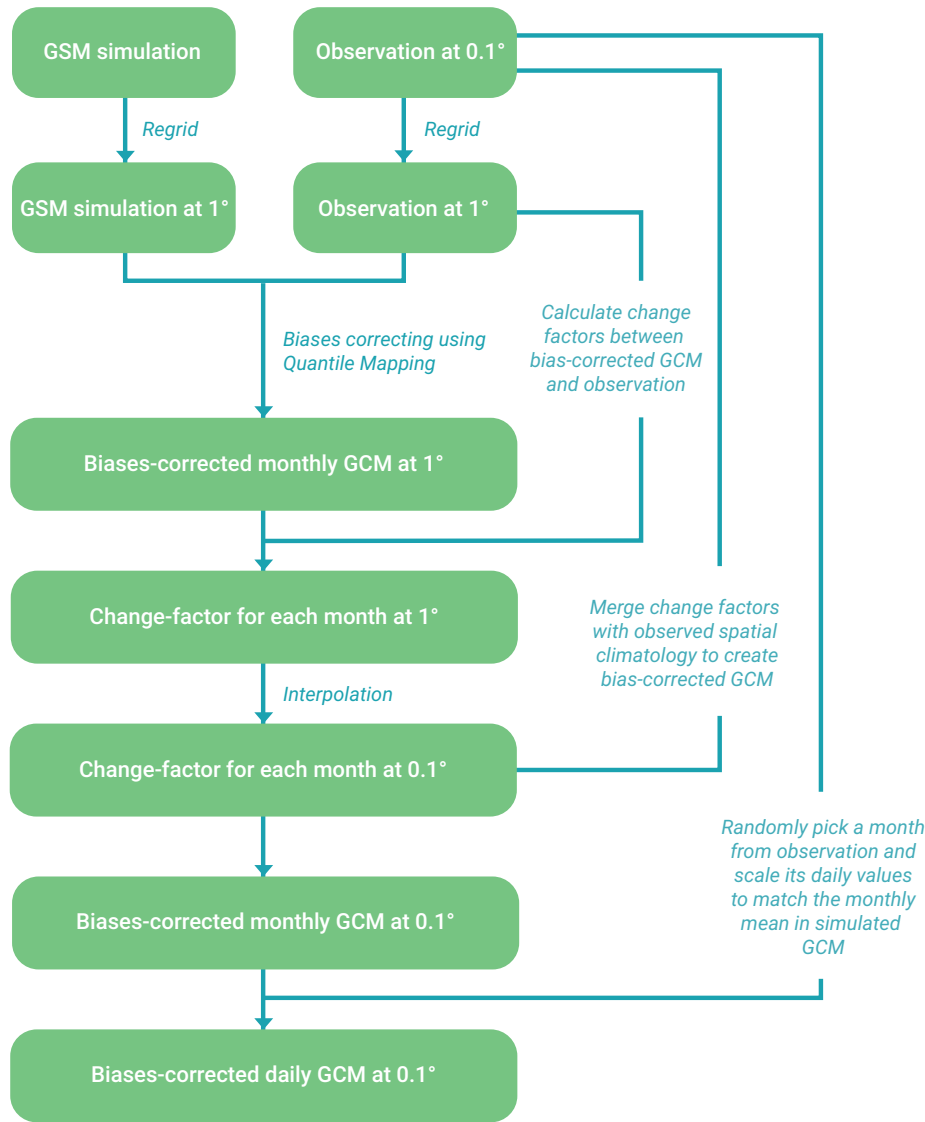
► **BC:** Firstly, the GCMs' temperature and rainfall variables and observed data (OBS) are processed to have the same horizontal resolution $1^\circ \times 1^\circ$ (approximately 100 km) by first-order conservative remapping. Next, quantile mapping (QM) is applied to the 1° data, to bias-correct the GCMs' simulated data using OBS. Cumulative distribution functions (CDF) for precipitation (P), average temperature (T2m), daily maximum temperature (Tx), daily minimum temperature (Tn) are constructed for monthly OBS and individual GCM's simulated data at every grid point. The bias between GCM and OBS at $1^\circ \times 1^\circ$ resolution is corrected by interchanging the GCM quantile with the OBS quantile which has a similar probability value. The major target of the QM is to figure out bias-corrected climate fields with the assumption:

$$X_{BC} = F_o^{-1}(F_{GCM}(X_{GCM}))$$

Where X_{BC} and X_{GCM} denote the bias-corrected GCM value and the original one in the testing stage, respectively. $F_{GCM}()$ and $F_o^{-1}()$ are the GCM CDF and the inverse CDF of OBS, respectively. For temperature, the linear trend at each grid point is separated from the temporal value chain before QM application, and added back to the remaining value (noise) that has been bias-corrected. This method ensures the trend of temperature change is conservative, as in the original GCMs [Wood *et al.*, 2004; Maurer, 2007; Sobie *et al.*, 2012].

► **SD:** The coefficients of temperature and precipitation change between the GCM future scenario and OBS are calculated via a difference (for temperature) or a ratio (for precipitation)

[Figure 1.7]
Implementation steps for the BCSD downscaling method



at 1° resolution. Before being included in the average values of the past observed climate to create future bias-corrected data, the change coefficients are interpolated to 0.1° grid resolution. The downscaled data are then temporally disaggregated to daily resolution, by randomly selecting one observed month in the past and

adjusting the values of the OBS days in the month to match the monthly values of the GCM bias-corrected data.

In this report, the BCSD-downscaled dataset is constructed with all 31 CMIP5 GCMs [Table 1.5] for the baseline period 1980–2005 and

future period 2006–2100. The RCPs used included RCP2.6, RCP4.5, RCP6.0, and RCP8.5. The OBS data contain 4 variables: P, T2m, Tx, Tn, sourced from a gridded dataset built for the period 1980–2005 with 0.1° horizontal resolution. The OBS data are constructed based on 481 precipitation and 157 temperature observation stations. The results of the BCSD statistical downscaling method are saved into netCDF (network Common Data Form) files and can be accessed in open source at the address:

https://remosat.usth.edu.vn/Download/dat_GEMMES_WP1/WP1_MODEL_OUTPUT/

Viet Nam climates corresponding to 1.5°C, 2°C, 3°C and 4°C global warming levels

Global warming levels (GWLs) 1.5°C, 2°C, 3°C and 4°C are defined when comparing global mean surface air temperature (GSAT) (20-year average values) for a certain time in the future with that for the period 1850–1900. The GWL year is estimated for each GCM and GHG scenario. The period corresponding to a given GWL for each of the 31 CMIP5 GCMs used in this report is inherited from the results of Hauser *et al.* [2021].

Table 1.6 displays information on the time (median year, start year, end year) when the GWLs 1.5°C, 2°C, 3°C and 4°C are reached for the different RCPs, based on the ensemble CMIP5 GCMs in Table 1.5.

With the dynamical and statistical downscaling results for Viet Nam obtained in this study, we will assess the change of regional climate corresponding to each GWL time defined by the respective GCM.

For example, to compute the temperature changes in Viet Nam corresponding to the 1.5°C GWL, 40 statistical downscaling experiments – using 10 GCMs and 4 GHG scenarios – are considered. Thus, 40 years {t1, t2, ..., t40} are obtained from the results of Hauser *et al.*, (2021; https://github.com/mathause/cmip_warming_levels) in which each GCM under every scenario reaches the 1.5°C GWL. The change associated with the 1.5°C GWL of the downscaling experiment *i* is defined as the difference between the 20-year average value centred by the time *t_i* and the baseline period 1986–2005. These 40 results are then used to define the average values of the temperature changes, as well as their respective uncertainty ranges.

[Table 1.5]

31 CMIP5 GCMs were used for input data serving for BCSD calculation

No.	Model ID	Resolution (°)		Applicable models (* symbolizes used GCMs)			
		Longitude	Latitude	RCP2.6	RCP4.5	RCP6.0	RCP8.5
1	ACCESS1-0	1.25	1.875		*		*
2	ACCESS1-3	1.25	1.875		*		*
3	BCC-CSM1-1	2.7906	2.8125	*	*	*	*
4	BCC-CSM1-1-M	2.7906	2.8125	*	*		*
5	BNU-ESM	2.7906	2.8125	*	*		*
6	CanESM2	2.7906	2.8125	*	*		*
7	CCSM4	0.9424	1.25		*	*	*
8	CESM1-BGC	0.9424	1.25		*		*
9	CESM1-CAM5	0.9424	1.25	*	*	*	*
10	CMCC-CM	0.7484	0.75		*		*
11	CNRM-CM5	1.4008	1.40625	*	*		*
12	CSIRO-Mk3-6-0	1.8653	1.875	*	*	*	*
13	GFDL-CM3	2	2.5	*	*		*
14	GFDL-ESM2G	2.0225	2	*	*	*	*
15	GISS-E2-H	2	2.5	*	*	*	*
16	GISS-E2-H-CC	2	2.5		*		*
17	GISS-E2-R	2	2.5	*	*	*	*
18	GISS-E2-R-CC	2	2.5		*		*
19	HadGEM2-CC	1.25	1.875		*		*
20	HadGEM2-ES	1.25	1.875	*	*		*
21	IPSL-CM5A-LR	1.8974	3.75	*	*		*
22	IPSL-CM5A-MR	1.2676	2.5	*	*	*	*
23	IPSL-CM5B-LR	1.8947	3.75		*		*
24	MIROC-ESM	2.7906	2.8125	*	*	*	*
25	MIROC-ESM-CHEM	2.7906	2.8125		*	*	*
26	MIROC5	1.4008	1.40625	*	*	*	*
27	MPI-ESM-LR	1.8653	1.875	*	*		*
28	MPI-ESM-MR	1.8653	1.875	*	*		*
29	MRI-CGCM3	1.12148	1.125	*	*		*
30	NorESM1-M	1.8947	2.5	*	*	*	*
31	NorESM1-ME	1.8947	2.5		*		*
Number of GCMs for each scenario				20	31	12	31

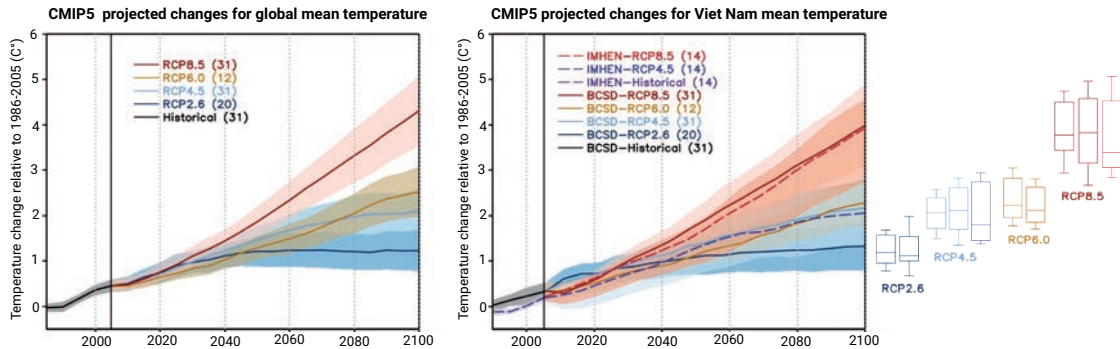
[Table 1.6]

Times when the GWLs 1.5°C, 2°C, 3°C and 4°C are reached for the different RCPs

	GWL 1.5°			GWL 2°			GWL 3°			GWL 4°		
	Median year	Start year	End year	Median year	Start year	End year	Median year	Start year	End year	Median year	Start year	End year
RCP2.6	2023	2008	2047	2039	2025	2081	NA	NA	NA	NA	NA	NA
RCP4.5	2027	2008	2055	2047	2024	2085	2073	2064	2078	NA	NA	NA
RCP6.0	2030	2011	2060	2053	2033	2078	2078	2072	2087	NA	NA	NA
RCP8.5	2023	2009	2042	2039	2023	2053	2062	2046	2087	2081	2065	2088

For each RCP and GWL, 3 values are identified including the median year, the earliest year and the latest year that the GWL is reached by the ensemble CMIP5 GCMs in Table 1.5. NA (not available) indicates no year is determined.

[Figure 1.8]
Global (left) and Viet Nam (right) temperature increase shown with 5-year moving average



Global (left) and Viet Nam (right) temperature increase shown with 5-year moving average. Global temperature data were obtained from the CMIP5 GCMs while those of Viet Nam were obtained from the dynamical downscaling experiments provided by IMHEN and from the BCSD statistical downscaling results. Coloured lines present the ensemble means of the experiments and coloured shaded areas show the uncertainty ranges (± 1 standard deviation) for each RCP. The number of experiments used to calculate each RCP is shown in brackets after each RCP name. Box plots on the right display the occurrence statistics (quartile, median, 10th and 90th percentile) for warming levels on global scale and in Viet Nam at the end of the century 2080–2099, relative to the baseline period 1986–2005. For each RCP, two or three box plots display global values from GCMs (left boxes), values for Viet Nam from BCSD (middle boxes) and from IMHEN (for RCP4.5 and RCP8.5, right boxes) at the end of the century.

3.2 Projection of temperature and rainfall in Viet Nam

Temperature

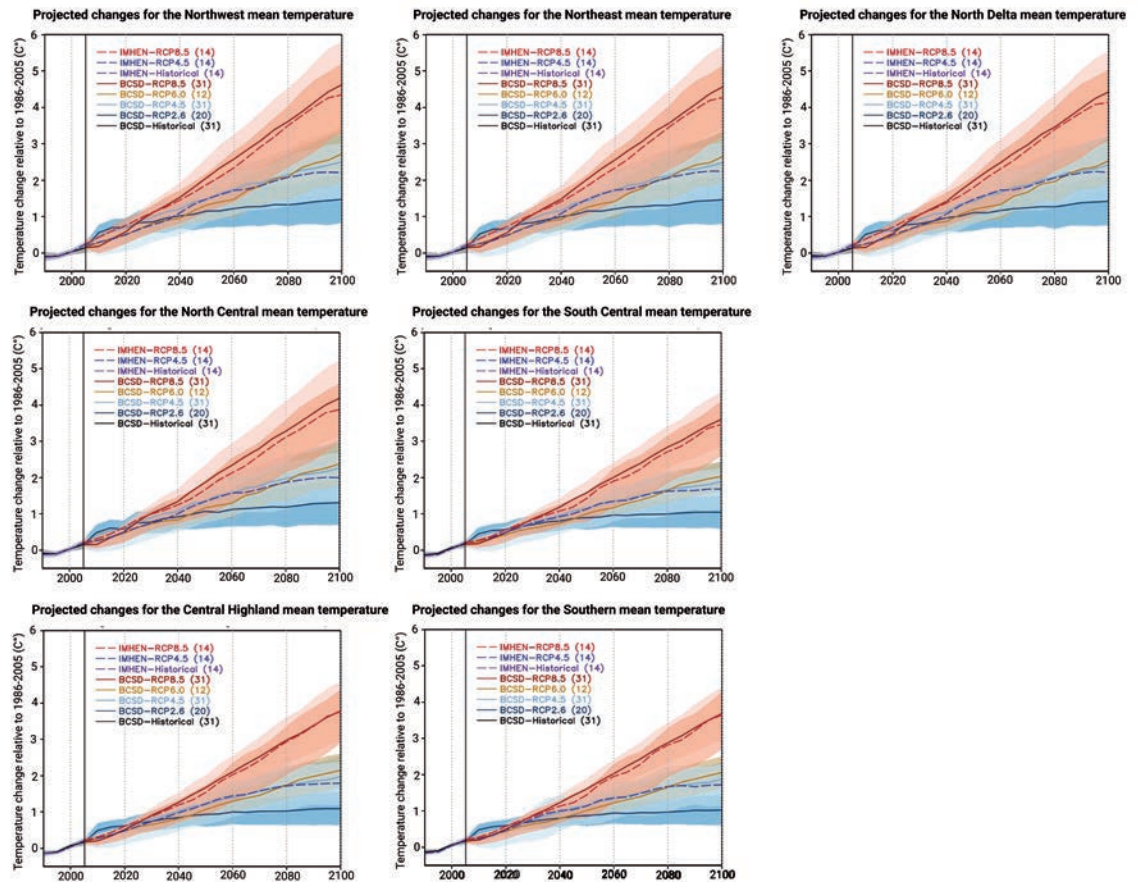
Average annual temperature

Future global and Viet Nam temperature levels compared to the reference period 1986–2005 are displayed in Figure 1.8. Overall, the rate of temperature increase in Viet Nam is slightly smaller than the global average, particularly for RCP8.5. The results of the dynamical downscaling method by IMHEN are rather similar to those of the BCSD statistical downscaling method. The average temperature in Viet Nam increases by $1.13 \pm 0.87^\circ\text{C}$ under RCP2.6 and by $1.9 \pm 0.81^\circ\text{C}$ under RCP8.5 in the middle of the XXIst century. At

the end of the XXIst century, temperature in Viet Nam increases by $1.34 \pm 1.14^\circ\text{C}$ under RCP2.6 and by $4.18 \pm 1.57^\circ\text{C}$ under RCP8.5. The uncertainty ranges (± 1 standard deviation) of the global and Viet Nam scenarios are relatively low in the first decades and gradually expand with time toward the end of the XXIst century.

Regarding the 7 climatic sub-regions of Viet Nam, temperatures in these sub-regions are projected to increase considerably in the XXIst century relative to the baseline 1986–2005 [Figure 1.9]. Projected temperature increases in the North, from Northeast to North Central, are higher than those in the South, from Central Highland to Southern Viet Nam.

[Figure 1.9]
Temperature increases in the 7 climatic sub-regions of Viet Nam



1.9. Similar to Figure 1.8, but for temperature increases in the 7 climatic sub-regions of Viet Nam at the end of the XXIst century based on the IMHEN and BCSD scenarios.

Table 1.7 shows how much temperatures are projected to increase in the 7 climatic sub-regions of Viet Nam in the middle and at the end of the XXIst century under RCP4.5 and RCP8.5. For the projected results of IMHEN at the end of the century, temperature increases in the North are in the range of $2.00\pm1.2^{\circ}\text{C}$ (in the Northern Central) under RCP4.5 and $4.34\pm1.68^{\circ}\text{C}$ (in the Northwest) under RCP8.5. In the South, temperature increases ranged around $1.67\pm0.96^{\circ}\text{C}$ (Southern Central) under RCP4.5 and $3.76\pm1.16^{\circ}\text{C}$ (Central Highlands) under RCP8.5. For the BCSD statistical downscaling results, temperature increases in the Northeast, Northwest and North Delta are $\sim 0.2\text{--}0.3^{\circ}\text{C}$ higher than those of IMHEN

under both RCP4.5 and RCP8.5, while they are $\sim 0.15\text{--}0.2^{\circ}\text{C}$ lower in the Northern Central region. In the South, the projected increases of BCSD temperatures are higher than those of IMHEN, ranging $1.88\pm1.21^{\circ}\text{C}$ (Southern Central) under RCP4.5 and $3.78\pm1.31^{\circ}\text{C}$ (Central Highlands) under RCP8.5.

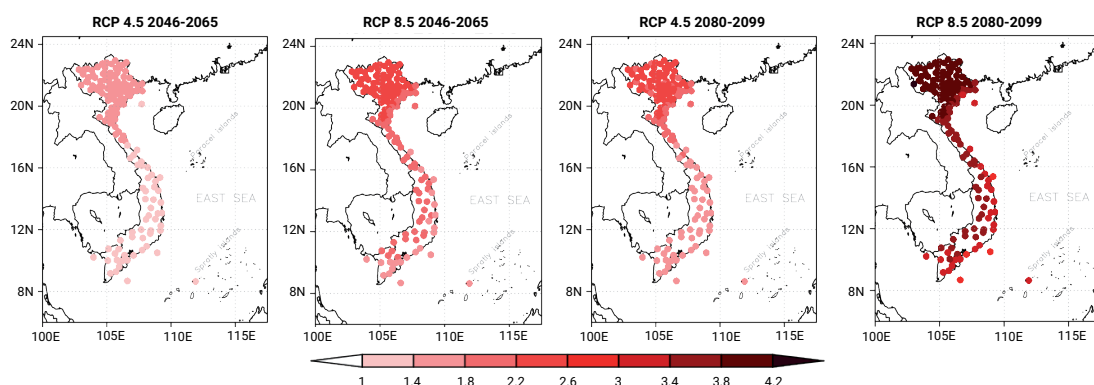
[Table 1.7]

Projected increases of average annual temperature in the 7 climatic sub-regions of Viet Nam by the IMHEN dynamical downscaling and the BCSD statistical downscaling experiments

Region		RCP4.5		RCP8.5	
		2046–2065	2080–2099	2046–2065	2080–2099
Northeast	BCSD	1.44 ± 0.80	2.49 ± 1.78	2.04 ± 1.00	4.57 ± 2.34
	IMHEN	1.48 ± 1.02	2.24 ± 1.36	1.86 ± 1.02	4.27 ± 1.89
Northwest	BCSD	1.48 ± 1.10	2.50 ± 1.97	2.07 ± 1.13	4.62 ± 2.57
	IMHEN	1.49 ± 1.13	2.21 ± 1.29	1.88 ± 1.14	4.34 ± 1.68
North Delta	BCSD	1.41 ± 0.83	2.41 ± 1.78	1.98 ± 1.12	4.42 ± 2.41
	IMHEN	1.48 ± 1.10	2.20 ± 1.38	1.80 ± 1.10	4.10 ± 1.77
North Central	BCSD	1.34 ± 0.84	1.86 ± 1.01	2.26 ± 1.68	3.68 ± 1.06
	IMHEN	1.34 ± 0.96	2.00 ± 1.20	1.65 ± 0.93	3.87 ± 1.30
Central Highlands	BCSD	1.21 ± 0.66	2.50 ± 1.97	1.67 ± 0.62	3.78 ± 1.31
	IMHEN	1.2 ± 0.98	1.79 ± 0.98	1.54 ± 0.96	3.76 ± 1.16
South Central	BCSD	1.14 ± 0.68	1.88 ± 1.21	1.57 ± 0.58	3.60 ± 1.21
	IMHEN	1.13 ± 0.77	1.67 ± 0.96	1.42 ± 0.86	3.47 ± 1.06
Southern Viet Nam	BCSD	1.15 ± 0.72	1.89 ± 1.21	1.61 ± 0.57	3.68 ± 1.06
	IMHEN	1.14 ± 0.88	1.72 ± 0.96	1.45 ± 0.93	3.64 ± 1.28

[Figure 1.10]

Annual temperature changes under RCP4.5 and RCP8.5



Projected annual temperature changes (average from the dynamical downscaling results) under RCP4.5 and RCP8.5 for the mid-century period 2046–2065 (left) and the end-century period 2080–2099 (right) relative to the baseline 1986–2005.

Figure 1.10 illustrates the projections for annual temperature changes at 150 meteorological stations in the middle and at the end of the XXIst century under RCP4.5 and RCP8.5. It is worthy to note that the dynamical downscaling experiments used here are also the experiments used in the updated 2021 scenarios [IMHEN, 2021]. As in global projections, it is found that temperature increases are more pronounced at the end of the century, with much higher increases under RCP8.5 compared to RCP4.5. The increases are more noticeable in the areas in the North, decrease gradually in the South, and register the lowest changes in the Southern Central, Southern Viet Nam and island stations.

More precisely, the dynamical downscaling experiments project a general increase of 1.2–1.7°C in annual temperature over the whole country in the middle of the century under RCP4.5; projected temperature in the North increases by 1.6–1.7°C, and that in the South increases by 1.2–1.3°C. Under RCP8.5 in the mid-century period, temperature is pro-

jected to increase by 1.7–2.3°C in all areas; projected temperature in the North increases by 2.0–2.3°C, and that in the South increases by 1.7–1.9°C. At the end of the century, i.e. the period 2080–2099, both RCPs indicate higher temperature increases compared to these in the mid-century period; projected temperature increases by 2.0–2.4°C in the North and by 1.8–1.9°C in the South under RCP4.5, and the highest temperature increases could reach 4.7°C under RCP8.5.

Seasonal temperatures are projected to increase from the middle to the end of the century under both RCP4.5 and RCP8.5 [Table 1.8]. The highest increase of 4.6°C occurs in summer at the end of the century under RCP8.5. Meanwhile, the temperature changes are projected to be the smallest in winter, with the highest increase of 2.2°C and 3.8°C at the end of the century under RCP4.5 and RCP8.5, respectively.

[Table 1.8]

Seasonal temperature changes (°C) under RCP4.5 and RCP8.5 averaged from the dynamical downscaling experiments

Time	RCP4.5		RCP8.5	
	Mid-century	End-century	Mid-century	End-century
Spring	1.3–1.7°C	1.7–2.3°C	1.8–2.4°C	3.1–4.2°C
Summer	1.3–1.8°C	1.7–2.5°C	1.7–2.5°C	3.3–4.6°C
Autumn	1.2–1.7°C	1.6–2.3°C	1.7–2.4°C	3.2–4.4°C
Winter	1.2–1.6°C	1.5–2.2°C	1.7–2.2°C	2.9–3.8°C

[Table 1.9]

Daily maximum and minimum temperature changes (°C) under RCP4.5 and RCP8.5, averaged from the dynamical downscaling experiments

Time	RCP4.5		RCP8.5	
	Mid-century	End-century	Mid-century	End-century
Tx	1.3–1.9°C	1.7–2.6°C	1.8–2.6°C	3.2–4.7°C
Tn	1.3–1.6°C	1.7–2.1°C	1.8–2.3°C	3.3–4.1°C

Temperature extremes

Annual daily maximum temperature Tx and annual daily minimum temperature Tn are also projected to increase under RCP4.5 and RCP8.5 [Table 1.9]. In the mid-century period under RCP4.5, an overall increase in Tx of 1.3–1.9°C is projected for Viet Nam as a whole; the North increases by 1.5–1.9°C and the South by 1.3–1.4°C. Under RCP8.5, Tx may increase by 1.8–2.6°C nationwide; the North increases by 2.3–2.6°C and the South by 1.8–1.9°C. In the end-century period 2080–2099 under RCP4.5, Tx is projected to increase by 1.7–2.6°C; the North increases by 2.0–2.6°C and the South by 1.7–2.9°C. Under RCP8.5, much higher increases of 3.2–4.7°C are projected for Tx, with the highest projected increases of 4.0–4.7°C observed in the North.

Annual daily minimum temperature Tn is projected to increase by 1.3–1.6°C in the mid-

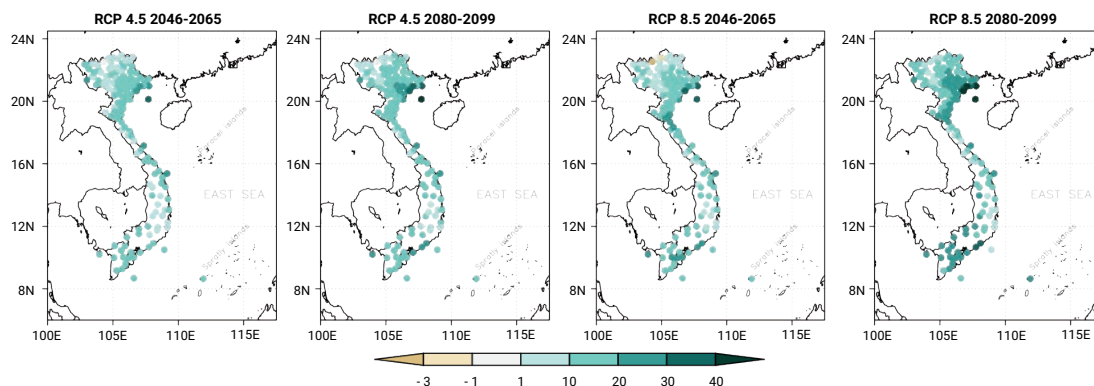
century 2046–2065 under RCP4.5. In the end-century period, Tn may increase by 1.7–2.1°C, with increases of over 2.0°C widespread in the North. In the mid-century under RCP8.5, Tn may increase by 1.8–2.3°C, with Tn in the North also projected to increase by over 2.0°C. At the end of the XXIst century, projected Tn generally increases by 3.3–4.1°C.

Rainfall

Past simulations and future projections for rainfall usually contain more uncertainties than those for temperature [Knutti and Sedláček, 2013; Ngo-Duc, *et al.*, 2017]. While GCM and regional downscaling results generally project increased temperatures in almost all parts of the world in the future, the results for rainfall are quite different. One model can project increased rainfall at a particular location while another shows decreased rainfall.

[Figure 1.11]

Annual rainfall changes under RCP4.5 and RCP8.5



Projected annual precipitation changes under RCP4.5 and RCP8.5 for the mid-century 2046–2065 and end-century 2080–2099 periods, average from the dynamical downscaling results.

In Viet Nam, results on rainfall projections certainly vary according to the model, region or scenario chosen. Therefore, in order to match the rainfall change results in the updated 2016 and 2021 scenarios [MoNRE, 2016; IMHEN, 2021], this section only discusses the projected rainfall results obtained with the five dynamical downscaling experiments provided by IMHEN.

Average rainfall

Annual average rainfall is projected to increase significantly throughout Viet Nam under both RCP4.5 and RCP8.5 [Figure 1.11]. The increases for the whole country may be 10–15% in the mid-century and 10–20% at the end-century under RCP4.5. In the mid-century under RCP8.5, annual rainfall is projected to increase by 10–15% for almost all Viet Nam, and by 20–30% in some islands and coastal stations. Projected rainfall partially decreases in Lao Cai and Ha Giang by a negligible amount, generally less than 5%. At the end of the century under RCP8.5, the increases are typically about 10–25% throughout Viet

Nam, reaching over 40% in some parts of the Northeast region.

Changes in rainfall during the rainy and dry seasons under the two RCPs have also been considered: they are projected to increase throughout most of Viet Nam in the future. Rainy season precipitation increases by 5–30% in the mid-century and 10–40% at the end-century under RCP4.5; under RCP8.5, the increases are 5–25% and 15–30% in the mid- and end-century respectively. Dry season precipitation is projected to increase by 8–20% in the mid-century and 10–25% in the end-century under RCP4.5, with relatively higher increases in the coastal Northeast region and lower increases in the Central Highlands and the Northern Central region. Under RCP8.5, 5–25% rainfall increases in the dry season are projected over almost all the country at the end of the century, except for some parts in the North Delta, southern Central Highlands and Southeast Viet Nam, where decreases of less than 5% are forecast.

[Table 1.10]
Changes of seasonal rainfall in Viet Nam under RCP4.5 and RCP8.5 relative to the baseline period 1986–2005, obtained from the dynamical downscaling results

Time	RCP4.5		RCP8.5	
	Mid-century	End-century	Mid-century	End-century
Spring	2–15%	2–15%	-5–10%	-2–10%
Summer	5–20%	3–25%	2–25%	10–25%
Autumn	5–25%	10–25%	5–25%	15–40%
Winter	5–15%	5–20%	5–25%	5–15%

[Table 1.11]
Changes in annual maximum 1-day precipitation (RX1day) and annual maximum 5-day consecutive precipitation (RX5day) under RCP4.5 and RCP8.5, obtained from the dynamical downscaling results

Time	RCP4.5		RCP8.5	
	Mid-century	End-century	Mid-century	End-century
RX1day	15–25%	20–35%	15–25%	25–40%
RX5day	10–20%	20–30%	15–25%	25–40%

The changes in seasonal rainfall are shown for all four seasons under the two RCPs in Table 1.10. Among the four seasons, autumn was forecast to experience the highest rainfall increase of up to 40% at the end of the century under RCP8.5. Spring rainfall increases by 2–15% in the mid- and end-century under RCP4.5 while it decreases in some places under RCP8.5. Summer and winter rainfall increases by 5–25% under both RCPs.

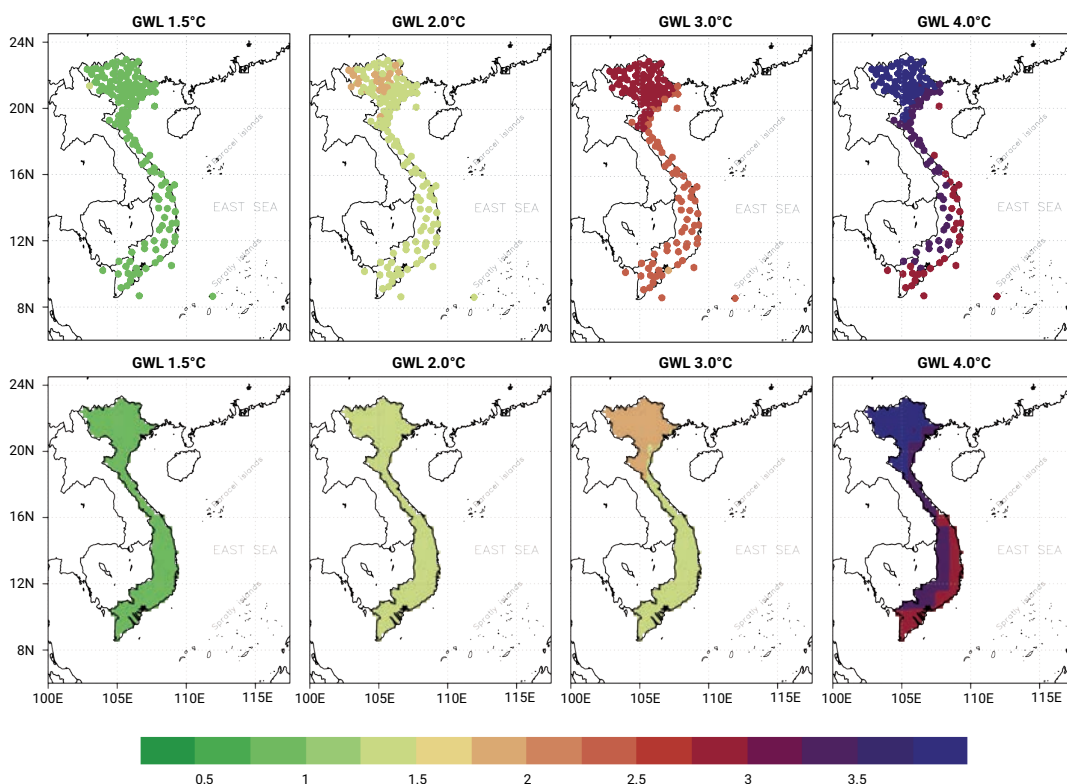
Precipitation extremes

Annual maximum 1-day precipitation (RX-1day) and annual maximum 5-day consecutive precipitation (RX5day) are projected to increase throughout Viet Nam in the XXIst century under RCP4.5 and RCP8.5 [Table 1.11].

RX1day is generally projected to increase by 15–25% under both RCPs for mid-century, and by as much as 24–30% and 25–40% respectively under RCP4.5 and RCP8.5 at the end of the century. Projected RX5day increases by 10–20% and 15–20% in the mid-century, and increases more strongly by 20–30% and 25–40% at the end of the century under RCP4.5 and RCP8.5, respectively. The North Delta region has the highest increase in both RX1day and RX5day at the end of the century.

[Figure 1.12]

Temperature changes in Viet Nam for different Global Warming Levels (GWLs)



Temperature changes in Viet Nam at the times when the GWLs are reached, relative to the baseline 1986–2005. Results obtained from all the dynamical downscaling experiments (upper panel) and from that of the BCSD statistical downscaling (lower panel).

3.3 Changes with global warming levels +1.5°C, 2°C, 3°C, 4°C

Based on the method described in Section 3.1.3, this section presents some results on temperature and rainfall changes in Viet Nam corresponding to the GWLs +1.5°C, 2°C, 3°C, and 4°C. The calculations were implemented with the ensemble of the dynamical downscaling experiments provided by IMHEN and that of the BCSD statistical downscaling. For the

BCSD method, the numbers of experiments used for identifying the changes corresponding to the GWLs +1.5°C, 2°C, 3°C, and 4°C are 76, 65, 33 and 18, respectively. For IMHEN, the numbers of experiments used are 20, 20, 20 and 10 respectively.

Temperature

The results for temperature changes in Viet Nam at the times the different GLWLs are reached are shown in Figure 1.12. It should be noted that the results from the BCSD

statistical downscaling ensemble are similar to these from the dynamical downscaling method.

In the case of the 1.5°C GWL (*i.e.* global warming level of 1.5°C relative to the period 1850–1900), annual temperatures over the whole country generally increase by 0.7–0.9°C relative to the baseline 1986–2005, with the highest increase in the North and the lowest in Central Viet Nam.

In the case of the 2°C GWL, typical increases are 1.1–1.5°C relative to the baseline 1986–2005, with the highest increase in the North (1.4–1.5°C) and the lowest in Southern Viet Nam (1.1–1.2°C).

When the GWL reaches 3°C, general increases are 2.2–2.8°C relative to the baseline 1986–2005, with the highest increase in the North (2.6–2.8°C) and the lowest in the coastal Southern Central region and Southern Viet Nam (2.0–2.1°C).

When the GWL reaches 4°C, general increases relative to the baseline 1986–2005 throughout Viet Nam are projected to be 3°C or higher, with the highest increase in the North (over 3.7°C) and the lowest (2.8–3°C) once again in the coastal Southern Central region and Southern Viet Nam. Meanwhile, precipitation in Central Viet Nam and the Central Highlands increases by 3.2–3.5°C.

Precipitation

The results for rainfall changes in Viet Nam at the times when the different GWLs are reached are displayed in [Figure 1.13](#). It should be noted that results obtained with the BCSD experiments for some regions can be significantly different from those obtained with the

dynamical downscaling method. The difference can be at least partly attributed to the difference in the number of GCMs used in determining the GWLs and the number of GHG scenarios used (the BCSD used 4 RCPs with a maximum of 76 GCM experiments, while IMHEN used 2 RCPs with 10 input GCMs).

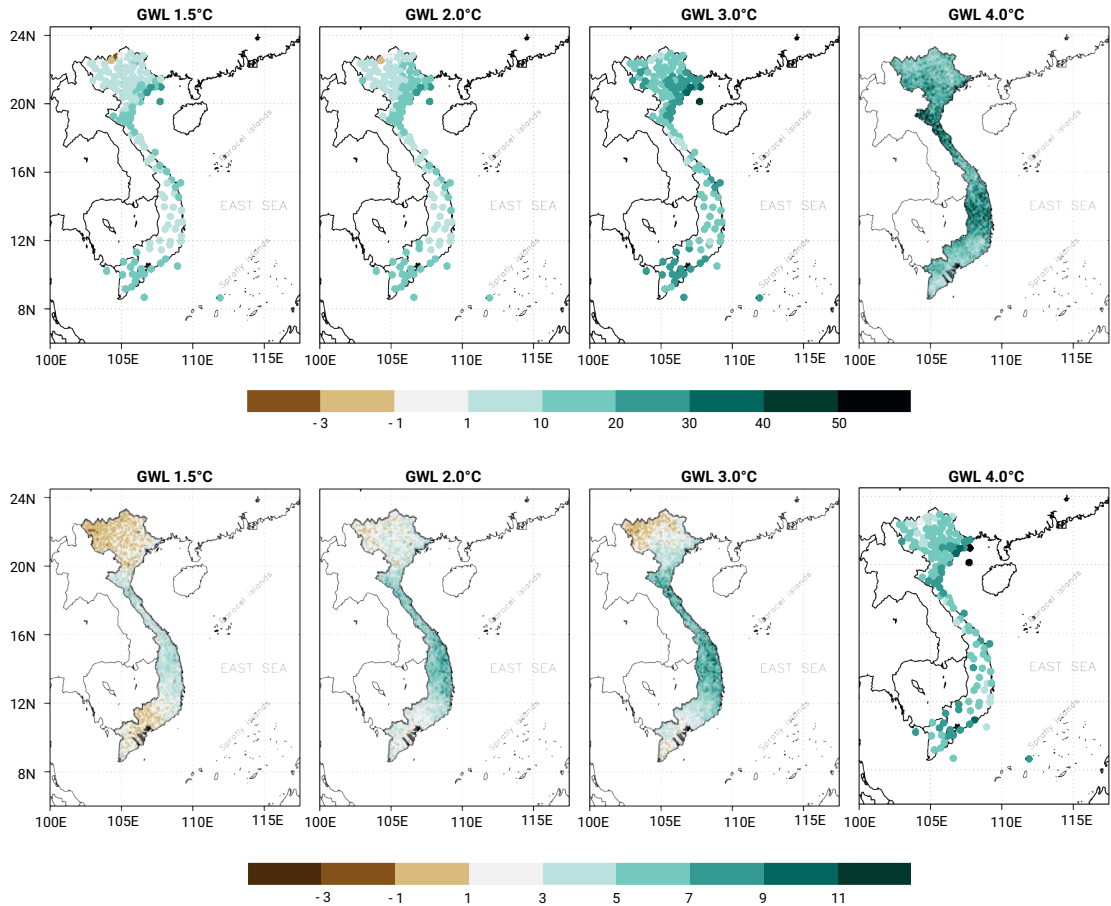
The results obtained with dynamical downscaling indicate that in the case of the 1.5°C GWL, annual rainfall is projected to increase over almost all Viet Nam by 0–20% relative to the baseline 1986–2005, with the highest increases of 10–20% forecast at some stations in Northeast, Northern Central and Southern Viet Nam. In the coastal areas and several island stations in the Northeast, the increases can reach over 20%. Projected rainfall increases slightly in the Central Highlands and the Southern Central region. For the BCSD method, the North and the South have small decreases with the 1.5°C GWL. Rainfall projected by the BCSD in Central Viet Nam and the Central Highlands also increases, but at a small rate of less than 5%.

With the 2°C and 3°C GWLs, annual rainfall changes are rather similar to the results with the 1.5°C GWL. However, the increasing rates are higher and the areas with decreased rainfall projected by the BCSD are reduced. For the 3°C GWL, rainfall at some island stations and the coastal Northeast region is even projected to increase by 40% in the dynamical downscaling experiments provided by IMHEN, while increases of up to 11% can only be found in the Northern Central and Southern Central regions and the Central Highlands, according to the BCSD results.

When the GWL reaches 4°C, both downscaling methods indicate increased future rain-

[Figure 1.13]

Rainfall changes in Viet Nam for different Global Warming Levels (GWLs)



Rainfall changes in Viet Nam at the times when the GWLs are reached, relative to the baseline 1986–2005. Results obtained from all the dynamical downscaling experiments (upper panel) and from that of the BCSD statistical downscaling (lower panel). Note the difference of scale between the two panels.
Unit: %

fall in Viet Nam. For the dynamical experiments, rainfall is projected to increase most by 10–30% in the North East, North Delta and Southern Viet Nam, and even by over 40% in some stations. Meanwhile, the BCSD method displays a 0–10% increase over almost the whole country; in some areas in Central Viet Nam and the Central Highlands, rainfall may increase by over 10%.

3.4 Sea level rise in response to climate change

Future sea level depends on future anthropogenic greenhouse gas emissions and the resulting global warming level. According to process-based modelling studies [IPCC, 2019], GMSL rise will continue in all climate scenarios, even if the global mean temperature

[Table 1.12]
Projections of global mean sea level rise compared to 1986–2005 [IPCC, 2019]

	2050	2100
RCP2.6	0.24 m (0.17–0.32, likely range)	0.43 m (0.29–0.59, likely range)
RCP8.5	0.32 m (0.23–0.40, likely range)	0.84 m (0.61–1.10, likely range)

[Table 1.13]
Projections of sea level rise in the coastal regions of Viet Nam compared to 1986–2005
[IMHEN, 2021]

	2050	2100
RCP2.6	0.24 m (0.13÷0.32)	0.44 m (0.27÷0.66)
RCP4.5	0.23 m (0.13÷0.31)	0.53 m (0.32÷0.76)
RCP8.5	0.27 m (0.19÷0.36)	0.73 m (0.49÷1.03)

were to be stabilized to less than 2°C above the preindustrial level (RCP2.6 scenario).

Up to 2050, it is argued that uncertainty in future GMSL is relatively small. Projections under the different RCP scenarios are relatively similar, with differences limited to a few centimetres. However, in the second half of the century, major uncertainties arise from the emission scenarios; projections diverge, ranging from 29 cm under RCP2.6 to 1.10 m under the worst-case scenario RCP8.5 [Table 1.12].

Based on the results from SROCC (2019), projections of sea level rise for Viet Nam have been updated [IMHEN, 2021]. Table 1.13 displays the projected sea level rise in the coastal region of Viet Nam for the different RCP scenarios. Note that the regional variations along Viet Nam coastlines are limited to a few cm.

However, it is worth noting that there is only medium confidence in these projections

[SROCC, 2019]. Indeed, the future behaviour of polar ice sheets, especially the Antarctic ice sheet, remains highly uncertain, due to limited observations, poorly understood physical processes and limitations in ice-sheet models. Mass loss from the Antarctic and Greenland ice sheets has tripled and doubled respectively over 2007–2016 relative to 1997–2006 [SROCC, 2019], and this acceleration has raised growing concerns about the potential crossing of irreversible thresholds, leading to irreversible ice sheet instability. This hypothesis is not taken into account in the aforementioned projections, which may thus underestimate future GMSL rise, even in the medium term. Hence, following the recommendations of SROCC (2019), stakeholders with low risk tolerance may want to also consider higher projections. It is currently estimated that there is a 17% chance that global mean sea level rise in 2100 will exceed 0.59 m under RCP2.6 and 1.10 m under RCP8.5 [IPCC, 2019]. According to the structured

judgement of 22 glaciological and modelling experts [Bamber *et al.*, 2019], there might even be a 5% probability of reaching extreme

values above 60 cm and 2 m in 2050 and 2100 respectively, under a high global warming scenario (5°C in 2100).

4. Conclusions

This chapter presented some updated assessments on climate change in Viet Nam. Observed daily data for the period 1981–2018 were used to assess past climate trends. The dynamical downscaling and BCSD statistical downscaling methods were applied to forecast climate change in Viet Nam in the XXIst century.

The key results presented in this chapter are as follows:

- ▶ Annual temperatures increased over the whole country, with a nationwide average increase of 0.89°C (~0.146°C/decade) for the period 1958–2018. Rates of increase vary between regions and seasons. The rates of increase were 0.205°C and 0.231°C per decade for the periods 1981–2018 and 1986–2018, respectively. This indicates that temperature is gradually rising over time, and was highest in the last decade. The numbers of hot days and very hot days increased; by contrast, the numbers of cold days and very cold days in the North decreased;

- ▶ Annual rainfall over the whole country slightly increased by 5.5% for the period 1981–2018, but with contrasting trends depending on the region under examination. Rainfall decreased at several stations in the North of Viet Nam, and increased at many stations in the North East, North Delta, South Central and Central Highlands regions. Rainfall extremes tended

to vary throughout the climatic sub-regions: they declined in stations in the coastal areas in the North Central region, and increased in many stations in the North East, North West and South Central regions;

- ▶ Both station and satellite altimetry data show an increasing sea level trend in the coastal areas of Viet Nam. The trend was about 3.6 mm/year for the period 1993–2018, with the highest rate of 4.2–5.8 mm/year from Quang Ngai to Binh Thuan, and a lower rate of 2.2–2.5 mm/year in the Southern region;

- ▶ The average temperature in Viet Nam in the middle of the XXIst century was projected to increase from 1.13±0.87°C under RCP2.6 to 1.9±0.81°C under RCP8.5, relative to the baseline period 1986–2005. At the end of the century temperature was projected to increase from 1.34 ±1.14°C under RCP2.6 to 4.18±1.57°C under RCP8.5. Temperature is expected to increase faster in the North than in the South;

- ▶ In the results of the dynamical downscaling experiments provided by IMHEN, annual rainfall was projected to increase in most parts of Viet Nam in the future. Under RCP4.5, projected annual rainfall increases throughout Viet Nam by 10–15% in the mid-century, and by 10–20% at the end of the century. Under RCP8.5, projected annual rainfall also increases by 10–15% over almost all Viet Nam in the middle of the XXIst century;

► Temperature and rainfall changes in Viet Nam corresponding to the times when the global warming levels (GWL) of 1.5°C, 2°C, 3°C, 4°C are reached, have been calculated using both the dynamical downscaling and the BCSD experiments. With all the different GWLs, temperature in Viet Nam was projected to increase, with the highest rate in the North and the lowest one in the coastal Southern Central region and Southern Viet Nam. Annual rainfall was projected to generally increase with the GWLs, especially in Central Viet Nam and the Central Highlands;

► The sea level rise in coastal areas of Viet Nam is projected to increase from 0.24 (0.13÷0.32) under RCP2.6 to 0.27 m (0.19÷0.36) under RCP8.5 in the mid-century period. At the end of the century, the projected increase is 0.44 m (0.27÷0.66) and 0.73 m (0.49÷1.03) under RCP2.6 and RCP8.5, respectively. It is worth noting that, due to large uncertainties in the future behaviour of polar ice sheets, much higher values — up to over 2 m in 2100 — cannot be ruled out.

One of the highlights of this Chapter is the successful application of the BCSD statistical downscaling method to construct the high-resolution (~10km) climate scenario set for Viet Nam with the input of 31 CMIP5 GCMs. With the BCSD method, future scenarios for Viet Nam are not only limited to RCP4.5 and RCP8.5 but also available for RCP2.6 and RCP6.0, which are the scenarios little mentioned in previous studies of Viet Nam.

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Chapter 2

Climate change and adaptation in Viet Nam contributions from environmental history

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Abstract

Through the knowledge it brings of past climate fluctuations and its description of how societies have adapted to those changes, history has an important contribution to make in refining global warming scenarios, particularly in terms of adaptation and resilience. This is the demonstration that this chapter provides for Viet Nam, by referencing varied sources that range from dendrochronology to the meteorological bulletins of the colonial period and the imperial archives. Thanks to this combination of archive material and sources from the natural sciences, we can retrace natural and climatic variations from the XIIIth century onwards – and well beyond, in the case of some data. It also enables us to grasp the climate knowledge and theories of the past, and to understand that the desire to intervene in the climate is not a new one. This chapter opens up new horizons for research: although not yet highly developed in Vietnamese historiography, they deserve particular attention as tools to both foster academic knowledge and support the development of contemporary climate policy.

Tóm tắt

Thông qua tri thức về thay đổi khí hậu trong quá khứ và mô tả về cách thức các xã hội thích ứng với những thay đổi đó, lịch sử có đóng góp quan trọng trong việc tiếp cận các kịch bản nóng lên toàn cầu, đặc biệt là với khả năng thích ứng và chống chịu. Chương này chính là sự phản ánh điều đó trong khung cảnh Việt Nam bằng việc thống kê các nguồn tài liệu khác nhau từ phân tích vòng tuổi thân cây tới dữ liệu trên các bản tin khí tượng thời thuộc địa và kho lưu trữ hoàng cung. Nhờ sự kết nối tài liệu lưu trữ với dữ liệu từ các ngành khoa học tự nhiên, chúng ta có thể tái hiện những biến động về tự nhiên và khí hậu từ thế kỷ XIII trở đi – thậm chí là từ trước đó nữa đối với một số loại dữ liệu. Chúng cũng cho phép chúng ta nắm rõ tri thức khí hậu và các lý thuyết tiếp cận trong quá khứ, để hiểu rõ rằng nỗ lực can thiệp vào khí hậu không phải là một vấn đề mới. Chương này sẽ mở ra những đường chân trời mới cho lĩnh vực nghiên cứu này: dù hiện tại vấn đề chưa được phát triển trong nền sử học Việt Nam, chúng xứng đáng có được sự chú ý đặc biệt như những công cụ để thúc đẩy tri thức học thuật và giúp cho sự phát triển của chính sách khí hậu hiện tại.

Résumé

L'histoire, par la connaissance des fluctuations passées du climat qu'elle apporte, et la description des adaptations des sociétés à ces changements, contribue fortement à affiner les scénarios du réchauffement climatique, particulièrement sur les questions d'adaptation et de résilience. C'est la démonstration qu'apporte ce chapitre pour le Viet Nam en utilisant une grande diversité de sources, de la dendrochronologie aux bulletins météorologiques de la période coloniale en passant par les archives de l'époque impériale. Cette combinaison d'archives et de sources issues des sciences naturelles permet de retracer les aléas naturels et climatiques depuis le XIII^{ème} siècle et pour certaines données parfois très au-delà. Elle permet aussi de saisir les connaissances et les théories du climat d'autrefois, et de comprendre que la volonté d'agir sur le climat n'est pas nouvelle. Ce chapitre ouvre ainsi de nouveaux horizons de recherche encore peu développés dans l'historiographie Vietnamiennne alors qu'ils méritent une attention particulière non seulement pour nourrir les connaissances académiques mais aussi appuyer l'élaboration des politiques climatiques contemporaines.

“We have only two ways to anticipate the impact of a future catastrophic climate change, neither of them particularly precise or entirely reliable. Either we “fastforward” the tape of history and predict what might happen on the basis of current trends; or we “rewind the tape” and learn from what happened during the global catastrophes in the past. Although many experts (mainly climatologist, sociologists, and political scientists) have tried the former, few have systematically attempted the latter.”

Parker, 2008, p. 1078

1. Introduction

Climate policies aimed at mitigating global warming, whether national or international, are the result of complex processes involving scientific evidence, the economic feasibility of instruments and proposed solutions, and – of course – diplomatic compromises between parties with varying interests in taking action [Aycut & Dahan, 2015]. This chapter focuses on the place occupied by climate history in providing evidence of global warming and its anthropogenic origin, and also in recalling past human concerns and adaptations to climate changes.

The history of climate is written by two very distinct communities: hard scientists (climatologists, meteorologists, glaciologists, palaeo-climatologists, atmospheric physicists, etc.) on the one hand, and professional historians on the other. The importance of the former has been decisive in providing evidence of the anthropogenic origin of climate change [Charney *et al.*, 1979; Crutzen, 2002; Steffen, Crutzen, & McNeil, 2007], and then in building an active climate diplomacy, particularly since 1988 with the creation of the Intergovernmental Panel on Climate Change [IPCC, 1990]. The role of professional historians, on the other hand, is relatively unknown, although their contributions are quite remarkable.

This chapter focuses on the originality of this latter community's contribution. We will defend the thesis that the sources deployed by climate historians produce a *human history of the climate* that is much more attentive to the observation of societies in the face of climate change than the *natural history of the climate* produced by climate scientists. For this reason, the climate history produced by historians is absolutely essential for policy-makers. It sheds light on the way in which past societies perceived and recorded climate fluctuations, how they adapted to them, and even how they sometimes tried to correct them through their actions.

The aim of this chapter is to highlight the potential contribution of history to the development of public policies to mitigate climate change. It is also to warn the reader that, despite the existence of some recent academic work [Lieberman & Buckley, 2012], this *human history of climate* remains largely under-researched for Viet Nam and Southeast Asia, and that it is precisely this kind of history that needs to be promoted, in order to encourage its development and quickly reap its benefits. This chapter will nevertheless show that a number of already-published works of Vietnamese environmental history have contributed valuable material, which deserves to be taken into account. In particular, these academic works show that the Vietnamese imperial

archives carefully recorded a number of climatic phenomena (such as typhoons, floods, droughts, etc.). Precursory work on these archives already allows us to glimpse how the Vietnamese people were able to develop different strategies for adapting to these recurring climatic phenomena, and also how the State (the emperors and mandarins) attempted to influence the climate [Langlet & Quach, 1995; Dyt, 2015; Phung, 2017; Liêm, 2018].

By unearthing the ways in which imperial power dealt with climatic calamities over past centuries, climate history helps to anchor contemporary debates on, and responses to, climate change in a long historical tradition that is currently largely unknown. We believe that anchoring contemporary climate challenges in national and local history provides a way of fully appropriating international greenhouse gas reduction objectives at the national level. These objectives are defined by international experts, who are quite rightly trying to govern the climate as a global commons, but who know little about the national and cultural specificities of societies in their relationship to climate — and nature in general — because it is not their job. This anchoring is also a response to many experts from the IPCC's Group 2 (responsible for assessing the regional impacts of climate change and adaptation measures), who have commented that the continental scales they work with are too broad to offer effective mitigation and adaptation measures. They suggest adopting more human scales (agricultural activities, transport, and urban planning in particular) [Le Treut, 2018]. Environmental history should make this re-appropriation possible. We hope that this chapter will contribute to this academic and policy-making goal.

The first part consists mainly in a discussion about what constitutes climate history. It first

recalls that the history of the climate is as old as humanity itself: people and societies have always paid great attention to the climate. It goes on to describe the specificities of the history of climate since its revival in the 1950s, particularly as concerns its treatment of sources and its definition of legitimate questions.

The second part is devoted to the immense potential of the Vietnamese primary sources for writing a rich climatic history of the country. It emphasizes that climate and weather — and the place allotted to them by society — are essential features of Viet Nam's classical culture. This explains why the Imperial Annals and a host of other sources carefully recorded all the climatic disasters that have struck the country.

The third part examines sources from the XIXth century to the present day. It includes the colonial archives of the French Meteorological and Climatic Service, and the contemporary archives of the Meteorological Services of the Socialist Republic of Viet Nam.

2. What is climate history? Ancient and modern approaches

Mankind's interest in the climate and in its influence on humans and societies is as old as history itself. Western historiography often traces it back to Aristotle's *Meteorologica*, which established a cosmology that saw meteors as the result of interactions (forces, principles, substances, essences, etc.) between the stars, the ether and the four elements of the Earth: earth, water, air, and fire. In this closed

universe [Koyré, 1962], the influence of the climate on humans has been a constant — and even central — concern of Aristotelian and Hippocratic medical thought over the centuries; it extends well beyond Kepler, as shown by the project of the astronomer Guiseppe Toaldo in the late XVIIIth century to develop *astrometeorology*, a science correlating weather with the position of the stars in order to forecast the weather using knowledge of the movement of the planets [Fressoz & Locher, 2020].

Similar cosmologies flourished in many parts of the world, even before Aristotle, and particularly in China (see the *Book of Documents* (Shujing), the *Book of Odes* (Shijing), the *Book of Mutations* (Yijing): there, the Dao and the male and female principles (*yin* and *yang*) were seen as the origins of a respiratory movement in the world (between 9 constellations, 5 planets and the 5 elements of the Earth (Metal, Water, Wood, Fire, and Earth) [Granet, 1934; Major, 1993; Cheng, 1997; Smith & Kwok, 1993; Tucker, 1994].

In both cases (classical Greek and Chinese cultures), the intimate correspondences between macrocosm and microcosm gave rise to the development of a deterministic conception of the world, which allowed scholars to infer other laws of nature from their general knowledge of the movement of the universe [Jullien, 1983]. All Chinese sciences are based on this determinism [Needham, 1973], and in particular those of the climate and its profound influences on humans, their health and their individual and collective destiny. The author of the *Huainanzi*, a synthesis of all cosmographic speculations in the Han period (the 2nd century B.C.) shows this particularly well:

“ As Heaven and Earth were not yet formed, as everything was vast, immense, dark

and aspectless, this was called the Great Beginning. The Dao began in the vastness of the void. It then took on contours. That which was pure and light rose and spread out to give Heaven. What was heavy and coarse was difficult. Therefore, Heaven was completed first, and the Earth formed only afterwards. The assembled essences of Heaven and Earth gave Yin and Yang. The concentrated essences of Yin and Yang gave the four seasons. The dispersed essences of the four seasons gave the ten thousand beings. The hot breath of Yang in accumulation gave fire, and the essence of the breath of fire gave the sun. The cold breath of Yin in accumulation gave water, and the essence of the breath of water gave the moon. (...) Of the breaths rejected by Heaven, those which are unleashed give the wind, of the breaths contained by the Earth, those which are harmonious give the rain. The furry and feathered beasts are the species that walk and fly: so they belong to the Yang. The animals with shells and scales are the species that crouch and hide: so they belong to Yin. (...) Beings of the same species shake each other, the root and the branches respond to each other. ”

Huainanzi, ed. ZZJC, p. 3 & 35,
quoted by Anne Cheng, 1997, p. 282

As we can see, the ancient civilizations shared common conceptions of the climate and its influence on human destiny for many centuries. Indeed, the interim of the 19th and 20th centuries — between these ancient cosmologies and the contemporary Anthropocene — when modern scientists set themselves the sole task of understanding the climate without acting on it, was short-lived in the overall history of mankind: contemporary climate change brings us back to this desire for human action on the climate.

Contemporary climate history, as a specific historiographical stream, emerged in the 1950s, at a time when western scientific culture had lost faith in the ancient cosmologies and the beliefs that man could influence the climate. Climate historians have thus distanced themselves from these old theories of reciprocal influence between man and climate, and adopted scientific methods to establish new approaches to climate history. They were mainly medievalists and modernists, who were moving away from economic history and rural history towards a 'geohistory' — like Fernand Braudel (1949) — that makes the environment, and the climate in particular, their real object of research. They combed the archives for a quantity of climatic information, which could be combined into thermometric series to reconstruct climatic trends on a cen-

tennial (or decennial for the most recent periods) scale (See [Box 2.1](#)).

Mobilising data from two distinct kinds of archives — human and natural — calls for imagination. The first ones, referred to as "human" because they have been created by humans, are made up of dynastic chronicles, letters and diaries, judicial and government records, newspapers and broadsheets, oral traditions, calendars for harvesting certain crops, harvest volumes, iconographic documents like glacier paintings or engravings, and archaeological information (such as inscriptions on structures that date flood levels, etc.). The second ones are created by "non-human beings" — like glaciers, pollens or trees — that have registered past climate variations, sometimes with extreme precision.

[Box 2.1]

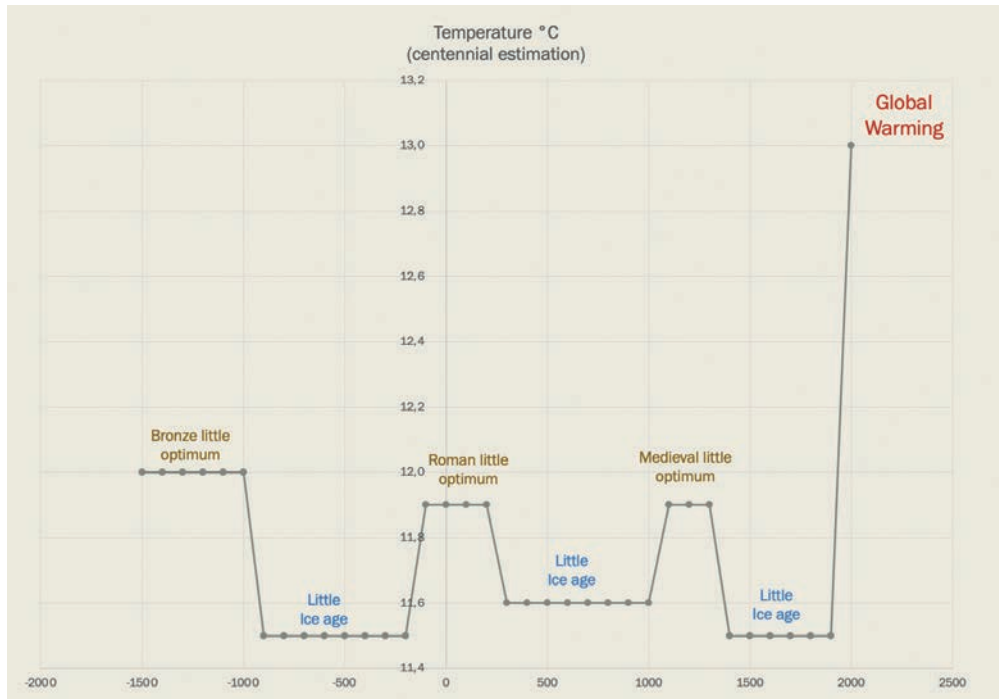
The founding fathers of climate history in the second half of the XXth century

Gordon Manley produced the first large thermometric series for England in 1946, which indicated monthly average temperatures for each year from 1659 to 1973 [Manley, 1946]; in 1955, Gustave Utterström published a history of the climate of Iceland and Sweden between the XIVth and XVth centuries (cooling period) and the XVIIth century, using a whole range of sources, in particular glacial chronologies and data from vines and cherry trees in England [Utterström 1955]; the medievalist John Titow in England discovered hundreds of unpublished texts in the manuscript accounts of the bishopric of Westminster on XIIIth century meteorology... [Titow, 1960]. In France in 1967, Emmanuel Le Roy Ladurie published *Histoire du climat depuis l'an Mil (History of the climate since the year 1000)*, an impressive compilation and an exceptional archival work [Le Roy Ladurie, 1967].

Ladurie very pragmatically raised questions of interdisciplinarity and collaboration of historians with the climate sciences, to compile "human archives" and "natural archives" of climate. He considers that the climate sciences (meteorology, palynology, archaeology, glaciology, atmospheric physics, etc.) should be auxiliary disciplines to the history of the climate and that, in consequence, historians should become familiar with these disciplines in order to be able to integrate their data into their own work. He himself seized upon dendrochronology (dating and identifying climatic variations using the annual growth rings of trees) and the American and Canadian tree-ring methods with enthusiasm. He also makes extensive use of phenology data (the study of the dates when certain plant phenomena — such as flowering or fruit ripening — take place). These data are present in the archives, particularly for plants such as grape vines. Because their advance or retreat also indicates climate changes, the glaciers of the Alps were a third significant source for Ladurie, who compiled all data concerning them in the communal and episcopal archives. Here again, he also used data from glaciologists: by citing data from the Aletsch glacier in Switzerland — which gives an idea of the climate in Western Europe from 1500 B.C — he encompassed a period of that includes almost all human history, thus initiating the early stages of global history.

[Figure 2.1]

Climate history in Europe from thermometric series and data from phenology, dendrochronology and glaciology



From E. Le Roy Ladurie, *Histoire du climat depuis l'an mil*, 1967.
Gathered by Frédéric Thomas

By combining all these types of data, historians have succeeded in reconstructing a very detailed chronology of climate change over the last three millennia. Figure 2.1, which is our synthesis made from the data provided by Ladurie, is a useful way of demonstrating the interest of the historian's methods. It shows the succession of seven major periods lasting several centuries, during which relatively mild climates, known as the 'Little Optimum', alternate with colder periods that historians are accustomed to calling the 'Little Ice Age', but which should not be confused with the last Pleistocene glaciation, the Würm, which lasted from 120,000 until 10,000 years ago.

Currently, the temporality that historians bring to climate history – thanks to their specific archival skills – is generally more precise than that of climatologists and glaciologists [Le Roy Ladurie, 1967, p. 48]. This has led Ladurie to conceptualise and defend “a *history of the climate for the climate, autonomous in its object*”, in which the climate is a historical object to be studied as such. In his introduction, he clearly states the nature of this project: “*Gradually, a broad perspective, from which this book stems, imposed itself on me: that of a climate to be studied historically for itself, and no longer only for its human or ecological impacts.*” (p. 25). From this perspective, the

history of the climate becomes an auxiliary science to the natural history of the climate, and departs from a conventional history centred on historical facts, which are always made up of humans, society, economic issues, culture, ideas, morals, religions, etc.

Alongside this Ladurian tradition, other approaches to climate history – focused more on the place of the climate in the life of

past societies – have also blossomed over the years, from Clarence Glacken's seminal *Rhodian shore* [Glacken, 1967] to the contemporary climate historians like James Fleming and Vladimir Jankovic (2011) and Jean-Baptiste Frescoz and Fabien Locher (2017), to name only few examples. In the next section, we will attempt to expose the various trends that are emerging in Vietnamese climate history.

3. Climate history of Viet Nam via the Imperial Annals

The climate of Viet Nam is particularly complex; it is the result of the encounter between the Chinese climate on the eastern side of the continent and the tropical monsoon climate of South-East Asia, and follows climatic regimes whose history is still only partially known, and whose advances are today much more the result of climatology and palynology based on natural archives (palynology, dendrochronology, lake sediments, coral reefs, etc.) than of human-archive based history.

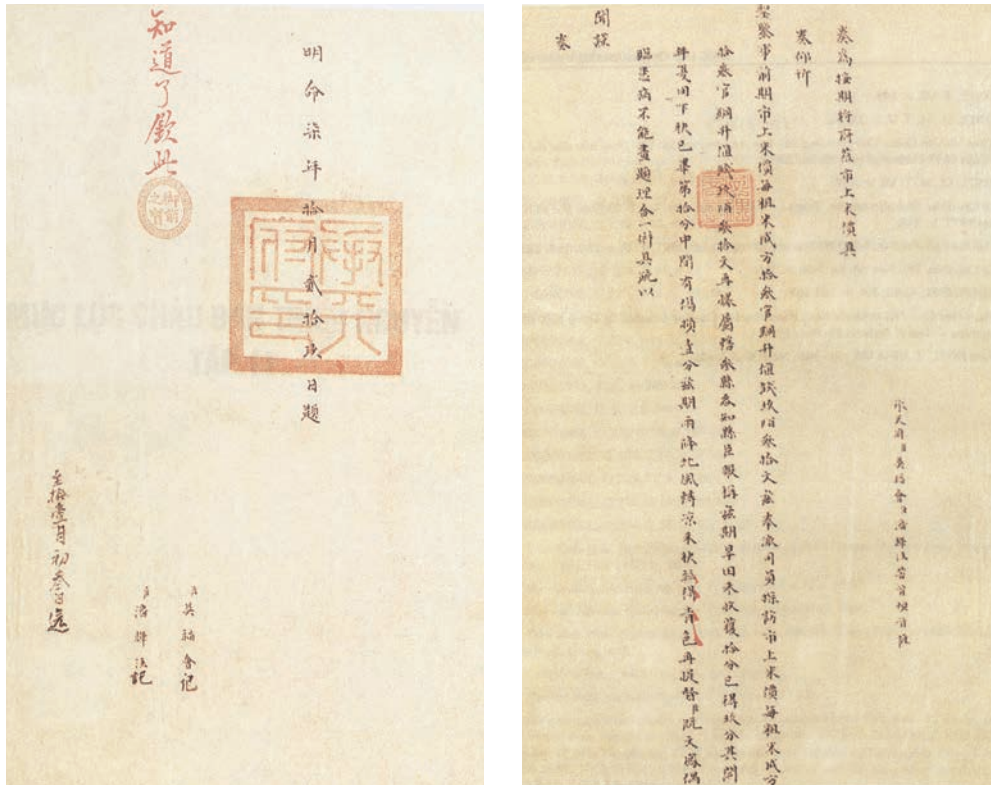
Nevertheless, the history of the climate in Asia, Southeast Asia and Viet Nam is not a total blank by any means. The Japanese historian Arakawa has notably published the annual dates of the first snowfall in Tokyo from 1632 to 1950 (this was the ritual day when the *daimos* came to pay their respects to the *shogun* Togukawa), and the Lake Suwa series for the period from 1444 to 1954, with the archives of a temple that recorded the dates of the lake's ice jam [Arakawa, 1954]. For Southeast Asia, the Australian historian Anthony Reid has ar-

gued that in the second half of the XVIIth century, the region suffered what was recognised as a Little Ice Age, which led to weaker monsoons, droughts and famines, and reduced the ability of the region's people and states to engage in trade, thus leaving the field open to European traders [Reid, 1993]. In Viet Nam, a new generation of young Vietnamese historians is demonstrating that local climate history is an emerging and very dynamic field, although primary sources still need to be mined to build long time series from existing archives.

In the first section we will begin by establishing a short review of the primary sources available to write the climate history of Viet Nam. In so doing, we will discover that there are almost two ways to build a history of climate in Viet Nam. One consists in examining the way the climate was considered in previous centuries: by analysing, for example, why – since practically the XIIIth century – the imperial power was so concerned by climatic issues and wanted an account of the weather. This kind of climate history pays particular attention to the cosmology and ontology of the classical Vietnamese culture that underpinned ways of thinking about the climate over the past century. The third section examines the second trend which, following in Le Roy Ladurie's

[Figure 2.2]

Report of rice price and weather conditions in Hue in the first quarter of 1826



Source: Nguyen dynasty state archive, memorials of the Minh Menh reign, vol. 20, National Archive N° 1.

footsteps, aims to rebuild the history of past climate thanks to a combination of natural and human archives. In a forth and final section, we will discuss the issue of climatic determinism in history, to highlight a certain inclination of many authors to develop such an approach to explain Viet Nam's national history.

3.1 Inventory of primary sources and the different “schools” to make them talk

Court reports and dynastic chronicles are among major sources of climatic informa-

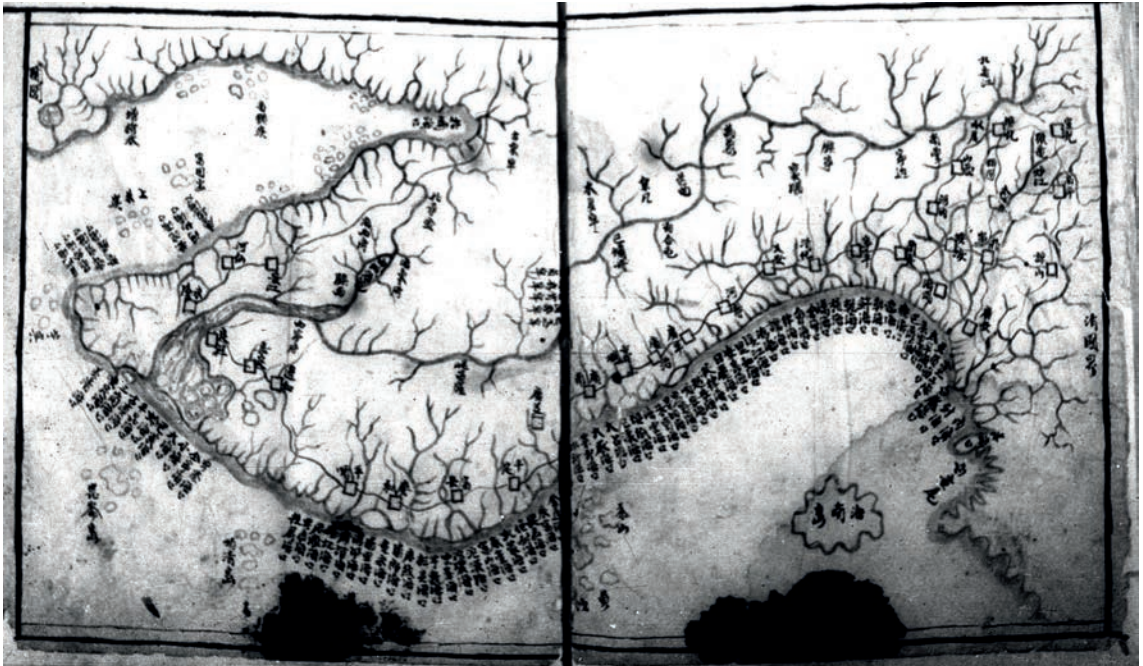
tion. Most important among them are the *Complete Book of the Historical Records of the Dai Viet* [Đại Việt sử ký toàn thư, 1697]. This book is the first extant dynastic chronicle of independent Viet Nam, dealing with the period from the early history of XIth century to the XVIIth century. From the XVIIth century, climate information is more abundant, and appears in the voluminous historical works produced by scholars of the Le and Nguyen dynasties. They include the first encyclopædia – the *Categorized Records of the Institutions of Successive Dynasties* [Lịch triều hiến chương loại chí, 1820] and the *Nguyen Veritable records* [Đại Nam Thực Lục, 1884].

Containing meteorological information, natural irregularities, calamities, pandemics, descriptions of natural landscapes and human responses to nature-fluctuated conditions, these documents are essential for understanding past Vietnamese society's experience of climate, and more broadly its relationship with nature. The Nguyen court established an organization called the Directorate of Imperial Observatory (欽天監). Among its many functions was measuring rain volume in the capital Huế (Đại Nam thực lục). Unfortunately, we know no more about how the Directorate of Imperial Observatory worked, and none of its records have survived.

Last but not least come maps and atlas collections produced between the XVth and 19th centuries. Although Viet Nam perused the Sinitic tradition of cartography [Whitmore, 1994], state authorities had invested heavily in mapping both communication lines and natural landscapes. Mountains, rivers, valleys, seaports, estuaries, canals, islands, and lagoons were recorded on paper in astonishing detail [Li, 2016; Liêm, 2016]. Map collections – such as the *Hong Duc Atlas* [Hồng Đức Bản Đồ, 1490], the Book of Maps of the Four Cardinal Points of the Southern Country [Thiên Nam tứ chí lộ đồ thư, 1686], and the Complete maps of Dai Nam [Đại Nam nhất

[Figure 2.3]

The Complete map of Dai Nam, illustrated with rivers and river estuaries



Source: Dai Nam Toan Do, A. 2959 (microfilm, EFEO, Paris).

thống toàn đồ, 1834] – are extremely valuable sources for reconstructing past topographies and their evolution over time under both human and natural impacts.

All these primary sources show without question that the history of Viet Nam has been constantly hit by violent climatic events, and that far from being exceptional, the alternation of droughts, floods and typhoons is Viet Nam's "normal" climatic regime due to its geographic position (Inter-tropical and East coastal region of a continent). Throughout the XIIIth, XIVth and XVth centuries, and repeatedly during XVIIth, XVIIIth and XIXth centuries, imperial chronicles report a high frequency of droughts, floods and typhoons.

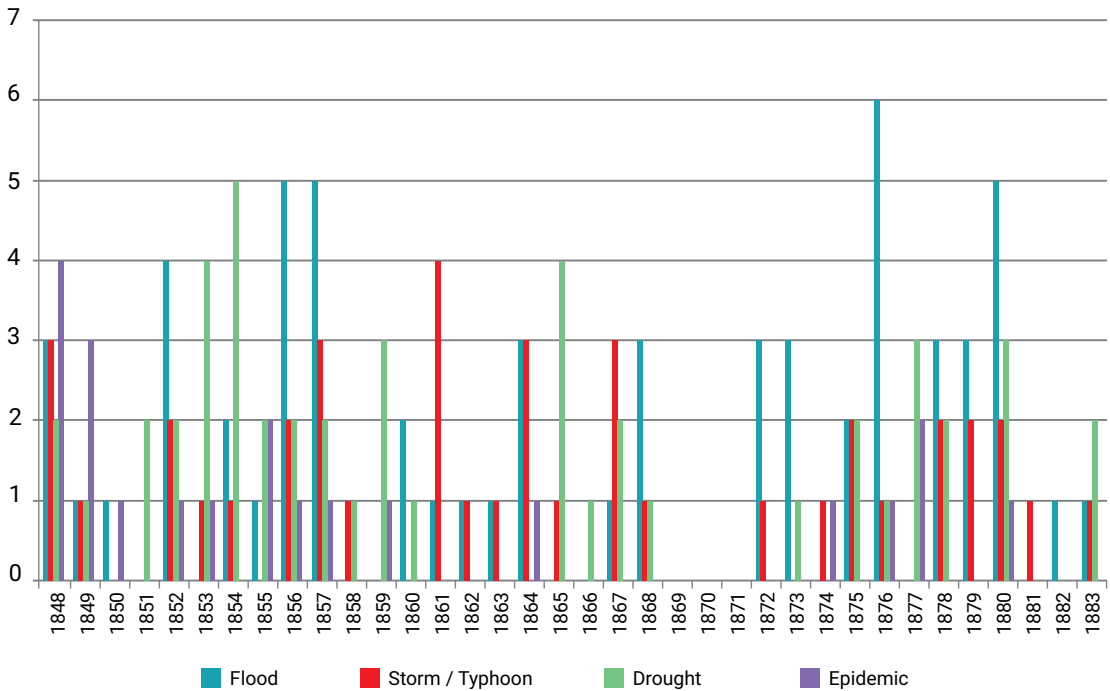
There is, however, much debate as to whether these sources can enable contemporary historians to trace the climatic trends of past centuries. To answer this huge question, it is important to consider the process that led to a climate event being recorded in imperial registers. What kinds of phenomena were selected? How were they selected? Why? By who? The historian's skill lies precisely in understanding the conditions of production for the sources they use.

Due to their cosmographic and political significance, which we will analyse in section 2.2, the selection of meteorological information was carefully guarded. In theory, court historians – guided by profession candour – were expected to recall all natural indications, and especially any anomalies because they represented Heaven's review of the ruler's conduct. On the other hand, the ruler had to commit to fully acknowledge all climatic events, whether good or bad, and to learn from those heavenly messages in order to behave better. In reality, dynastic chronicles and court records sys-

tematically selected meteorological 'data' to illustrate political messages. Natural signals were therefore carefully chosen. For example, when Gia Long (1802–1820) came to power in 1802, the Dynastic Veritable Record implied that the Mekong river in Sai Gon suddenly became fresh and crystal clear for miles. Two decades later, the emperor Minh Menh (1820–1841) received a memorial from Sai Gon officials, reporting that the river once again turned crystal clear for miles. That could only be a blessing from Heaven, indicating a prosperous age to come [*Đại Nam thực lục*, 1884].

This clearly shows that the climate data recorded in the dynastic chronicles cannot simply be regarded as a faithful reflection of past climate variations. This remark leads historians such as Catherine Dyt or Hieu Phung to distinguish their work from approaches focused on gleaning climatic information from dynastic chronicles to reconstruct the past climate history of Viet Nam, and its impact on political history. They propose a very different conception of climate history, consisting in using the climatic data registered in the chronicles to understand political changes, via the way climatic events were recorded. It is thus apparent that at least two approaches to the history of climate are emerging in Viet Nam. The first one focuses on the conditions of production of climatic data in the dynastic chronicles to write the history of the reflections, ideas and actions of the time on climatic phenomena. The second one takes climatic data in the Imperial Annals as serious proxy to reconstruct past climate history: it compares them with climatic information stemming from dendrochronology to build correlations between climatic variations and major events of political, social and economic history. In the following sections we are going to examine the progress of these two trends, taking care

[Figure 2.4]
Incidence of disaster during Tự Đức's Reign



Based on data compiled from the *Veritable Records* and the *Annales of the Propagation of the Faith* [Dyt, 2016].

not to separate them too much, since their complementary nature is essential for the advance of the climatic history in Viet Nam.

3.2 The emperor's climatic actions in the cosmological framework of early-modern Viet Nam

Viet Nam, deeply penetrated by the classical Confucian and Taoist culture of China that we alluded to in the first part, has developed similar conceptions and theories of the climate, and its influences on man and society. In this classical Confucian cosmology, meteorological calamities were interpreted as signals

of disturbances in the cosmos, and therefore as signs of a challenge to the mandate of Heaven (天命) which the sovereign was entrusted with to ensure harmony on Earth. Thus, climatic calamities constituted a double challenge for political power: they plunged the people into misery (with all the risks of revolt against the power that resulted), but they also directly challenged the legitimacy of power, which could be suspected of being immoral. As a result of these concerns, climatic events were meticulously calculated and carefully reported in official paperwork until the XIXth century during the Nguyễn period [Figure 2.4].

It is therefore hardly surprising that the imperial power developed what we might call a

climate policy¹ very early on. Vietnamese rulers even created specialized agencies to register extraordinary nature events: the Directorate of Sky-Watching or of Astronomy and dedicated buildings, like the Astral Tower named “Five Phoenixes” (Ngũ Phượng) in Thang Long (actual Hanoi). These premises appear to have existed since the XIth century; but its really during the XIIIth century that the Office of Supplication was transformed into the Astrological Service [Phung, 2017, pp. 163-65].

In 1248, the post of Royal Commissioner of Dikes (河堤使) was created [*Đại Việt sử ký toàn thư*, book 5, p. 15b]: it is from this date on that the Vietnamese Imperial Annals became a valuable source for climate historians, since floods and droughts are carefully mentioned. These events were a recurrent phenomenon, and their impact on crops was so serious that flood management via a dyke system became an important concern for the imperial power [*Đại Việt sử ký toàn thư*, book 5, p.20a]. While there is no evidence to suggest that the peasant rebellions of the late XIIIth century and the overthrow of the Tran dynasty in 1400 were direct consequences of an increase in flooding (as it is unknown whether there were fewer floods annually in earlier periods of political stability), it is clear that the recurrence of violent climatic events played an important role. The poor harvests following these floods explain why hungry tenants and sharecroppers plundered and burned down Hanoi several times at the end of the XIVth century [*Đại Việt sử ký toàn thư*, book 8, pp.17a-b, 36a]. When a new state emerged (the Ho dynasty, 1400–1407), they had to abandon the basin by relocating the capital 180 km to the south of Hanoi (present-day Thanh Hoa). In the XVth century,

the Imperial Annals show that the most fertile regions of the Red River Delta (Hai Duong, Son Tay, etc.), where royal and aristocratic fiefdoms and estates were located (*điền trang, thái ấp*), continued to be particularly affected by numerous and severe floods, leading to migratory flows and an significant number of village abandonments. Japanese scholars estimate that 3,120,000 people had left northern Viet Nam by the early XVth century [Sakurai, 1997, p. 133]. That forced migration and social violence provide a good example of how droughts and floods impacted on key political policies and state stability.

The rise of neo-Confucianism at the imperial court, from the XVth century onwards [Whitmore, 2010], made this cosmography increasingly prominent in the actions of the emperor. Currently, Hieu Phung – in her doctoral thesis focusing on XVth century Viet Nam – discusses Whitmore’s thesis by asking whether or not the Chinese Confucian cosmography can really be applied to understand the climatic ritual performed by the Vietnamese Kings of Dai Viet. Her analysis, based on several case studies, shows that before XVth century many of those rituals were still related to Buddhist and Taoist deities (like Jade Emperor), but that over time during the Lê dynasty, climate rituals (like calls for rain to stop drought) referred more and more to the Confucian theory of resonance between political justice and the harmony of Heaven/sky [Phung, 2017, pp.170-190]. For example, in response to the drought of 1438, the Imperial Annals report that the sovereign himself proclaimed a decree in which the moral responsibility of the sovereign and his administration were clearly engaged to explain this climatic calamity.

1. From this point of view, the contemporary need for governments to act to limit global warming is reminiscent of the climatic duties and obligations of the emperors of old.

“ Consistently throughout these years, droughts and insect infestations have re-

curréd while natural calamities frequently appear. During the fourth and fifth lunar months of this year, thunders repeatedly rattled those trees in front of the Royal Ancestral Temple in Lam Kinh (i.e., the hometown of the Le kings in Thanh Hoa). Contemplating these problems will show us some insights. Have I, the King, not cultivated my virtue and is my governing therefore abandoned to wild idleness? Is the Grand Councillor not competent and is he therefore not harmonizing and regulating [the operation of the court properly? Is our court not recruiting the right people and those who are worthy are therefore not being distinguished from those who are unworthy? Is bribery occurring openly and is the law court therefore being deluged with false accusations? Are the people overloaded with public construction projects and are they therefore becoming exhausted? Is the government overtaxing the people and are they therefore suffering further impoverishment? I have cited those problems in order to make self-reproach and I will perform a great amnesty. ”

Quoted by Phung, 2017, p. 186.

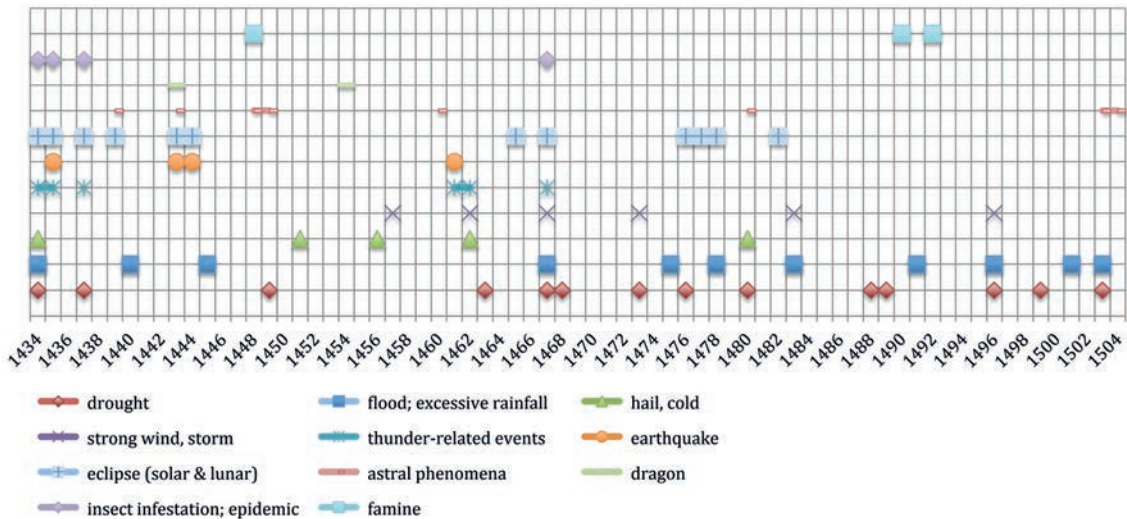
The bureaucrats believed “in their ability to adjust the current political situation by carefully observing and successfully reacting to meteorological portents” (quoted by Phung, 2017, p. 186). By the 1460s, Lê emperors also established the Nam-giao ritual: a sacrifice made by the emperor himself at the beginning of a new cultural cycle, to obtain the auspices of Heaven for a good harvest [Whitmore, 2010]. Over the centuries, the same cosmographic framework and the same ceremonies were maintained. Australian historian Kathryn Dyt has carefully described the conduct of the wind and rain call (*cầu đảo*) ceremonies, as codified by the Nguyen dynasty from Empe-

ror Gia Long to Tu Duc [Dyt, 2015]. She also demonstrates the importance and frequency of this ritual, its cost, and the strong involvement of the Emperor himself and the Ministry of Cults for its proper execution. Kathrin Dyt reports that in 1805, when the country was experiencing a serious drought from the North to the South of Viet Nam, the emperor Gia Long immediately issued “a proclamation imploring officials in all drought-stricken areas to set up an altar and conduct “calling for wind and rain” ritual, known as *cầu đảo*, for seven days and nights” [Dyt, 2015].

Speaking about China, Mark Elvin describes this Imperial power over the climate as a “moral meteorology” [Elvin, 1998]. Yet in Viet Nam, this power of the Sovereign over the meteors did not only result in religious rites like the Nam Giao, or striving towards greater moral probity in order to avoid the wrath of Heaven. It also led to empirical actions, like the construction of “cauldron-handle” dikes that began to be built in the mid XIIIth century, which aimed to limit and contain floods [Phung, 2017, 118]. In fact, the Emperor’s climatic action was both moral and empirical, with no real separation of the two *modus operandi*. Thus, the 1438 decree also stipulated construction of dykes to divert floods from the major rice producing areas; when the new dynasty moved the capital back to Đông Kinh (東京) (today Hanoi) in 1430 [Papin, 2001], it proceeded to build the Hong Duc dykes — the first flood diversion system to both secure the Imperial Capital, Đông Kinh, and extend the rice growing areas to the eastern and southern edges of the delta (the present-day provinces of Nam Dinh and Ninh Binh) [Kế, 1985]. Along the Day River (Ninh Binh), the remains of a 25 km long dyke, probably dating from the XVth century [Kế, 1985], testify to the ancient climatic action of the Emperors.

[Figure 2.5]

Natural incidents reported for the period from 1434 to 1504



Based on the *Complete History of Dai Viet* [Đại Việt sử ký toàn thư, 1697, quoted in Phung, 2017].

The work carried out by Hiều Phung, on the census of exceptional climatic, telluric and astronomical events recorded in the Imperial Annals in the XVth century, makes it possible to analyse the cosmological framework and rationality of the Emperor's climatic actions deeper still [Phung, 2017]. The diversity of the events recorded reveals the analogical thinking of the period [Thomas, 2003; Culas, 2019]. Together we find droughts, floods, storms and typhoons, earthquakes, insect invasions, epidemics and famines, eclipses and various astronomical phenomena, as well as appearances of dragons, as if all these phenomena and manifestations shared a kind of identity that could be brought to light by recording their recurrences [figure 2.5]. The mention of the dragon's appearance should come as no surprise. In both classical Confucian and popular culture, dragons were responsible for dispensing rain [Capitiano, 2008; Dyt, 2015]. Severe droughts or floods were

therefore interpreted either as a collective punishment inflicted on inhabitants for various faults, or as the forgetfulness of duties by a whimsical dragon. In both cases, the mediums led ritual sacrifices to the dragon variously to request, entice or intimidate the dragon into making or stopping rain. The Emperor (whose utmost symbol of power was a dragon) was also supposed to restore the balance for normal and regular rain [Zhang, 2009].

The belief that dragons dispensed rain should not be understood as a sign of the irrationality of pre-modern climatic thought. Both aquatic and aerial animals, dragons have a very strong consubstantiality with clouds and the atmospheric phenomena triggering rain in Chinese analogical thought. They are associated so closely with climatic phenomena that a number of Chinese scholars continuously made efforts to rationalize Confucian cosmography and popular beliefs by describing dragons as

almost climatic phenomena, as the following examples show: in the first century AD, Wang Chong explained, “*Clouds and dragons belong to the same category of being [associated with water]; therefore, their respective qi responds to each other and causes each other to appear.*”; Zhu Xi (1130–1200) explains that “*the dragon is an aquatic animal; therefore, when it comes out [of water] and encounters the yang qi [in sky], rain is formed. But ordinarily rain is formed when yin qi is in confrontation with yang qi. It does not necessarily involve the dragon.*” (quoted by Zhang, 2009). A very long Chinese rationalist tradition, very well described in Qiong Zhang’s article, constantly tries to make the Confucian cosmographic framework compatible with a naturalist explanation of climate phenomena. In the same vein, it is useful to recall that *thien tai* (天災) — literally “disasters caused by Heaven” — means “natural disasters”, a shortcut to better understand the relative equivalence of Heaven and nature in explaining natural disasters.

Hence, to analyse the Imperial Annals, historians must bear in mind that analogical thought in China and Viet Nam led to what Marcel Granet called a *naturism*, which led scholars to observe natural phenomena with the same rationalist and empirical approaches as scientific ones — an approach held to be the exclusive preserve of the scientific revolution of the European Renaissance. This fact should today help climatic scientists grasp the rationality and logic behind the imperial power’s action on the climate. It is irrelevant that the mode of analogical thinking appears irrational to contemporary scientists. The only significant element, unrelated to their cosmological framework and climatic theories, is that they have given rise to empirical observations of climatic phenomena and concrete

action to govern them. This last point leads us naturally to the second way of using this climate information, as a proxy to reconstruct the history of past climate trends.

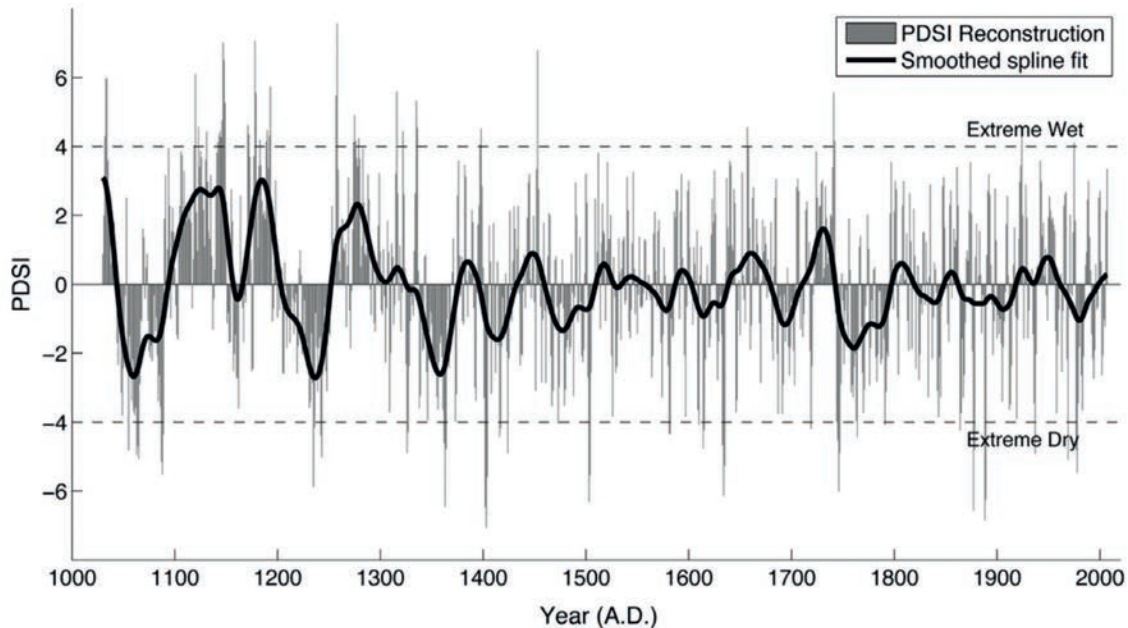
3.3 An almost constant drought/flood/typhoon regime over the century

Among the main historians currently working to reconstruct the climate of the past, we will rely particularly on the work of Lieberman, Buckley and their colleagues, who have particularly sought to build an interdisciplinary collaboration between historians and paleoclimatologists [Lieberman & Buckley, 2012].

Based on the *Complete History of Dai Viet* (1697), the *Histoire du Royaume de Tunquin* of Alexander De Rhodes (1651), and the *Imperially Ordered Mirror and Commentary on the History of the Viet* (1884), Buckley and his colleagues have shown that floods and droughts occurred every four years between 1720–1779 [Buckley *et al.*, 2010, 2014]. Droughts particularly damaged fifth-month rice cropping seasons, while floods destroyed mainly the tenth month crop in the delta’s core region [Sakurai, 1990, 1997]. This information — extracted from human archives — is completed with modern scientific data obtained, for example, from the shifting sea level or tree-ring analysis. Buckley and colleagues have found teak trees in north-western Thailand with well-defined annual growth rings, despite the subtropical climate, which distinguish locally-distinct wet and dry seasons since 1558. They have also succeeded in using dendrochronology techniques on *Fokienia hodginsii* (*Po Mu* in Vietnamese), cypress trees found in the mountains of North Viet Nam and in the Southern Highlands. These trees are somewhat equivalent to the

[Figure 2.6]

Precipitation in southern Viet Nam since one thousand years



■ Source: Lieberman and Buckley (2012, p. 1057).

Canadian Sequoia used by Emmanuel Le Roy Ladurie, and have provided a very long data set covering the last millennium from 1030 to 2008 [Lieberman & Buckley, 2012]. Climatic history in Viet Nam can also greatly benefit from including climatic data collected in South China and Southeast Asia [Buckley *et al.*, 2010, 2014; Bankoff & Christensen, 2016; Bankoff & Boomgaard, 2007; Boomgaard, 2005, 2007]. Such trans-national and trans-regional perspectives place the Vietnamese environment of the past in a broader context and longer time-frame.

Taking the period between 1300 and 1900 for instance, both Vietnamese and foreign sources are now able to shed light on periods of climatic extremes. The curve of precipitation in southern Viet Nam in Figure 2.6, for

example, has been measured using the Palmer Drought Severity Index (PDSI), and corrected with tree-ring-widths from cypress trees (*Fokienia hodginsii*) growing in the highlands of Viet Nam (Hoang Lien and Bidoup Nui Ba National Parks). The higher the PDSI, the higher the annual rainfall.

Although the sample size prior to 1250 is smaller than after 1250, the overall trend and multi-decadal structure of the reconstruction imply far wetter than average conditions throughout key portions of the Medieval Warm Period, consistent with La Niña-like base state conditions.

Lieberman and Buckley consider in their articles that flood, torrential rains, drought, and epidemics could provide the explanation for

the most dramatic upheavals of the country's history. The collapse of the Tran dynasty in the late XIVth century, for instance, which was long attributed to political and economic factors only, appears to them to be the direct outcome of an existential crisis, rooted in the desperate climatic situation of a long drought. It may have resulted in massive rebellions of distressed peasants, and invasion by the Dai Viet's southern neighbour, the Champa kingdom. Together, emigration, famine, disease, and Cham attacks may have slashed Dai Viet's population from around 3,000,000 in 1300 to barely half that a century later [Lieberman & Buckley, 2012]. They consider that the correlations they manage to weave between their climate series and the general history of the region clearly show the influence of variations in the monsoon regime on the genesis, apogee and collapse of the great kingdoms of the region: Angkor, Pagan and the Dai Viet [Lieberman & Buckley, 2012].

The same reasoning is applied to one of the most violent eras in the country's past: the XVIIIth century. The Palmer Drought Severity Index (PDSI) indicates that it was a period of extreme drought, the highest since the XIIIth century [Buckley *et al.*, 2014]. Droughts, drought-related famines, and epidemics could be responsible for the most devastating uprisings in Vietnamese history: the Tay Son movement, which led to the collapses of Nguyen Viet Nam from 1771–1785, and Trinh Viet Nam in 1786 [Li, 2015].

Finally, the thesis that the Nguyen dynasty and Vietnamese society was devastated by unusually frequent floods, tropical storms, droughts and epidemics at the eve of modernization and western colonisation is a seductive one. It would explain the collapse of the Nguyen dynasty under the assault of French

imperialism, as at least 400 uprisings took place between 1802 and 1883 [Liêm, 2018].

3.4 Critical analysis of climate determinism in history

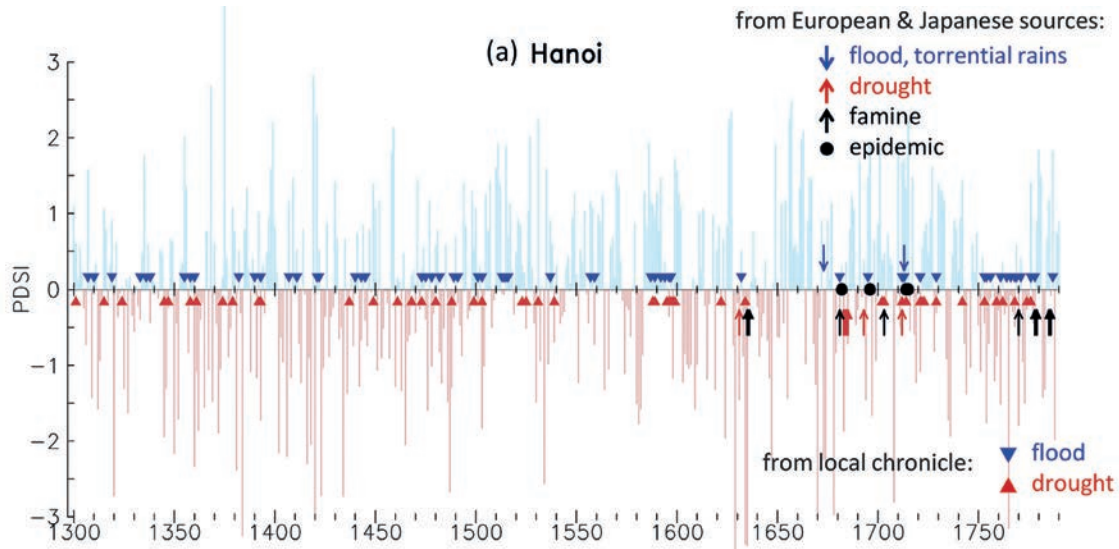
However, while it can be said that great economic misery and social instability undoubtedly contributed to the weakening of Nguyen power, and indirectly played into the hands of colonial interests, it would be over-simplistic to conclude that floods were the only cause of the people's misery, or that drought was the direct cause of colonization.

In fact, as the authors themselves acknowledge, the climatic history of Viet Nam is still at an early stage [Lieberman & Buckley, 2012, pp. 1095-96], and the correlations that are drawn between a still poorly-understood climatic history and the major political events of the State remain tenuous. For example, [Figure 2.7](#) — which aims to show the correlation between PDSI variation, the record of droughts and floods in the Imperial Annals, and famines and epidemics — does not really establish a clear chain of causality between climatic disturbances, famines and political upheavals. Therefore, the authors are unconvinced by climatic explanations that are not sufficiently well supported by causal relations, and lean towards Le Roy Ladurie's recommendations to proceed cautiously with the links between climatic history and general history (see [Box 2.2](#)).

If one really wanted to analyse the link between climate disasters and the Tay Son revolution, or the collapse of Nguyen dynasty and so on, it would be useful to start on the basis of the historical materialism of Karl Marx. In this framework, the “*modes of production*” (slave-

[Figure 2.7]

Reconstruction of PDSI (Palmer drought severity index) for Hanoi



Based on historical documents [Buckley *et al.*, 2014].

ry, feudalism, capitalism, socialism) are the result of a peculiar combination of “*productive forces*” and “*relations of production*”. The *relations of production* (the practices, customs and laws protecting society’s productive assets, *i.e.* property regulations, which govern relations between people and the objects, etc.) are generally considered the main factors generating the misery of the population, the wealth of the ruling classes, and therefore revolutions. Actually, environmental history and climate history raise the question of the place of nature and natural resources in the “*productive forces*”. In *The Capital*, the productive forces exclusively consist of twin inputs: “*human labor power*” and the “*means of production*” (financial capital, tools, productive machinery, commercial and industrial buildings, other infrastructure, technical knowledge, materials, plants, animals and exploitable land). Nature is not regarded as a means of production, because in the XIXth century nature was considered to

be inexhaustible [Neyrat, 2016]. Contemporary eco-Marxist thinkers aim to reintroduce natural capital into the Marxist framework, to explain today’s global environmental crisis [Malm, 2016]. Simple and ambitious, the project of environmental history does not propose to replace the Marxist explanation of history via the relations of production with an explanation of history by nature, but to reintroduce nature into the Marxist equation between forces of production and relations of production. This enables us to avoid all simplistic climatic or environmental determinism, while reintroducing the limits of the biosphere as a determining factor in the trajectories of societies, and today in humanity’s common future.

To conclude on these two main ways of dealing with the abundant climatic information contained in the imperial annals — the first centred on analysing the conditions of production of these data, the second on their use to

[Box 2.2]

Le Roy Ladurie's caution with regard to climatic determinism

Ladurie (1967) is part of a long tradition of French social sciences that are **critical of over-simplistic explanations of social phenomena via natural causes**. He thus strongly criticizes the various forms of climatic determinism that have flourished in the course of history, particularly the nationalist historiography of the XIXth century that explained the superiority of European peoples by the temperate climate of Europe, and thus justified the colonial domination and racism of the period. In keeping with this tradition, Ladurie begins the first chapter of *History of the climate since year 1000* by criticizing the “*perilous approach*” of the English historian Elsworth Huntington (1907, 1915), who explains the history of Mongol migrations via the climate in Asia, without even bothering to study climate history “*for itself*” (p. 27). He thanks the historian Gustave Utterström for having written a history of the climate in Scandinavia, this time “*for its own sake*”, but criticizes him for seeking explanations of economic developments in the XIVth and XVth, and the XVIIth and XVIIIth, centuries in somewhat frivolous climatic causes. Ladurie also refutes the idea that the vineyards north of Paris were abandoned because of excessive humidity in the XIVth century. He demonstrates from the archives of the abbey of Saint Denis that abandoning the vineyards was linked to a labour shortage after the Great Plague, which made working the vineyards very expensive and economically unviable. He also shows that throughout the XIVth century, the impact of the climate on human development was insignificant compared to the Great Plague (biological influence).

Secondly, Ladurie underlines the remarkable stability of the climate over the last three millennia, and concludes that the small amplitude of variations exerted “*little importance to human evolution*” (p. 25); this is the main reason why he rejects explanations of great episodes in human history (long migration, depression, economic expansion, etc.) by reference to fluctuations in climate. The mildness of the year 1000 cannot explain the great Western land clearings, he says, nor the so-called “*economic sluggishness*” of the XVIIth century by the rigours of the climate. Ladurie considers these links to be badly posed, unfounded and ultimately insoluble (p. 501). His position is therefore to separate the history of climate from the question of the influence of climate on general history.

Thirdly, even if he totally recognizes that the peasant harvests are highly dependent on the weather, Ladurie points out all the methodological difficulties of establishing robust causal links between climate variations and the way they affect local rural societies. The same large-scale climatic variations do not have the same effects on different agrarian systems and different cultivated species. Titow's work in England shows, for example, that dry seasons produce good harvests while rainy seasons produce bad harvests (pp. 498-99), but Ladurie shows that south of London, as in the Paris basin, the effects of spring and summer on harvests are more complex. He also points out that harsh winters do not have a negative effect on wheat harvests, that on the contrary rainy winters are negative, but that the influence of spring and summer on the harvest, if crucial, is not the same for northern, central and southern Europe. He also explains that moving from phenology data to climate assessment requires solid agronomic and ampelographic knowledge, since each vine and terroir reacts differently to variations in rainfall and temperature [Garnier, 1955]. The historian needed to be a great connoisseur of wine and vineyards, and of every Domain and Château he studied (it is no accident that in Burgundy, each micro-terroir is called a “climate”). Ladurie thus multiplies the examples to show that it is risky to establish causal links between crop performance and climatic performance (and *vice versa*); in this respect, he quotes an article by Slicher Van Bath from 1965 which shows “*the complexity of climate-harvest correlations*” (p. 496). Nothing is simple, Ladurie summarises: the data on climatic history are often too crude to be able to draw any well-founded conclusions as to the consequences it may have had on the history of the rural economy.

Thus, while Ladurie admits that — “*the Little Ice Age (in the XIVth century), especially when wars are added to it, can be linked to epidemics and famine episodes. For example, the one in 1314–1315 (which) killed 5 to 6% of the French population*” — he adds immediately after that the Little Ice Age of 300 AD does not explain anything about the end of the Roman Empire and the barbarian invasions. Similarly, while he admits that the small medieval optimum must have favoured the great land clearances of the period, he considers that political and social problems explain the upheavals of the French Revolution much more than poor harvests. In fact, Ladurie wants to be a serious historian, so he does not allow himself extrapolations and speculations that his sources do not allow him to defend.

Interestingly, Geoffrey Parker, in readdressing the issue of the climatic explanation for the ‘Global Crisis’ throughout the XVIIth century around the world, has provided ample evidence in favour of this explanation, and has criticised Ladurie's excessively ‘modest’ position, while acknowledging that it was justified at the time Ladurie published his *History of the Climate since the year 1000* [Parker, 2008, p. 1065].

reconstitute past climatic trends — we would like to return to the importance of organising their complementarity. It is only at the price of critical work on the sources, which really puts the quality of the climatic data to the test, that we will be able to claim to be able to make use of these data to draw up climatic series that will be usable by climatologists. For this to be possible, the historical data must be recorded

in accordance with criteria that are recognised as reliable climate data by historians, meteorologists and climatologists alike. Among these criteria, the analysis of possible biases at the time of recording the data is a crucial point, which falls within the historian's domain. This is an issue that we will return to in connection with the use of climate data from the colonial period, which we will now examine.

4. Contemporary climate history

4.1 French meteorological service during the colonial period

Colonial meteorological services are an important source for writing the contemporary climate history of Viet Nam. They provide the first modern statistical series that are readily available to sketch a history of the climate in the 19th and first half of the 20th centuries. The colonial administration progressively set up a meteorological and climatological service in Indochina, in charge of systematizing the recording of meteorological and climatic data in Indochina. Over the years, it developed a relatively dense network of meteorological stations, as shown on the map of these stations published in 1931 at the time of the Paris Colonial Exhibition [Figure 2.8].

Actually, meteorological and climatological services took some time to be established during the French colonisation. The process started in Cochinchina, where the Agricultural chamber and the Agricultural and Industrial Committee published some meteorological information in

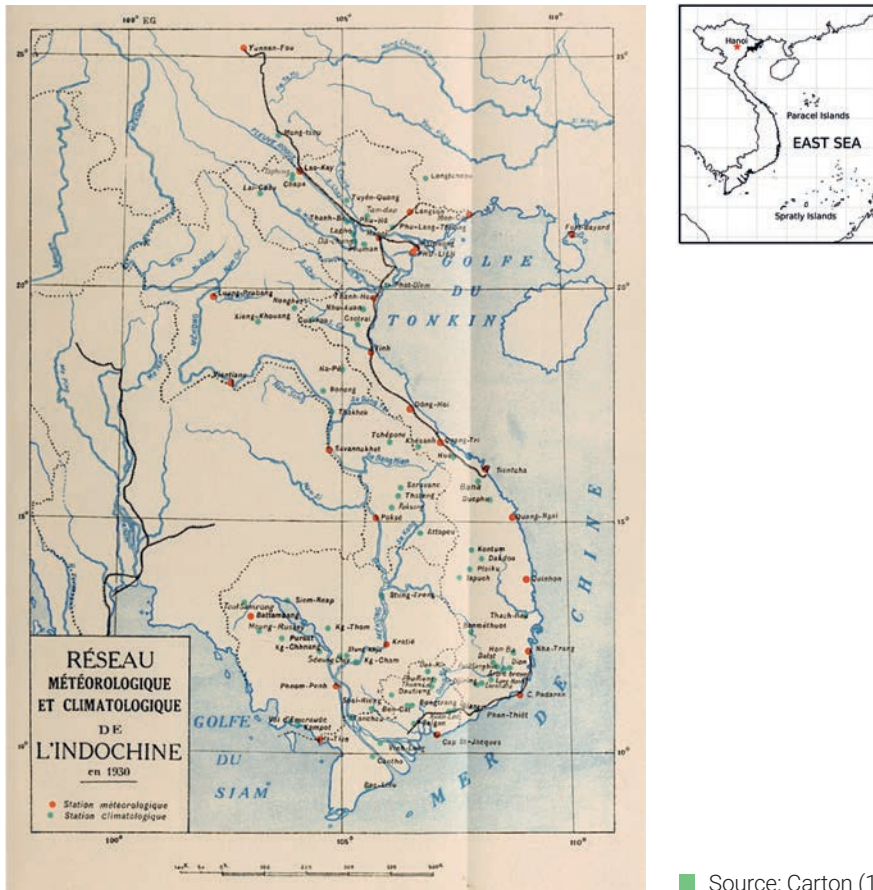
their Bulletin between 1865 and 1883, but no real meteorological service existed during the XIXth century. The first weather stations were established in 1897 [Lespagnol, 1902], and it was only in 1900, under the impetus of Governor General Paul Doumer, that the first unified Meteorological Service was set up. Around 10 principal stations and 20 secondary ones composed the network for the whole of Indo-china (*Annales de Géographie*, 1900)². From this date onwards and throughout the period of colonisation, the *Bulletin Économique de l'Indochine* published the monthly observations of the entire network. This network of stations was completed in 1902 by the creation of the Central Meteorological Observatory in Phủ Liễn (9 km from Haiphong), in the typhoon ac-

2. Saigon, Cap Saint-Jacques, Poulo-Condore, Ong-Yeni, Tay-ninh and Soc-trang (for Cochinchina); Nha-trang, Langsa, Tourane, Quin-hone, Hué, Dong-Hoi, Vinh and Than-hoa (for Annam); Hanoi, Haiphong, Quang-Yen, Hon-gay, Mon-cay, Lang-son, Cao-bang, Lao-kay, Ha-giang, Bac-kan and Van-bu (for Tonkin); Vientiane, Luang-Prabang, Savannakhek, Khong and Attopeu (in Laos); Phnom-penh, Kampot and Pursat (in Cambodia). (La météorologie dans L'Indo-Chine Française, *Annales de Géographie*, IX, 1900, p. 178.)

3. Voir *Annales de Géographie* (Bibliographie de 1899 n° 571 et de 1900, n° 506); dans le *Bulletin Économique de l'Indochine*, IV, 1901, Le Lay a publié "Climatologie comparée île Manille et des Stations de Backan et Hagiang dans le bassin de la Rivière Claire (Haut Tonkin), du 1^{er} novembre 1899 au 31 octobre 1900", pp. 139-144; "Résumé des observations des stations météorologiques primaires et secondaires de l'Indo-Chine pendant l'année 1900, pp. 243-259, etc.; de Bel-jonne, une intéressante étude: "Observations sur les mous-sons en Indo-Chine", pp. 797-801, cartes.

[Figure 2.8]

Meteorological and climatological station network in French Indochina, 1930



Source: Carton (1930a).

tion zone³. And it was only in 1907 that regular and usable meteorological observations were carried out by the Agricultural Services. Until 1927, the stations were mainly located along the coast, and it was not until the late 1920s that stations were set up in the Mekong valley, in the mountainous regions and on the central highlands. The responsibility for these stations was entrusted to agents of various services of the colonial administration or to personnel from certain private companies with an interest in climatology (plantations, Pasteur Institute, mines, etc.). In 1926, a Climatology and

Agricultural Meteorology Office was created at the Central Observatory of the Meteorological Service, with a mission to centralize and control the observations of the stations, to publish these observations in the periodicals of the Central Observatory and the General Inspection of Agriculture, Livestock and Forestry, as well as in special works. This office was also to centralize all documentation concerning the studies of tropical agricultural meteorology (in particular agricultural ecology) carried out in the various tropical countries of the world and concerning the work of the International

[Figure 2.9]

Meteorological stations at agricultural stations (Pho Hô and Lang Hanh)



Station expérimentale agricole et forestière de Phu-Hô (province de Phu-Tho, Tonkin) — La station climatologique : l'abri ; au premier plan l'héliographe.



Station de Phu-Hô : le géothermomètre enregistreur et les thermomètres pour l'étude de la température de l'air près de la surface du sol.



Station expérimentale de Quinquina, de Lang-Hanh (province de Haut-Donnai, Annam).
La station climatologique : à gauche, le pluviomètre et les thermomètres pour la température de l'air près de la surface du sol ; au fond, l'abri climatologique et la sonnette sur son mât ; à droite, l'héliographe sur sa table au centre. La station est entourée d'une haute palissade empêchant l'accès du bétail et des animaux sauvages (cochons, etc.) ; à la porte est une cabane pour servir d'abri à l'observateur.

The agricultural and forestry experimental station of Phu-Hô (in the middle region of Tonkin), was mainly devoted to coffee and tea tree research and the industrialization of their products; it was placed under the direction of Mr. Du Pasquier, Agronomist Engineer E. P. Z., specialized in these studies and Head of the Station, and Mr. Rémond Agronomist Engineer and Colonial Agronomist. The experimental station of Quinquina of Lang-Hanh, was located in the Haut-Donnai, South-Annam, at an altitude of 950 meters and directed by Mr. Frontou, Agronomist and Colonial Agronomy Engineer

Source: Carton (1930b).

Commissions of Agricultural Meteorology and Ecology, in order to make them available to the technical services concerned and to farmers.

The meteorological and climatological stations were equipped with the following instruments: a rain gauge, a minimum thermometer, a maximum thermometer, a recording thermometer, a psychrometer, a recording hygrometer, a Piche's evapometer, (all under an Eiffel shelter modified for tropical countries) and in addition a wind vane (model of the Central Observatory). The meteorological stations

were equipped with a mercury barometer and a recording barometer. The rainfall stations simply had a rain gauge.

It was essential that colonial meteorology and climatology be applied, particularly to colonial agronomy, as weather forecasting only made sense if it could meet the needs of tropical agriculture. The head of the Bureau of Climatology and Agricultural Meteorology at the Central Observatory of Indochina, Paul Carton, was thus an agricultural and colonial agronomy engineer. He described the challen-

ges of producing a climatology applied to tropical culture perfectly in several of his publications [Carton, 1930b]. For this purpose, the Climatology and Agricultural meteorology board (at the Observatoire Central du Service Météorologique) was to link the results of the stations and the Agricultural Services with the needs of colonial plantations and agricultural Companies. In fact, for Carton, meteorology and climatology had to contribute to what he then called “agricultural ecology” which, to be carried out successfully, required, according to him, the following conditions:

- 1] A well-developed network of climate and rainfall stations, with a good distribution of stations in the different regions of the country;
- 2] Phenological observations made at numerous points, equally well distributed. This implies the need to entrust responsibility for the climatological stations and the rain gauge stations to agents of the Agricultural Services and to farmers as much as possible.
- 3] Main stations for agricultural meteorology and ecology at the main agronomic stations, especially those specialised in the scientific study of certain field crops and in the selection and genetics of those plants.

An exhaustive examination of the archives of these stations and of this service would undoubtedly make it possible to produce new thermometric series, and thus write a history of climate in Viet Nam during the colonial times. As we can see, phenological data were collected during this period, but this data has yet to be examined; they are a rich potential source for the climatic history of Viet Nam in the first half of the XXth century, and could perhaps, with a bit of luck – the historian who hunts for archives always relies on luck – echo the data collected in the imperial archives to build long time series. In any event,

the work of a serious and persistent historian should be financed in order to bring out all the richness of these archives, and follow in the footsteps of the founding fathers of climatic history such as Ladurie.

To pave the way, we have begun to read the publications of those in charge of the Meteorological Service of Indochina. In 1930, Bruzon and Carton published their first synthesis of meteorological and climatological data [Bruzon & Carton, 1930]. The data on which they based their work extended from 1907 to 1927. Admittedly, there are many gaps in the data (only twenty stations provide continuous temperature and precipitation series over 20 years), but the authors’ synthesis is nonetheless the first ‘modern scientific’ study of the climate of the Indochinese peninsula. The decadal averages produced by the authors for the years 1907–1927 can also be compared with Gustave Le Cadet’s previous study published in 1917, with data from 1907 to 1915. The comparison is interesting because it shows a relative consistency between the two sources, but also reveals climatic fluctuations that the sagacious geographer Charles Robequin did not fail to note in his review of Bruzon and Carton’s work in the *Annales de Géographie* [Robequin, 1930]. Robequin, like any great geographer of the time, was a scholar and a devourer of data of all kinds, but was also fond of great syntheses; he emphasized the differences in the rainfall patterns of the various regions of the peninsula, based on maps of the isohyets in the two publications:

“ The relatively dry zone of Lower and Middle Tonkin widens between the coastal maximum of Moncay and that of Upper Tonkin (more than 2500 mm Chapa); the maximum of Central Annam narrows around Hue (2907 mm) but a comparable

maximum appears curiously enough in Lower Laos at South Attopeu; The western edge of the Annamite of Nha Trang is one of the wettest regions of Indochina (Hon-ba 3848 mm) above a remarkably dry coastal fringe (Padaran 789 mm); but the most considerable rainfall is received by the mountainous coast of Cambodia where some years of observations give an average of more than 4800 mm in 3 stations, one of which (Kas-kong) saw 7972 mm of rain fall in 1923! ”

Robequin, 1930

It would of course be unreasonable to infer changes in climate from these climatic variations. What Robequin is looking for (with his love of great syntheses) are rules, causes, laws – the laws of the climatic regimes that bathe the peninsula, and which still largely eluded the understanding of the time.

It would be very interesting if contemporary climatologists – the atmospheric circulation physicists specializing in the region – could follow in Robequin's footsteps and take hold of these data. For this to be possible, they would need the help of historians, whose job is precisely to unearth these data. Very small amounts of funding would be required to put such a study online; it would undoubtedly be of great service to the entire scientific community working on climate change in Southeast Asia.

Finally, it should be noted that from this period onwards, meteorology has been perceived as being very useful for typhoon prevention. In this regard, Carton emphasizes that *“the development of small individual T.S.F. reception posts will greatly facilitate the dissemination of regional forecasts, typhoon warnings, etc.”* [Carton, 1930b]. Bruzon and Carton devote

the entire second part of their book *Le climat de l'Indochine et les typhons de la mer de Chine* to constructing these forecasts. From the records of the Phu Lien Observatory (near Hai Phong), they succeeded in establishing the periodicity and seasonality of typhoons in the region, and noted that out of 128 typhoons observed between 1911 and 1928, 114 occurred between June and November, leading the authors to assert that the transitional periods preceding the winter monsoon and the summer monsoon were not the periods of maximum typhoon frequency, as some authors of the time thought. Again, clearing this type of data and making it available online for use in a more general history of observable changes in seasonal typhoon patterns over the XXth century would be of great service.

4.2 Meteorological services during the Democratic and Socialist Republic of Viet Nam

In 1945, just after setting up the interim government of the Democratic Republic of Viet Nam, President Ho Chi Minh signed a Resolution to establish the Meteorological Agency, given the importance of the role of meteorological services. In 1956, the Meteorological Department was renamed the Hydro-Meteorological Administration, and attached to the Ministry of Communications and Public Works. In 1958, the Prime Minister transferred it to the Ministry of Water Resources, and in 2002 to the Ministry of Natural Resources and Environment (MoNRE).

On 11 November 1994, the Government reorganised the HMS, which consist of 9 regional hydro-meteorological Centres (RHMC), and 8 institutional units. Its missions are to manage and exploit national meteorological and

hydrological networks (including basic investigation activities, forecasts, meteorological and hydrological data management), monitor air and water environments in support of natural disaster prevention and preparedness, socio-economic development, national security and defence of the country [Word Bank, UNISDR, 2013, p. 40].

Today, two departments of MoNRE have climate-related tasks: the Department of Meteorology, Hydrology and Climate change, and the National Centre for Hydro-Meteorological Forecasting. For the management of surface water and climatic hazards, the “Dyke Management and Flood Control Department” is attached to MARD. On the one hand, this underlines the importance of precise knowledge of the climate and its variations for Vietnamese agriculture, as was already the case more than a century ago. On the other, the National Hydro-Meteorological Service is an intermediary, even a bridge, between water management and environmental problems.

Throughout the decades of war, the attention paid by the Socialist Republic of Viet Nam to climate was therefore constant, and these few historical milestones can serve as a basis for the historian who wishes to gather the archives of these services and collect the meteorological data they contain. Nevertheless, there was little in-depth study of climate and its measurements in Viet Nam between 1945 and 1986, although for the period 1971–2010, Dang-Quang Nguyen, Renwick and McGregor (2013) show that temperature increases in different regions of Viet Nam are consistent with El Niño, while variations in global rainfall are insignificant for this period and do not appear to be determinant. The previous chapter of the present report, based on daily temperature registration from 70 stations, shows a

nationwide average increase of 0.89°C over 60 years (1958–2018), with a constant acceleration of the increase from one decade to the next.

It would be useful for climate historians to collect data from weather stations from the colonial period, to add this information to the models and scenarios of Vietnamese scientists and make them available to the various communities who might wish to work with them. Judging by the exploratory work we have conducted in this chapter — thanks to the GEMMES Viet Nam project — it would be quite feasible to link the data from the weather stations of the colonial period, from almost 1902 to 1954, with the contemporary series from 1961 to the present.

Numerous experiments in historical climate data rescue have been carried out around the world. Their main goal is to build good quality reference climate series (from “human archive” data), in order to produce “climate reanalysis”. A “reanalysis” is a scientific method of reconstructing the state of the atmosphere in the past from past meteorological observations⁴. This work requires four preliminary steps: consulting the archives, digitising the data, checking their quality and making them available to the public via national and international databases. Data quality control is an essential step for transforming the historical information into a useful data for climatologists. In order to be considered reliable, these data have to respect numerous criteria. MétéoFrance’s BD Clim database can be a good source of inspiration for setting up these criteria in a way suited to the case of Viet Nam⁵. Last but not least, we should em-

4. *Climate reanalysis*, Retrieved from <https://www.ecmwf.int/en/research/climate-reanalysis>.

phasize that even when the data are reliable, they are not very valuable if unaccompanied by metadata describing their sources and the conditions in which they were produced and collected. The production of metadata typically depends on the know-how of the historian, whose contribution is absolutely essential for climatologists to understand possible measurement biases and correct them as much as possible. This data standardisation work has been intensively implemented for the series in Europe and the United States (see Paul Edward, 2010).

5. Conclusion

This brief overview of the sources, methods and issues of climate history shows that climate history in general, and in Viet Nam in particular, makes a decisive contribution: firstly, to tracing the history of climate change on a human scale; and secondly, to understanding the way in which societies have taken up climate issues. Without claiming to have covered all the primary and secondary sources available for this type of historical research, this chapter has already demonstrated the abundance of sources and their interest. It therefore invites the Vietnamese University to develop this type of approach, by encouraging young historians to invest in the field of climate and environmental history.

Several approaches to climate history exist. In this chapter we have identified at least two

On this basis, it would be easy for Vietnamese historians and climatologists to set up an interdisciplinary program of climatic data rescue, in order to build long reference climate series for Viet Nam. It is important, in this respect, to understand that the Central Meteorological Observatory in Phủ-Liến, created by the French in 1902, is part of the centennial meteorological stations today recognised by the World Meteorological Organisation⁶. This recognition is a very good indication of the feasibility of such a project.

of them: the history of climate for what it says about past societies in the face of climate; the history of climate for what it says about past climates. Finally, we would like to refine these two categories by subdividing them into four distinct climate historiographies.

The first one is the history of the climate for the climate in the footsteps of Le Roy Ladurie. It aims to reconstitute past climates according to human accounts (human archives), and seeks a strong interdisciplinary approach with the historical climatology developed by climatologists from the natural archives of past climates. This is a first type of climate historiography, a first step to be developed, particularly if we want to get climatologists to work with historians.

The second type of historiography is more or less focused on studying the influences of climatic changes on the evolution of societies. For such a project to be possible, the first type of historiography must already be sufficiently advanced not to fall into a climatic determinism, without any serious scientific basis.

5. *Meteo France*. Retrieved from <http://archivesduclimat.meteofrance.fr/>

6. World Meteorological Organization, *What We do*. Retrieved from <https://public.wmo.int/en/our-mandate/what-we-do/>

Even if the results of this approach need to be consolidated, it already seems certain that violent and recurrent climatic events in the history of Viet Nam contributed to the outbreak of popular revolts and the overthrow of dynasties. This result is the historical confirmation that climate change has generated and will generate more and more political instability and social violence, which authors like Nordis and Gleditsch criticize the Intergovernmental Panel on Climate Change (IPCC) for not taking into account sufficiently in their scenarios [Nordis & Gleditsch, 2007].

The third type consists using the way political power acts on the climate and mitigates climatic disasters to infer information about cultural representations of the climate, the cosmos and a worldview – and also logics of thought, especially analogical thought that establishes a system of correspondence between elements that can appear separate in our current scientific culture. This kind of history of climate is already quite advanced in Vietnamese historiography. It should be pursued assiduously, because far from being dead, these thought patterns are very much alive and still strongly influence Vietnamese society and its relationship with the climate. Thus, if we want to understand how this society is capable of coping with the various phenomena of global warming that are already making themselves felt, ignoring these cultural facts – which to many seem out-dated and devoid of interest – would undoubtedly be to deprive ourselves of an important insight into the explaining individual and collective behaviour, hopes for change, the will to adapt, resilience, and even renunciation.

The fourth genre is a history of climate, focusing on how people react and adapt to climatic calamities. By examining the imperial annals,

four ways of reacting can be identified, which can be summarized by four actions: praying, fleeing, rebelling, and building dykes. These four modes of action/reaction strike us as very limited, and we strongly suspect that this poverty is more due to a lack of sources or the way historians have examined them so far, than to historical reality. It is true that the Imperial Annals are a codified literary genre that leaves little room for the description of everyday Vietnamese life. However, this is not the case with all the sources we have cited, and it is certain that a “micro-history” of a village – in the XVIIIth century for example, compiled from well-chosen archival sources – would be likely to bring back valuable information on the individual and collective actions of rural Vietnamese society in the face of climatic calamities. No historian has yet exploited archives in this way, and it will undoubtedly be when Vietnamese climatologists turn to them to ask for it, that this genre will be able to flourish as it does already in many countries in the world.

For this report, a few lessons from the past should already be underlined: firstly, the recurrence of violent climatic events, and secondly the correlative constant concern of the political power for climatic issues. From this point of view, as historians, we want to underline the relative similarity between the past moral duty of rulers to act on climate and the contemporary situation requiring effective measures to be taken to combat global warming. In fact, this chapter’s main lesson is perhaps this one: climate issues between the State and the people are not new to Viet Nam; they are part of the national history that the Imperial Annals allow us to trace back to at least the middle of the XIIIth century. This situation is not at all specific to Viet Nam. In their book, *Les Révoltes du Ciel* (*The Revolts of Heaven*), climate historians Fabien Locher and Jean-Baptiste Fressoz

made it clear that it was only in the 19th and 20th centuries that modern science – by focusing on understanding climate phenomena to forecast, rather than intervene on them – taught societies and State power to renounce their will to act on the climate.

With the Anthropocene, this historical parenthesis has closed, and scientists and societies must reconnect with a not-so-distant past will to act on the climate (with very different methods; mitigation, carbon sequestration and geo-engineering – rather than calls for rain – are the new technologies of the power). Logically, since the same causes often produce the same effects, it seems likely that the failures of contemporary rulers to act on the climate could result in socio-political disturbances, just as they did in the past, thus encouraging governments to take their duties seriously.

To finish we would like to return to Emmanuel Le Roy Ladurie. In 2015, almost half a century after the publication of *History of the climate since the year 1000*, a journalist asked him whether he subscribed to the thesis of the anthropic origin of global warming and the concept of the Anthropocene. Ladurie's answer is that of a man of culture. He refers to Plato, to the harmonies and correspondences between macro- and microcosms that we mentioned in the introduction to this first part.

“ In the *Gorgias*, Plato evokes the need for a harmonious balance between heaven, earth, gods and men, who together form a community. According to him, this community, called *Kosmos* by the ancient sages, must, in order to function, be bound together by friendship, love, respect for temperance, and a sense of justice, and not by disorder and disruption. However, the breakdown of this balance is obvious. Some have said that

it goes back to the intervention of agriculture, but the real disruption of the climate begins, for me, with the industrial revolution. Very quickly, we were able to see this reality with the retreat of the glaciers, which marked the gradual breakdown of the pact between man and nature. ”

Emmanuel Le Roy Ladurie,
L'Express, 2 February 2015

As we have seen, it is also in terms of the cosmographic balance between Heaven and Earth that the relationship between man and climate has most often been posed throughout the history of Viet Nam. We believe that combining Plato, Confucius and men of culture is a key requirement to build the dialogue between peoples necessary for global climate diplomacy; we believe that without this cultural dialogue, scientific evidence for climate change and economic calculations of its impact will never result in effective policies to manage climate as a common global resource, and thus remain collectively below the +2°C in 2100. This is also one of the key ideas that this chapter would like to convey to readers and policy makers: building international climate diplomacy requires bringing people's conceptions of climate closer together, while remaining fully aware of their different cultural underpinnings.

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Part 2

Social and economic impacts



SUMMARY | SOCIAL AND ECONOMIC IMPACTS

The second part of this report deals with the socio-economic impacts of climate change on a few key sectors of the Vietnamese economy, mainly agriculture and energy, and on a few key dimensions of Vietnamese society, mainly health and labour quality.

Infectious disease and mortality, two climate sensitive aspects of health

As Viet Nam develops, the mortality and morbidity due to infectious diseases is projected to drop from 33% and 38% in 1996 to 6% and 18% respectively in 2026. However, many infectious diseases remain endemic, including Tuberculosis, Chikugunya, Dengue, Rabies, Diarrhoea, and Respiratory Infections; there have also been episodes of Avian Flu. Infectious disease developments and mortality dynamics in Viet Nam may also be strongly affected by climate change. There is much evidence of significant positive association between temperature and infectious diseases, including increased cases of diarrhoea, enteric bacteria disease, and hand-mouth-foot diseases, for example.

By using data of provincial monthly infections of 28 types of diseases in 2009–2018 from the Viet Nam Ministry of Health, we estimate the short-term effects of weather variation (temperature, rainfall, wind speed, heatwave) and long-term effects of climate on the incidence of multiple infectious diseases (*i.e.* water-borne, airborne, and vector-borne) in Viet Nam, taking the role of public health expenditures for adaptation into account. Temperature and wind-speed affect three major types of infectious disease, including vector-borne, airborne, and water-borne, in all regions of Viet Nam, although at dissimilar levels. The strongest effect is found for vector-borne disease. The effects are heterogeneous across different climatic regions of Viet Nam and depend on the role of health-care expenditure. The cold region will have a higher incidence rate of diseases if the temperature rises. By contrast, the hot region will have a higher disease impact if the regional temperature falls.

The potential indirect cost of infectious diseases caused by future global climate warming is evaluated through the induced labour productivity loss: a 1% increase in disease infections leads to a decrease in the average hourly wage of approximately 0.05%. This is the marginal cost on worker productivity of an incremental change of temperature. It is only a part of the economic cost of infectious diseases. Indeed other costs include the loss in wages and the cost of preventing and treating the diseases. Furthermore, social costs include reduction of life expectancy and quality of life due to disease-related disability.

We also examine the effect of cold and heat waves on mortality in Viet Nam. We find robust evidence on the positive effects of heat waves on mortality. The effect of heat waves tends to increase when the heat wave lasts for a longer time, which is the case in all future climate change scenarios.

Agriculture climate dynamics and the specific case of rice

Over the past 30 years, strong agricultural growth has changed the socio-economic status of Viet Nam: improving food security, boosting agricultural exports, and creating livelihoods for people. At present, agriculture remains a key sector of Viet Nam's economy and social structure, contributing 18.4% of GDP, and employing 54% of the working population. Agricultural production accounts for approximately 34.71% of total land area, with rice, coffee, tea and pepper being the main crops. However, the agricultural sector has already been impacted by climate change, and projections for the next few decades indicate that climate warming trends are likely to accelerate.

With sea level rise affecting the two Deltas and the coastal regions, alongside changes in precipitation and temperature patterns, Viet Nam's agricultural sector is heavily exposed to the adverse impacts of weather variability and climate change, accentuated by human pressures. Long-run climate change and weather shocks have strong impacts on crop productivity and crop geographic distribution. Temperature and precipitation patterns and extremes, salinity intrusion, floods, and droughts are predicted to cause a major decline in crop production, in both of its components: crop yield and crop area.

Decline of crop yield predicted by climate scenarios: the impact of climate scenarios on **crop productivity** has been examined using a range of agronomic models that take into account temperature, rainfall patterns, water availability, atmospheric CO₂, and other factors to estimate the impact of climate change on crop yields. Predicted changes in yields vary widely across crops, agro-ecological zones, and climate scenarios, but most findings concur on the decline of crop yield under climate scenarios RCP4.5 and RCP8.5. Yield reduction rate in the Mekong Delta was found to vary from 4% to 7%, and from 7% to 10% respectively, under RCP4.5 and RCP8.5 scenarios for the 3 annual rice crops, with the highest rate (11%–16%) found in the major rice production provinces of An Giang and Dong Thap.

In terms of **crop geographical distribution**, we find for example that without adaptation, the risks of increasing salinity intrusion, of permanent inundation due to sea level rise, and of continuous resource exploitation (groundwater pumping and sand mining) would significantly reduce the land suitable for rice cultivation in the Mekong Delta. The loss caused by flooding would be up to 34% with an SLR of 25 cm in 2050. Equally, some 10% of the winter-spring rice area would no longer be suitable for rice cultivation due to saline intrusion, mainly in the provinces of Tien Giang, Vinh Long, Tra Vinh and Soc Trang [Figure 3]. It should be noted that the main threats to rice cultivation in the Deltas are relative sea level rise and increased salinity intrusions, and that both phenomena are accentuated by anthropogenic pressures.

Vulnerable populations dependent on agriculture threatened by climate change: our first results on the effects of flood, drought, temperature, precipitation, and typhoons on food security indices, per capita calorie intake and diet diversity indicate that flood, precipitation,

and typhoons impact household per capita calorie intake, but that drought and temperature change do not. Diet diversity is shown to be negatively impacted by the three extreme natural events taken into consideration: drought, flood and typhoon. In other words, Vietnamese farm households maintain constant calorie intakes when facing climatic shocks, at the cost of a significant decrease in their diet diversity.

Adapting agriculture while reducing emissions: climate change adaptation practices to be promoted for the agricultural sector should also contribute to mitigating Greenhouse Gas (GHG) emissions. Among the agricultural crops, rice cultivation is the most important source of GHG emissions. Methane emissions from rice production are responsible for 50% of emissions from agriculture, which in turn contribute 33% of the country's total greenhouse gas emissions. Therefore, improving rice production practices is key to reducing agricultural emissions. Rice farmers could be encouraged to apply climate change mitigation practices such as alternate wetting and drying, and to reduce the use of water, seeds, fertilizer, and pesticides. Emissions from rice paddies can also be reduced by rotating the use of land by introducing alternative activities like shrimp or fish farming. For example, instead of having three rice crops a year, a farmer could produce two rice crops and one shrimp harvest in the same field.

In conclusion, to tackle climate change, it is essential to continue investing in science and technology for short- and long-term solutions in the agricultural sector.

Energy demand and supply at ambiguous risk from a changing climate

Climate change is forecast to have a significant impact on Viet Nam's energy system. All other things being equal, each additional degree Celsius is estimated to increase household electricity consumption by 4.86% (confidence interval at 95%: 0.032–0.065) and firms' energy demand by 4.31% (confidence interval at 95%: 0.031–0.056). These significant effects, compounded by expected 5%–6% economic growth rate per annum, will put great pressure on the electricity generation sector in the long term.

On the demand side, electricity demand is forecast to increase significantly in relation to the Business As Usual (BAU) scenario as a result of temperature increase, ranging from 2.8% to 5.2% by 2050 under RCP4.5 and RCP8.5 scenarios, respectively. These increases result in corresponding increases in primary energy supply (due to the increase of input fuels for power generation) from 1.3% and 2.4%, as well in GHG emissions from power generation from 1.9% to 3.6% by 2050 under RCP4.5 and RCP8.5, respectively. The total cumulative additional costs of climate change impacts on electricity demand in the 2017–2050 period are approximately US\$ 4,227.1 million and US\$ 7,675.3 million with cumulative additional emissions of 161.9 MtCO₂e and 288.3 MtCO₂e under RCP4.5 and RCP8.5 respectively.

On the supply side, projected changes in hydropower production across several river basins due to climate change have also been investigated. Hydropower production shows a general positive relationship with precipitation levels. However, the range of projections for annual as well as monthly hydropower generation impacts are wide and uncertain. In addition, while the climate models broadly agree on an increase in future annual hydropower production across the basins, there are several months (mostly in the dry season) where the models disagree over whether there will be more or less hydropower production in the future. The high uncertainty in our projections is a result of various uncertainties arising from using downscaled GCM simulations and propagating through the subsequent hydrological and hydropower modelling processes which challenge power, social and economic planning.

For hydropower production, electricity generation output will increase in comparison with the BAU scenario due to the increase of rainfall under climate change scenarios. However, this increase is negligible and similar in both scenarios, RCP4.5 and RCP8.5, ranging from 0.04% to 0.13% of BAU's electricity generation output during the period 2017–2050. This increase in electricity generation output results in decreased input of other fossil fuels for power generation, as well as decreased social costs for hydropower production and GHG emission reduction. However, all these decreases are small and negligible compared to the damage and losses caused by climate change impacts on other areas. Total cumulative decreased costs for climate change impacts on hydropower production under RCP4.5 and RCP8.5 in the 2017–2050 period are approximately US\$ 1,121.8 million and US\$ 948.7 million, with cumulative decreased emissions of 43.0 MtCO₂e and 38.6 MtCO₂e, respectively.

For the whole energy system, climate change causes considerable negative effects on electricity demand, but brings positive effects on hydropower in the first half of the century in terms of electricity production.

Households and labor

We examine the effects of weather shocks on household income, especially agricultural income. By using the VHLSS dataset, we find that climate variability would harm household agricultural income, especially when the temperature is above 33°C, and the negative effect of weather shocks on poor households is four times larger than average. Secondly, this study also investigates how labour supply changes with regard to climate change. By using the Labour Firm Survey dataset, we find a negative relationship between climate change and working hours. On the demand side of the labor market, we identify how temperature affects firms' productivity. By using the Viet Nam Enterprise Survey, we find that an increase in temperature and precipitation would reduce firms' revenue, total factor productivity, output, and size.

Furthermore, we evaluate how climate variability affects individual behaviour and perception (i.e. decision to reallocate employment or migration decision, and attitudes towards environmental protection), along with their adaptation strategies. Our results suggest a non-linear effect of temperature change on employment allocation. In addition, we find that individuals are aware of extreme weather, whereas they are unaware of the gradually increasing temperature. A significant decline in hourly wage was exhibited at national scale across all RCPs, in which a reduction of 44.8% was projected by the end of the XXIst century under RCP8.5. We projected that by the end of the century, climate change implies a substantial reduction in hours worked (of up to 10%) at national scale. Moreover, the gender pay gap was projected to widen significantly in a warming climate. On the demand side of the labour market, firms' revenue would decline by approximately 14% (12%) across the northern (southern) regions; while total factor productivity of Viet Nam's firms is projected to drop from 4% to 14%.

TÓM TẮT | CHUYỂN ĐỔI KINH TẾ VÀ XÃ HỘI KHI ĐỐI MẶT VỚI BIẾN ĐỔI KHÍ HẬU

Phần thứ hai của báo cáo này đề cập đến các tác động kinh tế - xã hội của biến đổi khí hậu lên một số ngành chính của nền kinh tế Việt Nam (nông nghiệp và năng lượng) và một số vấn đề chính của xã hội (sức khỏe và chất lượng lao động).

Bệnh truyền nhiễm và tử vong, hai khía cạnh của sức khỏe dễ bị ảnh hưởng do khí hậu

Trong nghiên cứu về sức khỏe và môi trường, dịch bệnh truyền nhiễm và tỷ lệ tử vong là hai khía cạnh nhạy cảm đối với sự thay đổi khí hậu. Cùng với sự phát triển của Việt Nam, tỷ lệ tổn thất về tử vong và tỷ lệ mắc bệnh truyền nhiễm dự kiến sẽ giảm từ 33% và 38% năm 1996 xuống còn 6% và 18% vào năm 2026. Tuy nhiên, nhiều bệnh truyền nhiễm vẫn còn lưu hành bao gồm lao, HIV, sốt xuất huyết, bệnh dại, tiêu chảy, nhiễm trùng đường hô hấp và các đợt dịch cúm gia cầm. Có nhiều bằng chứng đáng kể về mối liên hệ đồng biến giữa nhiệt độ và các bệnh truyền nhiễm, ví dụ, gia tăng các trường hợp tiêu chảy, bệnh do vi khuẩn đường ruột, bệnh tay chân miệng. Các hiện tượng thời tiết khắc nghiệt cũng có thể làm tăng tỷ lệ tử vong và suy dinh dưỡng ở trẻ em. Mặc dù đã có bằng chứng rõ ràng về tác hại của các hiện tượng thời tiết và khí hậu khắc nghiệt, nhưng không có sự nhất quán về mức độ ảnh hưởng đối với sức khỏe và lây nhiễm bệnh tật trong các nghiên cứu.

Trong nghiên cứu này, bằng cách sử dụng dữ liệu hàng tháng của các tỉnh bị nhiễm 28 loại bệnh trong năm 2009–2018 từ bộ Y tế, chúng tôi ước tính tác động ngắn hạn của biến đổi thời tiết (nhiệt độ, lượng mưa, tốc độ gió, đợt nắng nóng) và ảnh hưởng dài hạn của khí hậu đối với tỷ lệ mắc bệnh truyền nhiễm ở Việt Nam, cũng như vai trò của chi phí y tế công cộng để thích ứng và giảm thiểu tác động. Kết quả cho thấy, nhiệt độ và tốc độ gió ảnh hưởng đến ba loại bệnh truyền nhiễm chính, bao gồm: lây truyền qua cơ chế lan truyền véc tơ (bởi virus, vi khuẩn...), đường không khí và đường nước cho tất cả các tỉnh vùng của Việt Nam. Tác động mạnh nhất được tìm thấy đối với bệnh do véc tơ lan truyền. Các tác động không đồng nhất giữa các vùng khí hậu khác nhau của Việt Nam và tùy thuộc vào chi tiêu cho y tế. Vùng lạnh sẽ có tỷ lệ mắc bệnh cao hơn nếu nhiệt độ tăng cao. Ngược lại, nơi nóng sẽ có tác động dịch bệnh cao hơn nếu nhiệt độ khu vực giảm xuống.

Chi phí gián tiếp tiềm ẩn của các bệnh truyền nhiễm do khí hậu toàn cầu nóng lên trong tương lai được đánh giá thông qua việc giảm năng suất lao động gây ra: tỷ lệ nhiễm bệnh tăng 1% dẫn đến giảm mức lương trung bình theo giờ khoảng 0,049%. Đây là chi phí cận biên đối với năng suất của lao động khi nhiệt độ thay đổi gia tăng và cần một số lưu ý. Đầu tiên, đây chỉ là một phần chi phí kinh tế của các bệnh truyền nhiễm. Chi phí trực tiếp là hao hụt tiền lương và chi phí phòng và chữa bệnh. Chi phí xã hội bao gồm giảm tuổi thọ và chất lượng cuộc sống do khuyết tật liên quan đến bệnh tật. Việc ước tính những điều này nằm ngoài phạm vi của nghiên cứu hiện tại nhưng trong các bối cảnh khác, những ước tính này là đáng kể.

Tiếp đến, chúng tôi xem xét ảnh hưởng của các đợt nóng và lạnh đến tỷ lệ tử vong ở Việt Nam. Chúng tôi tìm thấy bằng chứng mạnh về tác động đồng biến của các đợt nóng và lạnh đối với tỷ lệ tử vong. Điều này cho thấy rằng ảnh hưởng của một đợt nắng nóng lên tỷ lệ tử vong là đáng kể hơn và có cường độ lớn hơn ảnh hưởng của một đợt lạnh. Ảnh hưởng của các đợt nắng nóng có xu hướng gia tăng khi đợt nắng nóng càng kéo dài.

Kết quả cũng cho thấy những người lớn tuổi, đặc biệt là những người từ 80 tuổi, chủ yếu bị ảnh hưởng bởi thời tiết khắc nghiệt trong khi các đợt nóng và lạnh ảnh hưởng không đáng kể đối với những người dưới 40 tuổi.

Tác động của biến đổi khí hậu đối với nông nghiệp và trường hợp cụ thể của canh tác lúa

Trong 30 năm qua, tăng trưởng nông nghiệp mạnh mẽ đã làm thay đổi tình trạng kinh tế xã hội của Việt Nam: cải thiện an ninh lương thực, đẩy mạnh xuất khẩu nông sản, tạo sinh kế cho người dân. Nông nghiệp hiện nay vẫn là ngành then chốt trong cơ cấu xã hội và nền kinh tế của Việt Nam, đóng góp 18,4% GDP của Việt Nam và sử dụng 54% dân số lao động. Đất sản xuất nông nghiệp chiếm khoảng 34,71% tổng diện tích đất, với cây trồng chính là lúa, cà phê, chè và hồ tiêu. Tuy nhiên, ngành nông nghiệp đã bị tác động bởi biến đổi khí hậu, và các dự báo trong vài thập kỷ tới cho thấy xu hướng nóng lên của khí hậu có khả năng được đẩy nhanh.

Với mực nước biển dâng ảnh hưởng đến hai vùng đồng bằng và ven biển, cùng với những thay đổi về lượng mưa và nhiệt độ, ngành nông nghiệp của Việt Nam đang chịu nhiều tác động tiêu cực của sự biến đổi thời tiết và biến đổi khí hậu, tăng lên bởi áp lực của con người. Biến đổi khí hậu trong thời gian dài và các cú sốc thời tiết có tác động mạnh đến năng suất cây trồng và phân bố địa lý cây trồng. Các mô hình nhiệt độ, lượng mưa và các hiện tượng cực đoan, xâm nhập mặn, lũ lụt, hạn hán, được dự đoán là sẽ gây ra sự suy giảm lớn về sản lượng cây trồng, cả về thành phần, năng suất cây trồng và diện tích cây trồng.

Sự suy giảm **năng suất cây trồng** được dự đoán theo các kịch bản khí hậu: tác động của các kịch bản khí hậu lên năng suất cây trồng đã được kiểm tra bằng cách sử dụng một loạt các mô hình nông học có tính đến nhiệt độ, lượng mưa, lượng nước sẵn có, CO₂ trong khí quyển và các yếu tố khác để ước tính tác động của biến đổi khí hậu đối với năng suất cây trồng. Những thay đổi dự đoán về sản lượng rất khác nhau giữa các loại cây trồng, vùng sinh thái nông nghiệp và các kịch bản khí hậu, nhưng hầu hết các kết quả nghiên cứu đều đồng tình về sự suy giảm năng suất cây trồng trong các kịch bản khí hậu RCP4.5 và RCP8.5. Tỷ lệ giảm năng suất ở Đồng bằng sông Cửu Long thay đổi từ 4 đến 7% và từ 7% đến 10%, tương ứng với các kịch bản RCP 4,5 và RCP 8,5 cho 3 vụ lúa hàng năm, với tỷ lệ cao nhất (11–16%) được tìm thấy trong các tỉnh sản xuất lúa gạo lớn là An Giang và Đồng Tháp.

Về **phân bố địa lý cây trồng**, chúng tôi thấy rằng nếu không thích ứng, rủi ro gia tăng xâm nhập mặn, ngập lụt vĩnh viễn do nước biển dâng, và khai thác tài nguyên liên tục (bơm nước ngầm và khai thác cát) sẽ làm giảm đáng kể diện tích đất thích hợp cho trồng lúa ở đồng bằng sông Cửu Long. Thiệt hại lên tới 34% do lũ lụt với SLR là 25 cm vào năm 2050. Hoặc khoảng 10% diện tích lúa Đông Xuân sẽ không còn thích hợp để trồng lúa do xâm nhập mặn, chủ yếu ở các tỉnh Tiền Giang, Vĩnh Long, Trà Vinh và Sóc Trăng [Hình 3]. Cần lưu ý rằng mối đe dọa chính đối với việc trồng lúa ở các vùng đồng bằng là gia tăng ngập lụt do mực nước biển dâng và gia tăng xâm nhập mặn, và cả hai hiện tượng này đều bị tăng tốc bởi áp lực con người.

Dân số dễ bị tổn thương sống bằng nông nghiệp có khả năng bị đe dọa bởi biến đổi khí hậu: Kết quả đầu tiên của chúng tôi về tác động của lũ lụt, hạn hán, nhiệt độ, lượng mưa, bão đến các chỉ số an ninh lương thực, lượng calo bình quân đầu người và sự đa dạng trong chế độ ăn uống cho thấy rằng lũ lụt, lượng mưa và bão có ảnh hưởng đến lượng calo bình quân đầu người của hộ gia đình, nhưng không ảnh hưởng đến hạn hán và nhiệt độ. Sự đa dạng về chế độ ăn uống bị ảnh hưởng tiêu cực bởi ba sự kiện tự nhiên được coi là cực đoan, hạn hán, lũ lụt và bão. Nói cách khác, các hộ nông dân Việt Nam giữ lượng calo tiêu thụ không đổi khi đối mặt với những cú sốc về khí hậu, với cái giá phải trả là sự đa dạng trong chế độ ăn của họ giảm đi đáng kể.

Thích ứng nông nghiệp trong khi giảm phát thải: Các thực hành thích ứng với biến đổi khí hậu được thúc đẩy cho ngành nông nghiệp cũng cần góp phần giảm nhẹ phát thải khí nhà kính (GHG). Trong số các loại cây nông nghiệp, trồng lúa là nguồn phát thải KNK quan trọng nhất. Khí thải mê-tan từ sản xuất lúa gạo là nguyên nhân gây ra 50% lượng khí thải từ nông nghiệp, do đó đóng góp 33% tổng lượng khí thải nhà kính của đất nước. Do đó, việc cải thiện thực hành sản xuất lúa gạo là chìa khóa để giảm lượng khí thải nông nghiệp. Nông dân trồng lúa có thể được khuyến khích áp dụng các biện pháp giảm thiểu biến đổi khí hậu như làm ngập nước không liên tục (AWD), và giảm sử dụng nước, hạt giống, phân bón và thuốc trừ sâu. Cũng có thể giảm phát thải từ ruộng lúa bằng cách luân phiên sử dụng đất bằng cách đưa vào các hoạt động thay thế như nuôi tôm hoặc cá. Ví dụ, thay vì có ba vụ lúa một năm, một nông dân có thể sản xuất hai vụ lúa và một vụ thu hoạch tôm trong cùng một ruộng lúa.

Tóm lại, để giải quyết vấn đề biến đổi khí hậu, cần tiếp tục đầu tư vào khoa học và công nghệ cho các giải pháp ngắn hạn và dài hạn trong lĩnh vực nông nghiệp.

Cung cầu năng lượng và các rủi ro tiềm ẩn do tác động của biến đổi khí hậu

Biến đổi khí hậu được cho là có tác động đáng kể đến hệ thống năng lượng của Việt Nam. Nếu giữ những nhu cầu sử dụng khác không đổi, mỗi độ C tăng thêm được ước tính sẽ làm tăng mức tiêu thụ điện trong các hộ gia đình lên 4,86% (khoảng tin cậy ở mức 95%:

0,032–0,065) và nhu cầu năng lượng của các công ty tăng 4,31% (khoảng tin cậy ở mức 95%: 0,031–0,056). Những tác động này, cộng với tốc độ tăng trưởng kinh tế dự kiến 5–6% trên năm, sẽ tạo ra áp lực lớn đối với lĩnh vực phát điện trong dài hạn.

Về phía cầu, kết quả nghiên cứu cho thấy nhu cầu điện tăng đáng kể so với kịch bản BAU (phát triển thông thường) do nhiệt độ tăng, tương ứng từ 2,8% lên 5,2% vào năm 2050 theo các kịch bản RCP4.5 và RCP8.5. Nhu cầu điện tăng dẫn đến sự gia tăng tương ứng của nguồn cung cấp năng lượng sơ cấp thiết yếu (do sự gia tăng của nhiên liệu đầu vào cho phát điện) từ 1,3% và 2,4% cũng như gia tăng phát thải KNK từ sản xuất điện từ 1,9% lên 3,6% vào năm 2050 tương ứng theo các kịch bản RCP4.5 và RCP8.5. Tổng chi phí tích lũy của các tác động của biến đổi khí hậu đối với nhu cầu điện trong giai đoạn 2017–2050 tăng thêm khoảng 4.227,1 triệu USD và 7.675,3 triệu USD với mức phát thải cộng dồn lần lượt là 161,9 MtCO_{2e} và 288,3 MtCO_{2e} theo các kịch bản tương ứng RCP4,5 và RCP8,5.

Về phía nguồn cung, dự báo những thay đổi về sản lượng thủy điện trên một số lưu vực sông do biến đổi khí hậu cũng đã được nghiên cứu. Sản lượng thủy điện tăng cho thấy mối quan hệ đồng biến nói chung với lượng mưa. Tuy nhiên, phạm vi dự báo về tác động của việc phát điện hàng năm cũng như hàng tháng là rất rộng và không chắc chắn. Ngoài ra, trong khi các mô hình khí hậu phần lớn đồng thuận về việc sản lượng thủy điện hàng năm sẽ tăng trên các lưu vực, thì có một vài tháng (chủ yếu là vào mùa khô), các mô hình không thống nhất liệu sẽ có sản lượng thủy điện nhiều hơn hay ít hơn trong tương lai. Sự không bất định trong các dự báo của chúng tôi là kết quả của nhiều sự bất định khác nhau phát sinh từ việc sử dụng các kết quả mô phỏng các mô hình GCM, và càng tăng bất định thông qua các quy trình tính toán thủy văn và thủy điện, điều này là thách thức lớn cho kế hoạch quy hoạch năng lượng để phát triển kinh tế- xã hội.

Đối với sản xuất thủy điện, sản lượng phát điện sẽ tăng so với kịch bản BAU do lượng mưa tăng theo kịch bản biến đổi khí hậu. Tuy nhiên, mức tăng này là không đáng kể và tương tự trong cả hai kịch bản, RCP4.5 và RCP8.5, dao động từ 0,04% đến 0,13% sản lượng phát điện của BAU trong giai đoạn 2017–2050. Sự gia tăng sản lượng phát điện này dẫn đến giảm nhiên liệu đầu vào của các nhiên liệu hóa thạch khác để phát điện cũng như giảm chi phí xã hội cho sản xuất thủy điện và giảm phát thải KNK. Tuy nhiên, tất cả những mức giảm này là nhỏ và không đáng kể so với những thiệt hại và mất mát do tác động của biến đổi khí hậu đối với các khu vực khác. Tổng chi phí giảm tích lũy do tác động của biến đổi khí hậu đối với sản xuất thủy điện theo RCP4.5 và RCP8.5 trong giai đoạn 2017–2050 vào khoảng 1.121,8 triệu USD và 948,7 triệu USD, với mức phát thải giảm tích lũy lần lượt là 43,0 MtCO_{2e} và 38,6 MtCO_{2e}.

Đối với toàn bộ hệ thống năng lượng, biến đổi khí hậu gây ra những tác động tiêu cực đáng kể đến nhu cầu điện nhưng lại mang lại hiệu quả tích cực cho thủy điện về mặt sản xuất điện. Tuy nhiên, mức giảm chi phí xã hội và phát thải của thủy điện nhỏ hơn mức tăng thêm của chi phí xã hội và phát thải do tác động của biến đổi khí hậu đối với nhu cầu điện, và đối với hệ thống năng lượng, tác động của biến đổi khí hậu sẽ gây ra sự gia tăng đáng kể của chi phí

xã hội với mức tăng thêm tích lũy là 3.105,3 triệu USD và 6.726,5 triệu USD với lượng phát thải bổ sung tích lũy lần lượt là 118,9 MtCO₂e và 249,7 MtCO₂e vào năm 2050 theo RCP4,5 và RCP8,5. Con số này sẽ lớn hơn nếu tính đến tác động của biến đổi khí hậu đối với các lĩnh vực khác như thương mại, giao thông và sản xuất nhiệt điện.

Cần thúc đẩy các biện pháp công nghệ như tiết kiệm năng lượng trong các khu dân cư và công nghiệp và năng lượng tái tạo (như điện mặt trời và điện gió) nhằm góp phần đáng kể vào việc giảm phát thải KNK và phát triển kinh tế bền vững. Như đã phân tích ở trên, tác động của biến đổi khí hậu đến hệ thống năng lượng sẽ làm tăng mức tiêu thụ điện cho điều hòa, dẫn đến tăng tiêu thụ nhiên liệu, chi phí và phát thải KNK trong sản xuất điện. Việc giảm sử dụng điện cho máy điều hòa không khí thông qua việc khuyến khích sử dụng điều hòa nhiệt độ hiệu suất cao và các thiết bị tiết kiệm điện khác có thể giảm thiểu những tác động của biến đổi khí hậu. Nghiên cứu ở quy mô toàn cầu đã chỉ ra rằng biến đổi khí hậu có ít hoặc thậm chí tác động tích cực đến sản xuất thủy điện. Đánh giá định lượng của chúng tôi khẳng định xu hướng tương tự đối với Việt Nam trên quy mô quốc gia. Tuy nhiên, các tác động cục bộ được thể hiện là khác nhau trên toàn quốc. Các quá trình thủy văn ở nhiều lưu vực có khả năng bị thay đổi, và nguồn nước bị suy giảm có nghĩa là nhiều vùng của đất nước có thể bị đe dọa mất an toàn điện, đặc biệt là vào mùa khô, nếu các biện pháp giảm thiểu và thích ứng không được đưa ra một cách đầy đủ. Ngoài ra, sự bất đồng trong kết quả giữa các kịch bản phát thải carbon khác nhau và các mô hình khí hậu làm nổi bật những rủi ro liên quan đến sự bất định lớn hơn do biến đổi khí hậu gây ra, điều này là một thách thức đối với việc quy hoạch xã hội và kinh tế. Kết quả sơ bộ nêu trên là những yếu tố đầu tiên của nghiên cứu về tác động của biến đổi khí hậu đối với hệ thống năng lượng, một vấn đề mới ở Việt Nam. Đối với cả hệ thống năng lượng, biến đổi khí hậu gây ra những tác động tiêu cực đáng kể đến cầu về điện, nhưng lại có những tác động tích cực tới sản xuất thủy điện trong nửa đầu của thế kỷ.

Hộ gia đình và lao động

Chúng tôi mong muốn hiểu được tác động của biến đổi khí hậu đối với phúc lợi của người lao động, hộ gia đình và hiệu quả hoạt động của các doanh nghiệp. Thứ nhất, về phía cung của thị trường lao động, chúng tôi xem xét ảnh hưởng của các cú sốc thời tiết đến thu nhập của hộ gia đình, đặc biệt là thu nhập từ nông nghiệp. Sử dụng bộ dữ liệu VHLSS, chúng tôi thấy rằng sự biến đổi khí hậu sẽ gây hại cho thu nhập từ nông nghiệp của hộ gia đình, đặc biệt là khi nhiệt độ trên 33°C và tác động tiêu cực của các cú sốc thời tiết đối với các hộ nghèo lớn hơn gấp 4 lần so với mức trung bình. Thứ hai, nghiên cứu này cũng điều tra sự thay đổi của nguồn cung lao động liên quan đến biến đổi khí hậu. Bằng cách sử dụng bộ dữ liệu Khảo sát Công ty Lao động, chúng tôi nhận thấy mối quan hệ tiêu cực giữa biến đổi khí hậu và giờ làm việc. Về phía cầu của thị trường lao động, chúng tôi xác định nhiệt độ ảnh hưởng như thế nào đến năng suất của các công ty. Bằng cách sử dụng Khảo sát Doanh nghiệp Việt Nam, chúng tôi nhận thấy rằng sự gia tăng nhiệt độ và lượng mưa sẽ làm giảm doanh thu, năng suất, sản lượng và quy mô của các doanh nghiệp.

Hơn nữa, chúng tôi đánh giá sự biến đổi khí hậu ảnh hưởng như thế nào đến hành vi và nhận thức của các cá nhân (tức là quyết định phân bổ lại việc làm hoặc quyết định di cư và thái độ đối với bảo vệ môi trường) như là các chiến lược thích ứng của họ. Kết quả của chúng tôi cho thấy ảnh hưởng phi tuyến tính của sự thay đổi nhiệt độ đối với việc phân bổ việc làm. Ngoài ra, chúng tôi thấy rằng các cá nhân nhận thức được thời tiết khắc nghiệt trong khi họ không nhận thức được nhiệt độ tăng dần. Mức lương theo giờ giảm đáng kể được thể hiện trên quy mô quốc gia trên tất cả các RCP, trong đó dự kiến sẽ giảm 44,8% vào cuối thế kỷ 21 theo RCP8,5. Chúng tôi dự đoán rằng vào cuối thế kỷ này, biến đổi khí hậu đồng nghĩa với việc giảm đáng kể số giờ làm việc (lên đến 10%) ở quy mô quốc gia. Hơn nữa, chênh lệch lương theo giới được dự báo sẽ gia tăng đáng kể trong điều kiện khí hậu ấm lên. Về phía cầu của thị trường lao động, doanh thu của công ty sẽ giảm xuống còn khoảng 14% (12%) ở các khu vực phía bắc (phía nam); trong khi năng suất tổng nhân tố của các doanh nghiệp Việt Nam dự kiến sẽ giảm từ 4% xuống 14%.

RÉSUMÉ | TRANSFORMATIONS ÉCONOMIQUES ET SOCIALES FACE AU CHANGEMENT CLIMATIQUE

La deuxième partie de ce rapport traite des impacts socio-économiques du changement climatique sur quelques secteurs clés de l'économie vietnamienne, principalement l'agriculture et l'énergie, et sur quelques dimensions clés de la société vietnamienne, principalement la santé et la qualité du travail.

Maladies infectieuses et mortalité, deux aspects de la santé sensibles au climat

Au fur et à mesure que le Viet Nam se développe, le taux de mortalité et de morbidité dues aux maladies infectieuses devrait chuter de 33% et 38% en 1996 à 6% et 18% respectivement en 2026. Cependant, de nombreuses maladies infectieuses restent endémiques, notamment la tuberculose, le VIH, le chikungunya, la dengue, la rage, la diarrhée, les infections respiratoires, et il y a eu des épisodes de grippe aviaire. L'évolution des maladies infectieuses et la dynamique de la mortalité au Viet Nam peuvent également être fortement affectées par le changement climatique. Il existe de nombreuses preuves d'une association positive significative entre la température et les maladies infectieuses, par exemple, l'augmentation des cas de diarrhée, les maladies à bactéries entériques, les maladies main-bouche-pied. Les événements météorologiques extrêmes peuvent également augmenter la mortalité et la malnutrition chez les enfants. L'exposition in-utero à des conditions météorologiques extrêmes renvoie à un faible poids de naissance. Bien qu'il n'y ait aucun doute sur l'effet néfaste des conditions météorologiques extrêmes et des événements climatiques, il n'y a pas de cohérence dans l'ampleur de l'effet sur la santé et l'infection des maladies.

Dans cette étude, tout d'abord en utilisant une donnée des infections mensuelles provinciales de 28 types de maladies en 2009–2018 du ministère vietnamien de la Santé, nous estimons les effets à court terme de la variation météorologique (température, précipitations, vitesse du vent, canicule) et les effets à long terme du climat sur l'incidence de multiples maladies infectieuses (c'est-à-dire, d'origine hydrique, aérienne et vectorielle) au Viet Nam, en tenant compte du rôle des dépenses de santé publique pour l'adaptation. La température et la vitesse du vent ont une incidence sur trois grands types de maladies infectieuses, à savoir les maladies à transmission vectorielle, aérienne et hydrique, dans toutes les régions du Viet Nam, mais à des niveaux différents. L'effet le plus fort est constaté pour les maladies à transmission vectorielle. Les effets sont hétérogènes entre les différentes régions climatiques du Viet Nam et en fonction des dépenses de santé. La région froide aura un taux d'incidence des maladies plus élevé si la température augmente. En revanche, la région chaude aura un impact plus élevé des maladies si la température régionale baisse.

Le coût indirect potentiel des maladies infectieuses causées par le réchauffement climatique mondial futur est évalué par la perte de productivité du travail induite : une augmentation de

1% des infections de maladies entraîne une diminution du salaire horaire moyen d'environ 0,05%. Il s'agit du coût marginal sur la productivité des travailleurs d'un changement incrémental de température. Il ne s'agit que d'une partie du coût économique des maladies infectieuses. Les autres coûts seront la perte de salaire et le coût de la prévention et du traitement des maladies. Les coûts sociaux comprennent la réduction de l'espérance de vie et de la qualité de vie en raison de l'invalidité liée à la maladie.

Nous examinons l'effet des vagues de froid et de chaleur sur la mortalité au Viet Nam. Nous trouvons des preuves solides des effets positifs des vagues de chaleur sur la mortalité. L'effet des vagues de chaleur a tendance à augmenter lorsque la vague de chaleur dure plus longtemps.

La dynamique climatique de l'agriculture et le cas spécifique du riz

Au cours des 30 dernières années, la forte croissance agricole a changé le statut socio-économique du Viet Nam : amélioration de la sécurité alimentaire, augmentation des exportations agricoles et création de moyens de subsistance pour les populations. L'agriculture reste actuellement un secteur clé de l'économie et de la structure sociale du Viet Nam, contribuant à 18,4% du PIB Viet Namien et employant 54% de la population active. Les terres de production agricole représentent environ 34,71% de la superficie totale des terres, le riz, le café, le thé et le poivre étant les principales cultures. Cependant, le secteur agricole a déjà été touché par le changement climatique, et les projections pour les prochaines décennies indiquent que les tendances au réchauffement climatique sont susceptibles de s'accélérer.

Avec l'élévation du niveau de la mer affectant les deux deltas et les régions côtières, et les changements dans les régimes de précipitations et de température, le secteur agricole du Viet Nam est fortement exposé aux effets néfastes de la variabilité météorologique et du changement climatique, accentués par les pressions humaines. Les changements climatiques à long terme et les chocs météorologiques ont de fortes répercussions sur la productivité et la répartition géographique des cultures. Les régimes et les extrêmes de température et de précipitation, l'intrusion de salinité, les inondations, les sécheresses devraient entraîner une baisse importante de la production agricole, dans ses deux composantes, le rendement des cultures et la superficie cultivée.

Déclin du rendement des cultures prévu selon des scénarios climatiques : l'impact des scénarios climatiques sur la productivité des cultures a été examiné à l'aide d'une gamme de modèles agronomiques qui prennent en compte la température, les régimes de précipitations, la disponibilité de l'eau, le CO₂ atmosphérique et d'autres facteurs pour estimer l'impact du changement climatique sur les rendements des cultures. Les résultats de simulation montrent que les rendements varient considérablement selon les cultures, les zones agro-écologiques et les scénarios climatiques, mais la plupart des résultats concordent sur le déclin du rendement des cultures dans les scénarios climatiques RCP4.5 et RCP8.5 pour

2050. Le taux de réduction de rendement dans le delta du Mékong a été trouvé variant de 4 à 7%, et de 7% à 10%, pour respectivement les scénarios RCP4.5 et RCP8.5 pour les 3 cultures annuelles de riz, avec le taux le plus élevé (11–16%) trouvé dans les principales provinces productrices de riz d'An Giang et de Dong Thap.

En terme de répartition géographique des cultures, on prédit par exemple que sans adaptation, les risques d'intrusion saline croissante, celui d'inondation permanente due à l'élévation du niveau de la mer, et l'exploitation continue des ressources (pompage des nappes phréatiques et extraction de sable) pourraient réduire considérablement les terres propices à la riziculture dans le delta du Mékong. La perte irait jusqu'à 34% causés par l'inondation avec un SLR de 25 cm en 2050. Ou environ 10% de la surface de riz d'hiver-printemps ne serait plus adaptée à la culture du riz due à l'intrusion saline, principalement dans les provinces de Tien Giang, Vinh Long, Tra Vinh et Soc Trang [Figure 3]. Il est à noter que la principale menace pour la riziculture dans les deltas est l'élévation relative du niveau de la mer et l'augmentation des intrusions salines et que ces deux phénomènes sont accentués par les pressions anthropiques.

Population vulnérable vivant de l'agriculture menacée par le changement climatique : nos premiers résultats sur les effets des inondations, des sécheresses, des températures, des précipitations, des typhons sur les indices de sécurité alimentaire, l'apport calorique par habitant et la diversité du régime alimentaire indiquent que les inondations, les précipitations et les typhons ont un impact sur l'apport calorique par habitant des ménages, mais pas la sécheresse et la température. La diversité du régime alimentaire est affectée négativement par les trois événements naturels considérés comme extrêmes, qui sont la sécheresse, les inondations et les typhons. Autrement dit, les ménages agricoles vietnamiens maintiennent leurs apports caloriques constants face aux chocs climatiques, au prix d'une diminution significative de la diversité de leur alimentation.

Adapter l'agriculture tout en réduisant les émissions : les pratiques d'adaptation au changement climatique à promouvoir pour le secteur agricole devraient également contribuer à atténuer les émissions de gaz à effet de serre (GES). Parmi les cultures agricoles, la riziculture est la source la plus importante d'émissions de GES. Les émissions de méthane provenant de la production de riz sont responsables de 50% des émissions provenant de l'agriculture, qui à son tour contribue à 33% des émissions totales de gaz à effet de serre du pays. Par conséquent, l'amélioration des pratiques de production de riz est essentielle pour réduire les émissions agricoles. Les riziculteurs pourraient être encouragés à appliquer des pratiques d'atténuation du changement climatique telles que l'irrigation et séchage alternatifs (AWD), et à réduire l'utilisation d'eau, de semences, d'engrais et de pesticides. Les émissions des rizières peuvent également être réduites en alternant l'utilisation des terres en introduisant des activités alternatives comme la crevette ou la pisciculture. Par exemple, au lieu d'avoir trois récoltes de riz par an, un agriculteur pourrait produire deux récoltes de riz et une récolte de crevettes dans la même rizière.

En conclusion, pour faire face aux changements climatiques, il est essentiel de continuer à investir dans la science et la technologie pour des solutions à court et à long terme dans le secteur agricole.

L'offre et la demande d'énergie face aux risques ambigus du changement climatique

Le changement climatique est censé avoir un impact significatif sur le système énergétique du Viet Nam. Toutes choses égales par ailleurs, on estime que chaque degré Celsius supplémentaire augmente la consommation d'électricité des ménages de 4,86% (intervalle de confiance à 95% : 0,032–0,065) et la demande d'énergie des entreprises de 4,31% (intervalle de confiance à 95% : 0,031–0,056). Ces réponses importantes, combinées à un taux de croissance économique attendu de 5 à 6% par an, exposeront une grande pression sur le secteur de la production d'électricité à long terme.

Du côté de la demande, la demande d'électricité augmente considérablement par rapport au scénario de référence (ou Business As Usual) en raison de l'augmentation de la température, allant de 2,8% à 5,2% d'ici 2050 dans les scénarios RCP4.5 et RCP8.5, respectivement. Ces augmentations entraînent des augmentations correspondantes de l'offre d'énergie primaire (en raison de l'augmentation des combustibles utilisés pour la production d'électricité) de 1,3% et 2,4%, ainsi que des émissions de GES dues à la production d'électricité de 1,9% à 3,6% d'ici 2050 dans les scénarios RCP4.5 et RCP8.5, respectivement. Les coûts supplémentaires cumulatifs totaux des impacts du changement climatique sur la demande d'électricité au cours de la période 2017–2050 sont d'environ 4 227,1 millions de dollars US et 7 675,3 millions de dollars US, avec des émissions supplémentaires cumulatives de 161,9 MtCO_{2e} et 288,3 MtCO_{2e} dans le cadre du RCP4.5 et du RCP8.5 respectivement.

Du côté de l'offre, les changements prévus dans la production d'hydroélectricité dans plusieurs bassins fluviaux en raison du changement climatique ont également été étudiés. La production d'hydroélectricité présente une relation positive générale avec les niveaux de précipitations. Cependant, la gamme des projections pour les impacts annuels et mensuels de la production d'hydroélectricité est large et incertaine. En outre, alors que les modèles climatiques s'accordent largement sur une augmentation de la production annuelle d'hydroélectricité dans l'ensemble des bassins, les modèles ne s'accordent pas sur l'augmentation ou la diminution de la production d'hydroélectricité au cours de plusieurs mois (principalement pendant la saison sèche). La grande incertitude de nos projections est le résultat de diverses incertitudes découlant de l'utilisation de simulations MCG à échelle réduite et se propageant à travers les processus ultérieurs de modélisation hydrologique et hydroélectrique qui remettent en question la planification énergétique, sociale et économique.

En ce qui concerne la production hydroélectrique, la production d'électricité augmentera par rapport au scénario BAU en raison de l'augmentation des précipitations dans les scénarios

de changement climatique. Toutefois, cette augmentation est négligeable et similaire dans les deux scénarios, RCP4.5 et RCP8.5, allant de 0,04% à 0,13% de la production d'électricité du scénario BAU au cours de la période 2017–2050. Cette augmentation de la production d'électricité entraîne une diminution de l'utilisation d'autres combustibles fossiles pour la production d'électricité ainsi qu'une diminution des coûts sociaux de la production d'hydroélectricité et de la réduction des émissions de GES. Cependant, toutes ces diminutions sont faibles et négligeables par rapport aux dommages et pertes causés par les impacts du changement climatique sur d'autres domaines. Les coûts cumulatifs totaux des impacts du changement climatique sur la production d'hydroélectricité dans le cadre des scénarios RCP4.5 et RCP8.5 au cours de la période 2017–2050 sont d'environ 1 121,8 millions de dollars US et 948,7 millions de dollars US, avec des émissions cumulées réduites de 43,0 MtCO_{2e} et 38,6 MtCO_{2e}, respectivement.

Pour l'ensemble du système énergétique, le changement climatique a des effets négatifs considérables sur la demande d'électricité mais a des effets positifs sur l'hydroélectricité dans la première moitié du siècle en termes de production d'électricité.

Ménages et travail

Nous examinons les effets des chocs climatiques sur le revenu des ménages, en particulier le revenu agricole. En utilisant les données de l'enquête VHLSS, nous constatons que le changement climatique nuit au revenu des ménages, en particulier lorsque la température est supérieure à 33°C, et que l'effet négatif des chocs climatiques sur le revenu des ménages dans le secteur agricole est quatre fois plus important que la moyenne. Deuxièmement, cette étude examine également comment l'offre de travail évolue en fonction du changement climatique. En utilisant les données de l'enquête sur les forces de travail, nous trouvons une relation négative entre le changement climatique et les heures de travail/salaire horaire. Du côté de la demande du marché du travail, nous identifions comment la température affecte la productivité des entreprises. En utilisant l'enquête sur les entreprises du Viet Nam, nous constatons qu'une augmentation de la température et des précipitations réduirait les revenus, la productivité totale des facteurs, la production et la taille des entreprises.

En outre, nous évaluons comment la variabilité climatique affecte les comportements et la perception des individus (c'est-à-dire la décision de réaffecter l'emploi ou la décision de migration, et les attitudes envers la protection de l'environnement) en tant que stratégies d'adaptation. Nos résultats suggèrent l'effet non linéaire du changement de température sur la répartition des emplois. En outre, nous constatons que les individus sont conscients des conditions météorologiques extrêmes alors qu'ils ne sont pas conscients de l'augmentation progressive de la température.

Une réduction considérable du salaire horaire a été trouvée au niveau national dans tous les RCPs, avec une réduction de 44.8% projetée à la fin du 21^{ème} siècle dans le RCP8.5. Nous

trouvons qu'à la fin du siècle, le changement climatique implique une diminution substantielle du nombre d'heures de travail (jusqu'à 10%) au niveau national. Par ailleurs, l'écart de rémunération entre les sexes pourrait augmenter de manière significative avec le réchauffement climatique. Du côté de la demande du marché de travail, les revenus des entreprises pourraient diminuer à peu près 14% (12%) dans les régions du nord (sud), alors que la productivité totale des facteurs des entreprises vietnamiennes est prévue de diminuer de 4% à 14%.

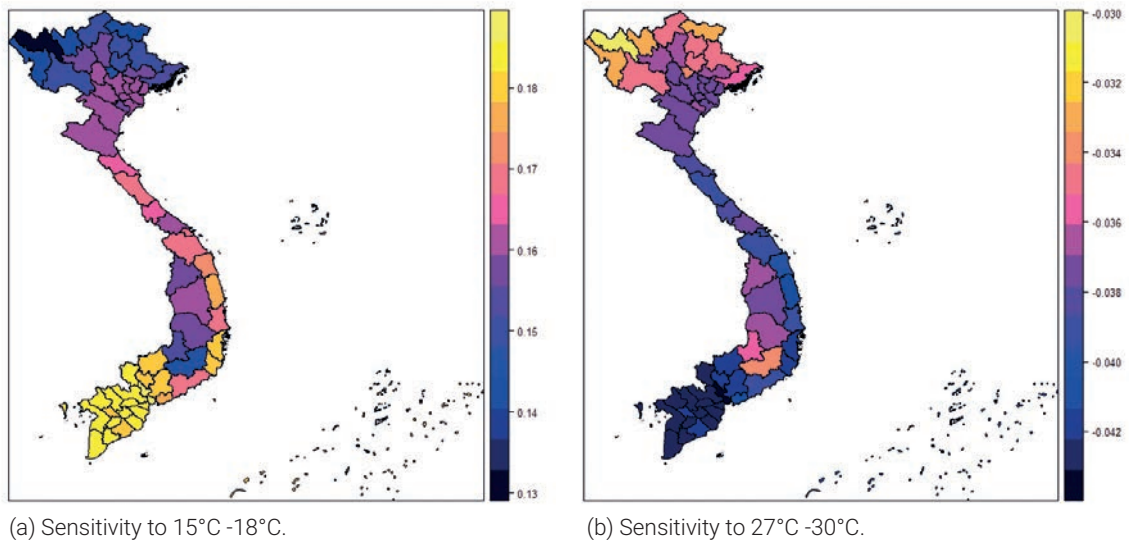
FIGURES | HÌNH

[Figure 1 | Hình 1]

Marginal effect of provincial climate on sensitivity of infections to temperature

Tác động biên của khí hậu theo tỉnh đến độ nhạy cảm của các bệnh nhiễm trùng với nhiệt độ

Effet marginal du climat par province sur la sensibilité des infections à la température



The figures represent the estimated effects of an additional day in the 15°C–18°C and 27°C–30°C temperature bins on the increase in disease infections (measured by the log of the number of infections in a specific province in a month), accounting for the long-run climate in the period 2009–2018.

A province with a hotter initial climate is less impacted by an additional day in the range 27°C–30°C, than in the range 15°C–18°C. The reverse is true for a province with a cooler initial climate.

Các số liệu thể hiện tác động ước tính của một ngày bổ sung trong các khoảng nhiệt độ 15°C–18°C và 27°C–30°C đối với sự gia tăng các ca nhiễm bệnh (được đo bằng nhật ký số ca nhiễm ở một tỉnh cụ thể ở một tháng), so với khí hậu giai đoạn tham chiếu 2009–2018. Một tỉnh có khí hậu ban đầu nóng hơn sẽ ít bị ảnh hưởng bởi một ngày bổ sung trong khoảng 27°C–30°C, so với trong khoảng 15°C–18°C. Điều ngược lại là đúng đối với một tỉnh có khí hậu ban đầu mát mẻ hơn.

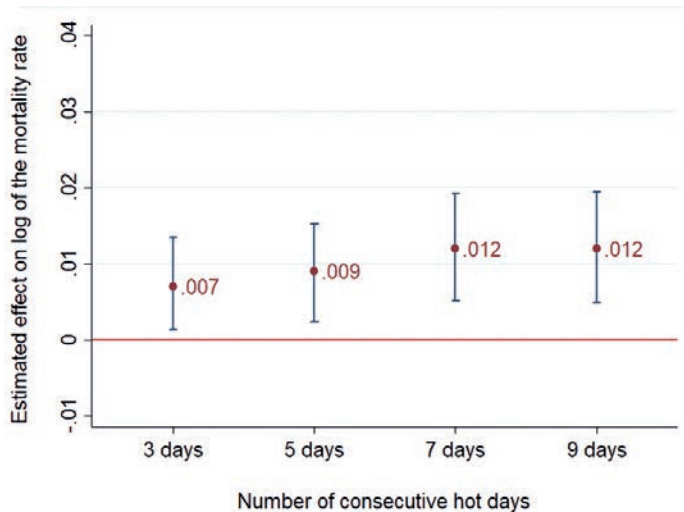
Les figures représentent les effets estimés d'un jour supplémentaire dans les plages de température de 15°C–18°C et 27°C–30°C sur l'augmentation des infections (mesurée par le logarithme du nombre d'infections dans une province spécifique au cours d'un mois), en tenant compte du climat à long terme sur la période 2009–2018. Une province dont le climat initial est plus chaud est moins touchée par un jour supplémentaire dans la plage 27°C–30°C que dans la plage 15°C–18°C. L'inverse est vrai pour une province dont le climat initial est plus frais.

[Figure 2 | Hình 2]

Impacts of heatwaves on mortality

Tác động của đợt nóng lên tỷ lệ tử vong

Impacts des vagues de chaleur sur la mortalité



This figure represents the estimated effects and their 95% confidence interval for the number of consecutive hot days in heat waves on the log of the mortality rate (measured by the number of deaths per 100,000 people in a month). A heat wave is defined as at least k (3, 5, 7, and 9) consecutive days which have daily mean temperature at or above the 95th percentile of the temperature distribution of a specific province within 20 years.

Hình này trình bày giá trị và 95% khoảng tin cậy của ước lượng tác động của số ngày nắng nóng liên tiếp trong các đợt nắng nóng trên logarit của tỷ lệ tử vong (được đo bằng số người chết trên 100.000 người trong một tháng). Một đợt nắng nóng được định nghĩa là ít nhất k ngày liên tiếp (với k có thể bằng các giá trị 3, 5, 7 và 9) có nhiệt độ trung bình trong ngày bằng hoặc cao hơn phân vị thứ 95 của phân bố nhiệt độ của một tỉnh cụ thể trong vòng 20 năm.

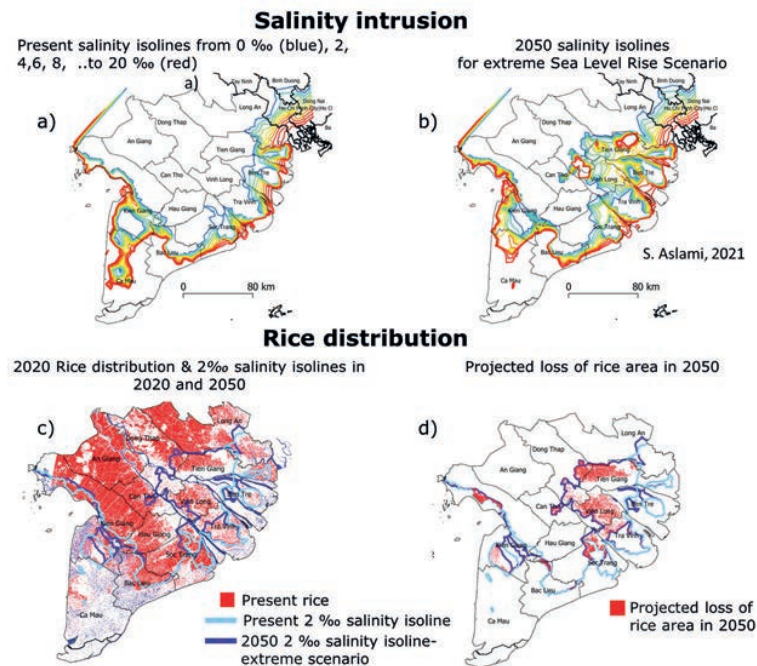
Cette figure représente les effets estimés, et leur intervalle de confiance à 95%, du nombre de jours chauds consécutifs dans les vagues de chaleur sur le logarithme du taux de mortalité (mesuré par le nombre de décès pour 100 000 personnes en un mois). Une vague de chaleur est définie comme au moins k (3, 5, 7 et 9) jours consécutifs dont la température moyenne quotidienne est égale ou supérieure au 95^e percentile de la distribution des températures d'une province spécifique.

[Figure 3 | Hình 3]

Present and projected salinity intrusion and rice cultivation area

Hiện tại và dự báo xâm nhập mặn và diện tích canh tác lúa ở đồng bằng sông Cửu Long

Intrusion de salinité actuelle et projetée et surface rizicole actuelle et projetée dans le delta du Mékong



Impact of salinity intrusion on rice area. a) Isolines of the present time surface water salinity from 0‰ the most inland to 2, 4, 6 ..20‰ (P50); b) Isolines from the projection for 2050 under scenarios RCP8.5 (river discharge), with extreme scenarios for subsidence (B2), riverbed level changes (RB3) and sea level rise (+60 cm) (Cf. Chapter 9); c) Winter-Spring rice map overlaid with isolines for 2‰ salinity (P50) for the present time (light blue) and for 2050 (dark blue); d) rice area (in red) which will be less suitable for rice cultivation in 2050.

Tác động của xâm nhập mặn đến diện tích lúa. a) Các ngưỡng độ mặn thời điểm hiện tại của nước mặt từ 0‰ trong đất liền nhất đến 2, 4, 6 ..20‰ (P50); b) Các ngưỡng độ mặn dự báo cho năm 2050 theo các kịch bản RCP8.5 (dòng chảy sông), với các kịch bản khắc nghiệt về sụt lún (B2), thay đổi mực đáy sông (RB3) và mực nước biển dâng (+60 cm) (xem Chương 9); c) Bản đồ lúa Đông Xuân 2020 phủ lớp phân lập độ mặn 2‰ (P50) thời điểm hiện tại (màu xanh lam nhạt) và năm 2050 (màu xanh lam đậm); d) Diện tích lúa (màu đỏ) sẽ ít thích hợp để trồng lúa vào năm 2050.

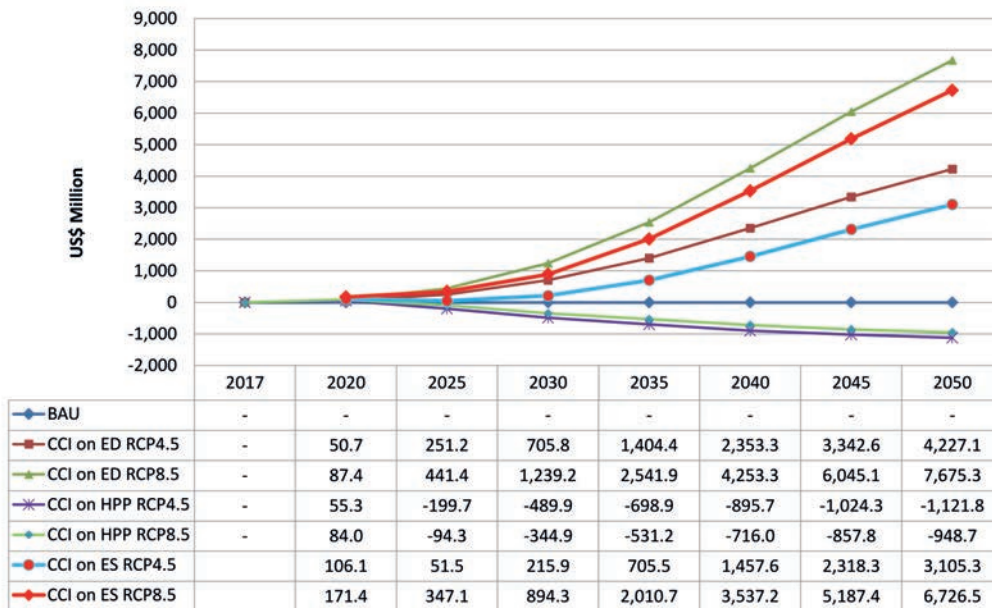
Impact de l'intrusion saline sur la surface rizicole dans le Delta du Mékong. a) Isolignes de la salinité actuelle des eaux de surface de 0‰ le plus à l'intérieur des terres à 2, 4, 6 ..20‰ (P50); b) Isolignes de la projection pour 2050 dans les scénarios RCP8.5 (débit fluvial), avec des scénarios extrêmes de subsidence (B2), de variation du niveau du lit de rivière (RB3) et d'élévation du niveau de la mer (+60 cm) (Cf. Chapitre 9); c) Carte rizicole hiver-printemps 2020 recouverte d'isolignes pour la salinité 2‰ (P50) pour la période actuelle (bleu clair) et pour 2050 (bleu foncé); d) surface rizicole (en rouge) qui sera moins propice à la riziculture en 2050.

[Figure 4 | Hình 4]

The socio-economic outcomes of the impacts of climate change on the energy system

Les résultats socio-économiques des impacts du changement climatique sur le système énergétique

Các kết quả kinh tế-xã hội của tác động biến đổi khí hậu đến hệ thống năng lượng



BAU: Business-As-Usual; CCI on ED RCP4.5= climate change impacts on electricity demand under RCP4.5;

CCI on HPP RCP8.5= climate change impacts on hydropower production under RCP8.5;

CCI on ES RCP4.5= climate change impacts on the energy system under RCP4.5.

Kịch bản phát triển thông thường; CCI on ED RCP4.5 = tác động của BĐKH đến nhu cầu về điện theo kịch bản RCP4.5; CCI on HPP RCP8.5 = tác động của BĐKH đến sản xuất thủy điện theo kịch bản RCP8.5;

CCI on ES RCP4.5 = tác động của BĐKH đến hệ thống năng lực theo kịch bản RCP4.5.

BAU : Business-As-Usual ; CCI on ED RCP4.5= impacts du changement climatique sur la demande d'électricité sous RCP4.5 ; CCI on HPP RCP8.5= impacts du changement climatique sur la production d'hydroélectricité sous RCP8.5 ; CCI on ES RCP4.5= impacts du changement climatique sur le système énergétique sous RCP4.5.

[Figure 5 | Hình 5]

Effect of weather shocks on Agricultural Income

Ảnh hưởng của nhiệt độ lên thu nhập từ nông nghiệp

Effet de chocs météorologiques sur le revenu agricole

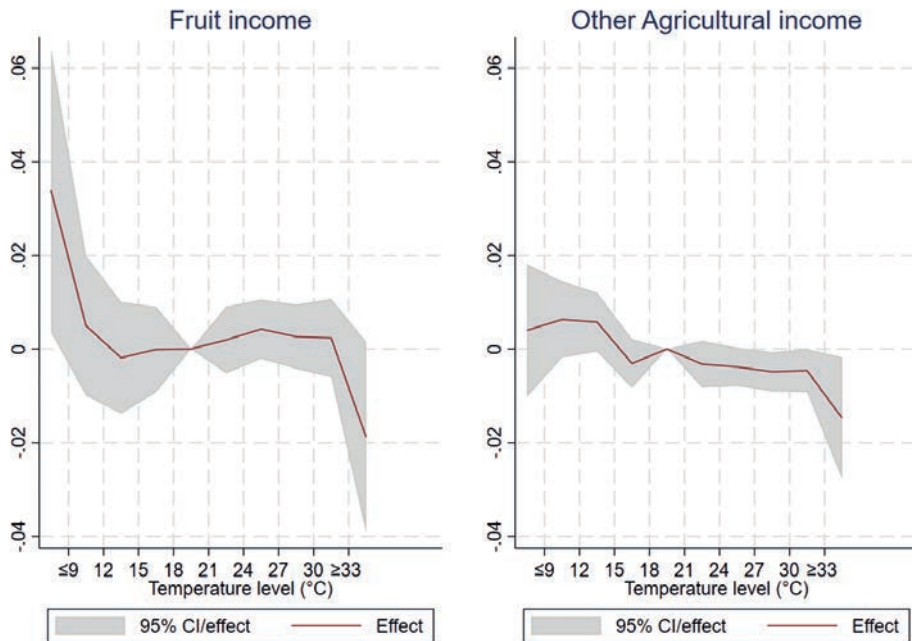


Figure 7 provides the visualization of the non-linear effect of temperature on fruit income per capita, and other agricultural income per capita with 95% confidence interval. Specifically, when the temperature is above 33 degrees, one additional day will reduce annual income from fruits by 1.89%. Additionally, one additional hot day will be associated with a 1.48% loss in the other agricultural income.

Hình 7 cung cấp hình ảnh trực quan về ảnh hưởng phi tuyến tính của nhiệt độ đến thu nhập bình quân đầu người từ trái cây và thu nhập bình quân đầu người nông nghiệp khác với khoảng tin cậy 95%. Cụ thể, khi nhiệt độ trên 33 độ, thêm một ngày nữa sẽ làm giảm thu nhập hàng năm từ trái cây khoảng 1,89%. Ngoài ra, một ngày nắng nóng nữa sẽ làm giảm 1,48% thu nhập nông nghiệp khác.

La figure 7 permet de visualiser l'effet non linéaire de la température sur le revenu des fruits par habitant, et sur les autres revenus agricoles par habitant avec un intervalle de confiance de 95%. Plus précisément, lorsque la température est supérieure à 33 degrés, un jour supplémentaire réduit le revenu annuel des fruits de 1,9%. En outre, un jour de chaleur supplémentaire sera associé à une perte de 1,48% des autres revenus agricoles.

RECOMMENDATIONS

For policy makers

Health

1] Human adaptation and public health strategy play an essential role in infectious disease outbreaks. Since the sensitivity of infectious disease to climate change is not the same between regions, adaptation strategies should be based on the local context with consideration to demography, socio-economic, geographical conditions, and the availability of preventive measures.

2] The loss of working capacity would be a catastrophic non-medical cost for a highly vulnerable population. Universal health care and insurance is an effective measure along with epidemic prevention.

3] The health budget of Viet Nam plays a role in lessening the sensitivity of infections to disease. Funding for infectious disease control and prevention mainly depends on local financial capacity. In the National Target Program, phase 2016–2020, the Project for communicable and non communicable diseases has been allocated 1576 billion VND from the State (58 million EUR), 735,384 billion VND (27 million EUR) from the local budget, and 2150 billion VND (79 million EUR) from ODA and external assistance. However, poor provinces with low annual public spending for infectious disease control would suffer a higher risk of epidemic. Thus the government should have support programs for poor provinces and disadvantaged groups to cope with the adverse effects of climate change and weather extremes on health care.

Agriculture

1] Review plans for the sustainable development of agriculture in an intersectoral context. This implies a combined assessment of a) climatic effects, b) current adaptive capacity, c) future projections of crop yield and geographic distribution, but also e) economic values of production, income and the livelihoods of farmers; and f) the cost to the environment.

2] Adapt the land use plan and crop calendars according to present and future climatic conditions in the different ecological zones.

3] Review farming techniques accordingly, eg. adapt to climate change while reducing pressures on the environment (reducing the use of resources and pollutants and reducing GHG emissions).

4] Apply and improve advanced agricultural practices developed on scientific bases such as ‘good agricultural practices’, integrated crop management (ICM); measures to save fertilizers and pesticides; water-saving measures, including alternate irrigation and drying (AWD) in rice cultivation; large-scale Climate Smart Agriculture practice such as agroforestry, annual crop rotation, alternating with aquaculture, for example rice-fish / shrimp, etc.

5] Integrate the control of anthropogenic pressures into adaptation and mitigation measures. To mitigate the two main threats to rice cultivation in the Mekong and Red River

Deltas — *i.e.* the increase in saline intrusion and that of relative sea level rise (enhanced by subsidence) — the existing plan consists in developing large- and small-scale infrastructure (dykes, locks, reservoirs, canal, dams, etc.) and developing adaptive agricultural technologies (salt-resistant varieties, conversion of rice to aquaculture, etc.). However, the most effective measure is the control of human pressures (for example, stopping the acceleration of groundwater extraction and sand extraction).

6] Operational use of advanced observation techniques such as satellite remote sensing to quantify the impact of climate change and to monitor adaptation and mitigation measures.

Energy

1] **Coordination within catchments:** Coordination — where international cooperation is needed — must be strengthened to better use water resources, including those for power generation purposes. For example, it has been demonstrated that the cascade design of large hydropower dams in Viet Nam could serve as an efficient tool to mitigate future adverse impacts from changes in climatic conditions. These coordination issues are further addressed in the case of the Mekong river in chapter 8 of this report.

2] **The diversity in the energy mix** should be maintained, to minimize the climate risk of any dominant power source, including hydropower. The investment in energy demand planning and the upgrade of transmission and distribution systems is critical to smooth out the local impact of climate change on hydropower spatially across the country.

3] **Forecasting capability using advanced technology** must be strengthened. Adequate investment in meteorological and hydrological data, monitoring and modelling is expected to enhance power planning and management based on scientific evidence, providing early warnings against climate risks, and increasing the power system's resilience.

4] **Building up the database on energy and related climate change impact scenarios:** Currently, Viet Nam still lacks a national data collection system on energy consumption and supply, as well as the energy data related to climate change. This limitation affects the studies on climate change impacts in the energy system.

Households and labor

1] **On climate change and poverty:** Currently, the national target program on poverty reduction has many poverty reduction policies focusing on poor communes, such as infrastructure development, poverty reduction, livelihood models, communication, etc., but does not pay enough attention to the issue of climate change. In contrast, the national plan of Viet Nam to adapt to climate change for the period 2021–2030, with a vision to 2050, despite recognizing that climate change is an existential threat to the goals of sustainable development and hunger eradication and there are actions that indirectly affect poverty (such as through employment, loss and damage reduction, etc.), does not directly address poverty in relation to climate change. In this regard, it might be necessary to study and develop livelihood models to respond to climate change for poor households, and have policies to improve their capacity to adapt to climate change.

2] On climate change and employment: In the National Plan for Climate Change Adaptation for the period 2021–2030, with a vision to 2050 for Viet Nam, climate change is integrated in employment policies with a focus on developing policies to create green jobs, support job transition and develop sustainable livelihoods for people. However, the plan may need to pay attention to businesses and policies to support businesses in adapting to climate change, and minimizing the negative impacts and damage from climate change.

3] On climate change and gender: There is a need to mainstream gender issues into policies to respond to climate change. In Viet Nam, there has been good progress on this. Current policies emphasize capacity-building for women, developing female human resources involved in the climate change adaptation process, and providing soft skills training for female workers to participate in new economic sectors in the context of climate change adaptation.

For researchers

Health

1] Located in both a temperate and a tropical zone with a diverse topography, Viet Nam's climate has a considerable amount of sun, a high rate of rainfall, and high humidity that vary significantly between regions. Therefore, more attention should be paid to the spatial heterogeneity impacts capturing the differences in the sensitivity of disease infection and mortality to weather conditions across regions.

2] In this study, our main interest is the impact of temperature on infectious disease, and heat and cold waves on mortality. However, wind-speed, rainfall and humidity also play important roles. Future research on wind-speed, rainfall and humidity may benefit from better information on climate change impacts on health and disease.

3] Climate change will induce changes in land use, potential changes in precipitation, flooding, and coastal erosion. These medium- to long-term changes are not covered in the study. All of these contribute to change in incidence of infectious diseases and need to be monitored to see the changes in their patterns.

4] Adaptation and coping strategies to climate change should be explored in future studies. Information on these issues will be useful for the government in designing policies to mitigate the effect of climate change. For large-scale datasets used for this study, missing information on specific investments could cause an omitted variable bias.

Agriculture

1] Research on adaptation and mitigation measures by simulating the impacts of climate change on agricultural production in the broader environmental, economic and social context.

2] Research on future crop production (productivity and cultivated area) based on climate scenarios, technological advances, and policy interventions. Due to substantial regional variations in impacts and responses, localized policy decisions are needed for effective measures.

3] Research on crop diversification, and on advanced agricultural techniques, considering

the economic and social values of agricultural production, the limitation of resources and the negative impacts on the environment.

4] Research, development and transfer of new plant varieties adapted to future conditions (salt tolerance, drought tolerance, etc.).

5] Research and develop techniques to mitigate CH₄ and other GHG emissions from agriculture (alternative flooding and drying for rice production, use of suitable fertilizers, change in crop calendar, etc.).

6] Research on future geographic distributions of crops, considering the different climatic scenarios that could change the optimal conditions for crop growth.

7] Refine agronomic models by improving the input parameters used in the simulations. The most important improvements could be made by taking into account the geographic diversity of crops, their growth cycle, irrigation, cultivation practices etc., which can be derived from remote sensing satellites.

8] Ensure consistency between assessments and simulations of climate effects on agriculture across Viet Nam. For example, for the projections concerning rice cultivation in the Deltas under the effect of saline intrusion and flooding due to SLR, the same scenarios of SLR, and the same detailed elevation models taking subsidence into account should be used.

Energy

1] **Energy demand:** In researching firms' energy consumption, we should be aware that there are several energy sources available. The objective of profit maximization causes firms to determine optimal amounts of alternative sources subject to their relative prices and production scale. Regarding household electricity demand, it is widely believed that residential demand tends to have a U-shaped form, under which a lot of electricity is used for heating and cooling purposes in very cold and very hot weather. Apart from using a quadratic form in temperature, researchers can divide temperature into many bins and see if there are remarkable patterns in the lowest and highest bins. Since uncertainty plays a key role in future temperature projection, we should consider many simulation values that are predicted by different models when forecasting future electricity demand.

2] **Energy supply:** In this study, hydropower was selected to analyse the potential impact of climate change on the supply side, given its importance in the broad energy mix. Future research may also consider the susceptibility of other aspects of energy supply, such as emerging renewable sources like solar and wind power. It would also be interesting to investigate the potentials of using storage technologies to mitigate the sensitivity of renewable energy to weather variability under changing climatic conditions. Future research on hydropower may benefit from better information on weather, climate and dam operation in upstream countries, and hydropower generation data at higher granularity (*ie.* daily step). Finally, climate change has a strong influence on precipitation over the Himalayas, as well as the melting of glaciers. Future research should incorporate these long-term effects to set guidelines for the future of climate change and water security.

Households and labor

1] Future research should aim to understand how households, individuals and firms adapt to climate variability. Precise estimations of the impacts of climate variability on labour relocation, crop switching, transition from farm to non-farm activities, and migration are necessary. It is important to analyse the costs and benefits corresponding to each adaptation strategy.

2] Chapter 6 only focuses on the impacts of temperature and precipitation on economic entities. Therefore, more studies are needed to investigate the effects of other climate factors, such as extreme weather events, typhoons, heat waves, cold waves, saline intrusion, and droughts on socio-economic aspects in Viet Nam.

3] In this study, we look at impacts on both sides of the labor market: supply and demand. While this is an interesting approach, the current approach uses static reduced-form models. We recommend that researchers build spatial dynamic models to better understand the links between both sides of the labor market with regard to climate change.

CÁC KHUYẾN NGHỊ

Đối với các nhà hoạch định chính sách

Sức khỏe

1] Chiến lược thích ứng của con người và sức khỏe cộng đồng đóng một vai trò thiết yếu trong việc bùng phát dịch bệnh truyền nhiễm. Do mức độ nhạy cảm của bệnh truyền nhiễm đối với biến đổi khí hậu không giống nhau giữa các vùng nên các chiến lược thích ứng cần dựa trên bối cảnh của địa phương có xem xét đến nhân khẩu học, kinh tế xã hội, điều kiện địa lý và sự sẵn có của các biện pháp phòng ngừa.

2] Mất khả năng lao động sẽ là một chi phí phi y tế rất lớn đối với nhóm dân số dễ bị tổn thương với trình độ học vấn thấp khi thu nhập của hộ gia đình chủ yếu phụ thuộc vào các sản phẩm sử dụng nhiều lao động như dịch vụ ngoài trời hoặc nông nghiệp thông thường. Có một thiệt hại kép trong trường hợp sản xuất nông nghiệp ở các vùng khí hậu nóng dễ bị tổn thương ở Việt Nam. Năng suất thấp hơn và mất sức lao động sẽ kéo dài khi mất mùa sẽ dẫn đến thiếu dinh dưỡng và làm suy yếu hệ thống miễn dịch là một vòng luẩn quẩn, sau đó có nguy cơ nhiễm bệnh cao hơn. Bảo hiểm và chăm sóc sức khỏe toàn dân là một biện pháp hữu hiệu cùng với phòng chống dịch.

3] Ngân sách y tế của Việt Nam có vai trò làm giảm bớt sự nhạy cảm của thời tiết đối với lây nhiễm bệnh. Kinh phí cho công tác phòng chống dịch bệnh truyền nhiễm chủ yếu phụ thuộc vào khả năng tài chính của địa phương. Trong chương trình mục tiêu quốc gia giai đoạn 2016–2020, Dự án phòng chống các bệnh lây nhiễm và không lây nhiễm đã được Nhà nước cấp 1576 tỷ đồng (58 triệu EUR), ngân sách địa phương 735,384 tỷ đồng (27 triệu EUR) và 2150 tỷ đồng (79 triệu EUR) từ nguồn vốn ODA và hỗ trợ bên ngoài. Tuy nhiên, các tỉnh nghèo có chi tiêu công hàng năm thấp cho việc kiểm soát các bệnh truyền nhiễm sẽ có nguy cơ xảy ra dịch bệnh cao hơn. Vì vậy, Chính phủ cần có các chương trình hỗ trợ cho các tỉnh nghèo và các nhóm yếu thế để đối phó với các tác động tiêu cực của biến đổi khí hậu và thời tiết khắc nghiệt đối với chăm sóc sức khỏe.

Nông nghiệp (agriculture)

1] Kiểm tra các kế hoạch phát triển bền vững nông nghiệp trong bối cảnh liên ngành. Điều này yêu cầu phải đánh giá tổng hợp các a) tác động khí hậu, b) khả năng thích ứng hiện tại, c) dự báo trong tương lai về năng suất cây trồng và phân bố địa lý, e) “giá trị kinh tế của sản xuất nông nghiệp, thu nhập và sinh kế của nông dân; và f) tác động tiêu cực đến môi trường.

2] Điều chỉnh kế hoạch sử dụng đất và lịch trồng trọt theo điều kiện khí hậu hiện tại và tương lai ở các vùng sinh thái khác nhau.

3] Xem xét kỹ thuật canh tác cho phù hợp, ví dụ. thích ứng với biến đổi khí hậu đồng thời giảm áp lực lên môi trường (giảm sử dụng tài nguyên và các chất ô nhiễm, giảm phát thải KNK).

4] Áp dụng và cải tiến các quy trình thực hành nông nghiệp tiên tiến được phát triển trên cơ sở khoa học như ‘thực hành nông nghiệp tốt’, quản lý cây trồng tổng hợp (ICM); các biện pháp tiết kiệm phân bón và thuốc bảo vệ thực vật; các biện pháp tiết kiệm nước, bao gồm

tưới và khô luân phiên (AWD) trong canh tác lúa. Thực hành 'Nông nghiệp Thông minh với Khí hậu' quy mô lớn như nông lâm kết hợp, luân canh cây trồng hàng năm, xen kẽ với nuôi trồng thủy sản, ví dụ lúa-cá / tôm, v.v.

5] Tích hợp việc kiểm soát các áp lực do con người gây ra vào các biện pháp thích ứng và giảm thiểu. Để giảm thiểu hai mối đe dọa chính đối với việc trồng lúa ở đồng bằng sông Cửu Long và sông Hồng là sự gia tăng xâm nhập mặn và gia tăng mức độ tương đối của mực nước biển dâng (tăng do sụt lún), Quy hoạch hiện tại bao gồm phát triển các cơ sở hạ tầng quy mô lớn và nhỏ (đê, cống, hồ chứa, kênh, đập, v.v.) và phát triển công nghệ nông nghiệp thích ứng (giống chống mặn, chuyển đổi lúa sang nuôi trồng thủy sản, v.v.). Tuy nhiên, biện pháp hiệu quả nhất là kiểm soát áp lực của con người (ví dụ, dừng việc tăng tốc khai thác nước ngầm và khai thác cát).

6] Vận hành sử dụng các kỹ thuật quan sát tiên tiến như viễn thám vệ tinh để lượng hóa tác động của biến đổi khí hậu và giám sát các biện pháp thích ứng và giảm thiểu.

Năng lượng (Energy)

1] **Sự phối hợp trong các lưu vực:** Phải tăng cường sự phối hợp khi cần hợp tác quốc tế để sử dụng tốt hơn các nguồn tài nguyên nước, bao gồm cả các nguồn nước cho mục đích phát điện. Ví dụ, bằng chứng là thiết kế bậc thang của các đập thủy điện lớn ở Việt Nam có thể là một công cụ hiệu quả để giảm thiểu các tác động bất lợi trong tương lai do thay đổi điều kiện khí hậu. Việc khôi phục, tân trang và nâng cấp các nhà máy trong hệ thống hiện có này nên được ưu tiên khi cần các nguồn điện bổ sung. Trong khi đó, các quy trình vận hành liên hồ chứa phải được giám sát chặt chẽ và cập nhật thường xuyên để tính đến những thay đổi của chế độ thủy văn do biến đổi khí hậu gây ra và sự xuất hiện của nhu cầu sử dụng nước cạnh tranh cho các mục đích khác nhau như năng lượng, thủy lợi, sản xuất và sử dụng trong cư dân. Việc lắp đặt bất kỳ công trình thủy điện mới nào đều phải được thực hiện theo một quy trình quy hoạch toàn diện có xem xét đến các chi phí môi trường, sinh thái và kinh tế xã hội và sự hài hòa với các công trình thủy điện hiện có.

2] **Đa dạng hoá các loại năng lượng:** Sự phát triển và sử dụng các loại năng lượng khác nhau cần được duy trì để giảm thiểu rủi ro khí hậu của bất kỳ nguồn điện nào đang chiếm ưu thế, bao gồm cả thủy điện. Việc đầu tư vào quy hoạch nhu cầu năng lượng và nâng cấp hệ thống truyền tải và phân phối là rất quan trọng để giải quyết các tác động cục bộ của biến đổi khí hậu đối với thủy điện trên cả nước về mặt không gian.

3] **Năng lực dự báo sử dụng công nghệ tiên tiến phải được tăng cường.** Việc đầu tư đầy đủ vào dữ liệu khí tượng thủy văn, giám sát và mô hình hóa dự kiến sẽ tăng cường quy hoạch và quản lý điện dựa trên các bằng chứng khoa học, đưa ra các cảnh báo sớm về rủi ro khí hậu và tăng khả năng phục hồi của hệ thống điện.

4] **Xây dựng cơ sở dữ liệu về năng lượng và các tác động liên quan đến biến đổi khí hậu:** Hiện nay, Việt Nam vẫn còn thiếu hệ thống thu thập dữ liệu quốc gia về tiêu thụ và cung cấp năng lượng cũng như dữ liệu năng lượng liên quan đến biến đổi khí hậu. Hạn chế này ảnh hưởng đến các nghiên cứu về tác động của biến đổi khí hậu đến hệ thống năng lượng. Do

đó, cần xây dựng cơ sở dữ liệu có thể tích hợp vào cơ sở dữ liệu của Tổng cục Thống kê để đáp ứng yêu cầu của các nghiên cứu liên quan đến năng lượng và biến đổi khí hậu cũng như các biện pháp thích ứng và giảm nhẹ.

Hộ gia đình và lao động

1] Về biến đổi khí hậu và nghèo đói: Hiện nay, chương trình mục tiêu quốc gia giảm nghèo có nhiều chính sách giảm nghèo, tập trung vào các xã nghèo như phát triển cơ sở hạ tầng, mô hình sinh kế giảm nghèo, truyền thông ... nhưng chưa quan tâm đúng mức đến vấn đề khí hậu thay đổi. Ngược lại, Kế hoạch quốc gia Việt Nam thích ứng với biến đổi khí hậu giai đoạn 2021–2030, tầm nhìn đến năm 2050, mặc dù thừa nhận rằng biến đổi khí hậu là mối đe dọa hiện hữu đối với các mục tiêu phát triển bền vững và xóa đói, nhưng vẫn có những hành động gián tiếp ảnh hưởng đến nghèo đói (chẳng hạn như thông qua việc làm, giảm mất mát và thiệt hại, v.v.) nhưng không giải quyết trực tiếp tình trạng nghèo đói liên quan đến biến đổi khí hậu. Về vấn đề này, cần nghiên cứu xây dựng các mô hình sinh kế ứng phó với biến đổi khí hậu cho hộ nghèo và có chính sách nâng cao năng lực thích ứng với biến đổi khí hậu.

2] Về biến đổi khí hậu và việc làm: Trong Kế hoạch quốc gia thích ứng với biến đổi khí hậu giai đoạn 2021–2030, tầm nhìn đến năm 2050 của Việt Nam, biến đổi khí hậu được lồng ghép trong chính sách việc làm, trọng tâm là xây dựng các chính sách tạo việc làm xanh, hỗ trợ chuyển đổi nghề và phát triển sinh kế bền vững cho người dân. Tuy nhiên, quy hoạch có thể cần lưu ý đến doanh nghiệp và các chính sách hỗ trợ doanh nghiệp thích ứng với biến đổi khí hậu, giảm thiểu tác động tiêu cực và thiệt hại của biến đổi khí hậu.

3] Về biến đổi khí hậu và giới: Cần lồng ghép các vấn đề giới vào các chính sách ứng phó với biến đổi khí hậu. Ở Việt Nam, điều này đã được thực hiện khá tốt. Các chính sách hiện hành nhấn mạnh vào nâng cao năng lực cho phụ nữ, phát triển nguồn nhân lực nữ tham gia vào quá trình thích ứng với biến đổi khí hậu và đào tạo kỹ năng mềm cho lao động nữ tham gia vào các lĩnh vực kinh tế mới trong bối cảnh thích ứng với biến đổi khí hậu.

Đối với các nhà nghiên cứu

Sức khỏe

1] Nằm trong khu vực ôn đới và nhiệt đới với địa hình đa dạng, khí hậu Việt Nam có lượng nắng lớn, lượng mưa lớn, độ ẩm cao và chênh lệch đáng kể giữa các vùng. Do đó, cần chú ý nhiều hơn đến các tác động không đồng nhất về không gian ảnh hưởng đến sự khác biệt của mức độ nhạy cảm của bệnh truyền nhiễm và tỷ lệ tử vong đối với điều kiện thời tiết giữa khác nhau theo vùng miền.

2] Trong nghiên cứu này, mối quan tâm chính của chúng tôi là tác động của nhiệt độ đối với bệnh truyền nhiễm và các đợt nóng và lạnh đối với tỷ lệ tử vong. Tuy nhiên, tốc độ gió, lượng mưa và độ ẩm cũng đóng những vai trò quan trọng. Nghiên cứu trong tương lai về tốc độ gió, lượng mưa và độ ẩm có thể giúp đưa ra thông tin tốt hơn về tác động của biến đổi khí hậu đối với sức khỏe và bệnh tật.

3] Biến đổi khí hậu sẽ gây ra những thay đổi trong việc sử dụng đất, những thay đổi tiềm ẩn về lượng mưa, lũ lụt và xói mòn bờ biển. Những thay đổi trong trung và dài hạn này chưa được đề cập trong nghiên cứu này. Tất cả những điều này góp phần làm thay đổi tỷ lệ mắc các bệnh truyền nhiễm và cần được theo dõi để biết được những thay đổi trong mô hình.

4] Các chiến lược thích ứng và ứng phó với biến đổi khí hậu cần được nghiên cứu thêm trong tương lai. Thông tin về những vấn đề này sẽ hữu ích cho chính phủ trong việc thiết kế các chính sách nhằm giảm thiểu tác động của biến đổi khí hậu. Đối với các bộ dữ liệu quy mô lớn được sử dụng cho nghiên cứu này, việc thiếu thông tin về các khoản đầu tư cụ thể có thể gây ra sai lệch vì biến bị bỏ sót. Chúng ta nên tìm các biến thay thế, biến công cụ hoặc thu thập dữ liệu bổ sung khác. Tuy nhiên, lưu ý rằng việc sử dụng các biến thay thế và các biến công cụ đi kèm với một loạt các giả định và vấn đề bổ sung, hầu hết chúng đều khá phức tạp và không dễ đáp ứng.

Nông Nghiệp

1] Nghiên cứu các biện pháp thích ứng và giảm thiểu bằng cách đánh giá tác động của biến đổi khí hậu đối với sản xuất nông nghiệp trong bối cảnh biến đổi môi trường, kinh tế và xã hội rộng hơn.

2] Nghiên cứu về sản xuất cây trồng trong tương lai (năng suất và diện tích canh tác) dựa trên các kịch bản khí hậu, tiến bộ công nghệ và các can thiệp chính sách. Do các tác động và ứng phó có sự khác biệt đáng kể giữa các vùng, các quyết định chính sách được bản địa hóa là cần thiết để có các biện pháp hiệu quả.

3] Nghiên cứu đa dạng hóa cây trồng và kỹ thuật nông nghiệp tiên tiến, dựa trên phân tích năng suất và giá trị kinh tế, xã hội của sản xuất nông nghiệp, tính cách hạn chế của tài nguyên, và tác động tiêu cực đến môi trường.

4] Nghiên cứu, phát triển và chuyển giao các giống cây trồng mới thích ứng với điều kiện tương lai (chịu mặn, chịu hạn ...).

5] Nghiên cứu và phát triển các kỹ thuật giảm thiểu phát thải CH_4 và các khí nhà kính khác từ nông nghiệp (tưới và khô luân phiên (AWD) trong canh tác lúa, sử dụng phân bón phù hợp, thay đổi lịch trồng trọt, v.v.)

6] Nghiên cứu về sự phân bố địa lý của cây trồng trong tương lai, xem xét các kịch bản khí hậu khác nhau có thể thay đổi các điều kiện tối ưu cho sự phát triển của cây trồng.

7] Hoàn thiện các mô hình nông học bằng cách cải thiện các thông số đầu vào được sử dụng trong mô phỏng. Những cải tiến quan trọng nhất có thể được thực hiện là sự phân bố địa lý của các loại cây trồng, thời điểm, chu kỳ sinh trưởng và thực hành tưới tiêu, thông tin có thể thu được từ các vệ tinh viễn thám.

8] Đảm bảo tính nhất quán giữa các đánh giá và mô phỏng các tác động của khí hậu đối với nông nghiệp trên khắp Việt Nam. Ví dụ, đối với các dự báo về canh tác lúa ở các đồng bằng bị ảnh hưởng của xâm nhập mặn và lũ lụt do SLR, nên sử dụng các kịch bản SLR giống nhau và cùng các mô hình độ cao chi tiết giống nhau.

Năng lượng (Energy)

1] Nhu cầu về năng lượng: Trong nghiên cứu về mức tiêu thụ năng lượng của các công ty, chúng ta biết rằng có nhiều nguồn năng lượng có sẵn khác nhau cho sản xuất. Mục tiêu tối đa hóa lợi nhuận khiến các công ty xác định lượng nguồn thay thế tối ưu tùy theo giá cả tương đối và quy mô sản xuất của họ. Bài toán cơ bản này dẫn đến việc xác định hàm cầu và chi phí cho các loại năng lượng đầu vào cho sản xuất. Về nhu cầu sử dụng điện của các hộ gia đình, người ta cho rằng nhu cầu sử dụng điện của các hộ gia đình có xu hướng hình chữ U, theo đó, rất nhiều điện năng được sử dụng cho mục đích sưởi ấm và làm mát trong thời tiết quá lạnh hoặc quá nóng. Ngoài việc sử dụng dạng bậc hai phi tuyến cho nhiệt độ trong phương trình ước lượng, các nghiên cứu có thể chia nhiệt độ thành nhiều khoảng, và xem liệu có các số liệu và tác động đáng chú ý có tồn tại trong vùng thấp nhất và cao nhất hay không. Sự bất định đóng một vai trò quan trọng trong việc dự báo khí hậu trong tương lai, chúng ta nên xem xét nhiều giá trị mô phỏng được dự đoán bởi các mô hình khác nhau khi dự báo nhu cầu điện.

2] Nguồn cung năng lượng: Trong nghiên cứu này, thủy điện được lựa chọn để phân tích tác động tiềm tàng của biến đổi khí hậu đối với nguồn cung, do tầm quan trọng của nó trong các loại năng lượng tổng hợp. Nghiên cứu trong tương lai cũng có thể xem xét tính nhạy cảm của các loại năng lượng khác, đặc biệt nguồn năng lượng tái tạo mới nổi như năng lượng mặt trời và năng lượng gió. Và cũng rất quan trọng khi xem xét tiềm năng của việc sử dụng các công nghệ lưu trữ để giảm thiểu sự nhạy cảm của năng lượng tái tạo đối với sự biến đổi của thời tiết trong điều kiện khí hậu thay đổi. Nghiên cứu trong tương lai về thủy điện có thể được hưởng lợi từ thông tin tốt hơn về thời tiết, khí hậu và hoạt động của đập ở các quốc gia thượng nguồn và dữ liệu sản xuất thủy điện ở mức độ chi tiết cao hơn (ví dụ data tần suất là theo ngày).

Hộ gia đình và lao động

1] Nghiên cứu trong tương lai nên nhằm mục đích tìm hiểu cách các hộ gia đình, cá nhân và doanh nghiệp thích ứng với sự biến đổi khí hậu. Cần có những ước tính chính xác về tác động của biến đổi khí hậu đối với việc di dời lao động, chuyển đổi cây trồng, chuyển đổi từ các hoạt động nông nghiệp sang phi nông nghiệp và di cư. Điều quan trọng là phải điều tra chi phí và lợi ích tương ứng với từng chiến lược thích ứng.

2] Chương 6 chỉ tập trung vào tác động của nhiệt độ và lượng mưa đối với các thực thể kinh tế. Do đó, cần có thêm nhiều nghiên cứu để khảo sát ảnh hưởng của các yếu tố khí hậu khác như các hiện tượng thời tiết cực đoan: bão, sóng nhiệt, sóng lạnh, xâm nhập mặn và hạn hán đến các khía cạnh kinh tế xã hội của Việt Nam.

3] Trong nghiên cứu này, chúng tôi xem xét tác động đến hai phía của thị trường lao động: cung và cầu. Mặc dù đây là một cách tiếp cận thú vị, nhưng cách tiếp cận hiện tại đang sử dụng các mô hình dạng thu gọn tĩnh. Chúng tôi khuyến nghị các nhà nghiên cứu xây dựng các mô hình động lực học theo không gian để hiểu rõ hơn về mối liên hệ giữa các mặt này của thị trường lao động trong điều kiện biến đổi khí hậu.

RECOMMANDATIONS

A l'intention des décideurs politiques

Santé

1] L'adaptation humaine et la stratégie de santé publique jouent un rôle essentiel dans les épidémies de maladies infectieuses. Étant donné que la sensibilité des maladies infectieuses au changement climatique n'est pas la même d'une région à l'autre, les stratégies d'adaptation doivent être basées sur le contexte local en tenant compte de la démographie, des conditions socio-économiques, géographiques et de la disponibilité de mesures préventives.

2] La perte de capacité de travail serait un coût non médical catastrophique pour une population très vulnérable avec un faible niveau d'éducation lorsque le revenu du ménage dépend principalement de produits à forte intensité de main-d'œuvre tels que les services de plein air ou l'agriculture conventionnelle. Il y a une double perte dans le cas de la production agricole dans les points chauds vulnérables du Viet Nam. Le cercle vicieux d'une baisse de rendement et d'une perte de capacité de travail persistera lorsque la mauvaise récolte entraînera une sous-nutrition et affaiblira le système immunitaire, exposant alors à un risque plus élevé d'infection. Les soins de santé universels et l'assurance sont une mesure efficace ainsi que la prévention des épidémies.

3] Le budget de la santé du Viet Nam joue un rôle attribué à la diminution de la sensibilité des infections aux maladies. Le financement du contrôle et de la prévention des maladies infectieuses dépend principalement de la capacité financière locale. Dans le programme cible national, phase 2016–2020, le projet pour les maladies transmissibles et non transmissibles a reçu 1576 milliard de VND de l'État (58 millions d'euros), 735 384 milliards de VND (27 millions d'euros) du budget local et 2150 milliards de VND (79 millions d'euros) de l'APD et de l'aide extérieure. Cependant, la province pauvre avec de faibles dépenses publiques annuelles pour la lutte contre les maladies infectieuses souffrirait d'un risque plus élevé d'épidémie. Ainsi, le gouvernement devrait avoir des programmes de soutien pour les provinces pauvres et les groupes défavorisés pour faire face aux effets néfastes du changement climatique et des phénomènes météorologiques extrêmes sur les soins de santé.

Agriculture

1] Examiner les plans de développement durable de l'agriculture dans un contexte intersectoriel. Cela implique une évaluation combinée a) des effets climatiques, b) de la capacité d'adaptation actuelle, c) des projections futures du rendement et de la distribution géographique des cultures, mais aussi e) des valeurs économiques des productions, des revenus et des moyens de subsistance des agriculteurs et f) du coût à l'environnement.

2] Adapter le plan d'occupation des sols et les calendriers des cultures en fonction des conditions climatiques présentes et futures dans les différentes zones écologiques.

3] Revoir les techniques agricoles en conséquence, par ex. s'adapter au changement climatique tout en réduisant les pressions sur l'environnement (diminuer l'utilisation des ressources, celle des polluants et réduire les émissions de GES).

4] Appliquer et améliorer les pratiques agricoles avancées développées sur des bases scientifiques telles que les 'bonnes pratiques agricoles', la gestion intégrée des cultures (GIC) ; mesures d'économie d'engrais et de pesticides ; mesures d'économie d'eau, y compris l'irrigation et séchage alternés (AWD) dans la riziculture ; pratique d'agriculture intelligentes face au climat (Climate Smart Agriculture) à grande échelle telles que l'agroforesterie, rotation des cultures annuelles, alternées avec l'aquaculture, par exemple riz-poisson/crevette, etc.

5] Intégrer le contrôle des pressions anthropiques dans les mesures d'adaptation et d'atténuation. Pour atténuer les deux principales menaces pour la riziculture dans les deltas du Mékong et du fleuve Rouge, qui sont l'augmentation de l'intrusion saline et celle du niveau relatif de l'élévation du niveau de la mer (augmenté par la subsidence), le plan existant consiste en le développement d'infrastructures à grande et petite échelle (digues, écluses, réservoirs, canal, barrages ..) et le développement de technologies agricoles adaptatives (variétés résistantes au sel, conversion du riz en aquaculture...). Cependant, la mesure la plus efficace est le contrôle des pressions humaines (par exemple, arrêter l'accélération de l'extraction des eaux souterraines et l'extraction du sable).

6] Utiliser de façon opérationnelle les techniques d'observation avancées telles que la télédétection par satellites, pour quantifier l'impact du changement climatique et surveiller les mesures d'adaptation et d'atténuation.

Énergie

1] **La coordination au sein des bassins versants** : La coordination là où la coopération internationale est nécessaire, doit être renforcée pour mieux utiliser les ressources en eau, y compris celles à des fins de production d'électricité. Par exemple, il est prouvé que la conception en cascade de grands barrages hydroélectriques au Viet Nam pourrait servir d'outil efficace pour atténuer les futurs impacts négatifs des changements climatiques. La réhabilitation, la rénovation et la mise à niveau des usines dans ce système existant devraient être prioritaires lorsque des sources d'énergie supplémentaires sont nécessaires. Parallèlement, les procédures d'exploitation inter-réservoirs doivent être strictement encadrées et régulièrement mises à jour pour prendre en compte les changements de régimes hydrologiques induits par le changement climatique et l'émergence d'une demande en eau concurrente à des fins différentes telles que l'énergie, l'irrigation, la fabrication et l'usage domestique. L'installation de toute nouvelle installation hydroélectrique doit faire l'objet d'un processus de planification global qui tient compte des coûts environnementaux, écologiques et socio-économiques et de l'harmonisation avec les installations hydroélectriques existantes.

2] **La diversité du bouquet énergétique doit être maintenue** pour minimiser le risque climatique de toute source d'énergie dominante, y compris l'hydroélectricité. L'investissement dans la planification de la demande d'énergie et la mise à niveau des systèmes de transmis-

sion et de distribution est essentiel pour lisser spatialement l'impact local du changement climatique sur l'hydroélectricité à travers le pays.

3] La capacité de prévision utilisant une technologie de pointe doit être renforcée. L'investissement adéquat dans les données météorologiques et hydrologiques, la surveillance et la modélisation devrait améliorer la planification et la gestion de l'énergie sur la base de preuves scientifiques, fournir des alertes précoces contre les risques climatiques et augmenter la résilience du système électrique.

4] Constitution de la base de données sur l'énergie et les impacts liés au changement climatique : Actuellement, le Viet Nam manque encore d'un système national de collecte de données sur la consommation et l'approvisionnement énergétiques ainsi que les données énergétiques liées au changement climatique. Cette limitation affecte les études sur les impacts du changement climatique sur le système énergétique. Par conséquent, il est nécessaire de développer une base de données pouvant être intégrée à la base de données de l'Office général des statistiques pour répondre aux exigences des études connexes sur l'énergie et le changement climatique ainsi que les mesures d'adaptation et d'atténuation.

Ménages et travail

1] Sur le changement climatique et la pauvreté : Les conclusions du rapport indiquent que le changement climatique a un impact plus négatif sur les ménages pauvres. On constate que les ménages pauvres ont subi plus de pertes de revenus. Cela signifie que le changement climatique peut appauvrir les pauvres, de sorte que la question du changement climatique devrait être sérieusement prise en compte dans les politiques de réduction de la pauvreté. En d'autres termes, il est nécessaire d'intégrer la question du changement climatique dans les politiques de réduction de la pauvreté ou inversement, d'examiner la question des pauvres dans les politiques de réponse au changement climatique. Actuellement, le programme cible national sur la réduction de la pauvreté comporte de nombreuses politiques de réduction de la pauvreté, se concentrant sur les communes pauvres telles que le développement des infrastructures, les modèles de subsistance pour la réduction de la pauvreté, la communication, etc. mais n'accordant pas suffisamment d'attention à la question du changement climatique. En revanche, le plan national du Viet Nam d'adaptation au changement climatique pour la période 2021–2030, avec une vision jusqu'en 2050, bien qu'il reconnaisse que le changement climatique est une menace existentielle pour les objectifs de développement durable et d'éradication de la faim et qu'il existe des actions qui indirectement affectent la pauvreté (par exemple par l'emploi, la réduction des pertes et des dommages, etc.) mais ne traitent pas directement la pauvreté en relation avec le changement climatique. À cet égard, il pourrait être nécessaire d'étudier et de développer des modèles de subsistance pour répondre au changement climatique pour les ménages pauvres et d'avoir des politiques pour améliorer leur capacité à s'adapter au changement climatique.

2] Sur le changement climatique et l'emploi : Les résultats du rapport montrent que les changements de température et de précipitations ont un impact négatif sur les heures de travail et les revenus des travailleurs. Les résultats montrent également que les effets des variables

climatiques sur l'allocation de l'emploi et la migration. Ces résultats ont été vérifiés par les impacts sur la demande de main-d'œuvre (c'est-à-dire que l'augmentation de la température moyenne et des précipitations entraîne une baisse des revenus, de la production, de la taille de l'entreprise et de la productivité). Celles-ci témoignent de la nécessité d'intégrer les enjeux du changement climatique dans l'emploi. Ceci est illustré dans le Plan national d'adaptation au changement climatique pour la période 2021–2030, avec une vision à 2050 du Viet Nam. Plus précisément, le plan intègre le changement climatique dans les politiques d'emploi en mettant l'accent sur l'élaboration de politiques visant à créer des emplois verts, à soutenir la transition professionnelle et à développer des moyens de subsistance durables pour les personnes. Cependant, selon les conclusions de ce chapitre, en plus des personnes, le plan devra peut-être prêter attention aux entreprises et aux politiques pour aider les entreprises à s'adapter au changement climatique, minimiser les impacts négatifs et les dommages du changement climatique.

3] Sur le changement climatique et le genre : L'une des conclusions notables de ce rapport est que les variables climatiques peuvent avoir des impacts négatifs sur les inégalités de genre, les femmes ont tendance à travailler plus mais gagnent moins lorsque la température augmente. En d'autres termes, le changement climatique peut augmenter l'inégalité entre les sexes en termes d'heures de travail et de rémunération. Cela prouve la nécessité d'intégrer les questions de genre dans les politiques de réponse au changement climatique. Au Viet Nam, cela s'est plutôt bien passé. Les politiques actuelles mettent l'accent sur le renforcement des capacités des femmes, le développement des ressources humaines féminines impliquées dans le processus d'adaptation au changement climatique et fournissent une formation aux compétences générales aux travailleuses afin qu'elles participent à de nouveaux secteurs économiques dans le contexte de l'adaptation au changement climatique. En outre, il peut envisager de promouvoir les modèles typiques adaptés aux femmes dans le contexte du changement climatique.

Pour les chercheurs

Santé

1] Situé à la fois dans une zone tempérée et une zone tropicale avec une topographie diversifiée, le climat du Viet Nam a une quantité considérable de soleil, un taux de précipitations élevé et une humidité élevée qui varient considérablement d'une région à l'autre. Par conséquent, une plus grande attention devrait être accordée aux impacts de l'hétérogénéité spatiale capturant la différence de sensibilité des maladies infectieuses et de la mortalité aux conditions météorologiques d'une région à l'autre.

2] Dans cette étude, notre intérêt principal est l'impact de la température sur les maladies infectieuses et les vagues de chaleur et de froid sur la mortalité. Cependant, la vitesse du vent, les précipitations et l'humidité jouent également un rôle important. Les futures recherches sur la vitesse du vent, les précipitations et l'humidité pourraient bénéficier de meilleures informations sur les impacts du changement climatique sur la santé et les maladies.

3] Le changement climatique entraînera des changements dans l'utilisation des terres, des changements potentiels dans les précipitations, les inondations et l'érosion côtière. Ces changements à moyen et long terme ne sont pas abordés dans l'étude. Tous ces éléments contribuent au changement de l'incidence des maladies infectieuses et doivent être surveillés pour voir les changements dans leurs schémas.

4] Les stratégies d'adaptation et d'adaptation au changement climatique devraient être explorées dans les études futures. Les informations sur ces questions seront utiles au gouvernement pour concevoir des politiques visant à atténuer les effets du changement climatique. Pour les ensembles de données à grande échelle utilisés pour cette étude, des informations manquantes sur des investissements spécifiques pourraient entraîner un biais de variable omise. Nous devons rechercher des proxys, trouver des variables instrumentales ou collecter d'autres données complémentaires. Notez cependant que l'utilisation de proxys et de variables instrumentales s'accompagne de tout un ensemble d'hypothèses et de problèmes supplémentaires, la plupart d'entre eux sont assez compliqués et difficiles à résoudre.

Agriculture

1] Recherche sur les mesures d'adaptation et d'atténuation par l'évaluation des impacts du changement climatique sur la production agricole dans un contexte d'évolutions environnementales, économiques et sociales plus larges.

2] Recherche sur la production végétale future (productivité et surface cultivée) basée sur des scénarios climatiques, d'avancées technologiques, et d'interventions politiques. En raison des variations régionales substantielles des impacts et des réponses, des décisions politiques localisées sont nécessaires pour des mesures efficaces.

3] Recherche sur la diversification des cultures, et les techniques agricoles avancées, considérant la productivité et les valeurs économiques et sociales des productions agricoles, la limitation des ressources et les impacts négatifs sur l'environnement.

4] Recherche, développement et transfert de nouvelles variétés végétales adaptées aux conditions futures (tolérance au sel, tolérance à la sécheresse..).

5] Rechercher et développer des techniques pour atténuer les émissions de CH₄ et d'autres GES provenant de l'agriculture (inondation et séchage alternatifs pour la production de riz, utilisation d'engrais adaptés, changement de calendrier des cultures..).

6] Recherche sur les futures répartitions géographiques des cultures, considérant les différents scénarios climatiques qui pourraient changer les conditions optimales pour la croissance des cultures.

7] Affiner les modèles agronomiques en améliorant les paramètres d'entrée utilisés dans les simulations. Les améliorations les plus importantes pourraient être apportées en tenant compte de la diversité géographique des cultures, celle de leur calendrier, de leur cycle de croissance et des pratiques d'irrigation, informations qui peuvent être dérivées des satellites de télédétection.

8] Assurer la cohérence entre les évaluations et simulations des effets climatiques sur l'agriculture à l'échelle du Viet Nam. Par exemple pour les projections concernant la culture du riz dans les deltas sous effet de l'intrusion saline et des inondations dues à SLR, les mêmes scénarios de SLR, et les mêmes modèles d'élévation détaillés tenant compte des subsidences devront être utilisés.

Énergie

1] Demande d'énergie: la recherche sur la consommation d'énergie des entreprises, nous devons être conscients qu'il existe plusieurs sources d'énergie disponibles pour les entreprises. L'objectif de maximisation du profit amène les entreprises à déterminer des quantités optimales de sources alternatives en fonction de leurs prix relatifs et de leur échelle de production. En ce qui concerne la demande d'électricité des ménages, il est largement admis que la demande résidentielle a tendance à avoir une forme en U sous laquelle une grande partie de l'électricité est utilisée à des fins de chauffage et de refroidissement par temps très froid et très chaud. En plus d'utiliser une forme quadratique de la température, les chercheurs peuvent diviser la température en plusieurs classes et voir s'il existe des modèles remarquables dans les classes les plus basses et les plus hautes. Étant donné que l'incertitude joue un rôle clé dans la projection de la température future, nous devons considérer de nombreuses valeurs de simulation qui sont prédites par différents modèles lors de la prévision de la demande future d'électricité.

2] Offre d'énergie: dans cette étude, l'hydroélectricité a été sélectionnée pour analyser l'impact potentiel du changement climatique du côté de l'offre, compte tenu de son importance dans le vaste bouquet énergétique. Les recherches futures pourraient également tenir compte de la susceptibilité des sources renouvelables émergentes telles que l'énergie solaire et éolienne. Il serait également intéressant d'étudier les possibilités d'utiliser les technologies de stockage pour atténuer la sensibilité des énergies renouvelables à la variabilité météorologique dans des conditions climatiques changeantes. Les futures recherches sur l'hydroélectricité pourraient bénéficier de meilleures informations sur la météo, le climat et le fonctionnement des barrages dans les pays en amont et des données de production hydroélectrique à une granularité plus élevée (c'est-à-dire au pas quotidien).

Ménages et travail

1] Les futures recherches devraient viser à comprendre comment les ménages, les individus et les entreprises s'adaptent à la variabilité climatique. Des estimations précises des impacts de la variabilité climatique sur la délocalisation de la main-d'œuvre, le changement de cultivation, la transition d'activités agricoles vers des activités non agricoles et la migration sont nécessaires. Il est important d'analyser les coûts et les bénéfices correspondant à chaque stratégie d'adaptation.

2] Le chapitre 6 se concentre uniquement sur les impacts de la température et des précipitations sur les entités économiques. Par conséquent, autres études sont nécessaires pour

étudier les effets des autres facteurs climatiques, tels que les événements météorologiques extrêmes, les typhons, les vagues de chaleur, les vagues de froid, l'intrusion saline et les sécheresses sur les aspects socio-économiques au Viet Nam.

3] Dans cette étude, nous examinons les impacts des deux côtés du marché du travail : l'offre et la demande. Bien qu'il s'agisse d'une approche intéressante, l'approche actuelle utilise des modèles statiques de forme réduite. Nous recommandons aux chercheurs de construire des modèles dynamiques spatiaux pour mieux comprendre les liens entre les deux côtés du marché du travail avec le changement climatique.

Chapter 3

Climate change impacts on health in Viet Nam

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Abstract

In this chapter, we look at the effects of climate variability on a range of tropical diseases and on general mortality. We find a strong impact of temperature on vector-borne and water-borne disease, where the incidence of infection is significantly decreased at temperatures below 15°C, but increased on the bin above 30°C for vector-borne disease. The impact is weaker on airborne diseases than the two other types. The effect of weather changes on the incidence of major diseases differs by climate region. Provinces located in the South and Southern Central Coast appear to have a higher level of sensitivity to infections at 15°C–18°C temperatures than other provinces. Regarding mortality, we find robust evidence on the positive effects of cold and heat waves on mortality. An additional day in a cold wave is estimated to increase the monthly mortality rate by 0.6%. The corresponding figure for a day in a heat wave is 0.7%. The effect of cold waves as well as heat waves tends to increase when the cold and heat waves last for a longer time. Compared with a cold wave, the effect of a heat wave on the mortality rate is more significant and of a larger magnitude. All climate change scenarios also imply an increase in the number of heat waves with a clear impact on mortality.

Tóm tắt

Chương này xem xét tác động của biến đổi khí hậu đối với một loạt các bệnh nhiệt đới và tỷ lệ tử vong nói chung. Kết quả cho thấy tác động mạnh của nhiệt độ đối với bệnh lây truyền qua véc tơ và nguồn nước, trong đó tỷ lệ nhiễm bệnh giảm đáng kể ở nhiệt độ dưới 15°C, nhưng tăng lên trên ngưỡng 30°C đối với bệnh do véc tơ truyền. Tác động được tìm thấy yếu hơn đối với các bệnh lây truyền qua đường không khí so với hai loại nêu trên. Ảnh hưởng của biến đổi khí hậu đến tỷ lệ mắc các bệnh nhiệt đới chính là khác nhau tùy theo vùng khí hậu của Việt Nam. Các tỉnh phía Nam và duyên hải Nam Trung Bộ có mức độ dễ bị nhiễm bệnh ở nhiệt độ từ 15°C–18°C cao hơn các tỉnh còn lại. Về tỷ lệ tử vong, chúng tôi tìm thấy bằng chứng rõ ràng về tác động gia tăng của các đợt nóng và lạnh đối với tỷ lệ tử vong. Thêm một ngày trong đợt lạnh được ước tính sẽ làm tăng tỷ lệ tử vong hàng tháng thêm 0,6%. Con số tương ứng cho một ngày trong đợt nắng nóng là 0,7%. Ảnh hưởng của các đợt nóng, lạnh có xu hướng gia tăng khi các đợt rét đậm, rét hại càng kéo dài. So với một đợt lạnh, ảnh hưởng của một đợt nắng nóng lên tỷ lệ tử vong là đáng kể hơn và có cường độ lớn hơn. Tất cả các kịch bản biến đổi khí hậu cũng hàm ý sự gia tăng số lượng các đợt nắng nóng với tác động rõ ràng đến tỷ lệ tử vong.

Résumé

Dans ce chapitre, nous examinons les effets de la variabilité climatique sur une série de maladies tropicales et sur la mortalité générale. Nous constatons un fort impact de la température sur les maladies vectorielles et hydriques, où l'incidence de l'infection est significativement réduite à des températures inférieures à 15°C, mais augmentée au-dessus de 30°C, particulièrement pour les maladies vectorielles. L'impact est en revanche plus faible sur les maladies transmises par l'air que sur les deux autres types. L'effet des changements climatiques sur l'incidence des principales maladies tropicales diffère selon la région climatique du Viet Nam. Les provinces situées dans le sud et la côte centrale sud semblent avoir un niveau de sensibilité aux infections plus élevé à des températures de 15°C–18°C que les autres provinces. En ce qui concerne la mortalité, nous trouvons des preuves solides d'effets positifs des vagues de froid et de chaleur sur la mortalité. On estime qu'un jour supplémentaire dans une vague de froid augmente le taux de mortalité mensuel de 0,6%. Le chiffre correspondant pour un jour de vague de chaleur est de 0,7%. L'effet des vagues de froid et de chaleur tend à s'accroître lorsque les vagues de froid et de chaleur durent plus longtemps. Par rapport à une vague de froid, l'effet d'une vague de chaleur sur le taux de mortalité est plus significatif et d'une plus grande ampleur. Tous les scénarios de changement climatique impliquent par ailleurs une augmentation du nombre de vagues de chaleur avec un net impact sur la mortalité.

1. Introduction

A direct effect of weather extremes is the deterioration of health of individuals. High temperature is found to be associated with cardiovascular, respiratory, cerebrovascular and blood cholesterol problems [Huynen *et al.*, 2001; Barreca *et al.*, 2016]. Climate variability can also affect the survival rate, and transmission of viruses and bacteria. There is extensive evidence on the positive association between temperature and infectious diseases [e.g., Jahani and Ahmadnezhad, 2011; Levy *et al.*, 2016; Wu *et al.*, 2016]. Extreme weather can increase mortality and malnutrition in children [e.g. Deschenes and Moretti, 2009; Anderson *et al.*, 2011; Deschenes and Greenstone, 2011; Simeonova, 2011; Barreca *et al.*, 2016]. In-utero exposure to extreme weather returns low birth weights [e.g., Deschênes *et al.*, 2009].

Although there is no doubt about the harmful effect of extreme weather and climate events, there is no consistency in the magnitude of the effect on health and disease infection [e.g., see review from Nichols *et al.*, 2009; Jahani and Ahmadnezhad, 2011; Phalkey *et al.*, 2015; Levy *et al.*, 2016]. The impact of climate events differs between nations, regions, communities and individuals, due to differences in their exposure and resilience to climate events [Phalkey *et al.*, 2015]. Existing studies display a wide diversity of empirical results; more empirical findings are required, to better understand the effects of climate on health status.

With a slim S-shape hugging more than 3,200 km of coastline in the monsoon belt of Southeast Asia, Viet Nam is considered to be one of tropical countries at highest risk from the impacts of climate change and weather-related loss events (hurricanes, floods, drought, etc.) [Eckstein *et al.*, 2019; Yusuf and Francis-

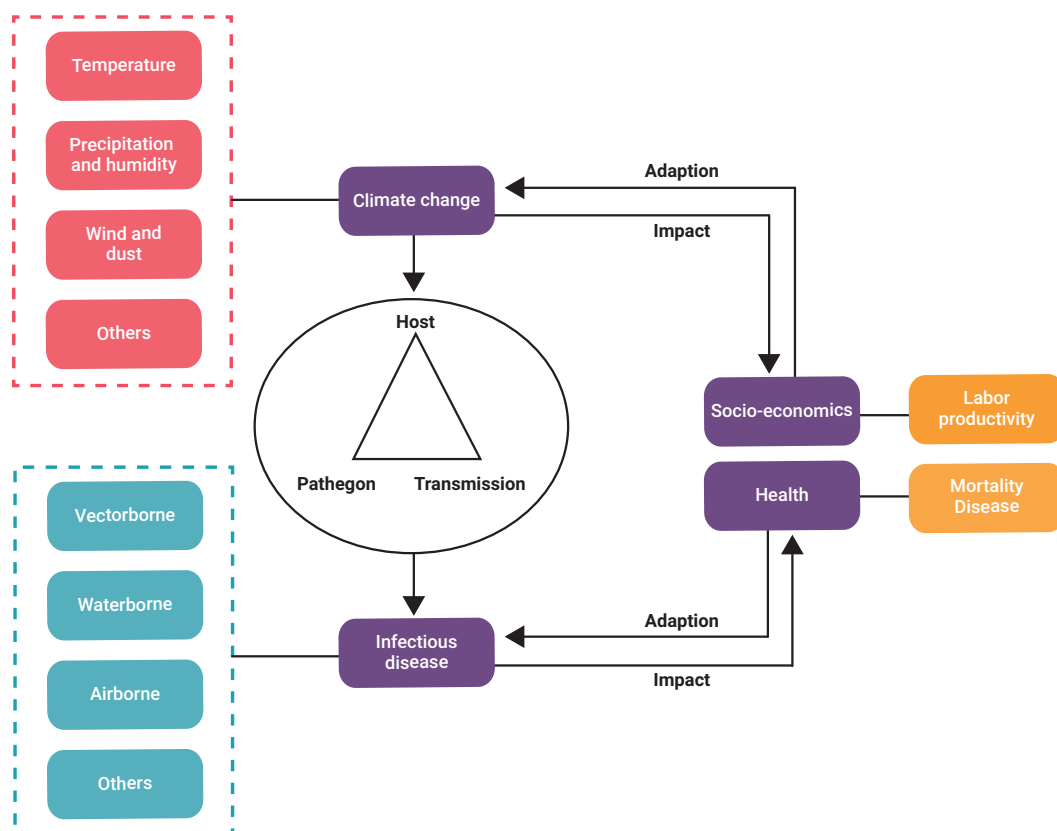
co, 2009]. With all meteorological projections pointing to the severe scenario, the number of people at risk of climate-sensitive diseases will increase dramatically in the absence of public interventions [Rocklöv *et al.*, 2014].

Previous studies have found a potential link between climate change and infectious diseases, but have mostly revealed the correlation with single diseases in a local context. Here, we provide a comprehensive study at the national level of Viet Nam, in the face of the acceleration in global warming.

This chapter has two objectives. Firstly, it estimates the short-term effects of weather variation (temperature, rainfall, wind speed, heatwave) and long-term effects of climate on the incidence of multiple infectious diseases (i.e., water-borne, airborne, and vector-borne) in Viet Nam, taking the role of public health expenditures for adaptation into account. In addition, the indirect economic costs of infectious disease is estimated through labour productivity loss due to diseases. Secondly it examines the effect of cold and heat waves on mortality in Viet Nam. The findings of this study are essential for health policy associated with climate change and adaptation strategies. A conceptual framework is presented in Figure 3.1.

This chapter is structured into four sections. The second section presents the effect of weather variations on the incidence of multiple infectious diseases in Viet Nam. The third section presents the effect of weather extremes on mortality. Finally, the fourth section summarizes the main findings and discusses several policy implications.

[Figure 3.1]
Climate change, infectious disease and humans



The figure presents the relationship between climate change, infectious disease and humans. Climate change is the variation of climate variables such as temperature, precipitation, wind. While pathogens are disease agents such as virus, bacterium, hosts are living organisms such as animals or plants where the pathogens dwell in. The change in climate will influence the life cycle and distribution of pathogens, hosts and their transmission environment. This impact of climate change will lead to the outbreak of many types of human infectious disease such as vector-borne, water-borne and air-borne disease. Climate change and infectious disease have an impact on socio-economics (e.g. labor productivity) and health (e.g. an increased rate of mortality and other health disease). In the long term, humans will respond to climate change and infectious disease by applying several adaptation measures.

Source: adapted from Wu *et al.*, 2016)

2. Climate change and infectious diseases

2.1 Climate change and infectious diseases in Viet Nam

Since 1980, the growing literature on climate change and infectious diseases has focused on water-, vector-, and mosquito-borne diseases [Sweileh, 2020].

Vector-borne disease

A vector-borne disease is transmitted from a host with an infectious pathogen to a susceptible human by an organism (mainly an arthropod). Major vector-borne diseases are malaria, dengue, rabies, and several neglected tropical diseases¹. The complexity of climate impacts on ecosystem services and the adaptation dynamics of pathogens, animals, and humans can change the transmission dynamic, the seasonal and geographical spread of vectors, and the virulence of the infectious pathogen. Temperature can impact several life-history traits of a vector, including egg viability, larval development, and adult lifespan [Couret and Benedict, 2014; Brady *et al.*, 2013]. In the temporal range of larval survival, higher temperatures can boost the development of larvae [Christofferson, 2016; Brady *et al.*, 2013]. In Viet Nam, with its variety of geographic and climatic conditions, outbreaks of vector-borne disease will differ for each region and time scale. Several well-researched and comprehensive studies have attempted to correlate climatic factors linked to climate change with cases of dengue and malaria, two common vector-borne infectious diseases in Viet Nam (see, for example, Kien *et al.* 2010 in 6 pro-

vinces, Toai *et al.*, 2016 in Khanh Hoa and Can Tho). These studies confirm evidence suggesting that the monthly number of dengue fever cases strongly correlates with major climatic factors and vector index (*i.e.*, vector density, Breteau index).

Water-borne disease

Water-borne disease (WBD) is prevalent across the Viet Nameese territory. With the dynamic of economic and environmental factors (*i.e.*, living standards, clean water supply, behaviour changes, nutrition), the role of climate change and climate variability can be captured with a relevant experimental design. Like many other tropical countries, Viet Nam often records the peak of WBD cases during the rainy season or after extreme weather events (*i.e.*, floods, storms, droughts), mainly due to the shortage of clean drinking water [Checkley *et al.*, 2000; Phung *et al.*, 2015]. Diarrheal diseases and dysentery vary by season, with the number of cases increasing in the hot-rainy season and vice versa. In particular, in a study for Thua Thien Hue and Danang, the authors found that rainfall and extreme weather events significantly affected the incidence of WBD [Kien *et al.*, 2010]. The authors also suggest the role of adaption measures such as an efficient management policy for water quality deterioration, an early warning system for epidemic risk, and moderating influences in the reduction of cholera cases.

Airborne diseases

In the context of global climate change, the effect of climatic factors on airborne disease has been examined by numerous studies. Researchers and authorities have focussed on airborne disease, especially when an outbreak has occurred, such as Hand-mouth-

1. <https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases>

foot (HFMD), avian influenza, and zoonotic diseases². Pathogens of airborne infectious diseases (*i.e.*, influenza, coronavirus, measles) tend to be sensitive to humidity conditions. For example, warm and wet conditions decrease the risk of COVID-19 spreading via aerosols [Mecenas *et al.*, 2020]. In contrast, absolute humidity in the wintertime boosts influenza transmission efficiency and survival more significantly than relative humidity [Xu *et al.*, 2014; Shaman and Kohn, 2009], but low relative humidity is also favourable for virus transmission [Lowen *et al.*, 2007]. Literature also suggests increased morbidity and mortality from communicable respiratory diseases as a result of heatwaves [Kan, 2011], inter-regional dust storms, and wind [Hamnett *et al.*, 1999; Chen *et al.*, 2010].

HFMD is currently a significant public health issue not only in Viet Nam, but also in other Asia-Pacific countries. Phung *et al.* (2017) use a Generalized Linear Model with Poisson family to assert that HFMD increased by 7% and 3.1% for a 1°C increase in monthly temperature above 26°C, and a 1% increase in monthly humidity above 76%. While HFMD decreases by 3.1% in connection with a 1mm increase in monthly cumulative rainfalls at the national scale, the results varied at a regional scale. Using temporal and space-time analysis by Nguyen, HX (2020), this dissertation finds that a 1°C increase in temperature was associated with a 1.7% increase of HFMD, and a 1% increase in humidity was associated with a 0.3% increase in HFMD.

2.2 Impact of climate change and infectious disease

Using monthly data of infectious disease incidence for 28 common diseases, public health expenditure, and weather in 63 provinces in Viet Nam (see Box 3.1), we aim to explore the influence of weather on disease infections, and the heterogeneous marginal effect of weather on infections across provinces based on provincial long-term climate and public health expenditure. We use a two-stage panel approach. In the first stage, we estimate the response function of disease-infected cases to the changes in weather. In the second stage, the local effect of weather variation is crossed with long-term climate and public health expenditure to capture the heterogeneous marginal effect of response function: the sensitivity of infection to temperature varies according to the provincial long-term climate and health budget (see Box 3.2).

Effects of weather on infectious diseases

Table 3.1 presents influences of daily temperature on infections by all types of diseases. Columns (1) to (3) incorporate a different range of fixed effects, from the province, month, and different category in column (1), to category-province in column (2), and category-province and category-month in column (3).

The results in column (2) show that disease infections significantly increase by a number of days with temperature under the bin of 15°C–18°C and 24°C–30°C compared to the reference bin. Specifically, one additional day with temperature under the bin 15°C–18°C, 24°C–27°C, and bin 27°C–30°C increases infectious disease incidence by approximately 1.021, 1.016, 1.014 cases, respectively.

2. 36% zoonotic pathogens are transmitted through airborne transmission.

[Table 3.1]

Weather effects on for 28 common diseases

Variables	Infectious disease incidence		
	(1)	(2)	(3)
Temperature			
≤15°C	0.002 (0.004)	-0.004 (0.003)	-0.004 (0.003)
15°C–18°C	0.012*** (0.004)	0.009*** (0.003)	0.009*** (0.003)
18°C–21°C	-0.008** (0.004)	-0.011*** (0.003)	-0.011*** (0.003)
21°C–24°C	-	-	-
24°C–27°C	0.006*** (0.002)	0.007*** (0.002)	0.007*** (0.002)
27°C–30°C	-0.001 (0.002)	0.005*** (0.002)	0.005*** (0.002)
≥30°C	0.001 (0.004)	0.005 (0.003)	0.005 (0.003)
Windspeed	0.128*** (0.016)	0.137*** (0.013)	0.137*** (0.013)
Rainfall	-0.004 (0.002)	-0.001 (0.002)	-0.001 (0.002)
Constant	6.422*** (0.103)	5.408*** (0.126)	5.408*** (0.122)
Fixed Effects			
Province	x	X	x
Month	x		
Category	x		x
Category x Province		X	x
Category x Month		X	x
Observations	22,680	22,680	22,680
R2	0.223	0.855	0.488
Adjusted R2	0.220	0.850	0.483
F Statistic	78.242*** (df = 83; 22596)	94.746*** (df = 198; 22481)	97.868*** (df = 219; 22460)

Note: *p<0.1; **p<0.05; ***p<0.01.

[Box 3.1]**Data sets**

Data on the monthly mortality rate of provinces during the 2000–2018 period are provided by General Statistics Office of Viet Nam (GSO). The mortality rate is computed from Population Change and Family Planning Surveys, which have been conducted annually by GSO since 2000. The sample size of these surveys is representative at the provincial level. Health care expenditure data is taken from Medical Statistical Yearbook from 2009 to 2018, published by the Ministry of Health. It is a yearly health budget at the provincial level of 63 provinces. The health budget accounts for treatment and preventative expenditures and health programs. Data on infectious disease is taken from the Infectious Diseases Statistical Yearbook from 2009 to 2018, published by the Department of Preventive Health, Ministry of Health. It is the number of monthly infections and deaths by each infectious disease at the provincial level of 63 provinces. We select 12 common diseases and separate them into three main categories, including vector-borne type (malaria, rabies, encephalitis, dengue), airborne type (mumps, chickenpox, influenza, measles), and water-borne type (dysentery, diarrhea, hepatitis, cholera). The number of infections of each category is then calculated as the sum of infections by four selected common diseases in this category.

Weather and climate data are obtained from over 172 weather stations across Viet Nam with the average temperature, rainfall, and wind speed from 2001 to 2018. According to WHO (1990, 2019), temperatures lower than 15°C with humidity above 65% were associated with respiratory hazards. A range from about 21–30°C was associated with minimal-risk high temperature. Based on these studies and the distribution of temperature in the data set, we then classified temperature into bins of 3°C, and the 21–24°C is selected as the reference of the comfortable indoor temperature. Average temperature is divided into 7 bins (below 15°C, 15°C–18°C, 18°C–21°C, 21°C–24°C, 24°C–27°C, 27°C–30°C, above 30°C).

On the other hand, we find a negative relation between disease infections and the number of days with the temperature under the bin 18°C–21°C. Nonetheless, there is no evidence for the impact of extreme temperature (below 15°C and above 30°C) on disease infections, which can be explained by the fact that the optimal life span of pathogens is typically found around 15°C–30°C [Rohr and Cohen, 2020]. However, this window will change as a result of climate change [Caminade *et al.*, 2014]. For example, areas which were previously below the temperature threshold for infectious disease transmission, such as the Highlands, may cross the threshold as a result of climate change. Evidence for the impact of temperature on disease infections can be found in the literature. For example, Phung *et al.* (2017) point out that a 1°C increase in monthly temperature above 26°C increases infections by

hand-foot-mouth disease in Viet Nam by 3.1%. One of the mechanisms could be rooted in the impact that temperature has on the life traits of pathogens [Courret and Benedict, 2014; Brady *et al.*, 2013; Christofferson, 2016].

Moreover, the results indicate that wind-speed significantly and positively impacts the number of disease infections, which is in line with Hamnett *et al.* 1999; Chen *et al.* 2010 on analysing the relationship between interregional dust storms and wind, and communicable respiratory diseases.

Heterogeneous marginal effect of weather sensitivity of disease infections

In this section, we estimate the relationship between provincial long-term climate, the

health budget and the sensitivity of infections to temperature. The provincial long-term climate and the health budget are the moving average of annual average temperature and annual total health budget in a given province from 2009 to 2018.

The results indicate that a province with long-term climate at a high temperature is less sensitive for all types of infection to one additional day under the temperature 24°C–30°C ($\alpha_1 = -0.002$), but more affected by one additional day under the temperature 15°C–18°C ($\alpha_1 = 0.007$). It indicates that in hotter provinces, infectious diseases are more impacted

by colder weather but less affected by higher temperature. And vice versa, in cold provinces, infectious diseases are less influenced by colder temperature, but more sensitive to hotter temperature. This finding reflects a sign of adaptability in the climate of hotter provinces to a hot range, and in colder provinces to a cold range of temperature. Similar evidence of adaptation has been found in other settings, for example, health [Carleton *et al.*, 2020], and agriculture [Bulter and Huybers, 2013]. Figure 3.2 shows the marginal effect of provincial climate on the sensitivity of infections to temperature. Provinces located in the south and southern central coast appear

[Table 3.2]

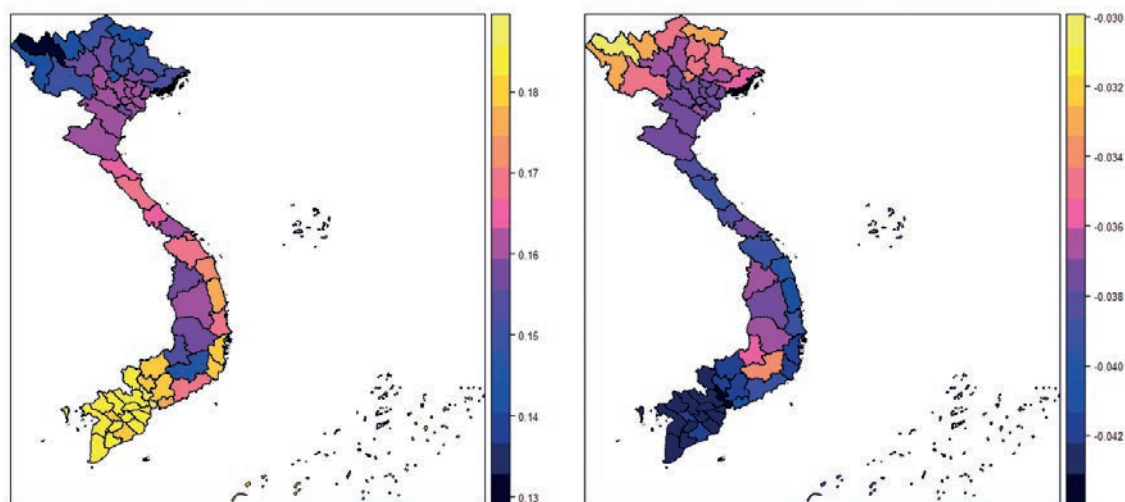
Marginal effect of provincial climate and health budget in sensitivity of disease infections to temperature

Variables	All types		Infections by disease					
	MeanT	MeanBudget	Waterborne diseases		Airborne diseases		Vector-borne diseases	
	MeanT	MeanBudget	MeanT	MeanBudget	MeanT	MeanBudget	MeanT	MeanBudget
≤ 15°C	-0.002 (0.002)	-0.006 (0.007)	-0.002 (0.003)	0.005 (0.006)	-0.002 (0.003)	0.004 (0.006)	0.002 (0.003)	-0.005 (0.006)
15°C–18°C	0.007*** (0.002)	-0.001 (0.007)	0.007*** (0.003)	-0.011* (0.006)	0.004 (0.003)	-0.007 (0.006)	0.004 (0.003)	-0.005 (0.006)
18°C–21°C	0.001 (0.002)	-0.012* (0.007)	0.001 (0.003)	-0.002 (0.005)	-0.001 (0.001)	0.001 (0.003)	0.004 (0.003)	-0.009* (0.005)
21°C–24°C	-	-	-	-	-	-	-	-
24°C–27°C	-0.002* (0.001)	-0.007 (0.004)	-0.002 (0.001)	0.004 (0.002)	-0.002* (0.001)	0.004* (0.003)	0.002* (0.001)	-0.004 (0.003)
27°C–30°C	-0.002* (0.001)	-0.005 (0.004)	-0.001 (0.003)	0.003 (0.005)	-0.003** (0.001)	0.006** (0.002)	0.002 (0.001)	-0.003 (0.002)
≥ 30°C	-0.001 (0.002)	-0.003 (0.005)	0.001 (0.003)	-0.002 (0.005)	-0.004 (0.003)	0.006 (0.005)	0.003 (0.003)	-0.005 (0.005)
Observations	22,680		22,680					
R2	0.489		0.490					
Adjusted R2	0.484		0.485					
F Statistic	92.979*** (df = 231; 22448)		86.710*** (df = 249; 22430)					

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Estimation with fixed effects including category x province and category x month.

[Figure 3.2]

Marginal effect of provincial climate on sensitivity of infections to temperature

(a) Sensitivity to 15°C–18°C.

(b) Sensitivity to 27°C–30°C.

The figures represent log of the ratio of number of infections in the year of 2050 to number of infections in the year 2015. The number of infections in the year of 2050 is projected under the SSP2 scenario and RCP 4.5. The scenario with the adaption controls for the effect of annual provincial health budget and long-run climate on the sensitivity of disease infections to temperature. Health budget is assumed to follow growth rate as GDP under the SSP2 scenario.

to have a higher level of sensitivity to infections at 15°C–18°C, but a lower level of being affected at 27°C–30°C, whereas the Northern and Tay Nguyen provinces are less sensitive to infections at 15°C–18°C, but more sensitive at 27°C–30°C. With respect to marginal effect by health budget, the results suggest that the health budget lessens the sensitivity of infections to all bins of temperature (although only sensitivity to the bin 18°C–21°C is found to be significant), reflecting the significant effect of public budget on disease control.

The study finds different marginal effects of the long-term climate and health budget on the incidence of infection across three disease

groups. For waterborne disease, provinces with hotter climates have higher sensitivity to infections at the colder range of temperature (15°C–18°C), but the health budget lessens the impact of this temperature range on infectious incidence. In the vector-borne type, a province with higher long-term temperatures has a higher level of sensitivity to infections at temperatures at the bin 24°C–27°C. The results are in line with previous theoretical models suggesting the development of the pathogen or vector was inhibited at temperatures below 21°C, but from 24°C, the incidence rate of vector-borne disease increases significantly with the rise in temperature [Brady *et al.*, 2014]. For airborne diseases, their sensitivity to one

additional day at temperature is lessened in a province with higher long-term temperature. However, the health budget is intensified by the increase in the provincial health budget. Although the positive relationship between budget and airborne diseases is unexpected, it should be re-examined with the lag time, because the actions of public agencies usually lag behind the outbreak of disease. For example, by observing the rise of disease occur-

rence, authorities spend a higher budget on control activities then the effects might delay in the successive periods. Moreover, public health care expenditure typically rises in line with public investment (*i.e.*, infrastructure, traffics), contributing to water and air pollution in developing countries [Chen *et al.*, 2010; Chung and Sobsey, 1993]. Infectious diseases have a higher risk of spreading during economic expansion [Adda, 2016] with the idea of

[Table 3.3]

Impact of infections by diseases on labor productivity

Variables	Dependent variable ln (Hourly Earning)
Age 36–50	1.558** (0.753)
Age 51–60	0.265 (0.745)
Male	1.854*** (0.654)
Having vocational degree	0.168 (0.689)
Elementary and secondary education	-0.048 (0.389)
College education	0.912** (0.433)
University graduate or above	-0.427 (0.535)
Insurance	1.537*** (0.118)
Infection	-0.049* (0.029)
Constant	1.308** (0.562)
Observation	567
R2	0.302
Adjusted R2	0.291
F Statistic	26.753*** (df = 9; 557)

Note: *p<0.1; **p<0.05; ***p<0.01.

mortality and business cycle by Ruhm (2000). Therefore, the no environmental-friendly outlay could increase the risk of communicable diseases to the local community.

2.3 Disease and productivity

We have tested the effect of disease infections on labour productivity. Labour data is taken from Labor Force Survey from the period 2010–2018. A dependent variable that represents labor productivity is the average hourly wage of labour in a given province in a specific year. Explanatory variables for labour characteristics are included in the model, including education, gender, and age. The results suggest a negative influence of infections on labor productivity. Specifically, a 1% increase in disease infections leads to a decrease in the average hourly wage of approximately 0.05%.

A lower wage premium for sicker workers indicated that the social rate of return to a relevant public health policy for infectious disease prevention is high. Integrating health insurance and educational attainment may play an important role when these non-disease factors significantly boost worker productivity. The higher average hourly wage for better-educated workers may indeed be not only a high private return to education but also a potential link to immeasurable health literacy.

2.4 Projection of future climate change impacts and adaptation

To capture the implications of adaptation to short-term weather shocks and long-term climate changes, we have used a two-stage model to illustrate the differences in future

impacts between adapted and non-adapted infection responses by climate projections. Data on the future evolution of the climate is obtained from [Chapter 1](#). To comprehensively simulate spatial heterogeneity in climate impact, we have used a high-resolution (0.1°) set of global, bias-corrected climate projections produced by the Bias Correction and Spatial Downscaling (BCSD) approach (see [Chapter 1](#) for the description of the technique). We use projected emissions from two Representative Concentration Pathways (RCP 4.5 and RCP8.5) to simulate emissions under those two emission scenarios up to 2100 [[Figure 3.3](#)]. The gridded data are aggregated to impact regions at district and province levels. For the health budget, we assume that the annual growth rate of the provincial health budget is similar to GDP growth rate following the SSP2 (Shared Socioeconomic Pathways).

[Table 3.4](#) lists the results of future impacts on infection corresponding to RCP4.5 and RCP 8.5, with and without adaption in some representative provinces. The second column is the average number of annual provincial infection cases. The last 8 columns are the rate of the number of infections in the year of projection over the number of infections in the year of 2015 that are induced by temperature. The effects of climate change are considerably decreasing in all scenarios across the country. The average provincial incidence of infection increases by 29% between 2015 and 2050 under RCP4.5 without adaption, but is reduced by 91% with adaption. The increase/decrease of incidence of infection varies across provinces. For example, in Hanoi City, the incidence of infection declines by 69% between 2015 and 2050 with adaptation, but increases by 26% without adaptation in the RCP4.5 scenario.

[Table 3.4]

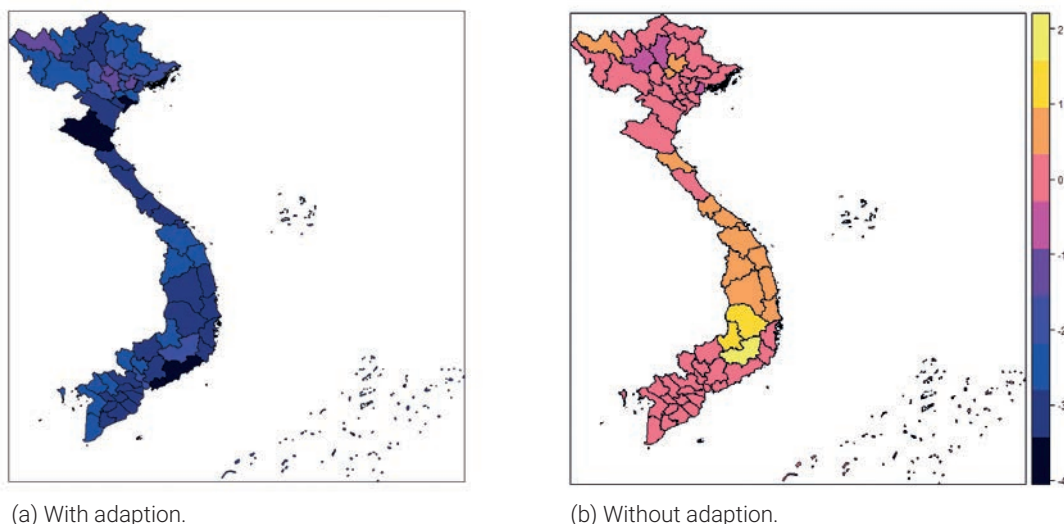
Future impacts of climate change on diseases with and without adaptations in some provinces

Province	Annual Infections (cases)	Changes in number of infections*							
		2050				2100			
		RCP4.5		RCP8.5		RCP4.5		RCP8.5	
		without	with	without	with	without	with	without	with
		adaption	adaption	adaption	adaption	adaption	adaption	adaption	adaption
Mean of 63 provinces	368395.3	1.29	0.09	1.29	0.09	1.29	0.02	1.36	0.04
Bac Ninh	283959	1.24	0.21	1.03	0.16	1.07	0.04	0.77	0.02
Binh Dinh	188191	1.53	0.05	1.47	0.05	1.42	0.01	1.28	0.02
Da Nang	202563	1.62	0.04	1.86	0.04	1.86	0.01	1.69	0.01
Dak Lak	529613	2.92	0.04	2.70	0.06	2.55	0.02	2.25	0.03
Dak Nong	74612	3.55	0.06	3.19	0.08	3.04	0.02	3.02	0.03
Dien Bien	367329	0.89	0.07	1.35	0.10	1.38	0.02	1.43	0.03
Dong Nai	279986	0.78	0.04	0.77	0.05	0.77	0.01	0.76	0.05
Gia Lai	262012	1.82	0.04	1.76	0.05	1.71	0.01	1.49	0.02
Ha Giang	439621	0.90	0.06	1.10	0.10	1.20	0.02	1.34	0.03
Ha Nam	251054	1.01	0.09	1.10	0.11	0.83	0.01	0.89	0.01
Ha Noi	1217263	1.26	0.31	1.22	0.26	0.85	0.02	0.85	0.01
Ha Tinh	432982	1.41	0.03	1.62	0.05	1.71	0.01	2.12	0.01
Ho Chi Minh	697497	0.88	0.15	0.87	0.17	0.87	0.06	0.86	0.27
Lao Cai	456009	1.15	0.07	1.40	0.10	1.45	0.02	1.67	0.04
Quang Binh	241620	1.03	0.06	1.20	0.08	1.51	0.03	1.83	0.02
Quang Nam	662230	1.51	0.11	1.73	0.10	1.96	0.02	1.82	0.02
Quang Ninh	148798	1.16	0.17	1.09	0.14	0.78	0.01	0.95	0.02
Thua Thien Hue	338460	1.78	0.05	1.79	0.06	2.15	0.01	2.24	0.01

Note: Number of infection is measured by Cases in the year of projection/Cases in the year 2015. Health budget is assumed to follow growth rate as GDP under the SSP2 scenario.

[Figure 3.3]

Infections change between 2015 and 2050 under the RCP4.5 and SSP2



The figures represent log of the ratio of number of infections in the year of 2050 to number of infections in the year 2015. The number of infections in the year of 2050 is projected under the SSP2 scenario and RCP4.5. The scenario with the adaption controls for the effect of annual provincial health budget and long-run climate on the sensitivity of disease infections to temperature. Health budget is assumed to follow growth rate as GDP under the SSP2 scenario.

3. Impacts of cold and heat waves on mortality

3.1 Mortality and weather extremes

Mortality in Viet Nam

Along with economic growth, Viet Nam has experienced an improvement in health. Life expectancy increased from 73 to 75 during the 2000–2018 period [World Bank, 2020]. However, the crude mortality rate did not decline during this period³. Estimates from the Population and Planning Surveys show that the

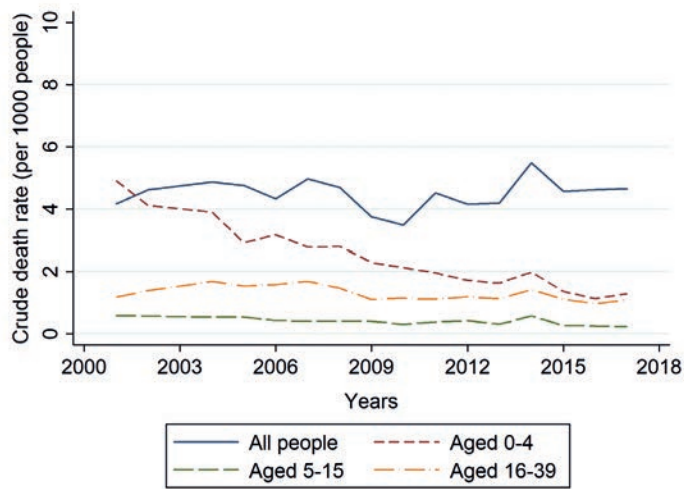
all-age mortality rate was around 5 deaths per 1000 people [Figure 3.4]. A key reason why the mortality rate has not declined over the past two decades is the reduction in the fertility rate. The government has recommended family planning with a limit of two children per family since 1988. The dramatic decline in childbirth rates is the most important reason for population aging in Viet Nam⁴. When the mortality rate is computed for different age groups, we can

3. The crude mortality rate is the number of deaths per 1,000 mid-year total population of the given geographical area during the same year.

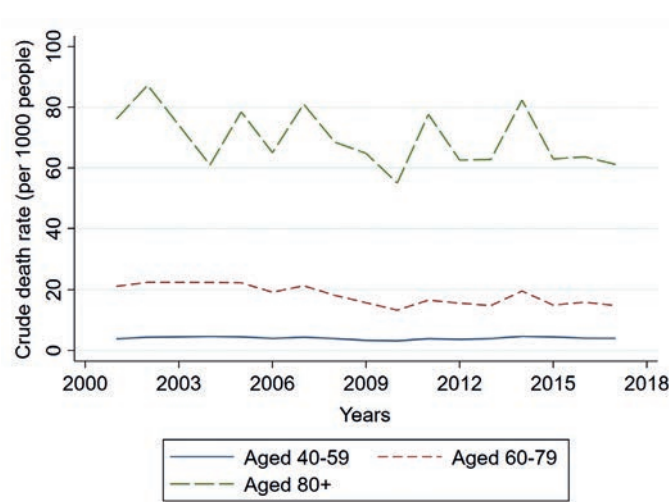
4. Viet Nam is among the most rapidly ageing countries in the world. According to GSO (2019), the aging index, which is equal to the ratio of the number of people from 60 to the number of children below 15 (measured in percent), has increased over time. The aging index increased by 13.3 percentage points from 35.5% in 2009 to 35.3% in 2019.

[Figure 3.4]
The crude mortality rate (per 1000 people) by age groups

Panel A. People aged 0-39



Panel B. People aged 40+



This figure reports the crude mortality rate for different age groups during the 2000–2018 period. Panel A presents the mortality rate for all the population and population groups below 40 years old, while Panel B presents the mortality rate for population aged from 40. Panels A and B have different scales of the y-axis.

see the decline in the mortality rate, especially for children under 5 and people aged 60 and older [Figure 3.4].

Like other countries, chronic diseases are the main cause of mortality in Viet Nam [WHO, 2014]. The leading cause of mortality in Viet Nam is stroke, which killed 112.6 thousand people, 21.7% of all deaths in Viet Nam [WHO, 2015]. The second cause of mortality is ischemic heart disease, accounting for 7% of deaths in Viet Nam. Other causes of mortality include Chronic Pulmonary Obstructive Disorder (accounting for 4.9% of deaths), lower respiratory infections caused by bacteria, viruses, or fungi (accounting for 4.8% of all deaths), accidents, cancers and other diseases [WHO, 2015].

There are 63 provinces in Viet Nam, and these provinces are grouped into 6 geographic regions: Red River Delta, Northern Midlands and Mountains, and Central Coast in the North and Central Highlands, Southeast and Mekong River Delta in the South. Figure 3.5 presents the geographic maps of the mortality rate and temperature (averaged over the 2000–2018 period). The poverty rate as well as the average temperature is fairly similar between provinces within a region. The correlation between mortality and temperature is not clear from these maps. However, it shows that the mortality rate is higher in the North, which has a lower average temperature, than in the South.

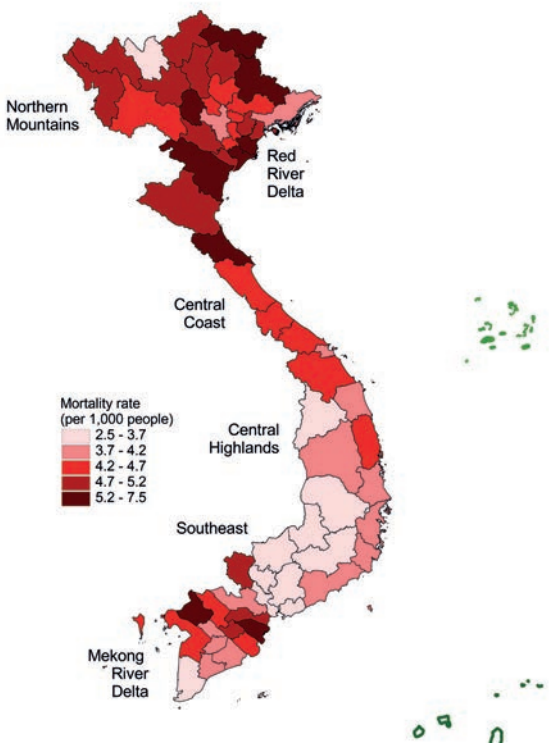
There are different ways to examine the relationship between temperature and mortality. A population-focused way is to estimate the temperature bins on mortality [e.g., Deschênes and Moretti, 2009; Deschenes and Greenstone, 2011; Burgess *et al.*, 2017; Carleton *et al.*, 2020]. The WHO (2018) suggests that the range of minimal-risk high temperatures is

about 15–30°C. Low and high temperature can cause health problems and result in risk of death. Temperatures lower than 16°C (61°F) with humidity above 65% were associated with respiratory hazards. The temperature-humidity index can be used to explore the effect of temperature and humidity on health [e.g., McGregor and Vanos, 2018]. In this study, we have tried to estimate the number of days within the temperature bins, but did not find significant effects for the number of days with low or high temperatures on mortality. Possibly, people in cold or hot areas have adapted to their local temperature. However, temperature shocks can cause health problems for people.

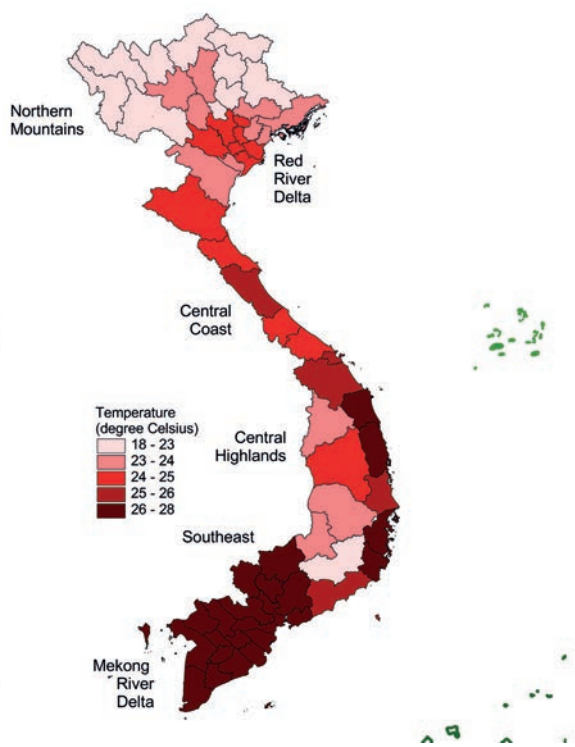
The effect of weather extremes, which are assessed by cold and heat waves occurring within a month, is the emphasis of this chapter. A heat wave is a term used to describe a period of very high temperatures. There are two issues in defining a heat wave: selection of a temperature threshold, and definition of the number of consecutive days of prolonged heat. Most studies use a threshold of a given percentile, such as the 90th, 95th or 98th percentile of the temperature distribution in a specific location [e.g., see review Perkins and Alexander, 2013; and Perkins, 2015]. The second issue in defining a heat wave is the duration of consecutive days equal to or above the temperature thresholds. Exposure to hot weather for a number of consecutive days has a more detrimental effect on health than exposure to few hot days that are spaced apart. A heat wave is often defined as at least 3 or 5 consecutive days with daily temperature above a given threshold [e.g., see review Perkins and Alexander, 2013; and Perkins, 2015]. Unlike the number of days in temperature bins, cold and heat waves can have harmful effects on health, since they are more extreme and last for several consecutive days.

[Figure 3.5]
Mortality rate and temperature

Panel A. Mortality rate (per 1,000 people)



Panel B. Average daily temperature (degree Celsius)



Panel A presents the crude death rate of province, measured as the number of resident deaths per 1000 population in a year. The map shows the mortality averaged over the 2000-2018 period. Panel B presents the average of the daily mean temperature of the province over the same period.

During the 2000–2018 period, we defined a heat wave as three or more consecutive days with daily mean temperatures at or above the 95th percentile of the year-round province-specific temperature distribution. Similarly, we define a cold wave as when the daily mean temperature is equal to or below the 5th percentile of the year-round province-specific temperature distribution for at least three consecutive days. We also define heat waves (and cold

waves) as at least 5, 7, and 9 consecutive days with daily mean temperatures at or above the 95 percentile (and at or below the 5 percentile) of the province-specific temperature distribution for robustness analysis.

The average number of days per year in cold and heat waves is shown in Panel A of Figure 3.6, which is calculated using the 5th and 95th percentiles of the province-specific tempera-

ture distribution. The figures are calculated as an average across province-by-year. The first bar in Panel A, for example, shows that the province-by-year average number of consecutive days in cold waves (defined as at least 3 cold days) is 14. In cold waves defined as at least 9 consecutive cold days, the average number of consecutive days is only 5.2. It should be noted that this average is below 9, as several provinces have not experienced a cold wave in several years. In heat waves, the average number of consecutive days is lower. For example, in heat waves defined as at least 3 and 9 consecutive hot days, the average number of consecutive days is 10.4 and 2.4, respectively.

During the 2000–2018 period, panel B of Figure 3.6 shows the average percentage of months with at least one cold or heat wave. The percentage is calculated by adding together the percentages from all provinces. It shows that between 2000 and 2018, 16.7% of months had at least one cold wave (which is defined as at least 3 consecutive cold days). The average percentage of months with at least three consecutive hot days experienced by heat waves is 13.6 percent. The percentage of months with at least one cold or heat wave is lower when cold or heat waves are defined for a longer period of time (at least 5, 7, or 9 days).

3.2 Impact of weather extremes on mortality

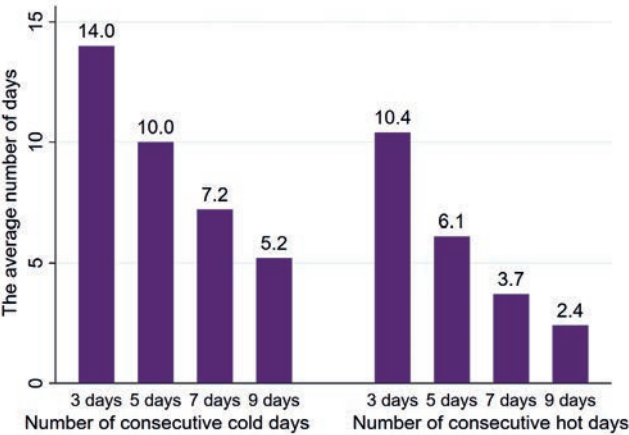
In this section, we explore the effect of cold and heat waves on the monthly mortality rate using a regression model. The regression model is presented in Box 3.2. We use both the mortality rate as well as log of the mortality rate as dependent variables. We regress these de-

pendent variables on cold and heat waves and control variables. The control include average yearly temperature, total annual precipitation, province-by-month fixed-effects, year-month fixed-effects, and province-specific time trend. The effects of cold and heat waves on mortality are measured by the coefficients of cold and heat waves in the regressions. The effects are summarized in Figure 3.7. In this figure, we graph the point estimate and the 95% confidence interval of the effects of cold and heat waves on the monthly mortality rate (Panel A and B of the figure) and the log of the monthly mortality rate (Panel C and D of the figure). The log of the death rate and the estimated effects of cold and heat waves are remarkably comparable. The results of the effects on the log of the mortality rate are used to interpret the results.

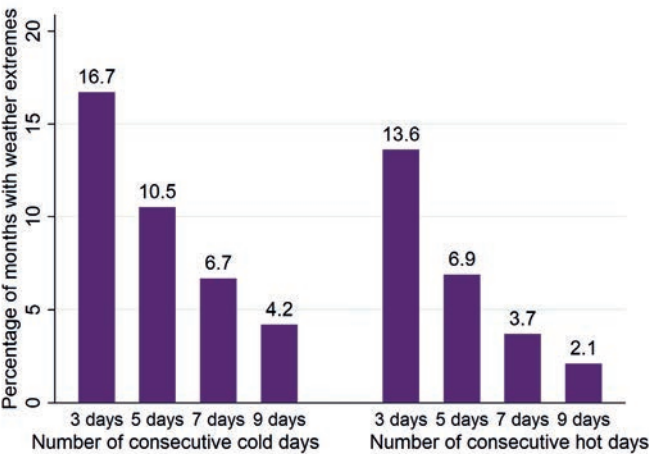
Overall, we find that both cold and heat waves increase the chance of death, and that the effect of both cold and heat waves increases as the cold and heat waves stay longer. The predicted coefficients of occurrence of at least one cold or heat wave within a month are plotted in Panel C of Figure 3.7. A cold wave lasting at least 5 days raises the monthly mortality rate by roughly 4.9 percent (significant at the 10% level), whereas a cold wave lasting at least 9 days increases the mortality rate by 6.5 percent (significant at the 5 percent level). When compared to a cold wave, a heat wave has a higher and more significant impact on the death rate. If there is a heat wave that lasts for at least 9 days in a month, the death rate rises by 13.5 percent. This shows how a protracted severe heat wave can have a significant impact. However, a heat wave lasting at least 9 days is uncommon. The average percentage of months with at least 9 consecutive hot days occurred only 2.1 percent of the time between 2000 and 2018.

[Figure 3.6]
Cold and heat waves

Panel A. The average number of consecutive days in cold and heat waves



Panel B. The percentage of months with cold and heat waves



Panel A of this figure presents the average number of days per year in cold and heat waves, which are defined based on the 5th and 95th percentiles of the province-specific temperature distribution and different durations of consecutive days. Panel B of the figure presents the average percentage of months in which at least a cold or heat wave (defined based on different durations of consecutive days) occurs during the 2000–2018 period.

Source: Nguyen *et al.* (2021).

Panel D depicts the estimated coefficients of the number of days in cold and heat waves on log of mortality rates. All the estimates are positive and statistically significant at the 5% level. An additional day in a cold wave of at least 3 consecutive days (relative to a day within the 5th–95th percentile temperature range) leads to an increase in the mortality rate of 0.6 percent. The corresponding figure for a day in a heat wave is 0.7 percent. For a cold or heat wave defined as at least 9 consecutive days, an additional day in the cold and heat wave increases the mortality rate by 0.6 and 1.2 percent, respectively.

Children and the elderly are more susceptible to harsh weather than others [e.g., see Basu, 2009; Arbuthnott and Hajat, 2017; Geruso and Spears, 2018]. Table 3.5 shows the coefficients of the number of days spent in cold and heat waves in death rate regressions for various age groups. There are 32 regressions in total, and the table only shows the estimated coefficients for each regression's number of days in cold and heat waves. The findings imply that only the elderly, particularly those over the age of 80, are harmed by weather extremes. For people under the age of 40, almost all cold and heat wave coefficients are statistically insignificant. All of the predicted coefficients of cold and heat waves are positive for adults over 40, indicating that they have a negative impact on their health. The death rate of adults over the age of 80 is significantly higher than that of younger people. In Table 3.5, we look at how the effects of cold and heat waves on mortality differ for men and women. Overall, there is no discernible difference in the influence on death rates between men and women.

We believe that cold and heat waves cause death primarily through a direct and detrimental influence on health for two reasons.

Firstly, cold and heat waves only have short-term effects on mortality. To examine the medium-term effect of cold and heat waves, we include one-month and two-month lagged variables of cold and heat waves to examine the sensitivity of the effect estimates, as well as the medium-term effect of cold and heat waves. Most lagged variables of cold and heat waves are positive but not statistically significant at conventional levels. This suggests that cold and heat waves do not have medium- or long-term effects on mortality. Second, we conduct regressions of per capita income of provinces with cold and heat waves over the course of a year to see if cold and heat waves have indirect effects on health by reducing income. We find little evidence that cold and heat waves have a major impact on income. As a result, income is not a factor in the increased mortality caused by cold and heat waves.

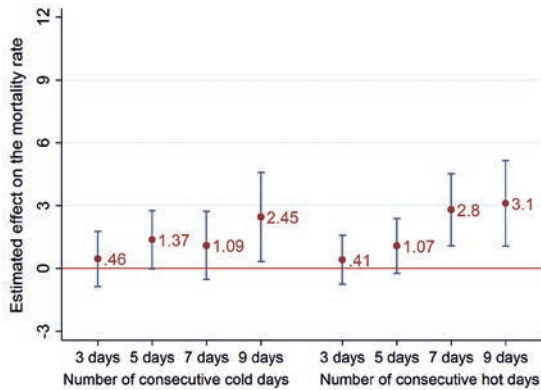
3.3 Projection

In this section, we use projection of daily data for Viet Nam using different Representative Concentration Pathway (RCP) scenarios to predict cold and heat waves in the 2020–2100 period. In the IPCC's fifth Assessment Report in 2014, four paths were employed for climate modelling and research. Different climate futures described in the pathways are all considered feasible, depending on the amount of greenhouse gases emitted in the coming years. The RCPs are named after a possible range of radiative forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m², respectively) [IPCC, 2019].

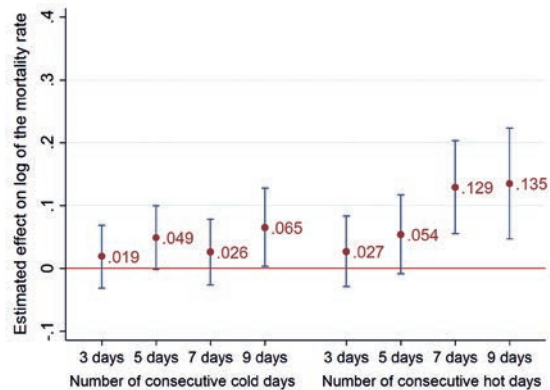
For the sake of simplicity, we assume that people's health and economic conditions, as well as their ability to adjust to climate change,

[Figure 3.7]
Estimated effects (and 95% confidence interval) of cold and heat waves on the all-age mortality rate

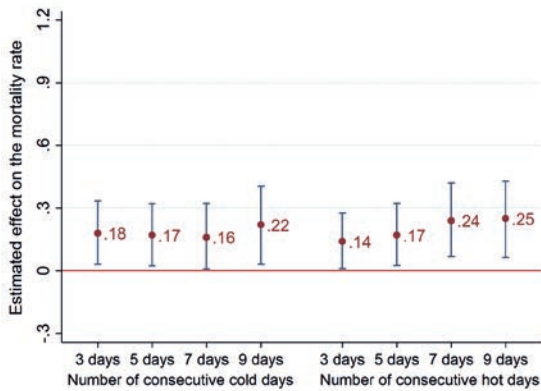
Panel A. Estimated effects of cold and heat waves on the mortality rate



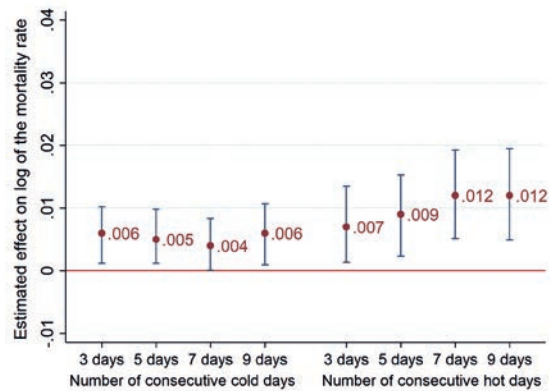
Panel C. Estimated effects of cold and heat waves on log of the mortality rate



Panel B. Estimated effects of the number days in cold and heat waves on the mortality rate



Panel D. Estimated effects of the number days in cold and heat waves on log of the mortality rate



■ Source: Nguyen et al. (2021).

[Table 3.5]

Regression of mortality rates for different population groups

Explanatory variables		Dependent variables							
		Mortality rate of people aged 0-4 (deaths per 100,000 people) (1)	Mortality rate of people aged 5-15 (deaths per 100,000 people) (2)	Mortality rate of people aged 16-39 (deaths per 100,000 people) (3)	Mortality rate of people aged 40-59 (deaths per 100,000 people) (4)	Mortality rate of people aged 60-79 (deaths per 100,000 people) (5)	Mortality rate of aged 80+ (deaths per 100,000 people) (6)	Mortality rate of males (deaths per 100,000 people) (7)	Mortality rate of female (deaths per 100,000 people) (8)
# days with at least 3 consecutive days below the 5 th percentiles of temperature		0.0891 (0.1421)	0.0409 (0.0267)	-0.0401 (0.0587)	0.1513* (0.0760)	0.8443 (0.5369)	5.2655*** (1.9113)	0.2940** (0.1190)	0.0743 (0.0768)
# days with at least 3 consecutive days above the 95 th percentiles of temperature		-0.0294 (0.1517)	-0.0002 (0.0382)	-0.0512 (0.0537)	0.2518** (0.1224)	0.4004 (0.4869)	4.5024** (2.0700)	0.1193 (0.1044)	0.1647* (0.0832)
# days with at least 5 consecutive days below the 5 th percentiles of temperature		0.1617 (0.1482)	0.0318 (0.0224)	-0.0122 (0.0519)	0.1558* (0.0785)	0.8126 (0.4943)	4.3609** (2.0221)	0.2737** (0.1127)	0.0752 (0.0706)
# days with at least 5 consecutive days above the 95 th percentiles of temperature		-0.1212 (0.1499)	0.0264 (0.0430)	-0.0254 (0.0627)	0.2554* (0.1342)	0.5119 (0.4683)	4.5884* (2.3812)	0.1525 (0.1035)	0.1924* (0.1090)
# days with at least 7 consecutive days below the 5 th percentiles of temperature		0.1671 (0.1580)	0.0555* (0.0326)	-0.0505 (0.0544)	0.1288* (0.0749)	0.9184 (0.5677)	4.0651* (2.0609)	0.2349** (0.1161)	0.0972 (0.0729)
# days with at least 7 consecutive days above the 95 th percentiles of temperature		-0.0297 (0.1548)	-0.0143 (0.0438)	-0.0439 (0.0616)	0.2302 (0.1649)	1.0251* (0.5177)	6.9202*** (2.4346)	0.1975* (0.1082)	0.2851** (0.1290)
# days with at least 9 consecutive days below the 5 th percentiles of temperature		0.1640 (0.1717)	0.0485 (0.0299)	-0.0298 (0.0634)	0.1810* (0.1007)	1.3919** (0.6492)	4.1322** (2.0547)	0.3063** (0.1296)	0.1342* (0.0767)
# days with at least 9 consecutive days above the 95 th percentiles of temperature		0.0282 (0.1683)	-0.0018 (0.0494)	-0.0748 (0.0680)	0.2076 (0.1813)	0.8034* (0.4470)	8.6812*** (2.4793)	0.2171** (0.1055)	0.2716** (0.1313)
Observations		12,639	12,639	12,639	12,639	12,639	12,639	12,639	12,639

Note: This table reports the coefficients of the number of days in cold and heat waves in regressions of the mortality rate of people at different age groups. A cold (heat) wave is defined as at least k (3, 5, 7, and 9) consecutive days which have daily mean temperature at or below the 5th percentiles (at or above the 95th percentile) of the temperature distribution of specific province. There are 32 regressions in total. The regression specifications are the same as those in Table A.1 in Appendix. The control variables include annual average temperature (°C), annual precipitation (mm), province-specific time trend, province-by-month fixed-effects, and year-by-month fixed-effects. Robust standard errors in parentheses. Standard errors are clustered at the province and year-by-month levels.

*** p<0.01, ** p<0.05, * p<0.1.

Source: Nguyen *et al.* (2021).

[Box 3.2]

Estimation of the effect of climate

Model to estimates the effects of climate on infectious disease

In the first stage, we estimate this equation

$$y_{cpmt} = \alpha + \sum_k^7 \beta_{1,k} T_{kpm} + \beta_2 Rainfall_{pmt} + \beta_3 Windspeed_{pmt} + v_c + \delta_p + \sigma_{cm} + \theta_{cp} + \epsilon_{pmt} \quad (1)$$

where y_{cpmt} is the number of infected cases in disease-category c of province p in the month m of the year t , T_{kpm} is the number of days in temperature bin k in province p in month m of year t , $Rainfall_{pmt}$ and $Windspeed_{pmt}$ are average rainfall and windspeed in the month m . We use four variables of fixed effects: v_c for category of diseases, δ_p for provinces, σ_{cm} for category $\times$ month and θ_{cp} for category $\times$ province.

The heterogeneous marginal effect of climate on infectious disease is captured in the function as:

$$y_{cpmt} = \alpha + \sum_k^7 (\alpha_0 + \alpha_{1k} MeanT_{(p)} + \alpha_{2k} Budget_p) * T_{kpm} + \beta_2 Rainfall_{pmt} + \beta_3 Windspeed_{pmt} + v_c + \delta_p + \sigma_{cm} + \theta_{cp} + \epsilon_{pmt} \quad (2)$$

where $MeanT_p$ is the sample-period average temperature of province p and $Budget_p$ is the average of budget that province p allocating on medical health care over sample period.

Model to estimates the effects of weather extremes on mortality

We estimate the effect of cold and heat waves on the mortality using the following regression:

$$\log(y_{pmt}) = \alpha_2 + \beta_{2c} Cold_{pmt} + \beta_{2h} Heat_{pmt} + X_{pmt} \theta_2 + P_{pm} + M_{mt} + T_p \delta_{2p} + u_{pmt}, \quad (3)$$

where y_p is the mortality rate of province p in month m of year t (per 100,000). In this study, we use both the mortality rate and log of the mortality rate as the dependent variables. $Cold_{pmt}$ is the number of consecutive days in a cold wave and $Heat_{pmt}$ is the number of consecutive days in heat waves in province p in month m of year t . The cold wave is defined as at least a number of consecutive days (3, 5, 7 and 9 days) with daily mean temperature at or below the 5th percentile of the province-specific temperature distribution, while the heat wave is defined as at least a number of consecutive days (3, 5, 7 and 9 days) with daily mean temperature at or above the 95th percentile of the temperature distribution. X_{pmt} is a vector of control variables. Our main control variables include the average of yearly temperature, which is calculated by averaging the daily mean temperatures in the province, and the total annual precipitation. We also control for the province-by-month fixed-effects, P_{pm} , and year-month fixed-effects M_{mt} . In addition, we include the province-specific time trend, T_p , which allows for province-specific time trends in the mortality rate. We adopt the multiway clustering technique of Cameron *et al.* (2011), which allows us to deal with the correlation of error within provinces over time and between provinces within a month simultaneously.

will remain unchanged in the future. As a result, we create the cold and heat waves for the 2020–2100 timeframe using the same 5th and 95th percentiles as the temperature distribution 2000–2018. Panels A and B of Figure 3.8 present the projected number of consecutive days in cold and heat waves under different RCP scenarios. In this graph, a cold (heat) wave is defined as at least 3 consecutive days with daily mean temperature at or below the 5th percentiles (at or above the 95th percentile) of the temperature distribution of specific province. Since the average temperature is projected to decrease in the coming year, the number of days in cold waves decreases quickly and is close to 0 in years 2050s. On the other hand, the number of days in heat waves increases significantly and reaches maximum figures in around 2060. The number of heat waves is largest for the RCP6.0 scenario and smallest for the RCP2.6 scenario.

To anticipate the number of fatalities per 100,000 people caused by cold and heat waves in the next years, we multiplied the predicted number of days in cold and heat waves by the estimated influence of cold and heat waves on mortality rate (0.18 and 0.14, respectively, as shown in Panel B of Figure 3.7). For the projection, we use the effect estimates of cold and heat waves on the mortality rate rather than the log of the mortality rate. The mortality rate is a more accurate means of estimating the number of people who will die as a result of future temperature extremes. Since we utilize the constant effect estimates of cold or heat waves on mortality, the forms of the number of fatalities caused by cold and heat waves (shown in Panels C and D) are quite similar to the morphologies of cold and heat waves. Heat-related deaths are expected to rise in the future, reaching a peak around 2060. These findings raise severe concerns regarding the health effects of future heat in Viet Nam.

4. Main conclusions and policy implications

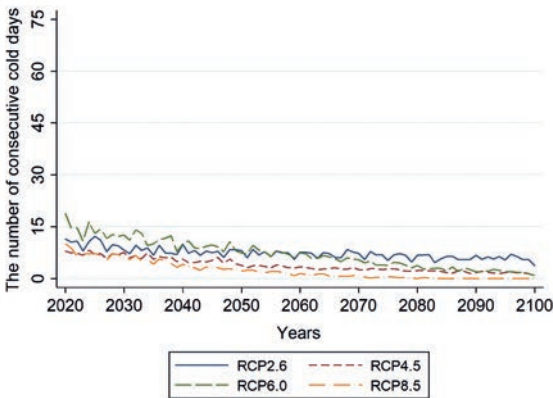
Understanding the effect of weather extremes on health has received great attention from scholars and practitioners. This chapter provides new insight into climate change's impact on infectious disease and mortality in Viet Nam. The diversity of climate in non-identical regions in Viet Nam generates different effects for climatic factors on communicable disease. We found that temperature and wind-speed affect infectious diseases — vector borne, airborne, and waterborne — for all

regions. The effects vary across the regions. A stronger effect is found for vector-borne disease than others.

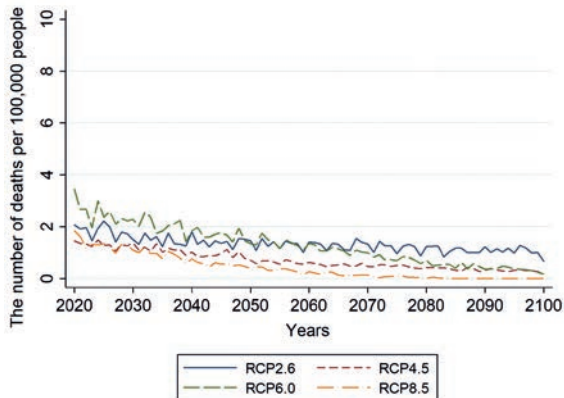
We find evidence for heterogeneous effects across different climatic regions and the role of health-care expenditures. A colder region will be more impacted by hot temperatures than cold temperatures. In contrast, a hot region will be more sensitive to cold temperatures than hot temperatures. There will be direct economic costs through expenditures for controlling and treating disease. Our analysis also highlights the indirect cost of disease impact caused by global climate warming. In our report, the indirect economic costs of infectious disease is estimated through

[Figure 3.8]
The projected number of consecutive days in cold and heat waves and the number of deaths under different Representative Concentration Pathway scenarios

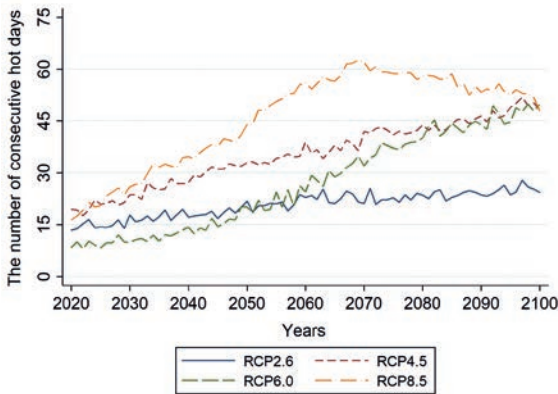
Panel A. The projected number of consecutive days in cold waves



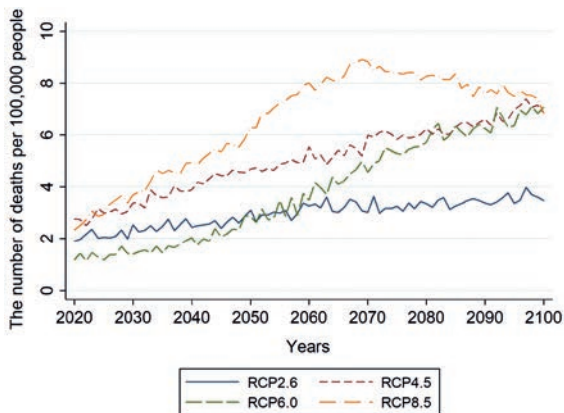
Panel C. The projected number of deaths per 100,000 people due to cold waves



Panel B. The projected number of consecutive days in heat waves



Panel D. The projected number of deaths per 100,000 people due to heat waves



This figure presents the projected number of consecutive days in cold and heat waves under different Representative Concentration Pathway scenarios and the estimated number of deaths due to these cold and heat waves over the 2020–2100 period. A cold (heat) wave is defined as at least 3 consecutive days which have daily mean temperature at or below the 5th percentiles (at or above the 95th percentile) of the temperature distribution of specific province.
Source: Nguyen et al. (2021).

labour productivity loss due to diseases: a 1% increase in disease infections leads to a decrease in the average hourly wage of approximately 0.05%. This is the marginal cost on worker productivity of an incremental change of temperature. Note that this is only part of the economic cost of infectious diseases. The direct costs will be the loss in wages and cost of preventing and treating the diseases. There are also substantial indirect costs, as incidence affects behaviour and investment in physical and human capital. Social costs include reduction of life expectancy and quality of life due to disease related disability. Estimating these are beyond the scope of the current study, but in other contexts these have been estimated to be significant [Goenka and Liu, 2020].

We find robust evidence on the positive effects of cold and heat waves on mortality. A cold wave with at least 5 consecutive cold days increases the monthly mortality rate by around 4.9 percent, while a cold wave with at least 9 consecutive cold days increases the mortality rate by 6.5 percent. The mortality rate in a month increases by 13.5 percent if there is a heat wave of at least 9 consecutive days in that month. The results also suggest that older people, especially those over 80, are mainly affected by the weather extremes. Cold and heat waves have negligible effects for people under 40.

Our findings raise some policy implications for policy makers as follows. First, human adaption and public health strategy play an essential role in the new scenario of infectious disease outbreaks. Since these vulnerabilities to climate change are not the same between regions, the adaption strategy should be based on the local context with respect to demography, socio-economic and geographical

conditions, and the availability of preventive measures. Since extreme events are on the increase, preventive care for older adults is vital in the susceptible regions.

Second, the loss of working capacity would be a catastrophic non-medical cost for a highly vulnerable population with low education attainment, when household income mainly depends on labour-intensive products such as outdoor services and conventional agriculture. There is a double loss in the case of agricultural production in the vulnerable hot spots in Viet Nam. The vicious circle of a lower yield and loss of labour capacity will persist when crop failure leads to under-nutrition and weakens the immune system, thus increasing the risk of infection. Universal health care and insurance is a proven effective measure, along with the epidemic prevention.

Third, although it requires further examination, the health budget has an important role in lessening the sensitivity of infections to disease. Funding for infectious disease control and prevention mainly depends on local financial capacity. In the National Target Program, phase 2016–2020, the Project for communicable and noncommunicable diseases was allocated 1,576 billion VND from the State (58 million EUR), 735.384 billion VND (27 million EUR) from the local budget, and 2,150 billion VND (79 million EUR) from ODA and external assistance. However, poor provinces with low annual public spending on infectious disease control suffer a higher risk of epidemic. Moreover, improving primary healthcare such as commune health stations and district hospital enhancement is considered to be advisable in Viet Nam, in order to reduce overload at national or provincial level. Some national evidence showed that total cost of primary healthcare service is reason-

nable for ordinary people. Furthermore, medical insurance cover in Viet Nam is high (>90%), but discrepancies exist among levels of health care. Thus the government should have support programs for poor provinces and disadvantaged groups to cope with the adverse effects of climate change and weather extremes on health care. Finally, the effect of cold waves as well as heat waves tends to increase when the cold and heat waves last for a longer time. Compared with a cold wave, the effect of a heat wave on the mortality rate is more significant and of a larger magnitude. In the future, if the temperature rises, more people will die because of heat waves. The adverse effects of temperature extremes on health require the government to pay attention to adaptation and coping strategies.

For scholars and researchers, we have the following suggestion. Firstly, located in both a temperate and a tropical zone with a diverse topography, Viet Nam's climate has a considerable amount of sun, a high rate of rainfall, and high humidity that vary significantly between regions. Therefore, more attention should be paid to the spatial heterogeneity impacts, to capture the differences in sensitivity to infection disease and mortality-to-weather conditions across regions. Next, in this study, our main interest has been the impact of temperature on infectious disease, and of heat and cold waves on mortality. However, wind-speed, rainfall and humidity also play important roles. Future research on wind-speed, rainfall and humidity may benefit from better information on climate change impacts on health and disease. Moreover, climate change will induce changes in land use, potential changes in precipitation, flooding, and coastal erosion. These medium-to long-term changes are not covered in the study. All of these contribute to a change in the incidence of infectious diseases, and need to

be monitored to see the patterns of change. Finally, adaptation and coping strategies for climate change should be explored in future studies. Information on these issues will be useful for the government in designing policies to mitigate the effect of climate change. For large-scale datasets used for this study, missing information on specific investments could cause an omitted variable bias. We should look for proxies, find instrument variables or collect other complementary data.

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Chapter 4

Agriculture in Viet Nam under the impact of climate change

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Abstract

Over the past 30 years, strong agricultural growth has changed the socio-economic status of Viet Nam: improving food security, boosting agricultural exports, and creating livelihoods for people. However, the agricultural sector has already been impacted by climate change, and projections for the next few decades indicate that the climate warming trends and anthropogenic pressures are likely to be accelerated.

In this chapter, we examine evolution in crop yields in the past decades, and its predicted evolution in the future. The results vary widely between crops, agro-ecological zones and climate scenarios, but most findings concur on the decline of crop yields in the 2030–2050 horizon. On the other hand, the habitat suitability for rice and other major crops will undergo drastic changes. We find that without adaptation, the risks of increasing saline intrusion, and that of permanent inundation due to sea level rise, will significantly reduce (up to 50% by 2050) the land suitable for rice cultivation in the Mekong delta. However, these two main threats to rice cultivation are accentuated by anthropogenic pressures (ground water pumping and sand mining), which require specific policies to be mitigated.

Among the adaptation practices, we highlight practices that mitigate the greenhouse gas emissions from agriculture. In particular, the Alternate Wetting and Drying irrigation of rice fields is a single mitigation practice that can reduce the methane emissions from rice fields in Viet Nam by 40%.

However, to derive adaptation and mitigation measures for the agriculture sector over the coming decades will require assessments against a background of wider environmental, economic and social evolutions.

Tóm tắt

Trong 30 năm qua, tăng trưởng nông nghiệp mạnh mẽ đã làm thay đổi tình trạng kinh tế xã hội của Việt Nam: cải thiện an ninh lương thực, đẩy mạnh xuất khẩu nông sản, tạo sinh kế cho người dân. Tuy nhiên, ngành nông nghiệp đã bị tác động bởi biến đổi khí hậu và các dự báo trong vài thập kỷ tới chỉ ra rằng xu hướng nóng lên của khí hậu và áp lực do con người gây ra sẽ được đẩy nhanh.

Trong chương này, chúng tôi xem xét sự tiến hóa về năng suất cây trồng trong những thập kỷ qua và dự đoán sự tiến hóa trong tương lai. Các kết quả thu được rất khác nhau giữa các loại cây trồng, vùng sinh thái nông nghiệp và các kịch bản khí hậu, nhưng hầu hết đều đồng tình về sự suy giảm năng suất cây trồng trong giai đoạn tương lai 2030-2050. Mặt khác, sự thích hợp về môi trường sống của lúa và các cây trồng khác sẽ có những thay đổi mạnh mẽ. Chúng tôi nhận thấy rằng nếu không có sự thích ứng, nguy cơ gia tăng xâm nhập mặn và ngập lụt dai dẳng do nước biển dâng sẽ giảm đáng kể (lên đến 50% vào năm 2050) diện tích đất thích hợp trồng lúa ở Đồng bằng sông Cửu Long. Tuy nhiên, hai mối đe dọa chính

đối với canh tác lúa được nhấn mạnh bởi áp lực con người (bơm nước ngầm và khai thác cát), đòi hỏi các chính sách hiệu quả để được giảm thiểu.

Trong số các thực hành thích ứng, chúng tôi nêu bật các thực hành giúp giảm nhẹ phát thải khí nhà kính từ nông nghiệp. Đặc biệt, việc tưới nước và làm khô xen kẽ trên ruộng lúa là một phương pháp giảm thiểu duy nhất có thể giảm 40% lượng khí mê-tan phát thải từ ruộng lúa ở Việt Nam.

Tuy nhiên, để đưa ra các biện pháp thích ứng và giảm thiểu cho ngành nông nghiệp trong những thập kỷ tới sẽ đòi hỏi những đánh giá dựa trên nền tảng của những tiến triển về môi trường, kinh tế và xã hội rộng lớn hơn.

Résumé

Au cours des 30 dernières années, la forte croissance agricole a changé le statut socio-économique du Viet Nam : amélioration de la sécurité alimentaire, augmentation des exportations agricoles et création de moyens de subsistance pour les populations. Cependant, le secteur agricole a déjà été touché par le changement climatique, et les projections pour les prochaines décennies indiquent que les tendances au réchauffement climatique et les pressions anthropiques sont susceptibles de s'accélérer.

Dans ce chapitre, nous examinons l'évolution des rendements des cultures au cours des dernières décennies et l'évolution prévue dans le futur. Les résultats varient considérablement entre les cultures, les zones agro-écologiques et les scénarios climatiques, mais la plupart des résultats concordent sur la baisse des rendements des cultures à l'horizon 2030–2050. D'un autre côté, les terres adaptées à la culture du riz et celles des autres cultures subiront des changements drastiques. Nous constatons que sans adaptation, les risques d'augmentation des intrusions salines, et celui d'inondations permanentes dues à l'élévation du niveau de la mer réduiront considérablement (jusqu'à 50% d'ici 2050) les terres propices à la riziculture dans le delta du Mékong. Cependant, ces deux principales menaces pesant sur la riziculture sont accentuées par les pressions anthropiques (pompage des nappes phréatiques et extraction de sable) dont la réduction nécessitera des politiques spécifiques.

Parmi les pratiques d'adaptation, nous soulignons les pratiques qui atténuent les émissions de gaz à effet de serre provenant de l'agriculture. En particulier, l'irrigation alternée des rizières est une pratique d'atténuation unique qui permet de réduire de 40% les émissions de méthane des rizières au Viet Nam.

Cependant, pour dériver des mesures d'adaptation et d'atténuation pour le secteur agricole au cours des prochaines décennies, il faudra des évaluations dans un contexte d'évolutions environnementales, économiques et sociales plus larges.

1. Viet Nam agriculture Past and present

1.1 Introduction

The agriculture sector plays a crucial role in Viet Nam's economy and society. In 2020, agriculture, forestry and fishing accounted for 14.85% of the country's GDP. The agriculture sector accounted for 33.06% of total employment in Viet Nam, with approximately 17.72 million people employed [Viet Nam General Statistics Office (GSO), 2021].

Viet Nam covers a total area of 331,698 km² and stretches over 15 latitudes (from 8° 35' N to 23°22' N), with a population of over 97.5 million [GSO, 2021]. The climate is diverse from north to south, divided into three distinct zones, including a subtropical humid climate in the North, a tropical monsoon climate in Central and South-Central regions, and tropical savannah in the Central and Southern regions. The north has four seasons, the south has a rainy season and a dry season. Annual rainfall ranges from 1,200 mm to 3,000 mm. The country is endowed with terrain and climate favourable to agriculture, including rice, coffee, rubber, tea, pepper, soybeans, cashews, sugar cane, peanut, banana, and many other agricultural products.

Viet Nam is divided into eight agro-ecological regions, according to climate and topography: the North West, the North East, the Red River Delta, the North Central Coast, the South Central Coast, the Central Highlands and the South East and the Mekong River Delta [Figure 4.1].

Agricultural production is specialized according to the characteristics of agro-ecological regions. While rice production is concentrated in two delta regions (Red River Delta and Mekong River Delta), the majority of cash crops are produced in the Central Highlands and the Southeast. The Northeast and Northwest are mountainous areas, where agricultural production mainly serves the needs of households, except in areas with favorable conditions for the development of industrial crops such as tea and rubber. Only about 15% of the land in the north is arable, concentrated in the lowland areas of the Red River Delta. In the centre, agriculture is distributed along the coast. Agriculture in the southern region is dominated by the Mekong Delta, one of the great rice-producing regions of the world.

Rice, the main staple of the Vietnamese diet, occupies 94% of arable land, is cultivated in all regions, and is the top crop in terms of planted area in 5 of the regions. The Mekong River Delta and the Red River Delta represent 54.47% and 24.80% of the national rice-planted area. In 2020, rice production amounted to approximately 42.7 million tonnes, making Viet Nam the 5th world rice producing country and 2nd rice exporting country [GSO, 2021].

The other crops with the largest planted areas vary among regions. In the Northern Midlands and Mountains, maize, fruit trees and perennial industrial plants dominate. In the North Central and South central coast regions, maize and cassava are respectively the second crop after paddy. The Highlands region is stand out for the prevailing perennial industrial plants (coffee, tea, etc.), far above the area planted with paddy, maize and cassava. In the South East region, perennial industrial plants (rubber, pepper, etc.) and fruit trees dominate. Among perennial industrial crops,

[Figure 4.1]
Viet Nam main agro-ecological zones



source: IMHEN

coffee had the highest production, amounting in 2020 to over 1.74 million tonnes, making Viet Nam one of the leading coffee producing and exporting countries worldwide [Statista Research department, 2021].

1.2 Past evolution of crop yield and crop planted area in Viet Nam

Climate change impacts agricultural production in two components: crop area and crop yield. Crop area can be reduced (or extended) following changes in habitat suitability under climate effects; whereas crop yield (or crop productivity) is affected by changes

in seasonal patterns of temperature, precipitation, and by adverse phenomena such as drought, inundation, saline intrusion, cold and hot spells, etc. However, factors other than climate include socio-economic and political factors contributing to changes of crop area, and technological advances in crop management contributing to changes in crop yield. For these reasons, studies using past survey data to relate changes in a single climate indicator (such as temperature) to changes in crop production can be severely biased.

As stated above, yield — the mass of harvested crop product in a specific area — is influenced by several factors. These factors are grouped into three basic categories known as techno-

logical (agricultural practices, managerial decisions, etc.), environmental (climatic condition, soil fertility, topography, water quality, etc.), and biological (seed varieties, diseases, insects, pests, etc.). It is worth noting that: a) the definition of 'crop yield' given by the FAO is 'harvested production per unit of harvested area for crop products'; and b) in most of cases, yield data are not measured, but obtained by dividing production data by data on harvested or planted area.

On a global scale, the yields of major crop types have had an increasing trend in the last decades. While yield-increasing trends have remained linear for some crops and countries, a yield plateau is evident in several cases. For example, yields are plateauing in some of the world's most important cereal-producing countries, such as wheat in Europe or rice in Korea and China [Van Ittersum and Cassman, 2013]. One hypothesis is that the yield stabilizes when it reaches the potential yield, which represents a biophysical ceiling on the attainable yield at a given location, or at a regional and national level [Tran *et al.*, 1997]. Yield potential is defined as the yield an adapted crop cultivar can achieve when crop management eliminates all limitations to crop growth and yield from nutrient deficiencies, water deficit or surplus, salinity, weeds, insect pests and pathogens.

Until the potential yield of a specific crop in a given environment is reached, the crop yield could have a steadily increasing trend owing to technological improvements, despite annual fluctuations due to climate effects. Beyond the stage where potential yield has been reached, variations in rainfall, temperature, and extreme weather events are the major causes of variations in crop yield. This is the case of agricultural production in many regions in the world, in

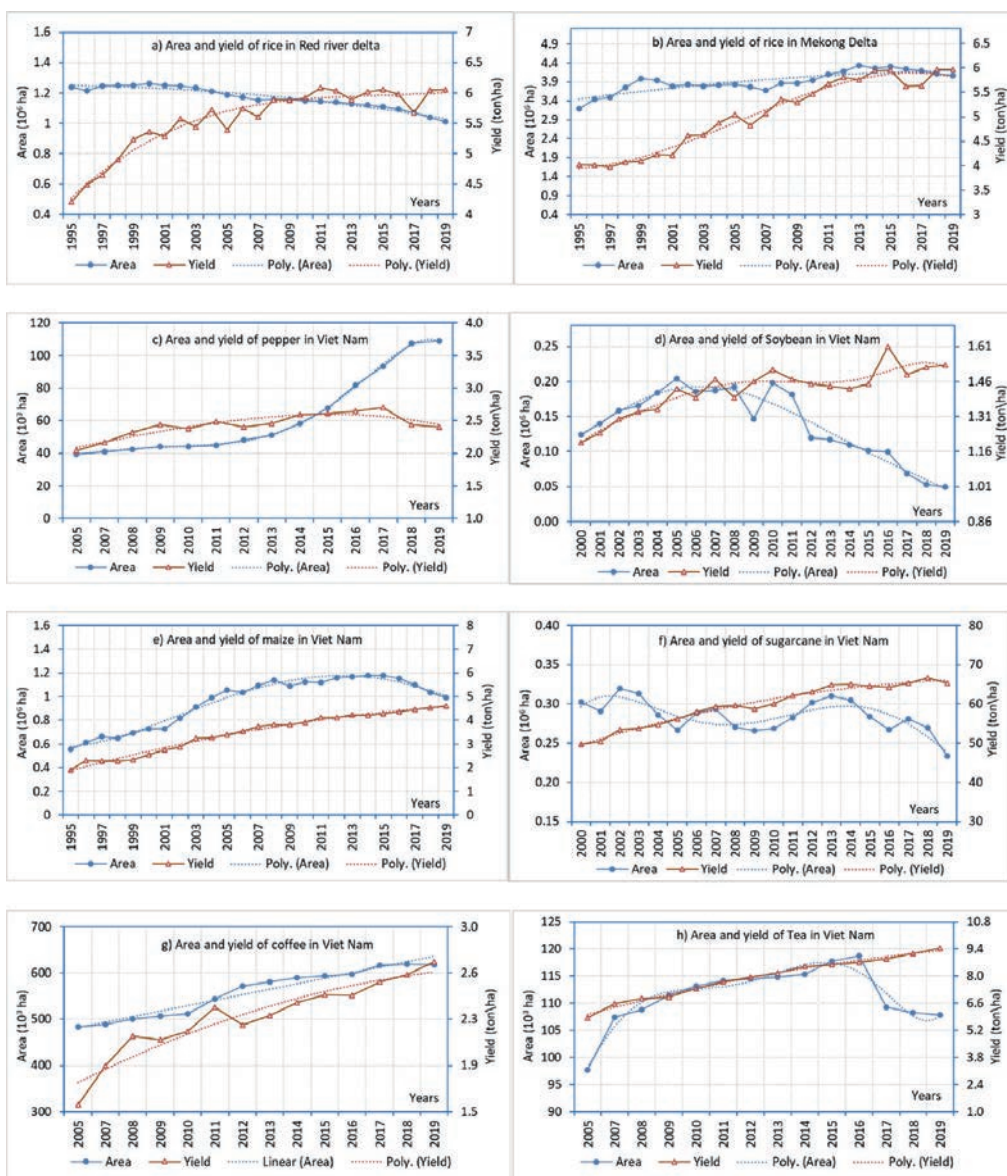
America or in Europe for example [Shaubberger *et al.*, 2018]. In addition, in the long run, intensive agricultural production characterized by the overuse of fertilizers and chemicals can lead to a decrease in crop productivity due to a decline in soil health and environmental damage, in the end making the land unsuitable for crop cultivation. In Viet Nam, the pressure to increase crop production has, since the early 1990s, resulted in both the expansion of land area dedicated to agriculture and the improvement of crop yields. The latter has been through intensification of crop management based on practices such as irrigation, use of large quantities of inputs like inorganic fertilizers and synthetic chemicals for pest and weed control, and increase in the number of annual crops per year on the same field. A wide range of technological innovations in agriculture, including genetic improvement of varieties, fertilizer technology, pesticides, farm machinery, agronomic and management practices, have been implemented to enhance crop productivity

Figure 4.2 shows the evolution of annual planted area and yield for paddy rice in the Red River Delta and Mekong River Delta, and for some major crop types (maize, soybean, sugar cane, pepper, coffee and tea) in Viet Nam. The graphs are based on statistical data provided by General Statistics Office since 1995, 2000 or 2005, depending on the crop type.

In Figure 4.2 a,b,c and d, the yield of paddy rice, pepper and soybean show an increasing trend from 1995, followed by a plateau or decrease in the yield, observed after different periods: 2009 for rice in the Red River Delta, 2014 for rice in the Mekong River Delta, 2015 for pepper, 2009 for soybean. For these crops, it could be interpreted that the potential yield has been reached, and that annual fluctua-

[Figure 4.2]

Evolution of annual planted area (blue) and yield (red) of major crop types in Viet Nam



Evolution of annual planted area (blue) and yield (red) for rice crop a) rice in Red River delta, b) rice in Mekong River delta, and for the main crop types in Viet Nam: c) pepper, d) soy bean e) maize, f) sugarcane, g) coffee, h) tea.

tions in the yields could be attributable to climate effects, as for example in 2016–2017, after the El Niño year.

On the other hand, the yields of maize, sugar cane, tea, and coffee show a continuous increase over the period [Figure 4.2.e,f,g,h]. A first interpretation is that management practices – such as irrigation, use of high-yield varieties, and use of large quantities of inputs – are still being optimised. For these crop types, at the country scale, the impacts of cultural practices appear to dominate any climate change effects up to now.

For crop planted area, the past evolution reflects decisions by farmers and communities, following national policies – through land use planning [e.g. Government of Viet Nam, 2019] – and also individual adaptation practices, to cope with variations in product demand in both the domestic market and international trade. It is important to note that the driver of change in crop area is not only crop production, but also overall crop grower revenue, which includes income after expenses from production and is calculated by subtracting farm expenses from gross farm income. For the production output per ha, the quality of crop product and its market value are therefore very important factors. The increase in crop planted area observed for pepper and coffee may denote that farmer revenue is still increasing; whereas the decrease of rice-planted area in the Red River Delta may indicate market competition with other crop types and other land use (e.g. urban expansion: the Red River Delta has a population density of 1,064 people per km², compared to 423 people per km² in the Mekong River Delta). Similarly, the abrupt decrease in tea-planted area in 2017 may denote that less farmers are willing to invest in tea plantation due to a regular decline in prices, fol-

lowing over-supply on the world market [Doan Ba Thoai *et al.*, 2019]. In 2019, the Food and Agriculture Organisation (FAO) of the United Nations estimated a surplus of about 75,000 tonnes of tea, and this figure is expected to increase to 128,000 tonnes in 2020. Likewise, planted area of maize, soybean, and sugar cane show a decreasing trend after an initial increasing phase.

However, farmers' decisions to change the crop type or land-use type are driven not only by the increase in income, but also by the need to adapt to climate change effects, when habitat suitability for a given crop is reduced by flood, drought, saline intrusion, or hot and cold spells, for example. Hence, the conversion or rotation of rice area into aquaculture in the Mekong Delta coastal provinces can be explained by the higher increasing rate of gross product per ha of aquaculture (mean annual increasing rate from 2012 of 7.2%, as compared to the mean rate of cultivated land of 3.7% (data from GSO 2021), but also by the need to adapt to drought and increased saline intrusions (see Chapter 9 and Chapter 10).

The changes in crop grown area therefore involve a continuous process of adaptation to weather, technology, economic and other influences, and result from a combination of autonomous adaptation (by farmers) alongside planned adaptation, as a consequence of government policy.

For the projections of future crop area, simulations can be made to determine the land area that will become unsuitable for crop growth [e.g. in Dang *et al.*, 2020], whereas the evolution of socio-economic and political factors is more difficult to predict. Over the coming decades, changes in diets and consumer preferences (e.g. falling demand for rice), market

liberalization, and trade (which will expose Viet Nam to higher quality product competition) will all have important effects on the demand for and the supply of agricultural products. The impacts of climate change on crop production have therefore to be assessed against a background of wider economic and social evolutions

1.3 Regional Climate stressors

The effects of climate on agricultural production can be separated into two types: 1] weather shocks, defined as extreme events such as extreme temperatures, floods, droughts and typhoons (or hydro-meteorological disasters), and 2] the long-term effects of changing temperature and precipitation.

Viet Nam is among the countries most vulnerable to climate-related events and climate change. Since the country lies in several eco-climatic regions, the risks are not the same from North to South.

According to the bulletins of Climate forecast and agro-meteorology for Viet Nam published by IMHEN (Viet Nam Institute of Meteorology, Hydrology and Climate Change), the impact of hydro-meteorological disasters on agro-ecological regions in recent years can be summarised as follows (see also Chapter 1 for temperature and precipitation trends over the past decades):

1] The Northeast and Northwest: in this region, the main crop type is rice, with 665.5 thousand ha (T ha), followed by fruit trees (264.7 T ha), and perennial industrial plants (149.8 T ha). Although the average annual temperature has been observed to increase, severe cold and damaging cold events have tended to be longer and more severe. For example, the cold spells

in January or February 2008, 2010, 2019, 2021 caused severe losses of transplanted rice, fruit and industrial plants.

2] The Red River Delta: the main crop in the delta is rice (983 T ha), and the second is perennial fruit trees (101 T ha). Like other deltas in the tropical belt, this area often faces floods, landslides, coastal erosion, water shortage, and saltwater intrusion in the dry season. Extreme weather patterns occur more and more and are becoming more complicated and difficult to predict. Rainfall is greatly reduced in the dry season. The annual rainy season tends to start late and to end early, resulting in a decrease in rainfall and runoff. In the coastal area of the Red River Delta in particular, thousands of hectares of rice in the spring crop suffer from drought or from reduction in irrigation water every year, due to reduced rainfall.

3] The North Central Region and South Central Coast: the main crop type is rice (1157 T ha), followed by maize, cassava, fruit trees and industrial plants (each around 100 T ha). Increasing temperature is one of the clear manifestations of climate change in these regions. The average annual rainfall has not changed much, increasing slightly, but with uneven distribution. Heavy rain is concentrated in a short time, and so often causes local flooding and landslides, and drought has increased during the dry season. Although the temperature has increased in winter, severe cold spells have also increased and last longer. The area of rice crops that lacks water at the end of the Summer-Autumn crop is increasing. Over the past 5 years, many reservoirs have been exhausted, and the downstream areas of the rivers are increasingly affected by saltwater intrusion. Floods also occur more frequently, causing many areas of annual crops to be flooded and to have to be replanted, or their yield to be si-

gnificantly reduced. In recent years, farmers in many places have had to convert their rice land to dry crops or rotate crops and intercrop short-term crops, and the rice crop calendar has been readjusted to avoid late drought and early flooding.

4] The Central Highlands: the main crop in the region is perennial industrial plants (1047.7 T ha), rice accounts for 246.8 T ha, followed by maize and cassava, each with about 200 T ha. This region is characterized by extreme climate events and natural disasters, such as **floods and flash floods in the rainy season; drought and extreme heat in the dry season**. Thunderstorms, tornados and hail occur more and more irregularly. The temperature has increased, annual rainfall has decreased and is distributed less evenly, and the dry season lasts longer. This, together with the reduction of forest area, has severely reduced water resources, causing increased drought, but also causes more floods in the rainy season. Hot weather and drought greatly affect the yield and quality of coffee trees, pepper and fruit trees. The increasing temperature trend also makes pests and diseases develop faster. Farmer adaptation consists in increasing irrigation, and pest and pathogen treatment; the latter may have a detrimental impact on the quality required for exported products.

5] The Southeast Region: the main crop in the region is perennial industrial plants (794.5 T ha), with rice and fruit trees accounting for 260.7 T ha, and 127.4 T ha respectively. The region has a relatively mild climate, with fewer natural disasters than the rest of the country. However, in recent years, **rainfall has decreased in the dry season and increased in the rainy season**, and many intense rains cause flash floods, landslides, and soil erosion.

6] The Mekong River Delta: this region is considered to be one of the three deltas in the world **most vulnerable to climate change and sea level rise** (cf. **Part 3** of this report). The region's main crop by far is rice (3963.7 T ha), followed by fruit trees (377.7 Tha). The risk of drought and saltwater intrusion often occurs during the Winter-Spring rice crops, particularly in El Niño years. Severe drought years such as 1977–1978, 1997–1998, 2015–2016 and 2019–2020 are all related to El Niño events, which greatly affect production and life in the Mekong Delta. Coastal provinces are strongly affected by saline intrusion from the second half of December to the end of April. Recently, saline intrusions tend to occur earlier, with increased salinity concentrations and duration, and are more invasive in the fields (cf. **Chapter 9**). In recent years, farmers in many provinces have had to readjust the crop calendar, to rotate rice with short-term crops, or to **convert their rice land to aquaculture**. It is worth noting that the rate of increase in aquaculture area in the Mekong Delta experienced an important surge after El Niño 2015–2016 (mean annual increase of 18.3 T ha in 2016–2019, as compared to 4.25 T ha in 2008–2015).

In summary, diverse impacts of hydro-meteorological disasters on agricultural production have already been observed in agro-ecological regions of Viet Nam. Over the last decades, autonomous adaptation by farmers, and policy interventions to avoid or to attenuate such impacts, have also been observed.

Regarding the effects of long-term changes in climate indicators on crop productivity, research has been conducted on the subject; its outcomes will be summarized in the following section.

1.4 Monitoring agriculture with satellite data

To assess the impacts of climate change on crop production in the past and present in Viet Nam, the approach usually adopted has been to use statistical data on crop production, crop yield and crop planted area, provided by General Statistics Office.

However, understanding the impact of climate change on agriculture requires the dynamic monitoring of crops planted and harvested area, monitoring of crop growth and yield indicators, and determining the crop calendar at a given site. In particular, in crop yield models, the effects of temperature, precipitation, saline intrusion etc. on crop development depend strongly on the crop growth stage. However, because of farmer adaptation to climate change, the crop calendar can vary substantially from the standard ones. For example in the Mekong Delta, the sowing period for the Summer-Autumn crop ranges from March 1 to May 30. But in recent years, sowing dates as late as the second half of June have been observed in many places in the coastal provinces of Ben Tre, Tra Vinh, Kien Giang, Soc Trang, Bac Lieu, Ca Mau, in order to avoid saline intrusions. Similarly, brief episodes of unusually high or low temperature can affect grain yield, especially if they occur at the reproductive phenological stage, which is most sensitive to temperature, but adaptations in management can avoid or attenuate some of the negative impacts.

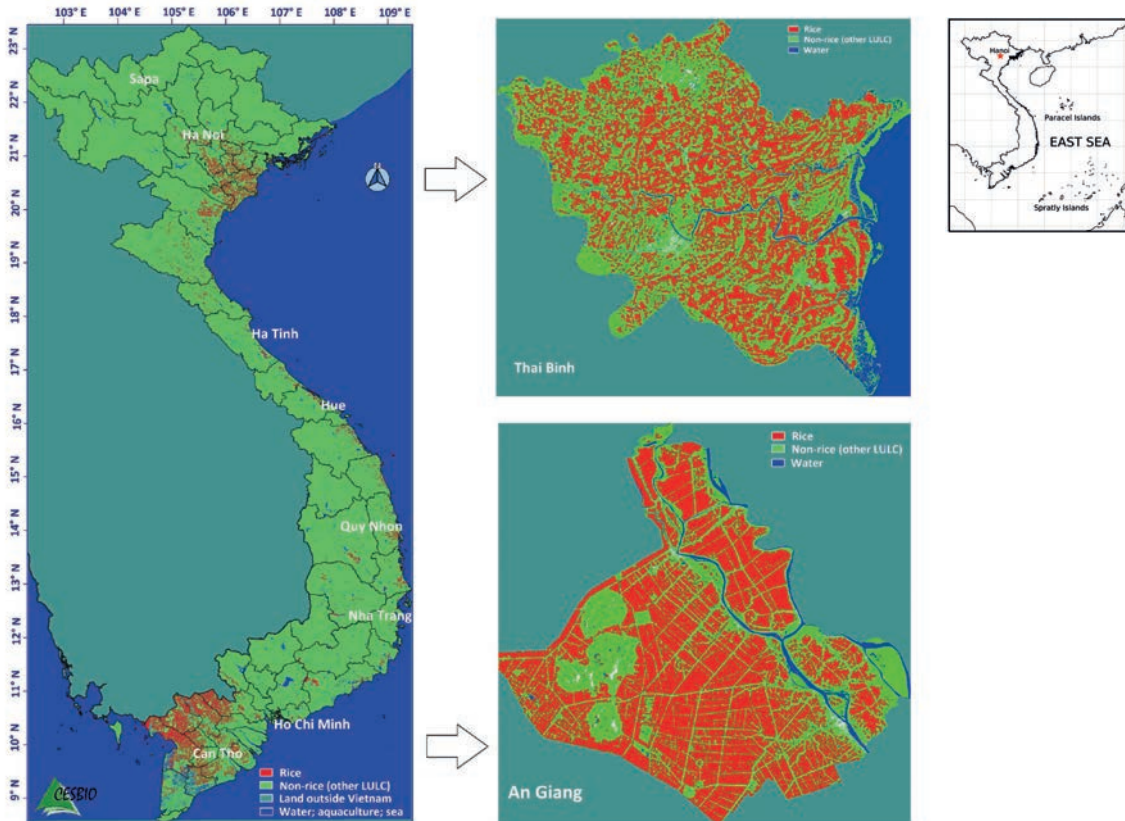
All these monitoring requirements are well suited to the capacities of Earth Observation techniques. In addition, multi-annual observations by satellites can provide information on adaptation measures adopted by farmers, or decided by policy regulations, such as changes

in crop calendar, cropping density (number of crops per year), changes in crop types or conversion to other land use, for example.

An observation system providing a synoptic view (e.g. for the entire Mekong Delta), combined with 10 m–20 m pixel size for observation at field level and a weekly repeated frequency, would be optimal. In addition, for Viet Nam as well as for other tropical countries, only radar systems can provide systematic observations, since the cloud cover is a limitation on the use of optical data. With the launch of Sentinel-1 (1A in 2014 and 1B in 2016), radar data from the ESA Copernicus programme are now available globally, at a 12-day interval for 1 satellite, and a 6-day interval for 2 satellites, at a pixel size of 10 m and swath width of 250 km. The data, accessible from the Internet and free of charge, constitute the most suitable Earth Observation data for agriculture monitoring in Viet Nam. In the future, the Sentinel-1 series (1C, 1D, etc.) is already planned, to ensure data continuity well into the middle of the century and beyond. Currently, Sentinel-1 data are used for rice monitoring in Viet Nam in different research and development projects (e.g. the GeoRice and the VietSCO projects). The focus on using Sentinel-1 data for rice monitoring has stemmed from past research results demonstrating the adequation of the specific Synthetic Aperture Radar data at C-band frequency to rice monitoring [Le Toan *et al.*, 1997; Bouvet *et al.*, 2009, 2011; Lam Dao *et al.*, 2009, Hoang *et al.*, 2020; Phan *et al.*, 2021].

Using Sentinel-1 data, it is possible to generate maps at 10 m resolution showing the presence and the growth stage of rice every 12 days for Viet Nam. At the end of a rice crop season, maps of harvested rice area for that season are generated. Figure 4.3 shows the Winter-Spring 2019–2020 rice map of Viet

[Figure 4.3]
Distribution of rice crop using remote sensing



Left: Map of Winter Spring rice season in 2020 in Viet Nam. Right: details of rice distribution in Thai Binh, and An Giang. The maps are generated using time series from Sentinel-1 data, from the European Copernicus programme. Map pixel size at 10 m, indicating rice in red, water surface in blue, other land use land cover types in green.

Nam, with details illustrated for the provinces of Thai Binh, and An Giang. These maps provide temporal and spatial rice crop distribution that can complement the *in-situ* survey data for agriculture statistics. The other assets of remote sensing-derived maps are linked to the ability to quantify and localize annual changes in rice area and rice crop calendar, and changes from rice to other land use, for example aquaculture.

Figure 4.4 shows an example of the loss in the rice-harvested area in 2020 in the province of Ben Tre, as compared to 2019, for the dry season Winter-Spring crop. In most cases, rice was sown but the plant development stopped. In these coastal regions, the harvest losses are often caused by saline water intrusions and drought effects. To investigate these possible causes, a map of saline intrusions, and a graph of the drought index for the year 2020

[Figure 4.4]

Observation of the reduction in rice area in relation with drought and salinity intrusion

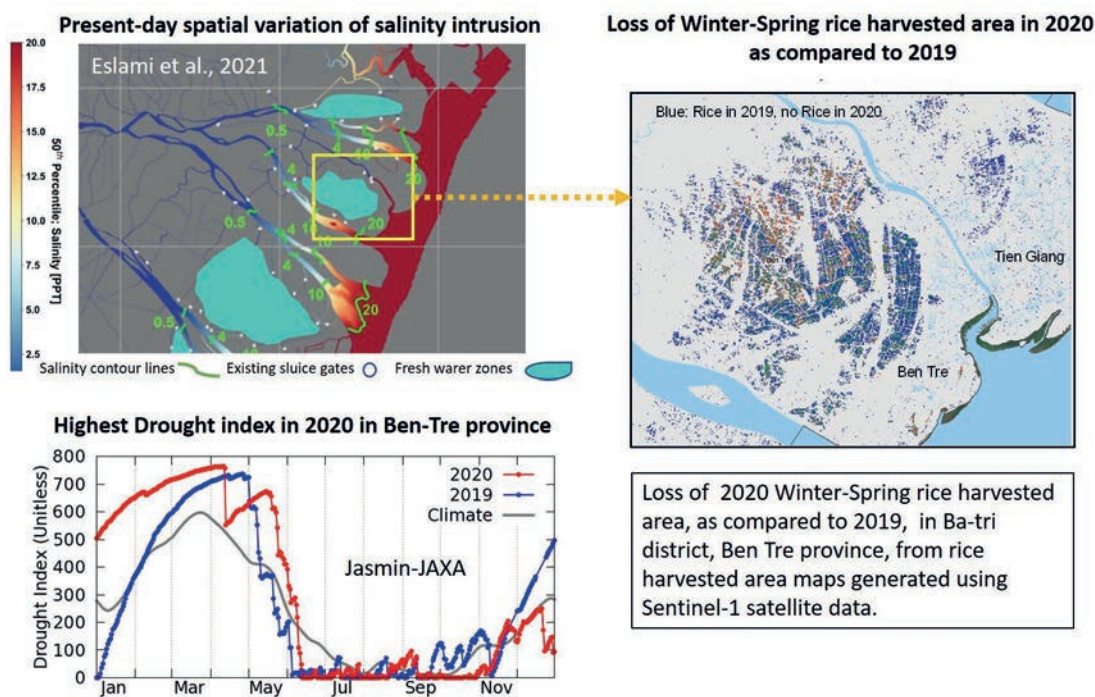


Figure 4.4 showing the reduction of Winter-Spring rice in the province of Ben Tre in 2020, as compared to 2019. Right panel: Change in rice harvested area from a comparison of the Winter-Spring rice map in 2019 and 2020. The blue color denotes rice-harvested area in 2019, and not harvested in 2020. Top left image: subset of the map indicating saline intrusions during a normal dry season [Eslami *et al.*, 2021], where salinity values in surface water (river, canals) are indicated, as well as the area of fresh water (in green color) protected from saline intrusion by sluice gates. Bottom left image: variation of drought index for Ben Tre, in 2020 (red), 2019 (blue) and for climatology (mean value over 2009–2014, in grey) from the Jasmin program developed by JAXA (the Japanese Space Agency).

https://suzaku.eorc.jaxa.jp/cgi-bin/gcomw/jasmine/jasmine_tsg.cgi

in the province of Ben Tre are also shown in Figure 4.6. In the saline intrusion map for a normal dry season [Eslami *et al.*, 2021], high salinity values are modelled in surface waters (river, canals) in Ben Tre, but rice could grow in the area of fresh water protected by sluice gates. In the graph of drought index for Ben Tre, the high drought index in January–April 2020 indicates that Ben Tre was hit by a more severe drought, as compared to 2019 and to

mean values over 2009–2014. The loss of rice-harvested area in Ben Tre could therefore be attributed to the drought effect. Outside the fresh water area, it is possible that the harvest loss was also caused by saline intrusion.

2. Predicted agriculture productivity under climate stressors

2.1 Meta-analysis of the impacts of climate change on crop yield

Over the forthcoming decades, it is expected that the gaps to potential yield will be narrowed down for most crop types in Viet Nam as a result of technological progress. For rice, which is by far the main crop in Viet Nam, the yield appears to have reached a plateau (of about 6 ton/ha), at least for the last 5–10 years at the scale of the Red River Delta and the Mekong River Delta (see Section 1.2).

Climate changes will in this case become the major causes of annual yield fluctuations, and possibly of the long term decreasing trend. Therefore, the projected trends in climate stressors will play a critical role in determining XXIst century agricultural production in Viet Nam. Given the complexity of the impacts on the range of crop types and the territorial diversity of the country, the magnitude of the impact that climate change will have on agricultural production cannot be determined unequivocally, and a large degree of uncertainty regarding these estimates is foreseen.

Research aimed at predicting the impact of climate change on agriculture production in Viet Nam is fairly recent (since 2010) and still rather limited. The main findings can be summarised as follows.

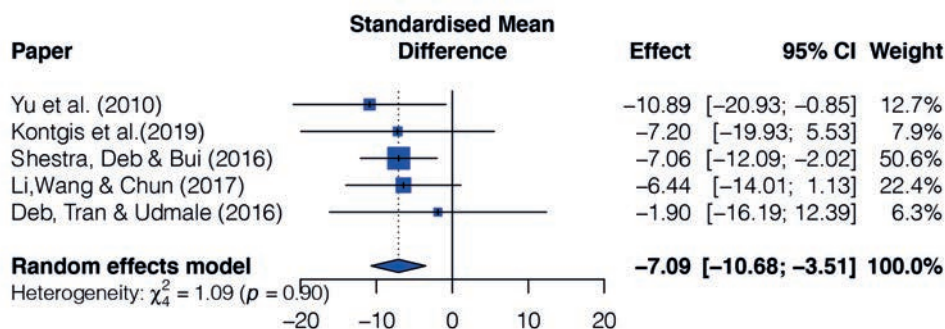
In general, most authors use crop models relating crop yield to climate indicators to simu-

late future yields under different climatic scenarios. The prediction results depend on the crop model used, the type of climate stressors (temperature, precipitation and others) considered, and the various climatic scenarios. Most studies estimate changes in crop yield by 2030 and 2050, for RCP4.5 and RCP8.5 climate scenarios, with respect to a baseline which is either the recent period's reported yields, or the potential yield.

Little research on Viet Nam has been undertaken to predict productivity of all crop types, and considering all climate stressors. For example, Gebretsadik *et al.* (2012) considered only water deficit as the main driver of productivity of tea, coffee, rubber, sugar cane, and other perennial crops and annual crops. Using a generic water deficit model to assess the impact of changing daily precipitation patterns on crop yields, the simulations for mid-century indicated a decrease in production for all of the crops, with yield reduction compared to potential yield ranging from -1.4% for annual crop, to -4% for perennial crops (tea, coffee, etc.).

However, most of the literature focuses on the impact of climate change on rice production, because of its importance in Viet Nam's agricultural sector. All authors agreed that **climate change by 2050 will cause a significant reduction in rice yield**, but the projections vary vastly depending on the rice crop season and the geographical area, indicating the importance of localized studies [Li *et al.*, 2007; Yu *et al.* 2010; Chun *et al.*, 2016]. Projections for the effects of temperature and precipitation at the province scale thus range from a small decrease or even positive impacts, to decreases greater than 30% [Deb *et al.* 2016, Shrestha *et al.*, 2016; Jiang *et al.*, 2019].

[Figure 4.5]

Meta analysis of past results on the impact of increasing temperature on rice yield

Meta analysis of the results reported in 5 selected published papers, on the impact of an increase of one degree of temperature on rice yield in percentage points. The weight given to each study result is calculated according to the 95% confident intervals of the estimates.

Note: Effect = impact on rice yield (in %), SE = Standard Error (in %), SMD = Standard Mean Difference (in %).

The work by Bingxin Yu *et al.* (2010), goes beyond the impacts of changes in rainfall and temperature on crop yields. The authors present a yield function approach that models technological advances and policy interventions to improve rice productivity and mitigate the impact of climate change. Using a multilevel mixed-effects model, the results indicate that rice production is likely to be severely compromised by climate change. However, the study suggests that investment in rural infrastructure – such as irrigation and roads – and human capital can mitigate the negative impacts of climate change. Due to substantial regional variations in impacts and responses, localized policy packages were found to be key for effective mitigation.

Overall, the results obtained in the different studies show the likely adverse impact of climate change on the agricultural production of Viet Nam. The uncertainty and fluctuations in the estimates might be explained by different factors. Part of it can be explained by different crop models which do not take the same type

of climate stressors into account, the different characteristics of the growing season, irrigation status, the geographical heterogeneity in the country, and, overall, the different future climate projections considered by the authors. Considering the uncertainties of the simulated results in the different research papers, a meta-analysis has been conducted to investigate the consistency of climate effects on crop yield across studies.

We performed a meta-analysis (random effects model) of the regression results to derive an average estimate of the change in rice yield, here as a function of temperature change. The input data are therefore the estimated slopes of the regressions and the associated standard deviations in individual studies. Figure 4.5 represents the outcome of a meta-analysis of five of the studies presented above, on the effect of changing temperature on the future rice yield. The effect reported is the impact of an increase of one degree of annual average temperature on rice yield in percentage points. By giving a weight to each of the studies de-

pending on the precision of the estimates, the pooled effect is -7.09%. This means that by increasing the temperature by one degree, rice yields are estimated to decrease by 7.09%.

However an analysis which only considers the effect of mean annual temperature on future rice yield will need to be complemented by analysis of the temporal pattern of temperature (for example Peng *et al.* (2004) found that rice yield decline is caused by increase in nighttime temperature). Also, the combined effects of temperature and precipitation need to be assessed.

Overall, despite the research's diversity of approaches, the review highlights the following:

- ▶ a decline of crop yield in Viet Nam, with yield reduction values of -4% for perennial crops and up to -10% for rice under RCP4.5 and -20% for RCP8.5, for the country as a whole; however, the predictions only considered the effects of long-term climate stressors (temperature and precipitation).
- ▶ substantial regional variation in impacts; the decrease could attain 30% for some provinces under study, for example. This indicates the necessity for localized studies, along with regional and national studies for mitigation measures,
- ▶ the need to consider not only the effect of projected temperature and water availability on crop yield, but also climate extreme events, which will result in the loss of crop production and, in the long term, in the reduction of crop habitat suitability.

2.2 Future projection of rice yield in the Mekong Delta

As stated in Section 1.2, crop yield (or crop productivity) depends not only on tempera-

ture and precipitation, but also on many other factors including soil characteristics, crop varieties, cultivation techniques, etc. In general, the trend in annual variation of crop productivity can be divided into two components: 1] trend productivity (due to changes in scientific and technical progress, such as varieties, fertilizers, farming techniques, etc.), which usually tends to increase over time and is usually approached using a linear function (cf. Figure 4.2); 2] weather productivity (due to changes in the environment, such as temperature, radiation, rainfall, saltwater intrusion, flooding, etc.), which depends on local conditions, and fluctuates from year to year.

In the Mekong River Delta, the mean rice yield for different crop seasons in 2020 is 6.01 tons/ha, but varies from 3.98–4.58 tons/ha (Tra Vinh, Camau provinces) to 6.14-6.56 tons/ha (Vinh Long, Dong Thap, An Giang, Kien Giang, Can-tho, Hau Giang) [GSO, 2020]. The yield also varies between crop seasons: the highest is Winter-Spring, owing to optimal solar radiation, in areas where irrigation water is sufficient, whereas the lowest is in Autumn-Winter, because of insufficient solar radiation and possible flooding effects. For example, the reported yields for 2020 in An Giang are 7.17 tons/ha, 5.83 tons/ha and 4.23 tons/ha; and in Tra Vinh, 3.54 tons/ha, 5.83 tons/ha and 3.78 tons/ha, respectively for the 3 rice seasons. The low yield in Winter-Spring rice in Tra Vinh could be linked to the lack of irrigation water and saline intrusion during the dry season.

For future rice yield prediction, only the weather impacts on productivity have been simulated through numerical models, taking projected local weather conditions into account. Up to now, many models have been used to simulate the growth and development of rice, and thus the final yield, such as:

WOFOST, SUCROS, ORYZA2000, SIMRIW, CERES-Rice, DSSAT, etc. Among these models, ORYZA 2000 has the advantages of being open source, easy to use, designed specifically for rice modelling, and continuously updated for new rice varieties [Bui T.Y. *et al.*, 2018].

This study used ORYZA2000, forced with projected climate data from RCP4.5 and RCP8.5 scenarios to project the 2030 and 2050 rice productivity in the Mekong Delta.

As mentioned in [Chapter 1](#), two downscaling methods, *i.e.* the dynamical and the statistical ones, were used to build future climate change scenarios for Viet Nam, including the Mekong Delta. The first method used the 19 dynamical downscaling experiments, provided by the Viet Nam Institute of Meteorology, Hydrology and Climate Change (IMHEN). The second method is based on the Bias Correction Spatial Disaggregation (BCSD) experiments applied for CMIP5 GCMs. However, for the Mekong Delta, the two methods provided very close projection in temperature up to 2080 but rainfall results are remarkably different (*cf.* [Chapter 7](#)). In this study, we use the projections from the dynamical downscaling experiments, which are also used in the latest national report on climate change and sea level rise scenarios from IMHEN (2021).

The future rice yield of each province in the Mekong Delta is estimated for the period 2020–2050, based on climate projections according to the RCP4.5 and RCP8.5 scenarios. The impacts of climate change are quantified by a comparison between simulated annual rice yields of Mekong Delta provinces for Winter-Spring, Summer-Autumn and Autumn-Winter crops for the period from 2020 to 2050, and the average yield of the last fifteen years

(2005–2020). The simulations have been based on hypotheses of the same cultural practices as present, and made use of an average crop calendar, rice varieties, and same crop management (irrigation, fertilization) for each province.

Using the method described in Bui T. Y. *et al.*, (2018), and extending the validation period from 2016 to 2020, the simulation results show that projected yield reduction varies between rice seasons and across provinces. For RCP4.5, future rice yields for the whole Mekong Delta could decrease by an average across the provinces of 4.10% in the Winter-Spring crop, 6.84% in the Summer-Autumn crop, and 6.71% in the Autumn-Winter crop. Yield reduction would be highest (-11%) in Dong Thap provinces for Winter-Spring crop; and Soc Trang (-13%) and An Giang (-13%) for the Summer-Autumn crop.

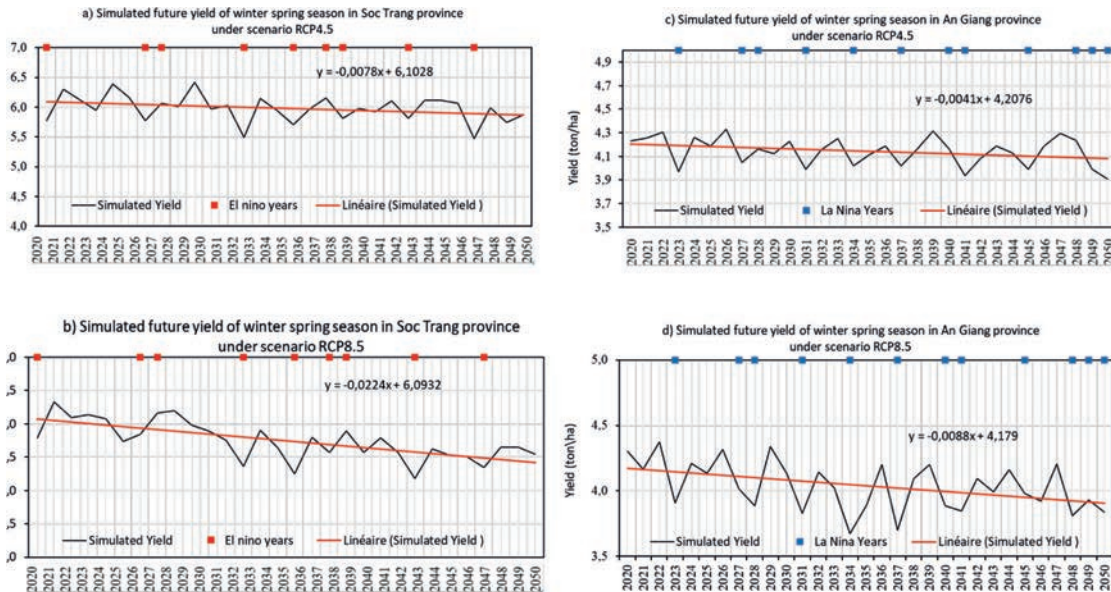
Under RCP8.5 scenario, the average reduction is estimated to be slightly higher, 6.38% in Winter-Spring crop, 9.40% in Summer-Autumn and 9.39% in Autumn-Winter.

It should be noted that in the simulations, **the effects of flooding and saline intrusion are not considered.**

Figure 4.6 illustrates the simulated rice yields of Winter-Spring in Soc Trang province and Autumn-Winter in An Giang province under RCP 4.5 [**Figure 4.6 a,c**] and RCP8.5 scenario [**Figure 6 b,d**]. It can be noted that the 30-year variations can be approached by a linear decreasing trend. By 2050, the average Winter-Spring rice yield is likely to decline to 5.5–6 tons/ha. Similarly, the average rice yield of Autumn-Winter is also likely to drop below 4 tons/ha. It should be noted that the simulated yield follows a decreasing trend from 2020

[Figure 4.6]

2020–2050 Model-based simulated rice yield for 2 selected provinces, under RCP4.5 and RCP8.5 scenarios



Rice yield simulated in the future, period 2020-2050, for winter-spring season, in Soc Trang province (left panels), in autumn-winter in An Giang province (right panels), for RCP4.5 scenario (top panels) and RCP8.5 (bottom panels). Red dots indicate El Niño year, with effects on winter-spring season in Soc Trang and Blue dots, La Niña year, with effects on autumn-winter season in An Giang.

to 2050, which could be approximated by linear trends. Annual yield fluctuates around the trend according to climate data input in the ORYZA 2000 model. During ENSO years, rice yields were generally below the trend line, while in El Niño years, factors such as temperature, evaporation, and sunshine hours are all higher, and rainfall lower than in a normal year during the period from April to May (Winter-Spring crop season). In La Niña years, rainfall for the Autumn-Winter crop is higher, while sunshine hours and temperature are lower than average.

In summary, the simulation results show a long term decreasing trend for rice yields in different provinces of the Mekong Delta, with accentuated inter-annual fluctuations during El Niño and La Niña years. However, the results could be updated by refining the input parameters used in the simulations. The most important improvements could be made by considering the geographical diversity of rice fields in each province, in terms of crop calendar, crop cycle duration, and irrigation practices, as observed by remote sensing satellites. This is the subject of current research work.

3. Projections of the reduction of crop area in the Mekong Delta

In many previously published papers, the focus has been mainly on the impacts of climate change on crop yield. However, for projection in crop production, the change in the number of crops per year and the reduction of the crop area need to be assessed. For this purpose, the methodology used in this study combines two research strands. The first, presented in section 2, is on the crop yield and the second, in this section, treats the projected changes in the area suitable for crop cultivation, which may lead to the reduction of crop-planted area.

Due to the complexity of studying all crop types in different eco-regions of Viet Nam, this study is focused on the rice crop in the Mekong Delta, driven by the importance of rice in Vietnamese economy [Kamil *et al.*, 2020], and also by the vulnerability of the Mekong Delta to climate change effects.

3.1 Projected reduction of rice grown area due to saline water intrusions

During the dry season, coastal areas of the Mekong River Delta face saline intrusions in surface waters. This natural process arises from the competition between the river and ocean forces within a given morphology, but is enhanced by anthropogenic activities in the Delta and sea level rise (see Chapters 7 and 9). Recent research has shown that the main driver of the increase in salt intrusion in the

Mekong Delta observed over the past 20 years is river bed level changes, caused by sediment starvation from upstream dams and excessive sand mining [Eslami *et al.*, 2019].

Soil and water salinisation in the dry season is a problem for crop production in the coastal Mekong Delta [Tuong T.P. *et al.*, 2003; Carew-Reid, 2007]. During low river flow periods, between March and April, saline water intrudes up to 40–50 km inland from estuaries through main river systems. The Ministry of Agriculture and Rural Development [MARD, 2011] reported that, out of 650,000 ha of high-yielding rice grown in the lower delta, about 100,000 ha of rice annually is at high risk of dry-season salinity intrusion [Nhan *et al.*, 2012].

The two most important rice growing seasons in the Mekong Delta are the Winter-Spring and Summer-Autumn seasons that occur before and after the salinity surge, respectively. Salinity levels normally begin to rise by the end of December (early dry season), reach a peak in March or April (late dry season), and fall afterwards. The tail end of the Winter-Spring season is affected by rising salinity. Similarly, for the Summer-Autumn season, farmers wait for rainfall to flush salinity out of the soil and irrigation water canals before planting. Historically, severe saltwater intrusions occurred in 1998, 2010 and 2016, when salinity levels began to rise earlier and peaked with concentration levels higher than normal. Further, some coastal areas have been exposed to consistent saline intrusion, and farmers have transitioned from rice to other more salt-tolerant crops or aquaculture.

Salinity increases the osmotic pressure of the soil water solution and inhibits plant water uptake, impacting plant development and leading to reduced crop yield [Paik *et al.*,

2020]. Most of the rice varieties grown today are damaged when water salinity reaches 4‰ or more. For salinity levels above 2‰, rice yields were found to be reduced by 20–45% when salt stress occurred during the tillering stage, and by 10–40% if salt stress occurred during the heading stage [Paik *et al.*, 2020]. In addition to damaging rice crop in the field, the time required to leach salt out of the field increases with higher salinity values, causing delay and reductions in rice yield in the next cropping season. However, the salinity referred to in the literature is often soil or ground water salinity measured in-situ, whereas the salinity measured at stations is water salinity measured in rivers or canals [Hoang *et al.*, 2021]. Relating soil salinity to surface and ground water salinity in the case of salt water intrusion is difficult, and depends on different factors (soil type, presence of salinity barrier gates, timing and duration of the salt water intrusion, etc.).

To investigate the effect of future salinity intrusion on Winter-Spring rice production, we have used simulations of surface water salinity under different scenarios (climate change and anthropogenic pressures) to assess which parts of the present rice-cropping area might become less suitable for rice cultivation.

Projections of surface water salinity have been taken from Eslami *et al.* 2021 (see modelling details in [Chapter 9](#)). Different simulations have been carried out to investigate the effect of climate change (sea level rise and river discharge anomalies) and of anthropogenic stressors (subsidence induced by groundwater extractions and riverbed level changes induced by sediment starvation) on future saline water intrusions. Results show that anthropogenic riverbed level incision

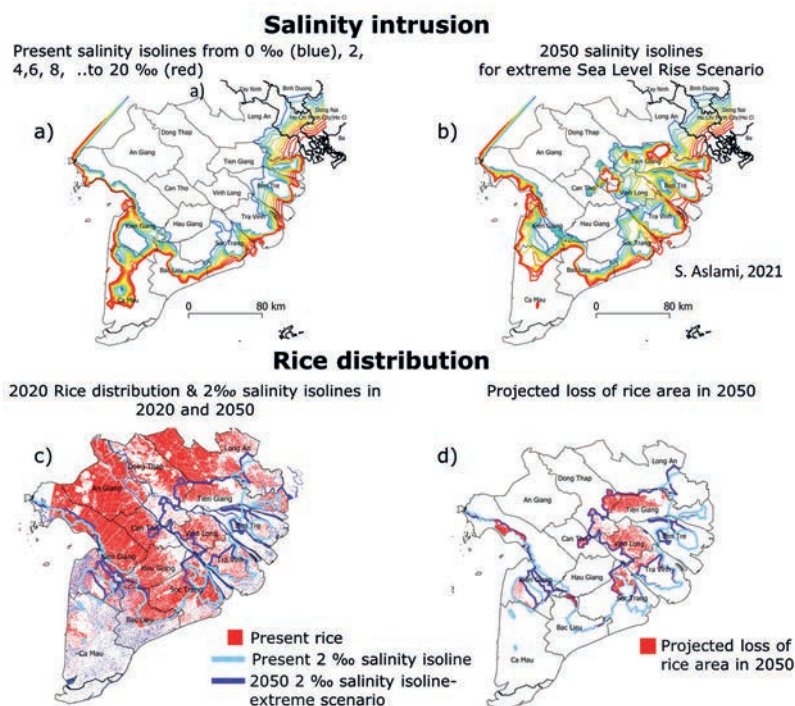
could increase the extension of land impacted by saline water intrusions by 10–25% in 2050.

[Figure 4.7](#) shows the contour lines of saline water intrusions for the present [[Figure 4.7a](#)] and as projected in 2050 [[Figure 4.7b](#)], according to a worst case scenario: river discharge as projected in RCP8.5; subsidence rates as driven by an annual 4% increase in groundwater extraction; continuous increase in riverbed level incision, in line with current trends; extreme global sea level rise scenario (+60 cm). The contours are overlaid on the present Winter Spring rice map of the Mekong Delta, [[Figure 4.7c](#)] produced using Sentinel-1 data. Note that coastlines are assumed to be unchanged despite the high relative sea level rise, that would cause parts of the delta to fall below sea level.

In order to determine the concentration in water salinity that allows farmers to grow rice, our approach consists in calculating the percentage of the present Winter-Spring rice cropping area within different salinity isolines of 0, 2, 3, 4, 5, and 6‰ (at 50% of the time or P50). The result indicates that at present, 78% of rice in the Mekong Delta is grown where water salinity is below 0.5‰. 7.4% of the rice area is grown in areas where surface water salinity ranges between 0.5 to 2‰, and 3.7% in areas with salinity between 2 to 4‰. Only 0.56% of current rice is found in areas where salinity exceeds 4‰. The important finding is that only 4.26% of the present rice area is grown in areas where salinity exceeds 2‰ 50% of the time. Because the contour lines do not encompass all the rice in the Mekong Delta – rice in Ca Mau, for example, is in a salt-protected area – the total is less than 100%. Therefore, we assume that rice can be grown under 2‰ of water salinity, but with a reduction in productivity when salinity exceeds 0.5‰. The value of P50 = 2‰ is

[Figure 4.7]

Present and projected Salinity intrusion and Rice cultivation area



Impact of salinity intrusion on rice area. a) Contour lines of the present time surface water salinity from 0 ‰ the most inland to 2, 4, 6 ...20 ‰ (P50) ; b) Contour lines from the projection for 2050 under scenarios RCP8.5 (river discharge), with extreme scenarios for subsidence (B2), riverbed level changes (RB3) and sea level rise (+60 cm) (Cf. Chapter 9) ; c) Winter-Spring rice map overlaid with contour lines for 2 ‰ salinity (P50) for the present time (light blue) and for 2050 (dark blue); d) rice area (in red) which will be less suitable for rice cultivation in 2050.

chosen to roughly assess the future area suitable for rice cropping.

Figure 4.7c shows the map of the present Winter-Spring rice overlaid with the contour lines of 2‰, for the present time (light blue curve) and the projection for 2050 (dark blue). Figure 4.7d shows the portion of rice area which could be lost in 2050 in this extreme scenario (for water salinity > 2‰). In this case, 143 000 ha (or 10.5% of the 1.36 M ha of 2020's rice-harvested area) are found less suitable for rice cultivation

in 2050. These are located mainly in the provinces of Tien Giang, Vinh Long, Tra Vinh and Soc Trang.

Mitigation of saline intrusion has been object of different measures [Nhan *et al.*, 2012]. In the MARD action plan to respond to climate change in the period of 2008-2020 [MARD & MOST, 2008], mitigation measures include: 1] development of large-scale salinity management structures (i.e. dykes, sluices and reservoirs), 2] development of small-scale

irrigation infrastructures (*i.e.* canals, sluices, pumping stations), 3] development of adaptive farming technologies (*i.e.* crop varieties, farming techniques). For Nhan *et al.* (2012), in areas with salinity levels of up to 4‰, adaptive varieties and farming techniques could help farmers maintain their rice production and income. For salinity levels exceeding 4‰, the adaptation strategy could involve the conversion of rice culture to rice - shrimp rotational farming to improve farmers' incomes and livelihoods. However, since riverbed level incision driven by sediment starvation is currently the main driver of enhanced saline water intrusion and will remain the greatest threat at least for the first half of the century (see [Chapter 9](#)), the most efficient mitigation measure remains the control of sand mining.

3.2 Projected reduction of rice-grown area due to potential inundation following relative sea level rise in the Mekong Delta

The combined effect of global sea level rise (SLR), land subsidence, and reduced sediment aggradation will cause the Mekong Delta to lose elevation relative to sea level [Minderhoud *et al.*, 2019]. Elevation loss increases the vulnerability to flooding and storm surges, and ultimately threatens the Delta with permanent inundation. Without adaptation, land that will be below sea level may be permanently inundated and no longer suitable for agriculture. In this study, we assess the extent of the present rice-grown area that is projected to fall below sea level, and is therefore at risk of inundation. For this purpose, we use projections of elevation changes based on scenarios of sea level rise and subsidence driven by groundwater extraction [Minderhoud *et al.*, 2019, 2020], as

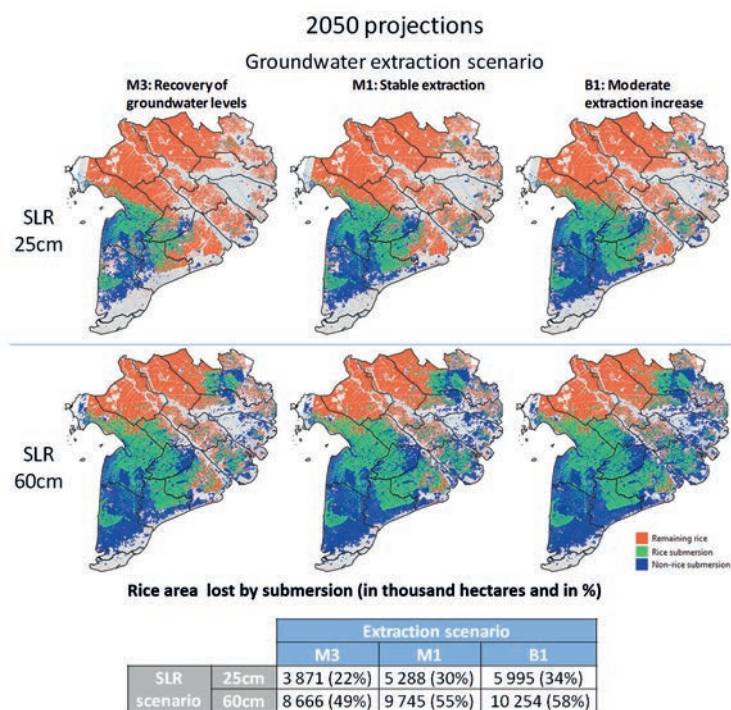
described in [Chapter 9](#). As a first order assessment, we assume that there is no adaptation and that all land areas falling below mean sea level would be inundated. Inundation maps are simulated for 2050 under 3 groundwater extraction scenarios: scenario M3 is based on the recovery of groundwater levels (gradual reduction of extracted volume), in scenario M1, groundwater extraction rates are stabilized at present-day level, and in B1, there is a moderate increase of extraction (steady annual increase: 2% of the 2018 volume). Two global sea level rise scenarios are considered: RCP8.5 (+25 cm, MoNRE, 2016) and an extreme, low-probability, scenario (+60 cm), reflecting potential polar ice-sheet instability. Note that updated SLR median projections for Viet Nam by IMHEN (2021) range between +24 cm (RCP2.6) and +27 cm (RCP8.5) (see [Chapter 1](#)).

Figure 4.8 shows that with SLR of 25 cm, the percent of rice-grown area that would be unsuitable for rice cultivation due to permanent inundation by sea water is between 22% and 34%, depending on the subsidence rates induced by groundwater extractions. The impacts are on the low-lying provinces of Kien Giang, Hau Giang, Soc Trang, Bac Lieu, Can Tho and Ca Mau. For an extreme SLR scenario, the percentage of impacted rice area would range between 49% to 58%. The above-quoted provinces would lose most of their rice area, and in addition, Long An and Tra Vinh would be partly impacted.

In summary, for the Mekong Delta, projections of salinity intrusion and potential permanent inundation due to relative sea level rise strongly reduce the land suitable for rice cultivation. Nearly 10% of rice grown area during the dry season could be lost because of saline intrusion alone, mainly in the eastern provinces of Vinh Long, Tien Giang, Soc Trang,

[Figure 4.8]

Rice field extent lost by submersion (in thousand hectares and in%)



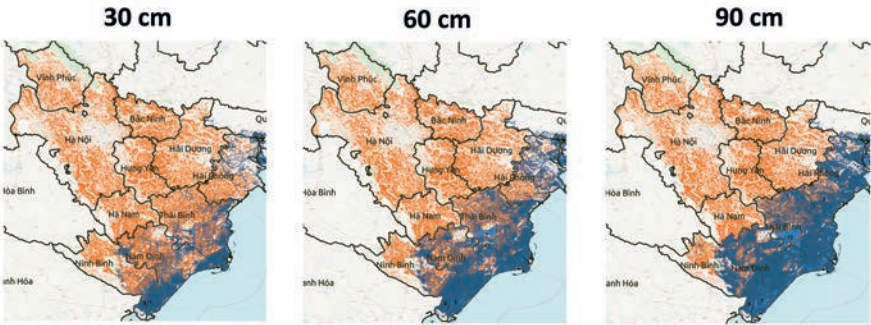
Maps of the 2016–2020 rice area that would be permanently inundated in 2050 under SLR of 25 cm (RCP8.5, top panels) and 60 cm (extreme, low probability) (bottom panels), along with 3 groundwater extraction scenarios, respectively in left, middle and right columns: in M3, recovery of groundwater levels (gradual reduction of extracted volume), M1: the same groundwater extraction (stabilizing extraction, no increase after 2020), and B1: moderate increase of extraction at a steady annual increase: 2% of the 2018 volume. Red color represents non-submerged rice land, green color submerged rice land, and blue color submerged non-rice land.

The inserted table shows the extent (in thousand ha) and percentage of rice area lost by flooding, as compared to the rice extent in 2016–2020.

Tra Vinh. In the case of inundation of areas falling below sea level, the loss of rice grown area in the Delta is projected to be 22 to 34%, up to 58% in case of extreme global sea level rise, located in the provinces of Kien Giang, Hau Giang, Soc Trang, Bac Lieu, Can Tho and Ca Mau. In addition to this loss, the reduction of rice yield due to temperature, drought, and salinity (0.5 to 2‰) is forecast at the 35–45% of the non-submerged rice area.

Without adaptation, by 2050 and with SLR of 25 cm, up to 34% of the present rice-grown area could fall below sea level. Assuming adaptation measures are taken to avoid inundation, saline water intrusions could decrease the area suitable for rice cultivation by 10% anyway. For the remaining rice land, the rice yield is expected to decrease by about 10% compared to 2020.

[Figure 4.9]
2050 projections of rice cultivation area under permanent inundation caused by different projected SLR in the Red River delta



Loss of rice field extent by submersion (in thousand hectares and in %)

Province	Rice planted areas (thousand ha)	Rice areas lost (%) for 3 SLR scenarios		
		30 cm	60 cm	90 cm
Quang Ninh	21	49%	55%	58%
Thai Binh	82	11%	23%	66%
Hai Phong	38	3%	8%	53%
Nam Dinh	76	8%	29%	68%
Ninh Binh	42	1%	7%	21%

Maps of the 2016-2020 rice area generated by Sentinel-1 satellite data that would fall below sea level for sea level rise scenarios of 30 cm, 60 cm and 90 cm in the Red River Delta. In blue, the rice area that would be submerged, in red, the non-submerged rice land. The inserted table shows the loss of rice field extent by submersion in the impacted provinces (in thousand ha, and in percentage) for SLR of 30 cm, 60 cm and 90 cm for the 4 most important rice provinces in the Red River Delta.

In the Red River Delta

For the Red River Delta and the rice-grown area in the centre of Viet Nam, flood maps provided by MoNRE under scenarios of SLR of 30 cm, 60 cm and 90 cm have been used to assess the area and percentage of the present rice area that would be submerged. Figure 4.9 shows the maps of submerged rice area and the percentage of submerged rice area in the 5 impacted provinces. The impact on the two most important rice provinces, Thai Binh and Nam Dinh, is of the order of 10% for SLR of 30 cm, 23 to 29% for SLR of 60 cm, and 66 to 68% for 90 cm.

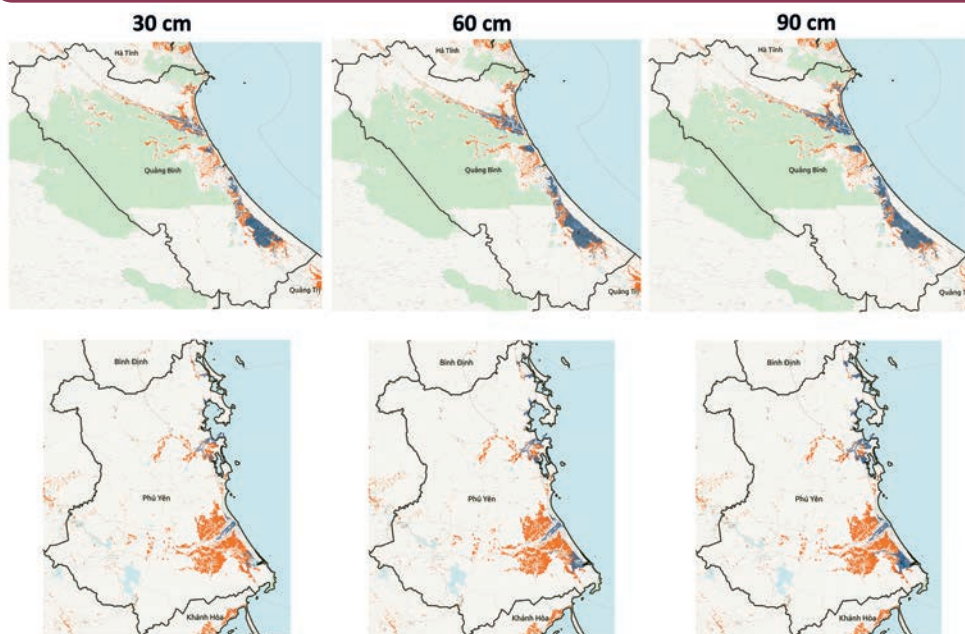
In summary, SLR of 30 cm will affect around 20,000 ha of rice area, and about 55,000 ha for 60 cm of SLR. The loss in rice area is much less important than in the Mekong Delta, however subsidence has not been taken into account. The effect of salinity intrusion also needs to be added.

In the Central provinces

In the central provinces of Viet Nam, the percentage of present rice cropping areas that would be impacted by sea level rise is smaller than in the Red River Delta. Figure 4.10 shows the maps of the two provinces in central pro-

[Figure 4.10]

2050 projections of rice cultivation area under permanent inundation caused by different projected SLR in Central coastal provinces



Loss of rice field extent by submersion (in thousand hectares and in %)

Province	Rice planted areas (thousand ha)	Rice areas lost (%) for 3 SLR scenarios		
		30 cm	60 cm	90 cm
Quang Binh	30	21%	33%	58%
Phu Yen	25.3	0%	0.7%	1.1%
Ninh Thuan	16	0%	0%	0.2%

Maps of the 2020 rice growing area generated by Sentinel-1 satellite data that would be submerged by flood water for sea level rise of 30 cm, 60 cm and 90 cm in Quang Binh (top panels) and Phu Yen (bottom panels) in the centre of Viet Nam. In blue, the rice area that would be submerged, and in red, the non-submerged rice land. The inserted table indicates the present rice growing area (in thousand hectares), and the percentage of submerged rice land for SLR of 30 cm, 60 cm and 90 cm for the 3 impacted provinces in the Centre Coastal provinces.

vinces of Viet Nam which would be impacted by SLR: Quang Binh and Phu Yen. Because of the topography of the Central provinces, only Quang Binh will be impacted by loss of rice area, around 21%, 33% and 58% respectively for 30, 60 and 90 cm, as shown in the inserted table.

However, in order to insure consistency between assessments for the Red River Delta and the Central provinces with that for the Mekong Delta, projections need to be made with the same relative SLR scenarios, based on detailed elevation models; subsidence in the low land delta also needs to be accounted for.

4. The impacts of climate change on nutrition and food security

In the previous sections, the impacts of climate change on agricultural production, in particular for rice, have been assessed. However, food production is only one component where food security and nutrition related to the population are concerned.

According to the World Food Summit, held in Rome in 1996, “food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life” [FAO, 1996]. This definition shows the multidimensional nature of the food security concept. FAO identifies four main dimensions to understanding food security:

- The first dimension is availability, which means sufficient and quality food production available to households. This dimension refers to an adequate supply for a healthy diet, but does not take people’s ability to get it into account.
- The second dimension, which is accessibility, is on the demand side. In addition to the first dimension, it takes households’ access to sufficient food into account, in relation to the resources or opportunities they have.
- The third dimension is diversity in the basket of foods consumed and the use of these goods. Indeed, a balanced diet is necessary for an adequate nutritional state.

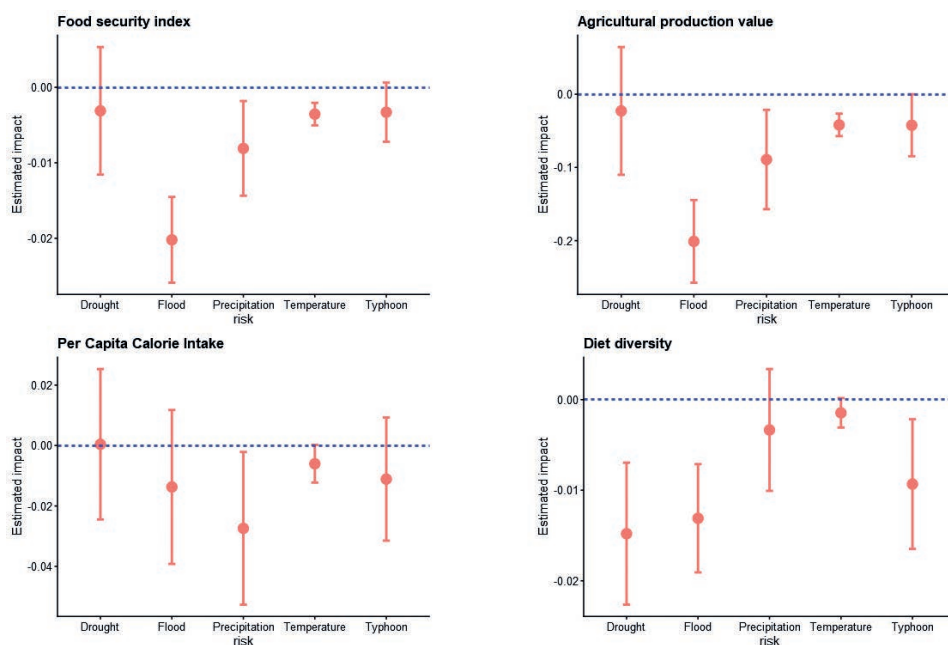
- The last dimension reflects the stability of the three aforementioned dimensions. To ensure food security, households must have access to sufficient, healthy and diversified food at all times.

Most work on the impact of climate change on food security in Viet Nam has focused on the first dimension of food security, and dealt with main crop production (see section 3 of this chapter). The other dimensions have only recently become subjects of interest. Thus, in line with the recent work on poverty by Narloch and Ulf (2018), Yoro Diallo [Diallo, 2019, 2021] presents new insights on the impact of environmental risks on food security and nutrition in Viet Nam. We provide a detailed analysis of the associations between, on the one hand, different indicators on household food security and nutrition, and, on the other hand, different climate-related and environmental risks. The approach is based on data from the Viet Nam Household Living Standards Survey (VHLSS), conducted by Viet Nam’s General Statistics Office (GSO). Estimations combine household data extracted from three VHLSS waves (2010–2012–2014), climate data (precipitation, temperature), and natural disaster data (drought, flood, and typhoon) from different global datasets [Diallo, 2021]. Only rural households are considered, as information on extreme weather event occurrence in VHLSS is only available for them.

Food security and nutrition indicators include the global food security index, total agricultural production, per capita household calorie intake, and diet diversity. Following Demeke *et al.* (2011), a food security index (FSI) is computed at the household level as the first component in a principal component analysis of different variables capturing the three first dimensions of food security. This component captures

[Figure 4.11]

Association of food security and nutrition indices with environmental risk



Food security index, agricultural production, calorie intake and diet diversity association with environmental risks.

41% of total observed data variance, and is mainly linked to the size of the farm (agricultural surface and production). Total agricultural production is measured by total value of crops including rice, vegetables, fruits, livestock, and aquaculture. This variable is taken as a proxy of food availability. Accessibility is proxied by a measurement of per capita calorie intake (PCCI) computed at household level using the same nutritional compositional table and PCCI computation technique as in Trinh *et al.* (2018). The diversity dimension of food security is proxied by a Simpson-type production diversity index [Vu, 2020].

Different environmental risks are taken into account. Of these, five are linked to climatic conditions: temperature and precipitation va-

riability, occurrence of extreme weather events such as flood, drought, or typhoon. Each year, temperature (resp. precipitation) variability is computed as the deviation of average temperature (resp. precipitation) for this year from the five previous year average, in the commune where the household is located. Occurrence of extreme climatic events over the last two years is recorded at communal level in VHLSS.

Certain environmental risks have expected effects on some food security dimensions. For instance, Mendelsohn *et al.* (1994) found a nonlinear effect of temperature and precipitation on agricultural production in the USA. Furthermore, extreme weather events worsen rural household poverty [Aroui *et al.*, 2015], limiting their access to a diverse and high-quality diet.

Estimated associations, with 95% confidence intervals, are summarized in [Figure 4.11](#).

Among the natural disaster variables, only the occurrence of flooding negatively affects food security as measured by FSI. A similar result is found regarding the impact of flooding on agricultural production. This consistency in the results for the two food security indices and agricultural production value is to be expected, as FSI mainly captures variability in the size of observed farms, which is measured using agricultural production. Nevertheless, mitigation tools for flood drainage and dyke protection against typhoons do not seem to be sufficiently developed.

The lack of impact of droughts on the FSI, agricultural production and Per Capita Calorie Intake can be explained by the irrigation strategy to adapt to climate change used by 40% of farmers. However, analysed VHLSS data from 2010 to 2014 do not cover the major drought events linked to El Niño in recent years, *i.e.* in 2016 and 2020.

Flood, precipitation and typhoon are found to impact household per capita calorie intake, but not drought and temperature. Households may substitute between food items when facing natural extreme events, and purchase food items that become cheaper compared to those whose prices increase due to the extreme event. This substitution effect seems to be corroborated by the negative significant impacts on diet diversity found for all the three considered extreme natural events, drought, flood and typhoon. In other words, Vietnamese farm households maintain constant calorie intakes when facing climatic shocks, at the cost of a significant decrease in their diet diversity.

Temperature shocks have a small but negative impact on all the dimensions of food security. Results exhibit the more significant negative impacts of precipitation shocks on all dimensions of food security, with a smaller effect on diet diversity.

In summary, analysis of the 2010–2012–2014 VHLSS survey data on four food security and nutrition indicators — *i.e.* global food security index, total agricultural production, per capita household calorie intake, and diet diversity — has shown that:

- a] Climate and natural disasters affect food security through agricultural production,
- b] Flood and precipitation affect food security index, agriculture production, and per capita calorie intake,
- c] Natural disasters affect diet diversity.

The results on projected lost rice production due to flood, saline intrusions and climate change in section 3 would directly lead to a decrease in the Food Security Index, whereas natural disasters are expected to decrease the nutrition indicators in the future. However, the analysis needs to be completed with recent VHLSS survey data, before simulating future projections of food security and nutrition for different climate scenarios.

5. Adapting agriculture while reducing emissions

Over the past 30 years, strong agricultural growth has changed the socio-economic status of Viet Nam: improving food security, boosting agricultural exports, and creating livelihoods for people.

However, the previous sections have shown that the agricultural sector has already been impacted by climate change, and projections for the next few decades indicate that climate warming trends and anthropogenic pressures are likely to continue to reduce agricultural production, unless there are effective measures for adaptation and mitigation (cf. [Chapter 9](#)). Further, these impacts are exacerbated by the pressures of increasing population and urbanisation, which threaten food security. (See also Yuen *et al.*, 2021). The most productive agricultural area of the country, the Mekong Delta, is forecast to be significantly impacted by relative sea level rise and saltwater intrusion, rendering the land less suitable for crop cultivation.

Viet Nam has been aware of the impacts of climate change for decades, and has been developing a robust policy framework to support adaptation strategies. In 2011 the government released the National Climate Change Strategy (2011–2020) [MARD & MOST, 2011], and in 2018, the National Adaptation Plan (NAP) (2020–2030), which stressed the importance of a comprehensive response to the impacts of climate change, specifically the threat to food security [MARD, 2018].

The NAP-Ag activities in Viet Nam aim to mainstream adaptation within the agricultural sec-

tor's planning processes. In order to maintain agricultural production in the context of increasing climate risks, many agricultural practices have been identified as having good adaptability to climate change.

At the same time, as part of the National Determined Contribution (NDC), Viet Nam aims to move towards low-carbon agriculture production. Climate change adaptation practices to be promoted for the agricultural sector should also contribute to mitigate Greenhouse Gas (GHG) emissions [Vietnam T.S., 2020].

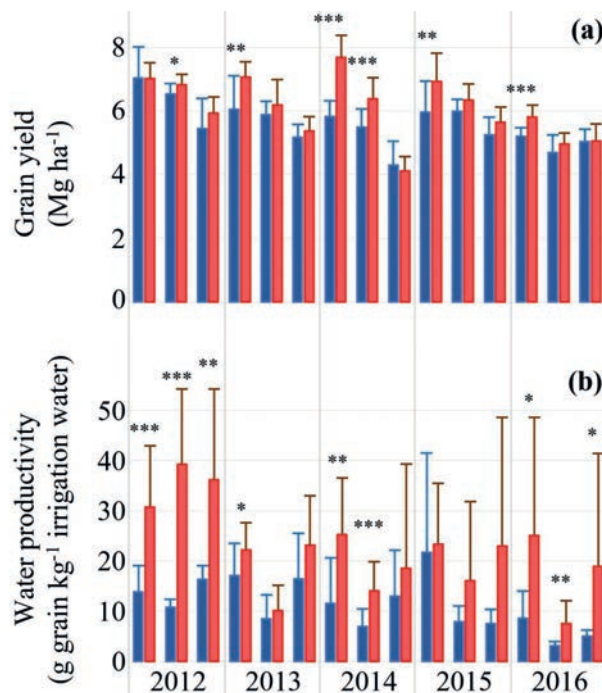
In fact, agriculture is the second-largest source of greenhouse gas emissions after the energy sector. The growth in agricultural production in recent years also creates significant impacts on the environment, as a result of the overuse of fertilizers, pesticides and irrigation water to increase productivity.

Among agricultural crops, rice cultivation is the most important source of GHG emissions. Viet Nam harvests around 7 million hectares of rice annually (7.470 million hectares over 4.129 million hectares of paddy land, according to GSO 2021), and methane emissions from rice production are responsible for 50% of emissions from agriculture, which in turn contributes 33% of the country's total greenhouse gas emissions. Therefore, improving rice production practices is key to reducing agricultural emissions.

Until now, intensive rice farming, which relied heavily on irrigation, has provided huge productivity gains under conditions of intensive resource use. Hydraulic controls, regulating floods and preventing saline intrusion have boosted production in the Mekong Delta and elsewhere. This has partly been through land reclamation, but mostly by enabling double or

[Figure 4.12]

Reduction of water use by AWD irrigation practices (blue) compared to Continuous Flooding, without significant impact on grain yield



Effect of Alternating Wetting and Drying versus Continuous flooding. Rice grain yield (Mg per ha) (a), and water productivity (g grain per kg of irrigation water) (b). Rice grain yields are shown for 14% moisture content equivalent. Values of continuously flooded field-water treatment (CF) and of alternate wetting and drying field-water treatment (AWD) are shown respectively as blue and red bars, which are arranged in chronological order from left to right, started from the winter–spring crop of the experimental year 2012. Error bars show standard deviations (n = 9). Significant differences between CF and AWD analysed according to Student t test are shown as *, **, and ***, respectively denoting significance at 10%, 5%, and 1%.

triple cropping in a single year. However, rice production is increasingly constrained by water scarcity and climatic events. High dependency on energy and technologies have also increased the fragility of the rice farming system.

Advanced farming practices have been recommended, such as integrated crop management (ICM), and 3 Reduction 3 Gains (3G3T) cultivation techniques (promoting the reduction of the three inputs seeds, fertilisers and insecticide to

bring three benefits: increased income, lower exposure and risk due to pesticides, and an improved environment with less pollution from farm chemicals), 1 Must 5 Decreases (1P 5G), integrated disease management (EPM), improved rice cultivation system through the System Rice Intensification (SRI), which recommends sowing sparsely, irrigating fields that are alternately flooded and non-flooded (Alternate Wetting and Drying, AWD), and reducing the use of chemical fertilisers and plant protection

products. Emissions from rice paddies can also be reduced by rotating the use of land, by introducing alternative activities like shrimp or fish farming. For example, instead of having three rice crops a year, a farmer could produce two rice crops and one shrimp harvest in the same paddy.

Creating a favorable environment for agricultural production to adapt to climate change and reduce emissions is one of Viet Nam's top priorities. However, the conflict between the long-term and the short-term interests of agricultural growth is a factor that limits the application of these good practices on a large scale in Viet Nam.

In this study, the focus is on the AWD practice, which could be applied as a measure of adaptation to the future scarcity of water, and a major measure in reducing GHG emissions.

Rice production requires large amounts of water (3,000-5,000 L kg⁻¹ rice, IRRI 2001), and has become a major source of the potent greenhouse gas methane (CH₄); about 11% of anthropogenic CH₄ emissions come from rice paddy submerged soils [IPCC, 2013], and among the major cereals, rice has the highest global warming potential due to the high CH₄ emissions [Linguist *et al.*, 2012]. Therefore, water-saving irrigation practices, which can potentially mitigate CH₄ emissions by oxidizing the soil environment (*e.g.* AWD), are should be disseminated in Viet Nam to ensure sustainable water demand, while lowering greenhouse gas emissions.

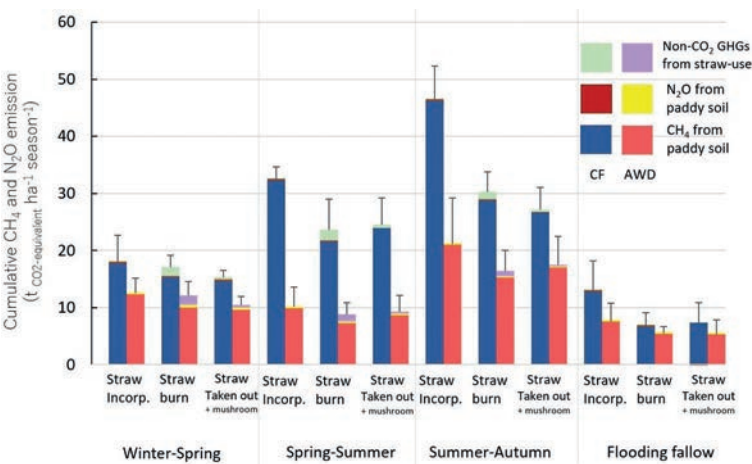
For drought and saline intrusion, water saving irrigation techniques are required as a counter measure. However, according to traditional knowledge, water saving irrigation could be detrimental to rice yield. The question was

studied during the last decade by experiments conducted to compare rice productivity and water productivity between Continuous Flooding (CF) and Alternate Wetting Drying (AWD). It was found in triple-cropping rice paddies in the Mekong Delta that the yield does not decrease, but rather increases slightly under AWD [Arai *et al.*, 2021; Uno *et al.*, 2021], whereas irrigation water productivity (grain weight per litre of water used) is significantly increased [Figure 4.12].

At the same time, the annually cumulative GHG CH₄ emission is significantly reduced. Figure 4.13 shows the results obtained from the 5-year experiment in 2012-2016 [Arai *et al.*, 2018], for which CH₄ and N₂O were measured. Different ways of managing straw after the harvest have also been studied (straw incorporated in the soil, straw burned and straw removed from the fields). The results show that a) CH₄ emissions is highly reduced by AWD for Spring-Summer rice and Summer-Autumn rice, for which the emissions are highest; the reduction is more moderate for the Winter-Spring dry season, and the fallow period, b) straw incorporated has the highest emission following the decomposition of the organic matter, c) annual nitrous oxide emissions make up only 0.2–7.1% of total greenhouse gas emissions (*i.e.* CH₄ + N₂O, CO₂ equivalent), and were negligible compared with CH₄ in terms of the global warming potential of the rice cropping system. These results indicate that intermittent irrigation is the most efficient way to reduce the total greenhouse gas emissions of rice production. In addition, straw incorporated in the soil must be avoided.

Regarding water saving under AWD, it is recommended to irrigate the fields when the water level drops to -15 cm beneath the soil level. However, it is difficult to locate the

[Figure 4.13]
Reduction of GHG emissions by Alternate Wetting and Drying (AWD) irrigation as compared to Continuous Flooding (CF) of rice fields



Cumulative methane from rice fields for continuously flooded fields (blue bar) and AWD fields (red bar). Nitrous oxide (N₂O: brown/red bars) and non-CO₂ greenhouse gases (GHGs: including carbon mono oxide, CH₄, N₂O and non-methane volatile organic carbon, as described in Arai *et al.*, 2016). The emissions are for three ways of straw management during each cropping season (winter-spring, spring-summer and summer-autumn) and flooding fallow season during 5 years from 2012 to 2016. Error bars show standard deviations (n = 3 samples x 5 years).

rice fields where AWD is effectively applied in the Mekong Delta. By assimilating radar data from the ALOS PALSAR satellite into the model, we found that about 22% of total rice paddy areas in the Delta were continuously flooded or irrigated before the water level drops to -5 cm [Arai *et al.*, 2021]. These results indicate that the Mekong Delta, like all the rice-growing regions in Viet Nam, still has huge potential to reduce its methane emissions and adapt to the predicted scarcity of water.

6. Summary

According to the 6th IPCC Assessment Report, global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered. Global warming of 1.5°C and 2°C will be exceeded during the XXIst century, unless deep reductions in carbon dioxide (CO₂) and other greenhouse gas emissions occur in the coming decades. Many changes in the climate system have become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of extreme heat, heatwaves, heavy precipitation, agricultural and ecological droughts in some regions, and the proportion of intense tropical cyclones [IPCC AR6, 2021].

With sea level rise affecting the Deltas and coastal regions, and with changes in precipitation pattern leading to flood and drought, Viet Nam is heavily exposed to the risks of weather variability and climate change. Long-term climate change and weather shocks have strong impacts on crop productivity and future crop geographic distribution. Temperature and precipitation patterns and extremes, saline intrusion, floods and droughts are predicted to cause major declines in crop productivity and crop area.

The impact of climate scenarios on **crop productivity** has been examined using a range of agronomic models, which take temperature, rainfall patterns, water availability, and other factors into account. Predicted changes in yields vary widely across crops, agro-ecological zones and climate scenarios, but most findings concur on the decline of crop yield under climate scenarios RCP4.5 and RCP8.5.

In terms of **crop geographical distribution**, for the climate change scenarios in 2030 and 2050, climate factors (temperature, precipitation, solar radiation, etc.), weather extremes, flood patterns, and saline intrusion will change in all agro-ecological zones, but the changes vary from North to South, and from coastal to inland areas, affecting the habitat suitability of rice and other major crops. This could have drastic effects on crop distribution in the future. It should be noted that the main threats for rice cultivation in the Deltas are relative sea level rise and increased saline intrusions, and that both phenomena arise mainly from anthropogenic pressures (groundwater pumping and sand mining).

Most of the emerging solutions in the agricultural sector for the next decade should focus on improving the sector's resilience in the face of weather, biological, environmental, social and commercial risks. Before adaptation, attenuation measures should be undertaken. For rice cultivation — the main component of the agricultural sector in Viet Nam — human pressures on the environment should be reduced. These include exploitation of groundwater and sand mining in the Deltas, and the practice of continuous flooding in all rice-growing regions in Viet Nam. On the other hand, the agricultural outcome should be quantified not only by the amount of harvest crops, but also by the market value of the crops and the cost of damaging the environment, while for vulnerable populations, food security and nutrition should be taken into consideration.

Approaches to risk management in agriculture — which will also constitute climate change adaptation measures — should therefore cut across infrastructure, technology, natural resource planning, management practices, and financial instruments.

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Chapter 5

A resilient energy system

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Abstract

Chapter 5 analyses the sensitivity of Viet Nam's energy system — including both demand and supply sides — to weather conditions, projects the potential impact of climate change and proposes adaptation strategies. Key results confirm the significant effect of fluctuations in weather factors such as precipitation and temperature on residential, commercial and industrial energy demand, and hydropower generation. One additional degree Celsius is estimated to increase household electricity consumption by around 4.9 per cent and firms' energy demand by around 4.3 per cent. In addition, climate change would introduce a great deal of uncertainty into hydropower generation, which currently accounts for a significant part of Viet Nam's energy production. Our projections under RCP4.5 and RCP8.5 for the 2017–2050 period using the Low Emissions Analysis Platform (LEAP) suggest climate change would cumulatively raise electricity demand by US\$ 4,227.5–7,675.3 million, and emissions by 161.9–288.3 MtCO₂e. Close monitoring, early planning, and prompt response measures based on strengthened scientific and technological capability are recommended, to cope with the various impacts of climate change on the energy system.

Tóm tắt

Chương 5 phân tích mức độ nhạy cảm của hệ thống năng lượng Việt Nam, bao gồm cả phía cung và cầu, đối với các điều kiện thời tiết, dự báo khả năng tác động của biến đổi khí hậu và đề xuất các chiến lược ứng phó. Các kết quả chính cho thấy sự biến động của các yếu tố thời tiết như lượng mưa và nhiệt độ đối đã ảnh hưởng đáng kể đến nhu cầu năng lượng khu vực hộ gia đình, thương mại và công nghiệp và sản xuất thủy điện. Ứng với mỗi độ C tăng thêm ước tính sẽ làm tăng mức tiêu thụ điện trong các hộ gia đình lên 4,86% và nhu cầu năng lượng của các doanh nghiệp lên 4,31%. Ngoài ra, biến đổi khí hậu sẽ gây ra nhiều bất ổn cho việc sản xuất thủy điện, hiện đang chiếm một phần đáng kể trong sản xuất năng lượng của Việt Nam. Các kết quả dự báo theo mô hình phân tích phát thải thấp (LEAP) trên cơ sở các kịch bản RCP4.5 và RCP8.5 cho thấy biến đổi khí hậu sẽ làm tăng thêm tổng nhu cầu điện, tương ứng với 4.227,5–7.675,3 triệu đô la Mỹ và 161,9–288,3 triệu tấn CO₂e phát thải tích lũy cho cả giai đoạn 2017–2050. Từ đó đề xuất các khuyến nghị như: giám sát chặt chẽ, lập kế hoạch sớm và các biện pháp ứng phó kịp thời dựa trên việc tăng cường năng lực khoa học và công nghệ để đối phó với các tác động khác nhau của biến đổi khí hậu đối với hệ thống năng lượng.

Résumé

Le **chapitre 5** analyse la sensibilité du système énergétique vietnamien — tant du côté de la demande que de l'offre — aux conditions météorologiques. Il projette l'impact potentiel du changement climatique et propose des stratégies d'adaptation. Les principaux résultats confirment l'effet significatif des fluctuations des facteurs météorologiques tels que les précipitations et la température sur la demande d'énergie résidentielle, commerciale et industrielle, ainsi que sur la production d'hydroélectricité. On estime qu'un degré Celsius supplémentaire augmente la consommation d'électricité des ménages de 4,9% et la demande d'énergie des entreprises de 4,3%. En outre, le changement climatique introduirait une grande incertitude dans la production d'hydroélectricité, qui représente actuellement une part importante de la production énergétique du Viet Nam. Selon nos projections dans le cadre des scénarios RCP4.5 et RCP8.5 pour la période 2017–2050, réalisées à l'aide du modèle LEAP, le changement climatique entraînerait une augmentation cumulée de la demande d'électricité de 4 227,5 à 7 675,3 millions de dollars américains, et des émissions de 161,9 à 288,3 MtCO_{2e}. Il est recommandé d'assurer une surveillance étroite, une planification précoce et des mesures de réaction rapide fondées sur le renforcement des capacités scientifiques et technologiques, afin de faire face aux différents impacts du changement climatique sur le système énergétique.

1. Introduction

In general, there is a strong connection between energy consumption and economic development. Viet Nam could serve as a prominent example. It has been “one of the best-performing economies in the world over the past decade” [WB, 2011], and maintained a GDP per capita growth rate second only to China [WB and MPI, 2016]. Rising power demand has accompanied economic growth. Viet Nam’s impressive average annual growth rate of 7.5% between 1995 and 2005 coexisted with a growth rate of 15% in demand for energy [Huu, 2015]. In terms of equity, Viet Nam succeeded in reducing its poverty rate from 58% in 1993 to under 6% (US\$3.2/day PPP) [World Bank, 2021]. In parallel, the proportion of households with access to electricity has risen substantially from under 2.5% in 1975 to 99% by 2016, comparable to higher average to upper middle-income countries like China or Thailand [World Bank, 2021]. In 2014, off-grid households accounted for less than 2%, and just under 3% reported unmet electricity needs [Ha-Minh and Nguyen, 2017].

Projections suggest that Viet Nam’s thirst for energy will continue to fuel its ambition of economic development and improve the living standards of its people. The baseline scenario of Power Development Plan VIII forecasts national power demand to reach 491.3 TWh by 2030, and 877.1 TWh by 2045 [IE, 2021]. These figures compare to 210.5 TWh in 2019. Meanwhile, per capita energy consumption is projected to increase to 4,588 kWh by 2030 [IE, 2021], from 985 kWh in 2010 [ADB, 2013]. The strong link between energy consumption and economic development in the past implies that a failure to satisfy energy demand may hinder or even reverse the development achieved. It has been shown that

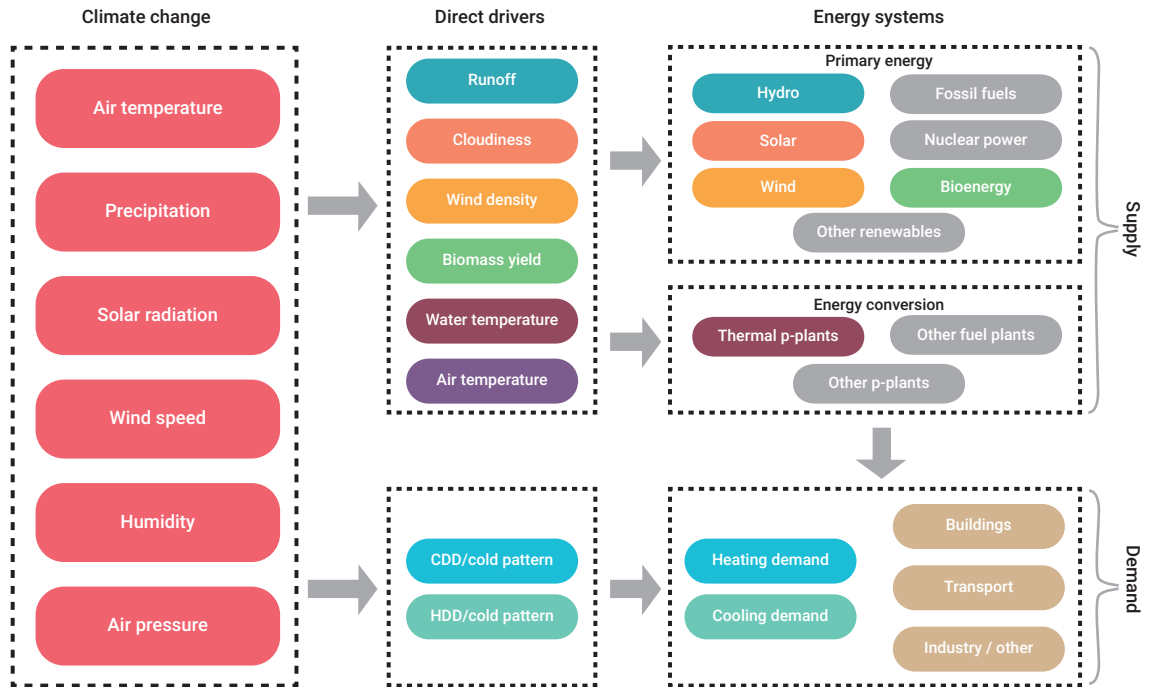
during its development progress, robust performance in Viet Nam has become more sensitive to power unreliability [Elliott *et al.*, 2021]. A reliable energy development strategy associated with thorough consideration of energy sources is pivotal to the country’s development.

Le (2019) found that the elasticity of electricity to GDP (growth rate of electricity consumption/ GDP growth rate) in Viet Nam is between 1.5 and 2: remarkably high compared to other countries at a similar level of development. This is reasonable, since in the initial stage of economic development, energy-intensive industries are likely to grow faster. However, they will give way to low-energy, high-efficiency industries in the future, when the economic structure changes.

In assessing climate change’s impacts on energy systems, Yalew *et al.* (2020) proposed a conceptual framework based on previous studies. [Figure 5.1](#) shows different elements of climate change that can directly influence various sources of energy supply, such as hydro, solar, wind, fossil fuels, nuclear power and bioenergy, and energy demand for heating and cooling purposes. In Viet Nam, coal, hydropower, and natural gas are the most important primary energy sources, accounting for 98.1% of total electricity production [[Figure 5.2](#)]. Of these three sources, hydropower generation is supposed to be most directly affected by climate change. Changes in precipitation and seasonal patterns due to climate change, especially extreme weather events, can result in reduced precipitation (or water flow) in dry seasons and reduced water level in reservoirs in almost all regions. This could in turn reduce capacity utilization of hydropower generation facilities. Consequently, as regards energy supply, this chapter confines itself to hydropower generation

[Figure 5.1]

Conceptual framework to assess climate change impacts on energy system



■ Source: Yalew *et al.*, 2020.

Up to now, 100% of all communes and 99.6% of all households in Viet Nam have access to the national electricity grid. In addition, increasing income and the rapid popularization of electrical home appliances has increased electricity demand among households and firms considerably. Climate change in the form of rising temperature and weather extremes will strongly impact residential electricity demand: mainly electricity consumption for air conditioners, refrigerators and electric fans.

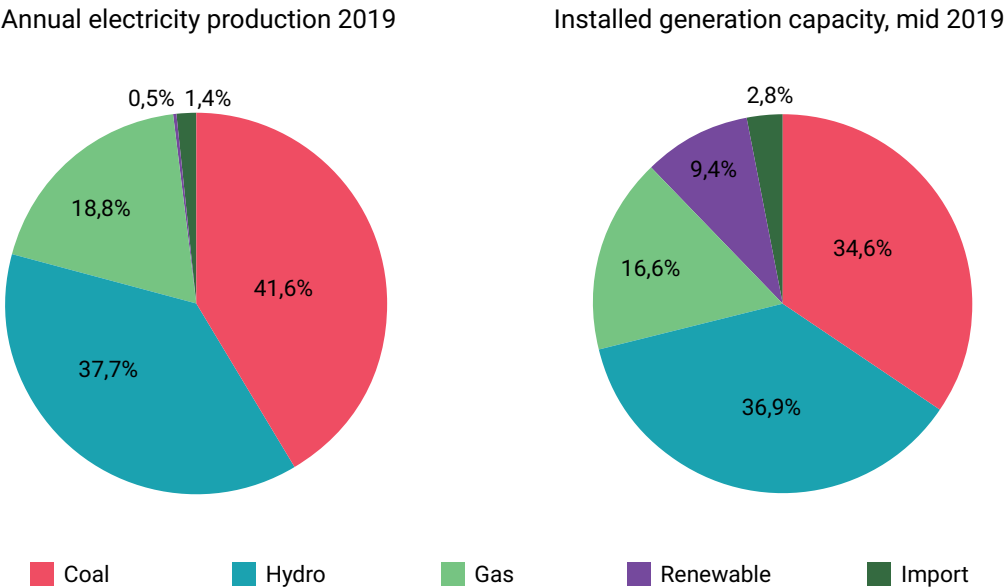
Therefore, the objectives of this study are to evaluate the impact of climate change on electricity demand, hydropower production, and the whole energy system up to 2050 in its

economic and environmental aspects and to propose measures to cope with this impact.

A range of different approaches or methods can be used to assess climate change impacts. These include quantitative and predictive models, empirical studies, expert judgment, and experimentation. Each of these approaches has its own advantages and weaknesses, and a good strategy may be to use a combination of approaches in different parts of the assessment or at different stages of the analysis.

Our study will first employ quantitative methods to evaluate impacts of climate change on electricity demand for both household cooling and manufacturing firms' consumption

[Figure 5.2]
Electricity production and installed capacity by source, 2019



■ Source: GIZ energy support programme, 2019.

of electricity, and on hydropower production. To assess the impacts on the whole energy system, we shall develop several scenarios for comparison. We start with the Business As Usual (BAU) scenario that outlines future energy consumption, assuming no impacts from climate changes. Then, under the Viet Nam climate change and sea level rise scenarios (hereafter referred to as climate change scenario), typical studies on the impacts of climate change on electricity demand and hydropower plants are used to develop scenarios for climate change impacts (CCI). In this study, the Low Emissions Analysis Platform (LEAP) is used as a tool to analyse and quantify the impacts of climate change on Viet Nam's energy system. LEAP is flexible and can be used to create models of different energy systems based on available data, ranging from bottom-up, end-use techniques, to top-down

approaches. Moreover, LEAP is also used to evaluate costs and benefits for different policy strategies on both demand and supply sides, to deal with the impacts of climate change on the energy system in Viet Nam.

This chapter is structured as follows. Sections 2 and 3 provide a separate assessment of climate change's impacts on electricity demand and hydropower production, respectively. Section 4 presents a comprehensive (integrated) evaluation of the energy system under different scenarios. In Section 5, several measures are proposed with associated social costs and benefits. Conclusions and recommendations are in Section 6.

2. Assessment of climate change's impacts on electricity demand

The impressive performance of the Vietnamese economy over the last few decades has been closely associated with the rapid expansion of the national grid to different parts of the country. Easy access to electricity for firms and households has improved not only productivity, but also living conditions for millions of people. Since it takes time to change electricity generation capacity, long-term planning requires a reasonably accurate forecast of future electricity demand. However, this task has been complicated by temperature rise due to global warming [Slingo and Palmer, 2011] (see [Chapter 1](#) for the past trends in temperature).

There is a rich literature on the effect of climate change, especially temperature, on electricity demand [Sailor and Pavlova, 2003]. This effect is mainly attributed to the rapid proliferation of electric cooling and heating appliances in firms and households, in residential and commercial/industrial sectors. While there have been many studies on household electricity demand [Conevska and Urpelainen, 2020], the extent of research on firms' electricity demand is more modest.

The objective of this section is to estimate the impact of temperature changes on electricity demand among firms and households, while observing other underlying determinants of electricity demand. Since firms are able to resort to different energy sources, such as electricity, gasoline, charcoal, diesel, gas, etc., we also consider substitution among these inputs as a result of prevailing relative input prices.

Then, we forecast firms' and households' electricity demands under different scenarios of temperature rise due to climate change and economic growth.

2.1 Methodology

Using different methods, most previous studies demonstrated that household energy consumption in developed and developing countries is related to various factors that can be classified into four categories, including household head characteristics, household characteristics, dwelling attributes, and climatic factors [Galvin and Sunikka-Blank, 2018].

Deschenes and Greenstone (2011) applied the panel approach with flexible functional forms to explore the relationship between climate changes and household electricity demand in the United States between 1968 and 2002. They found that daily temperatures have a significant impact. This relationship is non-linear, *i.e.* residential electricity consumption tends to increase considerably at the extremes of the temperature distribution. Since the temperature in Viet Nam typically ranges from 21°C to 35°C — higher than the estimated threshold temperature in Moral-Carcedo and Perez-Garcia (2015) — the heating needs for firms are correspondingly limited. In this chapter, we do not estimate a non-linear relationship between temperature and electricity demand.

In addition, electricity is only one of energy sources available to firms. The objective of profit maximization (or cost minimization), along with large-scale production, causes firms to consider alternative sources such as gasoline, charcoal, diesel, gas, etc. This is especially significant in developing countries, where electricity supplies tend to be unreliable and susceptible to exogenous shocks. Electricity

shortages, which may be frequent under extreme circumstances, can adversely affect firms' production and revenue [Abeberese, 2017]. As temperature increases under global warming, firms may plan lower production or switch to more modern, 'greener' or more labour-intensive technologies. The latter strategy requires consideration of possible substitution among factors of production, and among different fuels. Therefore, we apply econometric methods with the model in Bardazzi *et al.* (2015).

We are going to estimate two systems: (i) one with three production factors, *i.e.* labour, capital, and energy, and (ii) one with five fuel sources, *i.e.*, electricity, gasoline, charcoal, diesel, and gas (see Box 5.1 below). To estimate the im-

pact of temperature on household electricity consumption, we regress households' annual electricity spending on observed and unobserved attributes at the household level, and average temperature in the district in which households are located.

Another way to represent the non-linear relationship is to sort each day's average temperature into one of 14 temperature bins. They are the first, fifth, tenth, twentieth, thirtieth, fortieth, fiftieth, sixtieth, seventieth, eightieth, ninetieth, nine-fifth, and ninety-ninth percentiles of the temperature distribution. It is expected that on extremely cold and hot days, households are likely to consume more electricity for heating and cooling.

[Box 5.1]

The general share equation for both systems is adapted from Bardazzi *et al.* (2015):

$$S_{ift} = d_i + \tau_i temp_{ft} + \sum_{j=1}^{n-1} \alpha_{ij} \ln\left(\frac{p_{jft}}{p_{kft}}\right) + \beta_i \ln\left(\frac{Y_{ft}}{P_t}\right) + \delta_i \ln(\text{employment}_{ft}) + \sum_t \gamma_{it} year_t + \sum_l \theta_{il} industry_{fl} + \sum_m \omega_{fm} ownership_{fm} + u_{ift}, \quad (5.1)$$

where S_{ift} is the cost share of input i of the f^{th} firm in year t , $temp_{ft}$ is the t th year's average temperature in the province where the f^{th} firm was officially registered, p_{jft} is the j th input price, $\frac{Y_{ft}}{P_t}$ is the level of real output of the f^{th} firm, $year_t$, $industry_{fl}$ and $ownership_{fm}$ are the year, industry, and types of ownership dummies. Since the production function may not have constant returns to scale, we need to include the logarithm of the number of workers, $\ln(\text{employment}_{ft})$, as a proxy for firm size and three groups of dummy variables.

To estimate the impact of temperature on household electricity consumption, we regress a function of the form

$$\ln(q_{it}) = \alpha_i + \beta temperature_{it} + \delta temperature_{it}^2 + \gamma Z_{it} + u_{it}, \quad (5.2)$$

where $\ln(q_{it})$ is the natural logarithm of household i 's annual electricity spending (adjusted for electricity price) in year t , Z_{it} is a vector of observed attributes at the household level, α_i is time-invariant and unobserved household fixed effect, $temperature_{it}$ is average temperature of year t in the district in which household i is located. We add a quadratic term $temperature_{it}^2$ to account for the possible non-linear impact of temperature on electricity consumption.

A popular estimation equation that reflects the non-linear relationship with 14 temperature bins is [Maximilian, 2018; Deschenes and Greenstone, 2011]

$$\ln(q_{it}) = \alpha_i + \sum_{b=1}^{14} \beta_b D_{bit} + \gamma Z_{it} + u_{it}, \quad (5.3)$$

where D_{bit} is the number of days of which average temperature falls into bin b (experienced by household i in year t). Annual data postulate that $\sum_{b=1}^{14} D_{bit} = 365$ or 366, we need to drop one bin which is considered the base group to avoid perfect collinearity.

2.2 Estimated effects of temperature on residential, manufacturing, and aggregate electricity consumption

This chapter utilizes Viet Nam Enterprise Surveys conducted by the General Statistics Office (GSO) of Viet Nam. The surveys were initiated by the World Bank in 1998. They were designed to survey thousands of small, medium, and large companies across all geographic regions, so that they could be representative samples of firms in the economy. However, these surveys are subject to extensive missing data and measurement errors. We have used the last three surveys from 2016 to 2018, each of which covers around 500,000 businesses. As our panel dataset spans just three years, we do not expect there to be much variation in temperature experienced by firms. Therefore, the factor and fuel demand systems do not include a quadratic term in temperature like the residential electricity consumption function.

The estimation results of the factor demand system are displayed in [Table 5.1](#). With capital being chosen as the numeraire input, the system comprises two cost share equations for labour and energy. As temperature rises, firms are likely to spend relatively more on labour and energy, and less on capital. Labour and energy cost shares tend to increase 0.09 and 0.06% for each additional degree Celsius, all other things being equal. The median firm has to consume 4.31% more on energy. The same holds true if the firm size (measured in terms of the number of workers) grows. However, a 1% increase in a firm's real output is associated with a higher energy cost share (up by 0.06%), but a lower labour cost share (down by 0.06%).

Based on the Standard Industrial Classification (SIC), we divide firms into four industries: (i) agriculture, forestry, fisheries, and other sectors, (ii) mining, industry, and manufacturing, (iii) electricity, steaming, conditioner production, and (iv) water supply, construction, vehicle, automobile repairs and all services. The firms in industries (iii) and (iv) consume relatively more energy than firms operating in agricultural sectors. Labour cost shares are highest among firms in industry (iii), followed by the base group, then industries (iv) and (ii).

It should be noted that foreign – and domestic privately-owned firms employ Viet Nam's abundant factor of production – labour more intensively, as their labour cost shares are higher than those of state-owned enterprises. However, their energy consumption is comparatively lower than SOEs. All other things being equal, over time firms spend more on labour and less on energy. This is particularly desirable, as global warming requires a cutback on energy – especially fossil – consumption.

Although energy cost shares increase with temperature, the fuel demand system in [Table 5.2](#) shows that electricity and charcoal cost shares, among firms which are currently using five fuels, decrease while their diesel, gas, and gasoline cost shares rise. On hot days, the aggregated electricity consumption in both the residential and commercial/industrial sectors is expected to skyrocket, imposing intense pressure on the country's electric power generation and transmission system. Firms are inclined to resort to other energy sources, for example their own electric generators using diesel or gasoline, in order to cope with the higher electricity prices that are applied to their bigger usage load.

[Table 5.1]

Estimation results of factor demand system

Dependent variable	Labor cost share	Energy cost share
Average temperature	0.00088 (0.00010)***	0.00055 (0.00008)***
$\ln \left(\frac{P_{\text{labor}}}{P_{\text{capital}}} \right)$	0.12768 (0.00016)***	-0.01567 (0.00013)***
$\ln \left(\frac{P_{\text{energy}}}{P_{\text{capital}}} \right)$	-0.01312 (0.00012)***	0.03911 (0.00009)***
$\ln \left(\frac{Y}{P} \right)$	-0.00059 (0.00013)***	0.00062 (0.00010)***
$\ln(\text{employment})$	0.00423 (0.00024)***	0.00111 (0.00020)***
Industry 2	-0.01350 (0.00134)***	0.00068 (0.00108)
Industry 3	0.01092 (0.00332)***	0.06406 (0.00268)***
Industry 4	-0.00909 (0.00130)***	0.02783 (0.00105)***
Domestic privately-owned	0.01577 (0.00108)***	-0.01945 (0.00087)***
Foreign-owned	0.02051 (0.00131)***	-0.01755 (0.00105)***
Year 2017	0.00368 (0.00079)***	-0.00640 (0.00064)***
Year 2018	0.00855 (0.00052)***	-0.01297 (0.00042)***
R ²	0.84	0.53
Observations	179,208	179,208

Notes: The numeraire factor is capital. Constants are not reported.

*** significant at 1% level.

Source: Authors' calculation.

[Table 5.2]

Estimation results of fuel demand system

Dependent variable	Electricity cost share	Charcoal cost share	Diesel cost share	Gas cost share
Average temperature	-0.02460 (0.00360)***	-0.01804 (0.00217)***	0.03184 (0.00336)***	0.00393 (0.00135)***
$\ln \left(\frac{P_{\text{electricity}}}{P_{\text{gasoline}}} \right)$	-0.07890 (0.01539)***	0.00307 (0.00927)	0.04886 (0.01436)***	-0.00007 (0.00575)
$\ln \left(\frac{P_{\text{charcoal}}}{P_{\text{gasoline}}} \right)$	0.06540 (0.00858)***	0.03771 (0.00517)***	-0.04373 (0.00801)***	-0.03773 (0.00321)***
$\ln \left(\frac{P_{\text{diesel}}}{P_{\text{gasoline}}} \right)$	-0.04442 (0.00644)***	0.01504 (0.00388)***	0.03442 (0.00601)***	-0.00999 (0.00241)***
$\ln \left(\frac{P_{\text{gas}}}{P_{\text{gasoline}}} \right)$	0.00322 (0.00516)	-0.03022 (0.00311)***	0.02535 (0.00482)***	0.00079 (0.00193)
$\ln \left(\frac{Y}{P} \right)$	0.00783 (0.00255)***	-0.00332 (0.00153)**	-0.00320 (0.00238)	-0.00019 (0.00095)
$\ln(\text{employment})$	0.02391 (0.00592)***	-0.00803 (0.00357)**	-0.02620 (0.00553)***	0.01701 (0.00221)***
Industry 3	-0.20772 (0.05108)***	-0.13896 (0.03077)***	0.33036 (0.04768)***	-0.01385 (0.01909)
Industry 4	0.05326 (0.01283)***	-0.10330 (0.00773)***	0.08064 (0.01198)***	0.04117 (0.00480)***
Domestic privately-owned	0.03658 (0.02844)	-0.04248 (0.01713)**	0.01082 (0.02655)	-0.00991 (0.01063)
Foreign-owned	0.06433 (0.03845)*	0.00436 (0.02316)	-0.06914 (0.03589)*	0.00573 (0.01437)
Year 2017	0.00605 (0.04324)	0.01682 (0.02605)	-0.01636 (0.04037)	0.02921 (0.01616)*
Year 2018	0.11101 (0.03414)***	-0.04880 (0.02057)**	0.00463 (0.03187)	-0.03506 (0.01276)***
R ²	0.11	0.36	0.34	0.18
Observations	1,863	1,863	1,863	1,863

Notes: The numeraire fuel is gasoline. Constants are not reported.

***, **, * significant at 1%, 5%, 10% levels, respectively.

Source: Authors' calculation.

We do not forecast consumption for the five fuels due to the limited number of firms in the inter-fuel demand system. In Table 5.1, an increase in the real output $\frac{Y}{P}$ raises energy cost share, which shifts down over time thanks to technological progress. It seems that year dummies reduce energy cost share considerably. But we should be prudent because the time horizon in our sample is short. Forecasts about Viet Nam's real output growth between now and 2050 are taken from the BAU scenario (see Section 4 below for further detail). We assume that technical progress over time will mitigate the impact of real output growth on energy cost share by 2% per annum. For example, if real output increases by 5%, then as a result of technological progress, energy cost share in that year is subject to a 3% increase in real output.

Temperature projection is based on Global Circulation Models (GCMs) under different Representative Concentration Pathways (RCPs). Simulations of 31 models in the fifth phase of the Coupled Model Intercomparison Project (CMIP5) generate 31 values of average tem-

perature for each year. All of them are used to forecast firms' energy consumption. If there is no noticeable change in the current trend, by the middle of this century energy consumption in production will be more than two and a half times larger. This dramatic acceleration calls for promoting renewable sources, and switching to less energy-intensive industries or more energy-efficient technologies.

For residential electricity consumption, the dataset is compiled from the Viet Nam Household Living Standard Surveys (VHLSS) that were undertaken by the GSO every two years (in the years ending with even numbers) from 2002 to 2018. Since there are unobserved but important household-level attributes (effects) that cause heterogeneity in households' electricity consumption, we have constructed a panel dataset in which each household must show up at least twice over time. The GSO implemented a 50% rotation of households being interviewed from one survey to the next. Therefore, the panel dataset currently available is unbalanced.

[Table 5.3]

Estimation results of residential electricity consumption

	Equation (5.2)	Equation (5.3)
Average temperature	-0.27157 (0.08030)***	
Average temperature ²	0.00646 (0.00166)***	
D1		0.00678 (0.00083)***
D2		0.00135 (0.00040)***
D6		0.00188 (0.00032)***

	Equation (5.2)	Equation (5.3)
D7		0.00148 (0.00032)***
D8		0.00162 (0.00034)***
D9		0.00282 (0.00035)***
D10		0.00298 (0.00034)***
D11		0.00354 (0.00037)***
D12		0.00430 (0.00047)***
D13		0.00342 (0.00037)***
D14		0.00272 (0.00047)***
Ln(real income)	0.35377 (0.00456)***	0.34376 (0.00451)***
Household size	0.03445 (0.00206)***	0.03730 (0.00202)***
Self production	0.04579 (0.00711)***	0.04957 (0.00696)***
Housing area (m ²)	0.00140 (0.00006)***	0.00138 (0.00006)***
No. refrigerators	0.51007 (0.00677)***	0.50394 (0.00663)***
No. air conditioners	0.13708 (0.00736)***	0.13199 (0.00721)***
No. washing machines	0.14525 (0.00834)***	0.14482 (0.00815)***
No. electric water heaters	0.10544 (0.00833)***	0.10336 (0.00817)***
R ²	0.68	0.66
Observations	55,319	57,331

Notes: Household constants are not reported.

*** significant at 1% level.

Source: Authors' calculation.

Estimation results of equations (5.2) and (5.3) (see [Box 5.1](#) are reported in [Table 5.3](#). Coefficient estimates of household characteristics are very consistent in the two model specifications. The second column in [Table 5.3](#) shows that temperature has a nonlinear impact on residential electricity use. At the median temperature of 24.8 degrees Celsius, a one degree increase raises electricity consumption by 4.86%. However, as temperature goes up, electricity demand increases at an increasing rate. In the last column, we choose the third, fourth, and fifth bins which encounter the least electricity consumption as the base group. Each additional extreme cold day in bin 1 raises annual electricity demand by 0.68%. As it gets warmer, demand first decreases then increases at temperatures higher than 22.87 degrees Celsius. The fact that the coefficients of extreme hot bins 13 and 14

are smaller than that of bin 12 does not tally with the convex effect of temperature as indicated in Equation (5.2). A closer look at the dataset shows that most households which are exposed to excessively hot weather all year round are located along the coastal provinces. Frequent extreme weather conditions (including tropical storms and depressions) make local people more adaptive, *i.e.* less dependent on electricity.

The annual electricity consumption data blur seasonal temperature effects. Therefore, we have used the results of Equation (5.2) to forecast residential electricity demand in the future. If the current consumption pattern remains unchanged, then residential electricity consumption will increase by more than 80% by 2050.

3. Assessment of climate change's impacts on hydropower production

3.1 Introduction

Viet Nam has considerable potential to develop its hydropower, thanks to an intensive system of more than 2,360 rivers and streams longer than 10 km. The ten major rivers that can be adapted to hydropower construction have an approximate total potential capacity of 21–24 GW [UNIDO and ICSHP, 2013]. Such potential has been transformed into power supply to meet increasing power demand. With more

than 70 years of hydropower development since independence (in 1945) and an increase in construction of hydro-plants over the past two decades, Viet Nam has already exploited nearly 70% of its theoretical hydropower potential, compared with the global average rate of 35% [Huu, 2015]. In 2020, hydropower made up 30% of Viet Nam's installed power capacity, amounting to 20.7 GW [IE, 2021].

Hydropower is generally perceived as an affordable, adjustable and sustainable power source. However, it is sensitive to the variations in the hydrological conditions, which in turn respond to the variability of weather factors such as rainfall and temperature [IFC, 2015]. This concern is particularly relevant to Viet Nam, a country forecast to be severely affected by climate change. Some previous assessments provide relevant impli-

cations for the hydropower sector, including (1) increases in energy demand as a result of rising temperatures [MoNRE, 2010]; (2) the potential impact of changing stream flows on hydropower production [WB, 2011], and conflicts over water resources among the agriculture, industry and energy sectors [ADB, 2013]. However, these studies provide mainly qualitative assessments for general sectors, and call for more quantitative analysis.

The objective of this section is to quantify the potential impact of climate change on the generation of hydropower plants in large basins representing different climate zones across Viet Nam. More specifically, the analysis aims at (1) calibrating rainfall-runoff models to simulate inflows into selected hydropower plants at a daily time step; (2) setting up hydropower dam models for selected hydropower reservoir systems; and (3) quantifying the impact of climate change on hydropower production using the hydropower dam model and multiple GCMs and emission scenarios.

3.2 Methodology and Data

Figure 5.3 shows the general methodology applied to model the impacts of climate change on hydropower production. This framework has been applied to a large number of hydropower plants in main river basins across Viet Nam. According to Figure 5.3, quantifying climate change impacts on hydropower production is achieved in two main steps, as follows:

Step 1: Generate the multi-GCM and multi-scenario projections of daily inflows into the selected hydropower dams. Historical and projected climate variables from multiple GCMs are first processed to create the data input formats required for simulating inflows to hydropower dams. Rainfall – runoff models are then set

up for the selected river basins, using observed rainfall, temperature, runoff, topography, soil and land use datasets. We finally generate baseline and future inflows for all hydropower dams by forcing the calibrated rainfall – runoff models with the observed climate variables and multi-GCM climate variables under different emission scenarios.

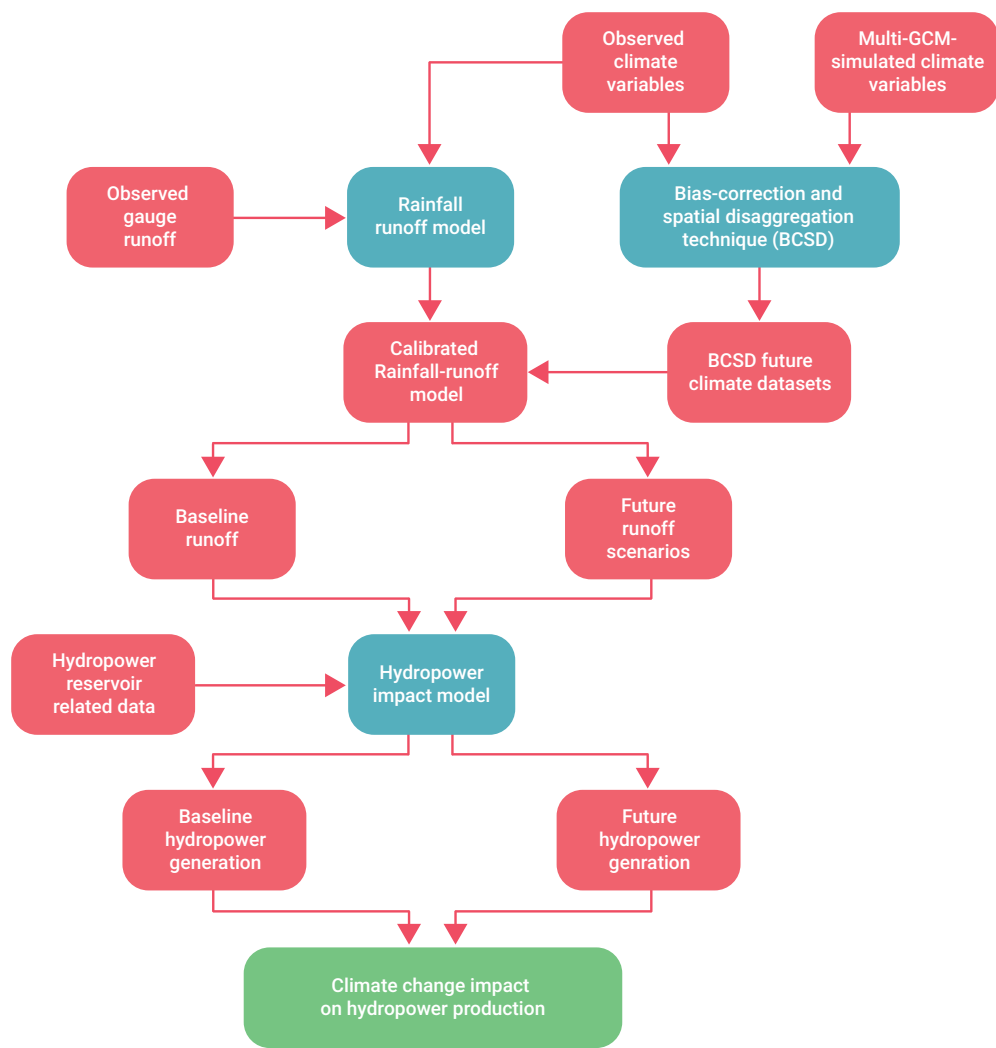
Step 2: Produce the multi-GCM and multi-scenario projections of hydropower production for all of the selected dams. In this step, we first need to build hydropower impact models for all of the selected hydropower dams, using their distinct physical-hydraulic characteristics and historical inflows simulated in Step 1. Then the hydropower impact models are forced using multi-RCM and multi-scenario inflow projections generated from Step 1 to produce the multi-RCM and multi-scenario projections of hydropower production for all of the selected dams. Finally, the potential impacts of climate change on hydropower production across Viet Nam are explored by statistical and visual exploratory analysis of the results.

The following subsections describe the methodology for hydrological simulation, hydropower generation modelling and the data sets used for the analysis in more detail.

Hydrological simulation

For discharge simulation purposes, we employ SWAT (Soil and Water Assessment Tool). This physically-based, continuous, semi-distributed model is widely used around the world to address numerous hydrologic and environmental problems [Gassman *et al.*, 2014]. The model is also applied in various contexts related to Viet Nam at different scales, and contributes to knowledge about drivers that might alter hydrological processes such as

[Figure 5.3]
Methodological framework flowchart



This figure shows a general methodology applied to model the impacts of climate change on hydropower production. According to this figure, the quantification of climate change impacts on hydropower production is achieved by two main steps: (1) Generate the multi-GCM and multi-scenario projections of daily inflows into the selected hydropower dams; (2) Produce the multi-GCM and multi-scenario projections of hydropower production for all of the selected dams.

climate change, deforestation, soil protection, crop conversion and hydropower activities.

For each given watershed, SWAT uses inputted topographic and hydrological data to partition the watershed into multiple sub-basins given a desired level of granularity. Subsequently, sub-basins are broken down further into hydrologic response units (HRUs), which are the smallest component of the analysis, with a specific profile of land cover, soil and management characteristics. The simulation of hydrological cycles at the watershed level is comprised of two processes. The land phase calculates runoffs at the HRU level, then aggregates them at the sub-basin level based on the water balance equation. Accordingly, changes in soil water content at a daily time step are explained by the difference between the amount of precipitation and the total amounts of processes including surface runoff, evapotranspiration, percolation and bypass flow exiting the soil profile bottom, and return flow. In the land phase, the total amount of runoff at the sub-basin level is calculated, and then routed to the main channel through the stream network such that water discharges downstream except for losses due to evaporation and transmission through the bed of the channel, and removal for agricultural and human use. The SWAT model is calibrated and validated using the sequential uncertainty fitting version 2 (SUFI-2) algorithm in SWAT-CUP.

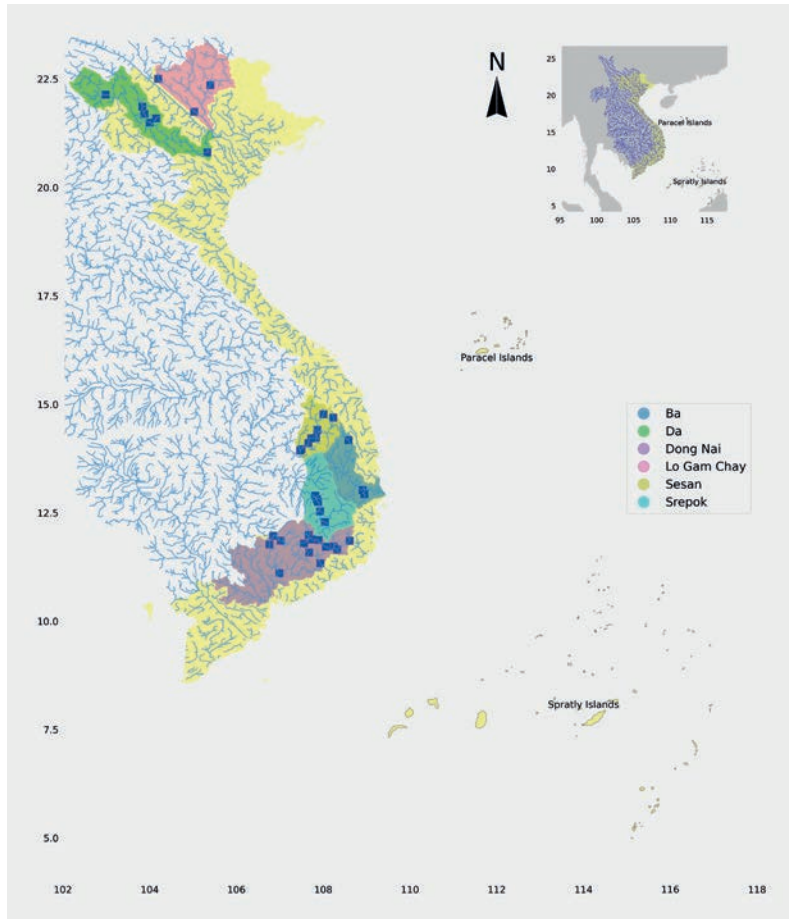
Hydro power generation modelling

Given the scope of this study, we employ both process-based and regression-based models to simulate hydropower generation. The former is used for basins where information is more complete, the coordination between existing dams is well known, and

the assumption on maximising power generation under constraints is plausible. The latter is used where the process-based model is less feasible or sensible. For example, there is a lack of information on meteorological variables beyond Viet Nam's border and their future trends that is consistent with the high-resolution meteorological datasets used in this study. The operational procedure of upstream dams located outside Viet Nam is also not accessible. This means modelling hydropower generation in affected basins requires a pragmatic approach that can tolerate missing information, and allows the model's explainability to be assessed given the lack of information. In addition, rule-based simulation is less likely to be applicable to basins where there is substantial competing water demand other than power generation, especially where anecdotal evidence on water conflicts are recorded.

For the process-based model, which is applied for the Dong Nai, Sesan and Srepok basins, we have reproduced the flow and diversion of water, and the physical operations of reservoirs and hydropower plants in a system of reservoirs and river reaches, by employing a river-reservoir system simulation model, namely HEC-ResSim model. HEC-ResSim was developed by the U.S. Army Corps of Engineers [HEC, 2007]. The HEC-ResSim model was widely and successfully employed in many previous studies around the world to model water resource allocation and reservoir operations at one or more reservoirs for a variety of operational goals and constraints, and also to generate production outputs from daily flow data [Piman *et al.*, 2016; Tilmant *et al.*, 2011; Uysal *et al.*, 2016]. The model uses an original rule-based approach plus user-specified operating rules for the operational goals and constraints that reservoir operators must

[Figure 5.4]
Analysed hydropower dams and basins (domestic area)



This figure uses underlying data from HydroSHEDS/HydroBASINS [Lehner *et al.*, 2008, Lehner and Grill, 2013], Rivers in South and East Asia [FAO, 2014], and Global Administrative unit layers [FAO, 2015].

use to meet multipurpose goals, including flood reduction, water supply, hydropower generation, and stream flow requirements. In our study, simulated daily flows for each sub-basin from SWAT are lumped at the dam sites and used as input to the model. In addition, physical, hydraulic, and energy characteristics, as well as operation rules for reservoirs, are also required inputs to the model.

Regarding the regression-based method, which is applied for the Da, Lo-Gam-Chay and Ba basins, we have fitted the observed series for monthly generation at each dam with a set of information about hydrological conditions and operation. We start with a simple empirical specification as proposed by Cole *et al.* (2014), which uses the quadratic function of contemporaneous simulated river flow to pre-

[Table 5.4]
Data sources

Data types	Sources	Notes
Basin boundary and river networks	FAO Rivers in South and East Asia and HydroBASINS	~ 30 arc-seconds
Digital Elevation Model (DEM)	HydroSHEDSvoid-filled DEM	~ 3 arc-seconds
Soil	Digital Soil Map of the World version 3.6	~ 5 arc minutes
Land cover	UMD Land Cover classification collection	~ 1 km pixels
Historical weather data	VnGP and VnGC dataset	0.1 deg ~ 10km, from 147 temperature and 481 rainfall stations
Climate change scenarios	Bias Correction and Spatial Downscaling (BCSD) GCM dataset (see Chapter 1 for more details)	0.1 deg ~ 10km, various models for 2 RCPs
Physical and hydraulic characteristics, operation rules of reservoirs, and hydropower production	Regulations issued by the Vietnamese Government on promulgating the reservoir operating procedures; Institute of Energy	Large hydropower plants with a capacity of more than 30 megawatts (MW)
Historical river flow	Viet Nam's Hydro-Meteorological Data Center	Most relevant stations

dict hydropower generation. We improve this specification in a number of ways. First, we model the dynamic effect and include a quadratic function of lagged simulated river flow to take into account the water storage role of large reservoirs attached to dams. Second, we model the impact of upstream dams where a cascade is formed. Technically, we include interaction terms between a binary variable for the operation of a particular upstream dam and the quadratic function of river flow to downstream dams. In another extension, we also take account of the cascade effect dependent on the simulated flow to upstream dams.

Data

In this study, we examine 6 major basins that are representative of different climate regions across the country. In addition, the hydropower plants in the selected river basins represent a significant contribution to national hydropower energy, accounting for more than 80% of the national installed hydropower capacity. The selected basins as illustrated in [Figure 5.4](#) include Da, Lo-Gam-Chay, Ba, Sesan, Srepok and Dong Nai.

Our analysis is based on a range of data as summarized in [Table 5.4](#). We note that for the projections of hydropower generation changes, we rely on projected daily time series for rainfall, maximum and minimum

temperature from 31 GCM simulations processed by the Laboratory for REmote sensing and MOdelling of Surface and ATmosphere (REMOSAT) (See [Chapter 1](#) for more details). Two emission scenarios are chosen, including an intermediate emissions scenario, referred to as RCP4.5 and a high emissions scenario, referred to as RCP8.5. Finally, for the purpose of evaluating the changes in hydropower production resulting from projected changes in climate, we set the baseline period to 1999–2018 and the future period to 2041–2060.

3.3 Results and Discussion

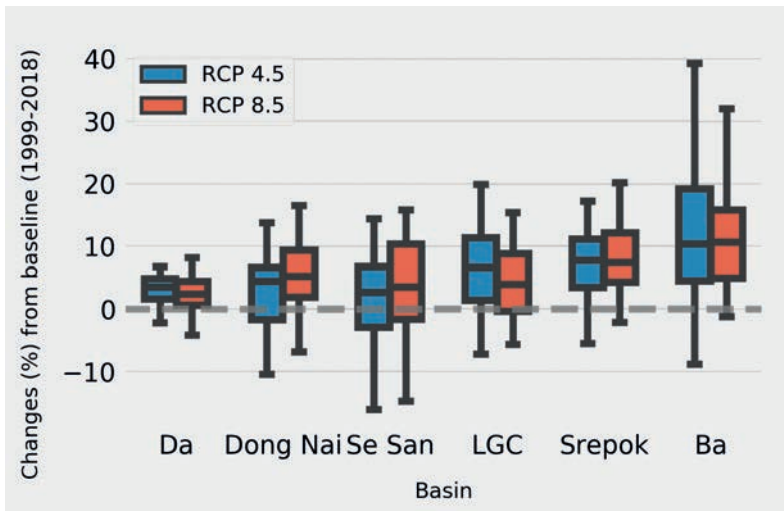
As can be seen from [Figure 5.5](#), climate change's impact on annual hydropower generation varies across the country, reflecting the climatic, topographic and hydrological diversity of Viet Nam. The impact is highly uncertain, with the sign being either positive or negative, dependent on climate models and emission scenarios. The ensemble medians of 31 climate models report an increasing trend in all basins under both studied RCPs, which is mainly driven by the increase in precipitation projected across the country by the mid-century (see [Chapter 1](#)). In many basins, climate change is however likely to reduce discharge in the dry season, putting pressure on hydropower generation and the energy system. We will, in turn, discuss the impact at basin level below.

Originating from China and flowing through the Northwest of Viet Nam, the Da river basin has played a critical role in the national hydropower system. It has hosted the country's largest hydropower plants, including Hoa Binh (1920 MW) since 1994 and then Son La (2400 MW) since 2012, and accounts for 43.9% of Viet Nam's installed hydropower capacity (as of 2017). Besides their impor-

tance in energy production, large reservoirs attached to hydropower cascades in Da River also contribute substantially to other purposes, such as irrigation and flood control for the downstream regions, including the capital Hanoi. Our projected changes in Da River's hydropower generation for the 2050s using RCP4.5 and 29 climate models (excluding 2 outliers GFDL-CM3 and MIROC5) vary between a decrease of 2.2% and an increase of 6.8% compared with the baseline period (1999–2018). Projections for RCP8.5 present a larger range of uncertainty, with changes from the baseline varying between -4.1% and +8.2% across 31 climate models. The median models for RCP4.5 and 8.5 suggest an increase in generation by 3.5% and 2.4%, respectively. A more detailed analysis suggests that climate change is more likely to reduce hydropower generation in Da basin between January-February and May-June. The ensemble median change in June is -3.7% for RCP4.5 and -4.7% for RCP8.5. A reduction in the hydropower production of large dams in early summer would be a cause for concern. It would coincide with the time when energy demand typically soars, chiefly for cooling purposes, and potentially compromises the power system's reliability.

The Dong Nai river basin is the second-largest national river basin, covering a drainage area of 40,863 km². The basin originates in the Central Highlands of Viet Nam, flows down through many provinces in the southern part of the country including Ho Chi Minh City, and finally pours into the East Sea. In terms of hydropower potential, the Dong Nai river has the second highest rank in Viet Nam, after the Da river basin. The total installed hydropower capacity of Dong Nai river basin reached about 2,650 MW, accounting for 17% of the total national hydropower capacity (as

[Figure 5.5]
Projected Annual Hydropower Generation by basin (2041–2060)



of year 2017). As can be seen in Figure 5.5, the ensemble median change in annual hydropower production is +5% under RCP4.5 and +6% under RCP8.5. The change ranges from -1% to +7% over the future period with RCP4.5 and from +2% to +10% with RCP8.5 [Figure 5.5]. Our projected changes in the Dong Nai river's monthly hydropower production also show large uncertainty among the 31 GCM simulations, and higher median increases are simulated under RCP8.5 for most months. Under RCP8.5, the majority of GCM simulations forecast increased changes in hydropower production for most months – with the exception of May, June and August – with the increased changes varying from 0 to 18%. The projected changes for May, June and August vary between -4% to 7% with RCP8.5. Under RCP4.5, results for hydropower production show a tendency for very marginal increases in many months, namely in January, February, May, June, and August, averaging 1% in a range of -7% to 5% across all the GCM models.

The Se San river is one of the major tributaries of the lower Mekong basin flows, located in the Central Highlands of Viet Nam and flowing down to north-east Cambodia. It has a total area of 17,300 km², of which 9,340 km² is in Viet Nam. The Se San river has the third-largest hydroelectric power potential after the Da and Dong Nai rivers, accounting for nearly 12% of the total national hydropower production (as of year 2017). As depicted in Figure 5.5, the majority of GCMs forecast increased changes in the annual hydropower production of the Se San river basin, and the RCP8.5 emissions scenario imply changes higher increased change than the RCP4.5 emissions scenario. We project an average change in the Se San river's annual hydropower of 3% in a range of -2% to 7 under RCP4.5, and of 7% in a range of -1% to 10% under RCP8.5 by the 2050s. Average monthly energy production results also show a more uncertain forecast for the months of December, January, February, June, July, and August compared to the other months under both scenarios. The simula-

tions for March, April, May, June and August show a projected change of hydropower production in both increasing and decreasing directions within a range of -7% to 5% across the GCMs and RCPs. For the other months, most of the GCM and emission scenarios agree on an increase in hydropower production within a range of 1% to 20%.

Lo-Gam-Chay is a trans-boundary basin, which originates in China and flows through many north-western provinces of Viet Nam. It is the second most important hydropower basin in the North, and accounts for 5.6% of the total national hydropower capacity. Though there is no consensus across all 31 models on the impact of climate change on annual hydropower generation in the Lo-Gam-Chay basin, most models report a growing tendency by the mid-century. The ensemble median changes under RCPs 4.5 and 8.5 are +6.6% and +4.0% respectively. More specifically, an increase in power generation is expected to be seen throughout the year, except for December–February (both RCPs) and May (RCP8.5). Generation in April is projected to increase substantially with middle projections of +25.4% (RCP4.5) and +19.2% (RCP8.5). Meanwhile, ensemble median changes in January and February report a decrease by 7.0%–11.0% under RCP4.5, and 9.0%–11.3% under RCP8.5.

The Srepok river basin is also one of the major tributaries of the Mekong River Basin, originating in the Central Highlands of Viet Nam, and flowing down to Cambodia before joining the Mekong mainstream. The basin has a total area of 30,900 km², of which 59% is in Viet Nam and 41% in Cambodia. The Srepok river basin also has potential to develop hydropower stations due to its topographic conditions, with the total installed hydropower capacity of 730 MW accounting for about 5% of total na-

tional hydropower capacity (as of year 2017). The ensemble of the 31 GCM simulations under RCPs 4.5 and 8.5 also produce increases in the Se San river's annual hydropower production, which ranges from 3% to 11% under RCP4.5 and from 4% to 12% under RCP8.5 [Figure 5.5]. The median of the 31 CMIP5 mean monthly hydropower generation data over the Se San river shows increases in the wet season (from June to December) and decreases in the dry season (from January to May). Results of the projections during the wet season (especially in August to November) have the least variance among all the GCM simulations, and show a significant increase averaging at 12%. There are relatively high uncertainties in the projected mean monthly energy production results in the dry season (especially in March, April and May) among the climate models, and the change is within the range of -25% to 25% for all the GCMs and scenarios.

Ba river is the largest river in the Central Coast, flowing through Kon Tum, Gia Lai, Đak Lak and Phu Yen. Rainfall and water resources are distributed unevenly in space and time, with competing interests and even conflicts in water usage recorded in many occasions. Our middle climate models report an increase between 10.4% and 10.6% in annual hydropower under RCPs 4.5 and 8.5 respectively. However, the uncertainty range is very wide, with a decrease of 8.8% (RCP4.5) and 18.8% (RCP8.5) reported in the worst case. Ensemble median changes under both RCPs in monthly generation report a moderate decrease between February and May, a substantial increase between October and December, and a marginal change in other months.

Several insights from the above analysis merit further discussion. Though the median results

suggest a potential increase in hydropower generation across the country due to more frequent and intense rainfall, the range of uncertainty must be taken into account in adaptive management. For example, power source planning should not be over-reliant on any single point estimate, such as the mean or median scenarios, but also consider the best and worst cases, such as wet and dry scenarios covered in our results for all 31 climate models. Second, as climate change could induce more extreme weather events such as droughts and floods and increase the seasonal variability of river flows, hydropower generation could become more volatile. As presented in our monthly analysis for some large basins, the reduction

in hydropower generation during the dry season due to a shortage of water is reasonably likely to occur. This calls for contingency plans to avoid power disruption adversely affecting firms' performance and household welfare. Meanwhile, climate-proofing engineering interventions could be considered to enhance the resilience of hydropower facilities in the face of higher risk of severe floods in wet seasons. Finally, as the impact of climate change tends to vary across basins, local monitoring is critical to provide early warnings, while regional and national coordination and management could help spatially to smooth out the adverse consequences of climate risks.

4. Assessment of climate change's impacts on energy system

4.1 Introduction

Energy systems can be vulnerable to climate change. Both energy demand and supply can be altered by climate change. Warmer winters can reduce space heating demand, and hotter summers can raise cooling demand. The supply side of the energy sector may also experience positive and negative impacts. For instance, hydroelectricity output may be enhanced in some regions thanks to increased rainfall patterns, but thermoelectric power may become more vulnerable due to lower summer flows and higher water temperatures [Ciscar and Dowling, 2014].

The objective of this section is to assess the impact of climate change on the energy system in Viet Nam, focusing on electricity demand and hydropower generation up to 2050, and to propose adaptation measures in response to these impacts.

Two groups of models can be distinguished for modelling climate impacts on the energy system: economic and engineering models. According to the way the energy system is represented, they can also be named top-down (economic) and bottom-up (engineering or techno-economic) models [Ciscar and Dowling, 2014].

A common feature of the economic models is that they use a standard economic demand equation, where energy demand is a function of energy prices, income and climate variables. Because the economic models typically use income and prices as variables, these models are well-suited for analysing tax and subsidy policies [UNEP, 1998].

Engineering models for analysis of the impacts of climate change typically involve the analysis of demand by end use (e.g., space heating, space cooling), using engineering principles. To assess climate change impacts, only a few end-uses need to be addressed, which simplifies the analysis. Engineering methods also can encompass hydrological models of the effects on hydroelectric generation for river flows [UNEP, 1998].

For this section, the assessment is based on the LEAP model, an engineering model developed for Viet Nam's energy system. In the LEAP model, demand for residential cooling from Section 2 would be broken down by urban and rural areas, and hydro power plants are classified according to river basins in different regions. To understand the integrated effects on the whole energy system, we simultaneously model temperature-induced changes in cooling demand, leading to changes in the capacity utilization of power generation and transmission lines, which themselves are affected by climate change. The model will use country-wide temperature and precipitation projections for the years 2020–2050 under various climate change scenarios. The differences between the BAU and climate change impact scenarios demonstrate the impacts of climate change on the energy system, in terms of primary energy consumption and production costs as well as GHG emissions.

4.2 Methodology and data assumptions

Methodology

The evaluations conducted for this section make use of two independent approaches. Regression approaches are used to analyse the

overall impact of changes in temperature and rainfall on electricity demand and hydropower production (as shown in Sections 2 & 3 above). Most of this section looks at modelling that is performed using a bottom-up energy accounting approach, using LEAP software.

Firstly, a BAU is developed to outline future energy demand during 2017–2050, based on GDP, population projections, electricity demand, fuel mix and costs for power generation, which are derived from the Power Plan Development (PDP) VIII draft version 05/2021, the National Master Plan for Energy Development, and other published documents.

Taking the BAU electricity projection (that is developed for PDPVIII) as a base, this model seeks to investigate the impacts of climate change on the aspects of the economy and environment over the next three decades. Two climate change impact scenarios (for electricity demand and hydropower production) have been developed for comparison to the BAU model. To enable the impacts of climate changes to be modelled, this model is supplemented with assumptions on: i) the relationship between temperature changes and electricity demand; ii) the relationship between rainfall and temperature changes, and annual hydropower production; and iii) what temperature and rainfall changes will take place under RCP4.5 and RCP8.5.

Data and assumption

These climate change impact scenarios are developed based on Viet Nam's climate change scenarios combined with forecasts for electricity demand and hydropower plants in a warming climate, with the input data and assumptions as follows:

[Table 5.5]

Annual average temperature changes (°C) in comparison with the 2017 baseline

	2025	2030	2035	2040	2045	2050	2055
RCP4.5	0.18	0.29	0.41	0.52	0.63	0.75	0.84
RCP8.5	0.31	0.51	0.72	0.93	1.15	1.39	1.62

Source: Authors' estimations based on RCPs 4.5 & 8.5 scenarios.

Basic energy and environmental data

In the generation module, data on power capacity, process efficiencies, capital cost, and operations and maintenance (O&M) costs were taken from Viet Nam's Nationally Determined Contributions for Energy and Transport Sectors and PDP VIII of Viet Nam.

In other modules (such as natural gas production, oil refining, crude oil production, and coal production), the capacity data and other data on process efficiencies, capital costs, O&M costs, and others were referred to the PDP VIII and other studies or overseas data.

The environmental externality costs are also included in this study. As yet, Viet Nam has not officially carried out any study on the external costs associated with electricity generation. Due to a lack of sufficient data and specific evaluations to calculate externality costs in the power sector, external cost factors are extrapolated from other relevant studies in China, including nitrogen oxides (NO_x), sulphur dioxide (SO₂), and particulate matter (PM₁₀). The average cost of CO₂ control is referred from studies in China and Europe [H.A Nguyen-Trinh and M. Ha-Duong, 2015].

Warming climate data

To generate climate change scenarios for Viet Nam, we rely on a national climate dataset

(downscaled from outputs of global climate models) that was developed by the Laboratory for REmote sensing and MOdelling of Surface and ATmosphere (REMOSAT) in chapter 1. Specifically, the bias-correction and spatial disaggregation technique [BCSD; Wood *et al.*, 2002] is used to disaggregate global simulations of 31 models contributing to the CMIP5 experiment under emission scenarios RCP4.5 and RCP8.5 to a 0.1 arc-degree resolution. We then estimate daily temperature for Viet Nam (from 1980 to 2005 for the historical simulation and from 2006 to 2100 for future simulations) by averaging daily mean temperature across all grid cells within Viet Nam. The daily time series is then aggregated by calendar year to get an annual time series of temperature over Viet Nam (from 1980 to 2100). This procedure is applied for each of the models available through this project.

Relationship between electricity demand and temperature changes

Changes in temperature will result in changes of electricity demand. The relationship between changes in temperature and changes in electricity demand is defined as the proportionate increase in the quantity of demand per 1°C increase in temperature.

Table 5.5 provides an overview of changes in annual average temperature using the 2017

[Table 5.6]
The increase rate of electricity demand due to climate change up to 2050

		2025	2030	In comparison with 2017		2045	2050
				2035	2040		
RCP4.5	Residential	0.87%	1.41%	1.99%	2.53%	3.06%	3.65%
	Industrial	0.78%	1.25%	1.77%	2.24%	2.72%	3.23%
RCP8.5	Residential	1.51%	2.48%	3.50%	4.52%	5.59%	6.76%
	Industrial	1.34%	2.20%	3.10%	4.01%	4.96%	5.99%

Source: Authors' estimations.

baseline. We note that each year (as shown in these exhibitions) was used as the notation to represent a specific 20-year period. For instance, “2017 temperature” was averaged using annual temperature for Viet Nam from 2008 to 2027. Similarly, future temperatures were also calculated for each of the 20-year periods (e.g. the 2025 temperature was calculated from annual temperature from 2016 to 2035).

The increase of average temperatures in climate change scenarios compared to those in 2017 is the basis for assessing the impacts of temperature changes on electricity demand in the period 2017–2050. The evaluative results on the impacts of climate change on residential and industrial electricity consumption (as indicate in Section 2.2) indicate that average ambient temperature has significant impacts on electricity consumption. An increase of 1°C in the temperature will result in an increase of 4.86% and 4.31% in residential and industrial electricity consumption, respectively. With these evaluative results, by 2050, the additional increase rate of residential and industrial electricity demand due to climate change will be 3.65% and 3.23% according to RCP4.5 and 6.76% and 5.99% according to RCP8.5 (see Table 5.6).

Relationship between hydropower production and rainfall changes

The amount of electricity that can be generated from hydropower plants depends not only on the installed generation capacity, but also on the variation in water inflows to the plants reservoirs. Higher precipitation could increase seasonal river flows and water storage in the reservoir. Thus, rainfall changes can directly affect hydropower output.

According to the RCP4.5 scenario, at the beginning of the century, annual rainfall will tend to increase by 5–10% in most of the country. By the mid-century, the rainfall will likely increase by 5–15% in general. Some coastal provinces in the Red River Delta, the North Central Coast and Central Coast may have rainfall rise by above 20%. As in the RCP8.5 scenario, annual rainfall will likely increase in most of the country at the beginning of the century, by 3–10% in general. By the mid-century, the increase trend of annual rainfall will likely be similar to the increase trend of the RCP4.5 scenario.

The evaluative results on the impacts of climate change on hydropower production indicate that hydropower production for all the river basins is projected to increase under

both RCP4.5 and RCP8.5. As shown in Section 3.3, the annual production change could be estimated ranging from -3.5% to +25.7% with RCP4.5 and from -3.3% to +23.1% with RCP8.5 over the future periods in the six main basins.

4.3 Climate change's impacts on the energy system

The results of modelling the impacts of climate change suggest that, given the assumptions we have made above, climate change's impacts on electricity demand in both the residential and industrial sectors could result in a significant increase in electricity demand. However, climate change impact on hydropower production suggests that climate change has little or even a positive impact on hydropower generation. Under the climate change scenarios (RCP4.5 and RCP8.5), the additional increase in electricity demand (from BAU scenario) is much higher than the additional increase in hydropower generation, resulting in increased fuels and costs for power generation, as well as primary energy supply and GHG emissions.

Increase in primary energy supply

Electricity demand significantly increases from the BAU scenario, due to the increase of temperature, ranging from 2.8% to 5.2% by 2050 under RCP4.5 and RCP8.5 scenarios, respectively. These increases result in corresponding increases of primary energy supply (due to the increase of input fuels for power generation) of 1.3% and 2.4% under RCP4.5 and RCP8.5, respectively. If the whole period from 2017 to 2050 is examined, the total cumulative additional increase of primary energy demand will show a large and rapid in-

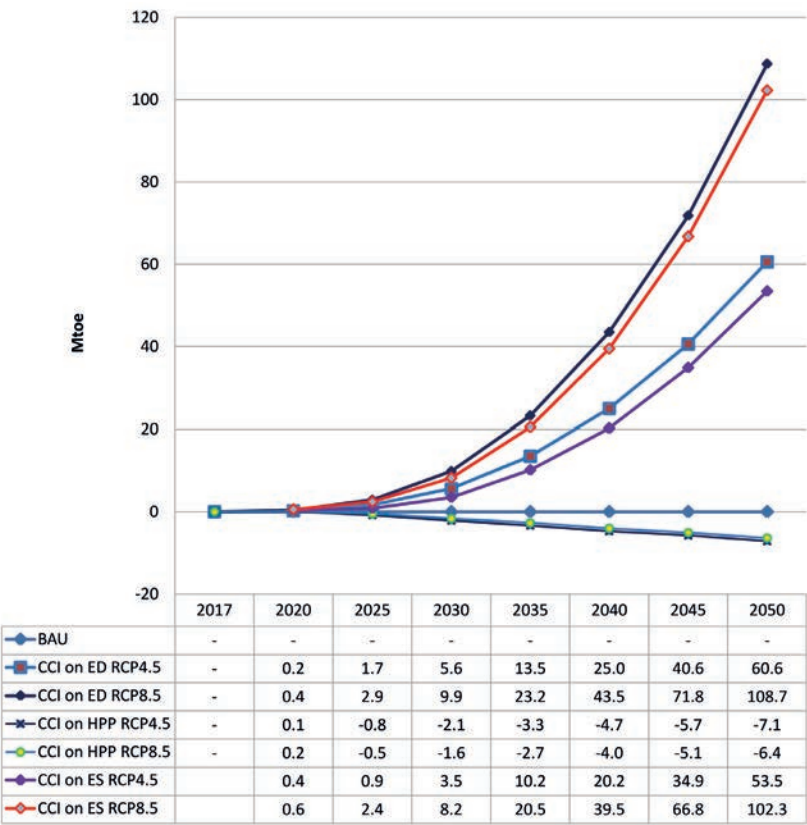
crease, from 1.7 Mtoe and 2.9 Mtoe by 2025 to 60.6 Mtoe and 108.7 Mtoe by 2050 under RCP4.5 and RCP8.5, respectively. These additional increases are mostly fuels used for power generation, to meet the additional increase of electricity demand due to climate change.

Contrary to the electricity demand due side, the increase in precipitation due to climate change will drive an increase in electricity generation output from hydropower. However, this increase is negligible and similar in both scenarios RCP4.5 and RCP8.5, ranging from 0.04% to 0.13% of BAU's electricity generation output during the period 2017–2050. This increase in electricity generation output results in the decrease of other substitute fuels used for power generation, and thus decreases the appropriate primary energy supply demand. The total cumulative decrease of other substitute fuels will be modest, with 7.1 Mtoe and 6.4 Mtoe by 2050 under RCP4.5 and RCP8.5, respectively. This decrease of primary energy supply is smaller than the additional increase in primary energy supply due to the impacts of climate change on electricity demand. On the energy system aspect, the impacts of climate change on the energy system will cause a significant and rapid increase of primary energy demand, with a cumulative additional increase from 0.9 Mtoe and 2.4 Mtoe by 2020 to 53.5 Mtoe and 102.3 Mtoe by 2050 under RCP4.5 and RCP8.5, respectively [Figure 5.6].

Increase in emissions from the power generation sector

As a result of the impact of climate change on electricity demand, the additional increase in fuels for power generation results in additional emissions increases from the power sector from 1.9% to 3.6% by 2050 under RCP4.5

[Figure 5.6]
Cumulative total primary energy supply demand up to 2050, CCI scenarios v.s BAU



BAU: Business-As-Usual / CCI on ED = climate change impacts on electricity demand.
CCI on HPP = climate change impacts on hydropower production.
CCI on ES = climate change impacts on the energy system.
Source: Authors' calculations.

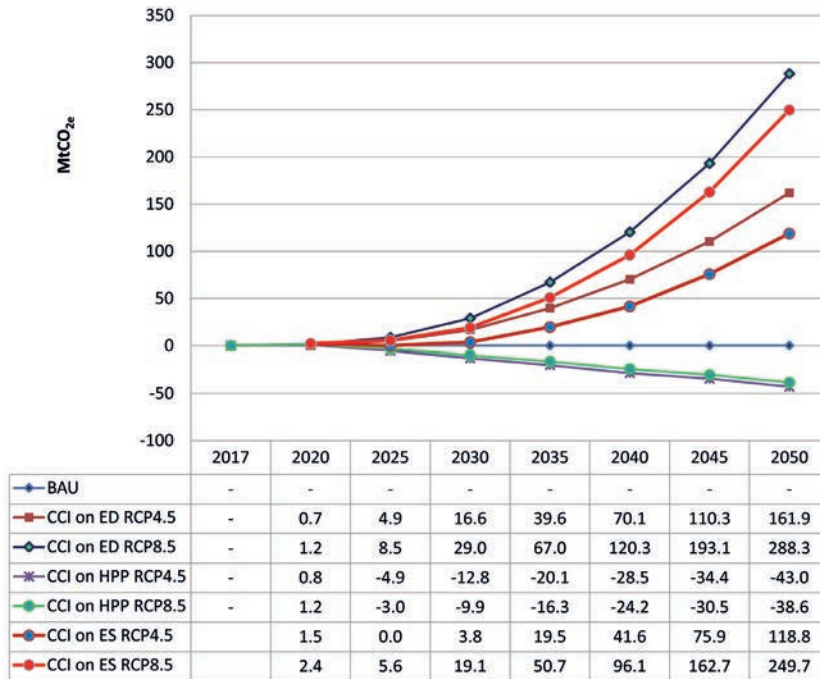
and RCP8.5, respectively. For the whole period 2017–2050, the total cumulative additional increase of emissions in the power sector will be significant, with 161.9 MtCO₂e and 288.3 MtCO₂e by 2050 under RCP4.5 and RCP8.5, respectively.

Contrary to electricity demand, the decrease of other substitute fuels used for power generation due to the increase in electricity generation output from hydropower under climate

change scenarios results in the decrease of CO₂ emissions from the power sector. The total cumulative decrease of CO₂ emissions from hydropower production will be modest with 43.0 MtCO₂e and 38.6 MtCO₂e by 2050 under RCP4.5 and RCP8.5, respectively. This decrease in emissions from hydropower is smaller than the additional increase in CO₂ emissions due to the impacts of climate change on electricity demand, and with respect to the energy system aspect, the impacts of climate change on the

[Figure 5.7]

Cumulative increase emissions in power sector, CCI scenarios v.s BAU



BAU: Business-As-Usual / CCI on ED = climate change impacts on electricity demand.

CCI on HPP = climate change impacts on hydropower production.

CCI on ES = climate change impacts on the energy system.

Source: Authors' calculations.

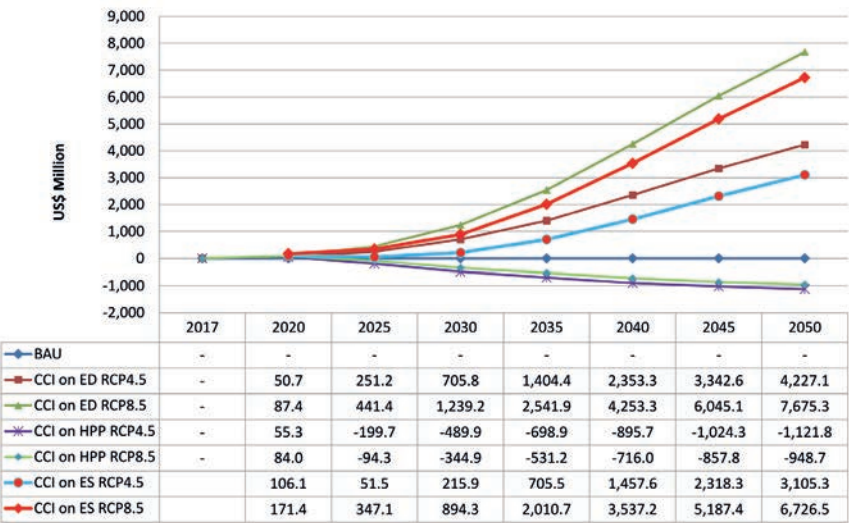
energy system will cause a significant increase in CO₂ emissions, with a cumulative additional increase of 118.8 MtCO₂e and 249.7 MtCO₂e by 2050 under RCP4.5 and RCP8.5, respectively [Figure 5.7].

Social cost impact of CCI scenarios

The increase in electricity demand as a result of climate change scenarios results in an increase in the costs for power production, including fuel costs and O&M costs, as well as additional external costs of GHG emissions. The calculation results [Figure 5.8] show that the total cumulative costs of CCIs on electri-

city demand under RCP4.5 and RCP8.5 in the 2017–2050 period (discounted at 10.0%) are approximately US\$ 4,227.1 million and US\$ 7,675.3 million, respectively: imported fuel costs account for most of that (at least 80%) in both CCIs, while the remainder represents external costs of GHG (around 10%), and operation and management costs for power generation (see Table 5.7 for more details). On the other hand, the increase in electricity production for hydropower due to CCI scenarios results in a decrease in other input fuels and thus in the costs of power generation, including costs for fuels and O&M costs, as well as additional external costs of GHG emissions.

[Figure 5.8]
The results of social-economic impact of climate change on energy system



BAU: Business-As-Usual / CCI on ED = climate change impacts on electricity demand
CCI on HPP = climate change impacts on hydropower production
CCI on ES = climate change impacts on the energy system.
Source: Authors' calculations.

The calculation results [Figure 5.8] show that total cumulative decreased costs of CCIs on hydropower production under RCP4.5 and RCP8.5 in the 2017–2050 period (discounted at 10.0%) are approximately US\$ 1,121.8 million and US\$ 948.7 million, respectively: imported fuel costs account for most of that (at least 80%) in both CCIs, while the remainder represents external costs of GHG (around 10%), and operation and management costs for power generation.

The decrease in hydropower's social costs is smaller than the additional increase in social costs due to the impacts of climate change on electricity demand, and with respect to the energy system, the impacts of climate change on the energy system will cause a significant increase in social costs, with a cumulative ad-

ditional increase of US\$ 3,105.3 million and US\$ 6,726.5 million by 2050 under RCP4.5 and RCP8.5, respectively. In both RCP4.5 and RCP8.5, the additional fuels are mostly imported fuels for power generation, which increases dependency on fuel imports and is thus a threat to national energy security.

5. Proposed adaptation measures responding to climate change

As analysed above, the impacts of climate change on the energy system can raise electricity demand, mostly for cooling uses, which is likely to lead to an increase in fuel consumption, costs and GHG emissions in power generation. The decreased use of electricity for cooling uses through the promotion of more efficient air conditioners and other electricity-efficient devices may mitigate these impacts of climate change on electricity demand. Similarly, the development of other alternative renewable electricity sources to reduce GHG emissions could be potential measures to respond to climate change.

The proposed adaptation measures responding to climate change are based on a cost-benefit analysis of the technological responses to climate change that are selected, including: Residential energy efficiency air conditioning (EE-AC), residential high efficiency refrigerators (EE-R), residential energy efficiency lighting (EE-L), solar photovoltaic power plants and wind power plants.

This section focuses on the cost-benefit analysis of EE and renewable energy (RE) technologies, based on basic assumptions and input data.

5.1 Basic assumptions

On the demand side, it is assumed that EE technologies such as residential air conditioning, residential refrigerators and residential

lighting will penetrate at high rate — at least 75% in rural areas and 90% in urban areas — and that EE technologies in the industrial sector will help save around 5.0% and 6.5% of energy demand by 2030 and 2050, respectively.

On power generation, solar PV and wind technologies are expected to achieve 50,000 MW and 40,000 MW respectively in 2050, replacing imported coal power plants (as referred from PDPVIII-Base case scenario).

Data on the economic and technical specifications of each EE and RE technology option are taken from WB's study and Viet Nam's Nationally Determined Contributions for Energy and Transport Sectors.

5.2. Social costs and benefits of proposed adaptation measures

Table 5.7 presents a summary of the results of the social-economic impact of climate change and adaptation measures in response to climate change, including costs and benefits of the impacts implemented in the 2017–2050 period (discounted at 10%), GHG emission reduction potentials and cost of avoiding GHGs.

From the calculation results [Table 5.7], some comments can be drawn, as follows:

► The calculations show that the total additional investment costs for wind power plants is US\$14,368.6 million, while it can save US\$ 13,150.4 million by economising fuel for power generation and reduce 1,521.5 MtCO₂e at an abatement cost of US\$ 0.8/tCO₂e. As for the economic aspect, the total investment cost is slightly higher than benefits, but this option is a good mitigation option with great GHG

savings and low GHG abatement costs: wind power could thus be one of options for adaptation measures. Other remaining measures are feasible because of high economic return and low GHG abatement costs, and could be good solutions in response to the impacts of climate change.

► Under climate change scenarios, the increase in electricity demand results in an increase in costs for power production and GHG emissions. The total cumulative costs of CCIs in the 2017–2050 period range from US\$ 4,227.5 million to US\$ 7,675.3 million (including the external costs of GHG emissions), with cumulative additional emissions of 161.9 MtCO₂e and 288.3 MtCO₂e under RCP4.5 and RCP8.5 respectively.

► The total costs (including investment costs and O&M costs) of adaptation measures for energy demand in residential and industrial sectors and renewable electricity development are approximately US\$ 21,239.7 million, resulting in social benefits of almost US\$ 31,770.7 million, with the majority accounted for in reduced fuel imports (US\$ 22,948.8 million), while it can also in reduced 2,837.7 MtCO₂e at an abatement cost of US\$ -3.7/tCO₂e. Thus, the implementation of these technology measures can save US\$ 10,531.1 million, which is higher than the costs of CCIs on electricity demand in the 2017–2050 period under RCP8.5, by US\$ 7,675.3 million at the discount rate of 10%. However, there is uncertainty over the discount rate, which could have a significant impact on the viability on benefits of the proposed measures. With a higher discount rate of 12%, these technology measures can save US\$ 5,559.1 million, which is still higher than the costs of CCIs on electricity demand under RCP8.5, by US\$ 5,205.0 million.

Therefore, implementing these technology measures not only completely eliminates the impacts of climate change, but also significantly contributes to GHG reduction and sustainable economic development. In the case of a higher discount rate of 13%, these technology measures can save only US\$ 3,854.7 million, which is lower than the costs of CCIs on electricity demand under RCP8.5, by US\$ 4,327.6 million, and become unfeasible.

[Table 5.7]

The results of social-economic impact of climate change and technology measures in response to climate change

	CCI on the energy system				Technology measures in response to CCI						Total
	CCI on ED RCP4.5	CCI on RCP8.5	CCI on HPP RCP4.5	CCI on HPP RCP8.5	Residential EEAC	Residential EER	Residential EE Lamps	Industrial EE Tech.	Solar PV	Wind Power	
Costs	4,227.5	7,675.3	1.9	6.2	1,410.3	396.3	583.0	2,760.1	1,721.4	14,368.6	21,239.7
At the demand side	-	-	-	-	1,410.2	396.1	582.0	2,759.0	0	0	5,147.3
At the supply side	4,227.5	7,675.3	1.9	6.2	0.1	0.2	1.0	1.1	1,721.4	14,368.6	16,092.4
Electricity generation	207.8	362.4							1,721.4	14,368.6	16,090.0
Energy production	38.9	70.0	1.9	6.2							
Imports	3,563.6	6,512.1									
Exports		2.3			0.1	0.2	1.0	1.1			2.4
Environmental Externalities	417.2	728.5									
Benefits	-0.4	-	-1,123.7	-954.9	-2,002.2	-698.9	-3,308.9	-8,342.2	-4,268.2	-13,150.4	-31,770.7
Electricity generation			-25.0	-18.2	-112.0	-41.8	-226.6	-469.3			-849.7
Energy production					-23.8	-7.4	-37.4	-76.9	-	-	-145.4
Imports			-925.3	-802.1	-1,640.2	-566.2	-2,592.9	-6,455.4	-2,869.5	-8,824.6	-22,948.8
Exports	-0.4		-0.5	-0.7				-	-	-	
Environmental Externalities			-173.0	-133.9	-226.2	-83.5	-452.0	-1,340.6	-1,398.7	-4,325.7	-7,826.8
Total Net Present Value	4,227.1	7,675.3	-1,121.8	-948.7	-592.0	-302.6	-2,726.0	-5,582.0	-2,546.8	1,218.3	-10,531.1
GHG Savings (MtCO ₂ e)	-161.9	-288.3	43.0	38.6	110.0	29.1	138.7	489.0	549.4	1,521.5	2,837.7
Cost of Avoided GHGs (USD/tCO₂e)	n/a	n/a	-26.1	-24.6	-5.4	-10.4	-19.7	-11.4	-4.6	0.8	-3.7

CCI on ED = climate change impacts on electricity demand, CCI on HPP = climate change impacts on hydropower production, EE-AC = energy efficiency air conditioning, EE-R = energy efficiency refrigerator, EE-L = energy efficiency lighting
Unit: 2017 US\$ million (discounted at 10.0% to year 2017). Source: Calculation results from LEAP model.

6. Conclusions and Recommendations

6.1 Conclusions

Climate change is likely to have a significant impact on Viet Nam's energy system. All other things being equal, each additional degree Celsius is estimated to increase electricity consumption among households by 4.86%, and firms' energy demand by 4.31%. These significant effects, compounded with an expected 5–6% economic growth rate per annum, will put great pressure on the electricity generation sector in the long term.

On the supply side, projected changes in hydropower production across several river basins due to climate change have been investigated. Hydropower production displays a generally positive relationship with precipitation levels. However, the range of projections for annual as well as monthly hydropower generation impacts is wide and uncertain. In addition, while the climate models largely agree on an increase in future annual hydropower production across the basins, there are several months (mostly in the dry season), where the models disagree over whether there will be more or less hydropower production in future. The high uncertainty in our projections is a result of various uncertainties arising from using downscaled GCM simulations, and propagating them through the subsequent hydrological and hydropower modelling processes which challenge power, social and economic planning.

For the whole energy system, we find that climate change causes considerable negative effects on electricity demand, but brings positive effects on hydropower in terms of electricity production.

For hydropower production, electricity generation output will increase in comparison with BAU scenario, due to increased rainfall under climate change scenarios. However, this increase is negligible and similar in both scenarios RCP4.5 and RCP8.5, ranging from 0.04% to 0.13% of BAU's electricity generation output during the period 2017–2050. This increase in electricity generation output reduces demand for fuels for power generation, as well as decreased GHG emissions. However, all these decreases are small and negligible compared to the damage and losses caused by the climate change impacts on other areas.

Electricity demand is significantly increased from the BAU scenario due to the increase of temperature, ranging from 2.8% to 5.2% by 2050 under RCP4.5 and RCP8.5 scenarios, respectively. These increases result in corresponding increases of primary energy supply (due to the increase of input fuels for power generation) from 1.3% and 2.4%, as well as GHG emissions from power generation from 1.9% to 3.6% by 2050 under RCP4.5 and RCP8.5, respectively.

The total cumulative costs of climate change impacts on electricity demand in the 2017–2050 period range from US\$ 4,227.5 million to US\$ 7,675.3 million, with cumulative additional emissions of 161.9 MtCO₂e and 288.3 MtCO₂e under RCP4.5 and RCP8.5 respectively. This number will be greater if we take into account the impacts on other areas, such as commerce, transportation, and thermal power production. We leave these additional aspects to the end of the project.

6.2 Recommendations

As analysed above, the impacts of climate change on the energy system will increase electricity consumption for air conditioners, which is likely to lead to an increase in fuel consumption, costs and GHG emissions in power generation. The decreased use of electricity for air conditioners through the promotion of more efficient air conditioners and other electricity-efficient devices may mitigate these impacts of climate change. Research at the global scale has suggested that climate change has little or even a positive impact on hydropower generation [Kumar *et al.*, 2011]. Our quantitative assessment confirms a similar tendency for Viet Nam at a national scale. However, local impacts are shown to vary across the country. Hydrological processes in many basins are likely to be altered. In addition, the disagreement in results between different carbon emission scenarios and climate models highlights the risks associated with the larger uncertainty introduced by climate change, which challenges power, social and economic planning.

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Chapter 6

Effects of climate variability on households, individuals and firms

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Abstract

This chapter evaluates the effects of climate variability on households, individuals, and firms in Viet Nam. First, we examine the impacts of weather shocks on household income using VHLSS 2002–2018. Second, we investigate how labour supply changes with regard to climate change, using the Labour Force Survey 2010–2018. Third, we identify how temperature affects firms’ productivity, revenue, output, and size. Fourth, we evaluate the adaptation of household and individuals, and their perception of climate variability. Fifth, we provide a case study of the Mekong River Delta responding to the severe drought of 2016. Based on the results and four climate scenarios, we provide projections for losses by the end of this century. We find several notable results. First, climate variability would harm household agricultural income (from fruits and non-crop components), especially when the temperature is above 33°C. We also find that weather shocks have negative impacts on poor households in comparison to other groups. Third, we find a negative relationship between climate change and working hours/hourly wage. Fourth, temperature’s increase reduces firms’ revenue, total factor productivity, output, and size. Fifth, our results suggest the non-linear effect of temperature change on employment allocation and migration. Sixth, we find that individuals are aware of extreme weather, but unaware of gradually increasing temperatures. Finally, we find that the 2016 severe drought led to a significant increase in migration rate in Mekong River Delta.

Tóm tắt

Trong chương này, chúng ta sẽ ước lượng những ảnh hưởng của biến đổi khí hậu (BĐKH) tới hộ gia đình, cá nhân, và doanh nghiệp tại Việt Nam. Trước tiên, ảnh hưởng của các yếu tố thời tiết tới thu nhập của hộ gia đình sẽ được nghiên cứu bằng cách sử dụng bộ dữ liệu Khảo sát mức sống hộ gia đình (VHLSS) từ năm 2002 tới 2018. Thứ hai, chúng ta sẽ xem xét cung lao động sẽ thay đổi như thế nào với những ảnh hưởng của BĐKH với bộ dữ liệu Điều tra lao động việc làm (LFS) trong giai đoạn 2010 tới 2018. Thứ ba, chúng ta sẽ nhận dạng cách mà nhiệt độ ảnh hưởng tới năng suất lao động, doanh thu, sản lượng đầu ra, và quy mô của các doanh nghiệp. Thứ tư, sự thích ứng của cá nhân và hộ gia đình cùng với nhận thức của họ đối với BĐKH sẽ được đánh giá. Và cuối cùng, chúng ta sẽ nghiên cứu tình huống của Đồng bằng sông Cửu Long khi phải ứng phó với hạn hán nghiêm trọng vào năm 2016. Dựa trên những kết quả và 4 kịch bản về khí hậu, chúng tôi cũng đưa ra một số dự báo về thiệt hại mà BĐKH gây ra tới cuối thế kỷ này. Một số kết luận đáng chú ý có thể rút ra từ chương này. Thứ nhất, BĐKH gây thiệt hại tới thu nhập từ nông nghiệp của hộ gia đình (bao gồm thu nhập từ cây ăn quả và các hoạt động phi trồng trọt), đặc biệt là khi nhiệt độ vượt quá 33 độ C. Chúng tôi cũng phát hiện ra rằng cú sốc về thời tiết có tác động tiêu cực tới hộ gia đình nghèo nhiều hơn các nhóm khác. Thứ ba, mối quan hệ nghịch đảo giữa BĐKH

và số giờ làm việc/ hoặc mức lương theo giờ cũng được khẳng định. Thứ tư, gia tăng nhiệt độ làm giảm doanh thu, năng suất nhân tố tổng hợp (TFP), sản phẩm đầu ra và quy mô của doanh nghiệp. Thứ năm, nghiên cứu này cũng gợi ý về tác động phi tuyến tính của thay đổi nhiệt độ tới sự phân bố và chuyển dịch lao động. Thứ sáu, chúng tôi phát hiện ra rằng, các cá nhân nhận thức được dạng thời tiết cực đoan, nhưng không biết được sự tăng nhiệt độ một cách dần dần. Và phát hiện cuối cùng là đợt hạn hán nghiêm trọng vào năm 2006 dẫn đến gia tăng tỉ lệ di cư một cách nhanh chóng tại Đồng bằng sông Cửu Long.

Résumé

Ce chapitre évalue les effets de la variabilité climatique sur les ménages, les individus et les entreprises au Viet Nam. Premièrement, nous examinons les impacts de chocs climatiques sur le revenu des ménages en utilisant l'enquête VHLSS 2002–2018. Deuxièmement, nous étudions comment l'offre de travail évolue en fonction du changement climatique, à l'aide de l'enquête emploi 2010–2018. Troisièmement, nous identifions comment la température affecte la productivité, les revenus, la production et la taille des entreprises à l'aide de l'enquête entreprises. Quatrièmement, nous évaluons l'adaptation des ménages et des individus, ainsi que leur perception de la variabilité climatique. Cinquièmement, nous fournissons une étude de cas sur la réponse du delta du Mékong à la grave sécheresse de 2016. Sur la base des résultats et de quatre scénarios climatiques, nous fournissons des projections de pertes d'ici la fin du siècle. Nous constatons plusieurs résultats notables. Tout d'abord, la variabilité climatique nuit au revenu agricole des ménages (provenant des fruits et des secteurs non cultivés), en particulier lorsque la température est supérieure à 33°C. Nous constatons également que les chocs climatiques ont un impact négatif sur les ménages pauvres par rapport aux autres groupes. Troisièmement, nous trouvons une relation négative entre le changement climatique et les heures de travail/salaire horaire. Quatrièmement, l'augmentation de la température réduit les revenus, la productivité totale des facteurs, la production et la taille des entreprises. Cinquièmement, nos résultats suggèrent un effet non linéaire du changement de température sur la répartition des emplois et la migration. Sixièmement, nous constatons que les individus sont conscients des conditions météorologiques extrêmes, mais ignorent l'augmentation progressive des températures. Enfin, nous constatons que la sécheresse de 2016 a entraîné une augmentation significative du taux de migration dans le delta du Mékong.

1. Introduction

The increasing impact of climate change has become a global threat, accelerating noticeably over the last decade [IPCC, 2014], including documented impacts on agriculture [Mendelsohn, 2007; Deschenes & Greenstone, 2007], human health [Markandya & Chiabai, 2009], and ecosystems [Munang *et al.*, 2013]. However, the costs and benefits of climate change are uncertain and unevenly distributed. For instance, the cost of dealing with its impact falls disproportionately on developing countries, whilst developed countries are trying to cut pollutant emissions to mitigate those impacts on the future economy. Climate change is also expected to increase the frequency and intensity of current extreme climatic events (e.g. heat waves, droughts, floods, and wildfires). These extreme events might have negative impacts not only on our life in general [McMichael *et al.*, 2012], but also in our communities [Frame *et al.*, 2020]. Both climate change and its consequences have always attracted the interest of policymakers and the public.

Researchers have focused on the potential for climate change to undermine progress towards economic development [Hallegatte *et al.*, 2016; Leichenko & Silva, 2014], while one small research stream focuses on the unequal distribution of the effects of climate change [Islam & Winkel, 2017; Marchiori & Schumacher, 2011; Mendelsohn *et al.*, 2006]. Its impacts are particularly disastrous for developing countries, and further degrade the resilience of the poor and vulnerable groups within them [Mendelsohn *et al.*, 2006; Mall *et al.*, 2011]. In developing countries, many people depend heavily on agriculture for income, but they have fewer resources to fall back on, and lower adaptive capacity with regard

to climate change [Hallegatte *et al.*, 2018]. For example, the poor tend to settle in risky areas where land is available and affordable, but where climate hazards are more likely to occur; therefore, their assets and livelihoods are more likely to be destroyed. Furthermore, they tend to work in 'exposed conditions' (i.e. they work outdoors, and directly exposed to the weather), so they are more vulnerable to environmental shocks and stressors. From a socio-economic perspective, the most negative effects of climate change are likely to occur in locations that are already economically marginal, and where livelihoods are already precarious [Samson *et al.*, 2011; Reyer *et al.*, 2017; World Bank, 2013]. As a result, the impact of climate change accentuates existing location-based inequalities and gives further momentum to the dynamics and incentives that drive economic migration.

However, poor and vulnerable groups are not homogenous. Disproportionate household and familial burdens, together with a relative lack of control over productive assets due to climate change, can enhance female vulnerability beyond that of men [Goh, 2012]. In particular, women are more likely to be impoverished than men, less capable of adapting to the impact of present and future climate change, and less likely to participate and contribute towards improving knowledge of the processes that facilitate gender-specific adaptation or mitigation efforts [Van Aelst & Holvoet, 2016]. Eastin (2018) argued that gender disparities in climate change vulnerability not only reflect pre-existing gender inequalities, but also reinforce them. Due to the gendered divisions of household labour, women often face greater challenges adapting to changes in environmental conditions, thereby reducing their livelihood opportunities and heightening resource scarcities.

Because of environmental impact, such as climate change, through its negative impacts on agricultural productivity (see Mendelsohn, 2007 for overview, and Trinh, 2018 for Viet Nam), the availability of water resources and flood frequency will alter the utility that a location offers to its population. Indeed, migration acts as a coping mechanism to climate change [McLeman & Smit, 2006; Perch-Nielsen *et al.*, 2008]. However, migration outcomes rarely emerge in a simple stimulus-response way, but are instead modified and shaped by the interaction of environmental changes and human, social, economic, and cultural processes [Hunter, 2005]. Migration is often undertaken to secure livelihoods in adverse environmental conditions [Black *et al.*, 2011].

There is a growing body of literature on the impact of climate on human migration. For example, Barrios *et al.* (2006) show the effect of rainfall on rural-to-urban migration in sub-Saharan Africa countries, whilst Mueller *et al.* (2014) emphasize the impact of heat stress on long-term migration in rural Pakistan. By following province-to-province movement of more than 7,000 households in Indonesia, Bohra-Mishra *et al.* (2014) also suggest that permanent migration is influenced by climatic variations (*i.e.* temperature, and rainfall changes), whereas episodic natural disasters seem have little impact on such migration. Climate change not only impacts domestic migration, but also international migration (see Cai *et al.*, 2016). Cai *et al.* (2016) provide an in-depth study about the climate-migration link across countries, which suggests a positive relationship between temperature and international emigration in the most agriculture-dependent countries. In addition, they show that migration flows to current major destinations are temperature sensitive.

Impacts caused by climate change directly affect not only individuals, but also firms' operations and productivity. There is growing literature about the effects of climate change on labour productivity [Heal and Park, 2016, Burke, Hsiang, and Miguel, 2015], and on aggregate macroeconomic productivity [Nath, 2020; Burke, Hsiang, and Miguel, 2015; Hsiang, 2010]. For example, Nath (2020) first attempts to use firm-level data to estimate the effect of temperature on productivity in manufacturing and services. He found that extreme heat reduces non-agricultural productivity, but less so than in agriculture. These productivity effects of climate change reduce welfare by an average of 1.5–2.7% overall, and up to 6–10% for the poorest quartile.

This study tries to understand the multi-dimensional influences of climate in Viet Nam. Firstly, it examines the effects of weather shocks on household income, especially agricultural income. Using the VHLSS dataset, we find that climate change would harm household agricultural income (from fruit and non-crop components), especially when the temperature is above 33°C. We also find the negative effect of weather shocks household income inequality as weather shocks damage income of poor households more than other groups. Secondly, this study also investigates how labour supply changes with regard to climate change. By using the LFS dataset, we find a negative relationship between climate change and working hours/hourly wage. Thirdly, we identify how temperature affects firms' productivity. By using the Viet Nam Enterprise Survey, we find that an increase in temperature and precipitation would reduce firms' revenue, total factor productivity, output, and size.

Furthermore, we evaluate how climate variability affects individuals' behaviours and percep-

tion (i.e. decision to reallocate employment or migration decisions, and attitudes toward environmental protection) along with their adaptation strategies. Our results suggest a non-linear effect of temperature change on employment allocation and migration. In addition, we find that individuals are aware of extreme weather, but unaware of the gradually increasing temperature.

We also provide a case study of migration in the Mekong River Delta. Residents in the Delta have chosen to migrate to urban areas or bigger cities to adapt to temperature increases. We found that the 2016 severe drought led to

a significant increase in the migration rate. Finally, we provide the projections for the effect of climate variability by the end of the century.

This study is structured as follows. Section 2, 3, and 4 illustrate the effects of climate change at different entity levels, including household, individuals, and firms, respectively. Section 5 discusses individuals' adaptation and perceptions towards climate change. Section 6 contains a case study of the effects of climate change in the Mekong River Delta. Section 7 provides the estimated consequences of climate change with projections from different scenarios.

2. Effect on households

2.1 Introduction

In this section, the marginal impact of weather conditions on Vietnamese household income will be measured. By allowing non-linearity, we try to assess how household revenue reacts to weather variations and extremely hot weather days. Combining income data from the Vietnamese Household Living Standards Survey (VHLSS) for the year 2002–2018 (9 waves of the survey) with temperature and precipitation data, we can use local deviations of income to estimate marginal response to changes in weather. It would be interesting to examine the effect of weather on the agricultural income of Vietnamese households. Despite a structural change in the economic development of Viet Nam since the 1990s, a large proportion of households still engage in farming activities that are prone to climate change [McCaig & Pacvnik, 2013]. We focus our analysis on Agri-

cultural income, which includes income from crops (rice, fruit, industrial crop, other food crop) and non-crop income (incomes from Forestry, Aquaculture, Living Stock).

In Viet Nam, 42% of the population still works in the agriculture sector, and 96% of the poor population derives its livelihood from agriculture, which is already subject to strong climate variability [Mora *et al.*, 2018; Pimhidzai, 2018]. Moreover, geographically located in fragile areas with regard to climate impact, Viet Nam has had to endure increasing damage because of its dynamically growing economy. The results of UNU-WIDER (2012) predicted a decrease ranging between 0.25 and 2.5% in Viet Nam's GDP by 2050 because of climate change, with high sea level rise and cyclones. In sectors of the economy, empirical evidence showed that those sectors, which depend more on climatic conditions, would face the most considerable losses. Therefore, estimating the impact of climate change on each household income is a crucial step in designing an efficient mitigation policy. It helps us by pinpointing the population

that should be targeted for specific adaptation programs.

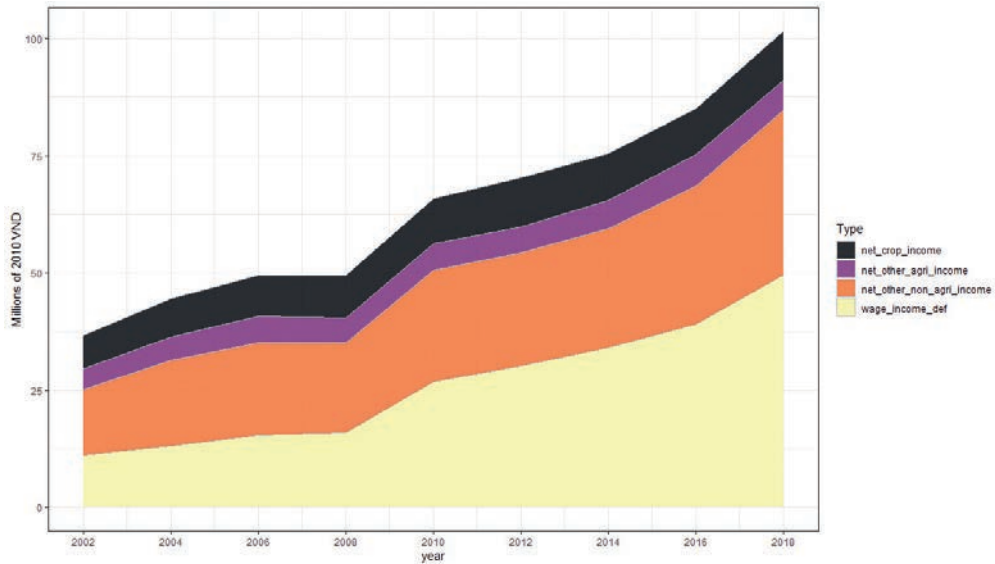
A large majority of the previous research analyses the relationship between weather variability and income across countries, with less attention to how climate variables affects different groups within the country. Dell *et al.*, 2009, based on a simple correlation that “hot countries tend to be poor”, estimated that one additional degree Celsius was associated with an 8.5% lower average income per capita. However, Acemoglu *et al.*, 2001, pointed out variables that make emerging countries poorer other than the temperature level. They argued that settler disease risk and mortality rate in colonial times, which is influenced by local weather, affect the following economic development. These studies used a naïve estimation, which should not therefore be considered as a causality. Auffhammer *et al.*, 2013, have gone further by using panel data to eliminate country-specific unobservable characteristics, which enable the impact of temperatures on incomes to be estimated causally. They estimated that one additional degree Celsius in temperature would bring about a 1.3 percentage point decrease in economic growth in developing countries.

At individual level, plenty of evidence has pointed out that extreme temperatures could reduce household incomes [de Laubier-Longuet *et al.*, 2019; Feeny *et al.*, 2021]. The reason for this income decrease is that high temperature dampens labour productivity and leads to a reduced labour supply [Lee *et al.*, 2014; Heyes and Saberian, 2019]. Graff Zivin *et al.*, (2018) showed that mental or cognitive acuity is the channel through which extreme temperatures exert a negative influence on labour productivity. There also exist some studies showing the negative impact of climate change on individual welfare in Viet Nam.

Narloch (2016), utilizing six different specifications for weather variables in rural Viet Nam, found an increase in temperature by one degree Celsius decreases total income by 20%. This negative impact of temperature on income is significant in term of magnitude. Trinh (2018) estimates the effects of climate change on Vietnamese farmer's net revenue during the period 2004–2012 by applying Ricardian approach. He found that while higher dry temperature increases net revenue per square meter by 6.320 thousand VND per Celsius degree, higher temperature in the wet season decreases net revenue by up to 17.527 thousand VND/°C.

Some methodological issues arise when estimating the impact of weather on income, which cannot be easily accounted for. First, the non-linear impact of climate variables on income [Burke *et al.*, 2015; Dell *et al.*, 2012; Deryugina and Hsiang, 2017]. This relation is based on the idea that variability in the weather conditions does not have a uniform impact on income: an increase of temperature by one degree from 18°C to 19°C might not have a similar impact to an increase from 33°C to 34°C. This is justification for Burke *et al.* (2015) when they used not only average temperature, but also added a quadratic term in temperature as explanatory variables. They found an inverted-U shape curve impact of temperatures on income for both poor and rich countries, with an optimal temperature for output at 13°C. Deryugina and Hsiang (2017), whom we followed in this research, went further by using the number of days in temperature and bins (number of days per year between a range of temperatures) as an explanatory variable in the income and income equality response function. This approach allows them to be closer to a non-parametric specification and effectively controls for within year heterogeneity of impact.

[Figure 6.1]
 Evolution of the component of the income (millions of 2010 VND)



Source: VHLSS (Author's computation).

The second issue related to estimating the impact of weather on income involves the heterogeneities that arise across the unit of analysis. Weather conditions rarely have the same impact in all countries or regions. Hence, naïve estimation, which does not control for specific fixed effect, might be confounded by unobserved characteristic such as contextual historical heritage and household characteristics. We then followed Auffhammer *et al.* (2013)'s approach by using panel data with fixed effects to get rid of all location-specific unobservable characteristics. They also allow for a correct and unbiased comparison within the year for income.

2.2 Data and Descriptive Statistics

Socio-Economic Data

This research uses the VHLSS dataset provided by the General Statistics Office of Viet Nam, which covers 2002 to 2018, with nine waves of the survey. A nationally and regionally representative sample of approximately 9,400 households was collected every two years. For each new wave, at least half of the households were kept in the study, and the other half was not surveyed again. However, an exception occurred in the 2010 survey, when the sample surveyed was totally renewed. This change acted as a limitation on this research, as we cannot track the households who participated in 2008 and 2010. Our final sample is composed of 90,480 households/repeated cross-section observation. This panel data al-

lows us to construct a panel dataset to get rid of unobservable characteristics of households. We convert all money values into 2010 VND using World Bank Consumer Price Index (CPI).

Figure 6.1 illustrates the evolution of the average income in Viet Nam during the period of interest, and the evolution of each income component. The substantial change in average income between 2008 and 2010 could be attributed to the change in the survey. Overall, thanks to the economic growth, annual average household income had risen from around 35 million VND in 2002 to over 100 million VND in 2018, although there was a slight decrease in 2018 due to the financial crisis. Income from wages accounts for the largest share of average household income, followed by other non-agriculture income (income from production, business, and services). Income from crop and other agriculture activities constitutes nearly a quarter of average income, and their share tends to decrease.

Climate Data

The climate data are from the Climate Prediction Center (CPC) of National Weather Service (provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, which is available from their website at <https://www.esrl.noaa.gov/psd/>). Daily temperature in the CPC is computed by the average of the maximum daily and minimum daily temperature.

2.3 Econometric model

We will start with the estimation of the non-linear effect of temperature on annual household income. Our main equation of interest is estimated by Ordinary Least Squares (OLS), the log of income (or income per capita) as a function of current and previous

weather, control variables, and household, year and region fixed effects (see Box 6.1). We follow the approach of Deyugina and Hsiang (2014), where the non-linear of the impact of weather on income is controlled by using annual within-county variation in the distribution of income. This method has an advantage in evaluating the marginal effect of temperature on a single day on end-of-year income, conditional on weather conditions observed during the whole year [Deschenes and Greenstone, 2011].

2.4 Main result

Using models specified in the section 2.3, we found that the effect of temperature on the total income of household is not apparent. The results vary depending on outlier elimination methods. Therefore, we conduct a further investigations of weather impact on various income sources. Table 6.1 reports the results of the regression of the log fruit income per capita, and the log other agricultural income per capita. The visualization of the non-linear effect of temperature is provided by Figure 2.1 with a 95% confidence interval, using the results from Columns (1) and (2). We found that the effect of warm days is not significant on the crop income. This result might reflect that those popular crops in Viet Nam are appropriate to sub-tropical weather, such as coffee, rice, corns, tea, and rubber. However, as shown in column (1), temperatures at a high level seem to negatively impact fruit crop income, including many kinds of crucial export fruits of Viet Nam such as longans, litchis, and rambutans jackfruits, and durians. Specifically, when the temperature is above 33 degrees, one additional day will reduce annual income by 1.89%. The effect of temperature on fruit crop income is quite significant in terms of magnitude when compared with the average daily contribution to yearly in-

[Box 6.1]

An relationship between income and weather conditions could be summarized by equation:

(6.1)

$$Y_{i,t} = \sum_m (\beta^m T_{i,t}^m + \phi^m T_{i,t-1}^m) + \sum_n (\sigma^n P_{i,t}^n + \eta^n P_{i,t-1}^n) + \beta_{i,t} X_{i,t} + \mu_i + \delta_t + \theta_r + \epsilon_{i,t}$$

Where:

- $Y_{i,t}$ is the log income per capita of household i at time t
- $T_{i,t}^m$ is the number of days which has the daily temperature belonging to the interval m
- $P_{i,t}^n$ is the number of days which has a daily level of precipitation within the interval n
- $X_{i,t}$ is a set of control variables: Age of the household's head; Gender of the household's head; Ethnic of the household's head; Proportion of working-age people (15–64) in household; Proportion of females in the household; Household location urban/rural; Binary for education of household head.
- μ_i , δ_t , and θ_r are household, year, and region fixed effects, respectively.
- $\epsilon_{i,t}$ is the error term.

Our principal coefficients of interest are β^m . It can be interpreted as the change in household income level of having one additional day in a given temperature interval, compared to the reference interval.

Following Deryugina and Hsiang (2017), we have constructed bins for temperature and precipitation. Our method is based on the assumption that the impact of temperature on income is constant within each bin. To generate weather variables, we picked the three nearest meteorological stations for each household, and average temperature and precipitation values were computed by using distance to station as weight value. For temperature, the dimensions are constructed as 10-degree-temperature bins: 0–9; 9–12; 12–15; 15–18; 18–21; 21–24; 24–27; 27–30; 30–33 and more than 33°C. Similarly, precipitation is constructed in 9 rainfall bins: 0–1 mm; 1–5 mm; 5–10 mm; 10–15 mm; 15–20 mm; 20–50 mm; 50–75 mm; 75–100 mm and more than 100 mm. We take temperature between 18 and 21 degrees Celsius and precipitation between 0 and 1 mm as the reference interval, with zero effect of this level on income. The reason we take this level as reference is because the temperature range 18–24°C is comfortable for human activities [WHO, 1990]. Lagged weather conditions are also added to prevent omitted variables bias. They also allow us to control for any potential effect of past temperature and precipitation on current income.

Our regression is a within-estimation as a household is compared itself when they experienced several types of weather. The fixed-effects control for both observable and unobservable characteristics of each household does not vary over time. While region fixed effects control for unobserved constant differences across regions, household fixed effects control for time-invariant characteristics of household. Year fixed effect, on the other hand, control for common trends, for example trend in climate or technological innovations.

We utilize standard errors that are clustered in two dimensions by year and region. It allows us to control for spatial correlation across regions and auto-correlation within region. Moreover, we use population sampling weights. Summary statistics of the main explanatory variables can be found in the table 6.1. There is one limitation from the data should be noted: the output variable “income per capita of household”, which was calculated by dividing the total household income by the total household members, depends heavily on household age structure and the occupations of household members. Therefore, we have added some control variables related to household structure (%Working, %Female) to try capture these factors clearly.

come ($1/365 \approx 0.27\%$). In the context of agricultural restructuring from rice to fruit crops due to climate change in the Mekong Delta [Tho, 2018], this impact requires our attention. More specially, the fruit sector is increasing its importance on Viet Nam's export balance. According to the General Statistics Office of Viet Nam (2017), between 2012 and 2015, Viet Nam's fruit export value grew by about 30% annually, reaching \$2.45 billion in 2016, surpassing crude oil exports by \$0.05 billion.

Outcome from other agricultural income sources has a similar pattern. Column (2) pointed out that the effect of high temperature is less intense in magnitude than the average effect on fruit crop income. One additional hot day will be associated with a 1.48% loss in the other agricultural income. The negative impact of cold temperatures seems to disappear, and a positive effect of cold days seems to emerge.

[Table 6.1]

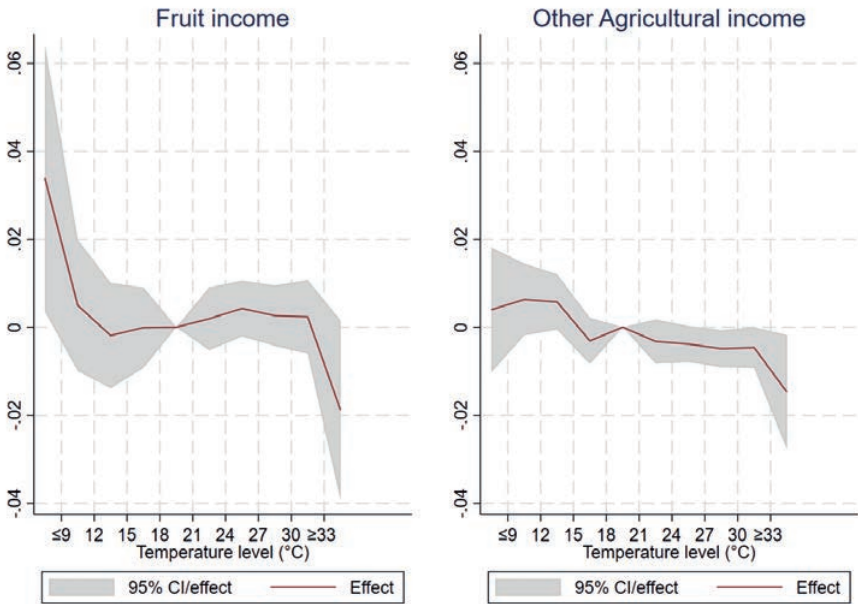
Regression of the log Fruit Crop Income per capita and log Other Agricultural Income (excluded Crop income) per capita on weather conditions

VARIABLES	(1) Log Fruit income pc	(2) Other Agricultural income pc
temp_under9	0.0339** (0.0154)	0.00397 (0.00724)
temp_9_12	0.00497 (0.00760)	0.00630 (0.00416)
temp_12_15	-0.00187 (0.00610)	0.00577* (0.00321)
temp_15_18	-9.13e-05 (0.00466)	-0.00309 (0.00266)
temp_21_24	0.00192 (0.00364)	-0.00322 (0.00254)
temp_24_27	0.00425 (0.00323)	-0.00382* (0.00208)
temp_27_30	0.00263 (0.00350)	-0.00487** (0.00214)
temp_30_33	0.00235 (0.00427)	-0.00462* (0.00234)
temp_above33	-0.0189* (0.0104)	-0.0148** (0.00663)
prec_100_plus	-0.0164 (0.0232)	-0.00300 (0.00951)
prec_1_5	-0.00305 (0.00186)	0.00258** (0.00121)

Variables	(1) Log Fruit income pc	(2) Other Agricultural income pc
prec_5_10	-0.00183 (0.00288)	0.00238 (0.00196)
prec_10_15	0.00118 (0.00395)	0.00706** (0.00313)
prec_15_20	-0.00446 (0.00485)	-0.00298 (0.00301)
prec_20_50	-0.00241 (0.00363)	-0.00223 (0.00225)
prec_50_75	0.0143 (0.0102)	-0.000422 (0.00598)
prec_75_100	-0.0100 (0.0209)	-0.0129 (0.0189)
Constant	6.625*** (1.701)	8.774*** (1.237)

Note: Standard errors clustered at region and year level are reported in parentheses. Lagged and control variables are included. Household, Year, and Region Fixed Effect are added. Constants and precipitation variables are not reported. ***, **, * significant at 1%, 5%, 10% levels, respectively.
Source: Authors' calculation.

[Figure 6.2]
Effect of weather shocks on Agricultural Income



Another critical dimension that might be worth examining is the distributional effects of weather conditions on household incomes. We extend the equation by adding interaction terms between the bin of temperature above 33 degrees and some demographic household variables, *i.e.*, Ethnic minority-headed household, Poor household (classified according to the government's criteria), and Female-headed household. Table 6.2 provides the outcome of regression. The coefficients of the interaction terms for female head and ethnic minority head are not statistically significant. However, being in a poor household aggravates the relationship between high temperature and income. Specifically, low-income families have to suffer an additional loss of 1.51% associated with one high-temperature day. Evidence supports an argument that climate change mitigation policy should focus on poor households, who are vulnerable to weather-induced fluctuations.

2.5 Conclusion

In this section, we have examined the complex relationship between incomes and weather shocks in Viet Nam. By utilizing a methodology that uses panel data to get rid of unobservable household characteristics, we computed the marginal response of Vietnamese household income to the occurrence of additional days in the temperature range. Our results provide evidence that climate change would harm household fruit income and other agricultural income, *i.e.*, an extra hot day above 33°C decreases annual household income by 1.89% and 1.48%, respectively. We also found that poor households have to suffer more losses in income. This result would be a good reference for policymakers to design a good mitigation policy.

However, there are some limitations in our research that make the results are less attractive. Firstly, the result of regression is not robustness

[Table 6.2]

Effect of temperature on the household income by demographic

Variables	(1) log_income_pc	(2) log_income_pc	(3) log_income_pc
temp_above33	-0.000506 (0.00212)	7.09e-06 (0.00213)	0.00399 (0.00401)
temp_above33_ethnic	-0.00341 (0.00746)		
temp_above33_poor		-0.0151** (0.00644)	
temp_above33_female			-0.00839 (0.00628)
Constant	10.16*** (0.329)	10.12*** (0.329)	10.09*** (0.328)

Note: Standard errors clustered at region and year level are reported in parentheses. Lagged and control variables are included. Household, Year, and Region Fixed Effect are added. Constants and precipitation variables are not reported. ***, **, * significant at 1%, 5%, 10% levels, respectively.

with the way by the method of eliminating the outliers. Secondly, though allowing for a non-linear relationship in the level of temperature, we have not allowed a non-linear impact of the number of days in each threshold. The effect of the fifth day above 33 degrees might differ from the first one. Thirdly, we do not consider other climate change variables related to global warming, such as storms, typhoons, sea level rise, or biodiversity changes. Those variables are

likely to change the magnitude of the impact of temperature. Moreover, one major limitation of works on different income sources is that they consider the impact of climate on each source in isolation from the others. But climate may affect not only total income, but also the proportion of the different sources in that total. Other income sources may be substituted for agriculture, for example. This is an open issue for future research.

3. Effect on individuals

This section primarily aims to investigate how labour supply changes with regard to climate change. This is an important economic concern, because any changes in labour productivity may have a direct effect on national output and individual incomes [Day *et al.*, 2019]. There is growing literature about the effects of climate change on labour productivity [Heal and Park, 2016; Burke, Hsiang, and Miguel, 2015]. Rising temperatures may increase labour productivity in regions with low baseline temperatures [Heal and Park, 2016],

whereas the effect is likely to be negative in most countries, especially lower-income countries [Burke, Hsiang, and Miguel, 2015]. In addition, at the individual level, warming directly affects labour supply (*i.e.* working hours), by changing the allocation time to labour beyond certain thresholds, especially in working conditions that are highly-exposed to the climate (*e.g.* in the agriculture sector). It is believed that temperature stress may affect workers in two instances: (i) it may directly cause physical or psychological discomfort, and (ii) it may thereby reduce task productivity, possibly altering the marginal return to an additional hour of labour supplied, or an increment of effort exerted within any given hour [Heal and Park, 2016].

[Box 6.2]

The effect of weather conditions on working hour and hourly wage could be illustrated by a equation:

$$\ln(Y_{i(p)t}) = \alpha + \beta C_{dt} + \gamma X_{it} + \theta_i + \delta_t + \varepsilon_{idt} \quad (6.2)$$

Where, $\log(Y_{i(p)t})$ is the logarithm of employee *i*'s hourly wages and hours worked (per week) at province *p* and year *t*; C_{pt} is a vector of climatic variables (*e.g.* average annual temperature and logarithm of precipitation); X_{it} is a vector of control variables, including individual characteristics (*e.g.* age, female, education), industry characteristics; θ_i and δ_t are province and year fixed effects, respectively. The fixed effect, θ_i and δ_t , help to ensure that any perceived effects of weather variations are not due to differences between provinces or years that may arise from omitted variables [Dell *et al.*, 2014].

Therefore, in this study, we combine the Labour Force Survey (LFS)¹, and the weather data at provincial level, from 2009 to 2018, to identify effects of temperature and precipitation on working hours and hourly wage.

The estimated results are shown in Table 6.3, in which column (1)-(3) shows the baseline model results on working hours, and hourly wages, irrespectively, after controlling individual characteristics and industry characteristics. The results show the negative relationship between climatic variables and working hours and hourly wages. Specifically, a 1°C rise in temperature is associated with a decrease of 0.5% in working hours while a 1 per cent rise in precipitation is associated with a decrease of around 2.5% in working hours. This implies that climate change affects the number of working hours that an individual works for. This is in line with Graff Zivin and Neidell (2014), which found a moderate decline in aggregate time allocated to labour at high temperature. However, their study also pointed out the heterogeneity across industry sectors based on their exposure to climate. For example, workers in industries with high exposure to climate, on average, reduce time allocated to labour by 14%. Similarly, we also see that individuals are, on average, paid less when temperature or rainfall increases. Specifically, a 1°C rise in temperature is associated with a decrease of approximately 11% in the hourly wage while a 1% rise in precipitation is associated with a decrease of around 4% in the hourly wage.

The results also confirm that women, on average, work less than men, and are paid less than men. However, it is difficult to comment on how climate change directly affects working

hours and hourly wages with respect to gender. Therefore, we have extended the model by adding the interaction term illustrated in column (2)-(4). In particular, women tend to work less hours than men when the temperature is increasing. Subsequently, women are still paid 0.5 per cent less than men when the temperature is increasing. However, the gender pay gap is not mainly due to women having lower qualifications, or working significantly fewer hours. It should be noted that women spend more time doing unpaid work. For example, women on average spend twice as many hours as men working to produce 'services for own use' [ILO, 2021]. This implies that climate change increases gender inequality in terms of working hours and pay. Our findings are in line with Eastin (2018)'s study, which showed that climate shocks and climatic disasters exert a broadly negative impact on gender equality.

In addition, we also consider the studied sample for the elderly group (*i.e.* 60+ years old), because a large proportion of those aged 60+ are working and mostly attached with vulnerable jobs (*i.e.* self-employed or unpaid family workers), and agriculture sector-related work with high exposure to climate. Specifically, we run the same estimates for the elderly group in agriculture, forestry and fishery industry.

Table 6.4 shows the estimated results for the elderly group working in agriculture, forestry, and fishery industry. We find that they work less hours as temperature and precipitation increase. The magnitude of the coefficients is bigger for this group than the 22–59 age group. Subsequently, the hourly wage is, on average, around 20% less as the temperature increases. However, the coefficient of precipitation is not statistically significant. This result suggests that this group is more vulnerable with regard to climate change.

1. The Labour Force Survey (LFS) conducted by the General Statistics Office (GSO) of Viet Nam is a representative data-set at regional level. It collects information about demographic characteristics and working activities for individuals aged 15 and above.

[Table 6.3]

Effects of temperature and precipitation on working hours and hourly wage

	Log of hours of work		Log of hourly wage	
	(1)	(2)	(3)	(4)
Temperature	-0.0057*** (0.0011)	-0.0050*** (0.0011)	-0.1055*** (0.0020)	-0.1038*** (0.0020)
Log precipitation	-0.0251*** (0.0020)	-0.0250*** (0.0020)	-0.0412*** (0.0035)	-0.0408*** (0.0035)
Age	0.0087*** (0.0002)	0.0087*** (0.0002)	0.0584*** (0.0004)	0.0584*** (0.0004)
Age ² /100	-0.0143*** (0.0003)	-0.0143*** (0.0003)	-0.0651*** (0.0005)	-0.0651*** (0.0005)
Female	-0.0626*** (0.0006)	-0.0139** (0.0061)	-0.2474*** (0.0010)	-0.1224*** (0.0117)
Female#Temperature		-0.0020*** (0.0002)		-0.0050*** (0.0005)
Diploma	-0.0170*** (0.0009)	-0.0171*** (0.0009)	0.2747*** (0.0016)	0.2745*** (0.0016)
Bachelor	-0.0245*** (0.0009)	-0.0246*** (0.0009)	0.4658*** (0.0018)	0.4655*** (0.0018)

Note: Sample (age 22–59). Industry characteristics, Province FE, and Year FE are added. Robust standard errors are reported in parentheses.

***, **, * significant at 1%, 5%, 10% levels, respectively.

[Table 6.4]

**Effects of temperature and precipitation on working hours and hourly wage
(for the elderly group in agriculture, forestry and fishery industry)**

	Log of hours of work	Log of hourly wage
Temperature	-0.0442*** (0.0147)	-0.1983*** (0.0235)
Precipitation	-0.0446*** (0.0162)	0.0264 (0.0248)

Note: Sample (aged 60 and 60+ in agriculture, forestry, and fishery industry). Industry characteristics, Province FE, and Year FE are added. Robust standard errors are reported in parentheses.

***, **, * significant at 1%, 5%, 10% levels, respectively.

4. Effect on firms

Previous sections have looked at the effects of temperature and precipitation on the supply side of labour market using Labour Force Survey and VHLSS. More important, in Section 3, we learnt that temperature and precipitation caused negative impacts on wages and hours worked for employees. To verify the mechanism, this section looks at the demand side of the labour market. We evaluate how temperature and precipitation affect firms using enterprise survey data (see Box 6.3).

The results are presented in Table 6.5. Apparently, an increase of average temperature of 1°C led to 3.4, 3.6, 6.9 and 2.2% declines in revenue, TFP, output, and firm size respectively. Similarly, a 1% increase in precipitation led to 3.4, 3.6, 6.9 and 2.2% declines in revenue, TFP, output, and firm's size respectively, but an 0.08% increase in productivity. These results highlight the importance of having appropriate policy to support firms in responding to global warming.

[Box 6.3]

We estimate the effects of temperature and precipitation on four important indicators for firms: revenue, total factor productivity, output, and size. Our general empirical specification is as follows:

$$\ln(Y_{i(p)t}) = \alpha + \beta C_{pt} + \gamma X_{it} + \theta_i + \delta_t + \varepsilon_{idt} \quad (6.3)$$

Where, $\ln(Y_{i(p)t})$ is the logarithm of revenue, total factor productivity, output, and size of firms at province p and year t ; C_{pt} is a vector of climatic variables (e.g. average annual temperature and logarithm of precipitation); X_{it} is a vector of control variables; θ_i and δ_t are province and year fixed effects, respectively. The fixed effects, θ_i and δ_t , help to ensure that any perceived effects of weather variations are not due to differences between provinces or years that may arise from omitted variables.

[Table 6.5]

Effects of climate variability on firms

	(1) Log of Revenue	(2) Log of TFP	(3) Log of output	(4) Log of Firm Size
Temperature	-0.0343*** (0.000)	-0.0359*** (0.000)	-0.0688*** (0.000)	-0.0220*** (0.000)
Log precipitation	-0.2887*** (0.000)	0.0828*** (0.001)	-0.0770*** (0.005)	-0.1930*** (0.000)

Note: Province FE, and Year FE are added. Robust standard errors are reported in parentheses.

***, **, * significant at 1%, 5%, 10% levels, respectively.

5. Adaptation and perception

5.1 Employment reallocation

Climate adaptation is undertaken to avoid the damage or take advantage of the opportunities posed by climate change [IPCC, 2014]. Different entities may have appropriate adaptation strategies to deal with climate change. At the individual level, workers may adjust their usual activities, or even change their employment to cope with this change. For example, they may reduce the share of agricultural activities, and gradually move out of agriculture, or may even decide to reallocate into different employment, especially service employment with some office jobs rather than 'exposed conditions' jobs. This resonates with the short-term employment effect, by which jobs are lost in directly affected sectors, and new jobs are created in replacement industries [Fankhaeser *et al.*, 2008].

Therefore, we have tried to understand individual behaviours concerning employment reallocation with regard to the climate change. It is anticipated that people will reduce their farming activities, or even move out agriculture, because of less favourable weather for agriculture. We model their employment allocation in three employment sectors, namely agriculture, industry, and services, by using the multinomial logit model (see [Box 6.4](#)).

The results in [Table 6.6](#) suggest the non-linear effect of temperature change on employment allocation. Rainfall is also one element to explain the employment allocation. The significant positive marginal effect of 0.062 implies that a 1% rise in rainfall is associated with an increase in the probability of wor-

king in the service sector by 6.2%. However, it is worth noting that employment allocation is influenced mainly by the policy on economic re-structuring/shifting and employment structure changes. The Vietnamese economic structure has been transformed from the primary agriculture sector to industry and services, which has subsequently changed employment structure from agriculture to industry and services. This is one of the main underlying mechanisms of internal migration in Viet Nam [Ho *et al.*, 2021]. Therefore, employment reallocation is believed to result from economic shifting, which we have not addressed in this study.

Moreover, [Figure 6.3](#) shows the marginal effects of temperature change on the probabilities of being in three employment sectors. In detail, the probability of being in the agriculture sector starts to reduce when the temperature exceeds 21°C, while the probability of being in the industry sector starts to drop when the temperature exceeds 24°C. In contrast to the agriculture and industry sectors, the service sector experiences an increasing propensity of workers when the temperature is over 24°C.

Gender differences are also apparent in employment allocation. On average, the propensity of females working in the service sector is approximately 7.5 per cent higher than that of males, while the propensity of females working in industry is 7 per cent lower than that of males. In addition, age does matter with regards to employment allocation. People are more likely to work in agriculture, but less likely to work in industry as they age, whereas the probability of being in services seems to increase even at the age of 57 (see [Figure 6.4](#)).

[Box 6.4]

The multinomial logit model assumes that everyone locates in one employment sector among mutually exclusive alternatives of these employment sectors. Comparing the maximum utility attainable given each employment sector, each individual locates in an employment that yields the maximum utility. Then, the probabilities of being in one employment sector are determined as follows

$$pr(emp_{i(d)t} = 1) = \frac{1}{1 + \sum_{j=2}^3 \exp(\beta_j C_{dt} + \gamma_j X_i + \delta_t)} \quad (6.4)$$

$$pr(emp_{i(d)t} = k) = \frac{\exp(\beta_k C_{dt} + \gamma_k X_i + \delta_t)}{1 + \sum_{j=2}^3 \exp(\beta_j C_{dt} + \gamma_j X_i + \delta_t)}, k = 2, 3 \quad (6.5)$$

Where $k=1$ presents the employment allocation in agriculture, which is chosen as the base category, and $k=2$ and $k=3$, respectively, illustrate the employment allocation in industry, and service.

[Table 6.6]

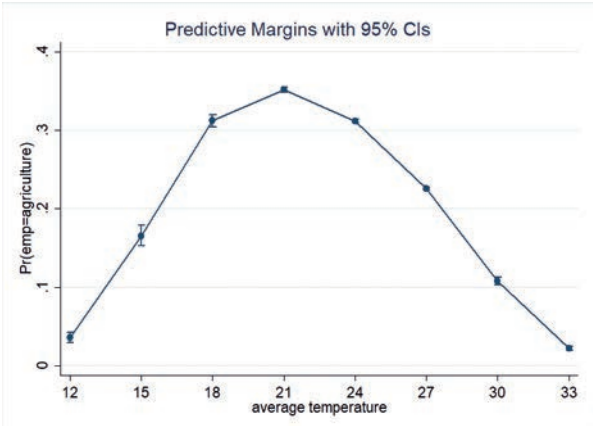
Probability to be employed in agriculture, industry, and service sector

	Agriculture	Employment allocation Industry	Service
Temperature	0.116*** (0.005)	0.216*** (0.006)	-0.332*** (0.006)
Temperature ²	-0.003*** (0.000)	-0.004*** (0.000)	0.007*** (0.000)
Log(Precipitation)	-0.051*** (0.001)	-0.010*** (0.001)	0.062*** (0.001)
Female	-0.005*** (0.001)	-0.070*** (0.001)	0.075*** (0.001)
Age	-0.006*** (0.000)	0.007*** (0.000)	-0.001* (0.000)
Age ²	0.013*** (0.000)	-0.017*** (0.000)	0.004*** (0.000)
Diploma degree	-0.308*** (0.002)	-0.082*** (0.001)	0.390*** (0.001)
Bachelor degree	-0.477*** (0.003)	-0.064*** (0.002)	0.541*** (0.002)

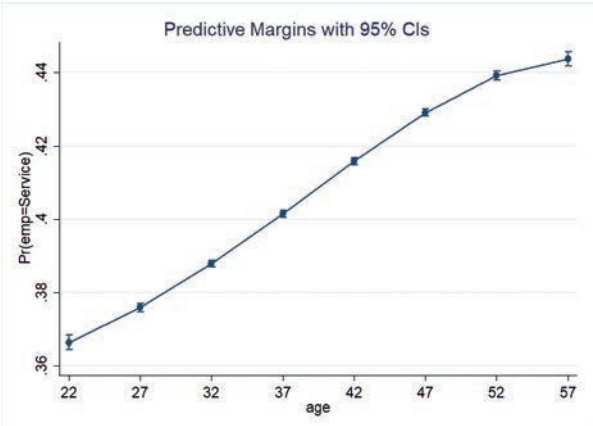
Note: Province FE, and Year FE are added. Robust standard errors are reported in parentheses.

***, **, * significant at 1%, 5%, 10% levels, respectively.

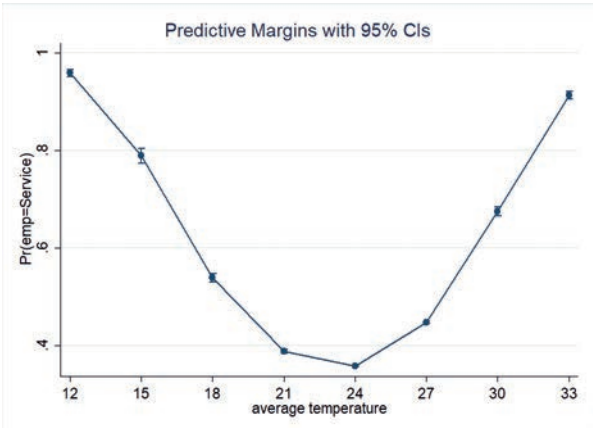
[Figure 6.3]
Marginal effect of temperature change on probability of being in employment sectors



(a) Agriculture employment



(b) Industry employment



(c) Service employment

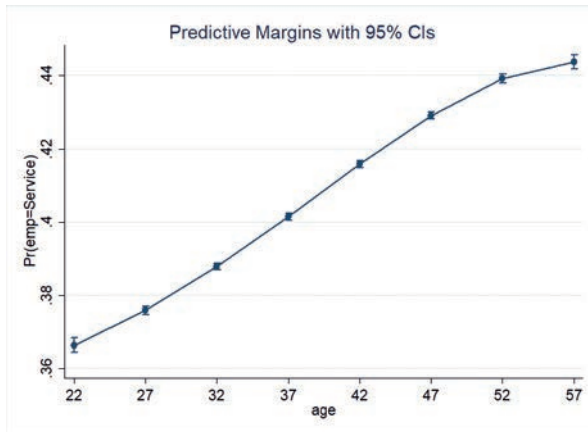
5.2 Migration

Alongside employment reallocation, one of the consequences of climate change is migration. Human migration in response to climatic variation has a long history. However, these migratory flows have been shaped by climatic influences on environment conditions, job movements, food and water availability, and social structures [Finlayson, 2005; Adamo,

2010]. Previous research on climate-induced migration has documented significant climate effects. However, the nature of these effects may vary considerably across regions. For example, Gray and Mueller (2012) found that rainfall deficits are a main driving factor for migration, while migration could be driven by temperature shocks [Mueller *et al.*, 2014] or temperature-related declines in crop production [Feng *et al.*, 2010]. Recently, Thiede

[Figure 6.4]

Marginal effect of age on probability of being in service sector



and Gray (2017) found that temperature and monsoon timing have significant effects on household migration in Indonesia, but not rainfall. Their study illustrates that climate variability is more important for short-distance population movements than long-distance moves, while delays in monsoon onset increase migration.

More recently, Nguyen (2020) found that negative income shocks (due to high rainfall extremes) encourage migration in rural Viet Nam, while Berlemann and Tran (2020) emphasized the effect of extreme weather events on migration in rural Viet Nam. Indeed, they found that temporary migration is primarily caused by droughts, whereas flood events tend to induce permanent emigration. However, migration due to temperature or rainfall changes do not seem very apparent in Viet Nam, with the exception of extreme weather events such as frequent droughts or floods. The reason is that the motivation for migration in Viet Nam is mainly due to economic factors (e.g. poverty, unemployment) in the departure areas, and personal development opportunities (e.g. job seeking with

higher income, better access to education) at destination areas [Ho *et al.*, 2021; Collins *et al.*, 2017]. For example, 80% of migrants are born in rural areas, and working-age members tend to migrate more than other members in the households [GSO, 2016]. Approximately 33% of rural-urban migrants have professional or technical qualifications, as compared to 25% of non-migrants, while around 25% of migrants have a college degree or higher, as compared to 17% of non-migrants [UNESCO, 2018]. More than half of migrants have better employment, and higher income at their destination, whereas just over 10% consider themselves to be worse off. During the period 2005–2019, the Southeast has always been a region with a positive net migration rate, at around 10%, and continues to increase, because it is a region not only with the fastest economic growth rate in the country, but also with an economic structure shifting strongly towards industry and services. It therefore attracts a large proportion of the labour force from neighbouring areas, whereas other regions have experienced a negative emigration rate [Ho *et al.*, 2021].

In short, the presence of environmental stressors will, in most cases, not automatically induce migration, with the exception of major environment hazards that leave local residents with no choice but to leave.

5.3 Individuals’ perception

Impacts caused by climate change are inevitable. Therefore, measures must be taken to adapt to these effects. It is believed that individuals’ perception of climate change is fundamental for any climate change adaptation strategies. Individuals’ perception of environmental protection would be the first approach for any further decisions (i.e. migration) to adapt to climate change, since migration is a big decision. Migration affects not only individuals themselves, but also other household members and the ecological system of the whole country.

In this study, we try to understand individual behaviours and perceptions with regard to climate change by using the last wave of World Values Survey 2020 (WVS)² alongside the weather data in 2019 at district level. In the WVS, there is a question about individual attitudes towards the environment. It asks whether the economy should be given a higher priority ranking than the environment. Therefore, we construct a binary variable as to whether an individual’s perception of the environment is more favourable as a dependent variable in the linear probability model, which is illustrated as below:

(5.6)

$$\Pr(environment_{att} = 1) = \alpha + \beta temp + \gamma X + \varepsilon$$

2. The World Values Survey is a data source of representative national surveys in almost 100 countries. However, the last wave of the WVS conducted in 2020 is about Viet Nam. The WVS allows us to measure individual attitudes towards the environment and the economy.

[Table 6.7]
Probability of individual attitude towards environment protection

	Environment protection	
	(1)	(2)
Temperature	-0.043 (0.444)	
Temperature ²	0.000 (0.009)	
Hotwave5d		0.037 (0.053)
Coldwave5d		0.083*** (0.016)
Attitude towards science & technology	0.003 (0.008)	0.002 (0.012)
Value of technology in life	-0.004 (0.006)	-0.004 (0.007)

Note: Robust standard errors are reported in parentheses.
***, **, * significant at 1%, 5%, 10% levels, respectively. Education, Individual, Household, and Region characteristics are added

We start with the base line model, which uses the average temperature at district level (shown in column 1 of 5–4). There is no link between temperature change and individual attitudes towards environmental protection. That is not what we expect. This also implies that people still care about economic activities and economic growth, rather than the environmental protection. It may be explained by the fact that Viet Nam is still a developing country, and people prioritise basic needs to environment. This is consistent with the insignificant statistical impact of household income at these low deciles. However, someone from the highest decile household income is more favourable to environmental protection.

6. Case study: Mekong River Delta

Scenarios of climate change conducted by both Vietnamese and international experts all rank Viet Nam among countries that are likely to be most seriously affected [MoNRE, 2016; WB and ADB, 2020; UNU-WIDER, 2013]. The Mekong river delta (MRD), with its low-lying coastal provinces, is more vulnerable to rising sea levels, and droughts that are more frequent, floods and saline intrusion (see part 3 of this report for details). The risks will be amplified by the potential impacts of dam operations along the Mekong River, from China to Laos, Thailand and Cambodia³. These forecasts push more actions to develop effective

3. When the dams in China and Lower Mekong Basin are in full operation, it is estimated that more than 50% of sediment and 75% of nutrient from the present load to the Mekong River Delta of Viet Nam will be likely reduced [Konishi, 2015].

Instead of using temperature as stated in column (1), we use the hot wave and cold wave variables in the regression, which are shown in column (2) of Table 6.7. The result shows the statistical significance of the cold wave, which means that an additional cold wave occurring at district level, other things being equal, increases the probability of someone's attitude towards environment protection by 8 percentage points.

The results from column (1) and (2) seem contradictory. However, we find these results very interesting, because they imply that people are aware of extreme weather, whereas people are unaware of the gradually increasing temperature.

adaptation measures for the region, a significant agricultural hub that currently hosts nearly 20% of the country's population⁴.

Recent reports reveal substantial socio-economic transformation happening in the MRD within the last ten years [VCCI and Fulbright, 2021]. Most notably, over the past decade, there was a large flow of people migrating out of the region, which was estimated to amount to up to 1.7 million people. The share of net emigration in the region was the highest among all regions of Viet Nam, nearly double the average rate of the country [Table 6.8].

The high level of emigration out of the MRD is driven by two major forces: (i) push factors (i.e. less favorable conditions for agricultural production due to climate change); and (ii) pull factors (i.e. rapid economic growth of the South East region attracting a large number of immigrants from neighboring regions).

4. 17.3 million people living in MRD in 2019 [VCCI, 2021].

[Table 6.8]

Population and Immigration by region, 2009–2019

	2019		Period 2009–2019	
	Population (mill. pp.)	Share (%)	Population growth (%)	Net immigration (‰)
Northern midlands and mountainous areas	12.5	13.0	1.2	-19.6
Red river delta	22.5	23.4	1.4	9.7
North central & Central Coasts	20.2	21.0	0.7	-25.2
Central Highland	5.8	6.1	1.4	-13.5
South East	17.8	18.5	2.4	70.7
Mekong river delta	17.3	18	0.05	-38.9
Whole country	96.2	100	1.1	0

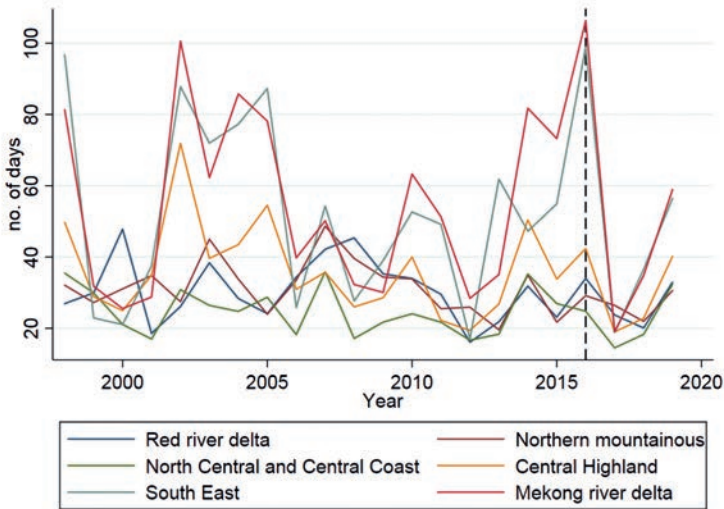
Source: VCCI and Fulbright (2021).

It is econometrically challenging to quantitatively disaggregate and measure the impacts of each factor. However, it is widely accepted that migration is one among several possible effective measures to counter severe conditions for agricultural production. Indeed, there is evidence of migrating as a coping measure for people in the MRD, especially in rural areas, in reaction to adverse climate shocks. Using data from more than 170 weather stations in Viet Nam since 1998, we notice a serious shock occurring in the MRD in the period 2014–2016, especially in 2016. [Figure 6.5.1](#) and [6.5.2](#) show that, in 2016, the region experienced a record high number of continuous days with virtually no rainfall (more than 100 days), and with temperature higher than the 95% percentile of temperature in the region since 1998 (more than 30 days). In addition, the region also suffers from high levels of saline intrusion (see [Chapter 9](#) in part 3 for details), which caused detrimental effects to

agricultural production. Reports from local governments rated the drought and saline intrusion in MRD in 2016 as most severe of the last 100 years in the region. Data from Annual Labor Force Survey (LFS) by the General Statistics Office (GSO) of Viet Nam show a surge in the number of people moving to urban areas in the South East region, and moving from the MRD to the three most developing destinations in the South East, including Ho Chi Minh City, Dong Nai and Binh Duong province. It is noted that the remarkable increase started in 2015 and lasted until 2017, with a one-year lag after the drought hit in the MRD. The LFS is conducted monthly, and asks people in the sample about the place they lived up to 12 months ago. This means that these people had made their decisions to move since 2014, and because of the shock in 2016, the number of migrants in 2017 continued to climb before dropping in 2018 [\[Table 6.9 \]](#).

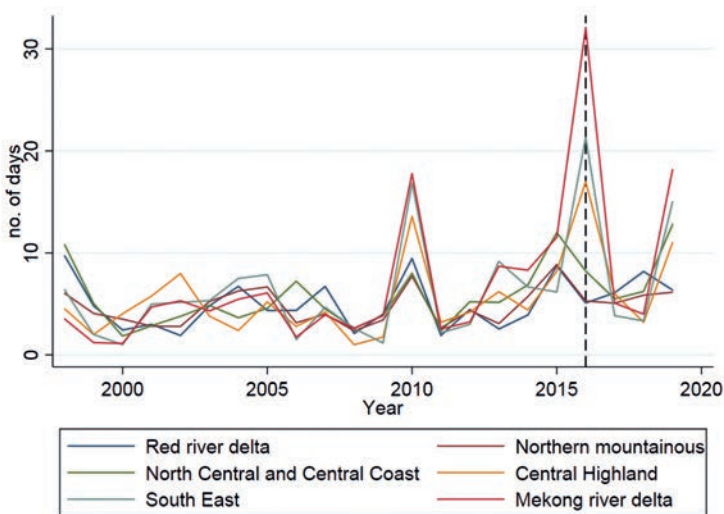
[Figure 6.5.1]

Number of continuous days with precipitation less than 1mm/day



[Figure 6.5.2]

Number of continuous days with temperature higher than 95% percentile of temperature since 1998



[Table 6.9]

Migration to some regions and provinces, 2013–2018

	Number of people moving from rural to urban area		Number of people moving in from MRD		
	Red river Delta	South East	Binh Duong	Dong Nai	HC Minh
2013	16,674	85,108	35,020	8,592	37,111
2014	16,603	51,550	12,166	4,773	12,783
2015	32,332	150,054	45,983	30,556	42,086
2016	24,511	110,057	45,147	12,544	30,767
2017	27,685	113,472	30,037	16,508	30,656
2018	25,838	56,681	19,149	2,685	23,305

Source: calculation from LFS.

[Table 6.10]

Impact of pro-long drought on income from agriculture of the households

	b/(se)
Maximum number of continuously no-rain days	0.002 (0.002)
Lag1.maximum number of continuously no-rain days	-0.003** (0.002)
Maximum number of continuously hot days	-0.004 (0.006)
Lag1. Maximum number of continuously hot days	0.007 (0.006)
Precipitation	-0.000 (0.000)
Lag1. precipitation	-0.000 (0.000)
Average temperature	0.113 (0.111)
Lag1. average temperature	-0.203 (0.434)

Note: Robust standard errors are reported in parentheses.

***, **, * significant at 1%, 5%, 10% levels, respectively. The set of additional controls at the household level includes age, gender, year of education of household head; size of household; ethnicity variable.

[Box 6.5]

The equation of impact of climate shock on agriculture income:

$$\ln(Y_{it}) = \alpha + \text{day\_prep\_min}_{ct} + \text{day\_temp95}_{ct} + \gamma X_{it} + \theta_c + \delta_t + \varepsilon_{it} \quad (6.6)$$

In this equation, Y_{it} is the income from agriculture of each household (adjusted to the price level in 2010). day_prep_min_{ct} is the number of continuous days without rain in province c in year t . day_temp95_{ct} is the number of continuous days with temperature higher than the 95% percentile of daily temperature in the region in period 1998–2018. X_{it} is a set of household characteristics (age, gender, year of education of the household head, size of the household, whether they are Kinh or ethnic minority group). θ_c and δ_t are province and year fixed effects; ε_{it} is the error term. Standard errors are clustered at provincial level.

To econometrically estimate the impact of climate shock on migration, we adopt a difference-in-different approach as in the following equation:

$$Y_{ct} = \alpha + \varphi \text{post}_t * \text{treated}_c + \gamma X_{ct} + \theta_c + \delta_t + \theta_c * \delta_t + \varepsilon_{it} \quad (6.7)$$

Y_{it} is the net number of people moving out of each province. We choose provinces in the Mekong River Delta as the treated group. The other provinces serve as the control group. The pre-treatment period is from 2013–2014, and treated period is from 2015–2017. θ_c , δ_t , and $\theta_c * \delta_t$ are a set of province fixed effects, year fixed effects and provincial linear trend. ε_{it} is the error term.

To estimate the impact of climate shock on agriculture income, we use data from the Viet Nam Household Living Standard Survey in 2014 and 2016 (see [Box 6.5](#)).

Results of the estimation of equation (6.1) are presented in [Table 6.10](#) provide strong evidence that a severe drought has a significant negative impact on income from agriculture for the households.

[Table 6.11](#) presents results of the estimation of equation (6.2) on Labour Force Survey data, showing the statistically significant impacts of the climate shock in 2014–2016 on the number of people moving out of provinces in the MRD. We also estimate equation (6.2), with the number of people moving from rural areas to urban areas in each province as the outcome variable. In this exercise, treated provinces are

provinces in the MRD and in the South East; the rest are in the control group. The results are presented in [Table 6.11](#), which show how the shock has pushed people to migrate to urban areas in the affected provinces.

Results from econometric estimations show that extreme weather does have negative impacts on the agricultural income for households. We also find evidence that households respond by migrating to the urban areas and nearby cities and industrial provinces. If this is the case, we will expect more people to move out of the Mekong River Delta to nearby provinces. This will have impacts on the labour market of both MRD and the nearby regions, especially the South East.

[Table 6.11]

Effects on the number of people moving out of each province

	Post*treated	Post*treated
Out-migrants	2618.383*** (827.0249)	2997.111*** (953.7446)
N	377	377
Province linear trend	No	Yes
F-stat	10.02	9.88
Adjusted R2	0.9093	0.9158

Note: Period of study: 2013-2018. LFS only provide information on the province of origin since the survey round in 2013. Level of significance: *** p<0.01 ** p<0.05 * p<0.1.

[Table 6.12]

Effects on the number of people moving from rural to urban areas in each province

	Post*treated	Post*treated
Rural-urban migrants	1668.734*** (947.349)	3069.835*** (1297.27)
N	500	500
Province linear trend	No	Yes
F-stat	3.1	5.6
Adjusted R2	0.8585	0.8519

Note: Period of study: 2011-2018. Level of significance: *** p<0.01 ** p<0.05 * p<0.1.

7. Projection

This Section summarizes projected changes in household income as well as labour organization in a warming climate. To generate these projections, we relied on a simulated temperature that was developed by the Laboratory for REmote sensing and MOdelling of Surface and ATmosphere (REMOSAT).

7.1 Methodology

As the basis for temperature observation, a gridded data product was developed at the 0.1 arc-degree resolution using Kriging interpolation [Switzer, 2014]. The gridded daily temperature (available from 1980 to 2018) was then used to downscale and bias-correct outputs of global circulation models (GCMs) to provide fine-scale projection of Viet Nam's climate under different Representative

Concentration Pathways (RCPs). Specifically, the bias-correction and spatial disaggregation technique [BCSD; Wood *et al.*, 2002] was used to disaggregate global simulations of 31 models contributing to the CMIP5 experiment under four RCPs (20 simulations for RCP2.6, 31 simulations for RCP4.5, 12 simulations for RCP6.0 and 31 simulations RCP8.5) to a 0.1 arc-degree resolution. The downscaled, bias-corrected daily temperature was available for two simulation periods: historical (from 1980 to 2005) and future (2006–2100). The daily time series were then aggregated by calendar year to get annual time series of Viet Nam's temperature (from 1980 to 2100).

It is informative to note that Viet Nam has a heterogeneous climate due to its complex topography, and the influences of regional climate patterns [Le *et al.*, 2019]. To assess regional impacts of changes in temperature to socio-economic factors, we used an established climate classification system [Nguyen *et al.*, 1994; Phan-Van *et al.*, 2009; Mai *et al.*, 2014]. We divided Viet Nam's mainland into seven climate regions (see Figure 6.6 for the boundary of these regions): the Northwest region (denoted as BI), the Northeast region (denoted as BII), the Red River Delta region (denoted as BIII), the North Central region (denoted as BIV), the South Central region (denoted as NI), the Central Highland region (denoted as NII), and the South region (denoted as NIII).

The annual temperature was then aggregated across Viet Nam as well as in each of the seven climate regions, to get national and regional average temperature for this assessment. The average temperature simulated during the 1986–2005 period was then used to represent historical climate conditions. The difference between projected temperature and historical temperature was then calculated

and used to project changes in the assessed socio-economic factors (*i.e.* hourly wage, hours worked, gender pay gap, firm revenue, firm TFP, firm output, and firm size; reported in section 3 and section 4 of this chapter). To reduce potential noise caused by inter-annual variabilities in temperature, we also applied a 20-year moving filter to projections of annual temperature from 2018 to 2100 (*e.g.* the value in 2050 is the average of annual temperature simulated over the 2031–2050 period).

The projected changes in temperature were then used to estimate future changes in the assessed factors for each of the available simulations separately. The mean of all simulations (under each RCP) was then calculated and presented in Table 6.13 in the Results section, to represent a projection of changes in socio-economic factors.

7.2 Results

In Viet Nam, a dominant increasing trend in temperature is projected across all greenhouse gas emission scenarios, leading to substantial changes across all socio-economic factors that have been selected for this assessment (*i.e.* hourly wage, hours worked, gender pay gap, firm revenue, firm TFP, firm output, and firm size). Although the rate of change varies across climate regions, the signals detected at the regional scale are generally consistent with those detected at the national level. For instance, Figure 6.6 illustrates the implication of climate changes for Vietnamese hourly wages, showing a substantial decline projected at the national scale across all RCPs by the end of the XXIst century. These patterns are highly correlated to what is detected across the seven climate regions, although the changes detected in the northern regions are relatively higher than those detected in their southern counterparts.

[Figure 6.6]
The boundaries of the climate regions in mainland Viet Nam

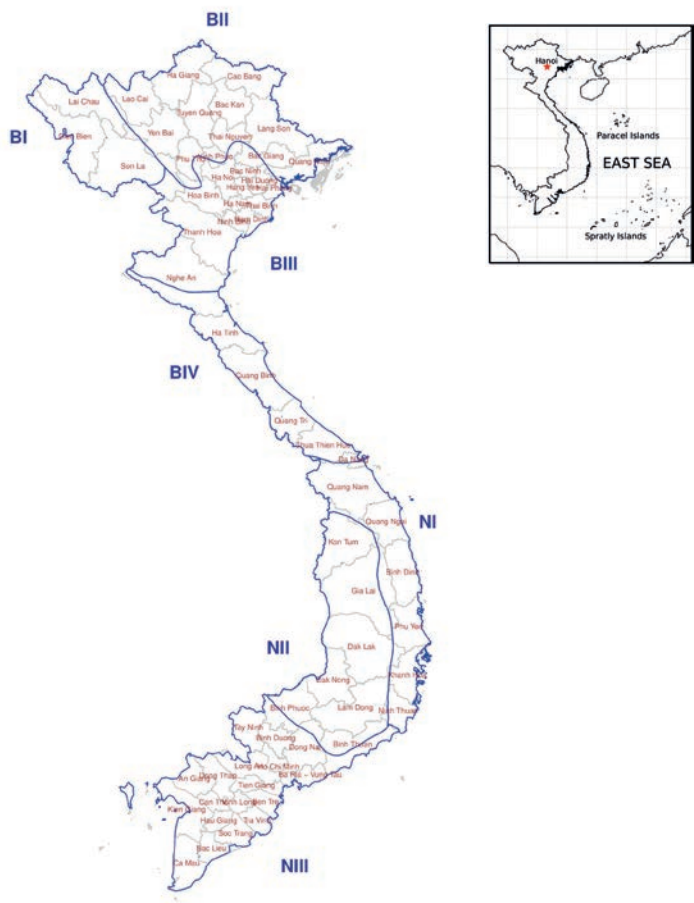
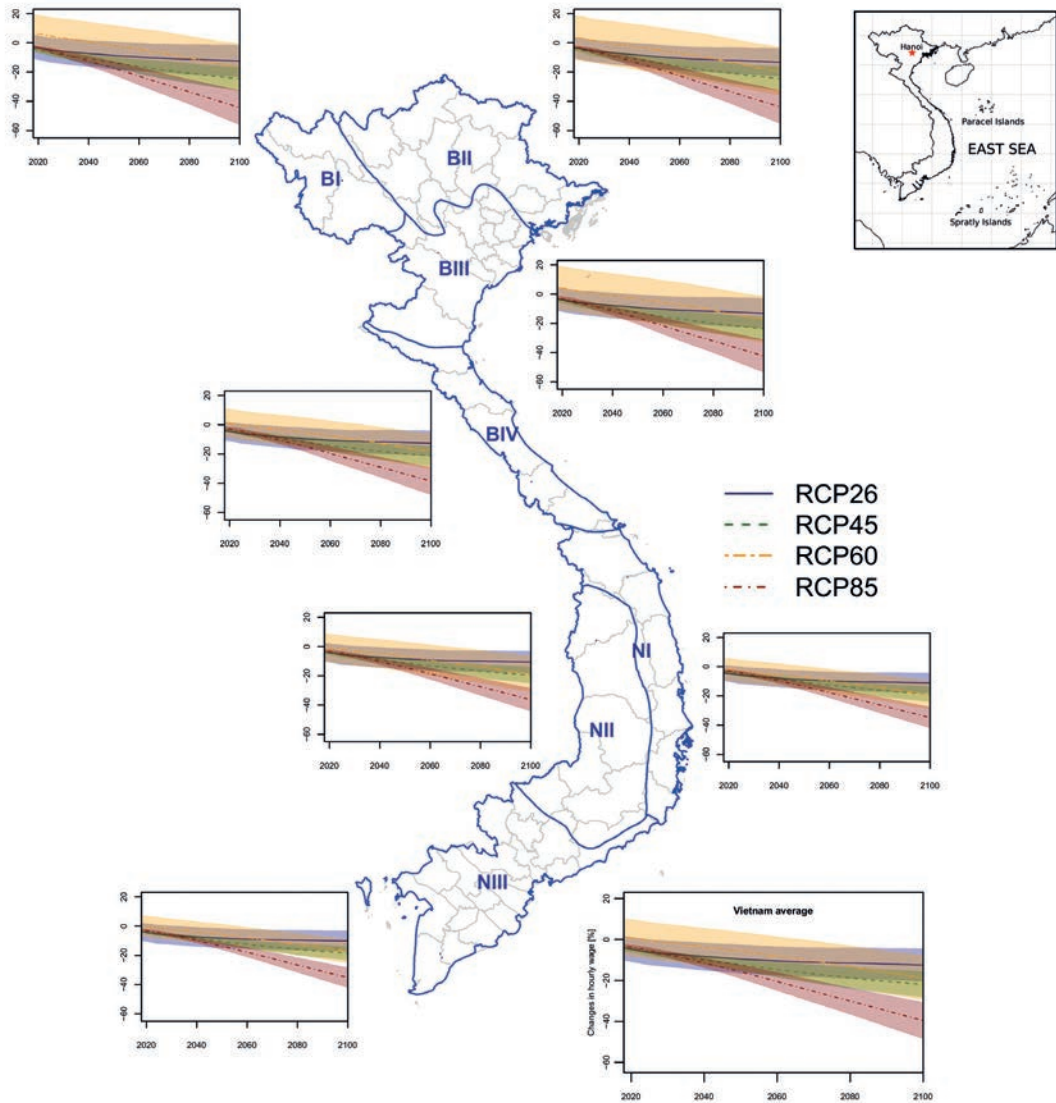


Table 6.13 summarizes projected changes in the assessed socio-economic factors across Viet Nam in 2050, 2075 and 2100 under four different RCPs. Climate change was projected to imply negative impacts on all of these factors (e.g. reducing hourly wage, widening gender pay gap, or slashing firm revenue) across all RCPs. Even in the most ambitious greenhouse gas emission scenario (RCP26), a persistent impact has been projected throughout Viet Nam, regardless of socio-economic factors. For instance, the gender pay gap is projected to increase (relative to the 1986–2005 baseline) slightly over the XXIst century, reaching

0.6% in 2100. Among four metrics representing firm performance, firm TFP is projected to be affected the most by climate change, with a reduction ranging from 4.1% to 12.9% compared to the baseline period in 2100. It is important to note that the impact is more severe under RCP8.5 (e.g. a change of 39.5%, 1.9% and 26% is projected for hourly wage, gender pay gap and firm output respectively by the end of the XXIst century) relative to the other scenarios, indicating the importance of more sustainable greenhouse gas emission scenarios to Viet Nam's economy.

[Figure 6.7]
Projected changes in hourly wage (in percentage)



■ Note: The uncertainty (+/- 1 standard deviation; represented by colour bands) and the average (mean; represented by the coloured lines) have been shown separately for each Representative Concentration Pathway (RCP).

[Table 6.13]

Projected changes (in percentage) of seven assessed socio-economic metrics across Viet Nam in a warming climate

Metric	RCP26			RCP45			RCP60			RCP85		
	2050	2075	2100	2050	2075	2100	2050	2075	2100	2050	2075	2100
Hourly wage	-9.5	-11.3	-12.4	-12.3	-17.7	-21.8	-5.7	-11.8	-18.6	-15.7	-27.6	-39.5
Hours worked	-0.5	-0.6	-0.6	-0.6	-0.9	-1.1	-0.3	-0.6	-0.9	-0.8	-1.3	-1.9
Gender pay gap	0.5	0.6	0.6	0.6	0.9	1.1	0.3	0.6	0.9	0.8	1.3	1.9
Firm revenue	-3.1	-3.7	-4.1	-4.0	-5.8	-7.2	-1.9	-3.9	-6.1	-5.2	-9.1	-12.9
Firm TFP	-3.3	-3.9	-4.3	-4.3	-6.1	-7.6	-2.0	-4.1	-6.4	-5.4	-9.6	-13.7
Firm output	-6	-8	-8	-8	-12	-15	-4	-8	-12	-10	-18	-26
Firm size	-2.0	-2.4	-2.6	-2.6	-3.8	-4.6	-1.2	-2.5	-3.9	-3.3	-5.9	-8.4

Note: For each of the greenhouse gas emission scenarios, the mean of all projections was provided.

8. Policy implications

This chapter has assessed the impacts of changes in temperature and precipitation on economic entities, including workers, businesses, and households. The chapter's findings add useful information to the literature, and provide evidence to support the process of policy-making in response to climate change. Unlike the results of the sectorial impact assessment, this chapter studies the impacts of climate variability on the welfare of workers, households and firms' performance. The chapter results provide several policy implications for Viet Nam's response to climate change, as follows:

► **On the impact assessment of climate change:** Various models and analyses in this chapter suggest ways and channels to assess the impacts of climate change on different actors in the economy. Assessing the impacts of climate change is necessary to provide a basis for reviewing, adjusting and promulgating

policies to respond to climate change. According to the revised Environmental protection Law in 2020, this assessment needs to be carried out in order to formulate appropriate climate change response policies. Currently, documents to guide local governments in their impact assessments are being prepared. The findings of this chapter show that climate change may have adverse effects on job creation, employment allocation, economic restructuring, household income, and business performance. Therefore, the climate change impact assessment should consider the impacts on these economic entities and aspects. In particular, the results show that the impact on the incomes of some vulnerable groups such as the poor and women should be paid due consideration.

► **On the impacts of climate change on agriculture and structural change:** The results of this chapter show the negative impact of increases in temperature on household income from agriculture. These are consistent with

the findings of other studies, particularly the impacts on livestock and fishing⁵. Specifically, the results indicate that there is a negative impact of weather shock on fruit income, suggesting that more policies to support agricultural sectors are needed. These results – together with findings on the impact of temperature and rainfall changes on the choice of workers to work in agriculture, industry, or services, and on migration – suggest that climate change will have a definite impact on employment and economic restructuring. Therefore, the issue of climate change should be considered when studying policy directions to promote the transformation of employment and economic structure in Viet Nam.

► **On climate change and poverty:** The chapter findings indicate that climate change has a more negative impact on poor households. It is found that poor households suffered more losses in income. This means climate change may impoverish the poor, so the issue of climate change should be seriously taken into account in poverty reduction policies. In other words, it is necessary to integrate the issue of climate change into poverty reduction policies or, vice versa, to examine the issue of the poor in policies to respond to climate change. Currently, the national target programme on poverty reduction has many poverty reduction policies focusing on poor communes, such as infrastructure development, poverty reduction, livelihood models, communication, etc. but does not pay enough attention to the issue of climate change. In contrast, the national plan of Viet Nam to adapt to climate change for the period 2021–2030, with a vision through to 2050, recognizes that climate change is an

existential threat to the goals of sustainable development and hunger eradication. The plan includes some actions that indirectly affect poverty (such as through employment, loss and damage reduction, etc.), but does not directly address poverty in relation to climate change. In this regard, it might be necessary to study and develop livelihood models to respond to climate change for poor households, and have policies to improve their capacity to adapt to climate change.

► **On climate change and employment:** The chapter results show that changes in temperature and rainfall have a negative impact on working hours and the income of workers. The results also show the effects of climate variables on employment allocation and migration. These findings have been verified through the impacts on labour demand (*i.e.* the increase of average temperature and precipitation lead to a decline in revenue, output, firm size and productivity). They provide evidence for the need to integrate the issues of climate change into employment policy. This is shown in Viet Nam's National Plan for Climate Change Adaptation for the period 2021–2030, with a vision through to 2050. Specifically, the plan integrates climate change into employment policies with a focus on developing policies to create green jobs, support job transition and develop sustainable livelihoods for people. However, according to the findings of this chapter, in addition to people, the plan may need to pay attention to businesses, and policies to support businesses in adapting to climate change, minimizing its negative impacts and resulting damage.

► **On climate change and gender:** One of the notable findings of this chapter is that climate variables may have negative impacts on gender inequality: women tend to work more but earn less when the temperature increases. In

5. For example, research results show that climate change is expected to reduce output of pig production by 1.1% of total pig output in Viet Nam [Nguyen TTN *et al.*, 2017], or negatively impacts the growth of animals, birds, reptiles, etc. [Nguyen Dac Manh *et al.*, 2020].

other words, the climate change may increase gender inequality in terms of working hours and pay. This provides evidence for the need to mainstream gender issues into policies to respond to climate change. In Viet Nam, this has been carried out quite well. Current policies emphasise capacity building for women, developing female human resources involved in the climate change adaptation process, and providing soft skills training female workers to participate in new economic sectors in the context of climate change adaptation. Besides, it may worth considering promoting the typical models which suitable for women in the context of climate change.

► **On the role of NGOs in climate change:** The results of this chapter, along with the results of many other studies, show that climate change can have adverse effects in many aspects of household well-being, especially for vulnerable groups such as the poor. Therefore, in order to respond well to climate change, it is necessary to approach the issue from multiple dimensions with the active participation of various actors, including proactive state agencies and international partners/organizations, individuals and communities, including non-government organizations (NGOs) and associations. In regard to working with households, many NGOs are currently very active participants in climate change adaptation, and play an important role in raising awareness as well as helping households to respond to climate change⁶. Government policies such as the National Plan to adapt to climate change need to mobilize the participation of these organizations more strongly, to join hands with the state and people to reduce negative impacts, strengthen resilience and enhance the adaptive capacity of households to climate change.

6. For example shown in the MPI and UNICEF (2021). Climate landscape analysis for Children in Viet Nam.

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Part 3

The Mekong emergency



SUMMARY | THE MEKONG EMERGENCY

This third part of the report focuses on the complex interlinkages between climate change impacts and local anthropogenic environmental changes in the Mekong region [Figure 1]. According to the 5th IPCC report, studying the effect of climate change on coastal regions cannot be independent of “local drivers of exposure and vulnerability”.

Viet Nam’s Mekong Delta (VMD) is the third largest delta on Earth, and currently home to 17 million inhabitants, whose livelihoods depend mainly on agricultural and aquacultural production. The region supplies more than half of Viet Nam’s rice production, 90% of which is exported, and is thus crucial for both national and international food security.

However, the VMD is subject to various drivers of change, of which anthropogenic drivers — namely hydropower dams, sand mining and groundwater extractions — pose the greatest threats in this first half of the century. The Delta is already under pressure, which leaves us with a limited window of opportunity for adaptation, since climate change effects will most probably start to dominate the threats in the second half of the century.

The VMD has long historical experience of dealing with water- and climate-related factors which can threaten agricultural production and livelihoods. However, the increasing impacts of climate change and anthropogenic activities challenge the sustainability of existing approaches, and call for new adaptation and mitigation measures.

Furthermore, the Delta is strongly influenced by the water governance of the whole Mekong basin, or lack thereof. Climate change adds a layer of uncertainty to the already complex water management problems. The current regional structure of governance and management for transboundary resources in the Mekong region is made up of a web of organizations, including different partners inside and outside the region. This scattered institutional architecture still needs to be fully aligned with the mitigation and adaptation objectives of the Paris Agreement, while acknowledging the full scope of local anthropogenic environmental dynamics.

Climate change

Temperature and precipitation

Over the last four decades (1981–2018), the VMD has experienced significant temperature and precipitation changes:

- The mean annual temperature has increased over the whole Delta, with an average trend of +0.76°C over 38 years. However, the number of hot and very hot days show contrasting trends depending on the weather station.
- In general, rainfall shows an increasing trend over most of the Mekong Delta, but the trend is only statistically significant at a few stations. Trends in rainfall extremes vary greatly between regions.

According to climate projections from dynamical downscaling (*i.e.* regional climate models), provided by IMHEN, past trends in temperature and precipitation are expected to strengthen in the coming decades:

- ▶ The mean annual temperature in the Delta is projected to increase by $1.74 \pm 0.92^{\circ}\text{C}$ under RCP4.5 and $3.56 \pm 1.25^{\circ}\text{C}$ under RCP8.5 by the end of the century, compared to 1986–2005. It is also informative to look at the warming level projected in the Delta for different global warming levels (GWL), to analyse the impacts of a global warming level reached earlier or later than in a given RCP scenario. Hence, when the GWL reaches 1.5°C , temperature in the whole Mekong Delta is projected to increase by 0.78°C . For a GWL of 3°C , the temperature rise projected in the Delta is 2.19°C [Figure 2].
- ▶ The mean annual rainfall is projected to increase by ~15% under RCP4.5 and 25% under the RCP8.5 by the late century, compared to 1986–2005.

Temperature projections from statistical downscaling (this report) are similar, with an average increase of $1.79 \pm 1.01^{\circ}\text{C}$ under RCP4.5, and $3.59 \pm 1.12^{\circ}\text{C}$ under RCP8.5 by the end of the century. However, results obtained for mean annual precipitation differ greatly from dynamical downscaling projections, with only limited changes (<10%) even for high global warming levels. This discrepancy will be investigated in further research.

Sea level rise

The current rate of global sea level rise is ~3.3 mm/year, and is projected to accelerate during the XXIst century. Depending on the climate scenario, the total projected rise ranges from 43 cm to 84 cm by the end of the century, but large uncertainties remain and higher values cannot be ruled out.

The VMD has an extremely low-lying delta plain [Figure 4]. The vast majority of the delta is elevated less than 2 m above local mean sea level, with an average elevation of ~80 cm. Therefore, it is extremely vulnerable to even small changes in relative sea level, which arise from the cumulative effect of global sea level change and “local” vertical land movements (*e.g.* land subsidence). Hence, ~30% of the Delta could find itself at elevations below sea level with a relative sea level rise of 50 cm.

Anthropogenic stressors and their impacts

Sediment starvation

Total sediment transported by the pristine Mekong river was estimated at ~160 Mt/year, but recent estimates show a 40–90% reduction in fluvial sediment supply to the VMD due to sediment trapping by upstream dams [Figure 3]. In addition, current sand mining within the VMD is estimated at 40–50 Mt/year, which, when added to sand mining in Cambodia and Laos, is likely to represent over 100% of the remaining total fluvial sediment supply.

The most important impact of sediment starvation is the high erosion rates of riverbed levels (10–15 cm/year) in the Delta, which have triggered tidal amplification in the range of

~2 cm/year. This has largely contributed to city flooding, and has increased salt intrusion in the range of 0.2-0.5 PSU/year over the past two decades. Sediment starvation has also decreased sediment supply to the coastline, which is currently eroding along the eastern coast.

The increase in saline water intrusion during the dry season observed over the last decades is also strongly driven by the declining freshwater supply from the Tonle Sap Lake, which is itself caused predominantly by mainstream hydropower development, which has shifted the hydrological regime of the Mekong River.

Relative sea level rise and climate change-driven discharge changes will most probably moderately (~10%) increase salt balance throughout the coastal provinces in the first half of the century. Anthropogenic riverbed level incision will remain the main driver of salinization of the Delta and, depending on future rates of sand mining, could increase the extension of land impacted by saline water intrusions by an additional 25% in 2050 (Figure 4 and Figure 5). In the second half of the century, relative sea level rise could dominate saline water intrusion.

Groundwater extraction

Rapid urbanization and intensified food production in the Delta has placed immense pressure on the water resources of the VMD. For example, within the aquaculture sector, demand for quality fresh/brackish water has significantly increased in the past decades. Consequently, groundwater extraction has been growing rapidly, with a 5-fold increase over the last 20 years. Current extracted volumes are ~2.5 10⁶ m³/day, with an annual increase of 4%/year. Groundwater over-extraction is the main driver of high land subsidence rates in the Delta (as large as 5 cm/year in some places), which is not currently compensated by new sediment deposits. As a result, the Delta is experiencing rapid elevation loss.

In the coming decades, relative sea level rise will predominantly be determined by the amount of subsidence, which for a large part depends on groundwater extraction. Should the rate of extraction remain at present-day levels, the average cumulative subsidence could be over 80 cm by 2100, which, combined with global sea level rise and lack of sedimentation on the floodplains, would cause the majority of the Delta to fall below sea level.

Adaptation dynamics in the Viet Nam's Mekong Delta

In the face of these threats, authorities have been encouraged to design adaptation pathways that emphasize rapid response capabilities in terms of investments or financial incentives, but that have in all cases been conceived as top-down strategies, and are not necessarily well-adapted to dynamic local conditions.

At the other end of the spectrum, farmers and local communities have spontaneously adapted their farming systems, under pressure from environmental or market factors, and diversified their production by paying more attention to a rational use of the environment.

But these uncoordinated changes mean that these spontaneous, bottom-up strategies are unlikely to scale up easily.

These different strategies interact with each other in complex ways, and it is in their interactions that the main sources of adaptive innovation are likely to be found.

The design of integrated multiscale models [Figure 6] allows us to better test the impact of policy decisions or management options in common climate scenarios. Between “*laissez-faire*” policies, in which the bulk of adaptation would rest on the shoulders of farmers, and top-down policies, in which no autonomy is granted to farmers, combinations between these two approaches are measured in these models as most beneficial for all actors in the system.

Climate policies in the Mekong, a regional coordination issue

Among other things, hydropower development in the Mekong region [Figure 3] has helped promote energy security, while contributing to flood and drought management within a low-carbon economy. However, alongside these immediate regional benefits, the impacts on the Mekong Delta’s hydrological dynamics, sediment and fish transport downstream are huge. Climate change adds an additional layer of complexity to this challenging exercise in transboundary resource governance. Understanding the interests and motivations of all actors is thus essential, while policy and scientific platforms and other innovative approaches could encourage dialogues with a view to potential collaborations.

We argue that traditional forms of state-led governance alone are inadequate in dealing with transboundary environmental issues. The Basin Development Strategy 2021–2030 of the Mekong River Commission recently called for “proactive regional planning”. Such “proactive regional planning” could play an integrative role, via joint mitigation investment projects and adaptation measures between countries, actors, and sectors under the general principle that water is a basic need and right of every Mekong inhabitant. It potentially transforms Mekong water into a common pool resource.

TÓM TẮT | NHỮNG ĐIỀU CẤP THIẾT CHO VÙNG ĐỒNG BẰNG SÔNG CỬU LONG

Phần ba của báo cáo này tập trung vào mối liên kết phức tạp giữa tác động của biến đổi khí hậu và những thay đổi về môi trường do con người ảnh hưởng tại vùng Đồng bằng sông Cửu Long [Hình 1]. Theo báo cáo IPCC thứ 5, nghiên cứu tác động của biến đổi khí hậu trên các vùng ven biển thể hiện sự liên quan nhiều đến “các tác nhân địa phương dẫn đến mức độ chịu tác động và khả năng bị tổn thương”

Đồng bằng sông Cửu Long (ĐBSCL) là đồng bằng lớn thứ ba trên thế giới, hiện có 17 triệu dân với sinh kế lệ thuộc chủ yếu vào sản xuất nông nghiệp và thủy sản. Khu vực này cung cấp hơn một nửa sản lượng lúa gạo của Việt Nam, trong đó 90% là cho xuất khẩu, và vì vậy đóng vai trò lớn trong an toàn lương thực quốc gia và thế giới.

Tuy nhiên, ĐBSCL hiện đang trước mắt những thay đổi, trong đó những thay đổi do chính từ hoạt động của con người như các dự án đập thủy điện, khai thác cát và nước ngầm đã và đang mang tới những rủi ro lớn trong một nửa đầu của thế kỷ. Như vậy, ĐBSCL đang đứng trước những áp lực nên cũng hạn chế đi cơ hội để ứng phó với biến đổi khí hậu. Chính vì vậy, ảnh hưởng của biến đổi khí hậu rất có thể trở thành mối nguy lớn nhất trong nửa sau của thế kỷ này.

ĐBSCL đã trải qua quá trình lịch sử dài đương đầu và sống với những tác nhân liên quan đến nước và khí hậu làm ảnh hưởng đến sản xuất nông nghiệp và sinh kế. Tuy nhiên, những ảnh hưởng tăng cường của biến đổi khí hậu và những hoạt động của con người sẽ là thử thách cho sự bền vững của các chiến lược hiện tại và trong quá khứ đang áp dụng, do đó đòi hỏi phải có những chiến lược thích ứng và giảm thiểu mới hơn.

Thêm vào đó quản lý tài nguyên nước cho vùng ĐBSCL gắn kết chặt chẽ với quản trị nguồn nước của cả khu vực, hoặc thiếu vắng một hệ thống quản trị như thế. Biến đổi khí hậu làm tăng thêm tính bất định khó dự đoán của các vấn đề phức tạp của quản lý tài nguyên nước. Cấu trúc quản trị hiện tại của vùng sông Mê Kông bao gồm một mạng lưới các tổ chức bao gồm các đối tác trong và ngoài các nước sông Mê Kông. Và cấu trúc rời rạc của chuỗi các tổ chức cần được gắn kết cũng như gắn với các mục tiêu giảm thiểu và thích ứng của Thỏa thuận Paris; song song đó cũng cần bao trùm những vận động về giữa con người và môi trường tại mỗi vùng, địa phương.

Biến đổi khí hậu

Nhiệt độ và lượng mưa

Trong 4 thập kỷ qua (1981–2018), ĐBSCL đã trải qua nhiều thay đổi đáng chú ý về nhiệt độ và lượng mưa:

- Lượng mưa trung bình hằng năm gia tăng trên cả vùng đồng bằng, với xu hướng tăng trung bình là +0.76°C trong 38 năm. Tuy nhiên, dữ liệu số ngày nắng nóng và rất nóng chỉ ra các xu hướng mâu thuẫn nhau tùy thuộc và trạm thời tiết.
- In general, rainfall shows an increasing trend over most of the Mekong Delta, but the trend is only statistically significant at a few stations. Trends in rainfall extremes vary greatly between regions.

► Nhìn chung, lượng mưa trung bình hằng năm chỉ ra xu hướng tăng (WM1) trên cả Đồng bằng, tuy nhiên, xu hướng đó chỉ có ý nghĩa về mặt thống kê trên một vài trạm đo đạc. Xu hướng của lượng mưa cực đoan dao động nhiều giữa các khu vực.

Theo những dự báo về khí hậu được chi tiết hóa động lực (ví dụ mô hình khí hậu cấp vùng), do IMHEN cung cấp thì xu hướng thay đổi về nhiệt độ và lượng mưa trong quá khứ sẽ tiếp tục gia tăng trong những thập kỷ tiếp theo như sau:

► Nhiệt độ trung bình hằng năm của ĐBSCL dự đoán sẽ tăng vào khoảng $1.74 \pm 0.92^\circ\text{C}$ theo RCP4.5 và $3.56 \pm 1.25^\circ\text{C}$ theo RCP8.5, tại thời điểm cuối thế kỷ, lượng tăng so với giai đoạn 1986-2005; Thông tin chỉ ra rằng cần quan tâm đến chỉ số ấm lên dự báo cho đồng bằng dựa vào các mức độ nóng lên toàn cầu (GWL) để khảo sát mức độ ảnh hưởng của nóng lên toàn cầu liệu có diễn ra sớm hơn hoặc muộn hơn kịch bản RCP đưa ra. Vì vậy, khi GWL đạt mức 1.5°C , nhiệt độ của cả vùng ĐBSCL dự báo sẽ tăng 0.78°C ; và khi GWL chạm ngưỡng 3°C , nhiệt độ sẽ tăng dự kiến ở mức 2.19°C [Hình 2].

► Lượng mưa trung bình hằng năm được dự đoán sẽ tăng $\sim 15\%$ theo RCP4.5 và 25% theo RCP8.5, tại giai đoạn sau của thế kỷ, chỉ số tăng này là so với giai đoạn 1986–2005.

Những dự báo nhiệt độ từ kết quả chi tiết hóa thống kê (theo báo cáo này) là giống nhau, với lượng gia tăng trung bình $1.79 \pm 1.01^\circ\text{C}$ theo RCP4.5 và $3.59 \pm 1.12^\circ\text{C}$ theo RCP8.5 vào cuối thế kỷ. Tuy nhiên, kết quả đạt được cho lượng mưa trung bình hằng năm có sự khác biệt lớn so với các dự báo từ chi tiết hóa động lực, với thay đổi ở mức giới hạn ($<10\%$), ngay cả với mức độ cao hơn của nóng lên toàn cầu. Sự chênh lệch này cần được nghiên cứu kỹ hơn trong tương lai.

Nước biển dâng

Tỷ lệ nước biển dâng hiện tại là ~ 3.3 mm một năm và dự báo có khả năng tăng lên trong thế kỷ 21. Tùy thuộc vào kịch bản khí hậu, khả năng tổng tăng của nước biển dâng vào cuối thế kỷ có thể lên đến từ 43 cm đến 84 cm, nhưng không chắc chắn, và con số cũng có thể cao hơn.

ĐBSCL là một trong những đồng bằng bằng phẳng và thấp nhất trên thế giới [Hình 4]. Phần lớn diện tích đồng bằng nằm ở độ cao dưới 2m so với mực nước biển, với trung bình địa hình cao khoảng 80cm. Vì vậy, ĐBSCL cực kỳ dễ bị tổn thương khi đứng trước những thay đổi nhỏ nhất về nước biển dâng tương đối, điều đang diễn ra do những ảnh hưởng tích lũy dần của nước biển dâng toàn cầu và sự chuyển dịch bề mặt đất theo phương đứng (như sụt lún đất). Vì vậy, 30% đồng bằng có thể sẽ nằm dưới mực nước biển khi nước biển dâng tương đối đạt mức 50 cm.

Các tác nhân gây căng thẳng do con người gây ra và tác động của chúng

Thiếu hụt trầm tích

Ước tính tổng lượng phù sa do sông Mekong vận chuyển khoảng 160 triệu tấn/năm, tuy nhiên các ước tính gần đây cho thấy nguồn cung cấp phù sa cho ĐBSCL giảm 40–90% do trầm tích bị giữ lại bởi các đập ở thượng nguồn [Hình 3]. Ngoài ra, khai thác cát hiện tại ở

ĐBSCL và vùng thượng nguồn ở Lào và Campuchia ước tính lên đến 40–50 triệu tấn/năm, ước tính hơn 100% tổng lượng phù sa phù sa cung cấp.

Các tác động quan trọng nhất của việc thiếu hụt phù sa là tốc độ bào mòn đáy sông cao ở ĐBSCL (10-15 cm / năm), làm tăng biên độ thủy triều khoảng 2 cm/năm điều này góp phần đáng kể gây ra tình trạng ngập lụt ở đô thị và gia tăng xâm nhập mặn khoảng 0,2-0,5 PSU/năm trong hai thập kỷ qua. Tình trạng thiếu hụt phù sa cũng đã làm giảm nguồn cung cấp phù sa cho bờ biển hiện đang bị xói mòn ở dọc bờ biển đồng .

Sự gia tăng xâm nhập mặn trong mùa khô được quan sát thấy trong những thập kỷ qua cũng do nguồn cung cấp nước ngọt từ hồ Tonle Sap giảm; nguyên nhân chủ yếu của vấn đề này là do phát triển thủy điện đã dịch chuyển hệ thống thủy lực của cả vùng sông Mê Kong

Mực nước biển dâng tương đối và những thay đổi về lưu lượng nước do biến đổi khí hậu có thể sẽ làm tăng (10%) ranh giới đường đẳng mặn ở các tỉnh ven biển trong nửa đầu thế kỷ. Các tác động lòng sông do con người gây ra sẽ vẫn là động lực chính của quá trình nhiễm mặn Đồng bằng và tùy thuộc vào tỷ lệ khai thác cát trong tương lai, có thể làm tăng thêm 25% diện tích đất bị ảnh hưởng bởi nước mặn xâm nhập vào năm 2050 (Hình 4 và Hình 5). Trong nửa sau của thế kỷ này, mực nước biển dâng tương đối có thể chi phối sự xâm nhập của nước mặn.

Khai thác nước ngầm

Đô thị hóa nhanh chóng và thâm canh cây trồng ở ĐBSCL đã tạo nên áp lực lớn đến tài nguyên nước. Ví dụ, nước ngọt hoặc nước lợ cho ngành nuôi trồng thủy sản đã tăng mạnh trong những thập kỷ qua. Do đó, khai thác nước ngầm đang tăng lên nhanh chóng, với mức tăng gấp 5 lần trong vòng 20 năm qua. Sản lượng khai thác hiện tại là 2,5 triệu m³/ngày, với mức tăng hàng năm là 4%/năm. Việc khai thác quá mức nước ngầm là nguyên nhân chính dẫn đến tỷ lệ sụt lún đất cao ở Đồng bằng (có nơi lên tới 5 cm/năm) mà không được bù đắp bằng các trầm tích mới. Kết quả là đồng bằng bị mất độ cao nhanh chóng.

Trong những thập kỷ tới, mực nước biển dâng tương đối trong tương lai chủ yếu sẽ được xác định bởi lượng sụt lún, phần lớn phụ thuộc vào việc khai thác nước ngầm. Nếu tốc độ khai thác vẫn ở mức hiện tại, thì độ sụt lún tích lũy trung bình có thể lớn hơn 80 cm đến năm 2100, kết hợp với mực nước biển toàn cầu dâng và thiếu phù sa ở các vùng đồng bằng ngập lụt, sẽ khiến phần lớn đồng bằng bị chìm dưới mực nước biển.

Sự thích ứng động ở Đồng bằng sông Cửu Long

Trước những mối đe dọa đã nêu, các cơ quan chức năng được khuyến khích thiết kế các lộ trình thích ứng nhấn mạnh khả năng phản ứng nhanh về đầu tư hoặc khuyến khích tài chính. Các trường hợp này được xem là các chiến lược từ trên xuống, có khả năng không thích ứng tốt với các điều kiện của địa phương.

Mặt khác, người nông dân và cộng đồng địa phương thích nghi một cách tự phát qua việc lựa chọn hệ thống canh tác phù hợp dưới tác động của các yếu tố môi trường và thị trường và đa dạng hóa sản xuất của họ thông qua việc quan tâm đến sử dụng hợp lý môi trường. Tuy nhiên những thay đổi không có sự phối hợp đa phần như một chiến lược tự phát, sự tự phát từ dưới lên khó có thể mở rộng ra quy mô rộng.

Các chiến lược khác nhau giữa nhà nước và người dân tương tác với nhau theo những cách phức tạp và chính trong sự tương tác của chúng, các thích ứng mới có thể được tìm thấy.

Việc thiết kế mô hình tích hợp nhiều cấp độ [Hình 6] cho phép chúng tôi kiểm tra tốt hơn tác động của các quyết định chính sách hoặc các lựa chọn quản lý trong các kịch bản khí hậu chung. Các chính sách thử nghiệm bao gồm: Chính sách «tự thích ứng», trong đó phần lớn sự thích ứng sẽ đặt lên vai người nông dân, chính sách thích ứng từ trên xuống, trong đó đưa ra các quy định mà không trao quyền tự chủ cho nông dân và chính sách kết hợp giữa hai cách tiếp cận. Trong đó chính sách phối hợp giữa hỗ trợ từ trên xuống của nhà nước và tự thích ứng của người dân được đo lường trong các mô hình này là có lợi nhất cho tất cả các tác nhân trong hệ thống.

Các chính sách khí hậu ở Đồng bằng sông Cửu Long, vấn đề hợp tác khu vực

Trong các hoạt động khác nhau thì phát triển thủy điện ở khu vực sông Mekong [Hình 3] giúp cải thiện an ninh năng lượng, đồng thời góp phần quản lý lũ lụt và hạn hán trong nền kinh tế phát thải các-bon thấp. Bên cạnh những lợi ích khu vực trước mắt này, các tác động đối với động lực thủy văn, vận chuyển phù sa và nguồn lợi cá ở vùng hạ lưu của Đồng bằng sông Cửu Long là rất lớn. Biến đổi khí hậu làm tăng thêm sự phức tạp cho quản trị tài nguyên xuyên biên giới. Do đó, việc hiểu rõ lợi ích và động lực của tất cả các bên liên quan là rất cần thiết, trong khi các nền tảng chính sách và khoa học cũng như các phương pháp tiếp cận sáng tạo khác có thể khuyến khích các cuộc đối thoại để hiện thực hóa các hợp tác tiềm năng.

Chúng tôi cho rằng chỉ riêng các hình thức quản trị truyền thống với sự dẫn dắt và chịu trách nhiệm chính bởi hệ thống quản lý công là không đủ trong việc giải quyết các vấn đề môi trường xuyên biên giới. Chiến lược phát triển lưu vực 2021–2030 của Ủy hội sông Mekong gần đây đã kêu gọi thực hiện “quy hoạch vùng chủ động”. Giải pháp “quy hoạch vùng chủ động” như vậy có thể đóng vai trò tích hợp các dự án hợp tác đầu tư và các biện pháp thích ứng giữa các quốc gia, các bên liên quan và các ngành theo nguyên tắc chung rằng nước là nhu cầu sống cơ bản và là quyền được tiếp cận của mọi một người dân vùng Mekong. Những giải pháp này sẽ tạo tiền đề cho khả năng chấp nhận định nghĩa quan trọng nước là nguồn tài nguyên chung (commons).

RÉSUMÉ | L'URGENCE DU MEKONG

La troisième partie de ce rapport se concentre sur les liens complexes entre impacts du changement climatique et changements environnementaux anthropiques locaux dans la région du Mékong [Figure 1]. D'après le 5ème rapport du GIEC, l'étude des effets du changement climatique sur les régions côtières ne peut pas se faire indépendamment de celle des "facteurs locaux d'exposition et de vulnérabilité".

Le delta du Mékong vietnamien (DMV) est le troisième plus grand delta de la planète. Il abrite actuellement 17 millions d'habitants, dont les moyens de subsistance dépendent principalement de la production agricole et aquacole. La région fournit plus de la moitié de la production de riz du Viet Nam, dont 90% est exportée. Elle est donc cruciale pour la sécurité alimentaire nationale et internationale.

Cependant, le DMV est soumis à divers facteurs de changement, dont des facteurs anthropiques, à savoir les barrages hydroélectriques, l'extraction de sable et l'exploitation des eaux souterraines, qui constituent la plus grande menace en cette première moitié du siècle. Le delta subit déjà d'importants changements et la fenêtre d'opportunité pour l'adaptation est donc limitée, puisque les effets les plus importants du changement climatique domineront ensuite très probablement les menaces dans la seconde moitié du siècle.

Le DMV a une longue expérience historique de la gestion des facteurs liés à l'eau et au climat qui peuvent menacer la production agricole et les moyens de subsistance. Cependant, les impacts croissants du changement climatique et des activités anthropiques remettent en cause la durabilité des approches existantes et appellent de nouvelles mesures d'adaptation et d'atténuation.

En outre, le delta est fortement influencé par la gouvernance de l'eau dans l'ensemble du bassin du Mékong, ou par son absence. Le changement climatique ajoute une couche d'incertitude aux problèmes de gestion de l'eau déjà complexes. La structure régionale actuelle de gouvernance et de gestion des ressources transfrontalières de la région du Mékong est constituée d'un réseau d'organisations comprenant différents partenaires à l'intérieur et à l'extérieur de la région. Cette architecture institutionnelle éparpillée doit encore être pleinement alignée sur les objectifs d'atténuation et d'adaptation de l'Accord de Paris, tout en reconnaissant toute la portée des dynamiques environnementales anthropiques locales.

Le changement climatique

Température et précipitations

Au cours des quatre dernières décennies (1981–2018), le DMV a connu d'importants changements de température et de précipitations :

- La température moyenne annuelle a augmenté sur l'ensemble du delta, avec une tendance moyenne de $+0,76^{\circ}\text{C}$ sur 38 ans. Cependant, le nombre de jours chauds et très chauds présente des tendances contrastées selon les stations météorologiques.
- En général, les précipitations montrent une tendance à l'augmentation sur la majeure partie du delta. Cependant, la tendance n'est statistiquement significative que pour très peu de stations. Les tendances des précipitations extrêmes varient considérablement d'une région à l'autre.

D'après les projections climatiques obtenues par descente d'échelle dynamique (c'est-à-dire avec des modèles climatiques régionaux), fournies par l'IMHEN, les tendances passées des températures et des précipitations devraient s'accroître au cours des prochaines décennies :

- La température moyenne annuelle dans le delta devrait augmenter de $1,74 \pm 0,92^{\circ}\text{C}$ dans le scénario RCP4.5 et de $3,56 \pm 1,25^{\circ}\text{C}$ dans le scénario RCP8.5 d'ici la fin du siècle (par rapport à 1986–2005). Il est également très instructif d'examiner le niveau de réchauffement projeté dans le delta pour différents niveaux de réchauffement global, afin d'étudier les impacts d'un niveau de réchauffement global atteint plus tôt ou plus tard que dans un scénario RCP donné. Ainsi, lorsque le réchauffement global atteint $1,5^{\circ}\text{C}$, la température dans l'ensemble du delta du Mékong devrait augmenter de $0,78^{\circ}\text{C}$. Pour un réchauffement global de 3°C , l'augmentation de température prévue dans le delta est de $2,19^{\circ}\text{C}$ [Figure 2].
- Les précipitations annuelles moyennes devraient augmenter d'environ 15% selon le scénario RCP4.5 et de 25% selon le scénario RCP8.5 à la fin du siècle (par rapport à 1986–2005).

Les projections de température obtenues par descente d'échelle statistique (ce rapport) sont similaires, avec une augmentation moyenne de $1,79 \pm 1,01^{\circ}\text{C}$ pour le RCP4.5 et de $3,59 \pm 1,12^{\circ}\text{C}$ pour le RCP8.5 d'ici la fin du siècle. En revanche, les résultats obtenus pour les précipitations moyennes annuelles diffèrent fortement des projections obtenues par descente d'échelle dynamique, avec seulement des changements limités ($<10\%$) même pour des niveaux élevés de réchauffement global. Cette divergence doit être étudiée dans le cadre de recherches ultérieures.

Hausse du niveau marin

Le taux actuel de hausse du niveau marin moyen global est de $\sim 3,3$ mm/an et devrait s'accroître au cours du XXI^e siècle. Selon le scénario climatique global, les projections d'augmentation varient de 43 cm à 84 cm d'ici la fin du siècle, mais de grandes incertitudes subsistent et des valeurs plus élevées ne peuvent être exclues.

L'altitude de la plaine deltaïque du DMV est extrêmement faible [Figure 4]. La grande majorité du delta se situe à moins de 2 m au-dessus du niveau marin moyen local, avec une élévation moyenne d'environ 80 cm. Par conséquent, le delta est extrêmement vulnérable même à des changements relativement faibles du niveau marin relatif, qui résultent de l'effet cumulé des changements du niveau marin global et des mouvements verticaux terrestre

“locaux” (e.g. la subsidence). Ainsi, ~30% du delta se retrouverait sous le niveau de la mer en cas d’augmentation du niveau marin relatif de 50 cm.

Les facteurs de stress anthropiques et leurs impacts

Appauvrissement en sédiments

La quantité totale de sédiments qui étaient transportés par le Mékong encore sauvage est estimée à ~160 Mt/an. Des estimations récentes montrent une réduction de 40–90% de cet apport de sédiments fluviaux dans le DMV en raison du piégeage des sédiments par les barrages en amont [Figure 3]. En outre, l’exploitation actuelle du sable dans le DMV est estimée à 40–50 Mt/an, ce qui, ajouté à l’exploitation du sable au Cambodge et au Laos, représente probablement plus de 100% de l’apport total restant de sédiments fluviaux.

Les impacts les plus importants de l’appauvrissement en sédiments sont les taux élevés d’érosion des niveaux du lit des rivières dans le delta (10–15 cm/an). Ce phénomène a entraîné une amplification des marées de l’ordre de ~2 cm/an. Ceci a largement contribué aux inondations urbaines, et a augmenté les intrusions salines de l’ordre de 0,2–0,5 PSU/an sur les 2 dernières décennies. Le manque de sédiments a également réduit l’apport sédimentaire au littoral, qui s’érode actuellement dans la plupart des endroits.

L’augmentation des intrusions salines pendant la saison sèche observée au cours des dernières décennies est également fortement favorisée par la diminution de l’approvisionnement en eau douce par le lac Tonle Sap. Cette diminution est elle-même causée principalement par le développement des barrages hydroélectriques, qui a modifié le régime hydrologique du Mékong.

L’élévation relative du niveau marin et les changements de débit fluvial induits par le changement climatique vont très probablement augmenter modérément (~10%) la salinisation le long des provinces côtières dans la première moitié du siècle. L’incision anthropique du lit des rivières restera le principal moteur de la salinisation du delta et, en fonction des futurs taux d’extraction de sable, elle pourrait accroître l’extension des terres touchées par les intrusions salines de 25% supplémentaires en 2050 (Figure 4 et Figure 5). Dans la seconde moitié du siècle, l’élévation relative du niveau marin pourrait être le facteur dominant des intrusions salines.

Extraction des eaux souterraines

L’urbanisation rapide et l’intensification de la production alimentaire dans le delta ont entraîné de fortes pressions sur les ressources en eau du DMV. La demande en eau douce/ saumâtre de qualité dans le secteur de l’aquaculture par exemple a significativement augmenté au cours des dernières décennies. Par conséquent, l’extraction des eaux souterraines a connu une croissance rapide, avec une multiplication par 5 au cours des 20 dernières années. Actuellement, les volumes extraits atteignent ~2,5 10⁶ m³/jour, avec une augmentation annuelle de 4%/an. La surexploitation des eaux souterraines est le principal moteur des

taux élevés de subsidence dans le delta (jusqu'à 5 cm/an à certains endroits), actuellement non compensée par de nouveaux dépôts sédimentaires. Par conséquent, le delta perd rapidement de l'altitude.

Dans les décennies à venir, l'élévation relative du niveau marin sera principalement déterminée par l'ampleur de la subsidence, qui dépend en grande partie de l'extraction des eaux souterraines. Si le taux d'extraction reste au niveau actuel, la subsidence cumulée moyenne pourrait être supérieure à 80 cm d'ici 2100, ce qui, combiné à l'élévation globale du niveau marin et à l'absence de sédimentation dans les plaines d'inondation, ferait passer la majorité du delta sous le niveau de la mer.

Dynamiques d'adaptation dans le delta du Mékong au Viet Nam

Face à ces menaces, les autorités sont encouragées à concevoir des voies d'adaptation qui mettent l'accent sur les capacités de réaction rapide en termes d'investissements ou d'incitations financières. Cependant, ces stratégies sont généralement conçues de façon "top-down" et ne sont pas nécessairement bien adaptées à des conditions locales dynamiques.

À l'autre extrémité du spectre, les agriculteurs et les communautés locales adaptent spontanément leurs systèmes agricoles, sous la pression de facteurs environnementaux ou de marché, et diversifient leur production en accordant une plus grande attention à l'utilisation rationnelle de l'environnement. Mais ces changements non coordonnés signifient que ces stratégies spontanées et "bottom-up" ont peu de chances de s'étendre facilement.

Ces différentes stratégies interagissent les unes avec les autres de manière complexe, et c'est dans leurs interactions que l'on peut trouver les principales sources d'innovation adaptative.

La conception de modèles intégrés multi-échelles [figure 6] nous permet de mieux tester l'impact des décisions politiques ou des options de gestion dans selon les scénarios climatiques. Entre les politiques de "laissez-faire", dans lesquelles l'essentiel de l'adaptation reposerait sur les épaules des agriculteurs, et les politiques descendantes, dans lesquelles aucune autonomie n'est accordée aux agriculteurs, les combinaisons entre ces deux approches sont mesurées dans ces modèles comme étant les plus bénéfiques pour tous les acteurs du système.

Les politiques climatiques dans le bassin du Mékong, un enjeu de coordination régionale

Le développement de l'hydroélectricité dans la région du Mékong [Figure 3] permet notamment de promouvoir la sécurité énergétique, tout en contribuant à la gestion des inondations et des sécheresses, dans le cadre d'une économie bas-carbone. Toutefois, outre ces avantages régionaux immédiats, les répercussions sur la dynamique hydrologique du

delta du Mékong et le transport des sédiments et des poissons en aval sont énormes. Le changement climatique ajoute une couche de complexité à ce défi de la gouvernance des ressources transfrontalières. Il est donc absolument nécessaire de bien comprendre les intérêts et les motivations de tous les acteurs, tandis que des plateformes politiques et scientifiques et d'autres approches innovantes pourraient encourager les dialogues pour concrétiser les collaborations potentielles.

Nous soutenons que les formes traditionnelles de gouvernance étatique ne suffisent pas à traiter les questions environnementales transfrontalières. La Stratégie de Développement du Bassin 2021–2030 de la Commission du Mékong a récemment appelé à une "planification régionale proactive". Cette "planification régionale proactive" pourrait jouer un rôle d'intégration par le biais de projets d'investissement conjoints en matière d'atténuation et de mesures d'adaptation entre les pays, les acteurs et les secteurs, en vertu du principe général selon lequel l'eau est un besoin et un droit fondamental de chaque habitant du Mékong. L'eau du Mékong pourrait ainsi potentiellement devenir une ressource commune.

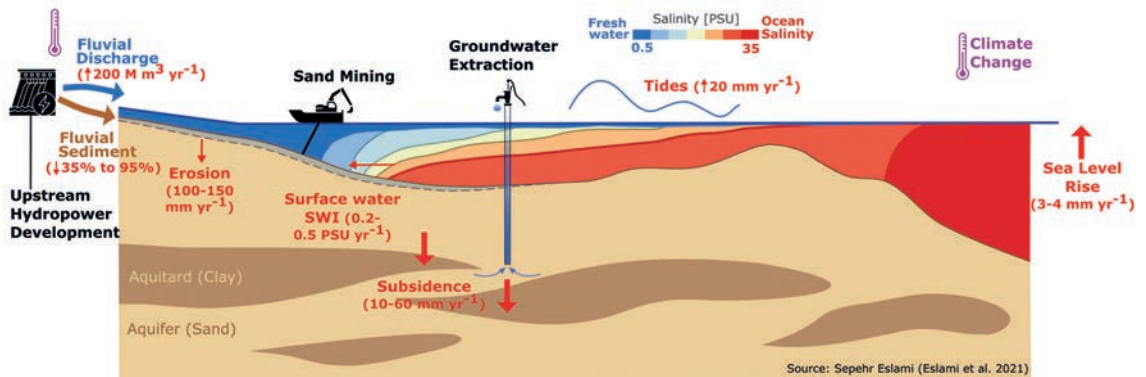
FIGURES | HÌNH

[Figure 1 | Hình 1]

Climatic and anthropogenic drivers of change in the VMD

Các tác nhân khí hậu và con người tạo ra thay đổi tại vùng ĐBSCL

Facteurs de changement climatique et anthropiques dans le delta du Mékong



An imaginary cross-profile of the Mekong Delta through its estuarine system, the observed rates of trends (red) and the primary anthropogenic (black) drivers along with climate change (purple).

Hình ảnh cắt ngang của ĐBSCL đến hệ thống cửa sông, quan sát tỷ lệ xu hướng (màu đỏ) và các hoạt động của con người (đen) kết hợp với các tác động của biến đổi khí hậu (tím).

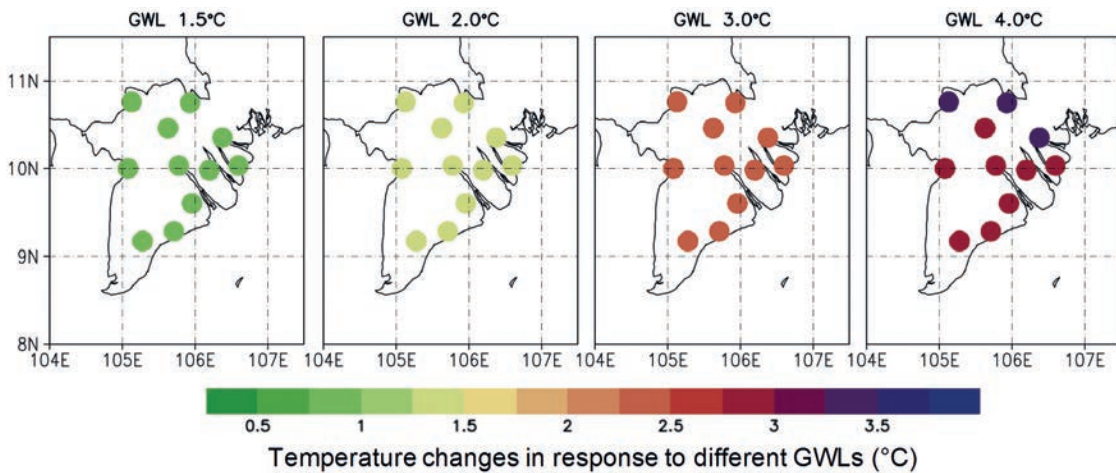
Profil imaginaire du Delta du Mékong à travers son estuaire, les tendances observées (en rouge), les facteurs anthropiques primaires (en noir) et les facteurs climatiques (en violet).

[Figure 2 | Hình 2]

Temperature changes in the Mekong Delta for different global warming levels (GWLs)

Thay đổi nhiệt độ tại Đồng bằng sông Cửu Long ứng với những mức độ nóng lên toàn cầu khác nhau (GWLs)

Changement de température dans le Delta du Mékong pour différents niveaux de réchauffement global



Temperature changes in the VMD at times when the GWLs are reached, relative to the baseline 1986–2005. Results obtained from the ensemble of the dynamical downscaling experiments.

Nhiệt độ thay đổi ở ĐBSCL tại các thời điểm ứng với các mức nóng lên toàn cầu (GWL) so với dữ liệu nền giai đoạn 1986–2005. Kết quả từ các thực nghiệm chi tiết hóa động lực.

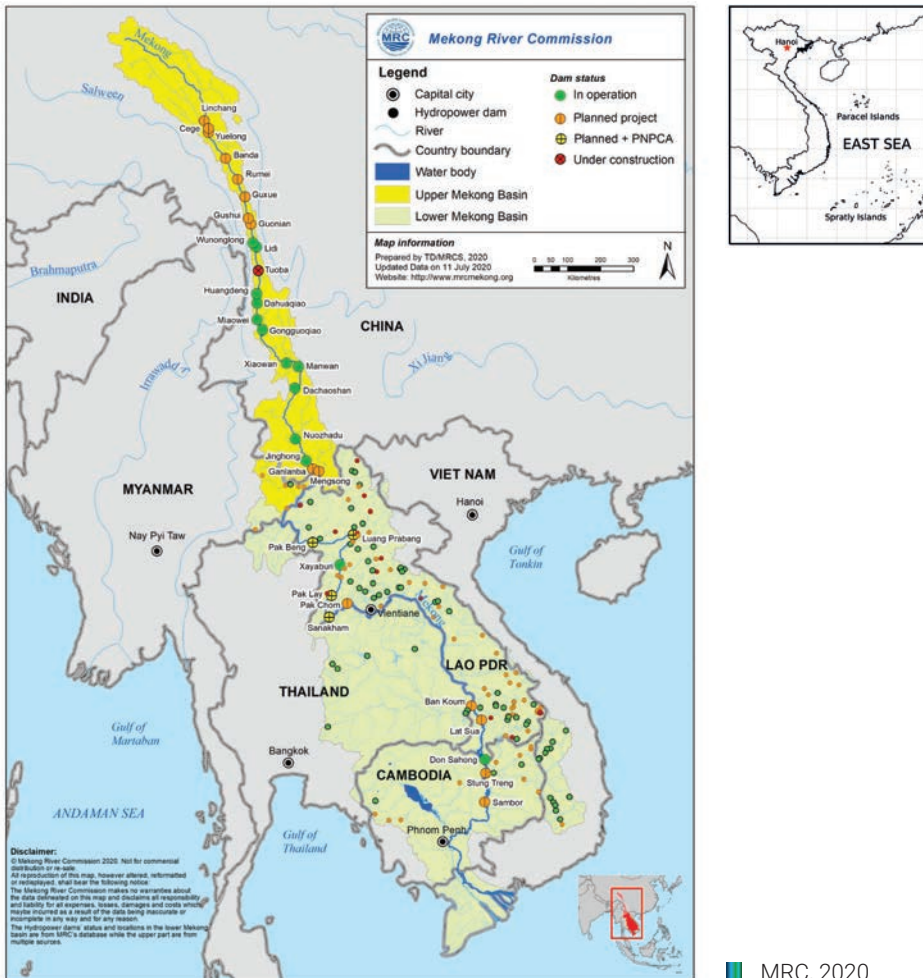
Changement de température dans le Delta du Mékong vietnamien au moment où sont atteints les niveaux de réchauffement global, par rapport à la période de référence 1986–2005. Les résultats proviennent des ensembles de simulations réalisées par descente d'échelle dynamique.

[Figure 3 | Hình 3]

Hdropower dam projects in the Mekong basin

Các dự án thủy điện trên dòng chính sông Mê Kông

Projets de barrages hydroélectriques dans le bassin du Mékong

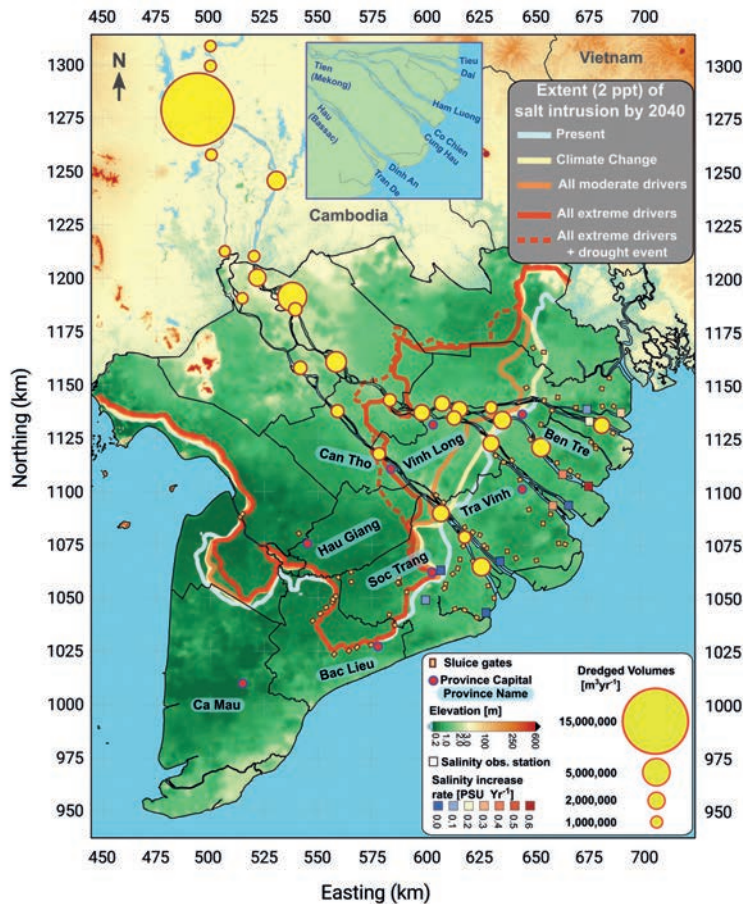


[Figure 4 | Hình 4]

Elevation, sand mining and saline water intrusions in the VMD

Cao độ, Khai thác cát và xâm nhập mặn ở ĐBSCL

Élévation, exploitation du sable et intrusions salines dans le delta du Mékong



Elevation map, observed salinity increase and sand mining volumes. Contour lines: present and projected peak salt intrusion under moderate and extreme scenarios of climate change, groundwater extraction-induced subsidence and riverbed level incision due to sediment starvation. Details and references in Chapter 9.

Bản đồ cao độ, tỷ lệ tăng xâm nhập mặn quan trắc và tổng lượng khai thác cát. Đường đồng mức: xâm nhập mặn hiện tại và tương lai trong kịch bản biến đổi khí hậu trung bình và cực đoan, sụt lún đất do khai thác nước ngầm và mức độ bào mòn đáy sông do thiếu hụt phù sa, giả định bờ biển không thay đổi. Chi tiết tham khảo tại Chương 9.

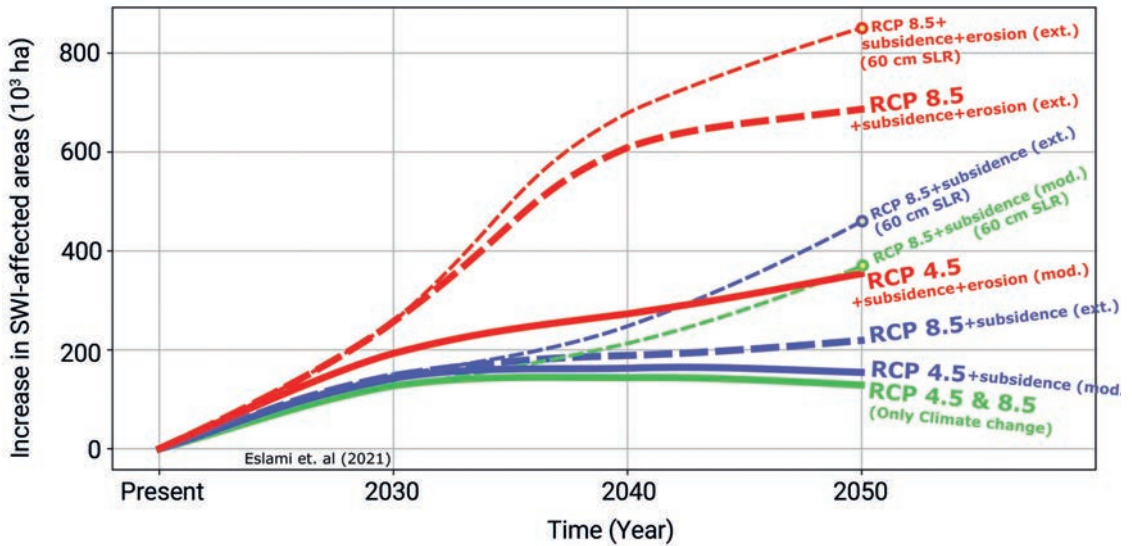
Carte d'élévation, hausses de salinité observées et volumes de sables extraits. Lignes de contour : maximum d'extension des intrusions salines actuelles et projetées pour des scénarios modérés à extrêmes de changement climatique, de subsidence liée à l'extraction des eaux souterraines et d'incision des lits de rivière liée à l'appauvrissement en sédiments. Détails et références dans le chapitre 9.

[Figure 5 | Hình 5]

Projections of increase in saline water intrusion- affected area in the delta

Dự báo gia tăng diện tích ảnh hưởng bởi xâm nhập mặn ở Đồng bằng

Projections d'augmentation de la surface affectée par les intrusions salines dans le delta



Projections of increase in SWI-affected area (2 PPT contour line in spatial P50 salinity projection maps) within the VMD under various combinations of scenarios of climate change projections (RCP4.5 and 8.5), moderate (mod.) and extreme (ext.) land subsidence, and moderate (mod.) and extreme (ext.) riverbed erosion, including the case of extreme SLR (+60 cm) in the year 2050. See details in Chapter 9.

Dự báo về xâm nhập mặn (ranh mặn 2 PPT trong bản đồ dự báo mặn xác suất 50%) ở ĐBSCL dựa trên sự kết hợp của các kịch bản dự báo biến đổi khí hậu (RCP4.5 và 8.5), sụt lún đất trung bình (mod.) và cực đoan (ext.) và bào mòn lòng sông ở mức trung bình (mod.) và cực đoan (ext.), bao gồm trường hợp nước biển dâng cực đoan (+60 cm) vào năm 2050. Xem chi tiết trong chương 9.

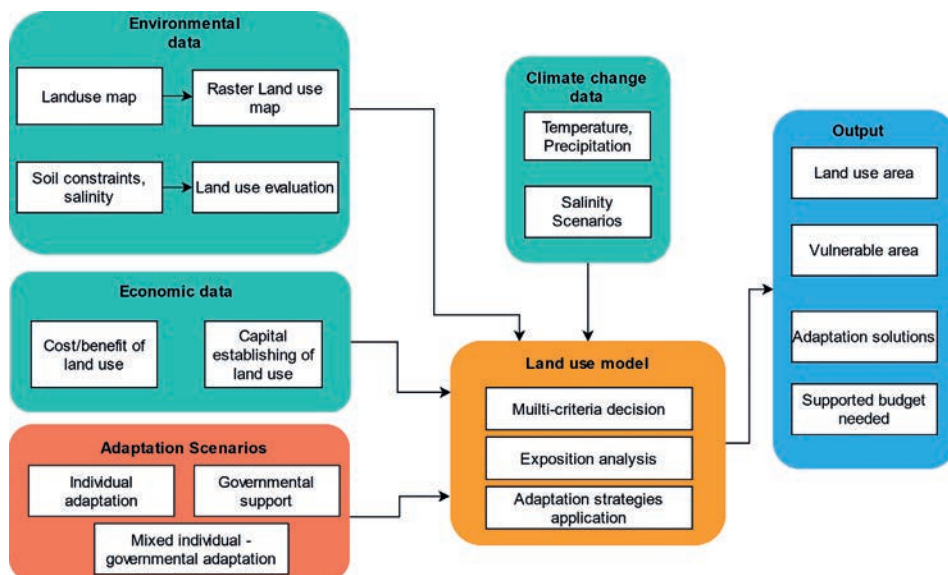
Projections d'augmentation de la surface affectée par les intrusions salines (contour à 2 PPT sur les cartes de projections du 50^{ème} percentile) dans le delta du Mékong selon diverses combinaisons de scénarios de changement climatique (RCP4.5 et RCP8.5), de subsidence modérée (mod.) ou extrême (ext.), et d'incision des lits de rivière modérée (mod.) ou extrême (ext.). Un scénario extrême de hausse du niveau marin (+60 cm) en 2050 est également considéré. Voir détails dans le chapitre 9.

[Figure 6 | Hình 6]

Model of land use change for adaptation strategies

Mô hình Chiến lược thích ứng trong sử dụng đất

Changement de température dans le Delta du Mékong pour différents niveaux de réchauffement global



RECOMMENDATIONS

For policy makers

A holistic approach in adaptation strategy is required, in the spirit of the recently released Resolution 120/NQ-CP 2017 on Sustainable and Climate Resilient Development of the Mekong Delta. Adopting incremental measures to remedy isolated problems may only shift the challenges from one aspect to another. Therefore, multi-processes and integrated solutions at the Delta and river basin levels – rather than at the local level – should be promoted, while also promoting a bottom-up innovation approach to adaptation.

Controlling sand mining:

Sediment starvation is currently one of the greatest threats to livelihoods in the Delta. Riverbed, bank and coastal erosion, and consequent saline water intrusions and partial elevation loss, are driven by sediment starvation. While halting all sand mining practices may be difficult in the short term, recycling technologies and alternative sources of sand/construction material should be vigorously pursued.

Reducing groundwater extraction

Groundwater extraction has been a major contribution to land subsidence, and could cause large parts of the Delta to fall below sea level in the coming decades. It is therefore crucial to implement mitigation measures to reduce groundwater use and stimulate groundwater recharge.

Reinstating controlled flooding

Water management in the VMD has historically involved dyke building, including high dykes after 2000, to protect settlements and rice fields. However, high dykes also cause several environmental problems: flood hazards are shifted downstream; sediment and nutrient deposition in the floodplains is inhibited, soil fertility decreases and elevation loss is increased; potential dyke-breaching increases flood risks. Hence, reinstating controlled flooding in the floodplains would bring many benefits:

- ▶ Sediment and organic matter deposition would contribute to mitigate elevation loss due to natural and anthropogenic subsidence;
- ▶ Nutrient deposition would sustain high biodiversity and productivity;
- ▶ The inundation would enhance fish recruitment;
- ▶ Functioning floodplains and healthy wetlands would reduce the risk of flooding in cities by lowering flood pulse water levels.

Transboundary river resource management

The transboundary natural resources of the Mekong River are managed in isolation. While there is some regulation on the amount of freshwater flowing in the river, there is limited regulation on sediment and water level management. These two latter parameters are equally important in river/delta management. One of the first potential solutions to decrease dry-

season saline water intrusion might, for instance, be to reinstate the water level of the Tonle Sap Lake, so the lake can act as a retention area for the VMD during the dry season.

Adaptation of farming systems to efficiently manage available freshwater resources and adapt to a more saline environment.

Both individual and government strategies are important in implementing adaptation plans. The forms in which government solutions and self-adaptation by farmers combine play an important role in the success of adaptation plans.

The government should focus on:

- ▶ Having specific policies to develop different sustainable farming systems, like rice - shrimp, rice - vegetables, 2 rice crops.
- ▶ Public education on environmental change and its drivers can raise awareness on the risks associated with for-profit intensive farming practices, and can promote bottom-up agricultural innovations.
- ▶ Promoting substantive research on the impacts of adaptation and mitigation plans.
- ▶ Local managers must be trained to raise awareness of climate change, and should have tools to help them develop adaptation plans such as changing cropping seasons and technical application in cultivation.

Capacity building

An intense capacity-building effort should target higher education and research institutions in Mekong countries, to ensure leverage effects and start a virtuous cycle leading to the science-based monitoring of the environmental transition.

For researchers

Technical assessment of climate change and anthropogenic activity impacts:

Scientific efforts for a detailed assessment of both climate change and anthropogenic activity impacts at the local and regional level should continue, in order to design appropriate adaptation and mitigation measures. They should include:

- ▶ applying new/modern technologies on monitoring,
- ▶ promoting open data, to allow analysis by the international scientific community
- ▶ building integrated information systems to support stakeholders in preparing production, investment and business planning in each sub-biophysical unit.
- ▶ Focusing on examining interactions between human, environmental and engineering systems, to avoid tackling the different issues in isolation

Design of integrated, multiscale “complex” models to support science-based policy dialogue

Models of adaptation are gradually becoming part of the authorities’ toolboxes, because the dynamics of interactions between human communities and their environment in a context as complex and changing as the Mekong Delta can no longer be apprehended by human expertise alone.

It is essential to be able to highlight and explore, albeit virtually, possible adaptation pathways resulting from the implementation of different policies.

One promising avenue is to focus on and invest in qualitative, data-driven modelling approaches (such as agent-based modelling), to support the representation and exploration of dynamic combinations of planned top-down and spontaneous bottom-up adaptation practices.

Such representations may seem complex and highly descriptive, yet they can foster creative thinking by keeping important features of the target system (e.g. spatial or social heterogeneity, multiscale interactions) in the models, so as to provide sufficient heuristic power to test various adaptation options and inform stakeholders.

In that respect, an important effort for training and capacity-building in data-driven models is necessary, to make these methodologies an integral part of the stakeholders' toolbox in the near future.

Make knowledge-use possible

It is crucial to ensure that research results are actually understood and used by both the stakeholders and civil society, so that relevant adaptation and mitigation actions can be implemented. Therefore, we recommend:

- ▶ Systematically linking researchers and their institutions to other stakeholders — policymakers, media, civil society, private sector, who are directly concerned by and have stakes in the foreseen outputs.
- ▶ Co-defining with the entities concerned by the research results how it can be most efficiently disseminated and understood (workshops bringing together both scientists and stakeholders, reports in plain language, interactive web portals, etc.).

We would like to emphasize the necessity of a paradigm shift towards sustainable development. It represents a unique opportunity for higher education and research institutions in the Mekong Region to position themselves as actors of change, by enabling science to take its place in the decision-making process.

CÁC KHUYẾN NGHỊ

Đối với các nhà hoạch định chính sách

Cần tiếp cận tổng thể trong chiến lược thích ứng cho vùng theo tinh thần của Nghị quyết 120 / NQ-CP 2017 về Phát triển bền vững và thích ứng với khí hậu của Đồng bằng sông Cửu Long. Việc áp dụng các biện pháp để giải quyết các vấn đề đơn lẻ chỉ có thể chuyển những thách thức từ khía cạnh này sang khía cạnh khác. Do đó, cần thúc đẩy nhiều quá trình và giải pháp tổng hợp ở cấp đồng bằng và lưu vực sông thay cho cấp địa phương, đồng thời ưu tiên cách tiếp cận đổi mới từ dưới lên để thích ứng.

Kiểm soát việc khai thác cát:

Tình trạng thiếu hụt phù sa hiện là một trong những mối đe dọa lớn nhất đối với sinh kế của vùng đồng bằng. Xói mòn lòng sông, xói lở bờ sông và bờ biển dẫn đến xâm nhập mặn và mất độ cao do thiếu phù sa. Trong khi việc dừng tất cả các hoạt động khai thác cát có thể khó khăn trong thời gian ngắn, các công nghệ tái chế và các nguồn cát/vật liệu xây dựng thay thế phải được theo đuổi mạnh mẽ.

Giảm khai thác nước ngầm

Khai thác nước ngầm đã góp phần lớn vào việc sụt lún đất và có thể khiến phần lớn của đồng bằng chìm xuống dưới mực nước biển trong những thập kỷ tới. Do đó, điều quan trọng là phải thực hiện các biện pháp giảm thiểu để giảm sử dụng nước ngầm và kích thích bổ sung nước ngầm.

Khôi phục lũ có kiểm soát

Lịch sử công tác quản lý nước ở ĐBSCL liên quan đến việc xây dựng đê bao, bao gồm cả hệ thống đê bao sau năm 2000 giúp bảo vệ các khu định cư và vùng canh tác lúa. Tuy nhiên hệ thống đê cao cũng gây ra các vấn đề về môi trường: Nguy cơ lũ lụt di chuyển xuống hạ lưu; Lượng phù sa và dưỡng chất ở vùng ngập ngập lũ bị ngăn chặn làm giảm độ phì nhiêu của đất và bồi tụ của Đồng bằng; tiềm ẩn nguy cơ lũ lụt từ hệ thống đê điều. Do đó, việc khôi phục lũ có kiểm soát sẽ mang lại nhiều lợi ích:

- ▶ Trầm tích và chất hữu cơ từ phù sa sẽ góp phần bồi đắp độ cao do sụt lún tự nhiên và con người;
- ▶ Sự lắng đọng chất dinh dưỡng sẽ duy trì sự đa dạng sinh học và năng suất cho cây trồng;
- ▶ Lũ mang theo nguồn cá cho đời sống người dân;
- ▶ Các vùng đồng bằng ngập lũ và đất ngập nước sẽ hạ thấp mực nước lũ làm giảm nguy cơ ngập lụt đô thị.

Quản lý tài nguyên sông xuyên biên giới

Các nguồn tài nguyên thiên nhiên xuyên biên giới của sông Mekong được quản lý một cách riêng lẻ. Một số nơi quy định về lượng nước ngọt trên sông, thì có một số nơi quy định hạn chế phù sa và quản lý mực nước. Trong khi tất cả các thông số này đều quan trọng như nhau trong quản lý sông và Đồng bằng. Một trong những giải pháp tiềm năng đầu tiên để

giảm xâm nhập mặn vào mùa khô là tái lập mực nước của hồ Tonle Sap, khi đó hồ có thể hoạt động như nguồn cấp nước trong mùa khô cho Đồng bằng sông Cửu Long.

Thích ứng trong lựa chọn hệ thống canh tác để sử dụng hiệu quả nguồn nước ngọt và thích ứng với xâm nhập mặn.

Chiến lược thích ứng của cả người dân và chính phủ đều quan trọng trong quá trình thực hiện các kế hoạch thích ứng. Các hình thức kết hợp giữa các giải pháp của chính phủ và sự thích ứng của người dân đóng vai trò quan trọng trong sự triển khai thành công các kế hoạch thích ứng.

Chính phủ nên tập trung vào:

- Có chính sách cụ thể để phát triển các hệ thống canh tác bền vững như lúa - tôm, lúa - rau màu, lúa 2 vụ.
- Giáo dục cộng đồng về sự thay đổi môi trường nhằm nâng cao nhận thức về những rủi ro từ việc thâm canh vì lợi nhuận, và thúc đẩy các đổi mới nông nghiệp từ dưới lên.
- Đầu tư cho nghiên cứu về các kế hoạch thích ứng và giảm thiểu tác động của biến đổi khí hậu.
- Đào tạo cán bộ quản lý địa phương để nâng cao nhận thức về biến đổi khí hậu và cần có các công cụ giúp họ xây dựng kế hoạch thích ứng như chuyển đổi lịch mùa vụ và áp dụng kỹ thuật trong canh tác.

Đối với các nhà nghiên cứu

Đánh giá về tác động của biến đổi khí hậu và các hoạt động do con người gây ra:

Các nỗ lực khoa học nhằm đánh giá chi tiết các tác động của cả biến đổi khí hậu và con người ở cấp địa phương và khu vực cần được tiếp tục nhằm xây dựng các biện pháp thích ứng và giảm thiểu phù hợp bao gồm:

- Áp dụng công nghệ mới và hiện đại về giám sát,
- Khuyến khích dữ liệu mở cho phép những phân tích của cộng đồng khoa học quốc tế
- Xây dựng hệ thống thông tin tích hợp để hỗ trợ các bên liên quan lập kế hoạch sản xuất, đầu tư và kinh doanh trong từng đơn vị sinh - vật lý
- Tập trung vào đánh giá những tương tác giữa hệ thống con người, môi trường và kỹ thuật để tránh việc xử lý các vấn đề rời rạc nhau.

Thiết kế các mô hình “phức hợp” tích hợp, đa mức độ hỗ trợ cho đối thoại chính sách dựa trên khoa học

Các mô hình thích ứng đang dần trở thành một phần trong hộp công cụ của các cơ quan chức năng do sự tương tác giữa các cộng đồng con người và môi trường trong bối cảnh phức tạp và thay đổi như Đồng bằng sông Cửu Long không thể chỉ dựa vào chuyên môn của con người.

Các mô hình có thể nêu bật và khai thác các lộ trình thích ứng có thể có từ việc thực hiện các chính sách khác nhau.

Một cách tiếp cận hứa hẹn là tập trung và đầu tư vào các phương pháp tiếp cận mô hình định tính, mô hình theo hướng dữ liệu, chẳng hạn như mô hình dựa trên tác nhân để hỗ trợ việc biểu diễn và khám phá các kết hợp năng động của từ trên xuống được lập kế hoạch và tự phát từ dưới lên được thiết lập các thực hành thích ứng.

Các biểu diễn như vậy có vẻ phức tạp và mang tính mô tả cao nhưng chúng thúc đẩy tư duy sáng tạo bằng cách giữ các đặc điểm quan trọng của hệ thống mục tiêu (Ví dụ: tính không đồng nhất về không gian hoặc xã hội, tương tác đa cấp độ) trong các mô hình, để cung cấp đủ sức mạnh kinh nghiệm để kiểm tra các phương án thích ứng khác nhau và thông báo cho các bên liên quan.

Do đó, cần tập trung đào tạo và xây dựng năng lực trong các mô hình theo hướng dữ liệu để biến những phương pháp luận này trở thành một phần không thể thiếu trong hộp công cụ của các bên liên quan trong tương lai gần.

Sử dụng kiến thức hiệu quả

Điều quan trọng là các bên liên quan và cộng đồng có thể hiểu rõ và ứng dụng các kết quả nghiên cứu, để những hành động thích ứng và giảm nhẹ có thể được thực thi. Vì vậy, nhóm nghiên cứu kiến nghị:

- ▶ Kết nối một cách có hệ thống nhà nghiên cứu, các đơn vị nghiên cứu và những bên liên quan khác như nhà hoạch định chính sách, báo đài, các tổ chức xã hội và cộng đồng, các nhóm tư nhân, và tất cả những đối tượng khác có quan tâm, chịu ảnh hưởng và liên quan trực tiếp đến những kết quả sẽ được nghiên cứu.
- ▶ Định nghĩa lại với các đối tượng có liên quan với kết quả nghiên cứu để đảm bảo việc phổ biến giúp hiểu rõ các nghiên cứu một cách hiệu quả nhất (như các hội thảo, thảo luận tập hợp cả nhà nghiên cứu, các bên liên quan, báo cáo bằng ngôn ngữ phổ thông dễ hiểu, tương tác qua các trang web, v.v.).

Chúng tôi nhấn mạnh tính cấp thiết của việc chuyển đổi định hướng sang hướng phát triển bền vững. Điều này nhấn mạnh cơ hội duy nhất để các đơn vị giáo dục sau đại học và nghiên cứu của vùng Mê Kông để khẳng định vị trí của họ như là một chủ thể trong sự thay đổi sắp tới, cụ thể bằng việc dùng khoa học để tham gia vào quá trình ra quyết định.

RECOMMANDATIONS

A l'intention des décideurs politiques

Une approche holistique de la stratégie d'adaptation est nécessaire, dans l'esprit de la résolution 120/NQ-CP 2017 récemment publiée sur le Développement Durable et Résilient au changement climatique du Delta du Mékong. L'adoption de mesures incrémentales pour remédier à des problèmes isolés ne peut que déplacer les défis d'un aspect à un autre. Il convient donc de promouvoir des processus multiples et des solutions intégrées à l'échelle du delta et du bassin fluvial plutôt qu'à l'échelle locale, tout en favorisant également une approche d'innovation ascendante pour l'adaptation.

Contrôler l'exploitation du sable

L'appauvrissement en sédiments est actuellement l'une des plus grandes menaces pour les moyens de subsistance dans le delta. L'érosion des lits de rivière, des berges et des côtes et, par conséquent, les intrusions salines et une partie de la perte d'élévation sont dues à l'appauvrissement en sédiments. Bien que l'arrêt total des extractions de sable puisse être difficile à court terme, les technologies de recyclage et les sources alternatives de sable/matériaux de construction doivent être vigoureusement recherchées.

Réduire les extractions d'eaux souterraines

L'extraction des eaux souterraines a largement contribué à la subsidence et pourrait faire passer de grandes parties du delta sous le niveau de la mer dans les prochaines décennies. Il est donc crucial de mettre en œuvre des mesures d'atténuation pour réduire l'utilisation des eaux souterraines et stimuler leur recharge.

Rétablir des inondations contrôlées

La gestion de l'eau dans le DMV a historiquement impliqué la construction de digues, y compris de hautes digues après 2000, pour protéger les habitations et les rizières. Cependant, les hautes digues posent également plusieurs problèmes environnementaux : les risques d'inondation sont déplacés vers l'aval ; le dépôt de sédiments et de nutriments dans les plaines d'inondation est empêché, ce qui diminue la fertilité des sols et renforce la perte d'altitude ; la rupture potentielle des digues augmente les risques d'inondation. Le rétablissement d'une inondation contrôlée dans les plaines inondables présenterait donc de nombreux avantages :

- Le dépôt de sédiments et de matières organiques contribuerait à atténuer la perte d'altitude due à la subsidence naturelle et anthropique ;
- Le dépôt de nutriments soutiendrait une biodiversité et une productivité élevées ;
- L'inondation augmenterait le recrutement de poissons ;
- Des plaines inondables fonctionnelles et des zones humides saines réduiraient le risque d'inondation dans les villes en abaissant le niveau des eaux de crue.

Gestion des ressources fluviales transfrontalières.

Les ressources naturelles transfrontalières du fleuve Mékong sont gérées de manière isolée. S'il existe une certaine réglementation sur la quantité d'eau douce qui circule dans le fleuve, la réglementation sur la gestion des sédiments et des niveaux d'eau est limitée. Ces deux derniers paramètres sont tout aussi importants dans la gestion du fleuve/du delta. L'une des premières solutions potentielles pour diminuer les intrusions salines en saison sèche pourrait, par exemple, consister à rétablir le niveau d'eau du lac Tonle Sap, afin qu'il puisse servir de zone de rétention pour le DMV pendant la saison sèche.

Adapter les systèmes agricoles pour gérer efficacement les ressources en eau douce disponibles et s'adapter à un environnement plus salin.

Les stratégies individuelles et gouvernementales sont importantes dans le processus de mise en œuvre des plans d'adaptation. Les formes de combinaison des solutions gouvernementales et de l'auto-adaptation des agriculteurs jouent un rôle important dans la réussite des plans d'adaptation.

Le gouvernement devrait se concentrer sur les points suivants :

- ▶ Avoir des politiques spécifiques pour développer différents systèmes agricoles durables comme riz - crevettes, riz - légumes, 2 cultures de riz.
- ▶ L'éducation du public sur le changement environnemental et ses moteurs peut sensibiliser aux risques associés aux pratiques agricoles intensives à but lucratif, et peut promouvoir les innovations agricoles ascendantes.
- ▶ Promouvoir des travaux de recherche approfondis sur les impacts des plans d'adaptation et d'atténuation.
- ▶ Les gestionnaires locaux doivent être formés afin d'augmenter la sensibilisation au changement climatique et devraient disposer d'outils pour les aider à élaborer des plans d'adaptation, tels que la modification des saisons de culture et l'application technique dans la culture.

Renforcer les capacités

Un effort intense de renforcement des capacités ciblant les établissements d'enseignement supérieur et de recherche des pays du Mékong doit être poursuivi, afin de garantir des effets de levier et d'amorcer un cycle vertueux conduisant au suivi scientifique de la transition environnementale.

Pour les chercheurs

Évaluation technique des impacts du changement climatique et des activités anthropiques

Les efforts scientifiques d'évaluation détaillée des impacts tant du changement climatique que des activités anthropiques au niveau local et régional doivent se poursuivre afin de concevoir des mesures d'adaptation et d'atténuation appropriées. Cela comprend :

- ▶ l'application de technologies nouvelles/modernes en matière de surveillance,
- ▶ la promotion des données en accès libre, afin de permettre leur analyse par la communauté scientifique internationale,

- la mise en place de systèmes d'information intégrés pour aider les parties prenantes à préparer la planification de la production, des investissements et des activités dans chaque unité sub-biophysique.
- Se concentrer sur l'examen des interactions entre les systèmes humains, environnementaux et techniques, afin d'éviter de traiter les différents problèmes de manière isolée.

Concevoir des modèles intégrés et multiscalaires "complexes" pour soutenir un dialogue politique fondé sur les sciences

Les modèles d'adaptation rejoignent progressivement la boîte à outils des autorités car la dynamique des interactions entre les communautés humaines et leur environnement dans un contexte aussi complexe et changeant que le delta du Mékong ne peut plus être appréhendée par la seule expertise humaine.

Il est essentiel de pouvoir mettre en évidence et explorer, même virtuellement, les trajectoires d'adaptation possibles résultant de la mise en œuvre de différentes politiques.

Une voie prometteuse consiste à se concentrer et à investir dans des approches de modélisation qualitatives, axées sur les données, telles que la modélisation "à base d'agents", afin de soutenir la représentation et l'exploration de combinaisons dynamiques de pratiques d'adaptation planifiées "top-down" et spontanées "bottom-up".

De telles représentations peuvent sembler complexes et très descriptives, mais elles peuvent favoriser la pensée créative en conservant des caractéristiques importantes du système cible (par exemple, l'hétérogénéité spatiale ou sociale, les interactions multi-échelles) dans les modèles, de manière à fournir une puissance heuristique suffisante pour tester diverses options d'adaptation et informer les parties prenantes.

À cet égard, un effort important de formation et de renforcement des capacités en matière de modèles basés sur les données est nécessaire pour que ces méthodologies fassent partie intégrante de la boîte à outils des parties prenantes dans un avenir proche.

Rendre possible l'utilisation des connaissances

Il est crucial de s'assurer que les résultats de la recherche sont réellement compris et utilisés par les parties prenantes et la société civile, afin que des actions d'adaptation et d'atténuation pertinentes puissent être mises en œuvre. Par conséquent, nous recommandons de :

- Mettre systématiquement en relation les chercheurs et leurs institutions avec les autres parties prenantes - décideurs politiques, médias, société civile, secteur privé, qui sont directement concernés par les résultats prévus et ont des intérêts dans ceux-ci.
- Définir conjointement avec les entités concernées par les résultats de la recherche la manière la plus efficace dont ils peuvent être diffusés et compris (ateliers réunissant à la fois des scientifiques et des parties prenantes, rapports en langage clair, portails web interactifs, etc.).

Nous tenons à souligner le nécessaire changement de paradigme vers le développement durable. Il représente une occasion unique pour les institutions d'enseignement supérieur et de recherche de la région du Mékong de se positionner en tant qu'acteurs du changement en permettant à la science de prendre part au processus décisionnel.

Chapter 7

The Mekong Delta in the face of increasing climatic and anthropogenic pressures

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Abstract

This chapter provides an overview of the geological and hydrological characteristics of Viet Nam's Mekong Delta, as well as of the main anthropogenic drivers of change. We also present the temperature and precipitation changes over the past four decades, and assess future climate change according to different global climate scenarios, applying statistical and dynamic downscaling methods.

Increasing temperatures are recorded at all stations in the Delta, with an average warming trend of $\sim 0.2^{\circ}\text{C}/\text{decade}$, while precipitation changes are more contrasted. By mid-century, temperature is projected to increase by 1.3°C to 1.8°C and precipitation by 15% to 20%, under climate scenarios RCP4.5 and RCP8.5 respectively. By the end of the century, the temperature increase could reach 1.7°C to 3.7°C , and the precipitation increase 15% to 25%, depending on the global climate scenario.

Climate change is not the only threat to the Delta's future: human activities in the delta or upstream have strong impacts on hydrology and sedimentology, and may exacerbate climate change impacts, or in some cases pose an even greater threat in the short- to mid-term. Sediment trapping by upstream dams and excessive fluvial sand mining are the main drivers of enhanced saline water intrusions, while ground-water over-extractions also drive high subsidence rates, and hence rapid relative sea level rise.

Adaptation measures implemented up to now may be effective in terms of aquaculture and agricultural production, but are not sustainable from a social, economic or environmental point of view. Therefore, a holistic approach is required to deal with future climate change and anthropogenic pressures, and to develop sustainable agriculture and aquaculture in the Delta.

Tóm tắt

Chương này cung cấp khái quát về đặc tính địa chất và thủy văn của đồng bằng Sông Cửu Long (ĐBSCL), cũng như các yếu tố tác động chính làm thay đổi những đặc tính này. Ngoài ra, chương này trình bày sự thay đổi về nhiệt độ và lượng mưa trong bốn thập kỷ vừa qua và đánh giá biến đổi khí hậu xảy ra trong tương lai theo các kịch bản phát thải khác nhau từ các mô hình khí hậu toàn cầu bằng phương pháp chi tiết hóa động lực và thống kê.

Sự gia tăng nhiệt độ được ghi nhận tại tất cả các trạm ở ĐBSCL, với mức độ gia tăng trung bình khoảng $0.2^{\circ}\text{C}/\text{thập kỷ}$, trong khi đó lượng mưa thay đổi tăng/giảm nhiều hơn. Đến giữa thế kỷ 21, nhiệt độ được dự báo lần lượt tăng từ $1,3^{\circ}\text{C}$ đến $1,8^{\circ}\text{C}$ và lượng mưa lần lượt tăng 15% đến 20% theo kịch bản phát thải RCP4.5 và RCP8.5. Cũng theo hai kịch bản này, nhiệt độ có thể tăng lần lượt đến 1.7°C và 3.7°C và lượng mưa sẽ lần lượt tăng lên 15% và 25% vào cuối thế kỷ này.

Biến đổi khí hậu không chỉ là mối nguy hại cho tương lai của ĐBSCL mà các hoạt động của con người tại đồng bằng hoặc thượng nguồn đã tác động lớn đến chế độ thủy văn và bồi lắng phù sa. Các tác động này kết hợp với biến đổi khí hậu sẽ tạo ra tác động lớn hơn trong giai đoạn ngắn và trung hạn. Suy giảm phù sa do các đập thủy điện và khai thác cát quá mức là các yếu tố chính gây xâm nhập mặn sâu hơn, trong khi đó khai thác nước ngầm quá mức gây gia tăng sụp lún đất và mực nước biển dâng nhanh hơn.

Các giải pháp đã được thực hiện có hiệu quả cho sản xuất nông nghiệp và thủy sản nhưng chưa bền vững về mặt xã hội, kinh tế và môi trường. Do đó, một cách tiếp cận toàn diện là yêu cầu cần thiết để ứng phó với biến đổi khí hậu trong tương lai và các tác động của con người để phát triển sản xuất nông nghiệp và thủy sản bền vững ở ĐBSCL.

Résumé

Ce chapitre présente les grandes caractéristiques géologiques et hydrologiques du delta du Mékong vietnamien, ainsi que des principaux facteurs anthropiques de changement. Nous présentons également les changements de température et de précipitations observés sur les quatre dernières décennies et évaluons les changements climatiques futurs selon différents scénarios climatiques globaux, en appliquant des méthodes de descente d'échelle statistique et dynamique.

Toutes les stations du delta enregistrent une augmentation de la température, avec une tendance moyenne au réchauffement de 0,2°C/décennie. Les changements de précipitations sont en revanche plus hétérogènes. D'ici le milieu du siècle, la température devrait augmenter de 1,3°C à 1,8°C et les précipitations de 15% à 20%, selon les scénarios climatiques RCP4.5 et RCP8.5 respectivement. À la fin du siècle, la hausse de température pourrait atteindre 1,7°C à 3,7°C et celle des précipitations 15 à 25%, selon le scénario climatique global considéré.

Le changement climatique n'est cependant pas la seule menace pour l'avenir du delta : les activités humaines dans le delta ou en amont ont en effet un impact important sur l'hydrologie et la sédimentologie. Elles peuvent exacerber les impacts du changement climatique ou, dans certains cas, être une plus grande menace à court ou moyen terme. Le piégeage des sédiments par les barrages en amont et l'extraction excessive de sable fluvial sont ainsi les principaux facteurs d'augmentation des intrusions salines, tandis que la surexploitation de l'eau souterraine entraîne des taux de subsidence élevés et donc une élévation rapide du niveau marin relatif.

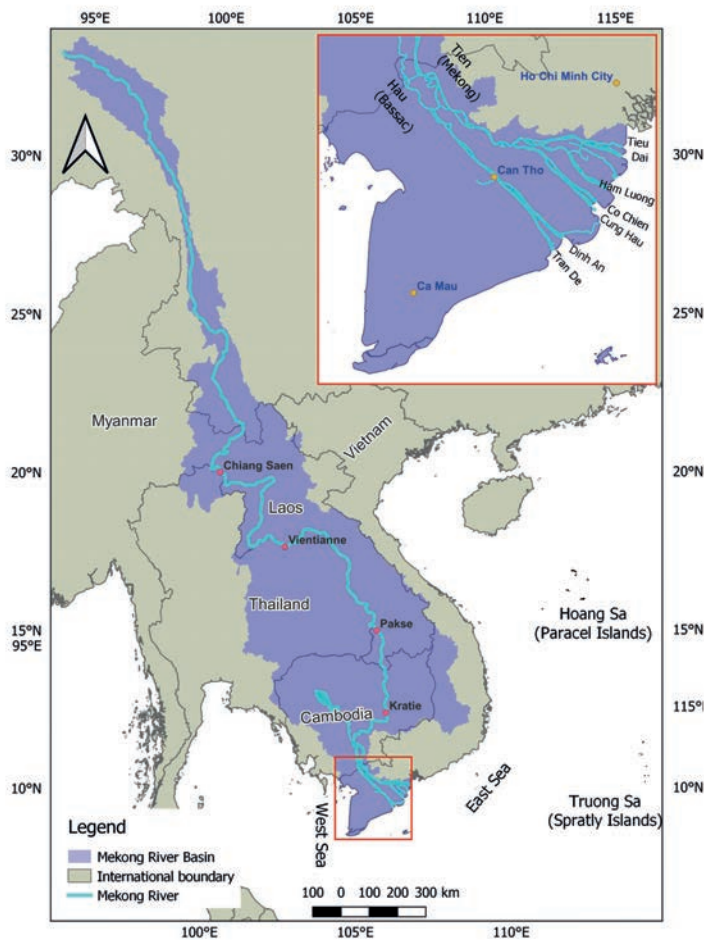
Les mesures d'adaptation mises en œuvre jusqu'à présent peuvent être efficaces en termes d'aquaculture et de production agricole mais ne sont pas durables d'un point de vue social, économique ou environnemental. Aussi, une approche holistique est nécessaire pour faire face tant au changement climatique futur qu'aux pressions anthropiques et développer une agriculture et une aquaculture durables dans le delta.

1. Introduction

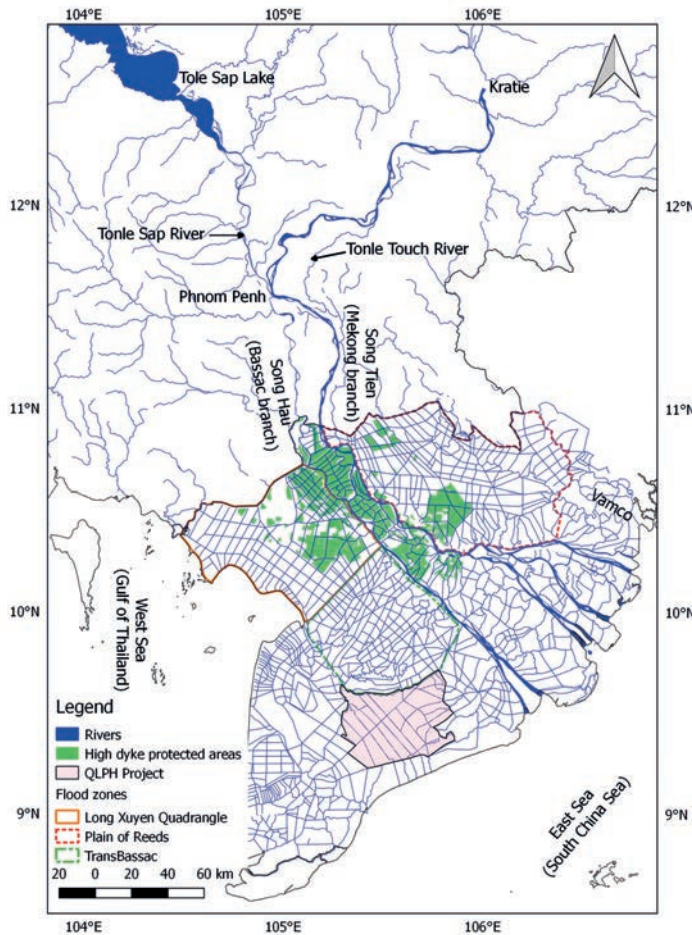
The Mekong is one of the largest rivers in the world [MRC, 2010]. It rises in Tibet, China, flows through five riparian countries over 4800 km, and draining a catchment area of 795,000 km² [MRC, 2005], before dividing into several branches in a delta and reaching the East Sea [Figure 7.1].

With its flat and low-elevation delta plain [Minderhoud *et al.*, 2019], Viet Nam's Mekong Delta (VMD) is highly sensitive to hydrological changes and global sea level rise, and therefore appears to be a "hotspot" of climate change impacts. It covers an area of about 4 million hectares, crossed by a complex network of rivers and canals [Figure 7.2], and is currently home to 17 million inhabitants, *i.e.* about

[Figure 7.1]
The Mekong River Basin and the Mekong Delta with its estuarine distribution network



[Figure 7.2]
The Mekong Delta's flood zones and its complex canals network



Source: Thanh *et al.*, 2020.

18% of Viet Nam's population [GSOVN, 2020]. Their livelihoods depend mainly on agricultural and aquaculture production. Often described as the "rice bowl" of Viet Nam (see Chapter 4), the VMD supplies more than half (~56%) of the country's rice production, 90% of which is exported [GSOVN, 2020]. Hence, the region is crucial for both national and international food security. However, agriculture and aquaculture in the delta strongly depends on water quality and availability. Water-related issues, including floods [MRC, 2009], droughts and

saline water intrusions [Nguyen *et al.*, 2021], are already challenging livelihoods in the delta and are expected to worsen in future decades, due to climate change and anthropogenic pressures. Further understanding projected climate change and the environmental impact of human activities is thus crucial to set up mitigation and adaptation strategies.

Different studies have already highlighted the vulnerability of the VMD to climate change [e.g. Van *et al.*, 2012; Tri *et al.*, 2013; Chapman

and Darby, 2016]. Several climate projections for the Mekong basin have been provided by global circulation models (GCM), and dynamical or statistical downscaling (see [Chapter 1](#)). Some of these projections have been used to assess the impacts of precipitation and temperature changes on the hydrological regime of the Mekong river, using hydrological modelling [e.g. Kite, 2001; Yoshimura *et al.*, 2009; Lauri *et al.*, 2012; Hoang *et al.*, 2015; Wang *et al.*, 2016]. Compared to 1971–2000, total upstream flow at Kratie is projected to increase by 3–8% under climate scenario RCP4.5, and by -7% to +11% under the RCP8.5 scenario over the 2036–2065 period [Hoang *et al.*, 2015]. Extreme flow occurrences are also expected to increase.

On the other hand, human activities in the delta or upstream in the Mekong basin have been shown to have strong impacts on the hydrology and sedimentology of the delta, including changes in the river flow and sediment trapping by upstream dams [Arias *et al.*, 2014a; Kondolf *et al.*, 2014; Eslami *et al.*, 2021a], excessive sand mining in the riverbeds [Bravard *et al.*, 2013; Eslami *et al.*, 2019b; Jordan *et al.*, 2019; Hackney *et al.*, 2020], groundwater over-extraction [Minderhoud *et al.*, 2017], fast-growing urbanization and surface drainage causing increased compaction of shallow sediments [Minderhoud *et al.*, 2018], and dyke-building to control natural flooding which impedes sedimentation [Thanh *et al.*, 2020]. These factors may exacerbate climate change impacts by causing land subsidence, for example, and enhance salinization, which may pose a greater threat in the short- to mid-terms [[Chapter 9](#)].

The VMD has long historical experience of dealing with water- and climate-related factors that can threaten agricultural production

(mainly floods, droughts and associated salinity intrusions, tropical cyclones and water pollution). A wide range of coping or adapting measures has been deployed at different levels. For instance, the provinces in the VMD have built and planned hydraulic structures to cope with floods and salinity intrusion [Thanh *et al.*, 2020], while the farmers may change their practices to adapt to these phenomena. However, the increasing impacts of climate change and anthropogenic activities challenge the sustainability of the different measures implemented so far.

As an introduction to the chapters focusing on the Mekong Delta in the present report, this chapter (i) presents the main geological and hydrological characteristics of the delta; (ii) analyses updated climate change projections for the delta; (iii) presents the anthropogenic pressures on the sedimentary regime and water resources; and (iv) reviews the measures currently being implemented to address water-related problems in the VMD. Some lessons learnt in adapting to climate-related problems will be presented, to contribute to future adaptation strategies. In addition, we also highlight opportunities for mitigating the anthropogenic pressures that have created undesired environmental changes in the Delta.

2. Geological and hydrological characteristics of the Delta

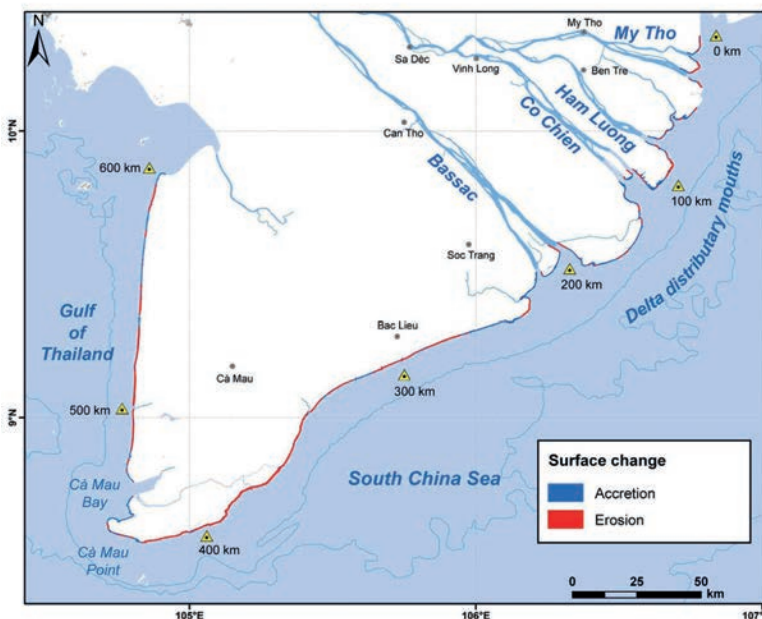
2.1 Evolution and elevation of the Delta

Deltas are geologically young landforms that have been formed during the past millennia. A delta is created when the volume of sediments accumulated over time at a location where a river enters a sea exceeds the volume (*i.e.* accommodation or accommodation space) that is created by sediment compaction and relative sea level rise. The surplus of both fluvial and marine sediments creates a delta extending into the sea. The elevation of this delta plain

is dynamic, and changes over time following sediment compaction and sea level fluctuations. When sea level rises, the elevation of a delta plain can be increased by deposition of new fluvial or marine sediments during floods, or by the production of organic sediments by vegetation on the delta plain.

The Mekong Delta was formed over the last 6,000–7,000 years, when the sea level in south-east Asia reached a relatively stable level following its rise after the last ice age [Hanebuth *et al.*, 2012]. Under the influx of large quantities of primarily fluvial sediments brought in by the Mekong River, the Mekong Delta started to form its apex in present-day Cambodia [Ta *et al.*, 2005; Tamura *et al.*, 2012]. Due to the combination of the relatively shallow sea-floor underlying the present delta and the large sediment influx [Anthony *et al.*, 2015], the

[Figure 7.3]
Shoreline changes of the Mekong Delta between 2003 and 2012



■ Source: Anthony *et al.*, 2015.

Delta rapidly extended during the last couple of thousand years to its present massive size, ranking it the third-largest delta plain on Earth [Coleman and Roberts, 1989].

The Mekong Delta used to progress seaward at a mean rate of >30 m/year [Liu *et al.*, 2017], but this rate decreased over the past decades, to become negative after 2005. Currently, most of the coastline is eroding [Figure 7.3], with high rates of up to 50 m/year, because of sediment starvation due to upstream dams and sand mining, subsidence (see Section 4 and Chapter 9), increased storms and sea level rise [Anthony *et al.*, 2015; Liu *et al.*, 2017; Tamura *et al.*, 2020].

Besides being one of the largest deltas, the Mekong Delta also has an extraordinarily flat and low-elevated delta plain. The vast majority of the Delta is elevated less than two meters above local mean sea level, with an estimated average delta plain elevation of some 80 cm [Minderhoud *et al.*, 2019]. Over a transect of more than 100 kilometres, running from the Cambodian border to the coast, the elevation of the delta plain changes by less than 2 metres (see Chapter 9). This makes the delta extremely vulnerable to relatively small changes in sea level or vertical land motion (e.g. land subsidence).

2.2 Hydrological regime

The Mekong River Basin (MRB) is delineated with its monsoon-driven seasonality. As a result, water discharge flowing into the Mekong Delta ranges from 1,700 m³/s to 40,000 m³/s, in dry and wet seasons respectively [Wolanski *et al.*, 1996; Le *et al.*, 2007]. Hence, during the dry season (NE monsoon, December to May), the Mekong River only provides 5–10% of the yearly discharge to the VMD, while the flood

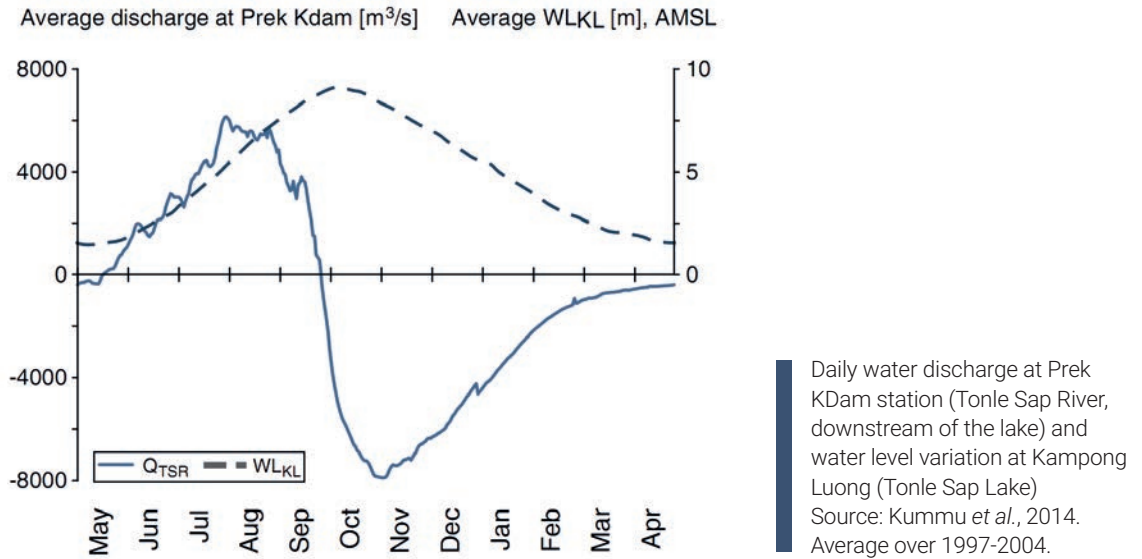
pulse of the wet season (SW monsoon, July to October) inundates the lakes and nourishes the floodplains with sediments and nutrients, driving major fish recruitment along the river (see Figure 7.2 for the location of the flood zones).

The MRB is stressed by significant anthropogenic and climatic drivers. The Mekong fluvial discharge (seasonal and annual) is projected to increase under most climate scenarios [Lauri *et al.* (2012); Thompson *et al.* (2013); Hoang *et al.* (2016); Hoang *et al.* (2019)] and will be subject to disruptions in known frequencies of flood and drought events. Moreover, hydropower development has altered the hydrological regime of the river by moderating the flood pulse and controlling the dry season discharge [ICEM, 2010], impacting the VMD's ecological cycle.

The pristine (pre-dam) Mekong River Basin provided two sources of fresh water for the VMD: the Mekong river itself, and the Tonle Sap Lake (TSL) in Cambodia (see location on Figure 7.2). The flood pulse of the wet season filled the TSL, the largest freshwater body in south-east Asia, covering 3,500 km² during dry seasons and 10,500 km² during wet seasons [MRC, 2005]. It played a crucial role in the hydrology of the VMD, acting as a retention area to feed the Delta along with the Mekong River during the dry season. Figure 7.4 shows the average water discharge (1997–2004) flowing in and out of the TSL at Prek Kdam station: the lake was filled with water from the Mekong River during flood seasons (June to October); then, after water levels at Kampong Luong (southern bank of the TSL) reached a peak of over 9 meters, the lake supplied water to the Delta, helping to maintain river flows and reduce salinity intrusion into coastal areas during dry seasons (October to May).

[Figure 7.4]

Average yearly water level and discharge variations of the Lake Tonle Sap



However, while the Mekong dry season discharge has increased over the past three decades [Figure 7.5], driven by climate change and hydropower operations [Eslami *et al.*, 2021b], water levels nowadays are hardly ever capable of filling Tonle Sap Lake to capacity during the wet season, due to the decrease in the Mekong discharge [Arias *et al.*, 2014b; Cochrane *et al.*, 2014]. Wet season water levels have followed a declining trend in the past two decades [Eslami *et al.*, 2021b]. Therefore, the Delta is short of TSL as its second freshwater source in the dry season, and experiences longer periods of dry seasons, driving a major exposure especially during drought events

2.3 Tides

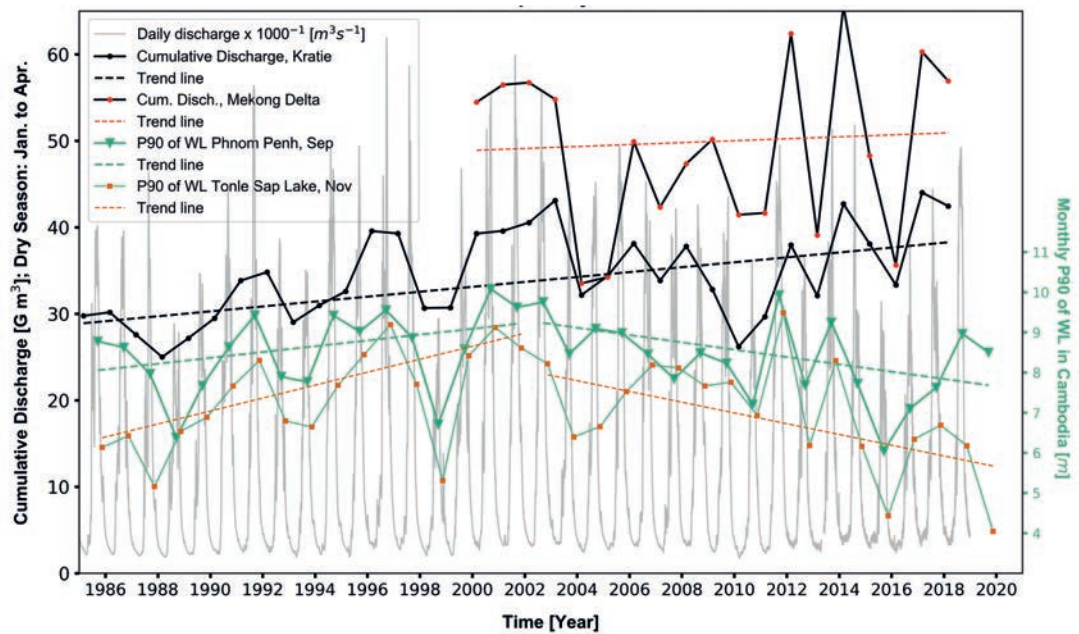
Tide is the most important hydrodynamic force in coastal areas. The Mekong Delta has complex interactions between the mixed diurnal-semidiurnal tide from the East Sea and the

diurnal tide from the West Sea (Gulf of Thailand). The greatest tidal differences occur in the East Sea, where they can reach up to 3.8 m, and decline gradually in the south-west direction [Eslami *et al.*, 2019a]. Tidal amplitudes in the West Sea are much smaller, ranging from 0.5 to 1 m [Unverricht *et al.*, 2013].

However, while the tidal ranges at Dinh An (the East Sea) are much larger than that at Rach Gia (the West Sea), the daily average water levels at Rach Gia are slightly higher. As a result, floods during the wet season are mainly drained to the East Sea.

During the flood season, tides still influence water levels in the coastal areas [Lê Sâm, 1996]. Yet the high fluvial discharge dominates water levels further upstream, and the tide does not travel beyond the Cambodian

[Figure 7.5]
Trends of the Mekong River discharge and water level



Left axis: Trends of upstream (Kratie) dry season cumulative discharge and downstream (Tan Chau + Chau Doc); Right Axis: monthly 90th percentile of water level and in Oct. and Nov. in Phnom Penh Port, Cambodia (right axis).
Source: Eslami; *et al.* (2021b).

border [Gugliotta *et al.*, 2017; Eslami *et al.*, 2019b]. On the other hand, during the dry season, tides are the main factor controlling water level variations in the Delta. Their effects can spread 190 km further inland in the estuary channels of the Mekong [Takagi *et al.*, 2016; Eslami *et al.*, 2019a].

3. Climate change in the Viet Nam's Mekong Delta

3.1 Climate change in the past

Past climate changes in the Mekong Delta presented in this section are based on daily temperature and rainfall data collected from 11 meteorological stations [Table 7.1] in the region over the period 1981–2018. We investigated the changes for several climatic variables, including 1] daily average temperature (T2m), 2] daily minimum temperature (Tn), 3] daily maximum temperature (Tx), 4] daily precipitation (R), and some extreme indexes such as 5] number of hot days (Su35: annual number of days with $T_x \geq 35^\circ\text{C}$), 6] number of very hot days (Su37: annual number of days with $T_x \geq 37^\circ\text{C}$), 7] an-

nual maximum 1-day rainfall (Rx1day), and 8] annual maximum 5-day consecutive rainfall (Rx5day). The results are shown as linear trends computed over the entire observation period (see Chapter 1).

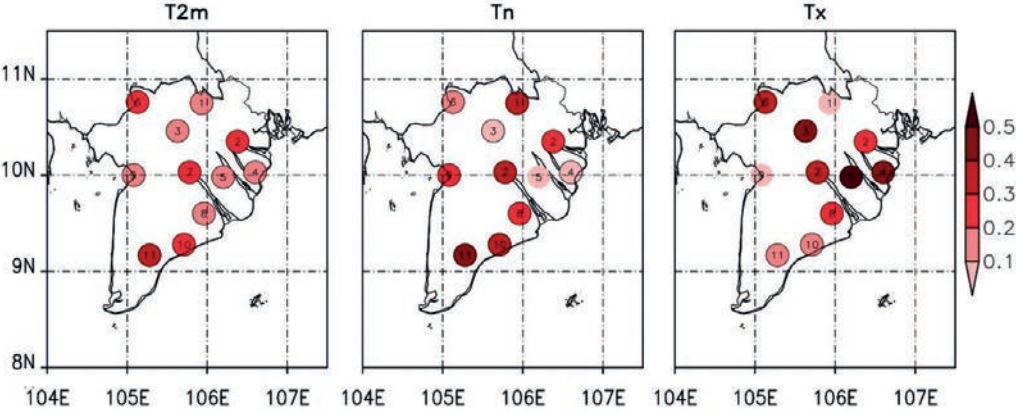
Figure 7.6 shows that temperature increased at all stations in the Mekong Delta over 1981–2018, with an average trend of 0.76°C increase over 38 years (*i.e.* $\sim 0.2^\circ\text{C}/\text{decade}$). Ca Mau station recorded the largest temperature increase of $\sim 0.32^\circ\text{C}/\text{decade}$, while Rach Gia station has the lowest increase of about $0.1^\circ\text{C}/\text{decade}$. Extreme daily temperature also increased at all stations. Daily maximum temperature (Tx) had an average increase of $0.28^\circ\text{C}/\text{decade}$; Cang Long station (Tra Vinh province) had the highest increase of $0.53^\circ\text{C}/\text{decade}$, while Moc Hoa station (Long An province) and Rach Gia station (Kien Giang province) recorded a negligible maximum temperature change of $0.05^\circ\text{C}/\text{decade}$.

[Table 7.1]

List of meteorological stations in the Mekong Delta, Viet Nam

No	Station name	Provinces	Longitude ($^\circ\text{E}$)	Latitude ($^\circ\text{N}$)
1	Moc Hoa	Long An	105.93	10.78
2	My Tho	Tien Giang	106.40	10.35
3	CaoLanh	Dong Thap	105.63	10.47
4	Ba Tri	Ben Tre	106.60	10.05
5	Cang Long	Tra Vinh	106.20	9.98
6	Chau Doc	An Giang	105.13	10.70
7	Can Tho	Can Tho	105.77	10.03
8	Soc Trang	Soc Trang	105.97	9.60
9	Rach Gia	Kien Giang	105.07	10.00
10	Bac Lieu	Bac Lieu	105.72	9.28
11	Ca Mau	Ca Mau	105.15	9.18

[Figure 7.6]
Temperature changes in the Delta for the period 1981–2018



Trends in daily average temperature (T2m), daily maximum temperature (Tx) and daily minimum temperature (Tn) over the lower Mekong computed by linear regression over 1981–2018. Stations with black contours indicate where trend is statistically significant at the 95% level. Number in each circle indicates the station as listed in Table 7.1. Unit: °C/decade.

At the same time, daily minimum temperature also increased across the region, with the highest increase of up to 0.47°C/decade in Ca Mau, and the lowest increase of 0.03°C/decade recorded at Cang Long station (Tra Vinh). In general, the average increase of Tn was higher than that of Tx in the Mekong Delta.

The number of hot days (Su35) and very hot days (Su37) varied significantly between regions [Figure 7.7]. Su35 increased in provinces such as Tien Giang, Ben Tre, Tra Vinh, An Giang, Can Tho and Ca Mau with a common increase from 1.4 to 5.7 days/decade over the period 1981–2018. Chau Doc station (An Giang) recorded the highest increase in Su35 up to 5.7 days/decade, and Ba Tri station (Ben Tre) had the lowest increase with only 1.4 days/decade. In contrast, areas such as Long An, Dong Thap, Kien Giang and Bac Lieu experienced a decrease in the number of

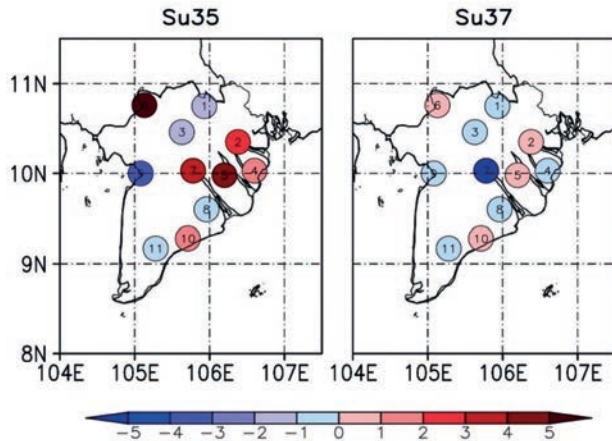
very hot days during this period from 0.1 to 1.8 days/decade. Additionally, Su35 did not change in Soc Trang province.

The number of very hot days (Su37) followed the same trend of change, but was not significant and weaker than the number of hot days in the whole Mekong Delta region, with an increase or decrease of 0.1 or 0.94 days/decade, respectively.

In general, rainfall show an increasing trend over the Mekong Delta in the period 1981–2018 [Figure 7.8], except for Ca Mau where a slight decrease of 1.9%/decade in annual rainfall was recorded. The largest rainfall changes of about 4.07%/decade occurred in Bac Lieu, while Ben Tre experienced negligible changes of about 0.5%/decade. Rainfall extremes varied greatly between regions. Annual maximum 1-day rainfall (Rx1day) decreased sharply by

[Figure 7.7]

Changes in the annual number of hot and very hot days for the period 1981–2018

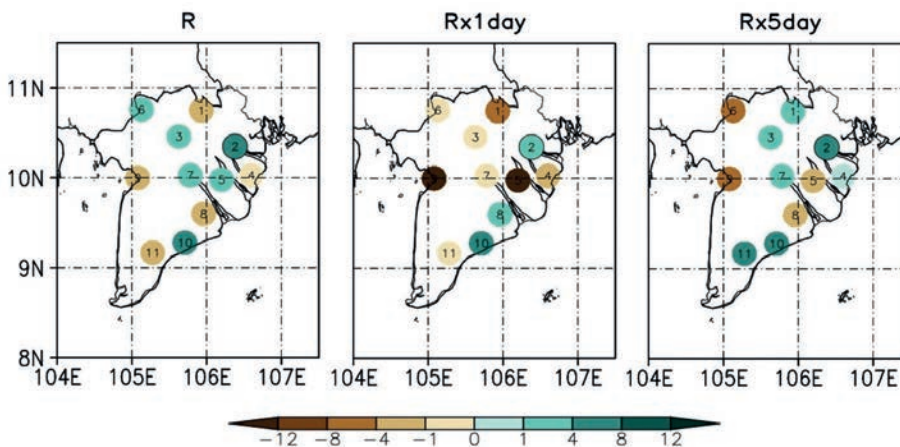


The trend in the number of hot days (Su35) and very hot days (Su37) computed by linear regression over the period 1981–2018. Stations with black contours indicate where the trend is statistically significant at the 95% level. The number in each circle indicates the station as listed in Table 7.1.

Unit: annual days/decade.

[Figure 7.8]

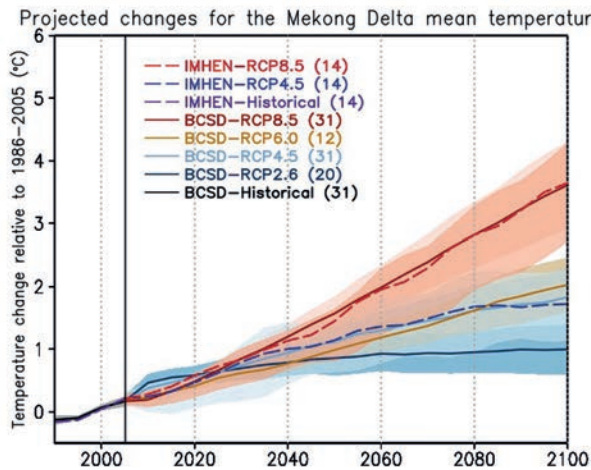
Rainfall changes in the Delta for the period 1981–2018



The trend in annual average rainfall (R), annual maximum 1-day rainfall (Rx1day), and annual maximum 5-day consecutive rainfall computed by linear regression over the period 1981–2018. Stations with black contours indicate where the trend is statistically significant at the 95% level. The number in each circle indicates the station as listed in Table 7.1.

Unit: %/decade.

[Figure 7.9]
Projected changes for the Mekong delta mean annual temperature



Projections of the mean annual temperature changes in the Mekong Delta compared to the baseline period 1986–2005, obtained from dynamical downscaling simulations provided by IMHEN and from BCSD methods. Coloured lines present the ensemble means, and coloured shaded areas show the uncertainty ranges (± 1 standard deviation) for each RCP. The number of experiments used to calculate each RCP is shown in brackets after each RCP name.

over 15 and 13%/decade in Tra Vinh and Kien Giang, respectively. Rx1day decreased by 5.3%/decade in Long An, 2.6% in Ben Tre. The remaining provinces of Tien Giang, Soc Trang, and Bac Lieu recorded an increase of 1.7–6.1%/decade in Rx1day, while An Giang did not record a noticeable change in Rx1day. In addition, annual maximum 5-day rainfall (Rx5day) in Bac Lieu, An Giang and Kien Giang decreased strongly by 6.5 and 4.4%/decade, respectively. Meanwhile, Rx5day increased by 1.0–6.2%/decade in Long An, Tien Giang, Tra Vinh, Bac Lieu, and Ca Mau. However, unlike temperature, the trend for rainfall is only statistically significant at very few stations.

3.2 Climate change projection in the Mekong Delta

As mentioned in [Chapter 1](#), two downscaling methods, *i.e.* the dynamical and the statistical ones, were used to build future climate change scenarios for Viet Nam, including the Mekong Delta. The following results were obtained by using:

- 1] 19 dynamical downscaling experiments – of which 14 experiments for temperature and 5 for rainfall – provided by the Viet Nam Institute of Meteorology, Hydrology and climate change (IMHEN);
- 2] Bias Correction Spatial Disaggregation [BCSD; Wood *et al.*, 2004] experiments applied for CMIP5 GCMs; the number of GCMs varied

depending on the RCPs: 20, 31, 12, 31 GCMs for RCP2.6, 4.5, 6.0, and 8.5, respectively.

It should be noted that the dynamical downscaling experiments used in this report are identical to those used in the latest national report on climate change and sea level rise scenarios from IMHEN (2021). Daily temperature and precipitation outputs from those dynamical experiments were corrected on the basis of observation data for the baseline period 1986–2005, and for the future period through to the end of the XXIst century. In order to match with the results in the latest reports from MoNRE (2016) and IMHEN (2021), this section focuses on the climatic projections from the dynamical downscaling experiments. More technical details can be found in [Chapter 1](#).

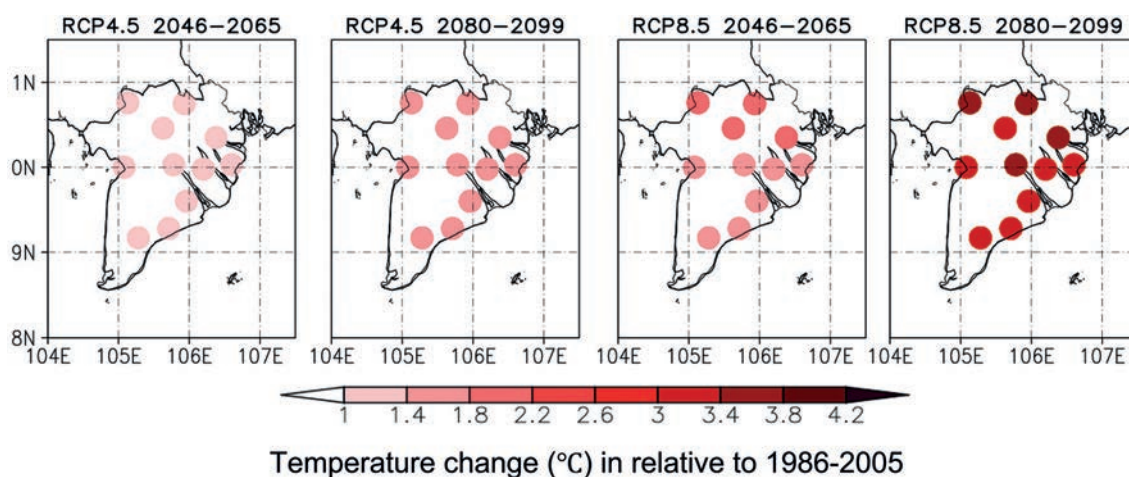
Results from dynamical downscaling

Figure 7.9 displays the temperature increase projected for the Mekong Delta in the XXIst century, compared to the baseline period 1986–2005. According to the IMHEN dynamical downscaling results, the mean annual temperature is projected to increase by $1.74 \pm 0.92^\circ\text{C}$ under RCP4.5 and $3.56 \pm 1.25^\circ\text{C}$ under RCP8.5 by the end of the XXIst century. The projections from the BCSD statistical method are similar, with a projected temperature increase of $1.79 \pm 1.01^\circ\text{C}$ under RCP4.5 and $3.59 \pm 1.12^\circ\text{C}$ under RCP8.5.

Figure 7.10 shows the annual temperature increase at 11 stations in the Mekong Delta during the mid and late XXIst century, under

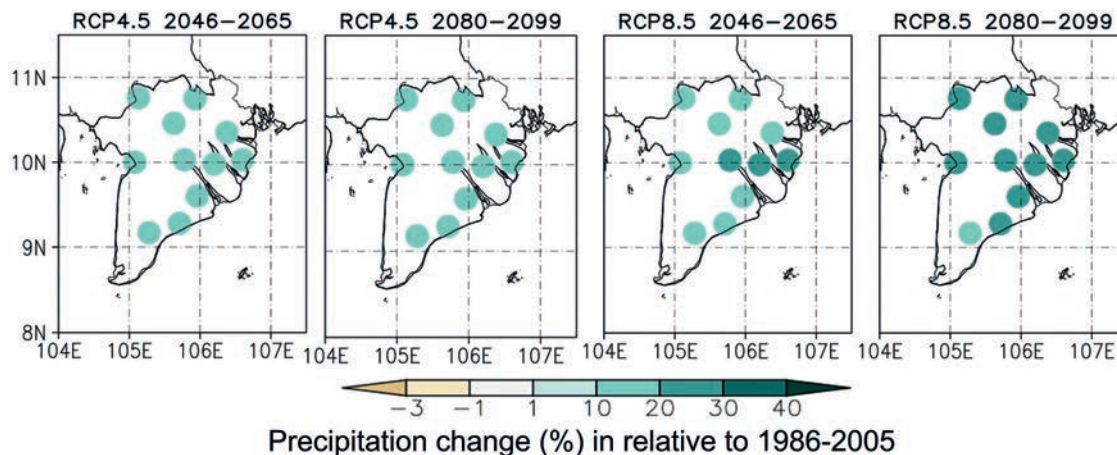
[Figure 7.10]

Projected annual temperature changes under RCP4.5 and RCP8.5



Projections are obtained from the dynamical downscaling ensemble for the mid-century period 2046–2065 and end-century period 2080–2099 relative to the baseline 1986–2005. Unit in °C.

[Figure 7.11]

Projections of annual rainfall changes under RCP4.5 and RCP8.5

Projections are obtained from dynamical downscaling for the mid- and end-century periods relative to the baseline 1986–2005.

Unit in %.

scenarios RCP4.5 and RCP8.5. Consistent with higher levels of global warming, the projected temperature is higher under RCP8.5 than under RCP4.5 for both the middle and the end of the century. Under RCP4.5, the mean annual temperature across the region is projected to increase by 1.3°C by mid-century, and by 1.7°C at the end of the century, compared to the baseline period 1986–2005. Meanwhile, under RCP8.5, temperature is projected to increase by 1.8°C by mid-century and by 3.2°C at the end of the century. An Giang, Long An and Can Tho are projected to experience the highest increase of over 3.4°C.

Rainfall projections from the dynamical downscaling experiments show an increase over the entire Mekong Delta region under both RCP4.5 and RCP8.5 [Figure 7.11]. Under RCP4.5, annual rainfall is projected to increase by ~15% in both the mid- and late-century periods. Meanwhile, under RCP8.5, increases

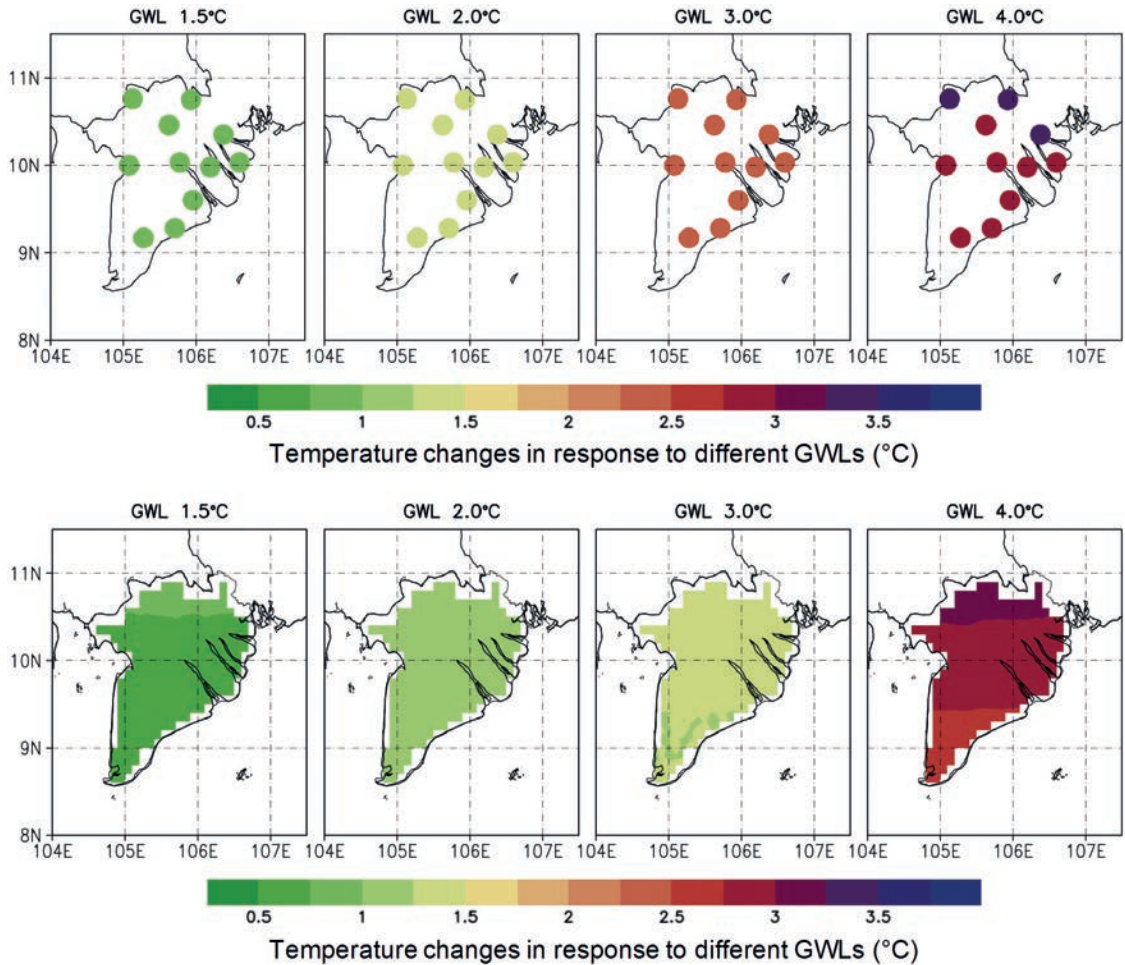
of 20% and 25% are projected for the mid-century and late-century periods, respectively.

Projections for different global warming levels

As discussed in [Chapter 1](#), in 2015, many countries around the world adopted the Paris Agreement with the aim of limiting global warming at the end of XXIst century to well below 2°C relative to the pre-industrial period, and endeavoured to limit the increase to 1.5°C. Identifying the magnitude of climate change in each region with various global warming levels (GWLs) is crucial for studying impact assessment and climate change response. In that context, we discuss below the projected changes of temperature and rainfall in the Mekong Delta at different GWLs from 1.5°C, 2.0°C, 3.0°C to 4.0°C above pre-industrial levels. Note that the global warming level in 1986–2005 is already 0.63°C above pre-

[Figure 7.12]

Temperature changes in the Mekong delta for different Global Warming Levels (GWLs)



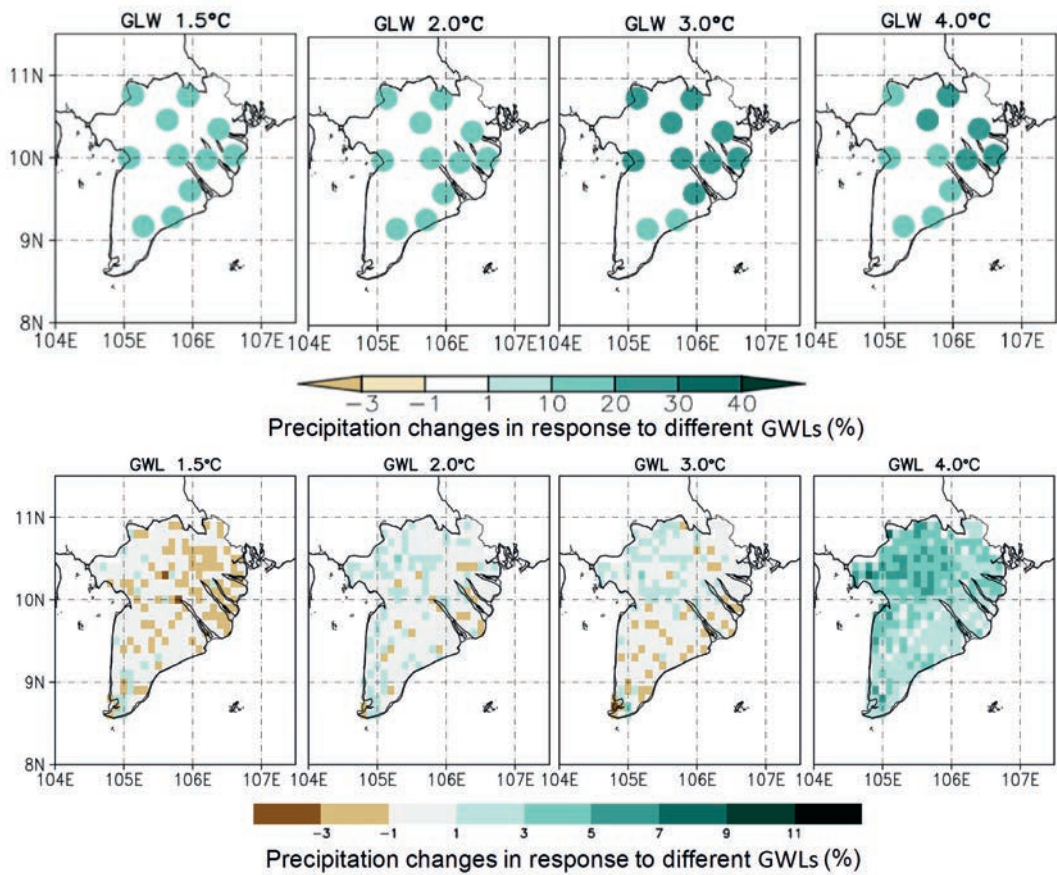
Temperature changes in the Viet Nam's Mekong delta at the times when the GWLs are reached, relative to the baseline 1986–2005. Results obtained from the ensemble of the dynamical downscaling experiments (upper panel) and from that of the BCSD statistical downscaling (lower panel).

industrial [Allen *et al.*, 2018]. The GWL calculations were implemented with the ensemble of the dynamical downscaling experiments provided by IMHEN, and that of the BCSD statistical downscaling [Chapter 1].

Figure 7.12 shows the temperature change in the Mekong Delta compared to 1986–2005, at

the respective times when the GWLs of 1.5°C, 2.0°C, 3.0°C, and 4.0° are reached. The BCSD statistical results are coherent with the IMHEN dynamical ones. When the GWL reaches 1.5°C, temperature in the whole Mekong Delta is projected to increase by 0.78°C, with the highest increase in Tien Giang (0.83°C) and the lowest in Kien Giang (0.76°C). When the GWL

[Figure 7.13]
Precipitation changes in the Delta for different Global Warming Levels (GWLs)



Changes of average annual rainfall in the Mekong Delta at the times when the GWLs are reached, relative to the baseline 1986–2005. Results obtained from the ensemble of the dynamical downscaling experiments (upper panels) and from that of the BCSD statistical downscaling (lower panels). Note the difference of scale between the two panels.

reaches 2°C, average projected warming in the Mekong Delta is 1.19°C; with the highest increase in Tien Giang (1.23°C) and the lowest in Soc Trang (1.15°C). At the 3.0°C and 4.°C GWLs, average warming in the Mekong Delta is projected to reach 2.19°C and 2.94°C, respectively; while Tien Giang still maintains the highest temperature increase of 2.28°C and

3.0°C; and Bac Lieu has the lowest increases of 2.14°C and 2.89°C, respectively.

Figure 7.13 displays rainfall changes in the Mekong Delta at the different GWLs compared to the baseline period 1986–2005. Unlike temperature, the rainfall results of BCSD are remarkably different from those of

IMHEN. When the GWL reaches 1.5°C, the dynamical experiments show rainfall increases in the range of 11.6–17.5% in the Mekong Delta, while the BCSD results shows slight rainfall decreases of less than 3% over most of the region. When the GWL rises to 2.0°C, the IMHEN experiments show a slightly larger increase in rainfall in the range of 13.6–18.5%; while the BCSD shows an increase of 3–5% and areas with increasing rainfall are projected to ex-

pand. For the higher GWLs of 3.0°C and 4.0°C, the increases in average rainfall obtained from the dynamical downscaling experiments in the Mekong Delta are 22.2% and 20.8%, respectively. Meanwhile, the BCSD results show respective increases of only 3.7% and 7.9%. At the 4.0°C GWL, both the statistical and dynamical experiments project increasing rainfall trends across the entire VMD.

4. Anthropogenic pressures

4.1 Upstream dams and sand mining drive sediment starvation

The flowing water and moving sediments of the Mekong River are fundamental to the existence of the Mekong Delta. Basin-wide alterations of natural water and sediment dynamics have had the biggest impact on the ecological and geophysical function of rivers and their deltas worldwide [Grill *et al.*, 2019]. Due to upstream impoundments and downstream interventions (e.g., channel fixing with levees, dyking populated areas), fluvial sediment supply to world deltas has decreased by 30% [Vörösmarty *et al.*, 2003; Syvitski *et al.*, 2009; Syvitski and Kettner, 2011; Besset *et al.*, 2019; Best, 2019], and 40–50 10^9 T/yr of global demand for sand [UNEP, 2019] is incising rivers and estuarine systems [Bravard *et al.*, 2013; Brunier *et al.*, 2014; Best, 2019]. Once one of the last uninterrupted rivers in the world, over the past three decades, the Mekong River has rapidly joined that trend, and sediment starvation has already caused irreparable damage along the river and

within the VMD. The estimate [Milliman and Farnsworth, 2011] of total sediment transported by the pristine Mekong river at the entrance of the delta was ~ 160 Mt yr⁻¹, but recent estimates show 40–90% reduction in fluvial sediment supply [Kummu and Varis, 2007; Walling, 2009; Kummu *et al.*, 2010; Koehnken, 2014; Lu *et al.*, 2014; Fan *et al.*, 2015; Manh *et al.*, 2015; Darby *et al.*, 2016; Dang *et al.*, 2018]. The effects of sediment trapping by dams under foreseeable future scenarios are expected to have already reached or to reach the VMD within the next 10–20 years [MRC, 2011]. The effect of sediment trapping on the coarse sediment (sand and gravel), which is a very small fraction of over-all sediment load, takes a long time to travel downstream, but the effect of fine sediment trapping can almost immediately travel to the Delta. Furthermore, although sand export is banned in Cambodia and Viet Nam, domestic consumption has persisted. Projections to 2040 [SIWRP, 2015] show over 1,500 M m³ demand within the VMD for infrastructure development. Current sand mining within the VMD and upstream in Cambodia, are estimated at 28 M m³/yr (40–50 Mt yr⁻¹) [Bravard *et al.*, 2013; Eslami *et al.*, 2019b; Jordan *et al.*, 2019]. “Considering that this does not account for sand mining in Cambodia, and possible illegal sand mining, only in Viet Nam, this amount

is likely to be close to 100% (or more) of the total fluvial sediment supply” [Eslami *et al.*, 2019b]. With this starvation exceeding natural replenishment, it leads to erosion of the capital sediment (older Holocene fossil deposits), and explains the incision of the riverbeds [Brunier *et al.*, 2014].

Rapid erosion of riverbed levels [Doan *et al.*, 2018; Eslami *et al.*, 2019b] has already resulted in significant tidal amplification and increased saline water intrusions within the VMD [Chapter 9]. The observed increasing trends for saline water intrusions along the estuarine channels – in the range of 0.2–0.5 PSU/year – is directly linked to sediment deprivation and riverbed erosion [Eslami *et al.*, 2019b]. Furthermore, although Mekong River dry season discharge has increased, total dry season discharge to the Delta has not changed significantly. Therefore, with deeper riverbeds and the relative sea level rise, the delta is far more vulnerable to saline water intrusions [Eslami *et al.*, 2021a]. Because of this combination, actual salinity intrusions in 2016 and 2020 already surpassed [IFRC, 2020] the 2050 projections, developed in 2015 [Smajgl *et al.*, 2015].

4.2 Surface and groundwater resources

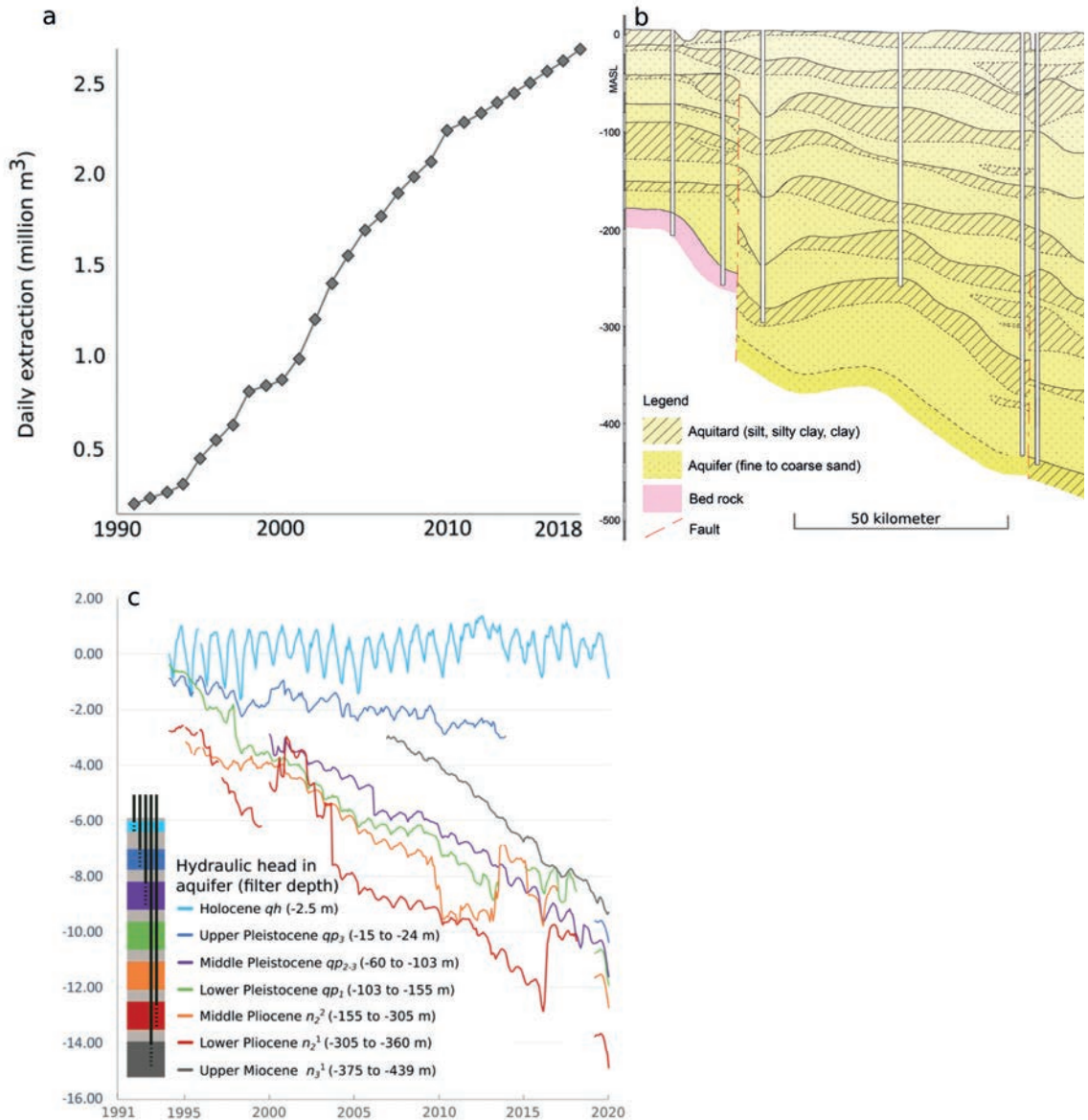
The VMD is highly populated, and the riparian countries in the Lower Mekong Basin are developing with a focus on economic growth. For growing economies, water is an important natural resource that fuels development. Rapid economic development leads to increased pressure on water availability. Water resources in the VMD are facing several challenges, which can be divided into external or internal origins.

The external factors influencing water resources in the VMD include the rapid development of hydraulic structures in the upstream countries, projected climate change and global sea level rise. The upstream countries have built and planned hydropower dams and irrigation projects on the mainstream and tributaries of the Mekong River. Due to the downstream location, any change in the upstream influences the VMD through changes in the flow regime and sedimentation [Lauri *et al.*, 2012; Van *et al.*, 2012; Manh *et al.*, 2015].

The internal factors consist of dykes, polders, infrastructure to prevent flooding and salt intrusion, and high water demand. The intensification of agricultural and aquacultural crops leads to increased freshwater use, and hence pressure on surface water resources from the Mekong river. Therefore, the local inhabitants look for other water resources and, as a result, groundwater extraction has been growing rapidly over the past three decades, from very limited amounts in the 1990’s to more than $2.5 \cdot 10^6$ m³/day nowadays [Minderhoud *et al.*, 2017]. The water is extracted from different aquifers (*i.e.* sand bodies) in the subsurface, at depths that range in some places to more than 500m. The water pressure (*i.e.* hydraulic head) in the aquifers has been monitored since 1990, when the groundwater situation was still rather undisturbed in many places. Since then, following the steady increase in extractions, the water pressure in the different aquifers has shown decreasing trends throughout the delta [Figure 7.15]. Following the drop in pressure, water is drained from fine-grained deposits (*i.e.* aquitards, low permeable layers separating the different aquifers), causing compaction of the aquifer-system and consequent land subsidence. This anthropogenically-driven compaction is currently the main driver of accelerating land subsidence in the VMD [Erban

[Figure 7.14]

Groundwater extraction in the VMD and impact on the aquifers



a) Estimated groundwater extraction in the VMD in million m³ per day showing a strong and consistent increase since the 1990s (modified after Minderhoud *et al.*, 2020b). b) Cross-sections of the multi-aquifer system, i.e. aquifers and aquitards, of the VMD from which groundwater is extracted at different depths (Modified after Minderhoud *et al.*, 2017). c) Hydraulic head time series measured for different aquifers in Soc Trang. All confined aquifers show consistent declines in hydraulic head driven by groundwater extraction. The declining trends are measured in aquifers throughout the VMD (Data by DWRPIS).

et al., 2014; Minderhoud *et al.*, 2020b) (Chapter 9 deals with delta elevation and land subsidence in greater detail).

In addition to causing land subsidence, groundwater pumping also increases groundwater salinization, as freshwater reserves are being replaced by salt water, causing additional loss of freshwater. As a result, fresh groundwater reserves are rapidly decreasing.

4.3 Elevation loss in the delta

Over the past decades, the factors controlling the natural dynamics of relative delta elevation have changed drastically in the VMD. This is the result of a combination of climatic and anthropogenic impacts. Increased flood control and sediment starvation have decreased the amount of sediments delivered to channels and

then to flood plains [Kondolf *et al.*, 2014; Li *et al.*, 2017], while global warming increases global sea level rise. Meanwhile, human activities in the delta have enhanced natural subsidence [Zoccarato *et al.*, 2018] and created additional human-induced subsidence [Minderhoud *et al.*, 2017, 2018] [see Chapter 9]. Subsidence is occurring throughout the Delta, at rates of up to several centimetres per year, and up to 5 cm/year in places [Erban *et al.*, 2014; Minderhoud *et al.*, 2020a]. And this subsidence is no longer counterbalanced by the deposition of new sediments. In consequence, the Delta is currently experiencing rapid elevation loss [Minderhoud *et al.*, 2020b]. As subsidence and consequential relative sea level rise act as amplifiers of other processes — including flood exposure — erosion and salinization are occurring at increasing rates in the Delta [Tamura *et al.*, 2020].

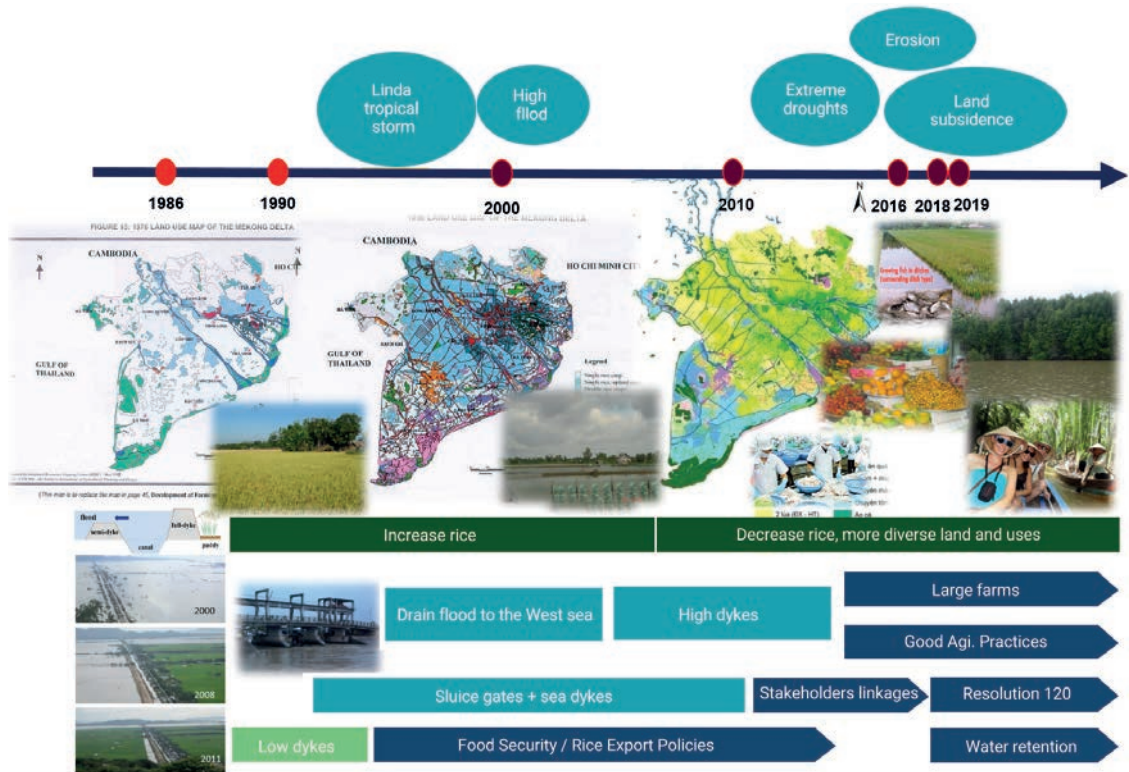
5. Discussion and conclusions

The VMD has extensive experience in mitigating and adapting to environmental changes. Figure 7.15 presents the evolution of adaptation to environmental problems in agricultural production since 1986 after the introduction of the “doi moi” (renovation) policy.

Water management in the VMD has historically followed the “Dutch dyke” strategy. It includes structures of dykes that encircle settlement and rice fields [Biggs *et al.*, 2009]. In the “doi moi” policy, agriculture and aquaculture were intensified and grown rapidly to supply food for local inhabitants and Viet Nam. A dense canal network was developed [Fi-

gure 7.2] in order to drain floods to the West Sea, and to clean acid sulphate soils. However, despite this strategy, the rice crops in the upper VMD were still damaged and destroyed by annual floods from August to October. The historic flood of 2000, in particular, caused enormous damage to infrastructure, residents’ properties and agricultural crops. After this hugely damaging flood, rice crops were protected by a dyke system that consists of both low dykes and high dykes [Thanh *et al.*, 2020]. The VMD provinces rarely constructed high dykes before 2000 [Duong *et al.*, 2016]. Since 2000, the upper VMD (An Giang and Dong Thap provinces) has built and planned high dykes to protect rice crops in the entire provincial area. Until 2009, the area protected by high dykes was about 1,222 km², covering around 35% of the An Giang province area, and

[Figure 7.15]
Evolution of climate-related events and adaptation measures



■ Source: Duc *et al.*, 2019.

this percentage increased to over 40% [about 1,431 km²] in 2011. Dong Thap has a much lower coverage of about 30%, corresponding to an area of 990 km².

At first, the dyke system was positive for rice cropping. However it is now recognized that dykes also have significant negative effects (see Chapter 9). First, they prevent the floodplains from playing their natural buffer role against flooding, deflecting and aggravating the floodpeaks [Triet *et al.*, 2017; Tran *et al.*, 2018; Thanh *et al.*, 2020] Tran *et al.*, 2018 found that flood peaks would be drastically

increased if high dykes were built in all the VMD floodplains. Secondly, high dykes inhibit the enrichment of agricultural soils with sediments and nutrients in the VMD floodplains, decreasing soil fertility and enhancing elevation loss. Hence, benefits in some places for agriculture are made at the expense of other communities or other sectors. Moreover, dykes may create a false sense of security, leading to more buildings and activities in flood-prone areas and then high damage if dykes are overtopped or fail. For example, some high dykes were broken in the 2011 flood season: 49 people were killed, and over

one hundred houses were flooded [Sikkema and van Halsema, 2019].

Recently, the VMD has seen increasing trends of salinity, and a higher frequency of extreme droughts and salinity intrusion during the dry seasons, with strong negative impacts on rice production in the coastal VMD. The observed trends are heavily linked to anthropogenic sediment starvation due to upstream trapping and sand mining, as well as the hydrological regime shift driven by hydropower operations [Eslami *et al.*, 2019b]. About 45% of the Delta area, approximately 1.77 million ha, is affected by salinity intrusion during the dry seasons [Vo, 2012]. In order to protect freshwater crops in this area, the central government continues to construct dykes and sluice gates to prevent saline water intrusions in coastal provinces, but this is a high-cost measure. Additionally, the operation of saltwater prevention structures may cause pollution of the surface water resource. For instance Phuong *et al.* (2017) found that chemical oxygen demand (COD) concentrations outside the Ba Lai sluice gate, which closes off one of the former nine river branches in Ben Tre province, are much higher than those inside the sluice gate.

Hard adaptive measures to the aforementioned environmental changes may be effective in terms of agricultural production, but are not sustainable from a social, economic or environmental point of view. Therefore, a holistic approach is required to deal with future environmental changes and projected climate change. Recently, Resolution 120/NQ-CP 2017 on Sustainable and Climate Resilient Development of the Mekong Delta was released. This resolution considers 8 different issues: traffic, education, rivers, connectivity,

wealth, talent, ageing, and gender. It is currently detailed by the Decision 1163/QĐ-TTg 2020 on approving the task of planning the Mekong Delta for the period 2021–2030, with a vision to 2050 issued by the Prime Minister. The national plan to adapt to climate change includes three groups of tasks and solutions:

- ▶ First, improving the effectiveness of climate change adaptation by strengthening the state's management capacity on climate change, and promoting the integration of climate change adaptation into strategic and regulatory system plans.
- ▶ Second, enhancing resilience and adaptive capacity for communities, economic sectors, and ecosystems through investment in adaptation actions, science, and technology to be prepared to adapt to climate change.
- ▶ Third, boosting disaster risk reduction and damage reduction, along with preparedness to respond to natural disasters and increased climate extremes due to climate change, such as via the establishment of regional coordination institutions and mechanisms for sustainable development in the Mekong Delta. Alongside this, promoting the training and development of human resources, scientific research, and technological development, as well as strengthening international cooperation and strategic communication to raise public awareness of the impacts of climate change.

Based on the guidance of Resolution 120, we propose an approach of participatory planning and integrated management for sustainable agriculture and aquaculture in the Mekong Delta. The approach includes the following steps :

- ▶ Conduct detailed assessments of climate change impacts at local levels. Then propose appropriate transformation;
- ▶ Undertake assessment of the social, economic and environmental impacts of land use transformation;
- ▶ Apply new/modern technologies on monitoring, data analysis and visualization to support stakeholders in preparing production, investment, and business planning in each sub-biophysical land unit.
- ▶ Inform the state management agency about the production situations, challenges, and opportunities to bring supportive solutions to farmers and businesses.
- ▶ Build integrated information systems that support stakeholder engagement in addressing production issues in the context of globalization and climate change.

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Chapter 8

Mekong transboundary resource governance in an era of changes

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1. The views expressed are those of the authors and not necessarily the views of the MRC, its member countries, and the affiliated institutions.

Abstract

After a recent history mired with conflicts, the Mekong region enters modern diplomacy with various interests and potential conflicts in using and amending transboundary resources. Climate change adds a layer of uncertainty onto current water resource management, and thus troubles any agreement for resource sharing. Until today, the implementation of resource governance schemes by national institutions remains a great challenge. The current regional structure for governance and management of transboundary resources of the Mekong is made up of six organizations with different frameworks involving different countries of the region as well as partners outside the region. This chapter argues that traditional forms of state-led governance alone are inadequate in dealing with transboundary environmental issues. A better approach has been proposed in the Basin Development Strategy 2021–2030 of the Mekong River Commission called “proactive regional planning”. At the planning level, “proactive regional planning” plays the role of integration with joint investment projects and measures between countries, actors, and sectors. Furthermore, the scale of action is important in transboundary resources governance, taking into account the diversity of interests of the different stakeholders, including those of the vulnerable groups. Four areas of future applied research are suggested to integrate environmental and climate changes into the complex governance of water and related national resources.

Tóm tắt

Sau giai đoạn bất ổn trong quá khứ, lưu vực sông Mekong bước vào giai đoạn ngoại giao hiện đại bao trùm những lợi ích khác nhau cũng như những mâu thuẫn tiềm tàng trong sử dụng các nguồn tài nguyên mang tính chất liên biên giới. Biến đổi khí hậu làm gia tăng thêm những điều không chắc chắn của các vấn đề về quản lý nguồn nước, và điều đó cũng ảnh hưởng đến các hợp tác chia sẻ tài nguyên của lưu vực. Đến giai đoạn hiện nay, việc triển khai các thể chế tầm quốc gia trong điều phối quản lý tài nguyên vẫn còn là một thách thức. Ở tầm khu vực, hiện nay cấu trúc quản trị tài nguyên bao gồm sáu tổ chức khác nhau hình thành qua các hợp tác giữa các nước trong và ngoài lưu vực Mekong. Chương này lập luận rằng phương thức quản trị truyền thống mà mỗi quốc gia điều phối đơn lẻ là không còn phù hợp để giải quyết các vấn đề môi trường liên biên giới. Một cách tiếp cận tốt hơn được đề xuất tại chiến lược phát triển lưu vực 2021–2030 của Ủy hội sông Mekong là “quy hoạch khu vực chủ động”. Ở cấp quy hoạch, “quy hoạch khu vực chủ động” có vai trò quan trọng trong quản trị tài nguyên cấp lưu vực, nhìn nhận cả những lợi ích và sự quan tâm khác nhau của các nhóm chủ thể, bao gồm nhóm dễ bị tổn thương nhất. Bốn lĩnh vực của các nghiên cứu ứng dụng được đề xuất để tích hợp môi trường và biến đổi khí hậu trong việc quản trị nguồn nước và tài nguyên quốc gia.

Résumé

Après une histoire récente entachée de conflits, la région du Mékong entre dans une ère de diplomatie moderne aux prises à des intérêts divers et des conflits potentiels dans l'utilisation et la modification des ressources transfrontalières. Le changement climatique ajoute une incertitude supplémentaire à une gestion déjà complexe des ressources en eau, et perturbe tout accord de partage dans ce domaine. A ce jour, la mise en oeuvre de schémas de gouvernance nationale des ressources reste un défi important. L'actuelle structure régionale de gouvernance et de gestion des ressources transfrontalières est composée de six organisations liant les pays du Mékong et différents partenaires en dehors de la région. Ce chapitre soutient que les seules formes classiques de gouvernance étatique ne suffisent pas à traiter des questions environnementales transfrontalières. Une autre approche a été proposée et approuvée à travers la Stratégie de Développement du Bassin 2021–2030 proposée par la Commission du Mékong, appelée "planification régionale proactive". Une planification proactive régionale permettrait une meilleure intégration des mesures et des projets d'investissement entre pays, acteurs et secteurs d'activités. Par ailleurs, la question des échelles de gouvernance des ressources transfrontalières est cruciale afin d'incorporer toutes les parties prenantes, y compris les groupes les plus vulnérables. Quatre axes de recherche appliquée sont suggérés pour permettre l'incorporation des dynamiques environnementales et climatiques dans la délicate gouvernance régionale de l'eau et des ressources naturelles associées.

1. Climate change in the Mekong region, a potential catalyst for socio-ecological imbalances

The Mekong region contains the world's 12th longest river, which flows from the Tibetan Plateau through China, Myanmar, Thailand, Laos, and through the rich Mekong Deltas in Cambodia and Viet Nam. Altogether, it drains a basin area of 810,000 km² and is home to over 65 million people. The basin plays a crucial role in the livelihoods of millions of people from six countries: Cambodia, China, Laos, Myanmar, Thailand, and Viet Nam. After a troubled history, the region has embraced modern diplomacy to tackle the various interests and potential conflicts associated with using and amending transboundary resources such as water and fish [Kittikhoun & Staubli, 2018]. While resource use and exploitation have contributed to socio-economic progress, the changes have also brought environmental disturbances, and various risks to the life and livelihoods of millions of people. Until today, people in the region have experienced various impacts from environmental changes, which include – but are not limited to – hydrological fluctuation, degradation of water and related resources, pollution from fast developing cities, deforestation, and others [Stibig *et al.*, 2014; Simpson, 2007; Hirsch, 2016; and [Chapters 7 and 9](#) of this report for the case of the Vietnamese Mekong Delta].

Climate change adds to these ongoing environmental problems by increasing the region's fragility. Various studies analyse possible changes in the region linked to climate change

scenarios. There are possibilities of higher temperature, increased precipitation, increased melting of glaciers in the Upper Mekong [Eas-
tham *et al.*, 2008], followed by a temporary increase in runoff, thus changing the seasonal discharge (*ibid*, Hoang *et al.*, 2016; [Chapter 5](#) of this report for the analysis of the impact of climate change on the hydro-energy supply). Another projection of climate change influence concerns the decline of groundwater recharge in short-medium-, and long-terms [Shrestha *et al.*, 2016]. The most likely impacts of climate change in the region are linked to temperature change (e.g. more severe drought), unexpected climatic events and hydrological alteration. In fact, a high confidence conclusion from the Intergovernmental Panel on climate change (IPCC) states that global warming is likely to reach 1.5°C between 2030 and 2052 if human activities associated with the industrial regime continue to increase at the current rate [IPCC, 2018]. [Chapter 1](#) and [7](#) of this report confirm these findings in the case of Viet Nam.

One meter of sea level rise was supposed to cause the displacement of 7 million inhabitants and flood the homes of more than 14.2 million people in the Vietnamese Mekong Delta [ADB, 2013] even before the elevation of the Delta was recently re-evaluated [Min-
derhoud, 2020]. This is even more critical in a country like Viet Nam, which is ranked fifth out of 233 countries in terms of direct extreme weather risk (physical climate impact) (see [Part 1](#) of this report for further details on this matter). The changes will either worsen or improve flooding and drought in the region. Negatively, there could be worse flooding events in the rainy season and droughts in the dry season in the basin, with increasing water shortage, and deeper and more uncertain salinization in the downstream Mekong Delta. While changes in hydrological system have

both positive and negative impacts, the risk is getting higher with uncertain weather and extreme events. Further impacts on livelihoods in the basin are under research and projection, e.g. the impact of climate change on agriculture and food security. So far, it is still unclear whether climate change could affect regional agriculture [Eastham *et al.*, 2008], or as Mainuddin *et al.* (2011) conclude, that food security in terms of total production appears unlikely to be affected in the future by the threat from global climate change (see Chapter 4 of this report for another approach to food security and climate change in Viet Nam). Yet, extreme weather events could hamper production and farmers' livelihoods. Recent research at a smaller scale asserts that climate change could depress rice yields in the Vietnamese Mekong River Delta (Kontgis *et al.*, 2019; see also Chapter 4 of this report for the case of rice in the Delta).

Climate change is one of various environmental issues that exacerbate already existing socio-economic impacts. Indeed, social stressors, including marginalization, lack of access and rights to natural resources, and poverty are interlinked with environmental changes. Due to socio-economic differentiation, the risks of climate change for natural and human systems vary between nations and between groups of people. It depends on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options [IPCC, 2018]. While each inhabitant is facing issues [O'Brien 2012, O'Brien and Sygna, 2013], the decisions made in a growing economy have put more people, assets, and resources in the path of encroaching climate change [McElwee, 2017]. In the end, climate change is not an external threat, but a problem both of development and for de-

velopment. Adaptation is thus about adapting with climate change (adopted from Pelling, 2011). The current complex situation points to the fact that business-as-usual is no longer appropriate. And integrating adaptation into 'development-as-usual' paradigms runs the risk of reproducing the system that creates vulnerabilities in the first place [Eriksen *et al.* 2014].

As stated above, climate change, as currently understood by the scientific world and general public, will likely affect socio-economic development, the safety of millions, and ecosystem dynamics, and has thus obtained special attention. Especially, uncertainty is a threat from climate change which adds to current water resource management, and thus perturbs any agreement for resource sharing [Bernstein *et al.*, 2008]. In the Mekong basin, it adds to the complexity of transboundary water diplomacy, which has been based on the use of diplomatic instruments to solve or mitigate existing or emerging disagreements and conflicts over shared water resources, for the sake of cooperation, regional stability, and peace [Schmeier, 2018; Kittikhoun & Staubli, 2018, Klimes *et al.*, 2019; Keskinen *et al.*, 2021]. Munia *et al.* (2020) state that any change in upstream basins, either due to changing climate or changes in water use, directly impact on downstream water availability – a property that makes transboundary water management challenging.

Transboundary governance of resources has never been an easy task. While livelihoods along the Mekong river and its tributaries are connected, through the flow of water and attached resources like sediment and fishes, the development and exploitation of those resources are confined within localities, mostly within national boundary. Often, the transboundary aspect of the national development of

hydropower, national parks, or conservation projects is not paid enough attention. Transboundary coordination is often the result of the involvement of development agencies, donors, national state agencies, and public-to-private entities from various countries. The current situation challenges the efforts for transboundary governance, and negotiation for collaboration. Adding to the ongoing environmental transformations caused by both national and international interventions over the last decades, climate change makes it more urgent to find a solution for sustainable management of transboundary water resources. This chapter provides insights into water diplomacy in

the region. Taking water and related natural resources as the main target of discussion, the chapter revisits the national and regional structures of governance, their potential and barriers in managing and/or enhancing transboundary resource management.

A paradigm shift in sustainable development and complexity analysis in the Mekong countries will be developed as a conclusion; new lines of policy recommendation will be proposed in the areas of knowledge production, anchored in sustainability science, innovative ways of conducting research and intensive capacity building.

2. National and regional governance structures of transboundary resources

Before discussing the regional structures on water governance, it is important to recognize recent developments in the Mekong countries in terms of advances in water and natural resource management (See [Box 8.1](#) below and MRC, 2021). These national institutions, laws and policies recognize the risks, especially to vulnerable people, of rapid development and climate change. Implementation remains a great challenge, but these provide frameworks for engagement and holding authorities accountable.

According to the non-governmental organization (NGO) Oxfam International, the Mekong governments have all recently improved in terms of their commitment to tackle inequalities in both policies and practices, with China, Thailand and Viet Nam ranking well. These countries also invest more than 15% on social spending, which is the recommended level to help address inequalities and other forms of injustices [Lim, 2021].

Beside the difficulties, countries in the Mekong basin are finding and making trials of better governance on water resource management. The basin is connected by the water flow, creating complex dynamics of socio-economic and political settings. The question is how national institutions could — together with the regional ones — enhance the governance of water and other resources across borders, with a view to sustainable development; and whether current progress in institutions has prepared for future uncertainty induced by climate change and its possible impacts.

[Box 8.1]

National advancement in water and natural resource management (compiled by authors)

Cambodia's national water law focuses on the sustainable utilisation and conservation of water resources and determines the rights and obligations of water users. It provides for the establishment of water-user groups to facilitate participation of local communities.

Laos has recently adopted a new water law and is finalizing its new National Water and Water Resources Management Strategy. The new law governs water use throughout the country and includes provision for environmental flows and new standards on pollution control. A national coordinating and monitoring center in relation to hydropower operations is being established. The amended Electricity Law 2017 and updated Policy on Sustainable Hydropower Development 2018 strengthened the planning, assessment and monitoring of major projects.

Myanmar is preparing a new water law based on integrated water resource management principles and is developing Integrated Water Resources Management (IWRM) plans for major river basins.

Thailand introduced a new water resources law in 2018 and established a new Office of National Water Resources under the Office of the Prime Minister to improve coordination across sectors and engagement on Mekong issues. A key feature of the arrangements is the further development of river basin organisations to support planning and implementation of IWRM and climate adaptation at a sub-basin scale.

Viet Nam's Resolution No. 120/NQ-CP on "Sustainable and Climate Resilient Development of the Mekong Delta" introduces a shift in emphasis for agriculture and seeks to further boost aquaculture. A key driver of the resolution is an effort to coordinate ministerial and provincial actions to achieve more sustainable and higher value development in the face of expected climate change impacts including rising sea levels, increased salinity intrusion and the risk of severe flooding.

When it comes to regional structures of governance and management for transboundary resources, including water resources, of the Mekong, there is a myriad and growing list of organizations and frameworks among the countries and different partners from outside the region. The main organizations include:

- ▶ The Association of Southeast Asian Nations (ASEAN);
- ▶ Mekong-Lancang Cooperation (MLC);
- ▶ and the Mekong River Commission (MRC).

Regional programmes such as:

- ▶ Greater Mekong Sub-region (GMS);
- ▶ Ayeyawady-Chao Phraya-Mekong Economic Cooperation Strategy (ACMECS);
- ▶ Mekong-US Partnership (MUSP);
- ▶ Mekong-Japan;
- ▶ and Mekong-Korea also touch on different

aspects of the issue although these do not have standing organizational frameworks [Figure 8.1].

The mandates and functions of these institutions are broad and specific, their actual performances varied, and their memberships and partnerships are inclusive and exclusive, depending on the angles one looks at.

ASEAN is the premier regional body in Asia, representing the ten Southeast Asian countries with a combined population of 650 million people as of 2018 – ranking 3rd in the world – and a US\$3 trillion economy as a bloc as of 2019 – making it the 5th largest economy. ASEAN was founded on 8 August 1967 by Indonesia, Philippines, Thailand, Malaysia, and Singapore, and expanded in the 1980s–1990s

[Figure 8.1]

Mekong related regional organizations, frameworks and programmes

Partnership with Mekong-related Cooperation Frameworks



■ Source: MRC.

to include Brunei Darussalam, Viet Nam, Laos, Myanmar, and Cambodia. ASEAN is governed by the ASEAN Charter, the binding document for ASEAN cooperation, which was signed in 2007. While only 5 members of ASEAN are in the Mekong, mainland Southeast Asia, there is a case to be made that the Mekong is important for all ASEAN countries, including maritime Southeast Asian states. For example, more than 60% of Southeast Asian maritime states' rice imports in 2019 came from mainland Southeast Asia, Thailand, Viet Nam and Cambodia in particular [International Trade Center, cited in Hoang and Seth, 2021]. Thailand and Viet Nam are the top two rice producers in the world, a lot of it from the Mekong. In addition, ASEAN's principles are "centrality", "connectivity", and "narrowing the development gap"; anything that makes the headlines in one part of the ASEAN region matters to all of it.

In terms of natural and water resource management, ASEAN has broad areas of work, including in water resources, environment, energy, disaster, climate change and waterborne transportation.

The key strategies and action plans are:

- ▶ ASEAN Cooperation on Environment, which promotes sustainable management of biodiversity and natural resources, including water resources, through the Strategic Plan of Action on Water Resources Management, and environmentally sustainable cities.
- ▶ ASEAN Plan of Action for Energy Cooperation (APAEC) 2016–2025, which is a regional blueprint for energy sector cooperation.
- ▶ ASEAN Agreement on Disaster Management and Emergency Response (AADMER), which strengthens emergency preparedness to reduce disaster losses.
- ▶ ASEAN Action Plan on Joint Response to climate change, which enhances scientific research collaboration on climate change, hydrological and agricultural management.

While five Mekong riparian countries are members of ASEAN, the sixth riparian (China) cooperates with ASEAN in the natural resource and environment areas through:

- ▶ ASEAN-China Strategic Partnership for Peace and Prosperity, which aims to improve navigation safety on the Lancang-Me-

kong River, water quality and environmental protection.

► ASEAN-China Strategy on Environmental Cooperation, which is to strengthen ASEAN-China cooperation on agreed priority areas of environmental protection by taking a coordinated and step-by-step approach with a view to achieving environmental sustainability in the region.

Along with the cooperation between China and ASEAN Mekong members, China and the Mekong countries themselves established the MLC mechanism in 2016. The MLC addresses 5 key priority areas such as: connectivity, production capacity, cross-border economic cooperation, agriculture and poverty reduction, and water resources, through the implementation of project-based initiatives. In the water and environment areas, MLC is guided by the Five-Year Action Plan on Lancang-Mekong Water Resources Cooperation 2018–2022 and the Lancang-Mekong Environmental Cooperation Strategy 2018–2022, including the Green Lancang-Mekong Plan. The organization is funded by various donors, with most fund comes from the Chinese government.

With respect to transboundary water governance, the MRC, established by the international Mekong Agreement in 1995 between the governments of the four Lower Mekong countries Cambodia, Laos, Thailand and Viet Nam, has a mandate to promote and coordinate the development and management of water and related resources of the Mekong. Building on a long history of cooperation since 1957, the MRC has worked in water-related sectors including irrigation, hydropower, navigation, flood and drought, environment in general, and climate change in the Mekong. Its core functions are river monitoring, forecasting, data and information management, basin planning,

implementation of MRC Procedures for water utilization, and dialogue and facilitation. China and Myanmar have been its Dialogue Partners since 1996.

The key cooperation strategies for the MRC are the Basin Development Strategy 2021–2030 and the MRC Strategic Plan 2021–2025, as well as various basin-wide sector strategies such as:

- Mekong Basin-wide Fisheries Management and Development Strategy;
- The Mekong Climate Adaptation Strategy and Action Plan;
- The Drought Management Strategy;
- The Sustainable Hydropower Development Strategy;
- Master Plan for Waterborne Transport;
- and the Strategy for Basin-wide Environmental Management.

Unlike other Mekong cooperation frameworks, the MRC has a comprehensive set of “Procedures” that govern the development and management of water and related resources in the Mekong, such as data sharing, water flow monitoring and maintenance, water quality monitoring and emergency response, water use monitoring, and notification, prior consultation and agreement before infrastructure projects proceed. The MRC’s basin strategies help the MRC support countries to find win-win outcomes, while its procedures allow the organization to bring countries together to prevent, manage, and resolve water-use disputes and disagreements.

Beside the three regional institutions, there are regional programmes that the Mekong countries and their partners have set up related to natural and water resource management. In 1992, the five Mekong countries and China established the GMS programme, with the

support and facilitation of the Asian Development Bank (ADB). The GMS, through its strategic plan 2012–2022, aims to foster regional cooperation and integration by encouraging a free flow of people and goods, strengthening infrastructure links to support economic expansion and urban corridor development, developing human resources, enhancing private sector participation, protecting the environment and promoting sustainable use of shared natural resources. The GMS cooperation framework covers environmental conservation, disaster management, and transport (navigation), through:

- ▶ GMS Core Environment Programme, which promotes biodiversity conservation and poverty alleviation, climate change adaptation and mitigation, and capacity development.
- ▶ GMS Cooperation in Energy, which aims to establish an integrated regional power market that will develop in a sustainable manner. ADB has incorporated lessons from hydropower projects in the Mekong tributaries financed by ADB and others, to promote best practices.
- ▶ GMS Cross-Border Transport Facilitation Agreement, which provides a framework for transport and trade facilitation efforts to facilitate efficient cross-border movement of goods, vehicles, and people in the sub-region.

The GMS investment programme is largely concentrated on connectivity and economic corridor development, especially roads, ports and rail (over 80%). The GMS is not directly involved in transboundary Mekong water resource management, acknowledging the lead role of the MRC in this area.

In 2003, the ACMECS was established, comprising of Cambodia, Laos, Myanmar, Thailand and Viet Nam. Initiated and driven by Thailand, it aims to strengthen economic collaboration and narrow the development gap

in the sub-region. In the ACMECS master plan 2019–2023, two of the three goals are:

- ▶ Seamless ACMECS, which focuses on filling in missing infrastructure and transportation links;
- ▶ and Smart and Sustainable ACMECS, which emphasises human development and application of modern technology.

Under Environmental Cooperation, ACMECS aims to enhance cooperation for environmental protection, climate change adaption, disaster mitigation, renewable energy development, and sustainable use of the natural resources of the Ayeyawady, Chao Phraya and Mekong rivers. Under Sustainable Agriculture, the programme aims to promote agricultural productivity, sustainable management of land and water, fisheries and wildlife resources.

Three external countries to the Mekong, the US, Japan and Korea, have also developed Mekong related cooperation programmes. In 2009, the United States initiated the Lower Mekong Initiative (LMI) with the five “lower” Mekong countries of Cambodia, Laos, Myanmar, Thailand and Viet Nam, prioritizing six pillars such as agriculture and food security; connectivity of infrastructure; environment and water; energy security; education, and public health. In the natural and water resources areas, the LMI had programs such as:

- ▶ LMI’s Master Plan of Action, which aims to enhance cooperation to promote inclusive, equitable, and sustainable economic growth while also protecting natural resources and ecosystems;
- ▶ Mekong Water Data Initiative which aims to develop science-based decisions on the shared river system;
- ▶ SERVIR Mekong Project, which supports the Mekong governments, stakeholders and MRC to prepare for and respond to disasters,

manage natural resources and improve food security through satellite [imagery and geospatial technologies](#).

After 10 years, the LMI morphed into the MUSP in 2019. Among other things, the MUSP covers initiatives in sustainable water use, natural resource management, and environmental protection, as well as human resource development.

In 2007, Japan reached out to the Mekong countries through the Mekong Japan Regional Partnership Program. The current guiding strategy for Mekong-Japan cooperation is the Tokyo Strategy 2018, with three pillars, namely:

- ▶ Vibrant and Effective Connectivity, which aims to improve the value-chain network in the Mekong region and beyond, particularly through the promotion of quality infrastructure;
- ▶ People-Centered Society Approach, which tries to make economic development in the Mekong region more balanced and sustainable through people-to-people exchanges of knowledge and experiences, and using technology to improve social outcomes;
- ▶ Realization of a Green Mekong, which focuses on measures against climate change and marine debris pollution, water resource management and disaster risk reduction.

In 2011, the Republic of Korea (ROK) and Cambodia, Laos, Myanmar, Thailand and Viet Nam adopted the Mekong-Korea Comprehensive Partnership for Mutual Prosperity, with an emphasis on six priority areas outlined in the Han River Declaration. The Mekong-ROK action plan for 2017–2020 lays out a vision for the sustainable development of the Mekong River Basin that complements existing works:

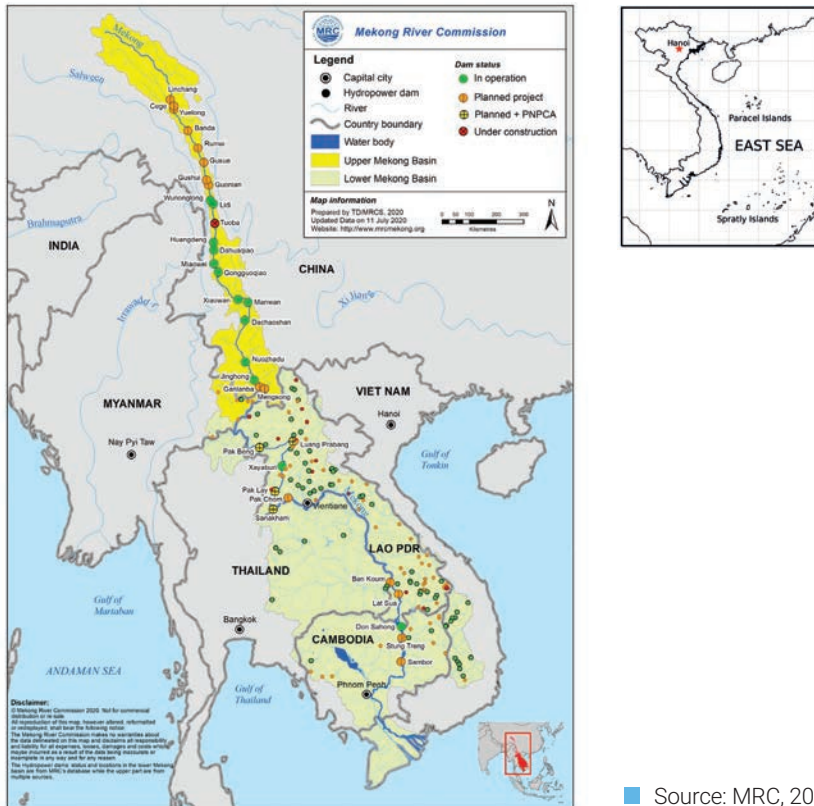
- ▶ ASEAN Connectivity that seeks to enhance connectivity through improved roads, railroads, airports, ports, and logistics;

- ▶ Sustainable Development that aims to preserve the ecosystem, promote green growth and strengthen the capacity of the Mekong countries in water resource management and climate change adaptation;

- ▶ Human-Centered Development that helps improve the quality of life for the people of the Mekong countries, with an emphasis on agriculture, rural and human development.

Each of these regional programs has different approaches to including voices from the communities and those in vulnerable situations. The GMS projects funded by ADB follow the standards and safeguards that the ADB prescribes. There are concerns, though, about selected national investment projects, including roads and rails, that are part of the GMS strategy (and economic corridors), but are funded directly by national governments and the private sector, that encroach on preserved national parks, biodiversity areas, or other places of value to the communities without adequate compensation. The Mekong-Japan and Mekong-Korea activities are mostly focused at the governmental and national level, although their strategies have to take a “people-centred” approach into account. The MUSP funds non-governmental actors and groups to build their capacities to engage better on Mekong issues, including through convening Civil Society Organisation (CSO) forums, academic exchanges, and tools to track and monitor developments in the region, especially dams — sometimes without explicit governmental approval. While this increases transparency and the capacity of the “public” to be aware of dam operation, it raises political tensions, affects cooperation, and continues to prevent official engagement from all the governments of the Mekong.

[Figure 8.2]
Hydropower dam project on the Mekong



■ Source: MRC, 2020.

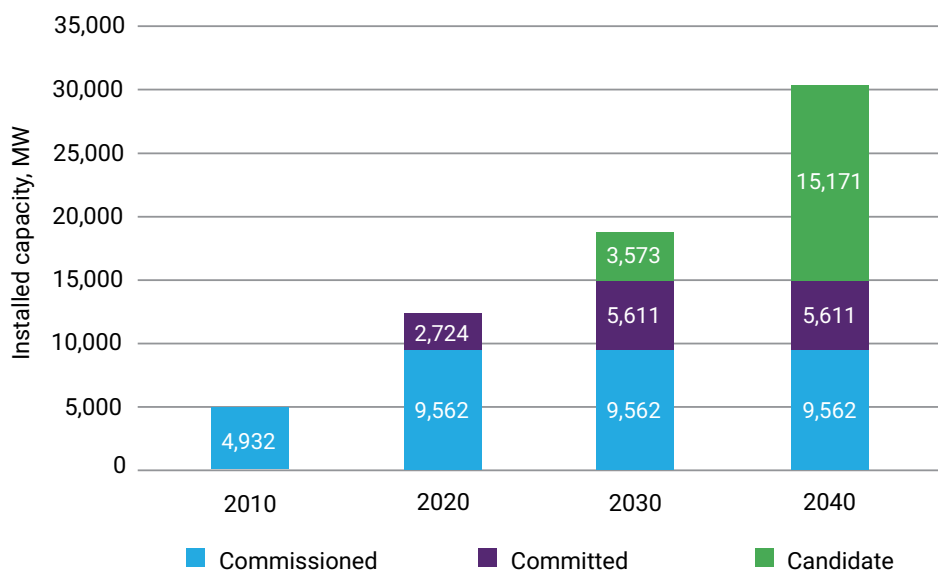
3. Business as usual or transformation: Water diplomacy in the Mekong region

"Water is life" (used by Le *et al.*, 2007 for the Mekong region) is one notion to show the importance of the resource to the people of the Mekong. In terms of human rights, everyone has a right to water access; it is also the foundation to link transboundary resources to the concept of commons. While there is still debate on how to integrate the idea of com-

mons into transboundary resources, from the governance viewpoint, transboundary environmental commons need networks of actors whose collective actions and values contribute to the everyday task of sustaining common pool resources, without which transboundary commons could not exist [Miller *et al.*, 2020]. It calls for the need for a holistic and collaborative water diplomatic approach for a sustainable Mekong region. This argument is not controversial. What is contested is the form it should take. Whatever it may be, there is a need to first strengthen governance and management at the national level, complemented by institutions, strategies, procedures

[Figure 8.3]

Current and projection of installed capacity of hydropower in the Lower Mekong region



Source: MRC.

and processes at the regional level. There is no substitute for strong institutions, policies and laws in each country, as this is where planning, implementation and monitoring primarily take place. Regional measures can certainly add value. How can water diplomacy at the regional level do this? Taking hydropower dam development as a case study, the complex connection between up- and down-stream and the position of various actors are analysed.

3.1 Dam development in the Mekong and its challenges

According to the MRC (2021), energy demand across Southeast Asia grew 60% over the past 15 years, and hydropower in the Mekong River Basin is expanding rapidly to help meet some of it, including for expanding transport and connectivity. Electricity generation from

Lower Mekong River Basin hydropower increased from 9.3 GWh to 32.4 GWh between 2005 and 2015. The gross value of the energy produced in 2015 was estimated at more than USD 2 billion, up from around half a billion a decade earlier.

As of 2019, the number of hydropower projects in the lower basin is 89, with 12,285 MW total installed capacity [Figure 8.2]. Of these, two are in Cambodia (401 MW installed capacity), 65 in Laos (8,033 installed capacity), 7 in Thailand (1,245 installed capacity) and 14 in Viet Nam (2,607 installed capacity). 14 dams with a total capacity of 3,000 MW are expected to come on line during 2016–2020, while 30 others are in the planning stage, with the majority finalizing Feasibility Studies. By 2040, hydropower is estimated to generate more than 30,000 MW [Figure 8.3].

After a period of regional and international conflicts, the countries of the lower Mekong region have entered a period of infrastructure expansion, urbanization and industrialization. In fact, as early as the 1960s-1970s, there was a development consensus among the riparian Mekong countries, as well as Western partners – especially the United States and international organizations like the UN – to develop the Mekong for economic growth (energy, irrigation, navigation) and flood control [Kittikhoun and Kittikhoun, 2021]. Only regional instabilities and conflicts in mainland Southeast Asia put a stop to those grand plans, including the building of large dams. Meanwhile, many countries around the world had already reaped great benefits – and great costs – from dam development. The United States by this time had built about 8,000 large dams. Australia built almost 500 large dams, while Japan had built nearly 450 of them. Norway became known as a hydropower powerhouse in Europe, with about 1,110 hydropower plants totalling 29,000 Megawatt of installed capacity.

In the lower Mekong, hydropower development began years ago in tributary basins of Thailand and Viet Nam, upstream of Cambodia. Over the last decade, after peace had returned to the region, hydropower development has expanded in the Lower Mekong River Basin (LMB), including in the main river, accompanied by increased private sector investment in power infrastructure. The growing demand for energy and realization of the resource value are some of the key drivers for hydropower development [Grumbine *et al.*, 2012]. Rapid economic integration via cross border power trade has also pushed investment toward more hydropower development. During the 1990s, this orientation was also supported by international development

orthodoxy regarding renewable energy compared to coal power, as shown by the support of international banks for large dams in the Mekong. Since 2006, contested plans have emerged for up to eleven dams on the lower mainstream, with the first project – the Xayaburi Dam – construction completed and now in operation [Middleton, 2014].

Damming the river is a solution for a developing country aiming at eliminating energy deficiency and poverty. When it comes to transboundary issues of environmental and social impacts, it gets more complicated. Hydropower, just like any other hydraulic infrastructure development, is an area in which technocratic approaches have dominated, with state-led efforts to control hydrology and expand irrigation schemes, expedited alongside agribusiness promotion and agricultural intensification policies. Such a regime is named by Blake (2019) as irrigationalism. The pro-large dam drivers, as asserted by Pearse-Smith (2014), are described as three biases of post-development: 1] it views rivers, and nature more generally, as an unrealized sources of economic growth and as an input to production; 2] it is less concerned with distributional impacts and could be inequitable as a result; and 3] it disempowers its supposed beneficiaries by de-politicizing the development decisions to pursue large dam projects. The second and last biases are the main causes of negative impacts posed by dam building. In some cases, these biases are mitigated, while in others, they remain challenges.

Hydropower projects in Laos are driven by investors and energy demand from importing countries like Thailand, Viet Nam, and Cambodia [Shannon, 2008; Middleton & Dore, 2015], and the country's own energy and economic development needs. Some point to a correla-

tion between the air-conditioning used in the shopping malls in Bangkok and fluctuating water releases from the Nam Thuen 2 dam, and downstream changes in Xe Bang Fai hydrology [Baird & Quastel, 2015; Marks & Zhang, 2019]. In the importing country, Thailand, the driver for the Electricity Generating Authority of Thailand (EGAT) to shift their investment to other countries like Laos and Myanmar is also a response to the social resistance against hydropower development in the country, as in the case of Park Mun dam [Foran & Manorum, 2009]. This incentive meets with the demand for investment from countries like Laos and Myanmar, paving the way for even more projects on the Mekong River. Indeed, the interests for energy supply when meeting the target to increase national revenue from nature-based measures like hydropower have resulted in a transnational coalition that is pro-hydropower development. In this structure, communities are often at lower level of power leverage compared to other actors such as government, banks, investors and probably also large consumers.

Hydropower development in the LMB brings both positive and adverse consequences. According to the MRC, the LMB could see economic gains from full hydropower development of more than \$160 billion by 2040 [MRC, 2018]. Development of hydropower brings positive synergies with other water related sectors as well, including expanding irrigation that is key to food security, provides access to electricity that is key to poverty reduction, contributes to navigation that enhances regional trade, and provides flood management and drought relief that is an important part of adapting to climate change. However, dam building, without adequate mitigation measures, also has negative impacts such as barriers to fish migration, trapping of sediments,

changing the flow regime of the river, and the associated consequences for livelihoods. Some suggest that the environmental and social costs on-site and downstream could probably outweigh the benefits of energy generation, improved navigability, and associated economic development [Kuenzer *et al.*, 2013]. By the nature of flow, the impacts of damming the Mekong and its tributaries go beyond one country boundary. However, upstream damming alone cannot be blamed for all the current environment changes downstream. There are other factors such as climate change, and other exogenous developments such as industrialization, urbanization, over-exploitation of fisheries, and extractive industries like sand-mining. Such uncertainty in evidence of correlation makes transboundary negotiation harder to reach.

Dam-building has been subjected to debate, inter-ministerial negotiation and contestation. Meetings were organized for negotiation between countries, and requirements were made for social and environmental impact assessments of the projects. Also, anti-dam and other civil society activities are part of the dynamic, yet confined to places where there is strong CSO activity. Downstream communities in Cambodia are unable to access the justice system in Viet Nam directly, to make claims to Viet Nam Electricity (EVN) for more support over the projects on Sesan river [Wyatt & Baird, 2007]. Middleton (2012) argues that foreign countries like Thailand export the environmental injustice associated with energy production across borders to Laos and Myanmar, where the rule of law and judicial systems are less developed. Or it is seen as a form of water grabbing [Matthews, 2012]. There is an unbalance in power levels, and thus to access to negotiation. Some rights have been subsumes to financial interests in maximizing power

production. This is accentuated when the ownership and finance of hydropower projects are increasingly private. Research has warned that while the private sector benefits from relatively short-term returns, the public sector is left responsible for long-term impacts. [Merme *et al.*, 2014].

The current issues of hydropower development, or management of the transboundary resources of the Mekong in general, are all about diverse interests. While governments and those that support hydropower often consider dams to be necessary for economic growth, energy security, poverty reduction and in the national interest, many in academic communities, NGOs and affected communities view dams as threat for population livelihoods and for the environment as a whole. Since a transboundary binding institution is not in place, communities within the dam-locating country are often not seriously consulted or recognized during the planning and implementation phases of the projects [Siciliano & Urban, 2017]. Part of the issue also points to the dominance of engineers in dam design and construction [Barrington *et al.*, 2012], and the clear lack of continuous presence of experts from other fields, such as system planning and social scientists. Despite the criticism of irrigationalism in Thailand [Blake, 2012] or water hydrocracy in the case of the Vietnamese Mekong Delta [Benedikter, 2014], the trend continues in different countries. At the regional level, the MRC's procedures and guidelines have been used in consultations over proposed mainstream dam projects. The Xayaburi and Don Sahong projects, to the credit of the Lao government and developers, have seen concrete improvements in mitigation measures following MRC's recommendations. Challenges remain in terms of dam operation, which needs to be

better coordinated to minimize impacts, with information and notification speedily shared with the public.

Climate change impacts on energy sector, both from demand increase and uncertainty in weather and water availability, are expected to be felt across borders. As explained in chapter 5 of this report, research at the global scale has suggested that climate change has little or even a positive impact on hydropower generation, and similar tendency has been confirmed for Viet Nam at a national scale. However, local impacts are shown to vary across the country [Manh-Hung *et al.*, 2021], and uncertainty in power supply may increase given the complexity of dam operation and management. When water is scarcer in the dry season, or during heavy floods in the rainy season, operating and managing hydropower dams become more complicated. Consequently, more threats are passed on to communities downstream of the dam site, and further downstream countries like Cambodia and Viet Nam. Along with increasing demand arising from higher standards of living, water management has become more critical and difficult. The possibility of temperature increases due to climate change will lead to an increase in energy demand in all countries.

► Middleton & Dore (2015) report that demand in Thailand is projected to double, from 32,600 MW in 2012 to 70,686 MW in 2030;

► Demand in Viet Nam may triple, from 21,542 MW in 2010 to 75,000 MW in 2020.

► When Viet Nam and Thailand need more electricity for electric cooling and heating appliances in firms and households, more incentive is provided for hydropower in Laos and Cambodia.

It then becomes a trade-off between human and economic needs and environmental protection.

There are potential and growing interests to maintain and further develop hydropower to promote energy security and cross-border trade, and contribute to flood and drought management and a low-carbon economy. Opportunities for operational improvement also exist for existing hydropower facilities to moderate downstream risks due to flood peaks, water level fluctuations and sediment trapping. Further utilising this opportunity requires a focus on sustainability and addressing risks and uncertainties both at project and transboundary levels. Potential transboundary impacts will need to be identified and mitigated collaboratively through national regulatory frameworks and guidelines, as well as applicable regional procedures and guidelines such as those of the MRC. To enhance sustainable development, any new power generation plans should consider the full range of viable generation sources, including complementary use of wind and solar, and ensure that supply does not run too far ahead of demand. Hydropower is a dominant aspect of transboundary water management in the Mekong. The current institutional setting could contribute greatly to sustainable management, especially under the current impacts of climate change.

Thus, part of the issue is the dominance of uncertainty. Uncertainty is not only the result of incomplete data and its analysis, but can also reflect diverse normative stances, as part of transboundary hydropolitics [Middleton, 2014]. The author assesses the situation of Xayaburi Dam as a high degree of uncertainty; outcomes are contested; stakes are high; and values between actors are not shared (*ibid*).

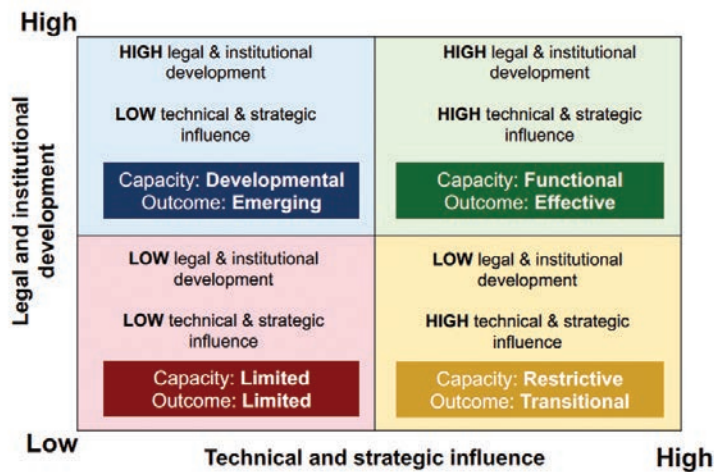
Such an analysis could also be applied to many other projects in the basin.

3.2 The challenges and potential for transboundary management: a water-diplomatic analysis

Focusing on water, regional, basin-wide or transboundary resource development and management invites both cooperative and conflictual dynamics. When there are disputes and conflicts, water diplomacy is a diplomatic mean to address them without resorting to coercive or overt punitive measures. It is about understanding and addressing complex water issues, challenges, and risks through negotiated solutions involving multiple stakeholders with differing positions and interests. Water diplomacy can be conceptualized using four interlinked aspects and dimensions — legal, institutional, strategic and technical [Kittikhoun and Schmeier, 2020]. The legal aspect points to laws, rules and procedures that are critical in spelling out obligations — the dos and don'ts — with respect to shared resource use. The institutional aspect covers the institutions and organizations that are set up, and what mandates they have, who they cover, who they exclude and what legitimacy they muster. The strategic dimension includes strategies and plans that offer common directions and aims, beyond parochial national interests. Finally, the technical part underlines all the rest with objective data, information and scientific advice in which to negotiate credible solutions.

While Kittikhoun and Schmeier apply this framework to assessing the role and effectiveness of the International of River Basin Organizations (RBO) all over the world in dealing with disputes, these aspects can also serve

[Figure 8.4]
Effectiveness of RBOs engagement in water diplomacy depends on legal/institutional development and technical/strategic influence



■ Slightly adapted from: Kittikhoun and Schmeier, 2020.

as a framework to propose how the regional architectures of water governance and management might collaborate for better water diplomacy outcomes [Figure 8.4].

In legal terms, the Mekong River basin is governed by the 1995 Mekong Agreement establishing the MRC with clear rules and procedures in terms of water utilization. However, a legal gap means this treaty covers only the Lower Mekong River basin, without the Upper Mekong or Lancang, in China and Myanmar. Another treaty-based organization – ASEAN – covers both Mekong and non-Mekong countries, but not the Upper Mekong riparian China. Thus, both the MRC and ASEAN frameworks do not have legal instruments to oversee both upper and lower Mekong River basins. The MLC, which covers all six riparian countries, does not have a legal mandate to manage Mekong transboundary water resources. A near future may see the emergence of an RBO covering the entire Lancang-Me-

kong River basin, and it will then be essential to use and build on the MRC Procedures on water utilization. While that may be some time away, the best hope for the whole of river management at present is for the MRC and MLC Water pillar to actively cooperate, with the support of ASEAN, in the institutional, strategic and technical levels as described below.

Institutionally, most Mekong-related institutions and mechanisms have Summit and ministerial level meetings, either stand-alone or alongside ASEAN or other summits. In some years, such as 2018, the government leaders of the Mekong countries met three times in three different cities within three months on Mekong issues – the 2nd MLC Leaders Meeting in January 2018, the 6th GMS Summit in March 2018, and the 3rd MRC Summit in April 2018. In addition, separately, the Mekong leaders met with leaders of Japan (10th Mekong-Japan Summit in October) and Korea (1st Mekong-Korea Summit in November).

In 2019, the ministers in charge of the water and environment of the Mekong met together for their annual MRC Council meeting in November. They or their deputies met again the following month under the 1st Ministerial Meeting of the MLC Water Resources Cooperation. Such existing institutions and a willingness to interact present both the complexity and an opportunity for joint transboundary resource governance.

At the policy coordination and technical guidance levels, there are three bodies that deal with water issues in the Mekong – the Joint Committee (JC) of the MRC, the Joint Working Group on Water Resources Cooperation of the MLC (JWG), and to some extent, the Working Group on Water Resources Management of ASEAN (AWGWRM). The JC deals with transboundary lower Mekong cooperation among four countries in the Mekong River basin, the JWG deals with broader water cooperation among six countries in the Lancang-Mekong region – including outside the Mekong River basin –, and the AWGWRM on exchanges of water experiences and expertise – on Mekong and non-Mekong affairs. Some countries have the same members for at least two of the three groups while most others do not.

► In Laos, the Laos National Mekong Committee Secretariat (LNMCS) is a member for both the MRC JC and the MLC JWG, while the Department of Water Resources is a member of AWGWRM. At least LNMCS and DWR are under the same ministry.

► For Thailand, the Thai National Mekong Committee Secretariat (TNMCS) is a focal point for both MRC and MLC while the Department of Water Resources is the focal point for ASEAN Water. Yet, TNMCS and DWR belong to different mother institutions.

For those that act as the same focal points, this increased efforts and costs to attend many meetings on the same topics, but reduced potential duplications. For those that have different focal points, this allowed focus, but increased coordination efforts among related line agencies. If it is not done well, this can lead to lack of communication and duplications of work.

While all three have mechanisms in place to facilitate high-level politics and technical discussions (expert groups, technical working groups, etc.), and have standing secretariats to provide technical and administrative support, each of them has different ways and means to engage broader stakeholders and non-governmental actors. ASEAN has the ASEAN Civil Society Conference/ASEAN Peoples' Forum (ACSC/APF), which is held annually in parallel to the ASEAN Summit, and is meant to bring civil society voices to governments on issues of justice, peace, equality and of course sustainability. The MLC water pillar holds an annual water resource cooperation forum as a platform to engage expertise and experiences from foreign academics and experts from multilateral institutions. No CSOs or NGOs have been invited yet.

The MRC has a standing Regional Stakeholder Forum (RSF) that is held one or twice a year to engage all interested parties outside government, include those NGOs that are critical of major infrastructure projects in Mekong issues. The MRC also hosts a major International Conference prior to its Summit to bring in both international and regional voices and expertise to the leaders. Finally, the MRC Secretariat in addition regularly holds dialogue meetings with CSOs and NGOs as well as the private sector, to clarify the MRC's role and

work, and to seek inputs and views. An independent observer writes:

“The MRC provided a forum for discussion and conflict resolution that was observable in real time by civil society organisations, media, donors, academics and other interested parties. Without the MRC and its PNCPA process – the Procedures for Notification, Prior Consultation, and Agreement –, there would have been a lack of procedures and guidelines to facilitate regional discussion of the impact of large-scale infrastructure. There would also have been a lack of transparency of planning, publicly accessible project documents, and various forms of research made available via the MRC website. The MRC, therefore, provided an important channel of communication, discussion, research, and information dissemination.”

International Rivers, 2019

From the above presentation of these institutional frameworks, their summits and meetings, it is hard to identify which one(s) matter most for critical Mekong issues. While it is good that the leaders convene often on Mekong issues, and that each framework has its own emphases and peculiarities, there should be an opportunity to streamline, integrate or hold back-to-back meetings in order to adopt a common strategic approach at the highest levels. And at the level of policy and technical coordination, there is an opportunity for some meetings of the MRC JC and MLC JWG to be integrated/jointly held, at least when considering similar issues under the consideration of both the MRC and MLC. And there could be a standing item in the AWGWRM to hear a report jointly prepared by the MRC Secretariat and the LMC Water Centre on joint businesses. This is in line with the cooperation framework between ASEAN and MRC,

and China cooperates actively with ASEAN in various ways. In the coming year of Mekong summits, it is preferable that the MRC Summit be held early and first, drawing in stakeholder voices through its mechanisms such as RSF and International Conferences, and then feeds into the summits of MLC, GMS, ACMECS and ASEAN. There is also an opportunity to integrate Mekong summits with partners (Japan, Korea, US, India, etc.), alongside ASEAN summits. To help make these happen, a strong coordination mechanism at national levels is needed, especially when there are different ministries, and departments within ministries, that are in charge of cooperation with different regional frameworks. While it has been difficult in the past to set up a well-functioning inter-ministerial decision-making platform at the national level due to the difference in how sector ministries perceive the need for integration [Suhardiman *et al.*, 2012], that does not mean the issue should not be discussed in the current context and better arrangements cannot be found.

At the strategic level, the water-related regional/basin strategies of ASEAN, GMS, MRC, ACMECS, and MLC try to facilitate win-win cooperation for all countries, balancing different needs and interests. Thus, economic development needs are recognized, as well as the needs to protect the environment and society. There is no strategy from any inter-governmental frameworks which says no to infrastructure development or dam building. This may be disappointing to some NGOs or Western donors, who say, for example, “Mekong institutions should work together to further deprioritize large-scale unsustainable hydropower projects, and instead promote leadership in green economies by exploring joint investment in large-scale alternative energy solutions such as solar and wind power”

[Lim, 2021; Weatherby and Elyler, 2017]. It is correct to say that some planned water infrastructure projects are not optimal and unsustainable, and should be replaced by better ones. But it is naïve to assert that the Mekong, in the face of current developments and climate change, can cope with water security issues, including severe floods and droughts in the future by just simply adopting green economies and solar and wind projects.

3.3 Institutional considerations for a better approach

Miller *et al.* (2020) confirm that traditional forms of state-led governance alone are inadequate in dealing with transboundary environmental issues. The authors define the hybrid-governance existing across domains of private, public, and communal property, and upward to connect grassroots communities with international NGOs, donor and lending agencies, big businesses, and multinational governmental institutions. In that way, those hybrid institutions and networked power relations have the potential to transcend administrative boundaries, and bridge policy gaps between geographically dispersed collectives of resource users. In order to achieve success, the key actors in multi-sector and multi-scalar partnerships need to commit to cooperating in joint actions that privilege a particular common environmental good over individual private interests, often in the face of significant power asymmetries between the actors involved (*ibid*).

A better approach has been proposed and agreed in the Basin Development Strategy 2021–2030, called “proactive regional planning” [MRC, 2021]. It recognizes that the countries and peoples of the Mekong could no

longer afford “reactive planning”, that is, to only deal with mitigating the adverse impacts of national projects, which have been assessed by MRC and others as sub-optimal, and for some projects, not sustainable from a basin-wide point of view [MRC, 2018]. Instead, proactive regional planning will examine and propose new national projects of basin significance, and joint investment projects and measures that the countries would consider for optimizing flood and drought management, energy production, navigation enhancement and environmental protection. The projects would be multi-purpose, and supplement the national projects planned by the countries.

They include projects:

- ▶ For watershed management: flow maintenance, enhancing the lifetime of storage reservoirs and contributing to reducing greenhouse gases;
- ▶ For the preservation of wetlands including riverine habitats: enhancing ecosystem services, biodiversity, capture fisheries, and tourism;
- ▶ For the creation of inter-seasonal storage for hydropower generation: which, under common operating rules increases dry season flows that can be shared;
- ▶ For the development of multi-purpose hydropower projects — for flood, drought, agriculture, navigation — for adaptation to increased floods and droughts in a transboundary context;
- ▶ For the development of trans-national parks: environmental protection and tourism;
- ▶ For navigation: for enhancing commercial navigation and safety, as well as projects based on new technology — such as floating solar on hydropower reservoirs —, and the relocation of unattractive projects — e.g. a hydropower project from a valuable untouched stream to storage-backed hydropower cascades.

These ideas are well in line with and support the implementation of the Mekong Adaptation Strategy and Action Plan (MASAP). Following extensive climate change assessments and consultations under the MRC's former climate change Adaptation Initiative, the MASAP was approved by the four Lower Mekong countries governments to focus on 7 strategic priorities: mainstreaming climate change into regional and national policies, programmes and plans; enhancing regional and international cooperation on adaptation; implementing transboundary and gender sensitive adaptation; supporting access to adaptation finance; enhancing monitoring, data collection and sharing; increasing capacity to develop adaptation strategies and plans; and improving outreach.

Proactive regional planning requires strong technical work, the last leg of the water diplomacy aspect: data collection and sharing, strategic studies and scenario assessments, and upgrading the current suite of decision support models and tools. Here, real collaborations among multiple partners are possible. Armed with strong data and a knowledge base of past studies about the Mekong, the MRC is in a good position to begin the work. Additional data can be from member countries, as well as from China and the LMC Water Centre on the upper part of the Mekong, including through the Lancang Mekong Information Sharing Platform. Satellite information can be obtained by cooperating with partners such as the US, Japan, Korea and others. The assessment work will be technically guided by the MRC Expert Groups on Basin Planning, as well as Data, Modelling and Forecasting, which could be expanded to include experts from China and Myanmar. This leads to the need to increase the capacity and raise awareness of various actors, in order to facilitate technical analysis, data and idea sharing. Knowledge

production and capacity building thus lies at the centre of our recommendation later in this chapter. Representatives of ASEAN, GMS, and other regional frameworks could be regularly engaged through the MRC Expert Group on Strategy and Partnership. Broader stakeholders, including CSOs and private sector, need to be engaged through specific meetings as well as Regional Stakeholder Forums. Summit and ministerial meetings of ASEAN, GMS, MLC, ACMECS and others could provide political directions and endorsement to the emerging win-win projects for the Mekong.

Countries need to work together to address the region-wide risks that development and climate change bring, and to accrue the gains and benefits that cooperate entails.

- ▶ Preventing and managing tensions and conflicts from transboundary resource use.
- ▶ Sharing data and information to minimize duplications and reduce costs, as well as to build trust and relationships between actors.
- ▶ Bringing in the private sector to engage in the planning process increases the likelihood of implementation of national and regional guidelines for major projects.
- ▶ Involving CSOs and NGOs enhances the understanding of the wider public, reduces misperception and opposition, and ultimately creates opportunities to provide more benefits in a more inclusive manner.
- ▶ Aligning the high-level gatherings keeps common strategic challenges at the top of the agenda and minimizes strategic conflict.

In addition, scholars recommend including the question of scale in adopting a holistic approach for transboundary governance. It is about rescaling the transboundary commons that could combine polycentric forms

of multi-scalar governance with cross-border impact assessments [Hirsch, 2020]. In that way, localized commons and transboundary development projects could be integrated into supranational framings of the commons. Mekong water is a commons pooled resource for all Mekong inhabitants. As an alternative, large hydropower dam projects are located within geopolitical debates about the sustainability of alternative energy sources such as wind and solar power [Tran & Suhardiman, 2020]. The sustainability of multi-sited transboundary commons around other river resources, such as wild catch fisheries, should be considered to find better solutions than just large-scale power-generated water infrastructure. Then, at planning level, “proactive regional planning” plays the role of integration, with joint investment projects and measures between countries, actors, and sectors.

Challenges persist in the domination of current pro-growth agendas, that often undermine the democratic ideal of collaborative

participation in hybrid environmental governance [Baker and Milne, 2015; South, 2018, cited by Miller *et al.*, 2020]. The outstanding question concerns the motivations of various actors in making the sector healthier. The fact that the revenue benefits to Laos appear to be positive — and wildly more so than any other development strategy the government could pursue — needs to be considered seriously [Cronin & Hamlin, 2012]. An understanding of the interests and motivations of all actors is needed. As Hirsch (2020) states, governance needs to be based on an understanding of flows of capital and distribution of interests between different social and environmental actors, just as much as on flows of fugitive resources or geopolitical power plays. Specifically, either transboundary regulations or local governmental rules to hold Thai, Vietnamese and Chinese firms accountable for their investments in hydropower, plantations and other entities in neighbouring countries, will improve and reduce the impacts of agrarian and water projects on local communities.

4. For a paradigm shift on the sustainable management of transboundary resources in the Mekong countries

Climate change adds uncertainty to the ongoing environmental and resource-use issues of the Mekong basin. In this context, transboundary governance of natural resources

faces challenges from high degrees of uncertainty, contested outcomes, and multiple actors with various interests. Current issues derive mainly from the perspective of national sovereignty and owned business. At the same time, current “undeniable” issues of environmental damage and climate change are a driver for progress. Miller *et al.* (2020) assert that history has shown that times of crisis, rupture, and displacement create opportunities to enact flexible governance.

Along with institutional trials and practices based on the principles of proactive regional planning, and holistic cross-border assess-

ment and decision-making, transboundary governance is part of the urgent need to move towards a “fair environmental transition”. All in all, the environmental changes linked with the acceleration of climate change, coupled with the management of water and related natural resources, raise the crucial question of interactions with inequalities, the social contract and economic growth at the scale of the Mekong countries. It is urgent to develop actions that tackle issues surrounding environmental transition and inequalities in Mekong countries; in order to respond to this challenge, hereafter four areas of recommendations are proposed in the field of knowledge and capacity-building.

The first is by undertaking an ambitious and extensive production of scientific knowledge on the different dimensions of the inequality-environmental transition nexus. This effort will result in a critical mass of knowledge to contribute to a deeper understanding of the societal changes necessary for the success of the environmental transition in the Mekong countries [Huynh *et al.*, 2021]. This research falls under the umbrella of Sustainability Science. This science of interactions, defined more by the questions it addresses than by any one scientific discipline, focuses on understanding the relationships of ecological and social phenomena studied at all scales, using a methodology based on a systemic approach to the humanity-environment-society triad. Interdisciplinary by nature, Sustainability Science encourages scientists to work with communities and to develop solutions for and with all stakeholders. In fact, in today's highly complex and difficult Human-environment systems — which associate diverse stakeholders with different interests, uncertainty and embedded injustice — the growing field of sustainability science has adopted a variety of useful approaches (such as co-production of knowledge, and hands-

on testing of interventions with local stakeholders), capable of assisting much-needed transformations [Messerli *et al.*, 2019].

The second and third recommendations are the core elements of an innovative way of doing research. First, it involves systematically linking researchers and their institutions with other stakeholders — policymakers, media, civil society, the private sector — who are directly concerned by and have stakes in the foreseen outputs. This link is expected to enhance the impact of scientific findings through their direct integration, simultaneously with their publication, into concrete actions, collective practices and public policies, which can be promoted through the undertaking of PhDs integrated into an ambitious framework of activities.

Second, based on the connections and network consolidated during implementation of the research, it is a matter of going further and making use of the knowledge produced. This is an important question about the format and visualization that scientific knowledge takes, carried out so that the results of research are understood beyond academic circles alone. The organization of regular and specific events for dialogue and exchange between scientists and other stakeholders will also enhance the impact of the findings. It is by supporting researchers and their institutions in their efforts for dissemination, and using modern means of communication, that scientific progress will be considered by decision-makers at its true value, i.e. indisputable knowledge, resulting from rigorous work, demonstrated and validated by the scientific community.

The fourth, and last axe of recommendation, is an intense capacity-building effort targeting higher education and research institutions

in Mekong countries, to ensure leverage effects and start a virtuous cycle leading to the science-based monitoring of environmental transition. The fundamental principle guiding the programme at this level is the belief that good research — that is, research that solves, or helps to solve, problems — requires skills that go far beyond scientific skills. Project writing, communication, management of financial and human resources, legal and ethical issues, communication and outreach are all essential elements for embodied research. And yet, these skills, which are peripheral to the purely scientific activity of research, are often ignored in higher education and research institutions in Southeast Asia.

Communication and knowledge management are central. Non-academic stakeholders' opinions and the extended peer community must play a role in monitoring the quality of the research process and results. The knowledge produced should be systematically shaped to be understood and disseminated beyond the academic sector, fuelling societal debates and directing the processes of change towards environmental transition.

This paradigm shift on sustainable development represents a unique opportunity for higher education and research institutions to position themselves as actors of change, by enabling science to influence collective decisions. They will be integrated into an international network committed to a responsible and pragmatic approach to research, leading to connected science. The participation of non-academic actors in the formulation, monitoring, and political and economic enhancement of the findings will ensure the development of close links between partners, producers and seekers of scientific expertise.

The long-term impact of these actions will stem from concrete and visible expected outcomes, both in terms of new knowledge and capacity building. They must bring about profound changes in the way research is carried out, and in the use of scientific results by economic and social actors, highlighting their usefulness and relevance to societal challenges. The connected science approach can be replicated in other contexts. The conclusions of the programme, distilled in a white paper that will serve as a roadmap to environmental transition, will contribute to identifying solutions to the most urgent socio-environmental problems faced by humanity.

Finally, the core of these recommendations is to contribute to building the next generation of policymakers for the environmental transition, a network of leading sustainability science experts in the Mekong countries, as well a network of local community actors and non-governmental organizations. Building local interdisciplinary scientific knowledge, guiding evidence-based public policies, and fostering scientific and policy regional coordination will ultimately help bring about the socioeconomic conditions for ecologically resilient economies in the region.

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Chapter 9

A question of water

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Abstract

Over the past three decades, the Mekong Delta has been subject to significant geophysical and environmental changes. In this context, the land is subsiding by an average ~1 cm/year, with local maximums of up to ~6 cm/year. The tides are rising at a rate close to ~2 cm/year, and salinity has increased by approximately 0.2–0.5 PSU/year. Rapid elevation loss is strongly linked to groundwater extraction, while rising tides and increased saline water intrusion are linked to rapid erosion of riverbeds, at rates of ~10–15 cm/year, in response to anthropogenic sediment starvation caused by downstream sand mining and upstream impoundments. We show that hydropower dams, sand mining and groundwater extraction pose the greatest threats in the coming three decades, while climate change will probably dominate the threats in the second half of the century. If the rate of groundwater extraction remains at present-day levels, the average cumulative subsidence – combined with sea level rise – could cause large parts of the delta to fall below sea level in coming decades. Meanwhile, in line with existing trends, anthropogenic riverbed level incision could increase the extension of land impacted by saline water intrusions by 10–30% in 2050. The window of opportunity for mitigation and adaptation is closing fast. We propose a number of policy recommendations that include **1**] Restricting sand mining and groundwater exploitation; **2**] Transformation of farming practices, **3**] Active diplomacy towards a joint regime of trans-boundary river resource management; and **4**] Reinstating natural flooding and advocating sedimentation to counterbalance subsidence.

Tóm tắt

Trong 3 thập kỷ qua, Đồng bằng sông Cửu Long (ĐBSCL) đã trải qua những thay đổi đáng kể về mặt địa vật lý và môi trường. Trong đó, mặt đất bị sụt lún trung bình khoảng ~1 cm/năm, và cao nhất là ~6 cm/năm. Mức nước thủy triều gia tăng với tốc độ ~2 cm/năm, và xâm nhập mặn gia tăng sấp xỉ 0.2–0.5 PSU/năm. Sự hạ thấp độ cao này liên quan chặt chẽ đến quá trình khai thác nước ngầm, trong khi quá trình gia tăng mực nước biển và xâm nhập mặn liên quan đến mức độ xâm thực lòng sông với tỉ lệ ~10–15 cm/năm, do thiếu hụt trầm tích từ khai thác cát và các hoạt động phát triển vùng thượng lưu. Chúng ta đã thấy phát triển thủy điện, khai thác cát, nước ngầm đang có những ảnh hưởng lớn nhất trong những thập kỷ tiếp theo cùng với tác động từ quá trình biến đổi khí hậu sẽ tiếp tục mạnh mẽ hơn trong nửa cuối của thế kỷ này. Nếu tiếp tục khai thác nước ngầm với tỉ lệ như hiện nay kết hợp với tác động cộng hưởng của mực nước biển dâng sẽ khiến một phần lớn ĐBSCL sẽ nằm dưới mực nước biển trong những thập kỷ tới. Ngoài ra, cùng với tác động nhân sinh gây thay đổi địa hình lòng sông, sẽ làm gia tăng xâm nhập mặn khoảng 10–30% vào năm 2050. Cửa sổ cơ hội để giảm thiểu và thích nghi sẽ đóng lại nhanh chóng nếu không có những hành động kịp thời. Chúng tôi, đề xuất một số gợi ý chính sách bao gồm: **1**] Hạn chế

khai thác cát và khai thác nước ngầm; **2**] Chuyển đổi mô hình sản xuất nông nghiệp phù hợp; **3**] Tích cực ngoại giao trong quản lý nước liên quốc gia; và **4**] Cần xem xét lại về vai trò của lũ và trầm tích trong việc cân bằng sụt lún ở ĐBSCL.

Résumé

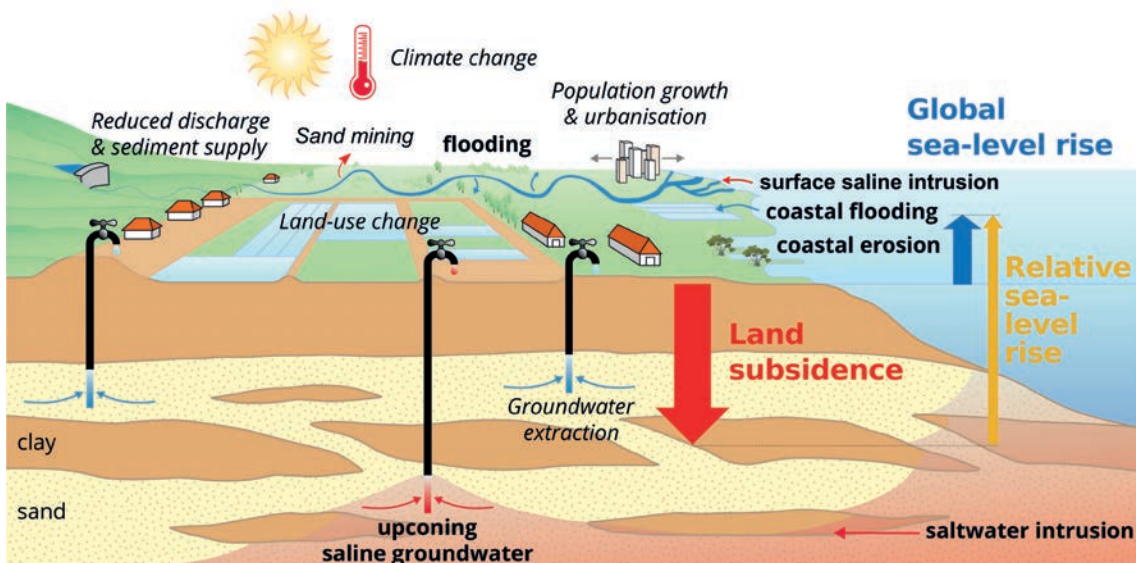
Au cours des trois dernières décennies, le delta du Mékong a connu d'importants changements géophysiques et environnementaux. Le taux de subsidence est de ~1 cm/an en moyenne, avec des maximums locaux allant jusqu'à ~6 cm/an. L'amplitude des marées augmente à un rythme de près de ~2 cm/an, et la salinité s'accroît d'environ 0,2–0,5 PSU/an. La perte rapide d'altitude est fortement liée à l'extraction des eaux souterraines, tandis que l'intensification des marées et l'augmentation des intrusions salines sont liées à l'érosion rapide des lits des rivières, à des taux de ~10–15 cm/an, en raison de l'appauvrissement sédimentaire causé par les retenues en amont et les extractions de sable. Nous montrons que les barrages hydroélectriques, l'extraction de sable et l'extraction des eaux souterraines constituent les plus grandes menaces dans les trois prochaines décennies, tandis que le changement climatique dominera probablement les menaces dans la seconde moitié du siècle. Si le taux d'extraction des eaux souterraines reste au niveau actuel, la subsidence cumulée moyenne — combinée à l'élévation du niveau de la mer — pourrait amener de grandes parties du delta sous le niveau de la mer dans les prochaines décennies. Parallèlement, conformément aux tendances actuelles, l'érosion anthropique du lit des rivières pourrait accroître de 10 à 30% l'étendue des terres touchées par les intrusions salines en 2050. La fenêtre d'opportunité pour l'atténuation et l'adaptation se referme rapidement. Nous proposons un certain nombre de recommandations politiques qui comprennent **1**] la restriction de l'extraction du sable et des eaux souterraines, **2**] la transformation des pratiques agricoles, **3**] une diplomatie active vers un régime commun de gestion des ressources fluviales transfrontalières et **4**] le rétablissement des inondations naturelles et la promotion de la sédimentation pour contrebalancer la subsidence.

1. Introduction

The Vietnamese Mekong Delta (VMD) is the third largest delta in the world, covering 48,900 km². The Mekong River branches out into 7 main VMD distributary channels before draining to the sea. In addition to these natural river branches, a large network of canals of varying sizes have been built over centuries, enabling navigation and irrigation [Chapter 7]. The sub-aerial delta plain of the VMD is one of the most fertile regions in the world, home to ~17 M people, and produces 50% of Viet Nam's food supply. Over the past decades, rapid urbanization and intensified agri/aquacultural production have put significant stress on the delta's natural resources, such as sand and fresh ground/surface water. Life and live-

lihood in the delta are punctuated by the tropical monsoon, with a wet season from July to October and a dry season from December to May, driving large seasonal variations of the hydrology [Chapter 7]. The average monthly discharge of the Mekong measured upstream (Kratie, Cambodia) ranges from $2 \times 10^3 \text{ m}^3\text{s}^{-1}$ in the dry season to $36 \times 10^3 \text{ m}^3\text{s}^{-1}$ during the wet season. During the latter season, the strong fluvial discharge drives a flood pulse that inundates the floodplains and brings new sediments and nutrients to the delta. The fluvial forces limit the salt intrusion from the sea in the estuary channels to only a few kilometres, whereas during the dry season ocean forces drive up-channel salt intrusion over tens of kilometres.

[Figure 9.1]
Changes in the Mekong delta



Drivers (*italic*) and consequences (**bold**) of changes in the Mekong delta. Relative sea level rise is the combined effect of global sea level rise and land subsidence. Source: P. Minderhoud (2019).

This densely populated area, crucial for Viet Nam's food security and international food exports, is under pressure from both climate change and anthropogenic stressors [Figure 9.1]. As a result of its low average altitude of ~80 cm above sea level [Minderhoud *et al.*, 2019], the sub-aerial delta plain seems particularly vulnerable to the global mean sea level rise (SLR) induced by climate change (See DEM in Figure 9.2). Current global rates are ~3.3 mm/year and are projected to accelerate during the XXIst century [Chapter 1] depending on the climate scenario. Large uncertainties remain as to the values which might be reached by the end of the century and beyond, but even in the most optimistic climate scenarios global mean sea level rise could exceed 40 cm in 2100, which could put the lowest areas of the delta at risk of permanent inundation [Bamber *et al.*, 2019a; Ministry of Natural Resources and Environment (MoNRE), 2016].

But global sea level rise is not the only driver of elevation change relative to the sea in the delta. Elevation change of the delta plain relative to local sea level depends on relative SLR, which arises from the cumulative effect of global sea level change and land vertical movements (*i.e.* land subsidence). As in many deltas worldwide [Nicholls *et al.*, 2021], current subsidence rates in the VMD outpace global sea level rise by an order of magnitude [Erban *et al.*, 2014; Minderhoud *et al.*, 2017, 2020]. Subsidence in a delta is a natural phenomenon driven by tectonic movements, isostatic adjustment, and natural compaction of unconsolidated sediments. Anthropogenic activities can enhance shallow natural compaction rates, for example by draining the surface water table for agricultural practices or by adding additional loading through infrastructure or buildings [Minderhoud *et*

al., 2018]. Furthermore, human activities can also trigger new subsidence processes, as shown in recent hydrogeological studies highlighting the role of excessive groundwater extraction driving aquifer-system compaction and leading to accelerating subsidence rates in the VMD [Minderhoud *et al.*, 2017, 2020]. Under natural conditions, the deposition of new sediments during floods can partially offset relative sea level rise by building up elevation. However, sediment starvation due to sediment trapping by upstream dams and flood control in the delta during the wet season deprives the floodplains of new sediments [Chapter 7]. Also, current accelerated subsidence rates are an order of magnitude larger than what could be compensated by new sediments under pristine conditions [Schmitt *et al.*, 2017]. As a result, the natural mechanism for coping with relative sea level rise no longer functions in the VMD, due to anthropogenic impacts upstream and in the delta itself. In the next decades, relative SLR may dramatically increase coastal flooding, erosion, and salt intrusion, all of which are already disrupting day-to-day life in the delta.

Salt intrusion in surface waters, as the main indicator for land use, has raised growing concerns over the past decade since life in the delta strongly depends on water quality and availability. In the past five years, record saline water intrusion events (in 2016 & 2019) have already resulted in huge financial and crop losses, and in freshwater shortages. Figure 9.2 shows how salt intrusion has been consistently and gradually increasing at some of the observation stations in the VMD. Climate change-driven sea level rise has often been blamed for the increase in experienced saline water intrusion events. However, salinity intrusion in surface waters is the outcome of a complex interplay of riverine and oceanic

forces in a given morphological setting, influenced by a large number of drivers. Therefore, salinity intrusion is not only influenced by climate change — as reflected in discharge variation, global sea level rise, evaporation, and precipitation etc. — but also by anthropogenic drivers that modify river discharge and water levels, or the bathymetry and geometry of river and estuarine channels [Eslami *et al.*, 2019b]. The most recent scientific findings on salt intrusion in the delta show that anthropogenic riverbed incision, driven by sediment starvation due to upstream impoundments and downstream sand mining, currently outpaces climate change effects by orders of magnitude [Eslami *et al.*, 2019b, 2021a, 2021b]. Riverbed-level changes simplify salinity intrusion in the deeper estuarine channels and amplify the tidal range that increases ocean forces in salt intrusion. As well as impacting salinity, tidal amplification exacerbates city flooding in subsiding cities of the VMD and creates a feedback loop that contributes to riverbed/bank erosion. While the VMD is already impacted by climate change, it is the combined and cumulative impact of climate change and “local drivers of exposure

and vulnerability” [Oppenheimer *et al.*, 2019] that determine the environmental pathways of the delta over the next decades.

This chapter aims to provide a holistic view of the past, present and future dynamics of change in the VMD regarding relative sea-level rise and saline water intrusions, by disentangling the effects of various environmental (sea level rise, natural subsidence, and river discharge anomalies) and anthropogenic (human-induced subsidence and sediment starvation) systems stressors. We exhibit the environmental pathways in the coming decades as they relate to elevation as well as saline water intrusion. For the latter, we show how climate change — through sea level rise and upstream discharge anomalies, extraction-induced land subsidence, and riverbed erosion — influences salinity in delta, developing a range of possibilities for the next 3 decades. [Figure 9.2](#) demonstrates a range of salt intrusion scenarios until 2040. The outcome offers crucial input for effective climate adaptation and anthropogenic mitigation strategies in the VMD.

2. Delta Elevation

2.1 A key parameter for the delta’s future

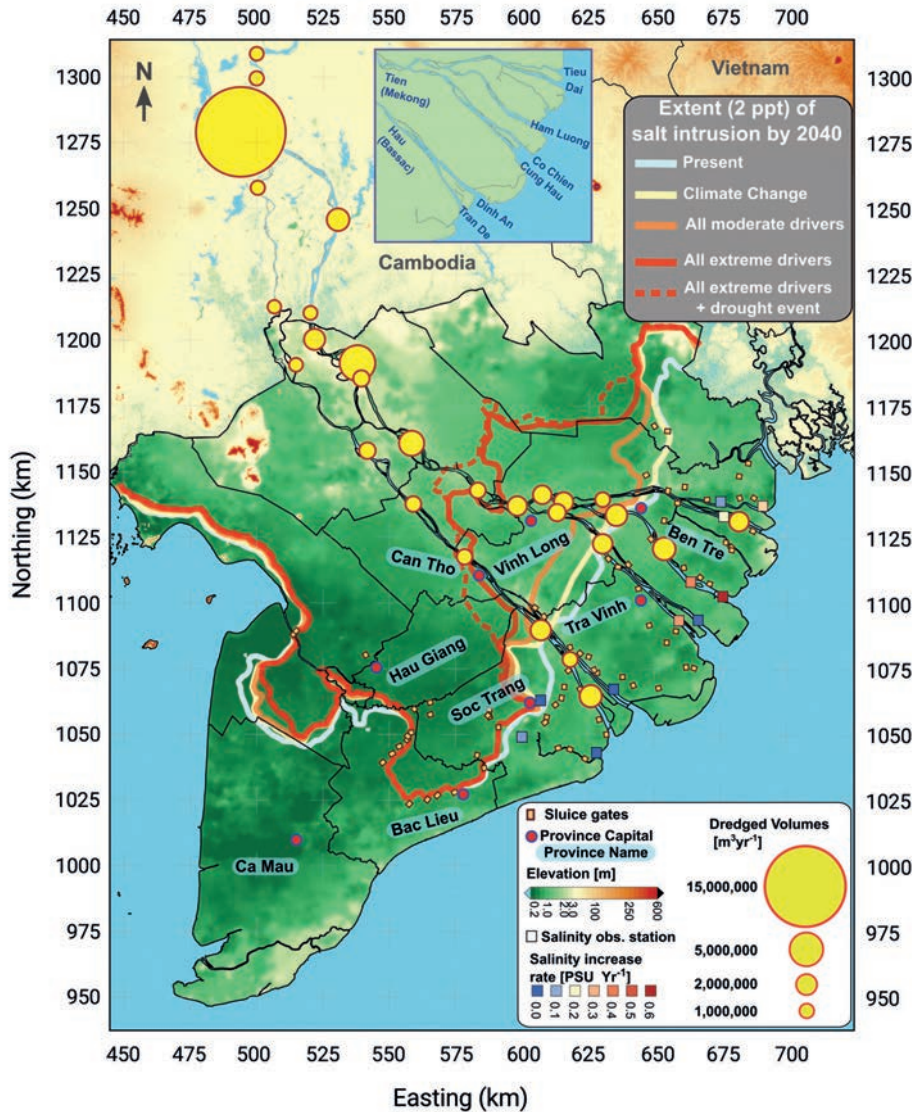
The elevation of the land surface relative to mean sea level is an important factor that determines the impact of climatic and environmental changes on life in a delta. Low elevation relative to sea level means increased

exposure of the delta, its inhabitants and its economic activities to flooding, salinization, and erosion. Lower elevation decreases resilience of the delta to changes in the environment and exponentially increases the costs of livelihood [Nicholls *et al.*, 2021].

2.2 Accurate elevation data crucial for risk assessment

It is imperative to have good estimates of present elevation and the relevant processes

[Figure 9.2]
Elevation, sand mining and saline water intrusions



Digital elevation map of the Mekong Delta [Minderhoud *et al.*, 2019], including the salinity increase rates at multiple stations [Eslami *et al.*, 2019b], the estimated sand mining volumes (scaled with surface area of the circles) [Eslami *et al.*, 2019b]; The sand mining figures upstream of the VMD are extracted from previous publications [Bravard *et al.*, 2013], but updated within the VMD; the contour lines show present and projected peak salt intrusion (2 PPT contour lines) under moderate and extreme scenarios of climate change (SLR and discharge variation under RCP scenarios), groundwater extraction-induced subsidence [Minderhoud *et al.*, 2020] and riverbed level incision due to sediment starvation [Eslami *et al.*, 2019b, 2021b], assuming the coastline remains unchanged (coord. system WGS84-UTM 48 N).

driving elevation change to create accurate future projections and reliable impact assessments, e.g. for sea level rise.

In the past, many assessments of exposure to sea level rise in the VMD have been based on globally available, satellite-derived elevation data. The problems with these public data are: 1] the relatively high vertical error, which is especially problematic for flat deltaic regions and 2] the fact that the data are referenced to a global approximate sea level (the so-called geoid), which can differ by several dm/m from the local sea level height [Box 9.1]. Almost all previous sea level rise impact assessments using satellite-derived data have omitted the required conversion from global to local sea

level, thereby creating a structural height bias that overestimated the elevation of the VMD [Carew-reid, 2008; Kondolf *et al.*, 2018; Schmitt *et al.*, 2017; Warner *et al.*, 2010] (see Box 9.1).

An exception to the above is the assessment by Climate Central using the Coastal DEM, an automated-error-removed DEM based on SRTM data [Kulp and Straus, 2019] and properly-converted vertical datum to local mean sea level. However, instead of overestimating elevation in the VMD, the automatic-generated Coastal DEM underestimates the elevation. According to the Coastal DEM, the average elevation of the VMD at present is already -0.5 m below mean sea level, which is not the

[Box 9.1]

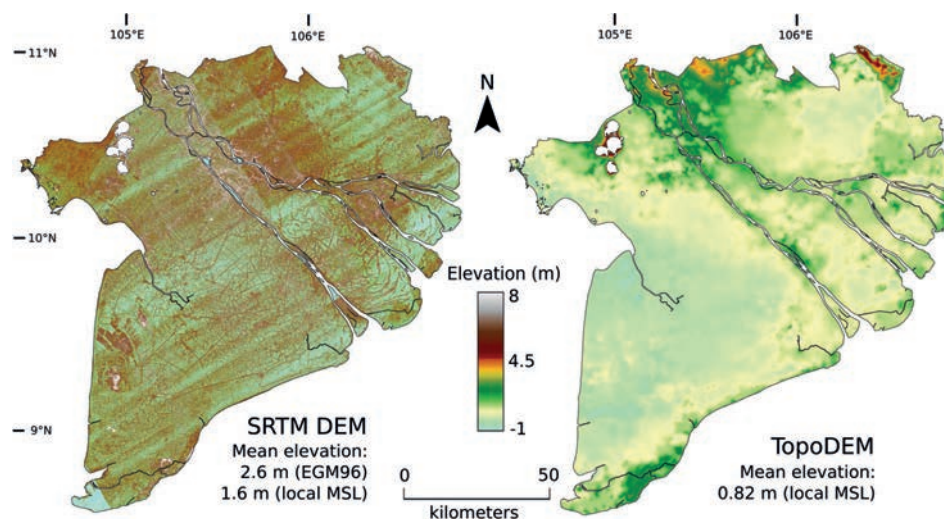
Elevation models of the VMD

Digital Elevation Models (DEMs) are fundamental inputs for inundation or sea level rise risk assessments. Projections of sea level rise are in the order of cm to dm at decadal timescales; hence ideally the DEM should provide a similar accuracy and precision. This holds true for DEMs created using high-accuracy elevation observation methods such as airborne-based laser altimetry data (LiDAR) or ground elevation measurements from geodetic surveys (e.g. spirit levelling campaigns). These high-level elevation data are available to Vietnamese ministries and used for internal sea level rise impact assessments but are not publicly accessible. As a result, many international studies have had to rely on globally available satellite-based DEMs instead, and predominantly NASA's SRTM DEM [Farr *et al.*, 2007]. Data quality issues and improper use have resulted in unreliable risk assessments for the VMD for the following two reasons:

1] The vertical absolute error of SRTM data is ~6.2 m in Eurasia [Rodriguez *et al.*, 2005] and the original SRTM data are binned to 1 m steps, which is up to two orders of magnitude larger than decadal rates of sea-level rise. The height errors result from canopy cover or buildings but also from data artefacts such as the obvious NE-SW-oriented striping pattern present over the VMD [Figure 9.3]. As a result, sea level rise risk assessments in the VMD using SRTM data predominantly show elevation inaccuracies rather than the actual sea level rise impact.

2] The vast majority of the assessments do not convert the vertical datum to local Mean Sea Level (MSL). Global satellite-derived DEMs are referenced to a global elevation datum, the so-called geoid, which is a model of global mean sea level based on gravity and Earth rotation, excluding local effects of winds and tides. The standard reference of the SRTM DEM is the Earth Gravitational Model of 1996 (EGM96). For the Mekong delta, local MSL differs + 1.01 m from EGM96 elevation at the tide gauge located at Ha Tien (average MSL from October 1992 to December 2010 based on AVISO altimetry data). As a result, risk assessments using the SRTM DEM that do correct for this, include a height bias (overestimation) of 1 m to local MSL, greatly underestimating the true risk.

[Figure 9.3]
Topography of the delta



SRTM DEM and TopoDEM of the VMD. The SRTM is purposefully referenced to EGM96, to show the large difference with the many previous sea level rise assessments that did not convert vertical datum to local MSL, which is about +1 meter higher. Average elevation is calculated for the delta plain excluding bedrock outcrops (Modified after Minderhoud *et al.*, 2019).

case; this would mean that large areas would be permanently inundated (P. Minderhoud, personal communication). The sea level rise impact assessment for the VMD, besides not accounting for vertical land motion, is thus dominated by this initial underestimate of elevation, and should be discarded.

Since 2012 at least, the Vietnamese government has produced its own internal sea level rise impact assessments for the VMD, based on high-accuracy data, which are superior to the publicly available satellite-based DEMs. However, until now, these sea level rise impact assessments only considered the climate change-driven global sea level rise, and did not include vertical land movement (*i.e.*, subsidence).

The significant errors in previous sea level rise impact assessments for the Mekong delta that resulted from (mis)using inaccurate satellite-based DEMs became clear for the international community in a recent publication [Minderhoud *et al.*, 2019]. The authors created the TopoDEM, based on data digitized by interpolating elevation points from a topographical map. The mean delta elevation of the delta according to TopoDEM is ~0.8 m above local mean sea level [Figure 9.3]. Although the TopoDEM enables far more accurate sea level rise assessments compared with the satellite-based DEMs, it has very low spatial resolution (0.5 km), an estimated vertical elevation error of 20–30 cm, and unknown source and acquisition data. The TopoDEM falls short in accuracy compared to the Viet-

nameese government's LIDAR-based elevation model. However, at present the TopoDEM is the best publicly available estimate of Mekong delta elevation and enables reasonable, spatiotemporal assessment of relative sea-level rise and its impact on flood risk and salinization, for example.

2.3 A sinking delta

It is common knowledge that sea level is not stable, but neither is the elevation of the land of a delta. While elevation in a delta is built by sediment deposition, it diminishes over time due to land subsidence. We define land subsidence here as gradual lowering of the land surface due to natural and human-induced processes that cause compaction and volume reduction of sediment in the subsurface (see [Box 9.2](#)). Hence, land subsidence does not include other, unrelated processes, like riverbank or riverbed erosion, slumps and landslides, or other sudden large changes in surface level. As the Vietnamese term for these phenomena does not differentiate between them, this often leads to confusion in media articles or in discussions. The total subsidence rate is defined as surface lowering over time resulting from the sum of all subsidence processes together. Final elevation change is the combined effect of elevation loss following subsidence and elevation gain by, for example, sedimentation. Following this definition, reduced sedimentation is not a cause of delta subsidence but rather a reduction of the natural compensation mechanism [Hoang *et al.*, 2016]. Over the previous decades, intensification of agricultural practices and on-going urbanisation have triggered and increased the impact of the anthropogenic subsidence drivers [Minderhoud *et al.*, 2018]. At present, the VMD is experiencing subsidence rates in the order of several cm/year,

a magnitude larger than current rates of global sea level rise. As sedimentation rates are too low to compensate for these high rates of relative sea level rise, the delta is losing elevation, predominantly as a result of land subsidence. In this section we discuss the causes of deltaic subsidence and highlight recent monitoring and modelling efforts in the VMD.

Measuring subsidence

Accurately monitoring subsidence in a delta as large as the VMD is a challenge: not just because of its scale, but also because of spatial and temporal variability of deltaic subsidence. The latter holds true especially for human-induced, accelerating subsidence [Minderhoud *et al.*, 2018]. Moreover, compaction of unconsolidated sediments can happen at different depths in the subsurface of the delta, from the top few centimetres down to hundreds of metres in depth. Subsidence rates in the VMD have been determined in various ways: [1](#) ground-based measurements and [2](#) space-borne observations using satellite-based interferometric synthetic aperture radar [InSAR]. No single measuring technique can resolve every subsidence process at all relevant temporal and spatial scales, and each method has its advantages and disadvantages. Therefore, the combined use of different measurement techniques is important, since they complement each other and together can provide a full overview.

Ground-based measurements of subsidence

Ground measurements generally have high vertical accuracies and can measure subsidence at millimetre scale. As the measured object is known, the measurement can be interpreted directly in relation to depth, e.g. a foundation-less monument at the delta sur-

[Box 9.2]

Drivers and processes of subsidence in deltas

Subsidence in a delta is the cumulative result of a range of different drivers and processes. Figure 9.4 gives an overview of processes and drivers that can cause and/or enhance land subsidence in deltas and coastal plains. Processes (in blue) are initiated by a driver (in black/green/red). Multiple drivers and processes can play a role at the same time and add to the total subsidence. Total subsidence depends on local conditions and can be highly variable spatially within a delta. Also, subsidence processes can accelerate and decelerate over time, and even vary throughout the year between wet and dry seasons and variations in anthropogenic drivers. In general, subsidence due to anthropogenic drivers can be reduced or even stopped, while natural subsidence is unavoidable.

Natural drivers (green in Figure 9.4) include compaction (or consolidation) of soft, unconsolidated sediments over time and with increased natural loading (e.g. new sediments or seasonal flooding), and effects resulting from solid earth movements such as tectonic activity or isostatic adjustment. Other natural processes causing subsidence are oxidation of organic material in the soil and ripening of clay soils.

Anthropogenic drivers stem from human activities that alter the natural situation in the delta both at the surface and in the subsurface (red in Figure 9.4). They can enhance natural subsidence processes or trigger new subsidence, for example by adding weight to the surface through buildings or infrastructure, lowering the surface water table or over-extracting groundwater. When water pumping reduces water pressure in the subsurface, sediments experience increased stress, driving pore space reduction and compaction. In sandy deposits a large part of this compression is reversible (i.e. elastic) and can be recovered when water levels increase again, but for silts and clays the process is largely irreversible (i.e. plastic). Groundwater extraction is notorious for creating the highest subsidence rates in deltas, up to several cm/year, and world-wide there are numerous examples of land subsidence caused by groundwater extraction, for example cumulative subsidence in Bangkok (2.1 m), Jakarta (4.1 m), Tokyo (4.3 m) and Shanghai (2.6 m) [Gambolati and Teatini, 2015].

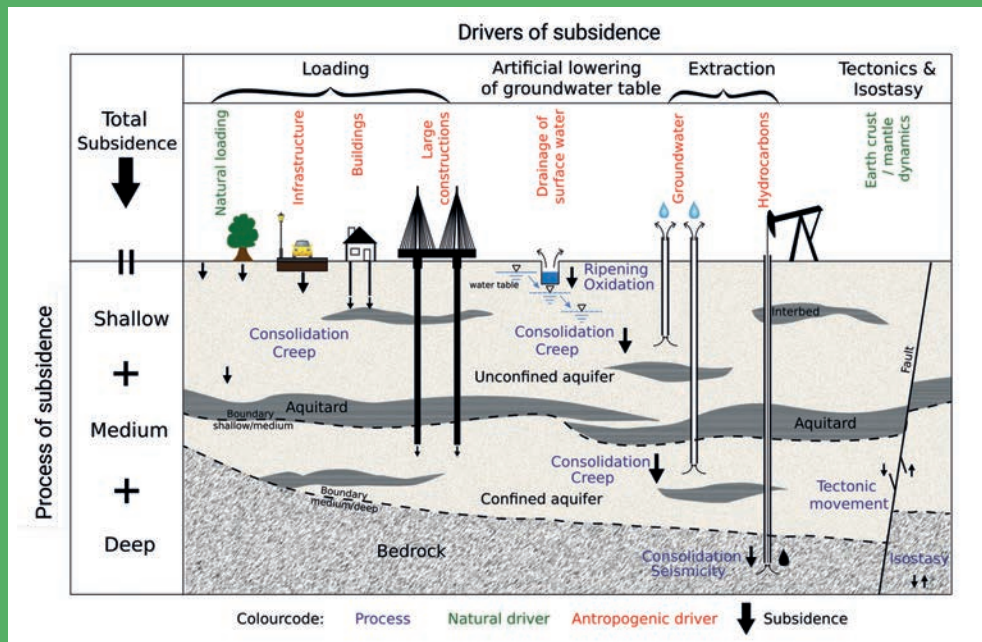


Figure 9.4 An overview of natural and anthropogenic drivers and processes of subsidence in a delta system (modified after Minderhoud *et al.*, 2015).

face, or a benchmark or extensometer fixed at a certain depth. Except for several monitoring stations that measure displacement continuously, the temporal resolution of observations is rather low (sometimes only a single measurement in several years). While this enables computation of longer-term average movements, it does not capture seasonality or temporal trends. Also, as the measurements are point measurements, they do not provide a spatial pattern and should not be interpolated over large areas, as this would ignore the spatial heterogeneity of subsidence and put too much weight on single point measurements and potential outliers.

Official MoNRE (Viet Nam Ministry of Natural Resources and Environment) measurements of subsidence are created based on 287 geodetic benchmarks at the delta surface throughout the delta. The benchmarks were measured in 2005, 2014, 2015 and 2017. The average subsidence rates between 2005 and 2017 attained peaks of 57 mm/year, with an average rate of 9.6 mm/year. Cumulatively, the benchmarks subsided on average 10.6 cm, with cumulative subsidence up to 62.6 cm. Although the interpolated map based on the point measurements should be viewed with strong reservations (see reasons above), these data show clear evidence of widespread downward vertical land motion throughout the delta between 2005 and 2017.

Other ground-based measurements of subsidence in the VMD include rod surface-elevation tables (RSETs), installed since 2010 at several locations in the Mekong Delta, especially in mangrove forests in the coastal zone. In combination with a surface marker horizon, the RSETs provide measurements of subsidence of the shallow, Holocene deposits. Reported subsidence rates for this shallow depth

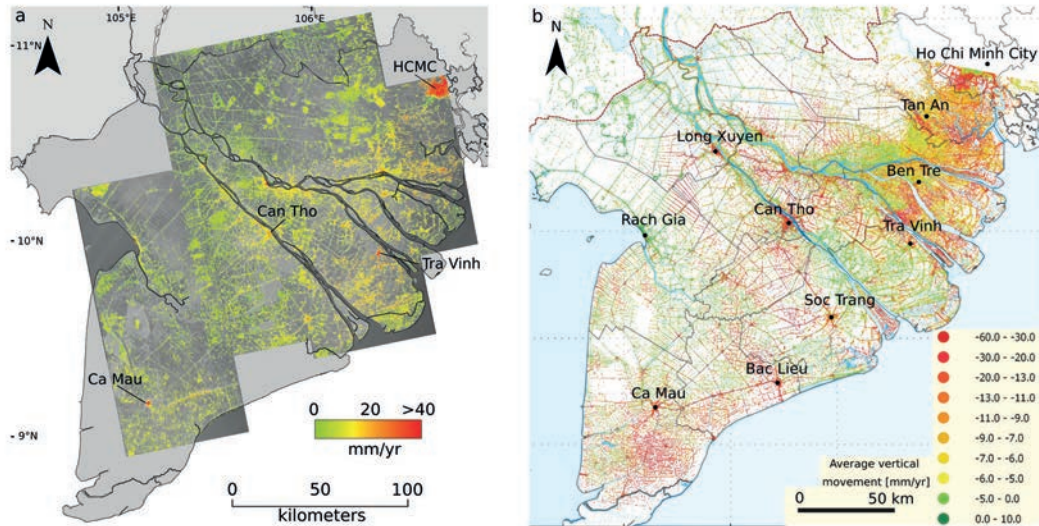
interval range between 13.4 and 46.2 mm/year (measured between 2010 and 2014, Lovelock *et al.*, 2015). The Viet Nam Institute of Geosciences and Mineral Resources (VIGMR) and the Norwegian Geotechnical Institute (NGI) installed three subsidence monitoring stations in Ca Mau province in 2017. These stations measure subsidence in the upper 100 m of the subsurface [Karlsrud *et al.*, 2017, 2019; Karlsrud & Vangelsten, 2017]. Two of the three stations provide reliable data, and measured 24 and 31 mm/year of subsidence (2017–2019). However, the sparse measurement times and short measurement intervals make these measurements unreliable, and insufficient to support the study's conclusion on fast (neo) tectonic movements in the VMD. Alongside direct measurements of subsidence, several studies have estimated subsidence indirectly, inferred from time series from river stage across the VMD [Fujihara *et al.*, 2015] and in the city of Can Tho [Takagi *et al.*, 2016]. On average, the river stage monitoring stations recorded an estimated subsidence of 17.1 mm/year between 1993 and 2014.

Space-borne subsidence observations

Space-borne observations, using satellite-based interferometric synthetic aperture radar (InSAR), have the advantage of providing an unprecedented spatial resolution of vertical land movement. However, the uncertainty of the rates is relatively large, due to relatively high atmospheric distortion in the region and limited availability of stable points to convert relative movements into absolute movement. InSAR renders the movement of surface reflectors, *i.e.* hard surfaces such as roads and rooftops that reflect the radar signal well. Therefore, it does not directly provide delta surface movements but should be interpreted through the movement of respective reflectors, which can be quite different: for example,

[Figure 9.5]

Subsidence rates estimated from satellite imagery (InSAR) over the period 2006–2010 (a) and 2014–2019 (b)



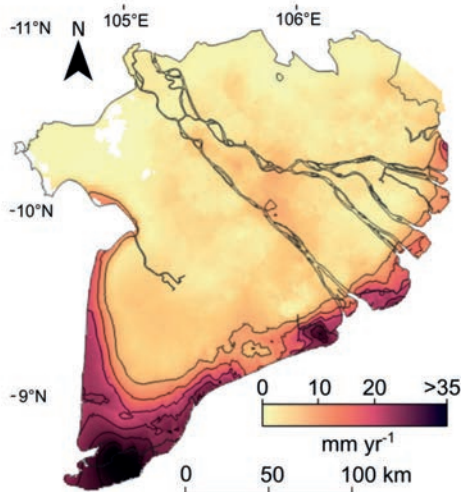
■ InSAR data source: a) Erban, *et al.*, (2014) and b) EU Copernicus EMSN062 after Minderhoud *et al.* (2020b).

roads without foundations versus buildings with deep foundations [de Wit *et al.*, 2021]. The first InSAR analysis for the Mekong Delta was performed by [Erban *et al.*, 2013, 2014]. The studies showed that large parts of the delta experienced subsidence rates varying from 0–40 mm/year over the period 2006–2010, with a structural measurement error of 5–10 mm/year [Erban *et al.*, 2013], and an additional uncertainty (up to 10 mm) related to the selection of stable (zero-movement) reference points of the different satellite image tiles. Apart from these relatively high uncertainties, the studies revealed the widespread occurrence of subsidence in the delta.

In 2019 new satellite-based subsidence quantifications became available for the cities of Ca Mau, Rach Gia and Long Xuyen and their direct surroundings for the period November 2014 to January 2019. Land subsidence rates were derived following the persistent

scattered interferometry (PSI) technique, using Sentinel-1 sensor data as part of a Copernicus project (project code: EMSN-057). In a second Copernicus EMS project (EMSN-062), almost the entire Mekong Delta was analysed. The datasets show subsidence rates up to 60 mm/year, which are significantly higher than the INSAR-estimates [Erban *et al.*, 2014] from a decade earlier (2006–2010) [Figure 9.5a]. This may point to acceleration over time. Another important difference is that whereas in the 2006–2010 analysis cities and densely populated areas were clearly the locations experiencing the highest rates of subsidence, the 2014–2019 data reveals new subsidence hotspots located in agricultural areas [Figure 9.5b]. These datasets show that high subsidence rates are now occurring in areas away from dense urbanisation, which is a new phenomenon compared to a decade earlier.

[Figure 9.6]
 Simulated rates of natural compaction



Estimated maximum natural compaction of Holocene clays in the VMD (Modified after Minderhoud, 2019).

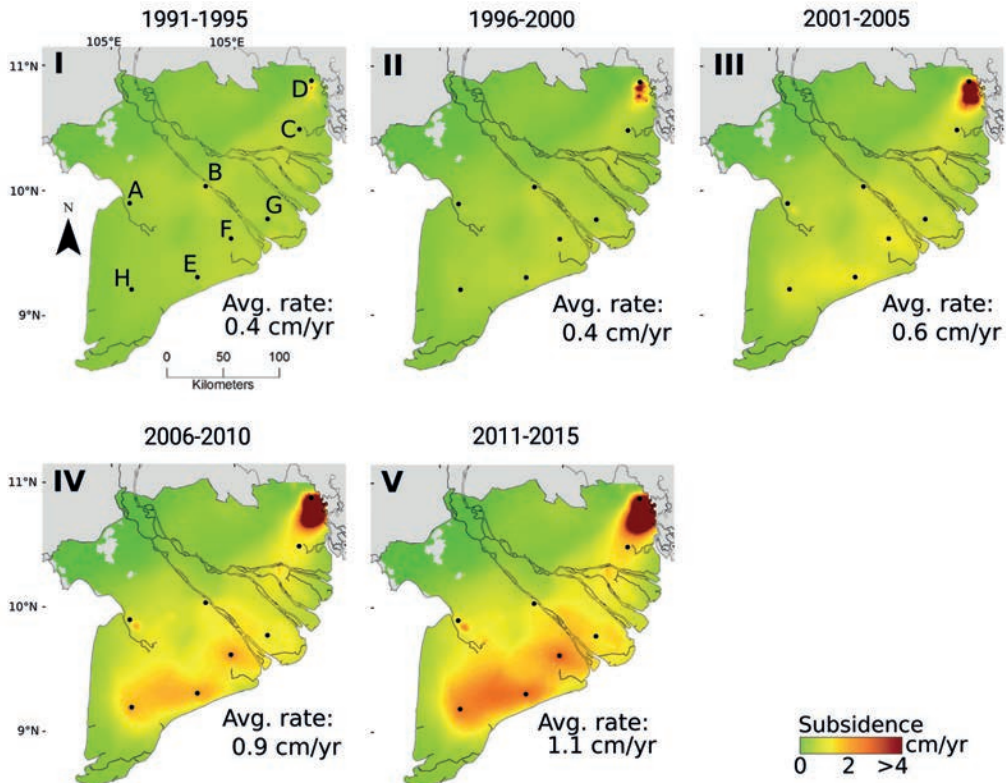
Modelling subsidence in the Mekong delta

The use of computer models is a way to increase understanding and create physics-based interpolation and predictions of observed subsidence. Models enable the quantification of subsidence beyond the spatial and temporal scale of observations. When properly calibrated and validated against observations, they can be used to create process-based interpolations, *i.e.*, maps. These maps can be superior to the mathematical interpolation of point measurements since they incorporate physical processes and spatial variability. No single computer model is capable of modelling all the relevant processes at different depths in a delta. Therefore, unlike measurements of total subsidence, a model is built to simulate specific processes and drivers, thus addressing only a part of the total subsidence in the delta. For the VMD, two numerical models have been created, targeting two distinct subsidence processes:

1] shallow, natural compaction of Holocene sediments [Zoccarato *et al.*, 2018] and 2] aquifer-system compaction following groundwater extraction, and consequent changes in the hydrogeological situation in the delta. Both models were built using large sets of field data and were calibrated and validated using observations of subsidence.

Using a novel computer code, the shallow natural compaction of Holocene sediments was modelled for a 2D transect in the Ca Mau peninsula, following the progradation of the delta in the last 4000 years [Zoccarato *et al.*, 2018]. This novel approach revealed that the combination of high progradation rates and high compressibility of clay deposits can be responsible for unprecedentedly high rates of natural compaction in the youngest parts of the VMD. The model confirmed that the high shallow compaction rates measured in these areas by RSETs (13.4–46.2 mm/year) could be of natural origin. Recently, the first delta-wide map of maximum potential natu-

[Figure 9.7]
Simulated rates of extraction-induced subsidence



Simulated extraction-induced subsidence showing the gradual acceleration following increased groundwater extractions in the VMD [Minderhoud *et al.*, 2017].

ral compaction was created, by interpolating the 2D-modelled compaction using the spatial distribution of clays in the shallow Holocene delta deposits [Figure 9.6].

Groundwater extraction is a well-known driver of anthropogenic-induced subsidence in deltaic areas. In the VMD the volume of extracted groundwater has seen a steady increase over the last decades [Chapter 7]. The water is extracted from different aquifers (*i.e.*, sand bodies) in the subsurface, which in some places reach depths over 500 m. The water pressure

(*i.e.*, hydraulic head) in the aquifers has been monitored since 1990, when the groundwater situation was still fairly undisturbed in many places. Since then, following the steady increase of extractions, water pressure in the different aquifers has shown decreasing trends throughout the delta [Chapter 7]. Following the drop in pressure, water has been drained from fine-grained deposits (*i.e.*, aquitards, low permeable layers separating the different aquifers), causing compaction of the entire aquifer-system.

The impact of groundwater extraction on subsidence in the VMD was studied using a delta-wide 3D hydro-geological model that simulated groundwater extractions, groundwater flow and pressure change, and conse-

quent compaction of subsurface layers [Minderhoud *et al.*, 2017]. The modelling results revealed the accelerating trend of aquifer-system compaction in the VMD following the increase in groundwater exploitation [Min-

[Box 9.3]

Environmental drivers of salt intrusion

Salt intrusion within the deltaic surface water systems is mainly driven through the estuarine channels. Estuarine salinity is determined by the competition between 1] upstream (dispersive) salt transport by density gradient and ocean forces (e.g. tides) against the 2] downstream (Eulerian) salt transport, e.g. by river discharge within 3] a given morphology [Geyer and MacCready, 2013; Pritchard, 1952; Savenije, 1993, 2005]. Therefore, alterations in any of the three main determinants of salt intrusion translate into changes in estuarine salinity and its extent of intrusion.

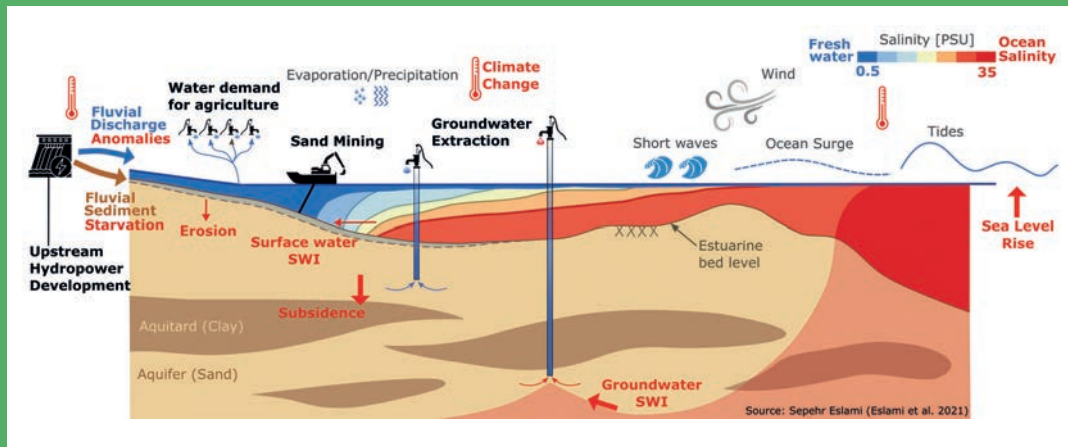


Figure 9.8 A cross-profile of a delta through its estuarine system, and the primary anthropogenic (black) and climatic (grey) drivers of change (red)

Global rising temperatures [IPCC, 2014] modify precipitation/evaporation patterns that both directly, and through upstream discharge anomalies [Winsemius *et al.*, 2016], influence fresh-saline water dynamics. Oceanic thermal expansion and melting of the ice sheets and glaciers increase ocean water levels [Bamber *et al.*, 2019; IPCC, 2014] and impact oceanic tidal patterns [Pickering *et al.*, 2017] that affect estuarine salinity. Estuarine bathymetry (the 3rd determinant) itself responds to the rising seas and changing tides [Leuven *et al.*, 2019]. Along with climatic changes, ever-growing agri-/aqua-cultural developments are sources of stress on fluvial freshwater resources. Upstream impoundments have reduced fluvial sediment supply, leading to morphological changes such as bed/bank/coastal erosion [Anthony *et al.*, 2015; Dunn *et al.*, 2019; Syvitski and Milliman, 2007; Syvitski and Saito, 2007]. Rapid urbanization and demand for freshwater have generated increased groundwater extraction, leading to subsidence in rates and orders of magnitude that exceed current sea level rise [Erban *et al.*, 2014; Minderhoud *et al.*, 2017; Syvitski *et al.*, 2009]. The combination of all the above-mentioned drivers [Figure 9.8] influences change in estuarine salinity.

derhoud *et al.*, 2017]. While there was little extraction-induced compaction in the 1990s, the rates of aquifer-system compaction increased steadily in the following decades to a delta-average subsidence rate of 11 mm/year, locally exceeding 25 mm/year in 2015 [Figure 9.7]. The accelerating trend in subsidence suggested by the model was confirmed by recent InSAR observations, compared with earlier observations [Figure 9.5].

Subsidence processes in deltas can be distinguished between the larger, regional scale — which causes general landscape lowering — and local events, often causing infrastructural damage and local differential subsidence. In the VMD, two main processes are currently generating high subsidence rates at the regional scale, leading to elevation loss of up to several cm per year: 1] natural compaction of shallow sediments, and 2] groundwater extraction-induced aquifer-system compaction. Natural shallow compaction rates are highest along the coastline where young fine-grained deposits are present — e.g. (former) mangrove

forests in the southern part of the delta — and may reach up to 20–30 mm/year, which can be amplified by anthropogenic land-use change and drainage. Aquifer-system compaction following excessive groundwater extraction has been accelerating in the last decades and may locally reach rates of ~30–40 mm/year, depending on local hydro-geological settings and extraction schemes. Other large-scale processes, such as tectonics, isostasy and hydrocarbon-reservoir compaction, generally cause much lower subsidence rates [Frederick *et al.*, 2019; Kooi *et al.*, 1998], and there is no solid evidence suggesting the VMD is an exception to this. At local scale (e.g., in cities), loading by infrastructure and buildings is an additional significant driver of subsidence. Variable surface loading can cause differential subsidence at small spatial scales, and can cause damage to buildings and infrastructure [de Wit *et al.*, 2021]. Furthermore, other drivers, such as groundwater extraction and drainage, also tend to be larger in urban areas, causing additional subsidence. This explains the subsidence hotspots in Can Tho and other large cities in the VMD.

3. Salt intrusion

3.1 Salinity in deltas

Salt intrusion in deltaic surface and groundwater systems is a natural process [Bierkens and Wada, 2019; Mac Cready and Geyer, 2010; Jay and Dungan Smith, 1990; Monismith *et al.*, 2002; Werner and Simmons, 2009]. While fresh-saline dynamics in the groundwater system follow timescales in the order of decades, the dynamics of salt intrusion in the surface

waters vary at timescales in the order of hours, influenced by numerous natural and anthropogenic drivers [Box 9.3]. Among the exposures and vulnerabilities, increased salt intrusion is a major threat to livelihoods in deltas. Considering its impact on water supply, food, and job security, agri-/aqua-cultural activities and the ripple effects on the human geography of deltas and beyond, recovery from — or adaptation to — increased salinity can take generations. As in several other deltas worldwide [Bucx *et al.*, 2014; Echezuría *et al.*, 2002; Gong and Shen, 2011; Hoep-

ner *et al.*, 2008; Kashef, 1983; Nguyen *et al.*, 2017; Rabbani *et al.*, 2013; Ralston and Geyer, 2019; Takeda *et al.*, 2016; Zia *et al.*, 2017], the Mekong delta [Khang *et al.*, 2008; Smajgl *et al.*, 2015], is experiencing increased salt intrusion. The trends are observed both in the groundwater and surface water systems, but here we focus on the surface water systems. Many academic or policy documents associate salt intrusion with global sea level rise and more significant drought events [Mekong Delta Plan, 2013; Khang *et al.*, 2008; Smajgl *et al.*, 2015]. Nevertheless, in itself, salt intrusion is a sophisticated three-dimensional phenomenon [Box 9.3] that is highly sensitive to the “local drivers of exposure and vulnerability” [Oppenheimer *et al.*, 2019]. The VMD is exemplar of a system that is stressed under all climatic and anthropogenic drivers. Therefore, a comprehensive process-understanding of the VMD calls for assessing a wider range of geophysical drivers (e.g., See Box 9.3).

3.2 Systems Observations

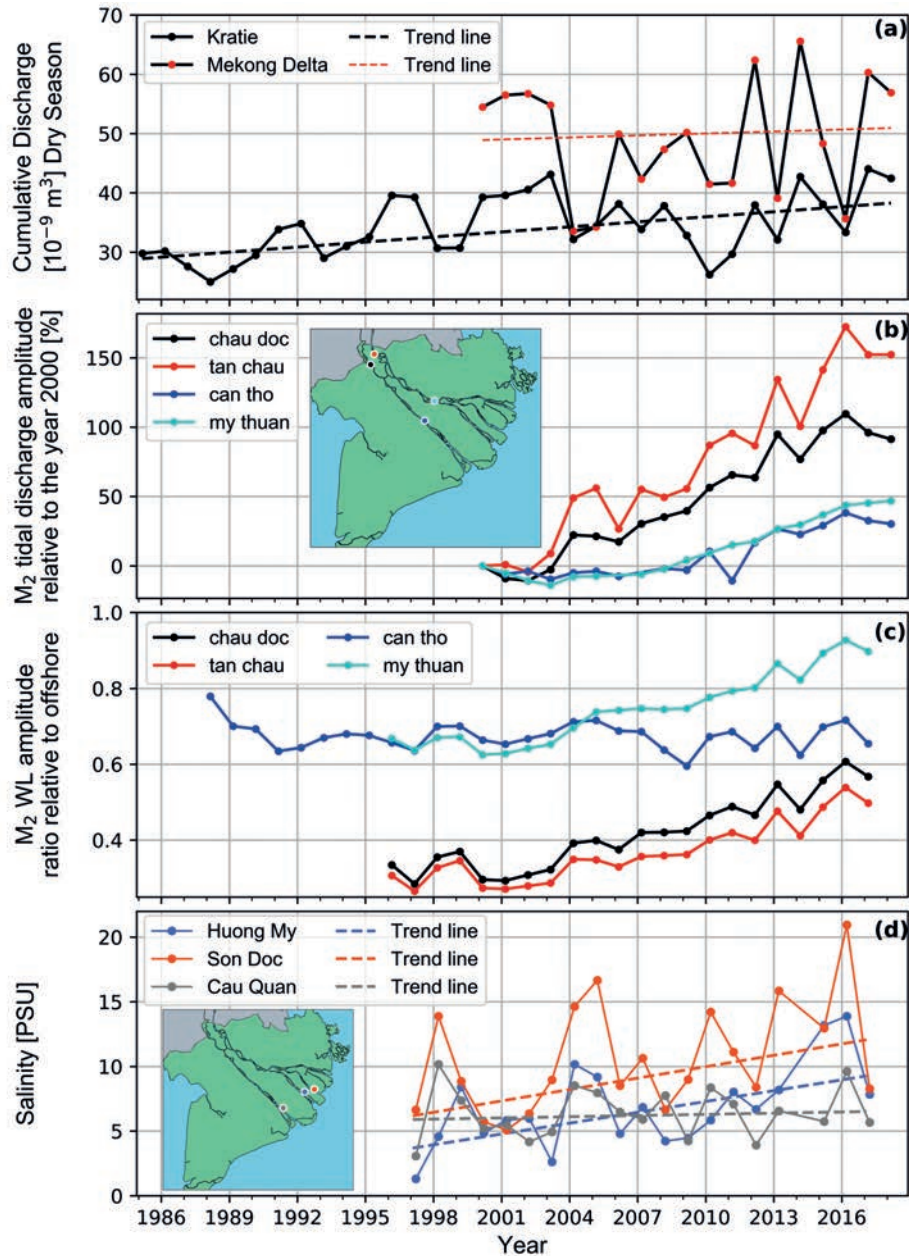
Trends for the highest 5% (P95) observed salinity during the dry season show an average 0.2 PPT/year increase over the last two decades [Eslami *et al.*, 2019b] at multiple stations along the main VMD channels [Figures 9.2 and 9.9d]. They show a spatial asymmetry: except for the Dinh An distributary of Hau River, all channels show a temporal increase in salt intrusion. In principle, salt intrusion is the outcome of competition between fluvial (discharge) and marine (tidal mixing) forces within a given geometry/bathymetry [Box 9.3]. Figure 9.9.a shows that dry season cumulative discharge of the Mekong River at Kratie, Cambodia, as well as at the stations within the VMD, does not exhibit any decli-

ning trend in the last two decades. In fact, cumulative dry season discharge in Kratie has been increasing [Hoang *et al.*, 2019; Lauri *et al.*, 2012; Li *et al.*, 2017; Hoang *et al.*, 2016; Thompson *et al.*, 2013]. While Mekong River discharge has followed an increasing trend, due to the declining role of the Lake Tonle Sap [chapter 7], freshwater supply to the delta has not increased. However, the fact that there is no clear decline in total discharge implies that increased salt intrusion is driven by other environmental drivers.

On the contrary, the tidal discharge amplitude (horizontal tide, Figure 9.9b) relative to the year 2000 shows a consistent and significant increasing trend at all stations, varying from 40% in Can Tho and My Thuan with larger tidal discharge, to 150% in Tan Chau with smaller tidal discharge. At the same time, tidal water level amplitude (vertical tide, Figure 9.9c) relative to offshore shows a substantial increase, except in Can Tho. While offshore tidal amplitude has increased by ~1.2–2 mm/year due to sea level rise [Nhan, 2016], vertical tidal amplification within the VMD has followed an approximately 15–20 mm/year trend. Significant tidal amplification, along with increasing trends of tidal propagation speed [Eslami *et al.*, 2019b], provides solid evidence of a substantial increase in river depths, which explains the adaptation of the salinity structure to the new condition. The tidal dynamics [Eslami *et al.*, 2019b], validated by hydrographic observations [Binh *et al.*, 2020; Eslami *et al.*, 2019b; Vasilopoulos *et al.*, 2020], imply an average 2–3 m riverbed incision over the past two decades. When two (ocean forces and bathymetry) out of the three main determinants of salt intrusion change, this results in a new estuarine salinity balance that is characterized by further intrusion.

[Figure 9.9]

Hydrological and hydrodynamic changes over the last decades



Dry season cumulative discharge of the Mekong River and cumulative fluvial discharge to the delta and its trends (a); tidal discharge variation relative to the year 2000 (b); changes in tidal amplitude relative to offshore indicating tidal amplification in the delta (c); trends of salinity (P95) variations at three different stations along the estuaries of the delta.



[Figure 9.10] Sand mining in the delta

Sand mining and sand barges in An Giang (a) and Tien Giang (b) provinces, Viet Nam.
Pictures: Courtesy of Huynh Buu Dau / Tuoi Tre News.

Riverbed level incision (~15 cm/year) [Binh *et al.*, 2018; Eslami *et al.*, 2019b; Vasilopoulos *et al.*, 2020] is responsible for the increased salt intrusion length in the delta, while the anthropogenically-altered hydrological regime [Chapter 7] caused by upstream hydropower operations is responsible for the frequently observed longer periods of salinity. Sediment starvation due to upstream entrapment of over 350 tributary and 14 mainstream dams, and large amounts of sand mining [Figure 9.10] in Viet Nam, Cambodia, and Laos (several times larger than the total fluvial sediment

supply [Bravard *et al.*, 2013; Brunier *et al.*, 2014; Eslami *et al.*, 2019b; Jordan *et al.*, 2019] have resulted in the observed riverbed level incisions that drive salinity further inland [Eslami *et al.*, 2021a]. Furthermore, historically, Lake Tonle Sap provided freshwater to the delta until late January. But with the observed peak water level decline in the Mekong River, Lake Tonle Sap does not store water to its capacity, and often drains by mid-late December, resulting in the maximum dry season salinity increase taking place earlier than before, and the delta experiencing a longer period of salinity.

4. The delta's future

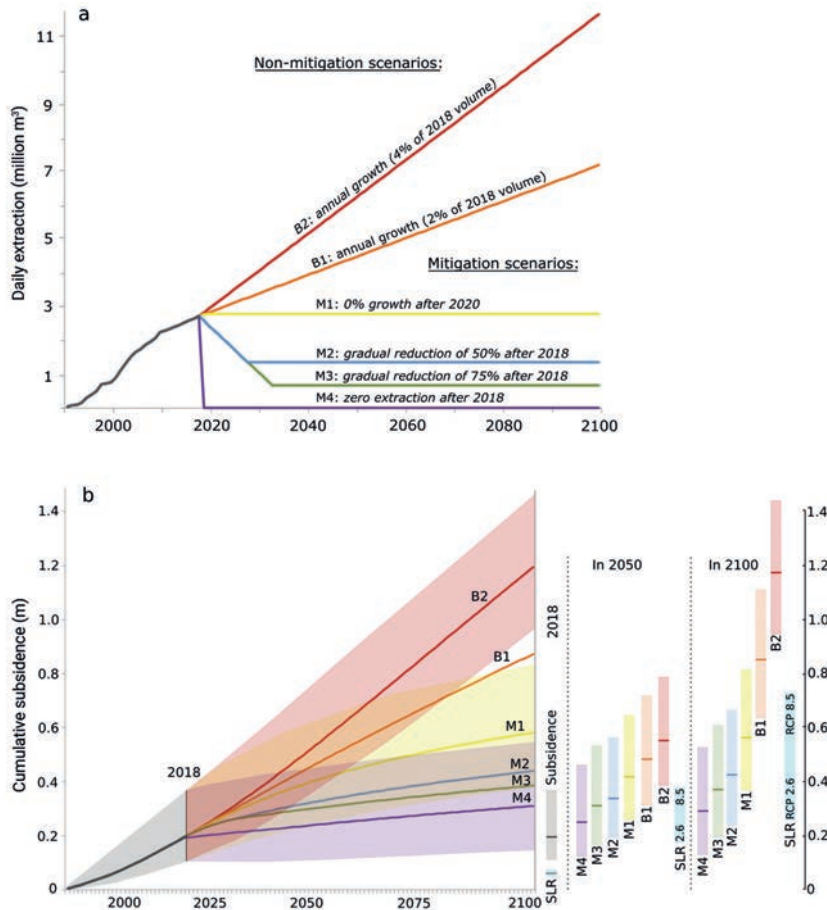
4.1 Elevation loss

The delta is losing elevation in relation to sea level due to the combination of climate change-induced sea level rise [Chapter 1], subsidence resulting from both natural and anthropogenic processes, and reduced sediment deposition. As the delta has an extremely low elevation above the sea, relative sea level rise poses a major and urgent threat to the delta. Projections of elevation are important to assess future flood exposure, saline water intrusion and potential permanent inundation as parts of the delta fall below sea level. Although subsidence is related to a large number of drivers and processes, only large-scale regional processes need to be considered, since local processes – such as sinking of individual objects or buildings – do not contribute to general delta elevation loss. As described above, the two main subsidence processes are natural shallow compaction and extraction-induced aquifer-system com-

paction, with the latter being the dominant driver of present-day subsidence.

The effect of potential future groundwater extraction and consequent subsidence was modelled using the aforementioned 3D model, following several mitigation and non-mitigation scenarios of groundwater extraction during the XXIst century [Figure 9.11]. The amount of future extraction-induced subsidence will strongly depend on the amount of future groundwater extraction, with much lower subsidence rates associated with stronger reductions in extraction. It also became clear that in the coming decades, almost regardless of the level of mitigation, extraction-induced subsidence will outpace global sea level rise in the VMD. However, in the second half of the century, the mitigation scenarios show equal or lower rates of subsidence in comparison to gradually increasing sea level rise. For the VMD, this means that directing efforts on mitigating subsidence by reducing groundwater extractions is the most efficient way to reduce relative sea level rise in the near future.

[Figure 9.11]
Groundwater extraction scenarios and induced subsidence

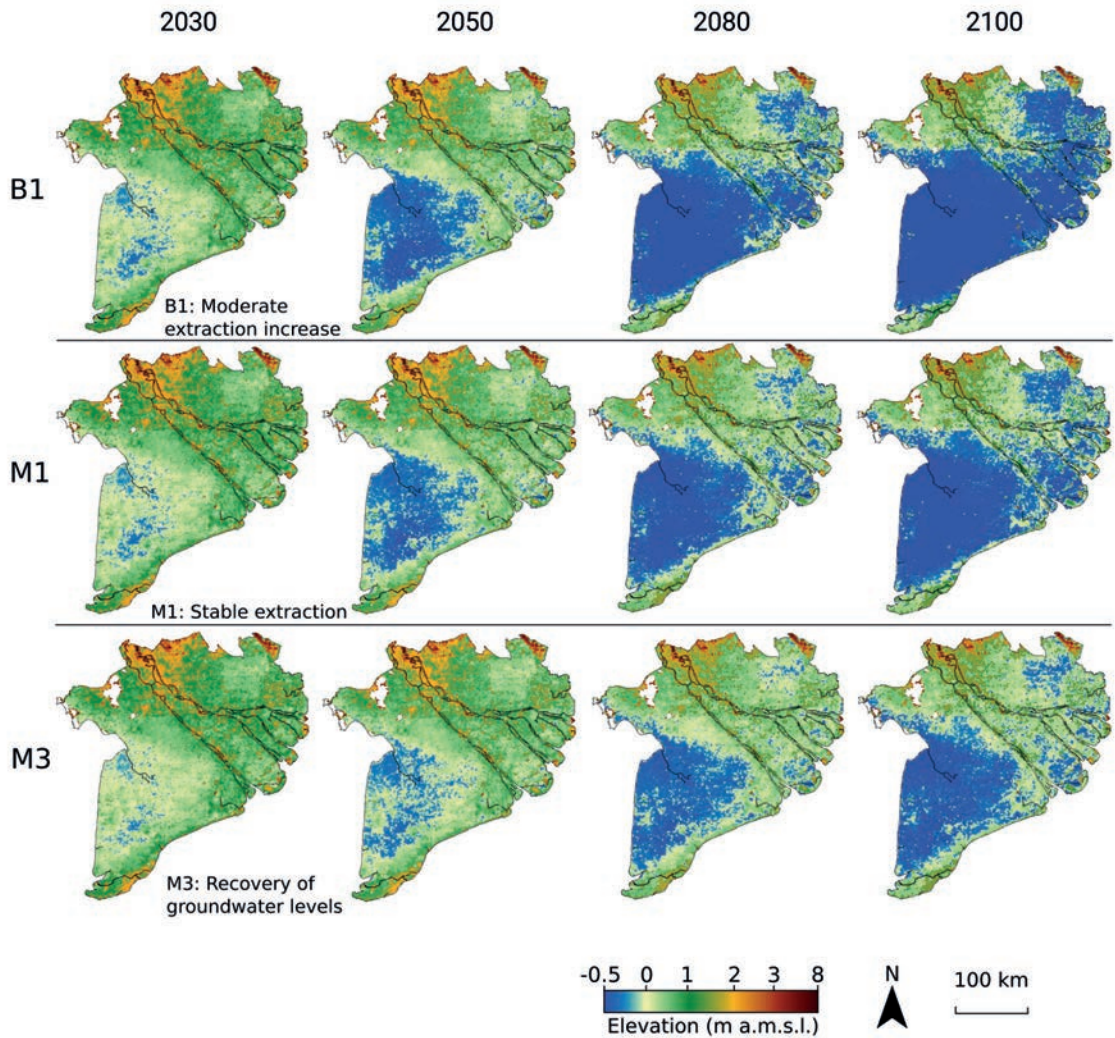


(a) Groundwater extraction pathways for the XXIst century for different (non-)mitigation scenarios modelled in the VMD [Minderhoud *et al.*, 2020]. (b) Evolution of cumulative delta-average subsidence following the extraction pathways. Solid lines show the best-estimate model results, and the colours cover the range between the least and most conservative model. Time slices for 2050 and 2100 show the comparison of extraction-induced subsidence and sea level rise following IPCC SROCC scenarios [Minderhoud *et al.*, 2020].

In a naturally functioning delta, subsidence is counterbalanced by sediment deposition on the delta surface. However, there are no delta-wide data or estimates of present or future sediment deposition in the VMD. Therefore, it is not possible to create spatially explicit calculations including exact quantifications for sedimentation. Although unlikely in the pre-

sent situation, especially considering the strong decline in fluvial sediment reaching the delta, it can be assumed that natural compaction is being compensated by sediment deposition. Following this assumption, delta-wide future elevation was projected following projections of sea level rise and extraction-induced subsidence [Figure 9.12].

[Figure 9.12]
Projections of future elevation



Projections of future elevation with extraction-induced subsidence following three extraction scenarios and global sea level rise according to the mid-range (RCP4.5) projection. Elevation is in metres above mean sea level based on the TopoDEM [Minderhoud *et al.* 2019a, 2019b]. Additional elevation loss by subsidence because of natural compaction is assumed to be counterbalanced by elevation gain through deposition of new sediments.

4.2 Salinity in the delta

This section presents the results of recent projections of future salt intrusion in the delta, carried out within the framework of the GEMMES Viet Nam and the Rise and Fall projects [Eslami *et al.*, 2021b], using a state-of-the-art numerical model [Eslami *et al.*, 2019a, 2021a] of the VMD (Delft3D-FM). This project combined the results of the first delta-wide 3D surface-water model of the VMD, stretching from Kratie to 70 km offshore, and the first hydrogeological model of the VMD [Minderhoud *et al.*, 2017] (Section 2.3.), to examine the effect of both climate change-related and anthropogenic drivers of change in isolation and in combination.

Climate change drivers of salt intrusion

Global climate change can impact salt intrusions in the VMD through sea-level rise and variations in fluvial discharge to the delta. The rates of sea level rise are set to increase in the coming decades [Chapter 1], with potentially substantial implications for salt intrusion in the VMD (and other deltas). On the other hand, due to anomalies in evaporation and precipitation, river discharge is generally expected to increase in the first half of the century [Guerra-Chanis *et al.*, 2019; Hoang *et al.*, 2019; Lauri *et al.*, 2012; Hoang *et al.*, 2016; Thompson *et al.*, 2013], which could potentially reduce salt intrusion. Therefore, it is the combined effect of increased freshwater supply and sea level rise that determines the role of climatic drivers on salt intrusion in the delta. Figure 9.13a shows projected sea level rise [MoNRE, 2016] along the VMD coast under RCP4.5 and RCP8.5 climate scenarios. These projections are relatively similar, with an increase of 23 cm and 25 cm respectively in 2050. However, considering the upper tail

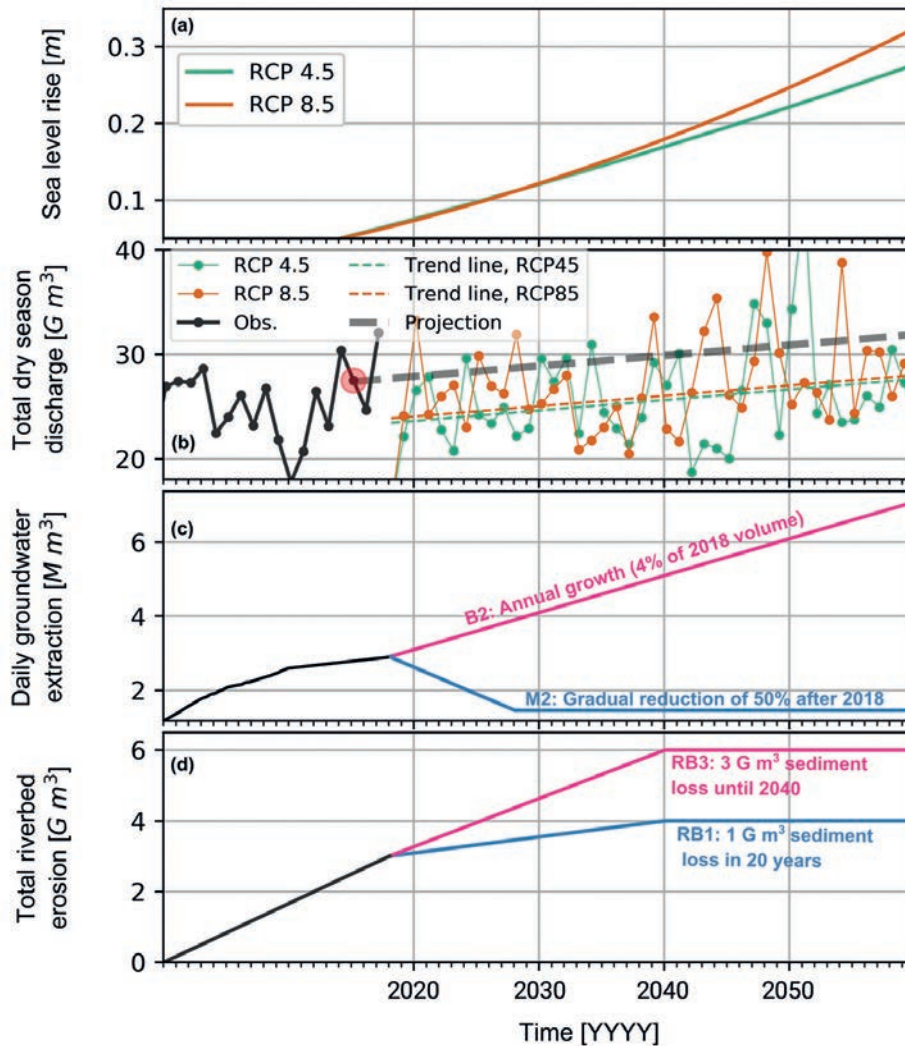
behaviour and uncertainties in sea level projections, an additional extreme scenario of a 60 cm rise by 2050 is also considered [Bamber *et al.*, 2019]. Figure 9.13b shows that dry season cumulative upstream discharge is projected to increase until 2050 (including the effects of hydropower development) under both RCP4.5 and RCP8.5 scenarios. These trends were obtained by the regional Integrated Catchment Model (INCA) [Wade *et al.*, 2002; Whitehead *et al.*, 1998, 2019] (forced by the Global Circulation Model GFDL-CM) and validated by comparison with five different global climate models simulated by PCR-GLOBWB [Sutanudjaja *et al.*, 2018] used in the Aquaduct Flood Project [Sutanudjaja *et al.*, 2018; Ward *et al.*, 2020], (see Eslami *et al.* (2021b) for further details). This study considers the year 2015 (non-drought) as the baseline, and linearly increases discharge towards 2050 following these trend lines to provide a non-exaggerated projection of salt intrusion in the delta. Given the observed hydrological regime shift of the Mekong River, it is realistic to assume that Lake Tonle Sap has zero contribution to the VMD freshwater supply during the peak of the dry season from January to April (see Chapter 7).

Anthropogenic drivers of salt intrusion

The anthropogenic drivers are categorized under spatially-varied extraction-induced land subsidence [Minderhoud *et al.*, 2017], and riverbed level changes due to sediment starvation [Bravard *et al.*, 2013; Eslami *et al.*, 2019b]. Two different scenarios are considered for each driver:

► Figure 9.13c shows two opposing extreme and favourable scenarios for groundwater extraction [Minderhoud *et al.*, 2020], leading to projected land subsidence due to

[Figure 9.13]
 Scenarios for drivers of saline water intrusion



Scenarios of salt intrusion drivers [Eslami *et al.*, 2021b], climate change-driven sea level rise (a) and discharge variation (b); scenarios of groundwater extraction (c) and sediment loss from the riverbeds (d).

aquifer-system compaction. Given the provisions incorporated in Resolution 120 of the Vietnamese government, we may expect reduction in groundwater extraction. The M2 scenario reflects 5% annual reduction to 50% total extraction volume by 2050. B2 is consi-

dered as the extreme scenario (business as usual) with a 4% annual increase in extraction rates following the trends witnessed over the past 25 years [Minderhoud *et al.*, 2020] (see Section 4.1). The subsidence rates are translated into local bed level changes

of canals and rivers, assuming a constant coastline.

► The average 2–3 m riverbed level incisions [Eslami *et al.*, 2019b; Vasilopoulos *et al.*, 2020] over the past two decades (Section 3.2) are equivalent to losing $\sim 2\text{--}3 \times 10^9 \text{ m}^3$ (150–200 M m³/year) due to sediment starvation. Considering the $1 \times 10^9 \text{ m}^3$ demand for sand through to 2040 [SIWRP, 2015] and the continuous erosion caused by upstream suspended sediment trapping, two scenarios for riverbed changes through to 2040 are considered, assuming that erosion ceases beyond 2040 due to rising awareness and lack of erodible material [Figure 9.13d]. RB3 assumes erosion rates identical to the past 20 years (business-as-usual) and RB1 assumes significantly lower (one third) erosion over the next two decades.

Projections of salt intrusion

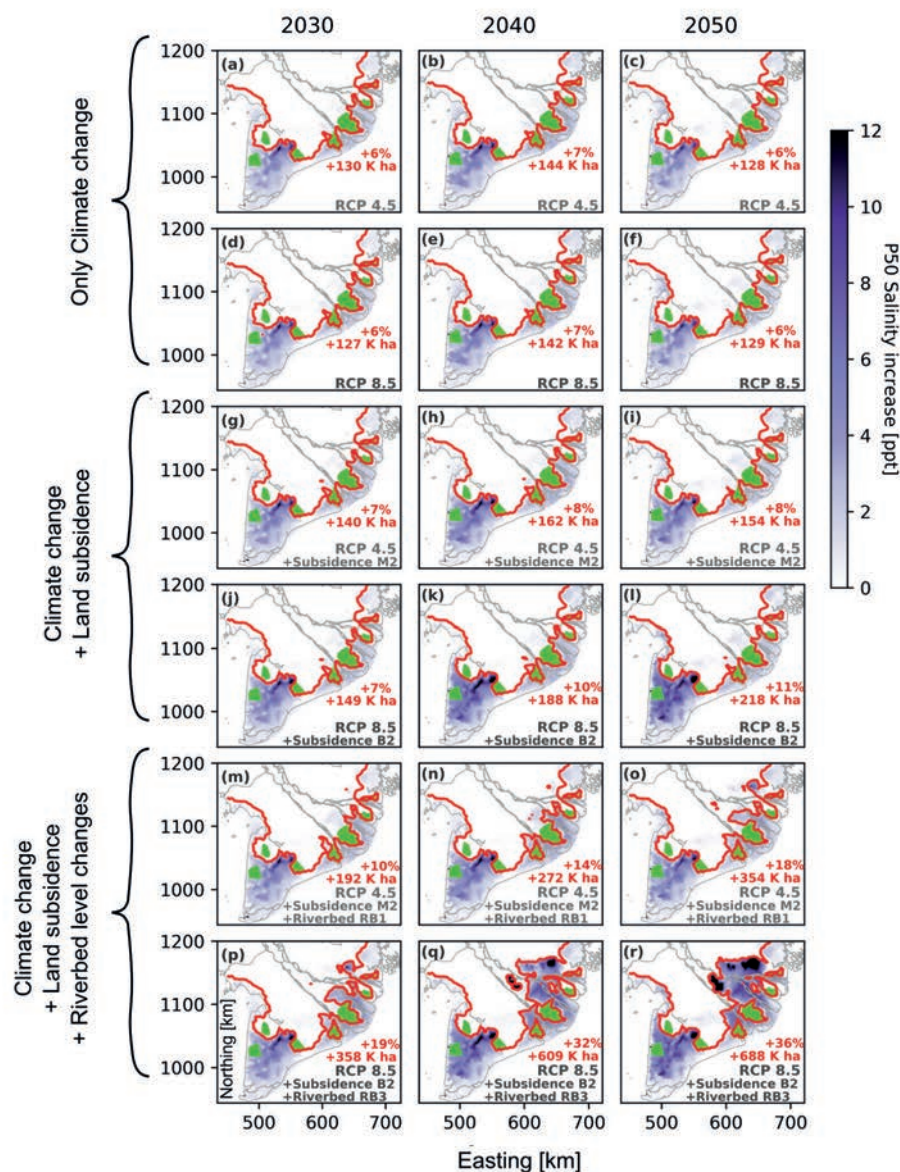
The isolated and combined effects of climate change and other drivers are presented in Figure 9.14. They describe a wide range of possibilities for the spatial distribution of the dry season median (P50) salinity increase across the delta. Spatial variation of net salinity increase, relative to the base case scenario (year 2015), shows how a present-day normal year could change over the next three decades. Climate change alone [Figure 9.14a–f] can increase salinity by 2–2.5 ppt by 2040 in all coastal provinces and add $\sim 6\%$ additional areas affected by salinity. However, within the estuarine networks, the effect of absolute sea level rise is balanced by upstream discharge increase. Additional land subsidence [Figure 9.14g–i], especially under extreme scenarios, similar to the effect of climate change, mainly increases salt intrusion in the coastal provinces by an additional average 0.5–1 PPT by

the year 2040 and adds 2–6% additional salinity-affected areas with limited impact on salinity dynamics in the estuarine channels. However, even moderate scenarios of riverbed level changes dramatically increase salinity in the estuarine channels (an additional 5–30 km) and consequently increase areas affected by salt intrusion within the delta. Riverbed level changes, depending on sediment supply and sand mining practices (within and beyond the delta), can increase the total areas affected by salinity by an additional 5–25% by 2050 (an additional 150–500 10^3 ha of land). Given the uncertainties in various drivers of change, we may expect a range of possibilities from ~ 5 to $\sim 40\%$ increase ($+100$ to $700 \times 10^3 \text{ ha}$) in areas affected by saline water intrusion by 2050.

Within the VMD provinces, Ca Mau Peninsula is most vulnerable to sea level rise and land subsidence, while provinces such as Bac Lieu, Soc Trang and Kien Giang are also highly impacted. On the other hand, the estuarine system is most sensitive to riverbed level changes. Therefore, in keeping with observed trends over the past two decades [Eslami *et al.*, 2019b], we expect stronger response in the Tien estuarine system compared to Hau River in the all-drivers scenarios, mainly due to the fact that we expect little to no change in the lower Hau (downstream of Can Tho) estuarine channel depths [Allison *et al.*, 2017]. This means that even provinces further inland, such as Vinh Long and Dong Thap (currently with no experience of salt intrusion), will potentially have limited/no direct access to fresh river water during the dry season. Note that, under all-driver scenarios, in an extreme drought event similar to 2016 or 2019, saline water can creep up to $\sim 150 \text{ km}$ inland (see Figure 9.2 and Eslami *et al.*, 2021b for further detail). Sensitivity analysis shows that these projections can vary significantly de-

[Figure 9.14]

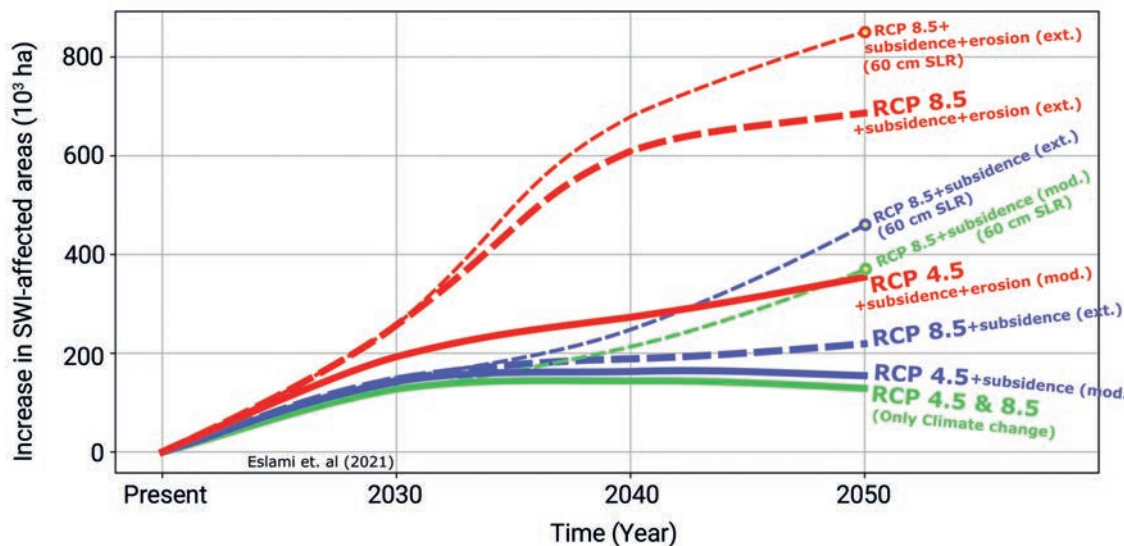
Scenarios of increase in saline water intrusion under climatic and anthropogenic drivers



Spatial distribution of P50 (average) **salinity increase** and the extent of salt intrusion (2 PPT absolute salinity contour line) under RCP4.5 (uneven rows) and RCP8.5 (even rows) CC scenarios for CC scenario only (a-f); combined effect of CC and land subsidence (g-l); combined effect of CC, land subsidence and bed level incision (m-r); the green areas define the existing freshwater zones (mainly by sluice gates); the red percentage per panel is the increase in salinity-affected surface area relative to the present-day conditions, and the red number in thousand hectares [K ha] per panel shows increase in area affected by salt intrusion under that scenario.

[Figure 9.15]

Projections of increase in areas affected by saline water intrusion



Projections of **increase** in SWI-affected area (2 PPT contour line in spatial P50 salinity projection maps) within the VMD (10) under various combinations of scenarios of climate change projections (RCP4.5 and 8.5), moderate (mod./M2) and extreme (ext./B2) land subsidence, and moderate (mod./RB1) and extreme (ext./RB3) riverbed erosion, including the case of extreme SLR in the year 2050.

pending on environmental or policy changes [Eslami *et al.*, 2021b]. For example, if the Hau Riverbed levels – downstream of Can Tho – incise (which we do not expect), this will have massive repercussions for the Can Tho province. Furthermore, extreme sea level rise (+60 cm) in response to accelerated Antarctic ice-sheet melting [Bamber *et al.*, 2019] may significantly worsen salt intrusion within and outside the estuarine channels, with an additional 9–13% to the total areas affected by salinity, with dramatic implications for land-use and adaptation strategy, even if the coastlines were maintained.

Despite considering a range of sensitivity ana-

lyses, the undisputed overall conclusion is that riverbed level changes pose the greatest threat in increasing salt intrusion in the next 2–3 decades. Figure 9.14 summarizes the expected temporal change in areas affected by salinity under different scenarios, including the scenario considering the effects of extreme sea level rise. Under climate change alone, the areas affected by salinity will decline between 2040 and 2050. However, this will not be the case if sea level rise accelerates beyond RCP8.5 projections, and this can also not be extrapolated beyond 2050, as the climate projections – especially upstream discharge – diverge beyond 2060. Therefore, there may be a larger number of environmen-

tal pathways in the second half of the century. The effect of land subsidence is more local, and especially impacts the coastal provinces that are already experiencing salinity. Assuming a stable water-/coastline, its impact on the aggregate areas affected by salinity is

expected to be limited. Note that the decelerated all-drivers increase in salinity between 2040–2050 is mainly due to the assumption that riverbed levels will stabilize beyond 2040 (see Eslami *et al.* 2021b for further detail).

5. Main conclusions and policy implications

This report integrates the effects of climatic and anthropogenic drivers of change within the Mekong Delta. It addresses in detail the past, present and future dynamics of two main trends: 1] elevation loss (land subsidence + sea level rise) and 2] increased salt intrusion in the surface water system.

Under existing rates of sea level rise (~3 mm/year) and climate scenarios, current rates of domestic anthropogenic groundwater extraction-induced land subsidence (~10–40 mm/year, spatially varying) exceed the impact of global climate change. Depending on the policy development and enforcement, as well as the sea level rise acceleration rates towards second half of the century, a large part of the delta's sub-aerial surface may descend permanently below mean sea level.

Furthermore, the effect of current climate change impact on increased salt intrusion has been shown to be limited. In the first half of the century, the increased river discharge during the dry season can partially counterbalance salt intrusion, especially in the estuarine channels. However, in coastal pro-

vinces distant from the river, salinity will still increase (0.1 PPT/year). While land subsidence marginally impacts salt intrusion in the surface water, sediment starvation — driven by upstream hydropower development and sand mining (within and beyond the delta), resulting in riverbed level incisions — has been the biggest driver of increased salt intrusion over the past decade, and will perhaps continue in the first half of the century. By our best estimates, we conclude that in the next three decades, environmental change in the delta will be dominated by human-induced activities and the exploitation of natural resources (sand and water). However, depending on the state of human activities in the next two decades, from the mid-century on global climate change and [potentially] accelerated sea level rise may become the main agents of change. Therefore, adaptation and mitigation policies in the coming decade are fundamental to the fate of the delta's livelihood and the cost of adaptation to climate change.

5.1 Main conclusions

► The VMD is subject to various drivers of change, of which the anthropogenic drivers — namely hydropower dams, sand mining, land-use change, and groundwater extraction — pose the greatest threats in the first half of the century, while climate change

effects such as fluvial discharge anomalies and higher frequency of extreme events are expected to become larger threats in the second half of the century.

► The VMD has an extremely low-lying delta plain, with an average elevation of about ~0.8 m above local mean sea level; ~30% of the delta plain will fall below sea level with a relative sea level rise of 50 cm. DEMs derived from satellite data tend to overestimate the true elevation of the VMD, which previously led to underestimation of the delta's exposure to sea level rise.

► Land subsidence in the VMD has accelerated over the past two decades due to human activities. Current rates of subsidence exceed global sea level rise by an order of magnitude, ranging from 10 mm/year to locally more than 50 mm/year. Although partly caused by natural compaction, much of the accelerating subsidence results from groundwater extraction, which has increased 5-fold over the last 20 years.

► Land subsidence together with global sea-level rise determine relative, or experienced, sea level rise. In the coming decades, future relative sea level rise will predominantly be determined by the amount of subsidence, which for a large part depends on human-controlled groundwater extraction. Extraction-induced subsidence alone has the potential to cause large parts of the delta to fall below sea level within coming decades. Should the rate of extraction remain at present-day levels, the average cumulative subsidence could be larger than 80 cm in 2100. Assuming sedimentation will counterbalance natural compaction and combined with a mid-range absolute sea level rise projection, groundwater extraction-induced subsidence can cause the

majority of the delta to fall below sea level by the end of this century.

► While land is subsiding (~1 cm/year) and sea level is rising (~3 mm/year), tidal amplitudes in the delta (especially within the Tien River) have been increasing at alarming rates of 1–2 cm/year. This, together with higher subsidence rates in urban areas (~2–4 cm/year), has a considerable impact on exacerbated city flooding. Tidal amplification (increase in both vertical tidal water level and horizontal tidal discharge), driven by riverbed incisions (10–20 cm/year), is also expected to have significant impact on riverbank erosion, which remains to be studied in further depth.

► Salt intrusion is a growing concern, and salinization has been an increasing trend over the past two decades (0.2–0.5 PSU/year in the coastal areas). Among other drivers such as sea level rise, discharge anomalies and land subsidence, the main driver of the increase in observed salt intrusion over the past 20 years has been riverbed level changes (in rates of 10–15 cm/year) caused by sediment starvation from upstream dams and excessive sand mining.

► Relative sea level rise will most probably cause only moderate increases in the salt balance in the coastal provinces during the first half of the century. Climate change-driven variations have limited impact on salt intrusion (5–6% increase in salinity affected areas). Anthropogenic extraction-induced land subsidence can further increase salinity in the coastal provinces and add an additional 2–6% to areas affected by salinity. Anthropogenic riverbed level incision remains the main driver of salinization of the delta and can impact an additional 10–25% of land in the delta. The

only exception to this conclusion is the case of extreme acceleration of sea level rise (e.g., 50–60 cm by 2050). In the second half of the century, relative sea level rise may become the dominant driver of salt intrusion.

5.2 Policy implications

► **Elevation as a natural asset:** Elevation of the delta, whether sub-aerial (land) or subaqueous (submerged riverbeds), should be considered as a valuable natural asset/resource to be protected rather than exploited. The lower the delta's land and riverbeds, the more vulnerable it is to natural hazards. While "Resolution 120" restricts groundwater and sand exploitation, the scientific evidence demonstrates a much shorter window (than the projected government plans) to implement the changes required to control natural resource exploitation.

► **Mitigating subsidence through groundwater management strategies:** The rate of relative sea level rise in coming decades will largely be determined by the effectiveness of mitigating human-induced subsidence, mainly by reducing groundwater extraction. This requires finding alternative fresh water sources to meet demand. In addition, smart extraction strategies — e.g., relocating extraction to areas that are of higher elevation or less sensitive to subsidence — may moderate the impact. Managed aquifer recharge (MAR) and aquifer storage and recovery (ASR) strategies — i.e. storing harvested rainwater or river water underground during wet season and recovering it during dry season, — may also help to speed up the recovery of water levels in the aquifers, thereby mitigating further extraction-induced subsidence.

► **Controlling sand mining:** Sediment starvation is one of the greatest threats to the livelihood of the delta. Riverbed, bank and coastal erosion and, consequently, saline water intrusion and partial elevation loss are driven by sediment starvation. Sand mining in the extraction volumes currently practised is a major contributor to sediment starvation. Its harmful effects are not only local, but also ripple upstream and downstream (in the tidal system). Enforced regulations seem to be an inevitable choice that needs to be implemented in the short term, for otherwise the irreversible effects of this practice will force policy makers to bring it to an abrupt halt. While halting all sand mining practices may be difficult at short notice, a search for recycling technologies and alternative sources of sand/construction material must be vigorously pursued to minimize the waste and assure efficient use of construction materials.

► **Reinstating flooding in the delta:** While uncontrolled flooding in cities should be avoided, controlled flooding in the floodplains can be significantly beneficial. As previous priorities of the delta were to maximize food production, a shifting paradigm towards sustainability is required. While empoldering and diking were popular in the late 1990s and early 2000s, the paradigm has to smoothly shift to reinstate natural and controlled flooding of the floodplains. Flooding helps the deltaic systems in at least four ways: (a) transport of new sediment to the delta surface to build elevation, (b) it is a major source of nutrients to the floodplains, (c) it creates ecological succession zones with high biodiversity during seasonal flooding, as well as fish spawning habitats, and (d) while within the VMD, city flooding is driven by a combination of land subsidence [Minderhoud *et al.*, 2017] and tidal amplification [Eslami *et al.*, 2019b], inundated flood

plains form buffer zones that lower flood pulse water levels, thereby reducing undesired flood risk in cities.

► **Aim for multi-processes and integrated solutions** in delta systems and at the river basin level rather than individual problems. The physical geography of the Mekong River Basin and the Vietnamese Mekong Delta is a highly interconnected one, which calls for multi-disciplinary, multi-sectorial and integrated adaptation/mitigation strategies. Failure to acknowledge this and adopting only incremental measures to remedy isolated problems will likely shift the challenges from one aspect to another. For example, addressing riverbank erosion in isolation from its main drivers, or independently of riverbed and coastal erosion, will likely worsen the other two (note that further riverbed erosion will significantly exacerbate saline water intrusion). Similarly, large-scale development of sea dikes will cut off the marine sediment supply to the coastal hinterland that is highly dependent on this supply to compensate for the high natural compaction rates.

► Active diplomacy towards **a joint regime of trans-boundary river resource management** (discharge, water level and sediment). Trans-boundary natural resources of the Mekong River are managed in isolation. While there is some regulation on the amount of freshwater discharge, there is limited regulation on sediment and water level management. These latter two parameters are equally important in river/delta management, as lack of sediment has been the culprit for much of the unfavourable environmental change and water level anomalies that have modified the hydrological regime, and thus the duration of the dry season. This active diplomacy could be through empowering

the Mekong River Commission (MRC) as a true and strong moderator in managing the trans-boundary resources of the Mekong River.

► In light of the above, perhaps one of the first potential solutions to dry season salt intrusion would be to form an alliance with Cambodia, which is equally dependent on the ecosystem of **Lake Tonle Sap**, to restore the lake's water levels so that it can act as a retention area during the dry season for the Mekong Delta.

► **Transformation of farming practices** to efficiently manage available surface freshwater resources. Analysis shows that [Eslami *et al.*, 2021b] a 25% reduction in surface water demand can help reduce ~100 10³ ha of areas affected by salt intrusion up to the year 2050. Therefore, efficient use of surface water in irrigation planning — as one of a raft of adaptation/mitigation measures — could make a significant contribution to reducing the impact of salt intrusion.

► While **promoting any kind of sedimentation (organic/inorganic), mixed models of sustainable rice and aquaculture**, or shrimp-mangrove farming could significantly benefit the food, physical and ecological resilience of the delta and its population. By promoting flooding of the farms, bringing suspended sediment to the fields during the wet season, and shifting to brackish aquaculture in times of limited freshwater — while adapting to the more saline condition — the VMD can restore sedimentation in the delta at the individual farm level. Such sustainable farming should, however, be implemented without aggravating environmental quality. Conjunctive use of rain and surface water, as it has long been practiced in the coastal provinces of the VMD [Özdemir *et al.*, 2011; Thuy *et al.*, 2019], can

reduce groundwater extraction for domestic consumption.

► Adaptation measures such as **mixed farming practices** may have challenges in terms of water quality. However, these measures also normally function best at a large scale, where farmers' solidarity helps maintain water quality in the delta at sustainable levels by reducing the use of toxic chemicals and encourages sustainable community farming.

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Chapter 10

Adaptation strategies in the Mekong delta

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Abstract

The objective of [Chapter 10](#) is to present how computational models can be used to represent and understand the interactions between adaptation strategies adopted at different spatial and social scales in several climatic scenarios. These models are variations of a basic model called LUCAS (for Land Use Change for Adaptation Strategies), a spatially explicit agent-based model designed as a combination of social, economic, and environmental dynamics with individual land use change decisions. LUCAS simulates the complex interactions between individual and collective strategies, and their combined and cumulative effects on land use over time. Given a set of assumptions, parameters and scenarios, it provides a picture of land use in the Mekong Delta in 2030, with a vision through to 2050. We show that being able to use a model to consider adaptation efforts at the individual level and proposed strategies at the regional level simultaneously enables a very fine evaluation of the effectiveness of the latter, but also that this approach supports the subsequent integration of more specialized models (rice yields, salt and sediment transport, demographic evolution, groundwater dynamics, etc.). Although kept simple for the purposes of this chapter, virtual experiments based on models like LUCAS have the potential to change the way adaptation planning is conducted in the future.

Tóm tắt

Mục tiêu của [Chương 10](#) nhằm trình bày kết quả ứng dụng mô hình tính toán biểu diễn sự tương tác giữa các chiến lược thích ứng trên phạm vi không gian và xã hội ứng với các điều kiện khí hậu khác nhau. Các mô hình này là các tùy chỉnh của mô hình cơ bản được xây dựng có tên LUCAS (Chiến lược thay đổi sử dụng đất thích ứng). Đây là một mô hình đa tác tử, trong đó dữ liệu không gian được thiết kế kết hợp với các yếu tố kinh tế, xã hội, môi trường và các quyết định thay đổi sử dụng đất của người dân. Mô hình LUCAS mô phỏng các tương tác phức tạp giữa các chiến lược cá nhân người dân và tập thể dưới các tác động tổng hợp và tích lũy của các yếu tố trong sử dụng đất theo thời gian. Dữ liệu đầu vào để hiệu chỉnh và kiểm chứng mô hình được thu thập từ bản đồ hiện trạng sử dụng đất năm 2015 và được giải đoán bổ sung từ ảnh vệ tinh Sentinel 2 cho năm 2020. Dựa trên các giả định, các kịch bản được xây dựng để cung cấp bức tranh về hiện trạng sử dụng đất ở Đồng bằng sông Cửu Long năm 2030 tầm nhìn đến năm 2050. Kết quả đánh giá các chiến lược sử dụng đất thích ứng với biến đổi khí hậu thông qua mô hình cho thấy các chiến lược thích ứng có xem xét đồng thời các nỗ lực thích ứng ở cấp độ người dân và các chiến lược đề xuất ở cấp vùng mang lại hiệu quả tích cực. Ngoài ra, cách tiếp cận mô hình này cũng cho phép tích hợp LUCAS với các mô hình chuyên biệt hơn như mô hình ước đoán năng suất lúa, sự vận chuyển muối và phù sa, phát triển dân số, nước ngầm. Mặc dù được đơn giản hóa cho mục đích của chương này nhưng các thí nghiệm ảo dựa trên LUCAS có khả năng đóng góp trong quá trình lập kế hoạch thích ứng trong tương lai.

Résumé

L'objectif du [chapitre 10](#) est de présenter comment des modèles informatiques peuvent être utilisés pour représenter et comprendre les interactions entre les stratégies d'adaptation à différentes échelles spatiales et sociales dans plusieurs scénarios climatiques. Ces modèles sont des variations d'un modèle de base appelé LUCAS (pour Land Use Change for Adaptation Strategies), un modèle à base d'agents offrant une combinaison de dynamiques sociales, économiques et environnementales avec des décisions individuelles de changement d'utilisation des terres. LUCAS simule les interactions entre les stratégies individuelles et collectives et leurs effets combinés et cumulatifs sur l'utilisation des terres. Compte tenu d'un ensemble d'hypothèses, de paramètres et de scénarios, il fournit une image de l'utilisation des terres dans le delta du Mékong en 2030, avec une vision jusqu'en 2050. Les données d'entrée pour la vérification et la calibration du modèle sont collectées à partir de la carte d'utilisation des terres pour 2015 et interprétées à partir d'images Sentinel 2 pour 2020. Nous montrons que la possibilité de considérer dans un modèle, simultanément, les efforts d'adaptation au niveau individuel et les stratégies proposées au niveau régional permet une évaluation très fine de l'efficacité de ces dernières, mais aussi que cette approche favorise l'intégration ultérieure de modèles plus spécialisés (rendements rizicoles, transport de sel et de sédiments, évolution démographique, dynamique des eaux souterraines, etc.) Bien qu'elles soient restées simples pour les besoins de ce chapitre, les expériences virtuelles basées sur LUCAS ont le potentiel de changer la façon dont la planification de l'adaptation est menée à l'avenir.

1. Introduction

As described in detail in [Chapter 1](#), climate change will affect human communities in Viet Nam by altering environmental conditions such as temperature, precipitation, and sea level, as well as the energy [\[Chapter 5\]](#), water [\[Chapter 3\]](#), food [\[Chapter 4\]](#), and transportation systems on which these communities depend. In the Vietnamese Mekong Delta in particular, this may exacerbate existing local stressors and have a significant impact on the agricultural sector. Indeed, in recent years, the combined effects of fluctuations in profits from agricultural and aquaculture production, changes in management policies, and increases in various environmental stresses have seriously affected agricultural production in the coastal provinces of the Mekong Delta [Nguyen Xuan Hien *et al.*, 2016; Wassmann *et al.*, 2004].

The anticipated impacts of climate change (increased saltwater intrusion due to subsidence and sea level rise [\[Chapter 9\]](#), increased duration of drought periods due to rising temperatures, and decreased availability of freshwater are then going to weigh on farmers' vulnerability in a concerning way. Furthermore, groundwater extraction, which is supposed to partially offset this vulnerability, actually worsens the situation by increasing subsidence throughout the Delta [Minderhoud *et al.*, 2020], which will exacerbate saline intrusion.

To adapt to these unavoidable changes, national and provincial planning authorities are being mobilized to design plans at the regional level to reduce these impacts, and support the sustainable development of the region by promoting resilient adaptation of ecosystems,

communities, and infrastructure. As described in [Chapter 11](#), this may involve multiple interventions, such as building new infrastructure, better land and resource use planning, financial incentives, or crop and land use diversification. In parallel to these medium- to long-term planned adaptation strategies, farmers and local communities are not standing still. They are experimenting with individual, sometimes short-term strategies, dictated by their perception of environmental changes (e.g. shifting from rice cultivation to aquaculture in response to soil salinization) or economic opportunities (e.g. shifting to intensive agriculture to benefit from good market conditions). These individual strategies might differ from those of the planners, and may even be contradictory and barely generalizable at regional scale, yet they are one of the key drivers of the global adaptation process and cannot be overlooked [\[Chapter 11\]](#). Although land use change in the Mekong Delta is guided by ten-year plans, some models have shown [Drogoul *et al.*, 2016] that actual land use can be explained by a predominance of these individual choices, at the plot or village level, which are constrained by environmental suitability and health and, of course, economic factors such as the existence of a value chain. Encouraged since the early 1990s by an incentive policy, this has led to a gradual intensification of crops, which has accompanied and fuelled the prodigious leap forward in Vietnamese agriculture over the past 20 years. However, this intensification has also had the consequence of weakening both the value chains (over-dependent on monocultures) and the environment (additional inputs, water requirements, etc.) and making them much more vulnerable to climate change, sea level rise, changes in ecosystems and pests [Phan *et al.*, 2010], or extreme weather events caused by climate change.

These different trends are being scrutinized in a growing number of studies measuring or assessing the effects of climate change — primarily sea level rise — on agriculture in the Mekong Delta, and highlighting recommendations for adaptation, both at the local level for farmers and communes and at the global level for the government [Vu Thuy Linh, 2020]. In a number of these studies, the adaptation policies advocated are modelled and evaluated in certain scenarios [Holman *et al.*, 2019], which are themselves derived from the results of numerical simulations of the consequences of climate change. Assuming that the main actors of change were farmers, much work has called for relatively profound changes on their part, inviting them to modify their agricultural practices or land use to minimize the impact of the coming changes on their incomes [Bong *et al.*, 2018; Vu Thuy Linh, 2020]. But this call for the conversion of individual agricultural practices overlooks two fundamental aspects: first, the scaling up or generalization of practices considered virtuous on a small scale is not at all guaranteed to deliver on its promises at larger scales; second, the lack of coordination between individual adaptations risks leading to practices that would only be governed by immediate profit, or that would compete for access to shared resources (water, quality soils, seeds, etc.). These two aspects bear the risk of aggravating an already serious situation.

At the other end of the spectrum, many authors have looked at ways to better help authorities define good adaptation strategies in an increasingly uncertain world, for example by proposing adaptation pathways, notably in Bosomworth *et al.* (2015), Lin *et al.* (2013) or Haasnoot *et al.* (2019). The latter emphasize that traditional planning (a 10-year plan, with a 5-year reassessment), as practiced in land

use, is no longer adapted to these new threats and should be replaced by dynamic adaptation pathways, where key steps such as vulnerability assessment, definition of adaptation or investment plans should be reviewed and updated every year, by assessing the current impact of climate change. These new approaches to planning provide welcome capabilities to adapt more quickly and flexibly to changes, some of which are inevitable. However, like their predecessors, they ignore the essential role played by spontaneous adaptation at the individual level, choosing instead to imagine an ideal world in which farmers could change crops at will, according to planned adaptation needs at a higher level.

Research and training efforts are now underway to support the capacity of institutions to plan climate adaptation using model-based or scenario-based resources and tools. They are still far from being routinely used, however, because they cannot embrace all the richness that adaptive practices in this environment cover at multiple scales. But, as is already the case for climate change impact assessment, models are gradually becoming part of the planners' toolbox, simply because the dynamics of interactions between human communities and their environment in a context as complex and changing as the Mekong Delta can no longer be understood by human expertise alone [Kelly *et al.*, 2013]. However, the design of these models raises two challenges: 1] they must support multidisciplinary contributions, as their scope extends beyond climate-related issues to encompass social, economic, and ecological issues; and 2] they must represent the complexity of socio-ecological processes that must adapt, including individual-level behaviours and decision-making processes, as well as global, nationwide dynamics and constraints [Chapter 13]. So, although all specialists agree that

adaptation to the effects of climate change will require a profound change in land use in the Mekong Delta — whether it is decreed by the authorities, decided autonomously by local communities, or the result of the interaction between these two processes — very few tools (an interesting exception being Smaijl *et al.*, 2015b) can really support a scientific approach to this change so far.

The objective of this chapter is therefore to present how one can use computational models to represent and understand the interactions and feedbacks between adaptation strategies adopted at these different levels. By exploring the response of these models in several scenarios, we show how to evaluate large-scale adaptation strategies while simultaneously accounting for the effect of individual decisions. These models are variations of a basic model called LUCAS (for Land Use Change for Adaptation Strategies), a spatially explicit agent-based model designed as a combination of social, economic, and environmental dynamics with individual land use change decisions. LUCAS is programmed to simulate the complex interactions between individual and collective strategies, and their combined and cumulative effects on land use over time. Given a set of assumptions, parameters and scenarios (including climate scenarios, of course), its main objective is to obtain a picture of land use in the Mekong Delta in 2030, with a possible view through to 2050, to effectively support the work of planners.

In the model, farmers and their fields are explicitly represented, and subjected to several processes ranging from large-scale environmental dynamics, socio-economic and climatic changes, to individual decision-making based on local perception of these changes. Input data for model verification and calibra-

tion were collected from the existing land use map in 2015, and interpreted from Sentinel 2 satellite imagery in 2020 [Chapter 4]. Among the many climate change scenarios, temperature, precipitation [Chapter 1] from 2015 to 2050 and sea level rise (SLR) data with RCP4.5 and 8.5 scenarios [Chapter 9] were selected. Assuming that understanding the adaptive dynamics at work and proposing adaptation strategies at the scale of the Mekong Delta should be as much about the choice of the individual farmers as it is about the orientations of the government planners, LUCAS relies on an agent-based modelling approach [Drogoul *et al.*, 2002] that supports the exploration, in different scenarios, of dynamic combinations of these bottom-up and top-down practices, in order to best inform the decision-making of the authorities concerned.

Although it proposes to explore the effects of these combinations by immersing them in scenarios running to 2030, with a vision through to 2050, this chapter is not intended to offer predictions on the state of Vietnamese stakeholders' adaptation to climate change at that date. We will indeed introduce models in which humans are not passive actors but can instead adopt options or make choices that will defer impacts, transform vulnerabilities, and ultimately modify the system itself. The consequence of these highly nonlinear characteristics is that the model presented in this chapter allows everyone, by changing the assumptions and parameters, to explore the possible trajectories of the system. It cannot, of course, predict which ones will be the most likely, but it provides clues to decision makers about the impact of their decisions on these trajectories.

After a detailed description of the context of adaptation to climate change in the agricultural sector — in which we review both its

vulnerabilities and the policies implemented to address them — this chapter presents the LUCAS (Land Use Change for Adaptation Strategies) model, which was designed as a virtual laboratory, on the scale of the Mekong Delta, to simulate and evaluate the performance of different adaptation strategies and their combinations, at different levels, in different climatic, demographic or economic scenarios. Three simple strategies are presented and evaluated: the first one is based only on individual farmers' choices, without any help or hindrance from the government; the second one is based only on governmental decisions, without spontaneous adapta-

tion by farmers; and the third one is based on a combination of these two approaches, in which the government supports the individual choices that seem relevant to reducing the impacts of climate change. We conclude with a discussion on the interest of better promoting this type of modelling approach in the field of climate change adaptation — as it enables all the contributions of the different stakeholders to be taken into account, thus facilitating the construction of consensual adaptation strategies — and describe the future work we will undertake to develop, disseminate and use LUCAS.

2. Environmental change and climate change adaptation in the Mekong Delta

2.1 Land use changes in the Mekong Delta

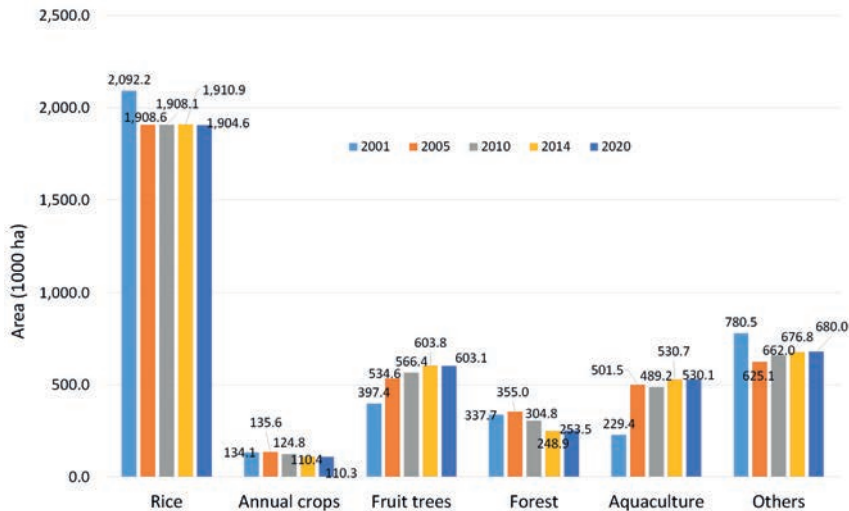
The Mekong Delta is a collection of 13 disparate provinces, which nevertheless have in common the fact of having a predominantly rural population. Although the rural population has tended to decrease since 2008 — following a general dynamic in Viet Nam, accentuated by the rural exodus and the decrease in fertility (according to UNESCO (2016), 34% of Vietnamese live in urban areas: if the growth rate of the general population is 1% per year, that of the urban population is 3.4% per year, and that of the rural population is only 0.4%) — it is still a large majority (74.86% according to General Statistic Office, 2020) in the Mekong

Delta. If there is to be adaptation to climate change, it will necessarily involve adaptation of this population and its agricultural practices, in particular its use of land.

The ability to adapt to climate change in rural areas depends on an understanding of its current and future impacts by policy makers and citizens. In that respect, one of the most important tools promoted by the Government to integrate climate change adaptation and disaster risk reduction into farming practices is land-use planning [Government of Vietnam, 2019; MoNRE, 2021b].

In recent years, land use change in the Mekong Delta has been analysed in numerous reports, which showed that land use change is affected by socio-economic and environmental factors [Drogoul *et al.*, 2016] in which the changes take place mainly according to the profitability of the farming methods when the environment is favourable [Nguyen Thanh *et al.*, 2021].

[Figure 10.1]
Land use changes in the Mekong Delta



Source: MoNRE, 2016, 2021a; Prime Minister of VN, 2001, 2007.

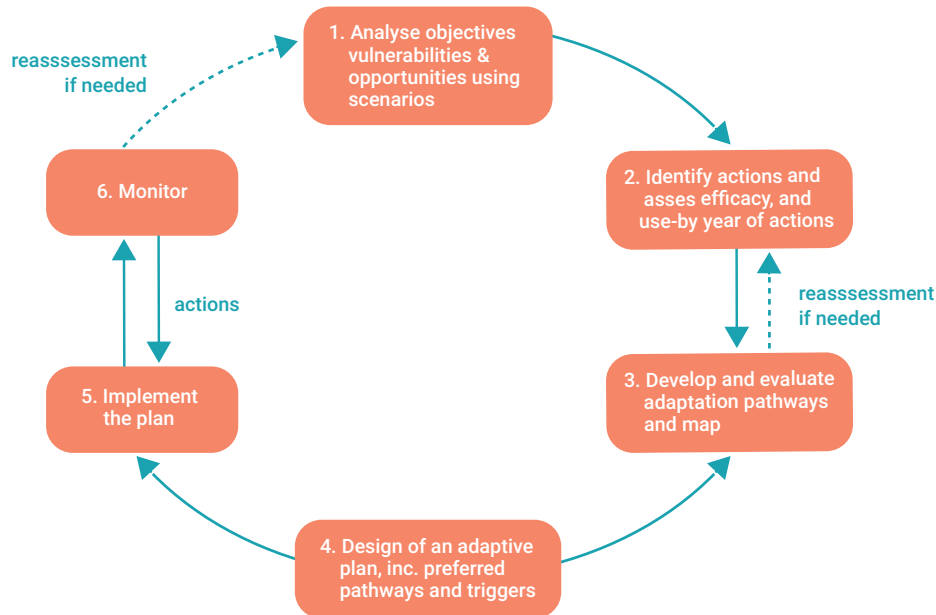
Regarding the statistical data on agricultural land-use of the Mekong Delta during the period 2000–2020 [Figure 10.1], it is easy to see a trend to shift away from rice to other land uses in the first period (2001–2005), a shift representing more than 170,000 ha. At the same time, the surface area dedicated to shrimp aquaculture has doubled from 229,350 ha to 501,500 ha. Young *et al.* (2002) showed that in early 2000, the market price of rice was near or below the production cost, which explains that a huge number of farmers have shifted their land-use away from rice. After that first period, the rice area still remained around 1.9 million hectares for a long time, while a more progressive shift towards fruit trees occurred (doubling over the whole period). After the initial shock increase in 2005, the aquaculture area decreased over the next 5 years, then reverted to an increasing trend from 2014 until 2020. In this period of 20 years, the forest decreased from more than 330,000 ha to 253,500 ha.

Historical data reveal a very difficult management problem: while farmers (sometimes because of governmental production quotas) tend to change their land use to intensive rice production in diked systems or undertake conversions from rice-shrimp to intensive shrimp farming, the consequences of climate change (extreme weather events, soil and water salinity, etc.) are expected to have a significant impact on these very specific crops, potentially turning them into highly unsustainable strategies.

2.2 Land use adaptation solutions in the Mekong Delta

It is difficult to draw a clear line between the solutions implemented as a consequence of national adaptation policies — through public investment, for instance — and individual adaptation practices; both, of course, have an

[Figure 10.2]
The dynamic adaptive policy pathways (DAPP) approach



■ Source: Deltares, 2021, simplified from Haasnoot *et al.*, 2013.

influence on the solutions adopted by farmers and communities.

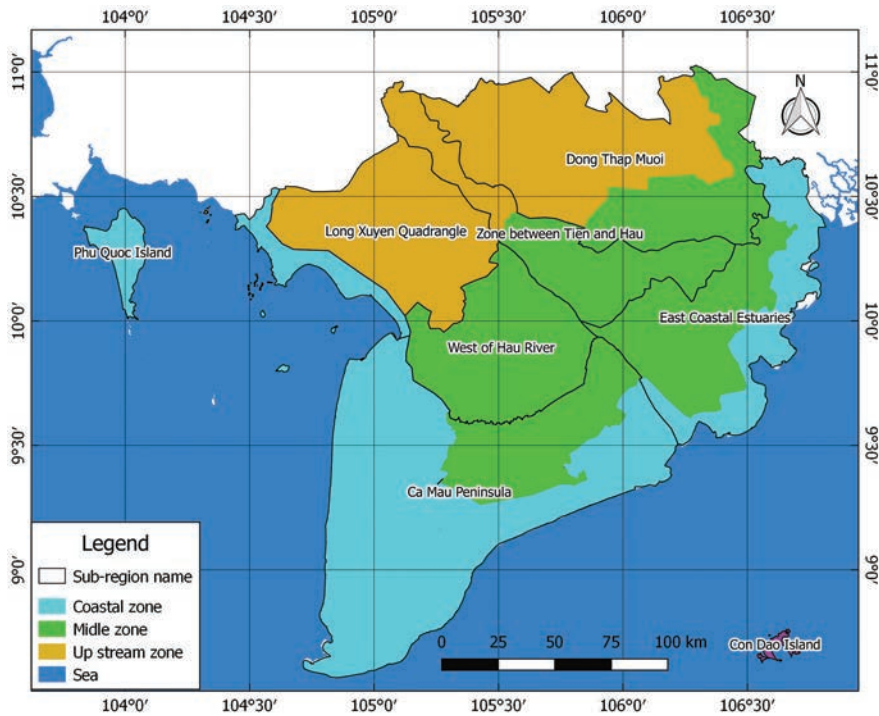
National strategies and individual adaptation by farmers

Whether at the national or regional levels, many researchers have been interested in defining adaptation plans for authorities [Haasnoot *et al.*, 2020; Bosomworth *et al.*, 2015]. An adaptation plan specifies actions to be taken immediately, in order to be prepared for the future. Implementing an adaptation plan requires being able to explore different adaptation pathways.

As far as national strategy is concerned, the national plan for adaptation to climate change

for the period 2021–2030, with a vision for 2050, signed by the Prime Minister [Prime Minister of VN, 2020], officially puts the focus on improving the effectiveness of climate change adaptation through strengthening state management of climate change, and promoting the integration of climate change adaptation into the strategic system and regional planning. Following the general policies of the government, many authors [Vu Thuy Linh, 2021] suggested strategies for action at government sites to implement the adaptation plans. It emphasizes public investments to support farmers in solutions such as renovating existing irrigation systems, investing in information equipment, automatic monitoring systems, scientific and efficient agricultural management, exploiting freshwater systems,

[Figure 10.3]
Ecological zoning for agriculture development in the Mekong Delta



Source: Bong *et al.*, 2018.

and focal sewers to reduce natural hazards (cf. [Chapter 11](#)).

Another solution is to manage the conversion using an administrative tool. The departments of Natural Resources and Environment limit land use conversion via adaptation plans and annual land use plans: land registration management offices do not grant conversion permits to people when the conversion takes place spontaneously, according to personal economic interests rather than as part of the government's plan [The President of S.R. Vietnam, 2013]. Besides, especially for shrimp, farmers have to register at the Popular Committee of their parcel commune when they want to establish intensive and semi-intensive

farming activities [Ben Tre Committee, 2016]. There is also an attempt to convince people to adopt climate change-adapted farming systems, such as 2 rice seasons and 1 vegetable season [Bong *et al.*, 2018], or 2 rice seasons and 1 rice-shrimp season in vulnerable areas [Loc *et al.*, 2017].

Regarding local government policies for land use conversion in adaptation to Climate change, the local government (An Giang province) has supported farmers who want to convert from 3 rice seasons to 2 rice seasons and 1 freshwater shrimp season, with support on shrimp varieties and technical transfer [An Giang Committee, 2015].

Evers & Pathirana (2018) showed that rural communities can be dynamic and able to continuously adapt to a changing environment. However, rural communities in the Mekong River Basin often lack financial and institutional resources for formal adaptation planning [Chapter 12]. Thus, financial support from government and social resources are also key to adaptation strategies.

Land use adaptation and farmer decision-making

At the individual scale, many adaptation solutions are a result of agricultural expertise [Bong *et al.*, 2018; Pongthanapanich *et al.*, 2019], including adaptation in aquaculture and agriculture farming systems in line with temperature increases and rainfall decreases: as an example, the transformation of agricultural structures from a single-crop specialization in rice production towards a multiple-crop model with a rotation of rice and crops (vegetables and corn) has been observed. This kind of adaptation has taken place in some provinces of the Long Xuyen Quadrangle, in the intermediate zone between the Tien and Hau rivers, and in the Eastern coastal provinces (Tra Vinh, Ben Tre, Soc Trang) [Bong *et al.*, 2018] [Figure 10.3].

Besides, farmers applied advanced and water-saving irrigation solutions for shallow crops, industrial factories and fruit trees with high commercial and economic value. In coastal areas, people store rainwater in addition to building freshwater settling tanks, which is an economical and effective solution in conditions of saline intrusion [Vu Thuy Linh, 2021]. In aquaculture, farmers need to apply high technology to minimize dependence on natural factors, by controlling the aquatic environment and using roofs to control rain-

fall and temperature [Pongthanapanich *et al.*, 2019].

Climate change and sensitivity of farming systems

Climate change effects will strongly impact the different farming systems, but with varying and sometimes opposite effects. Saline intrusion (in part due to sea level rise) will produce suitable conditions for shrimp farming, but the temperature increase will heighten the risk of this system [IEFP of Vietnam, 2015]. Research into tolerance ranges of typical farming systems (rice, shrimp) to salinity level, temperature, and precipitation have shown that the mean temperature increase forecast in climate change scenarios may stay within the tolerance range of catfish, but negatively impact the growth of shrimp [Hargreaves & Tucker, 2003; Phuc *et al.*, 2017]. Bui Quang Te (2003) noted that shrimps are very sensitive to temperature variations. If the temperature exceeds the allowable limit, it can lead to mass decrease or even death of the shrimps. For tiger shrimp, the most suitable temperature is between 28°C and 32°C. When the water temperature in the pond is 37.5°C, only 60% of shrimps survive. The Nutritionists at Kasetsart University [Banrie, 2012] have also suggested that the best temperature for shrimp is between 29 and 31°C.

Precipitation also plays an important role in brackish water shrimp farming: a sudden increase or decrease in precipitation will greatly affect the growth and development of shrimp: heavy rains induce a drop of salinity, and affects pH in ponds, which cause the shrimp to be shocked, die or grow slower.

2.3 Vulnerability assessment and adaptation to climate change

As far as adaptation policies are concerned, the identification of exposure and the assessment of vulnerability are very important steps to build adaptive solutions [Smajgl *et al.*, 2015a].

Many approaches have been proposed in the literature to identify vulnerable areas. As an example, Hailegiorgis *et al.* (2018) used an agent-based model of agricultural production and household incomes to identify vulnerable areas depending on their adaptive capacity (among other factors). In their study, Mackay & Russell (2011) used the Comparative Vulnerability and Risk Assessment (CVRA) methodology and framework to estimate overall vulnerability given five factors: population, poverty, agriculture and livelihoods, industry and energy, and urban agglomerations and transport. Vu Thuy Linh (2021) proposed tools to support vulnerability assessment based on GIS, remote sensing and the analytic hierarchy process. These tools are effective in a specific climate model, but they are difficult to apply in other climate models (there are at least 31 models, [Chapter 1](#)).

In addition, it is necessary to determine the vulnerability based on dynamic weather factors, which come from a variety of weather scenarios proposed. With a dynamic of socio-economic data, vulnerability assessment is a big challenge as a result of variable factors, which need to be reassessed every year for annual land-use plans.

Therefore, there is a need for dynamic assessment tools to be applied in flexible climate change adaptation frameworks. Some models propose to formulate the choice of crop

rotation as a multi-criteria decision problem: for each plot, the farmer chooses a crop rotation, according to an evaluation at farm level of several criteria (financial risks, expected incomes, workload and farmer habits) [Martel *et al.*, 2017]. Other works focus only on the crop allocation problem. Houet *et al.* (2010) consider the crop allocation problem as an optimization problem, and solve it by computing the maximal flow of the possible transition graph. For the case of Viet Nam, land use change models have been applied in the northern mountainous regions of the country [Castella *et al.*, 2014; Le *et al.*, 2010] and in the central mountainous areas. In the Mekong Delta, Truong *et al.* (2015) showed the interest of using an agent-based model to study land-use changes in a small-scale area at village level.

3. Model proposed for climate change adaptation

In this section, we present LUCAS (Land Use Change for Adaptation Strategies), the land use change model we have developed to study and assess adaptation strategies. The purpose of this model is twofold: (i) to compute the land use areas exposed to risks due to climate change effects, and (ii) to simulate the land use changes in the Mekong Delta year by year under the influence of adaptation strategies at various levels. Land use patterns are affected by temperature, precipitation, and salinity intrusion during the dry season.

In recent years, many models have been developed to simulate land use change, in particular in agricultural territories [Janssen & van Ittersum, 2007]. In this context, many works have highlighted the importance of the farm scale for understanding the evolution and dynamics of agricultural landscapes [Houet *et al.*, 2010; Schaller *et al.*, 2012]. Other works have also highlighted the impact of social influences on farm management choices [Cullen *et al.*, 2020].

Agent-based modelling is a particularly suitable approach to study the system at this scale, and the complex interactions between environment and society. This approach consists in explicitly representing the actors composing the system in the form of autonomous and heterogeneous computer entities in interaction, referred to as agents. Agent-based models are useful not only in analysing socio-environmental systems or predicting management outcomes [Rounsevell *et al.*, 2012; Schulze *et al.*, 2017], but also for highlighting

emergent behaviours resulting from governance choices [Bourceret *et al.*, 2021].

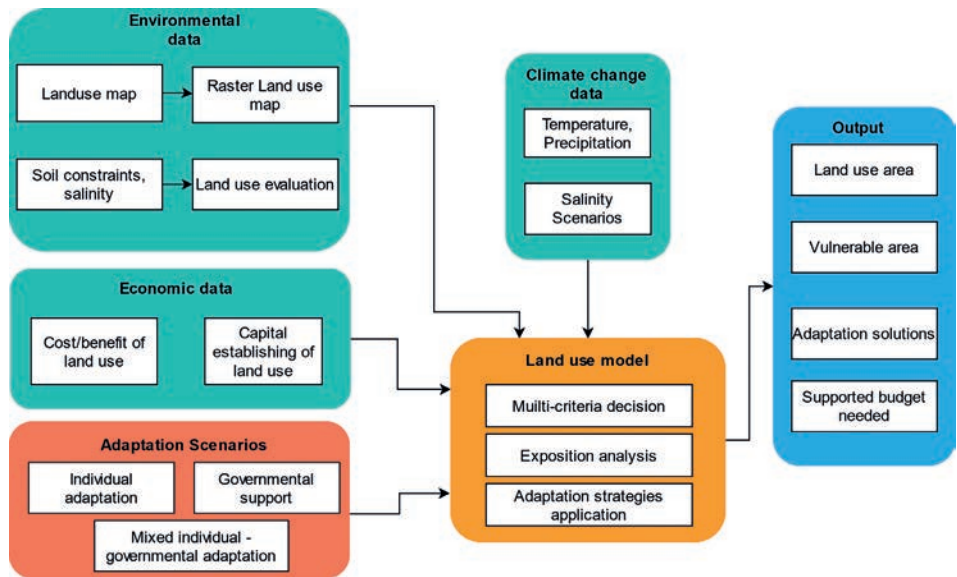
LUCAS is based on this modelling approach. The entities modelled as agents are the farmers who will have to make decisions concerning the type of land-use to implement for their agricultural parcels.

3.1 Overview of the model

The conceptual model is presented in [Figure 10.4](#). As mentioned before, the dynamics of the model come from the change in land use of agricultural parcels: each simulation step (representing one year), farmers select the appropriate type of land use using multi-criteria decision-making. Four criteria are used: profitability, land suitability, capacity for conversion to other land uses, and influence of other farmers. Thus, land use decisions are based on socio-economic and environmental factors, which include soil characteristics, salinity, and dyke-protected areas. In the land use change process, the level of exposure of agricultural land use types is assessed considering the influence of temperature and precipitation during the dry months of the year.

For the spatial component, the model is based on a raster representation of the study area, *i.e.* an image made up of pixels. Using LUCAS thus requires importing the raster map of the land use of the area at the date corresponding to the beginning of the simulation. We consider six possible types of land use for the study area: 2 rice crops, 3 rice crops, fruit trees, annual crops, aquaculture, and rice-shrimp rotation.

[Figure 10.4]
Conceptual structure of the LUCAS model



3.2 Scales and entities represented

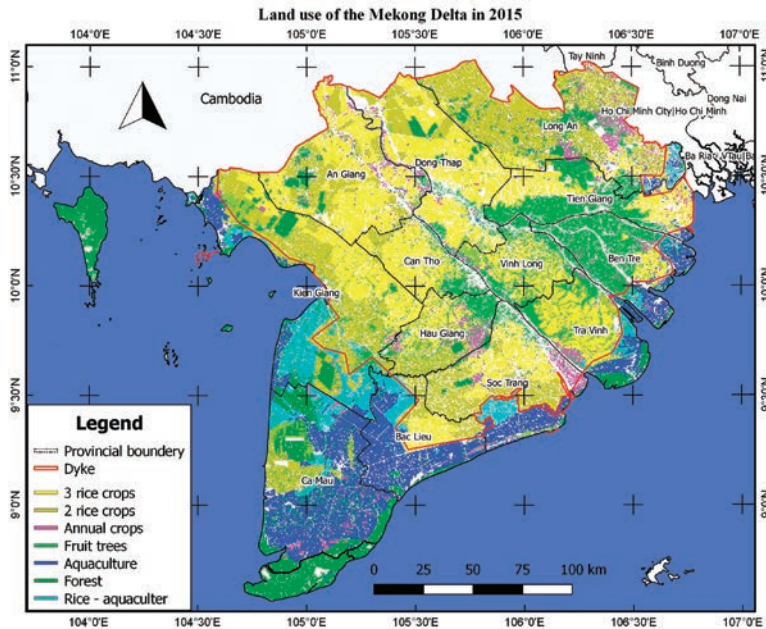
The simulation model has been designed to be executed at the scale of the Mekong Delta region (around 40,500 km²). The smallest spatial units taken into consideration are farmer’s agricultural parcels. The simulations are launched from a specific starting year (2015), and last 15 years (to 2030), each simulation step representing one year. Figure 10.5 shows the 2015 land use map for the Mekong Delta.

The data object of the model is shown in Figure 10.6 the main type of agents in the model are farmers. As the model’s objective is not precisely representing the geometry of each agricultural parcel, but rather simulating the evolution of the territory on a large scale, we considered that a farmer-agent is characterized by one cell on the map (500 x 500 m). A cell in the map thus represents a farmer and also, at the same time, his/her agricultural parcels with their land

use type. In this map, we only select the six dominant land uses: 3 rice (*i.e.* 3 rice crops per year), 2 rice, Vegetables, Aquaculture (Shrimp), Fruit trees, Rice - shrimp.

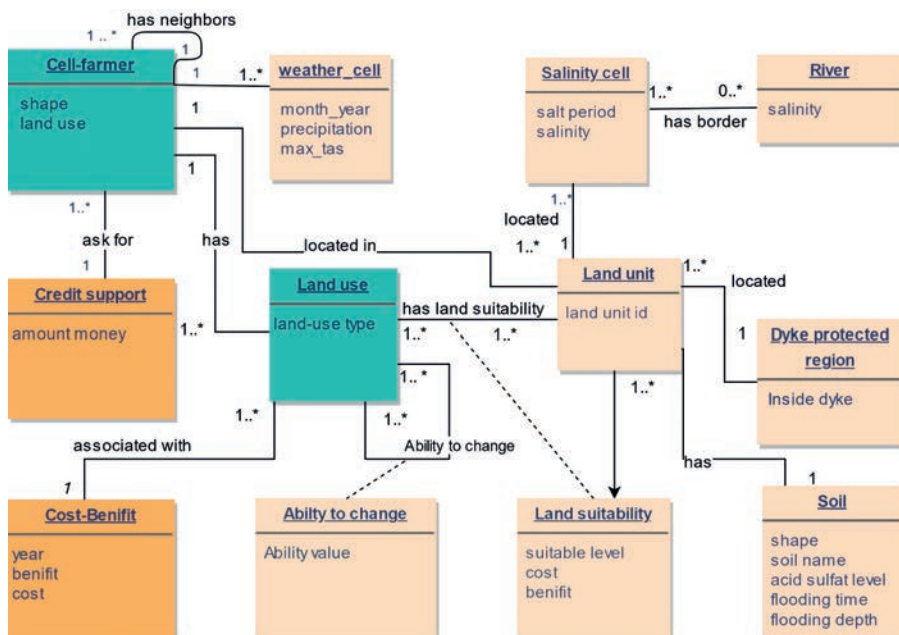
Each cell is located in a land unit region which is a spatial component with soil properties (texture, acid sulphate level, time and depth of flooding), and salinity (salinity level and duration). The land unit map in this study is overlaid with soil and water layers [Figure 10.7], in which each soil object is made up of a soil name, and acid sulphate level (active or potential acid sulphate depth). Also, the water properties of each land unit compose its salinity and salinity duration. Based on land units and land use types, a land suitability table was generated using the land evaluation method, [FAO, 1981] and classified into 4 levels: S1: Highly suitable; S2: suitable; S3: Lightly suitable and N: Not suitable. Thus each Cell can refer to the most suitable land use in the land suitability table.

[Figure 10.5]
The land use map of the Mekong Delta in 2015

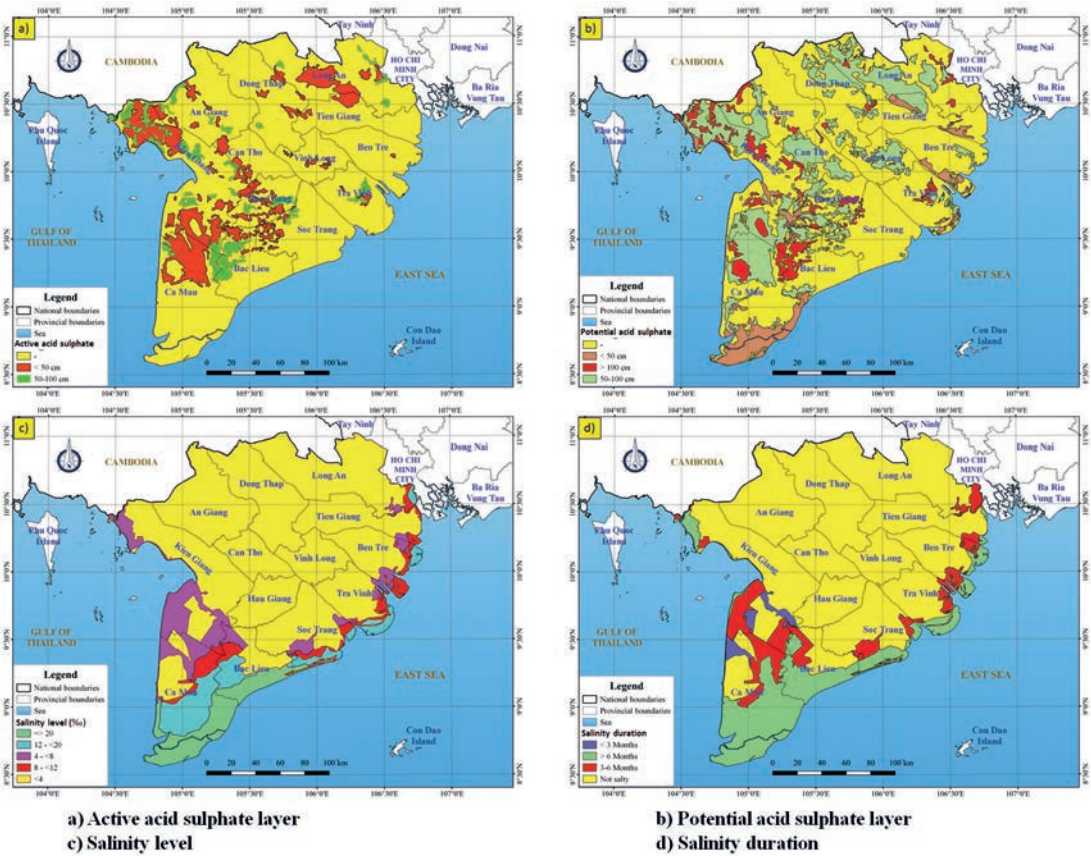


Source: Generated from land use map of 13 provinces in the Mekong Delta, MoNRE, 2015.

[Figure 10.6]
Entities of the LUCAS model



[Figure 10.7]
Property layers of the land unit map



Source: Land Resources Department - CTU, 2014.

For each land use, a data table registers the ability to change from each land use to other land use types. This ability measures how easily one land use can change to another land use, in terms of technique and capital. This data table is collected by local agricultural experts as in Table 10.1.

As presented above, individual adaptations are mainly driven by economic factors (in a suitable environmental context). This can be explained by the existing economic benefit of shifting from the dominant land use in the Mekong

Delta [Nguyen Hong Thao *et al.*, 2019]. Thus cost and benefit for each land use is coded in a data table in the model, to be used for land use multi-criteria analysis. In this model data is collected as in Table 10.2.

3.3 Process overview and scheduling

The model can be summarized by three main dynamics: (i) the annual farmers' decision to change their parcel land use type, (ii) the

[Table 10.1]

Ability level of changing among the land use types

	3 rice seasons	2 rice seasons	Vegetables	Shrimp	Fruit trees	Rice - shrimp
3 rice seasons	1	1	0.75	0	0.5	0
2 rice seasons	1	1	0.5	0	0.75	0
Vegetables	0	0.5	1	0	0.5	0
Shrimp	0	0	0	1	0	0.5
Fruit trees	0	0	0	0.25	1	0
Rice - shrimp	0	0	0	0.75	0	1

■ Note: 0- Not able to change; 1 - easy to change.

[Table 10.2]

Benefit of dominant land use types in the Mekong Delta

Land use type	Profit (Million VND/ha)	Cost (Million VND/ha)	Labor (Days/ha/year)
3 rice seasons	58.48	52.31	92
2 rice seasons	42.42	34	78
Rice - shrimp	86.62	61.38	86
Fruit trees	184.00	62	115
Vegetables	88.07	114.24	233
Aquaculture (Shrimp)	277.23	308.18	217

■ Source: Data survey in Soc Trang Province in 2018, Nguyen, 2021.

computation of exposition to climate change-related risks of the land cells, and (iii) the application of adaptation strategies (if any) based on the risk evaluation. Adaptation strategies can be either no strategy (base scenario), individual-level adaptation (scenario 1), government-level adaptation (scenario 2), or mixed-level adaptation (scenario 3).

Land use change due to individual decision

At each simulation step (*i.e.* one year), farmer-agents are able to change their land-use type. To this end, each farmer-agent first evaluates the benefits of converting to each existing land-use type using a weighted mean of

the 4 criteria, and then selects the land-use type that maximizes it. In order to take the intrinsic inertia of these production change processes into account, we consider that only some of the farmers (randomly selected) will be able to change their land use at each simulation step. This number of farmers will be defined from a conversion rate parameter.

For i , a farmer-agent, l , their current type of land use, and l' the new land use type to evaluate, the benefit to convert from type l to l' is calculated as follows:

$$\text{convertibility}(i, l, l') = \frac{\sum_{c \in \{\text{profit}, \text{suitability}, \text{ability}, \text{others}\}} W_c \times \text{Val}_c(i, l, l')}{\sum_{c \in \{\text{profit}, \text{suitability}, \text{ability}, \text{others}\}} W_c}$$

- W_c the weight of the criteria c . Values are obtained when calibrating the simulated map in 2020 with the land use map in 2020.
- $\text{Val}_c(i, l, l')$ the value of the criteria c for a conversion from the land-use type l to the land use l' for the farmer agent i .

4 criteria are taken into account:

- ▶ **Profit:** The yearly profitability of each land use type is one of the main reasons leading to land use conversion. This factor is an economic adaptation when people try to find a suitable farming model to improve their lives.
- ▶ **(Land) suitability:** This criterion represents the adaptation of a land-use type (i.e. an agricultural activity) to a specific environment. When environmental conditions change, the adaptation level of land-use types also changes. The suitability evaluation is performed according to the FAO's work [FAO, 1981]. The 4 suitability levels are standardized from 0: non suitable to 1: most suitable.
- ▶ **Ability (to convert):** This criterion measures how convenient it is to switch from the current land-use to another one. In farming systems, the transition from one type to another depends on the conditions in which new farming

types can be established. In some cases, some switches (e.g. from shrimp to fruit trees) will be very difficult, whereas a switch from deep shrimp ponds in intensive shrimp farming to rice cultivation will not be possible. This ability criteria value is computed given a table of values associated to each transition $\text{LandUse1} \rightarrow \text{LandUse2}$.

- ▶ **(Influence of) others:** As shown by some studies, farmers are influenced in their production choices by their neighbours [Le Quang Tri et al., 2008]. The value of this criterion corresponds to the proportion of farmer agents in the immediate neighbourhood (the 8 cells around the cell representing the farmer) having chosen this type of land use.

Parameter and indicators of the model

In implementing the adaptation strategies, there are the key factors that should be taken into account in order to measure the impact of climate change in agricultural land use. We first identify the main indicators of climate changes, then define the parameters, so that the model can be used for analysing possible solutions.

- ▶ **Exposure area:** In case of temperature and precipitation changes in the dry season, the exposure areas of rice and shrimp would be damaged.
- ▶ **Vulnerability area of rice and aquaculture:** The areas of rice and aquaculture still facing risk of damage when the adaptation strategies are applied.
- ▶ **Tolerance parameters for rice:** The sensitivity of rice is identified by the maximum temperature of rice or the minimum precipitation tolerated. These are used to identify the exposure area of rice.

► Tolerance parameters for shrimp: the two parameters implemented to calculate the exposure of shrimp are the maximum tolerable temperature and maximum rainfall sensitivity.

► Adaptation parameters: In this model we try to identify the adaptation percentage parameter for individual farmers and the government. In which there are 4 parameters: percentage of rice farmers self-adapted, percentage of aquaculture farmers self-adapted, percentage of rice farmers and aquaculture farmers supported by the Government. These parameters are detailed in the adaptation strategies.

Exposure evaluation

In order to inform the adaptation strategies, the model computes the areas that can be exposed to risks from effects of climate change: we consider here only effects of temperature, and precipitation evolution and salinity intrusion by SLR. Two types of crops are distinguished: crop culture (rice, short-term crops, fruit trees) and aquaculture (shrimp).

Concerning crop culture, if the cell concerned is located in an area protected by dyke systems, but the monthly highest temperature in the dry season (December to May) exceeds the crop tolerance threshold and the rainfalls are lower than the tolerance rainfall threshold, the crop is considered risk-exposed. Aquaculture cells are evaluated as risk-exposed when precipitation is above the cut-off threshold (reducing salinity in the ponds). The total area at risk for aquaculture and crop culture is determined by the total area at risk for each type.

Adaptation strategies

In the base scenario, no adaptation strategy is applied. When one of the following scenarios

of adaptation is selected, adaptation is made on the cells at risk. Each of the strategies is characterized by a set of parameters, mainly representing the rate of adoption of adaptation strategies.

We consider three types of adaptation strategies:

► **Individual-level adaptation:** farmers will seek an appropriate land use to eliminate risks. To this end, the ones who have chosen “3 rice crop” land use will change to a more adapted one, e.g. “2 rice crop” land use. If the land use is “shrimp”, the farmer will have to invest money to be able to use new techniques to avoid the risk. Two parameters control this scenario: the rates of farmers having 3-rice crops (resp. aquaculture) having adopted this adaptation strategy. The adapted land use types supply less profit than the intensive ones, but in terms of total profit, farmers can avoid a loss of capital for the third crop (for rice), and very heavy capital investment for shrimp.

► **Government-level adaptation:** the government will help farmers eliminate risk; its policy focuses on two axes: investing in infrastructure, such as dykes, sluice gates, irrigation canals (which will help farmers with rice-crops), and helping people with capital (through helping them to access bank loans at low interest rate) and technology to adapt (which will mainly help farmers with shrimp aquaculture). Farmers will keep the same land use, but will have a certain probability of eliminating their risk exposition. Two parameters control this scenario: the rates of farmers having 3-rice crops (resp. aquaculture) that will be helped by this adaptation strategy.

► **Mixed-level adaptation:** this scenario combines individual adaptation and government-based adaptation. The government-based part

is also more realistic, as it is based on Decree 35 dated in 2015 [Government of Viet Nam, 2019] and updated by Decree 62/ND-CP dated in 2019 [Government of Viet Nam, 2019]. In these decrees, economic support is invested to convert from 3 rice crops to 2 rice crops and shrimp rice farming with 1,000,000 VND/ha.

4. Climate change adaptation strategies with modelling approach

Based on the approach proposed by [Haasnoot *et al.*, 2013], we have used our proposed dynamic model to assess the adaptation strategies of farmers in land use adaptation. In the following, we first identify a climate and sea level rise scenario, then evaluate the vulnerabilities of the various land uses. Based on these results, adaptive strategies have been proposed and assessed to reduce their impact.

4.1 Scenarios of climate change in 2030 and 2050

In order to detect exposure to effects of climate change for different farming systems, 4 scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5 have been simulated [Chapter 1]. Under the Paris Agreement on climate change, all countries must take action to keep global temperature rise below 2°C above pre-industrial levels [UNFCCC, 2015]. However, the goal is to make every effort to shift to RCP2.0, which is already almost out of reach. Thus we have chosen to use data from the RCP8.5 scenario as input

For intensive shrimp production, policy support allows people to continue to borrow from banks to continue their activities the following year. Two parameters control this scenario: the rates of farmers having 3-rice crops (resp. aquaculture) that will be helped by this adaptation strategy.

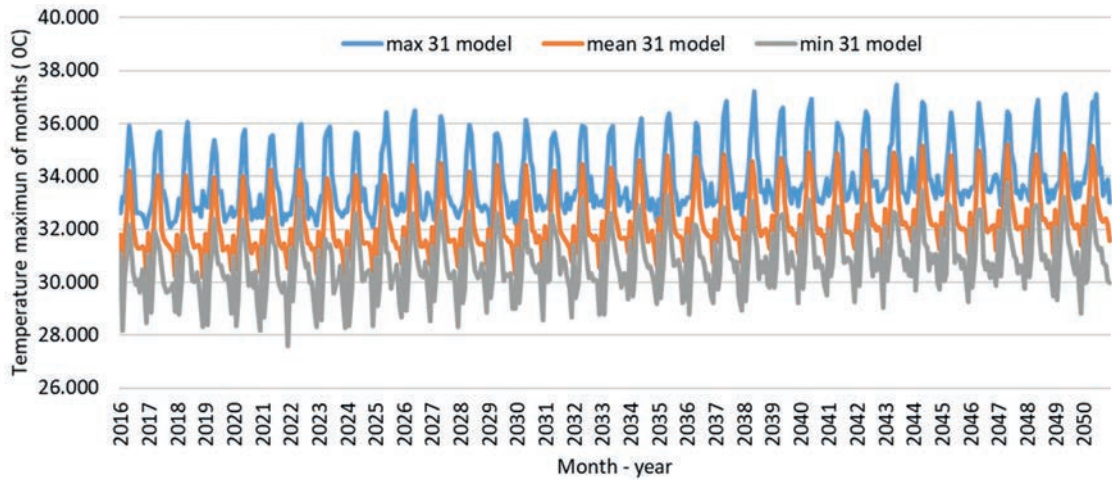
data in our scenarios. Average, maximum, and minimum temperature per month from 31 climate models [Chapter 1] for the period 2016 to 2050 in the Mekong Delta is plotted in Figure 10.8. We can observe that temperatures have a clear increasing trend. This phenomenon could lead to extreme events like drought and saline water intrusion like those that occurred in 2016 and 2020 in the Mekong Delta.

Precipitation in the Mekong Delta has been calculated using the monthly average of all the pixels in the Mekong Delta mainland. The chart in Figure 10.9 displays the data for maximum, minimum and average precipitation from 31 climate models [Chapter 1] for the period 2016 to 2050. We can observe that, maximum total precipitation in the rainy season is nearly the same, and that — conversely — rainfall in the dry season should increase. As analysed in Chapter 1, daily temperature variations from one day to the next can be huge, which may strongly impact aquaculture farming systems.

Figure 10.10 shows the salinity intrusion map in 2030 under the scenarios RCP4.5 and 8.5 (cf. Chapter 9), taking into account the dyke and sluice gate systems; it takes into account increase of saline intrusion due to sea level rise and subsidence, and the current salinity in dry season. This kind of map is used to evaluate the exposed land use types impacted by salinity.

[Figure 10.8]

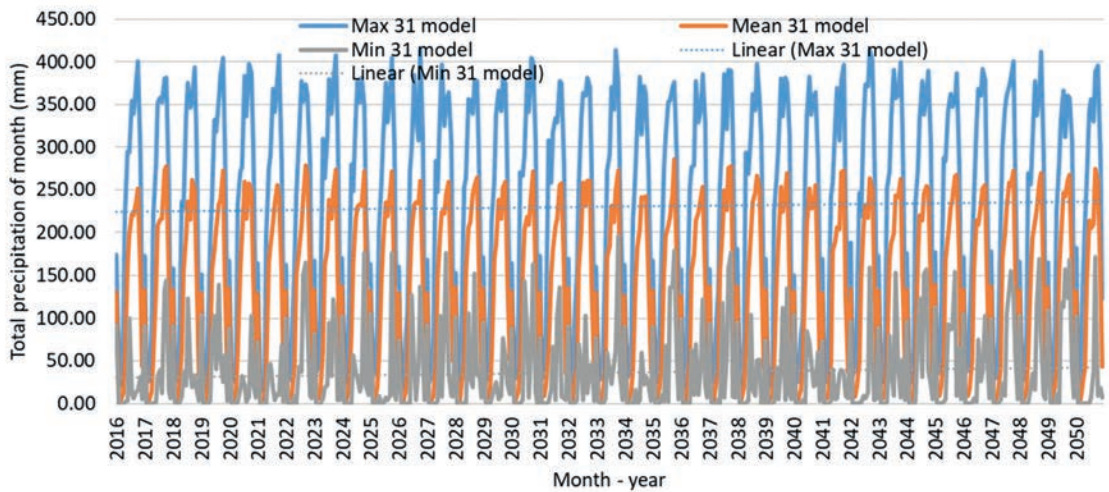
Monthly maximum temperature of the Mekong Delta until 2050



■ Source: Generated from 31 climate models with RCP8.5, Chapter 1.

[Figure 10.9]

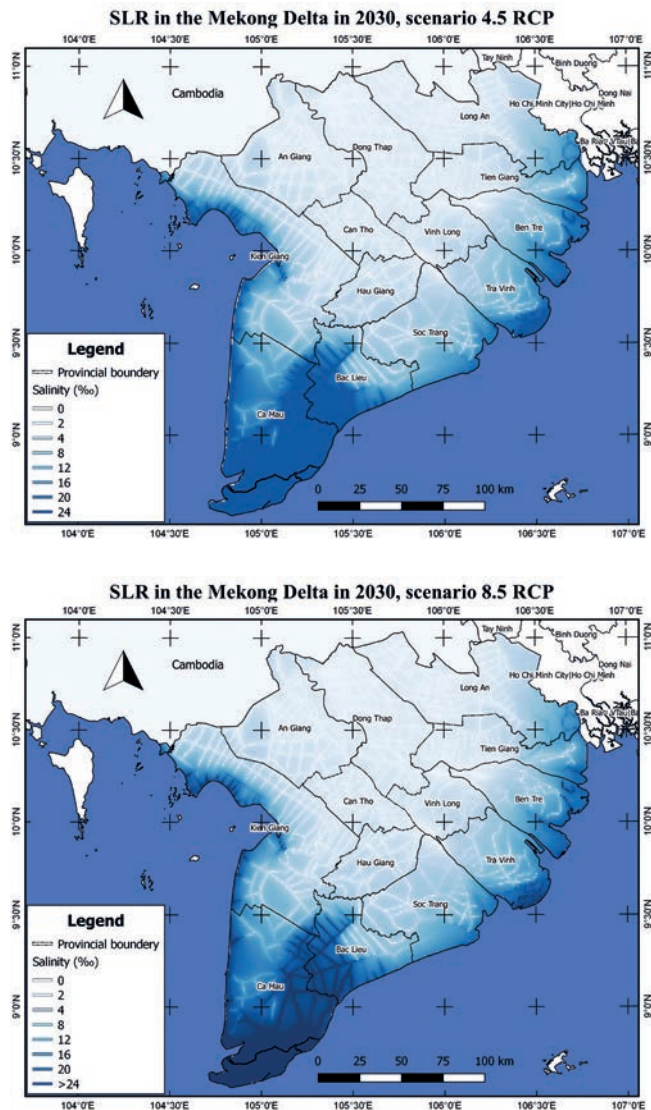
Monthly total precipitation from 2016 to 2050



■ Source: Chapter 1, RCP8.5.

[Figure 10.10]

Salinity map of the Mekong Delta in 2030 with RCP4.5 and 8.5 scenarios



Source: Generated from Chapter 9, RCP4.5 and RCP8.5.

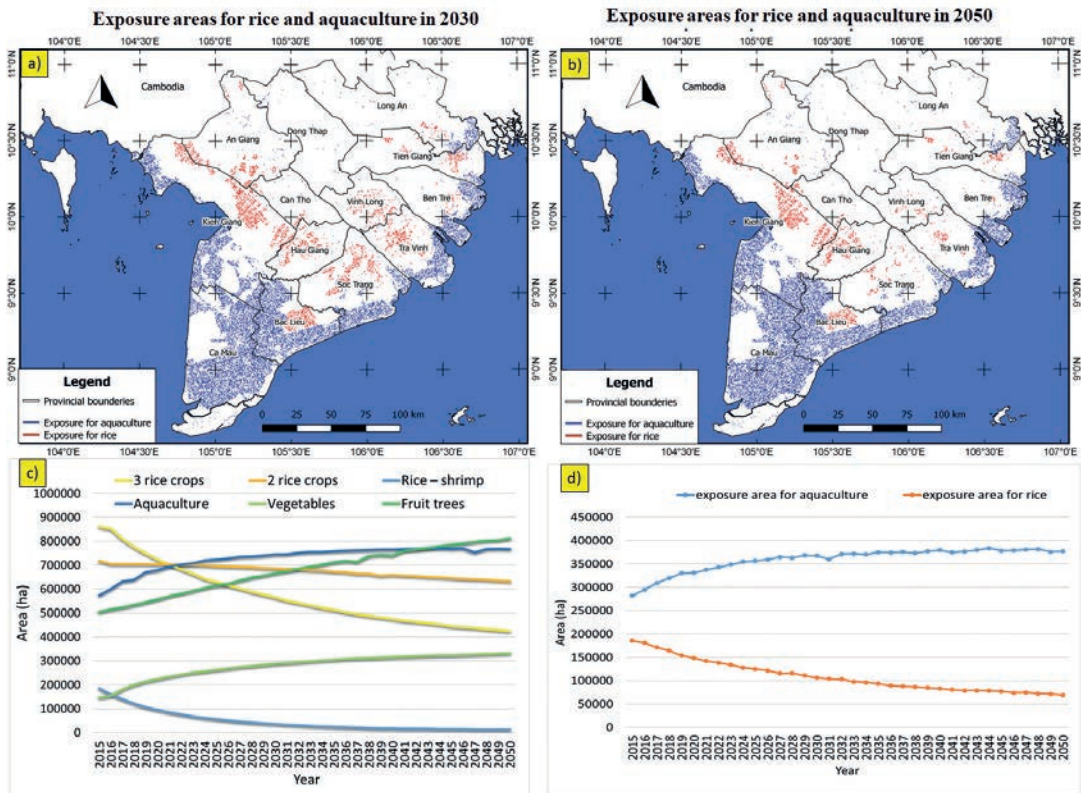
4.2 Using model to analyse impacts of climate change on land use

A very important step in the adaptive pathway approach is being able to dynamically assess exposure of land uses to climate change. To

evaluate the worst case, we use the presented model to evaluate the affected areas with standard land use types, where the weather scenario is aggregated by taking the highest temperature, and lowest precipitation for each month from 31 climate models, and salt intrusion from the RCP8.5 scenario.

[Figure 10.11]

Land use change and exposure areas for rice and shrimp until 2050



The main land use types in the Mekong Delta are aquaculture and rice, and are sensitive to extreme events caused by climate change. Their impact (and in particular saline intrusion) is stronger during the dry season (from December to end of April). For this reason, we consider this specific period of time to explore possible climate thresholds that could impact agricultural activities.

As far as rice is concerned, temperature and rainfall in the dry season affect the structure of the crop, and saline intrusion affects crop tolerance. When a system of dykes and sluice gates prevents saline intrusion in the fields, the cultivation area is not directly affected. Concer-

ning shrimp farming, saltwater intrusion appears to be favourable for shrimp farming. However, unusual climatic changes during the dry season would affect aquaculture. As described in the section above, a sudden increase in precipitation over several days, or high temperature, affects the growth of shrimps.

Although many studies (c.f. Section 2.2) have studied the tolerance of various crops and aquaculture to effects of climate (in particular thresholds of minimum and maximum temperature and precipitation), it is hard to determine which is the impact threshold. Looking historical precipitation in the dry season in the coastal provinces of the Mekong Delta, Truong

(2018) found that total dry season precipitation for the 8 provinces (Bac Lieu, Ben Tre, Ca Mau, Kien Giang, Long An, Soc Trang, Tra Vinh, Tien Giang) varied from 200 to 400 mm per season. In 2016, the precipitation in this region was lower than 200 mm, which was one of the main causes of the 2016 drought. Associated with risk for shrimps, the high precipitation in 2011–2012 was associated with risk in the Mekong Delta: the shrimp damage of Soc Trang in 2011 was over 20,000 ha, compared with a lower 9,000 ha in other years [DARD Soc Trang, 2012]. As a typical case, we selected a threshold of temperature greater than 33°C and maximum precipitation in a month under 120 mm for rice, and greater than 33°C or maximum precipitation greater than 400 mm for aquaculture, to provide a detailed look at the impacts of climate on land use. Figure 10.11 shows the results when the model takes only the criteria influenced by the weather into account, without considering additional adaptation strategies. The affected areas of rice (red areas) and shrimp (blue areas) are displayed in Figure 10.11 for the years 2030 and 2050. Simultaneously, the surface area for each land use type is plotted; it highlights the fact that the trend of converting from 3 rice crop to other crops (2 rice crops, vegetables, fruit trees), and from cultivated land to shrimp, should continue in the next few years due to saline intrusion from sea level rise.

The results of these initial experiments have illustrated the evolution of land use under the sole influence of multi-criteria selection, without taking adaptation strategies into account. In the following section, we go further by introducing adaptation strategies to face the risks induced by climate change.

4.3 Adaptation strategies based on land use adaptation model

The LUCAS model is used to estimate land use conversion under environmental and socio-economic changes, and to test the adaptation scenarios. The 3 adaptation scenarios are defined in Section 3.3.

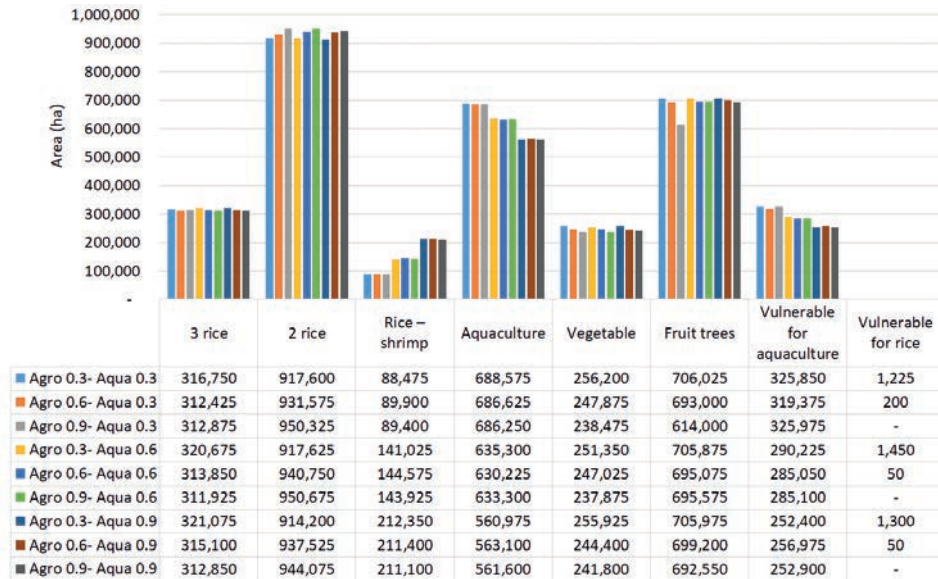
Individual adaptation strategies

The simulations with scenario 1 represent the vulnerable area with reference to the value of the two parameters: the Proportions of crop (resp. rice-shrimp) farmers applying adaptation strategy. Figure 10.12 shows that, when the proportion of households adapting is high, the area of land with 3 rice crops decreased while other crops increased. The rice - shrimp area is still high due to a decrease in conversion to aquaculture, which is reflected in the small aquaculture area. Besides, the vulnerable area for rice and shrimp significantly decreased, which is the basis for convincing people to choose adaptation solutions and choose suitable farming systems to reduce risk.

The results show that vulnerable areas will be reduced when farmers select the suitable land use in relation with climate change: for aquaculture households investing in mitigating the impact of weather conditions, farmers stopped converting from rice-shrimp to shrimp. It appears that the higher the number of households applying adaptation measures, the less the remaining exposed area decreases. In addition, we can observe that the most influential parameter is the rate of rice farmers applying adaptation strategies (this could be due to the larger surface area of rice crops in the Delta). Especially when this rate is 90% for both land use groups, the area at

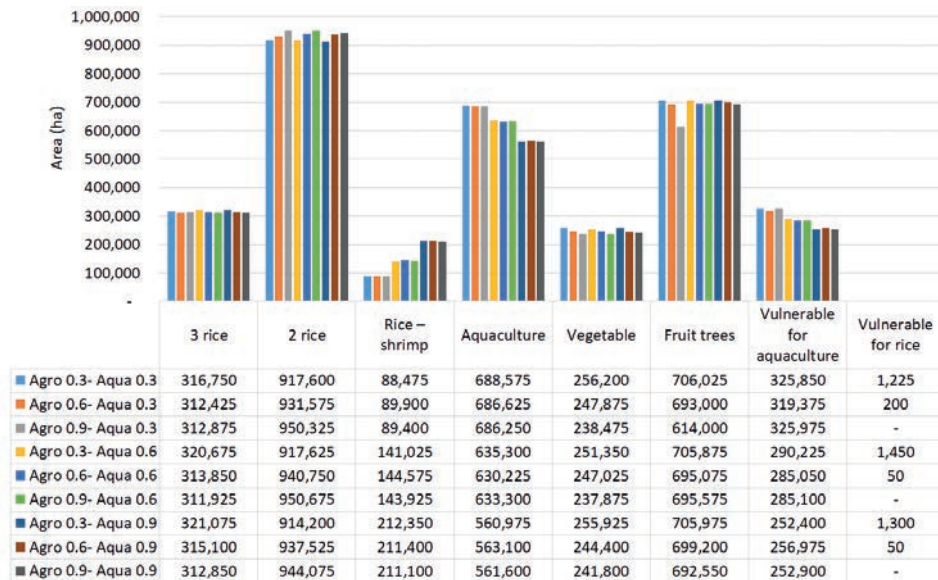
[Figure 10.12]

Land use area in 2030 with different adaptation percentage in scenario 1



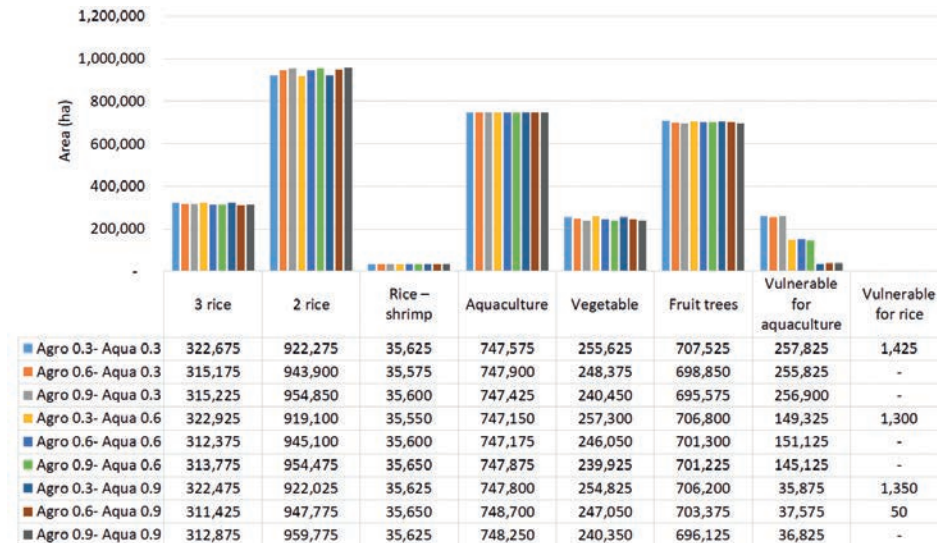
[Figure 10.13]

Land use area in 2030 with different adaptation percentage in scenario 2



[Figure 10.14]

Land use area in 2030 with individual and governmental mixed adaptation in scenario 3



risk is reduced to the lowest level. However, in practice, this still depends on the percentage of households able to apply adaptation measures, and the percentage of households that are mainly attracted by the profit factor.

4.4 Government strategies for supporting adaptive plans

More generally, Figure 10.13 summarises the analysis of government support for both rice crops and aquaculture, controlled by two parameters: the rates of farmers having 3-rice crops (resp. aquaculture) that will be helped by this adaptation strategy. Also, Figure 10.13 shows the surface area of each land use and the percentage of areas at risk. The results clearly show that the higher the adaptation rate, the smaller the vulnerable area. With go-

vernment assistance on technical support, infrastructure investment and economic policies, vulnerability will be reduced. This fact helps to support advocacy efforts, integration of recommendations, and training activities on agricultural techniques to limit the impacts of climate change, while the government can maintain the agro-economic development rate thanks to high-profit land-use.

4.5 Optimized adaptive scenario

In scenario 3, the support rate and individual adaptation rates were tested with the LUCAS model, which analysed the support rates for rice growers, and rice growers with shrimp. The survey results in Figure 10.14 show that as the rate of government support increases,

the area cultivated in 3 rice crops decreases thanks to the support policies. When shrimp farmers get loans and technical support for intensive shrimp farming, the area of shrimp farming increases. On the other hand, the cost of support under Decree 62 [Government of Viet Nam, 2019] for the affected area also increases when the percentage of farmers supported increases (from VND 69 billion to VND 195 billion VND/year).

4.6 Comparisons between the three scenarios

In order to compare the effects of each scenario visually via the land use map, we first set all the parameters to an intermediate value (we chose a medium (60%) adaptation percentage for each adaptation type). Figure 10.15 shows the comparison between the 3 scenarios on simulated land use in 2030.

[Figure 10.15]
Land use in 2030 of three adaptation strategies

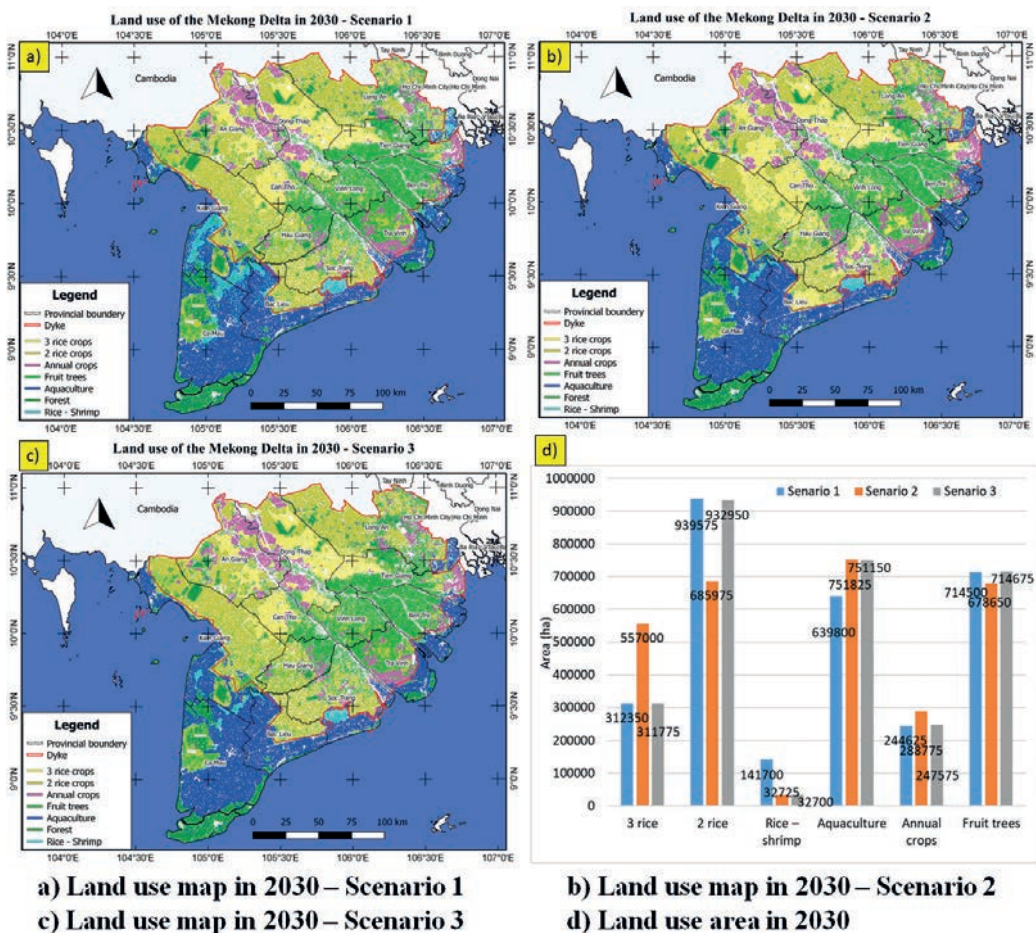


Figure 10.15 shows the land use map in 2030 for 3 adaptation scenarios. The maps of scenario 1 and scenario 2 present a contrast. Aquaculture and 3-rice crop areas in scenario 1 are lower than in scenario 2: in scenario 1, because farmers selected the highly suitable land use, people had to revert from shrimp to shrimp - rice when they saw the risk of climate change. The land use map in scenario 3 [Figure 10.15c] represents a combination of scenario 1 [Figure 10.15a] and scenario 2

[Figure 10.15b]. Here, the 2-rice crop area in scenario 1 and the aquaculture area in scenario 2 were combined in scenario 3. The solution in scenario 3 shows that to maintain high profits and minimize risks due to climate risks, farmers and authorities need to coordinate, with the government advising people to choose an adaptation model, and also providing capital and technical support when people select the suitable farming system.

5. Conclusion

Although the impacts of climate change are still uncertain, there is a growing consensus that they will be devastating in regions such as the Mekong Delta, due to a harmful combination of its hydro-geophysical characteristics, ever-increasing anthropogenic pressure, and past choices in favouring intensive agriculture.

Faced with this threat, the effects of which are beginning to be felt, particularly with regard to the increasing salinization of soils, public authorities and farmers are not remaining inactive. The former are thinking about setting up adaptation pathways, which are less rigid than strategies planned over 10 years because they can be revised regularly, but which still presuppose rapid intervention capacities in terms of investment or financial incentives, and which in any case remain top-down strategies, and thus not necessarily always well-adapted to dynamic local conditions. The latter change their land use autonomously, under the pressure of environmental factors or changes in sectors and markets, and begin to

diversify local production by also paying more attention to a rational use of the environment and inputs, but these uncoordinated changes in practice make this bottom-up strategy unlikely to scale up easily.

All of these strategies obviously interact and feedback with each other in ways that are highly dependent on local conditions and the environments involved, making any exercise in forecasting or evaluating their future impacts on Delta adaptation very tricky. Nevertheless, in order to carry out foresight exercises, many authors have chosen to focus on only one of the two approaches, providing advice and guidance to farmers or, on the other hand, proposing new planning strategies to governments. These exercises are essential for implementing adaptation policy, but so far have captured only part of the picture.

The chapter we conclude here presents an attempt to carry out the same type of foresight exercises, while making sure not to oversimplify the interrelationships between spontaneous and planned adaptation, which can be sources of innovation or major changes in the dynamics of the system considered. Construc-

ted as a series of simulation experiments using a model called LUCAS (Land Use Change for Adaptation Strategies), this approach makes it possible to represent both individual choices and collective decisions within a single model of the geographical and environmental reality: farmers, like public authorities, are artificial computer agents programmed to perceive their simulated environment, but also to exchange with other agents, and to decide on the best action to take to satisfy a set of objectives (guaranteeing income, not depleting resources, etc.) The simulated environment and artificial agents can then be immersed in different scenarios (climatic, but also demographic, political or economic) and their performance evaluated using statistical tools equivalent to those used in reality.

Three policy scenarios, corresponding to three main management options, have been presented in this chapter, in the framework of the common climate scenario RCP8.5. The first corresponds to a *“laissez-faire”* policy on the part of the government, in which the bulk of the adaptation would rest on the shoulders of farmers, without their choices being hindered or supported by a planned policy. The second is a policy in which no autonomy is granted to farmers, with all decision making being done at the central level and then imposed on individuals. Finally, the third approach presents one way to marry these two approaches in order to maximize their respective benefits and minimize their negative feedback.

The latter is measured, unsurprisingly, as the most beneficial for all actors in the system, and appears to be an interesting way to think about and develop feasible adaptation plans. However, whatever its interest, the lesson to be learned from this chapter does not necessarily lie in this result, but rather in the metho-

dology that made it possible. There are indeed many proposals for adaptation policies that reconcile bottom-up and top-down dynamics, but very few proposals that make it possible to assess their relevance, in advance, in different scenarios. In this respect, the LUCAS model offers a framework and a test bed that should make it possible, in the future, to explore and compare different combinations of adaptation policies, but also to co-construct these combinations and to share these results with users who are not necessarily scientists. The main characteristic of these new approaches is indeed that the dichotomy between scientists, in charge of “measuring”, “understanding” or “predicting”, and policy-makers who act on this information to “decide” and “act”, appears to be out-dated [Edmonds & Moss 2005]. What does this imply for the design of models to support adaptation-planning activities? At least three main points:

- ▶ Promoting multidisciplinary model building: the diversity of factors that can contribute to adaptation planning requires a multidisciplinary approach to model design, associating climate scientists with ecologists, social scientists and urban planners [Masson *et al.*, 2014].
- ▶ Accepting the “necessary” complexity of adaptation models: to support creative thinking, important features of the target system (e.g. spatial or social heterogeneity, multi-scale interactions) must be maintained in the models, so as to provide them with sufficient heuristic power when testing options. The result is complex descriptive models [Edmonds & Moss, 2004] in which it is impossible to predict “most likely” outcomes: they are not meant to be validated and will not provide “solutions”; instead, they must be sufficiently “explorable” to describe outcomes that might be possible

under certain system trajectories [Kelly *et al.*, 2013], which stakeholders can then use as a starting point for their deliberations or negotiations.

► Supporting stakeholder engagement in model design: this engagement is essential to their effective use in planning [Reed *et al.*, 2013]. It must materialize in a structured, inclusive and iterative cycle of exchanges on shared objects to support a common assessment of adaptation strategies [Sempé *et al.*, 2006]. This requires the use of flexible models, which can be iteratively refined/modified and which are not tied to a given scale, so that they can be effectively manipulated by various stakeholders, each with their own perspectives [Guyot *et al.*, 2006].

In this chapter, we believe we have provided a compelling example, with LUCAS, of the value of these new modelling approaches in planning the adaptation of a system as complex as the Mekong Delta to climate change. LUCAS is an open model, available in open-source¹, and can be programmed, simulated and explored on the GAMA simulation platform [Taillandier *et al.*, 2019], itself the result of a long-standing scientific collaboration between Vietnamese and French researchers. It is also an evolving model, which we hope can serve as a basis for the construction of operational tools for adaptation planning in the Mekong Delta.

1. https://github.com/tcquang/MK_landuse.git

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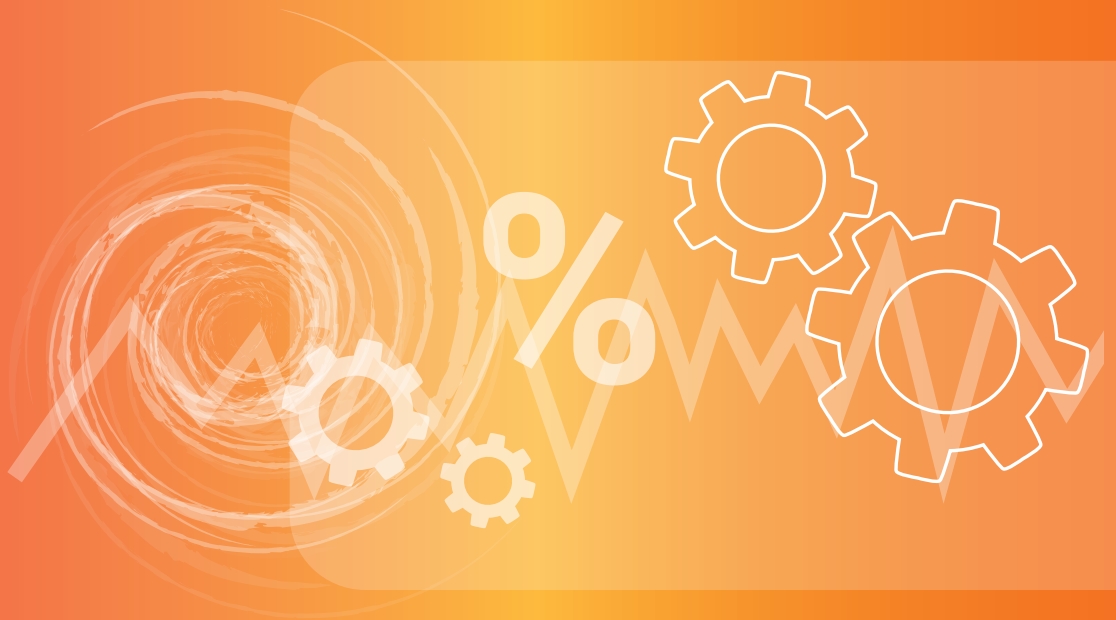
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Part 4

Macroeconomics of climate impacts and adaptation



SUMMARY | MACROECONOMICS OF CLIMATE IMPACTS AND ADAPTATION

This fourth part of the report deals with climate impacts and adaptation strategies at the national level. In this part, we provide key insights about: the cross-sectoral and cumulative effects of climate change in Viet Nam; adaptation policies and their implementation; and the mobilisation, allocation, and use of funding for adaptation. The findings of our analysis can be used to enhance the quality of policy implementation, and contribute to the effective and sustainable mobilisation and use of resources for adaptation.

Climate change adaptation in Viet Nam, from policies to practices

National adaptation policies

The submission of the Viet Nam Initial National Communication to the United Nations Framework Convention on climate change (UNFCCC) in 2003 was an important milestone in further accelerating climate actions in Viet Nam. Since then, a significant number of important policies have been developed and approved, such as the National Strategy on climate change (NSCC), the National Adaptation Plan (NAP), and the recently-approved Law on Environmental Protection 2020 (LEP). Furthermore, the post-2020 NSCC and the National Action Plan to Respond to climate change (NAPRCC) for the 2021–2030 period is expected to be submitted to the Prime Minister by the end of 2021. A fundamental element is underway to foster climate change responses in line with the socio-economic and sustainable development plans of Viet Nam. Following national adaptation policies, ministries and provincial level governments have developed their own adaptation policies at their respective levels.

Regarding post-2020 adaptation policy in Viet Nam, adaptation interventions are classified into three categories corresponding to three main adaptation targets, including (i) strengthening resilience and enhancing adaptive capacity; (ii) mitigating risk and damage from climate change-related disasters, and enhancing preparedness to respond to extreme weather and natural disasters; and (iii) strengthening national adaptive capacity through institutional improvement, capacity-building, securing resources, promoting international cooperation, and implementing international obligations.

These various key national adaptation policies define the fundamental guiding principles that need to be applied, such as: introducing official guidelines for integrating adaptation policies; the need for adaptation and disaster planning to be based on vulnerability and risk assessment; consideration of uncertainties; mainstreaming adaptation into sectorial and local development planning; paying more attention to soft measures; enhancing the implementation of adaptation policies at the sectorial and local levels; strengthening capacity-building; enacting a monitoring and evaluation system; employing incentives and effective mechanisms to engage with and mobilize resources from the private sector; improving stakeholder participation in adaptation planning and implementation. These principles in-

dicating the high quality of adaptation policies that aim to promote integrated, holistic, and inclusive approaches, and take the inter-linkages between sectors and regions, and short-term and long-term actions into account. Despite the long list of results and achievements described in this chapter, there are still a number of limitations in the implementation of adaptation policies in different sectors and at provincial and lower levels.

Implementation of adaptation policies at the local level

The findings of our case studies in the North, the Centre and the Mekong Delta confirm that the guiding principles of national policies have only partially been implemented, and that actions poorly address needs at the local level.

The lack of technical and financial resources, capacity-building and an integrated institutional scheme dedicated to climate change issues remain crucial challenges. Furthermore, strengthening weather forecasts and early warning systems, and raising awareness on adaptation is still needed to improve preventive and proactive actions. Moreover, very few actions address the structural drivers of vulnerability. Consequently, our research into local post-disaster responses shows that short-term reactive responses often override proactive and preventive strategies. In a context of uncertainty about future climatic events, the ability of local actors to mobilize various resources to restore and implement everyday pragmatic adjustments, and to develop multiple options (e.g. multiple sources of income) to cope with shocks, reveals a high degree of flexibility at the local level that can foster adaptive capacity and reinforce resilience. However, while these actions are efficient in the short-term and should be supported, they are not sufficient to face and absorb the potential impacts of climate change in the long term. They need to be accompanied by forms of external support that encourage more planned adaptation strategies.

Ultimately, practical achievements also demonstrate that social capital, collective actions, the mobilization of contributions from multiple actors (community, NGOs, private sector, state organization, civil society), and local knowledge can play an essential role in successfully implementing adaptation policies that take each local and specific context into account.

Financing climate change adaptation in Viet Nam

Viet Nam has made significant efforts in financing adaptation activities. The country has also received substantial financial support, often in the form of Official Development Assistance (ODA), from bilateral and multilateral cooperation. During the period 2012–2018, Viet Nam mobilised nearly USD 7 billion from ODA sources for environmental protection and climate change projects. In addition, international non-governmental organizations (NGOs) have also provided important support to Viet Nam, especially at the local level.

An important challenge in analysing the state and the dynamics of adaptation finance concerns the availability of good statistical data. To date, there is a lack of operational tools

and comprehensive systems to consistently monitor and assess adaptation finance. Therefore, measuring the effectiveness of adaptation policies and the impact of adaptation finance is not always straightforward. In addition, the lack of consistency in reporting systems, and of a clear definition of adaptation finance makes it difficult to assess whether funding for a development project contributes to adaptation, and to assess the immaterial resources mobilised for adaptation, especially at the community level.

Our findings suggest that advancing the adaptation agenda is not only about getting more financial resources, but also about how existing funding is used. According to existing data, resources for adaptation funding have been used mainly for large-scale hard infrastructure interventions. Although hard infrastructure may be critical for tackling future climate changes, it may barely contribute to adaptation if not carefully designed and planned. In addition, the dominance of hard infrastructure implies that limited attention has been paid to soft measures, such as integrated planning improvement and green infrastructure, and to addressing fundamental drivers of vulnerability. For example, despite significant funding for climate change response in Viet Nam over the last ten years, the provincial government still lacks staff with appropriate training and sufficient capacity in climate change assessment and planning, and there are even no staff at all dedicated to climate change issues at the district and commune levels.

Another important financial gap is the critical lack of funding for adaptation at the provincial and, especially, the community levels. For instance, according to our study, overall actual funding to implement the provincial action plan to respond to climate change (CAP) remains relatively limited. In many areas such as Bac Kan, Ninh Thuan, and Dien Bien provinces, there is no or very limited local finance to add to the national funding that was used to develop their CAPs. This problem can be attributed to the large share of adaptation funding dedicated to large-scale infrastructure projects that are often directly managed by national agencies, the limited use of development resources to support adaptation due to the lack of effective integration of climate change adaptation into development planning, and the lack of effective engagement of and contribution from the private sector. We argue that filling these gaps will be crucial to increase and sustain funding for climate change adaptation at the provincial and lower levels.

The macroeconomics of climate change and adaptation in Viet Nam

The social and economic effects of climate impacts on the Vietnamese economy as a whole are estimated using an integrated macroeconomic framework. Indeed, this is essential to understand the cross-sectoral and cumulative effects of climate changes, not only across Viet Nam, but also in relation with its main trade partners.

We found that direct damage represents an average of 1.8% of annual GDP losses in the case of a temperature increase of 1°C relative to the pre-industrial period 1851–1900. This

loss becomes 4.5% for a 1.5°C increase, 6.7% for a 2°C increase, and up to 10.8% for a 3°C increase. Integrating damage functions into the macroeconomic model, by 2050, average losses are larger than direct damages by around 30%. In addition, we estimate the annual GDP losses due to typhoons in the period 1993–2013 at 2.4%. Uncertainties remain about the future impacts of typhoons combined with climate change scenarios. Finally, evidence is given that notwithstanding limitations due to uncertainty in the full range of climate projections, climate change through “international damage spillovers” is expected to reduce Viet Nam’s long-term growth rate over the next 40 years.

We confirm that climate change adaptation will be more effective if it is mainstreamed into master plans (Master plan 2021–2030 and vision to 2050). The agriculture and energy sectors are at risk from future climate impacts. They are also a potential source of greenhouse gas mitigation as shown in Viet Nam’s NDC. This suggests that it would be possible to combine mitigation and adaptation measures for these two sectors in order to better mobilise financial resources. On a more social level, public health and social protection policies must now be designed to take climate change into account. Finally, the Ministry of Industry and Trade of Viet Nam should consider investigating the hypothesis of further international spillover damage.

TÓM TẮT | TIẾP CẬN KINH TẾ VĨ MÔ TRONG ĐÁNH GIÁ TÁC ĐỘNG VÀ THÍCH ỨNG VỚI KHÍ HẬU

Trong phần 4, báo cáo tập trung phân tích các tác động của khí hậu và các chiến lược thích ứng ở cấp quốc gia. Các thông tin mang tính nền tảng được đưa ra bao gồm: tác động tích lũy và liên ngành của biến đổi khí hậu ở Việt Nam; các chính sách thích ứng và việc thực hiện chúng cũng như huy động, phân bổ và sử dụng các nguồn tài chính cho thích ứng. Các kết quả của báo cáo này có thể góp phần hỗ trợ tăng cường chính sách, nâng cao khả năng thực thi chính sách và góp phần huy động, sử dụng hiệu quả, bền vững các nguồn lực cho thích ứng.

Thích ứng với biến đổi khí hậu ở Việt Nam, từ chính sách đến thực tiễn

Các chính sách thích ứng quốc gia

Việc đệ trình Thông báo Quốc gia lần thứ nhất theo yêu cầu của Công ước Khung của Liên hợp quốc về Biến đổi Khí hậu (UNFCCC) vào năm 2003 là một dấu mốc quan trọng để thúc đẩy hơn nữa các hành động về khí hậu ở Việt Nam. Theo đó, một số chính sách quan trọng đã được xây dựng và phê duyệt như Chiến lược Quốc gia về Biến đổi Khí hậu (NSCC) và Kế hoạch quốc gia thích ứng với biến đổi khí hậu (NAP), đặc biệt gần đây nhất Luật Bảo vệ Môi trường 2020 (LEP) đã được thông qua. Ngoài ra, NSCC sau năm 2020 và Kế hoạch hành động quốc gia ứng phó với biến đổi khí hậu (NAPRCC) giai đoạn 2021–2030 dự kiến sẽ được trình Thủ tướng Chính phủ vào cuối năm 2021. Nội dung cơ bản của các tài liệu này là thúc đẩy ứng phó với biến đổi khí hậu phù hợp với các kế hoạch phát triển kinh tế - xã hội của Việt Nam. Sau khi các chính sách thích ứng quốc gia được ban hành, các bộ và chính quyền cấp tỉnh đã xây dựng các chính sách thích ứng của riêng mình ở cấp tương ứng.

Đối với chính sách thích ứng sau năm 2020 ở Việt Nam, các hoạt động thích ứng được phân thành ba loại tương ứng với ba mục tiêu thích ứng chính, bao gồm (i) tăng cường khả năng chống chịu và nâng cao năng lực thích ứng; (ii) giảm thiểu rủi ro và thiệt hại từ các thiên tai liên quan đến biến đổi khí hậu, tăng cường khả năng sẵn sàng ứng phó với các hiện tượng thời tiết khắc nghiệt và thiên tai; và (iii) tăng cường năng lực thích ứng của quốc gia thông qua cải thiện thể chế, nâng cao năng lực, đảm bảo nguồn lực, thúc đẩy hợp tác quốc tế và thực hiện các nghĩa vụ quốc tế.

Những chính sách này định hình các nguyên tắc cơ bản cần áp dụng trong thực hiện thích ứng như: xây dựng các hướng dẫn chính thức về lồng ghép thích ứng với biến đổi khí hậu; sự cần thiết phải tính đến các yếu tố rủi ro và tính dễ bị tổn thương trong công tác lập kế hoạch thích ứng và giảm thiểu rủi ro thiên tai; tính đến các yếu tố bất định; lồng ghép thích ứng vào quá trình lập quy hoạch phát triển ngành và địa phương; tăng cường việc áp dụng các giải pháp phi công trình; cải thiện việc thực thi các chính sách thích ứng của các ngành và các địa phương; thúc đẩy nâng cao năng lực; xây dựng và triển khai hệ thống giám sát và đánh giá; áp dụng các giải pháp khuyến khích và cơ chế hiệu quả để huy động sự tham gia và nguồn

lực từ khu vực tư nhân; tăng cường sự tham gia của các bên liên quan trong công tác lập và triển khai kế hoạch thích ứng. Các nguyên tắc này đảm bảo tăng cường hiệu quả của các chính sách thích ứng thông qua thúc đẩy phương pháp tiếp cận tổng hợp, tổng thể và bao trùm, đồng thời có tính đến mối liên kết giữa các ngành và khu vực, các hành động ngắn hạn và dài hạn và sự không chắc chắn của biến đổi khí hậu.

Mặc dù đạt được nhiều kết quả và thành tựu, vẫn còn một số hạn chế trong việc thực hiện các chính sách thích ứng ở các ngành, lĩnh vực khác nhau cũng như ở cấp địa phương và tại cộng đồng.

Thực hiện các chính sách thích ứng ở cấp địa phương

Kết quả nghiên cứu điển hình của chúng tôi ở miền Bắc, miền Trung và Đồng bằng sông Cửu Long chỉ ra rằng các nguyên tắc định hướng của chính sách thích ứng quốc gia chỉ được thực hiện một phần và các hành động được thực hiện giải quyết nhu cầu của địa phương một cách kém hiệu quả.

Việc thiếu các nguồn lực kỹ thuật và tài chính, năng lực cũng như một khung thể chế tích hợp riêng cho các vấn đề biến đổi khí hậu vẫn là những thách thức quan trọng. Hơn nữa, cần tiếp tục tăng cường hệ thống dự báo thời tiết và cảnh báo sớm, nâng cao nhận thức về thích ứng để thúc đẩy các hành động ứng phó chủ động hơn. Hơn nữa, rất ít hành động thích ứng ở cấp địa phương giải quyết được vấn đề cấu trúc của tính dễ bị tổn thương. Do đó, những hiểu biết có cơ sở của chúng tôi về các ứng phó sau thiên tai tại địa phương cho thấy rằng các phản ứng ứng phó ngắn hạn thường thay thế các chiến lược chủ động phòng ngừa. Trong bối cảnh không chắc chắn về các sự kiện khí hậu trong tương lai, khả năng của các địa phương trong huy động các nguồn lực khác nhau để khôi phục, thực hiện các điều chỉnh thực tế hàng ngày và xây dựng nhiều phương án (ví dụ, đa dạng hoá nguồn thu nhập) để đối phó với các cú sốc thể hiện tính linh hoạt cao trong nâng cao năng lực thích ứng và củng cố khả năng chống chịu ở cấp địa phương. Tuy nhiên, trong khi những hành động này có hiệu quả trong ngắn hạn và cần được hỗ trợ, chúng không đủ để đối mặt và chống lại được những tác động tiềm tàng của biến đổi khí hậu về lâu dài. Chúng cần được kết hợp với các hình thức hỗ trợ từ bên ngoài để tăng cường quá trình hoạch định chiến lược thích ứng.

Cuối cùng, những thành tựu thực tế cũng chứng minh rằng nguồn vốn xã hội, các hành động tập thể, huy động sự đóng góp của nhiều bên (cộng đồng, tổ chức phi chính phủ, khu vực tư nhân, tổ chức nhà nước, xã hội dân sự) cũng như kiến thức địa phương có thể đóng vai trò thiết yếu hỗ trợ thực hiện thành công các chính sách thích ứng có tính đến bối cảnh từng địa phương cụ thể.

Tài chính cho thích ứng với Biến đổi khí hậu ở Việt Nam

Việt Nam đã có nhiều nỗ lực trong việc huy động nguồn lực tài chính cho công tác thích ứng với Biến đổi khí hậu (BĐKH) và đã nhận được sự hỗ trợ tích cực của các tổ chức song phương

và đa phương chủ yếu thông qua các chương trình hỗ trợ phát triển chính thức (ODA). Trong giai đoạn 2012–2018, Việt Nam đã huy động được gần 7 tỷ đô la Mỹ từ nguồn ODA cho các dự án bảo vệ môi trường và biến đổi khí hậu. Bên cạnh đó, các tổ chức phi chính phủ cũng đã có nhiều đóng góp quan trọng cho công tác thích ứng với BĐKH ở Việt Nam đặc biệt là ở cấp cộng đồng.

Một thách thức quan trọng của việc phân tích vấn đề tài chính cho thích ứng là sự hạn chế và sẵn có của các dữ liệu thống kê có chất lượng. Hiện nay, ở Việt Nam chưa có các công cụ hiệu quả và hệ thống toàn diện để theo dõi và đánh giá tài chính cho thích ứng. Điều này gây khó khăn cho công tác đánh giá hiệu quả của các chính sách thích ứng và tác động của việc sử dụng ngân sách cho thích ứng. Bên cạnh đó, việc đánh giá đóng góp của các dự án phát triển đối với công tác thích ứng cũng như tích hợp các nguồn lực phi tài chính cho thích ứng đặc biệt là ở cấp cộng đồng gặp nhiều khó khăn do sự thiếu nhất quán trong hoạt động báo cáo tài chính về thích ứng và do khái niệm tài chính cho thích ứng chưa được định nghĩa một cách rõ ràng.

Nghiên cứu của chúng tôi cho thấy, để tăng cường hiệu quả của các chương trình thích ứng chúng ta không chỉ phải huy động thêm nguồn lực tài chính mà còn phải lưu ý đến cách thức sử dụng ngân sách. Theo dữ liệu hiện có, ngân sách cho thích ứng đã và đang được phân bổ chủ yếu cho các dự án công trình hạ tầng quy mô lớn. Mặc dù các công trình này có thể quan trọng trong việc ứng phó với BĐKH trong tương lai, nếu không được quy hoạch và thiết kế một cách cẩn trọng chúng có thể chỉ đóng góp hạn chế trong việc tăng cường khả năng thích ứng (Eckardt *et al.*, 2016) hoặc thậm chí tạo ra những tác động bất lợi về lâu dài (Balboni, 2019). Ngoài ra, tập trung vào các giải pháp công trình dẫn tới việc các giải pháp phi công trình như cải thiện công tác quy hoạch tích hợp, phát triển hạ tầng xanh, và các dự án giải quyết nguyên nhân gốc rễ của tình trạng dễ bị tổn thương không nhận được sự quan tâm thỏa đáng. Ví dụ như, mặc dù Việt Nam đã phân bổ một lượng ngân sách đáng kể cho công tác ứng phó với BĐKH trong hơn 10 năm qua nhưng đội ngũ cán bộ liên quan ở cấp tỉnh vẫn thiếu về số lượng và yếu về năng lực. Đa số cán bộ ở các phòng, ban liên quan không được đào tạo bài bản về BĐKH. Cấp huyện và xã thậm chí không có cán bộ phụ trách vấn đề BĐKH.

Một tồn tại quan trọng khác về tài chính cho thích ứng là sự thiếu hụt đáng kể nguồn lực tài chính cho hoạt động thích ứng ở cấp tỉnh, huyện, xã và đặc biệt là cấp cộng đồng. Ví dụ như, theo nghiên cứu của chúng tôi, tổng ngân sách để triển khai Kế hoạch hành động ứng phó với BĐKH ở cấp tỉnh là hết sức hạn chế. Ở nhiều địa phương như Bắc Kạn, Ninh Thuận và Điện Biên, ngoài ngân sách của Trung ương hỗ trợ cho việc xây dựng kế hoạch hành động thì các tỉnh này không có hoặc có rất ít ngân sách để triển khai (Bac Kan PPC, 2015; Dien Bien PPC, 2015; Ninh Thuan PPC, 2015). Vấn đề này có thể được lý giải bởi những nguyên nhân như: sự tập trung ngân sách cho các công trình hạ tầng quy mô lớn thường do các cơ quan cấp quốc gia quản lý, sự hạn chế trong việc huy động và sử dụng nguồn lực cho phát triển để hỗ trợ các mục tiêu thích ứng do những hạn chế trong việc lồng ghép thích ứng với BĐKH vào công tác quy hoạch phát triển và vào các quy định tài chính và quy trình xây dựng

ngân sách, và sự thiếu hiệu quả trong việc huy động sự tham gia và đóng góp của khu vực tư nhân. Chúng tôi cho rằng, giải quyết những tồn tại này có ý nghĩa quan trọng trong việc cải thiện và đảm bảo tính bền vững của nguồn lực tài chính cho công tác thích ứng tại các địa phương và cộng đồng.

Tiếp cận kinh tế vĩ mô trong đánh giá tác động và thích ứng với khí hậu

Các tác động kinh tế và xã hội của biến đổi khí hậu lên tổng thể nền kinh tế Việt Nam được ước lượng bằng một khung tích hợp vĩ mô. Thực vậy, rất cần thiết để tìm hiểu các tác động giữa các ngành và tác động tích lũy của biến đổi khí hậu ở Việt Nam và cũng như trong mối quan hệ với các đối tác thương mại chính.

Chúng tôi tìm ra rằng thiệt hại trực tiếp ước tính hằng năm trung bình là 1.8% GDP so với kịch bản cơ sở khi nhiệt độ tăng lên 1°C so với thời kỳ tiền công nghiệp 1851–1900. Thiệt hại sẽ là 4,5% khi nhiệt độ tăng 1,5°C, 6,7% khi nhiệt độ tăng 2°C và lên đến 10,8% khi nhiệt độ tăng 3°C. Sau khi tích hợp các hàm thiệt hại này vào mô hình kinh tế vĩ mô trữ lượng-lưu lượng nhất quán của kinh tế Việt Nam để đánh giá tác động liên ngành và tổng hợp của biến đổi khí hậu, đến năm 2050, thiệt hại vĩ mô trung bình có thể lớn hơn so với thiệt hại trực tiếp khoảng 30%. Bên cạnh đó, chúng tôi nhận thấy thiệt hại hằng năm GDP do bão trong giai đoạn 1992–2013 ước tính là khoảng 2.4%. Hiện nay, rất khó dự đoán các cơn bão trong tương lai ứng với các kịch bản khí hậu khác nhau. Cuối cùng, các bằng chứng cho thấy rằng bất chấp những hạn chế gây ra bởi tính bất định trong các kịch bản biến đổi khí hậu, biến đổi khí hậu, thông qua các thiệt hại lan tỏa từ quốc tế sẽ có thể làm giảm tốc độ tăng trưởng lâu dài của Việt Nam trong 40 năm tới.

Người ta khẳng định rằng thích ứng với biến đổi khí hậu sẽ hiệu quả hơn nếu nó được lồng ghép vào các quy hoạch tổng thể (Quy hoạch tổng thể 2021–2030 và tầm nhìn đến năm 2050). Các ngành nông nghiệp và năng lượng có nguy cơ bị ảnh hưởng khí hậu trong tương lai. Chúng cũng là một nguồn tiềm năng giảm thiểu khí thải nhà kính được thể hiện trong NDC của Việt Nam. Điều này cho thấy cần kết hợp các biện pháp giảm thiểu và thích ứng của hai lĩnh vực này để huy động tốt hơn các nguồn lực tài chính. Về khía cạnh xã hội, cần lưu ý vấn đề biến đổi khí hậu trong xây dựng các chính sách về y tế công và bảo hiểm xã hội. Cuối cùng, Bộ Công Thương Việt Nam nên xem xét điều tra thêm giả thuyết về các thiệt hại từ quốc tế khác.

RÉSUMÉ | MACROÉCONOMIE DES IMPACTS DU CHANGEMENT CLIMATIQUE ET DE L'ADAPTATION

Cette quatrième partie du rapport aborde les impacts du changement climatique et les stratégies d'adaptation au niveau national. Dans cette dernière partie du rapport, nous proposons des analyses sur les effets intersectoriels et cumulatifs des changements climatiques au Viet Nam, sur les politiques d'adaptation et leur mise en œuvre et sur la mobilisation, l'allocation et l'utilisation des financements dédiés à l'adaptation. Les résultats de notre analyse visent à appuyer la mise en œuvre des politiques et à favoriser un usage efficace et pérenne des ressources pour l'adaptation.

L'adaptation au changement climatique au Viet Nam : des politiques aux pratiques

Les politiques d'adaptation au niveau national

La remise de la Contribution Nationale du Viet Nam à la Convention cadre des Nations Unies sur les changements climatiques (CCNUCC) en 2003 a été une étape importante pour accélérer la mise en œuvre des actions pour le climat au Viet Nam. Depuis lors, un nombre important de politiques ont été élaborées et entérinées, comme la Stratégie Nationale sur le Changement Climatique (NSCC), le Plan National d'Adaptation (PAN) ou la loi sur la protection de l'environnement 2020 (LEP) récemment approuvée. Il est également prévu que la NSCC post-2020 ainsi que le Plan d'Action National de Réponse au Changement Climatique (NAPRCC) pour la période 2021–2030 soient soumis au Premier ministre d'ici fin 2021. L'un des éléments fondamentaux de ces diverses politiques est de définir des réponses au changement climatique qui s'inscrivent dans les plans de développement socio-économique et de développement durable du Viet Nam. Conformément aux politiques nationales d'adaptation, les ministères et les gouvernements provinciaux ont élaboré leurs propres politiques d'adaptation à leurs niveaux respectifs.

En ce qui concerne les politiques d'adaptation post-2020, les interventions peuvent se classer en trois catégories, correspondant aux trois principaux objectifs de l'adaptation : (i) renforcer la résilience et améliorer les capacités d'adaptation ; (ii) atténuer les risques et les dommages des catastrophes liées au changement climatique, et améliorer la prévention; et (iii) renforcer la capacité d'adaptation au niveau national en améliorant l'environnement institutionnel, en renforçant les capacités, en sécurisant les ressources financières, en renforçant la coopération internationale et en appliquant les obligations internationales sur le climat.

Ces différentes politiques nationales d'adaptation posent les principes fondamentaux qui doivent être appliqués, comme la nécessité d'élaborer des approches intégrées et systémiques ; la prise en compte des incertitudes liées au changement climatique ; favoriser des stratégies d'adaptation proactives; prendre en compte la vulnérabilité et les risques ; intégrer l'adaptation dans la planification et les politiques de développement ; mobiliser et

engager activement toutes les parties prenantes concernées ; promouvoir des actions multi-bénéfiques et des mesures d'adaptation "légères" (non infrastructurelles), basées sur les écosystèmes et les communautés; et établir un système de suivi et d'évaluation de l'adaptation au changement climatique. Ces principes soulignent l'ambition et la qualité des politiques d'adaptation au Viet Nam, qui visent in fine à promouvoir des approches intégrées, holistiques et inclusives, prenant en compte les interdépendances entre les secteurs et les régions, les actions à court et à long terme, ainsi que les incertitudes liées au changement climatique. Mais, comme le montre en détail le [Chapitre 11](#), malgré les nombreux résultats déjà obtenus, la mise en œuvre des politiques d'adaptation dans différents secteurs et aux niveaux provinciaux et locaux rencontre d'importantes difficultés.

La mise en œuvre des politiques d'adaptation au niveau local

Les résultats de nos études de cas dans le Nord, le Centre et le delta du Mékong (Sud) confirment que les principes fondamentaux des politiques nationales ne sont que partiellement mis en œuvre et que les actions sur le terrain ne sont pas toujours adaptées aux besoins spécifiques à chaque contexte. Le manque de ressources techniques et financières, les besoins prégnants en renforcement des capacités ainsi que la faiblesse des dispositifs institutionnels dédiés aux enjeux du changement climatique restent des défis majeurs. En outre, l'amélioration des prévisions météorologiques et des systèmes de prévention associés à des campagnes de sensibilisation à l'adaptation s'affirment comme des domaines prioritaires pour favoriser à la fois des actions de prévention efficaces et des actions d'adaptation proactives. De plus, très peu d'interventions abordent les facteurs structurels de la vulnérabilité. Par conséquent, nos enquêtes de terrain sur les réponses locales aux événements climatiques extrêmes montrent que les actions réactives à court terme dominent au détriment des stratégies d'adaptation préventives ou proactives. Dans un contexte de forte incertitude sur les événements climatiques (et économiques) futurs, la capacité des acteurs locaux à mobiliser diverses ressources pour se remettre des chocs, à inventer diverses adaptations pragmatiques au quotidien et à développer de multiples options en parallèle (par exemple, en multipliant les sources de revenus) dévoile une importante flexibilité au niveau local qui peut favoriser les capacités d'adaptation au changement climatique et renforcer la résilience. Cependant, si ces diverses initiatives locales s'avèrent efficaces sur le court-terme et doivent être reconnues et appuyées, elles risquent de ne pas être suffisantes pour faire face et absorber les impacts du changement climatique. Des formes de soutien extérieur favorisant la mise en place de stratégies d'adaptation davantage planifiées doivent les accompagner.

Enfin, nos observations de terrains indiquent que le capital social, les formes d'actions collectives, le recours aux contributions matérielles et immatérielles de multiples acteurs (communauté, ONG, secteur privé, organisations étatiques, société civile), ainsi que les savoirs locaux peuvent jouer un rôle essentiel dans la réalisation de politiques d'adaptation, en prenant davantage en considération la spécificités des différents contextes locaux.

Financer l'adaptation au changement climatique au Viet Nam

Le Viet Nam a fait des efforts importants dans le financement des activités d'adaptation. Le pays a également bénéficié de soutiens financiers conséquents dans le cadre de coopérations bilatérales et multilatérales, souvent sous la forme d'aide publique au développement (APD). Au cours de la période 2012–2018, le Viet Nam a ainsi mobilisé près de 7 milliards de dollars issus de l'APD pour des projets de protection de l'environnement et de lutte contre le changement climatique. Des organisations non gouvernementales (ONG) internationales ont également apporté un soutien important au Viet Nam, en particulier au niveau local.

La disponibilité de données statistiques fiables constitue un défi majeur pour l'analyse de l'état et de l'évolution du financement de l'adaptation. Il n'existe actuellement pas d'outils opérationnels permettant de surveiller et d'évaluer systématiquement le financement de l'adaptation. Dans ces conditions, il est particulièrement difficile de mesurer l'efficacité des politiques d'adaptation et l'impact du financement de l'adaptation. De plus, compte tenu du manque de cohérence des systèmes de suivi existants et de l'absence de définition claire du financement de l'adaptation, il est difficile d'évaluer si le financement d'un projet de développement contribue à l'adaptation et de comptabiliser les ressources immatérielles mobilisées pour l'adaptation, notamment au niveau communautaire.

Nos résultats indiquent que l'amélioration des programmes d'adaptation ne repose pas seulement sur l'obtention de ressources financières supplémentaires, mais aussi sur les manières concrètes dont le financement est utilisé. Selon les données existantes, les ressources dédiées au le financement de l'adaptation ont été principalement utilisées pour la construction d'infrastructures à grande échelle. Bien que les infrastructures peuvent s'avérer dans certains cas efficaces pour faire face aux futurs changements climatiques, elles peuvent également ne pas être appropriées aux futurs aléas si elles ne sont pas soigneusement conçues et planifiées, et conduire finalement à une mal-adaptation. En outre, la prédominance des investissements pour les infrastructures se fait au détriment des mesures dites "légères", telles que l'amélioration de la planification intégrée ou les "infrastructures vertes" et des initiatives qui abordent les facteurs fondamentaux de vulnérabilité. Par exemple, malgré d'importants financements pour l'adaptation au changement climatique au Viet Nam au cours des dix dernières années, les gouvernements provinciaux manquent toujours de personnels dotés d'une formation appropriée et ne disposent pas des compétences suffisantes pour l'évaluation et la planification du changement climatique. Au niveau des districts et des communes, il n'y a pas de personnel responsable des questions de changement climatique.

Un autre défi important est le manque de financement dédié à l'adaptation au niveau provincial et surtout au niveau local (communes, villages). Par exemple, le financement mis à disposition pour la mise en œuvre des Plans d'Action Provinciale de Réponse aux Changements Climatiques (PAC) demeure relativement limité. Dans de nombreuses régions, telles que les provinces de Bac Kan, Ninh Thuan et Dien Bien, il n'y a pas, ou très peu, de financements issus des budgets provinciaux pour compléter les financements en provenance

du budget national pour la mise en œuvre des CAP. Ce problème peut être attribué à la part importante du financement de l'adaptation dédiée aux projets d'infrastructure à grande échelle, qui sont souvent gérés directement par les agences nationales. Il s'explique également par le manque d'intégration effective de l'adaptation au changement climatique dans les plans de développement provinciaux, tendance qui se traduit par l'utilisation limitée des ressources dédiées au développement pour soutenir l'adaptation. Enfin, ce problème est également lié aux modes de fonctionnement des budgets, aux réglementations en place et au manque d'engagement et de contribution efficaces du secteur privé. Nous soutenons qu'il est primordial de combler ces lacunes pour augmenter et maintenir le financement de l'adaptation aux changements climatiques aux niveaux provincial et plus local.

La macroéconomie du changement climatique et de l'adaptation au Viet Nam

Les effets sociaux et économiques des impacts climatiques sur l'économie vietnamienne dans son ensemble sont mesurés à l'aide d'un cadre macroéconomique intégré. En effet, il reste essentiel de comprendre les effets transversaux et cumulatifs des changements climatiques, non seulement à l'intérieur du Viet Nam, mais aussi en relation avec ses principaux partenaires commerciaux.

Les résultats indiquent que les dommages directs représentent de 1,8% du PIB annuelle par rapport au scénario de référence en cas d'une augmentation de 1°C par rapport à la période pré-industrielle 1851–1900. Cette perte devient de 4,5% pour une augmentation de 1,5°C, de 6,7% pour une augmentation de 2°C et jusqu'à 10,8% pour une augmentation de 3°C. En intégrant les fonctions des dommages directs dans le modèle stock-flux cohérent du Viet Nam, d'ici à 2050, les dommages en moyenne sont supérieurs aux dommages directs de 30%. De plus, nous estimons les pertes annuelles du PIB dues aux typhons sur la période 1992–2013 à 2,4%. Des incertitudes subsistent quant aux impacts futurs des typhons combinés aux scénarios de changement climatique. Enfin, nous montrons que les impacts climatiques sur les partenaires commerciaux du Viet Nam devraient contribuer à réduire le taux de croissance à long terme du Viet Nam au cours des quarante prochaines années.

In fine, l'adaptation au changement climatique sera plus efficace si elle est intégrée dans les plans directeurs (plan directeur 2021–2030 et vision à l'horizon 2050). A titre d'exemple, nous avons montré dans ce rapport comment les secteurs de l'agriculture et de l'énergie étaient menacés par les futurs impacts climatiques. Or ils constituent également une source potentielle d'atténuation des gaz à effet de serre, comme le montre la contribution nationale du Viet Nam. Cela suggère une possibilité de combiner les mesures d'atténuation et d'adaptation de ces deux secteurs afin de mieux mobiliser les ressources financières. Sur un volet plus social, les politiques de santé publique ou de protection sociale doivent désormais se penser en intégrant la contrainte climatique. Enfin, le ministère vietnamien de l'industrie et du commerce devrait envisager d'étudier plus avant l'hypothèse des retombées internationales des dommages climatiques sur les partenaires du Viet Nam.

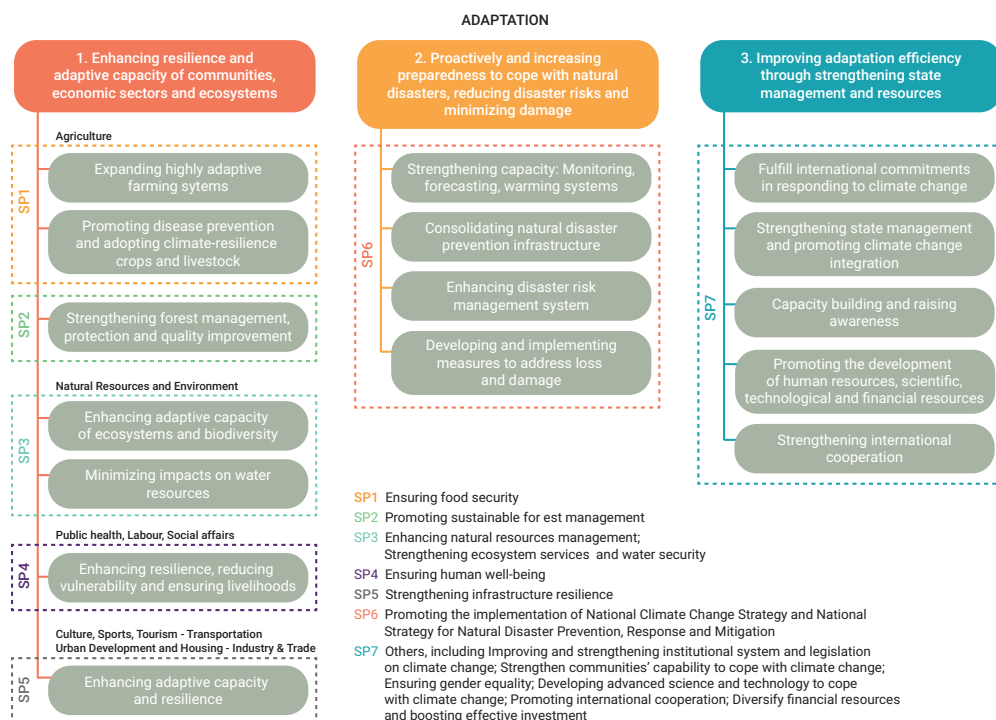
FIGURES | HÌNH

[Figure 1 | Hình 1]

Key strategic priorities and development approaches of post-2020 adaptation policies in Viet Nam

Các ưu tiên chiến lược và hướng tiếp cận xây dựng các chính sách thích ứng sau năm 2020 ở Việt Nam

Priorités stratégiques et approches du développement des politiques d'adaptation post-2020 au Viet Nam



To internalize international commitments and be tailored to the socio-economic development plans, post-2020 adaptation interventions are categorized into three main adaptation targets followed by seven key development strategic priorities.

Để nội địa hóa các cam kết quốc tế và đảm bảo phù hợp với các kế hoạch phát triển kinh tế - xã hội, các hoạt động thích ứng sau năm 2020 được phân thành ba mục tiêu thích ứng chính cùng với bảy ưu tiên chiến lược phát triển tương ứng.

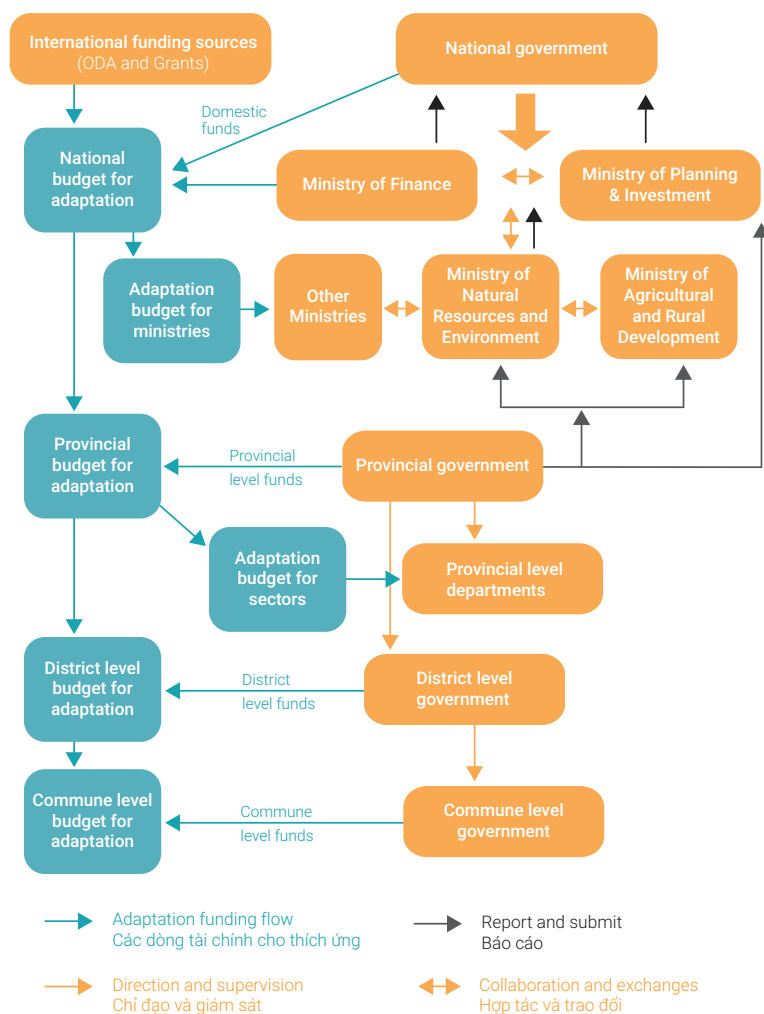
Afin d'internaliser les engagements internationaux et de les aligner aux plans de développement socio-économiques, les activités d'adaptation post-2020 sont classées en trois principales cibles selon sept priorités stratégiques de développement.

[Figure 2 | Hình 2]

Formal adaptation financial flow

Các dòng tài chính chính thức cho thích ứng

Les flux formels du financement de l'adaptation

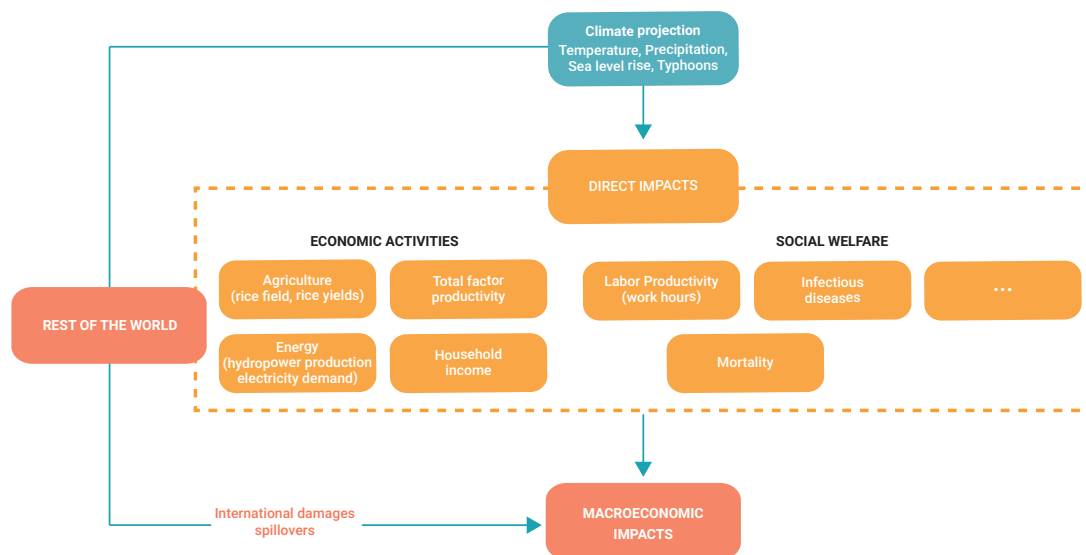


[Figure 3 | Hình 3]

An open integrated framework to assess climate damage in Viet Nam

Khung tích hợp mở để đánh giá thiệt hại do khí hậu ở Việt Nam

Un cadre intégré et ouvert pour évaluer les dommages climatiques au Viet Nam



The integrated framework used in this report allows for the measure of direct impacts on key socio-economic variables and their macroeconomic effect. It remains open to additional sectorial impacts.

Khung tích hợp được sử dụng trong báo cáo này cho phép đo lường tác động trực tiếp đến các biến kinh tế-xã hội chính và tác động kinh tế vĩ mô của chúng. Nó vẫn để ngỏ cho các tác động ngành bổ sung.

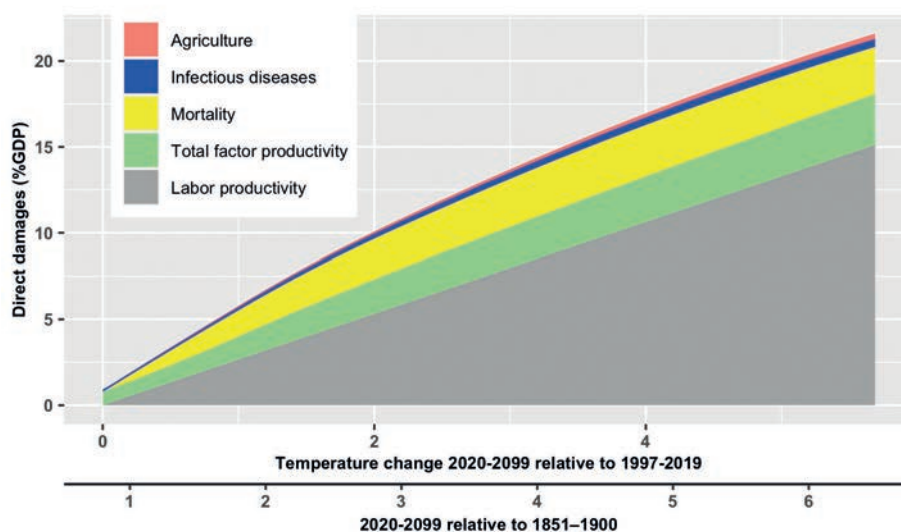
Le cadre intégré utilisé dans ce rapport permet de mesurer les impacts directs sur les variables socio-économiques clés et leur effet macro-économique. Il reste ouvert à des impacts sectoriels supplémentaires.

[Figure 4 | Hình 4]

Estimates of total direct damages by sectors

Ước tính tổng thiệt hại trực tiếp theo các ngành

Estimations des dommages directs totaux par secteurs



Total direct damage to the Vietnamese economy by different sectors as a function of VNMST change 2020–2099 relative to 1997–2019 (contemporary climate) and relative to 1851–1900 (pre-industrial climate). The temperature of the pre-industrial period is estimated from observation dataset and HadCRUT5 (with a coarse resolution of $5^\circ \times 5^\circ$).

Tổng thiệt hại trực tiếp đối với nền kinh tế Việt Nam theo các lĩnh vực khác nhau như một hàm theo sự thay đổi của nhiệt độ Việt Nam 2020–2099 so với 1997–2019 (khí hậu gần nhất) và so với 1851–1900 (thời kỳ tiền công nghiệp). Nhiệt độ của thời kỳ tiền công nghiệp được ước tính từ dữ liệu quan sát và HadCRUT5 (với độ phân giải là $5^\circ \times 5^\circ$).

Dommages directs totaux à l'économie vietnamienne par différents secteurs en fonction du changement de VNMST 2020–2099 par rapport à 1997–2019 (climat contemporain) et par rapport à 1851–1900 (climat pré-industriel). La température de la période pré-industrielle est estimée à partir de la base de données d'observation et de HadCRUT5 (avec une résolution grossière de $5^\circ \times 5^\circ$).

RECOMMENDATIONS

For policy makers

Mainstreaming national adaptation as development

- 1] Mainstream climate change adaptation into development planning and into budgeting regulations and processes. Specifically:
 - Available resources allocated for development projects and programs should be mobilized for adaptation and used in complementary ways that meet both development and adaptation objectives. To do so, a detailed and clear legal foundation and guidelines for mainstreaming need to be in place.
 - Take climate change impacts into account in master planning for the period of 2021–2030 and vision to 2050 at the national, sectorial, regional and provincial levels. Although this has been regulated in the new Environmental Protection Law, the guidance for this mainstreaming needs to be made available soon to be in line with the master planning process.
 - Integrate vulnerability and risk assessment as well as climate and socio-economic uncertainty considerations into adaptation decision making;
- 2] Take international damage spillovers into account to foster relevant measures for mitigating the negative impacts of trade, especially in the next report of the Ministry of Industry and Trade of Viet Nam on the topic.

Funding adaptation

- 3] Funding for adaptation should prioritize projects that address fundamental drivers of vulnerability, and more attention should be paid to multi-purpose interventions and soft measures;
- 4] Practical measures and mechanisms for private sector engagement are required to increase and diversify financial resources for adaptation;
- 5] Make full use of the network of Vietnamese local development funds in adaptation and mitigation projects, in order to better take local needs and those of the most vulnerable groups into account.

Translation of national adaptation policies into local practices

Vulnerable groups

- 1] Adjust existing adaptation policies to reflect local context and the needs of vulnerable groups;
- 2] Strengthen the technical support for all stakeholders, especially the most vulnerable groups.

Local planning

- 3] Mainstream adaptation into sectorial and local development planning;

4] Promote a holistic application of hard and soft adaptation measures, including non-infrastructure approaches to resilience building and nature-based solutions.

Monitoring and evaluation

5] A practical and comprehensive tool and mechanism need to be in place to systematically track, monitor and evaluate how adaptation funding is used, and to what extent adaptation projects contribute to reduce vulnerability and increase resilience.

Capacity building

6] Strengthen capacity and understanding of relevant government and non-government actors and local communities with regard to adaptation planning, and adaptation project development and implementation, to improve the effective use of adaptation funding.

For researchers

1] Adaptations to climate change are embedded into broader socio-political systems and are thus shaped by many factors that go far beyond climate change issues. They can be strong levers or limitations for adaptation practices. Therefore, it is important to develop multi-level holistic extended studies that address the complexity of contexts in which adaptation actions take place.

2] Conduct research focusing on the implementation of adaptation policies and projects, in order to document local responses in situ, along with the unexpected effects of the interventions, and everyday adjustments to contingent environmental and/or socio-economic variations. Understanding and acknowledging these dynamics, and the deviations between what was planned and what actually takes place, would help to identify and replicate successful practices, and to make appropriate adjustments to current and future interventions.

3] To advance adaptation in Viet Nam, upcoming studies should focus more on resilience and adaptive capacity evaluation, vulnerability and risk assessment, and climate and socio-economic uncertainty estimation. Their findings can provide valuable information for adaptation decision-making, and contribute to strengthening the monitoring and evaluation system for adaptation in Viet Nam.

4] Broaden the scope of sectorial impact coverage in the macroeconomic model, integrating the impacts on tourism, other agricultural sectors, the impacts of short-term extreme events, and the relative impacts in Viet Nam compared to the rest of the world.

5] Assess adaptation strategies at the macroeconomic level via proxies based on scenarios built with an adaptive and collaborative approach.

6] Investigate how impact assessment results are affected by the new climate and socio-economic scenarios emerging from the latest IPCC report.

CÁC KHUYẾN NGHỊ

Đối với các nhà làm chính sách

Lồng ghép/Tích hợp thích ứng với biến đổi khí hậu của quốc gia vào các mục tiêu phát triển

1] Lồng ghép/Tích hợp thích ứng với biến đổi khí hậu vào các mục tiêu phát triển và dự kiến khung pháp lý và các quy trình, quy định. Cụ thể như sau:

– Các nguồn ngân sách dành cho các chương trình và dự án phát triển cần được huy động cho thích ứng với biến đổi khí hậu và sử dụng để đảm bảo đồng thời các mục tiêu phát triển và thích ứng. Để làm được như vậy, cần có một khung pháp lý cụ thể và rõ ràng cùng với các hướng dẫn để triển khai;

– Tính đến những tác động của biến đổi khí hậu trong các quy hoạch tổng thể giai đoạn 2021–2030, tầm nhìn 2050 ở các cấp quốc gia, ngành, vùng và các địa phương. Mặc dù đã đưa vào Luật Bảo vệ môi trường mới, thông tư hướng dẫn cho việc lồng ghép cần sớm được ban hành để đảm bảo tính phù hợp với quá trình xây dựng quy hoạch phát triển tổng thể.

– Lồng ghép đánh giá rủi ro và khả năng dễ bị tổn thương cũng như tính đến các yếu tố không chắc chắn về khí hậu và kinh tế xã hội trong quá trình ra quyết định về thích ứng với biến đổi khí hậu;

2] Tính đến các tác động lan tỏa về thiệt hại ở quy mô quốc tế để có thể đưa ra những chiến lược nhằm giảm nhẹ các tác động bất lợi về thương mại, đặc biệt trong báo cáo sắp tới của Bộ Công Thương về chủ đề này.

Tài chính cho thích ứng

3] Nguồn lực tài chính cho thích ứng với biến đổi khí hậu cần phải ưu tiên cho các dự án tập trung giải quyết các nguyên nhân gốc rễ của tình trạng dễ bị tổn thương và cần lưu ý hơn đến các dự án đa mục tiêu cũng như các giải pháp phi công trình;

4] Cần có các biện pháp và cơ chế thiết thực để huy động sự tham gia của khu vực tư nhân nhằm tăng cường và đa dạng hóa các nguồn lực tài chính cho thích ứng;

5] Tận dụng tối đa mạng lưới các quỹ phát triển địa phương của Việt Nam về thích ứng và giảm nhẹ khí hậu để xem xét và đáp ứng tốt hơn nhu cầu của địa phương và các nhóm dễ bị tổn thương nhất.

Từ các chính sách thích ứng quốc gia tới các giải pháp cụ thể tại địa phương

Các nhóm dễ bị tổn thương

1] Điều chỉnh các chính sách thích ứng hiện có để phản ánh bối cảnh địa phương và nhu cầu của các nhóm dễ bị tổn thương;

2] Tăng cường hỗ trợ kỹ thuật cho tất cả các bên liên quan, đặc biệt là các nhóm dễ bị tổn thương nhất.

Quy hoạch địa phương

3] Lồng ghép/tích hợp thích ứng vào các quy hoạch phát triển ngành và địa phương;

4] Thúc đẩy áp dụng một cách toàn diện các giải pháp thích ứng công trình và phi công trình, bao gồm các phương pháp tiếp cận phi công trình để xây dựng khả năng chống chịu và các giải pháp dựa vào thiên nhiên.

Giám sát và đánh giá

5] Cần có một công cụ và cơ chế thực tế và toàn diện để theo dõi, giám sát và đánh giá một cách có hệ thống việc sử dụng ngân sách dành cho thích ứng và mức độ các dự án thích ứng đóng góp vào việc giảm thiểu tình trạng dễ bị tổn thương và tăng khả năng chống chịu.

Nâng cao năng lực

6] Nâng cao năng lực và hiểu biết của các tổ chức chính phủ và phi chính phủ liên quan và các cộng đồng địa phương trong lập kế hoạch thích ứng, xây dựng và triển khai thực hiện các dự án để cải thiện hiệu quả sử dụng các nguồn lực cho thích ứng.

Đối với các nhà nghiên cứu

1] Thích ứng với biến đổi khí hậu gắn liền với các hệ thống chính trị - xã hội và do đó được định hình bởi nhiều yếu tố chứ không chỉ riêng các vấn đề về biến đổi khí hậu. Các yếu tố này có thể thúc đẩy mạnh mẽ hoặc làm cản trở các nỗ lực về thích ứng. Vì vậy, việc triển khai các nghiên cứu mở rộng có tính đến sự phức tạp của bối cảnh địa phương nơi các hành động thích ứng diễn ra là hết sức quan trọng.

2] Thực hiện các nghiên cứu về việc triển khai các chính sách và dự án thích ứng nhằm tài liệu hóa các giải pháp ở địa phương, các tác động không mong muốn của các can thiệp và những khác biệt giữa kế hoạch ban đầu và những gì diễn ra trong thực tế cũng như những điều chỉnh hàng ngày để thích nghi với những thay đổi về kinh tế, xã hội và môi trường. Sự hiểu biết thấu đáo về những vấn đề này sẽ giúp phát huy và nhân rộng những thành công cũng như đưa ra những điều chỉnh phù hợp cho các giải pháp hiện tại và trong tương lai.

3] Để nâng cao khả năng thích ứng ở Việt Nam, các nghiên cứu sắp tới cần tập trung nhiều hơn vào đánh giá khả năng chống chịu và thích ứng, đánh giá mức độ dễ bị tổn thương và rủi ro, cũng như phân tích tính không chắc chắn về khí hậu và kinh tế xã hội. Kết quả của những nghiên cứu này có thể cung cấp những thông tin có giá trị cho việc ra quyết định về thích ứng và góp phần tăng cường hệ thống giám sát và đánh giá về thích ứng ở Việt Nam.

4] Mở rộng phạm vi bao trùm các tác động tới các ngành trong mô hình kinh tế vĩ mô và lồng ghép các tác động đến du lịch, các lĩnh vực nông nghiệp khác, tác động của các hiện tượng thời tiết cực đoan ngắn hạn và tác động tương đối ở Việt Nam so với phần còn lại của thế giới.

5] Đánh giá các chiến lược thích ứng ở cấp độ kinh tế vĩ mô thông qua các kịch bản được xây dựng dựa trên cách tiếp cận hợp tác và thích ứng.

6] Nghiên cứu về sự ảnh hưởng của các kịch bản mới về khí hậu và kinh tế xã hội xuất hiện trong báo cáo mới nhất của IPCC đến các kết quả đánh giá tác động.

RECOMMANDATIONS

A l'intention des décideurs politiques

Intégrer l'adaptation aux stratégies de développement

1] Intégrer l'adaptation au changement climatique dans la planification du développement et dans les réglementations et processus budgétaires. Plus précisément :

- Les ressources disponibles allouées aux projets et programmes de développement doivent être mobilisées pour l'adaptation et utilisées de manière complémentaire afin de répondre aux objectifs de développement et d'adaptation. Pour ce faire, il est nécessaire de mettre en place une base juridique détaillée et claire ainsi que des lignes directrices pour cette intégration.

- Prendre en compte les impacts du changement climatique dans la planification générale pour la période 2021–2030 et la vision à 2050 aux niveaux national, sectoriel, régional et provincial. Bien que cela ait été réglementé dans la nouvelle loi sur la protection de l'environnement, les orientations pour cette intégration doivent être disponibles rapidement pour être en phase avec le processus de planification générale.

- Intégrer l'évaluation de la vulnérabilité et des risques ainsi que les considérations relatives aux incertitudes climatiques et socio-économiques dans la prise de décision en matière d'adaptation.

2] Prendre en compte les retombées des dommages internationaux afin d'aboutir à des mesures pertinentes pour atténuer les impacts négatifs sur le commerce, notamment dans le prochain rapport du ministère de l'Industrie et du Commerce du Viet Nam sur le sujet.

Financer l'adaptation

3] Le financement de l'adaptation devrait donner la priorité aux projets qui s'attaquent aux facteurs fondamentaux de la vulnérabilité et une plus grande attention devrait être accordée aux interventions polyvalentes et aux mesures "douces".

4] Des mesures pratiques et des mécanismes d'engagement du secteur privé sont nécessaires pour accroître et diversifier les ressources financières destinées à l'adaptation.

5] Utiliser pleinement le réseau des fonds de développement locaux vietnamiens dans les projets d'adaptation et d'atténuation afin de mieux prendre en compte les besoins locaux et les groupes les plus vulnérables.

Traduction des politiques nationales d'adaptation dans les pratiques locales

Groupes vulnérables

1] Ajuster les politiques d'adaptation existantes pour refléter le contexte local et les besoins des groupes vulnérables ;

2] Renforcer le soutien technique à toutes les parties prenantes, en particulier les groupes les plus vulnérables.

Planification locale

- 3]** Intégrer l'adaptation dans la planification du développement sectoriel et local ;
- 4]** Promouvoir une application globale des mesures d'adaptation, matérielles et immatérielles, y compris les approches non infrastructurelles de renforcement de la résilience et les solutions fondées sur la nature.

Suivi et évaluation

- 5]** Un mécanisme pratique et complet doit être mis en place pour suivre, contrôler et évaluer systématiquement la manière dont le financement de l'adaptation est utilisé et dans quelle mesure les projets d'adaptation contribuent à réduire la vulnérabilité et à accroître la résilience.

Renforcement des capacités

- 6]** Renforcer les capacités et la compréhension des acteurs gouvernementaux et non gouvernementaux concernés et des communautés locales en ce qui concerne la planification de l'adaptation, l'élaboration et la mise en œuvre des projets d'adaptation afin d'améliorer l'utilisation efficace des fonds d'adaptation.

Pour les chercheurs

- 1]** Les adaptations au changement climatique s'inscrivent dans des dynamiques sociopolitiques plus larges et sont donc façonnées par de nombreux facteurs qui vont bien au-delà des questions de changement climatique. Ils peuvent constituer de puissants leviers ou des limites pour les pratiques d'adaptation. Dans ces conditions il est utile de mener des recherches multi-niveaux et transversales permettant de saisir la complexité des contextes où se déroulent les actions d'adaptation. En partant d'une connaissance précise de ces contextes, les interventions d'adaptation seront davantage inscrites dans les pratiques sociales, les institutions, les capacités d'adaptation et les besoins, et auront donc plus de chances d'être efficaces.
- 2]** Mener des études de suivi des politiques et projets d'adaptations permettant de documenter in situ les réactions locales, les effets inattendus des interventions et les ajustements quotidiens aux contingences environnementales et/ou socio-économiques. Une reconnaissance et une compréhension fine de ces dynamiques ainsi que des écarts entre ce qui était prévu et ce qui se passe réellement permettrait d'identifier et de reproduire des expériences réussies et d'ajuster les interventions en cours et à venir.
- 3]** Pour améliorer les politiques d'adaptation au changement climatique, les études à venir devraient se concentrer davantage sur l'évaluation de la résilience et de la capacité d'adaptation, sur l'évaluation de la vulnérabilité et des risques, ainsi que sur l'estimation des incertitudes climatiques et socio-économiques. Leurs résultats peuvent fournir des informations précieuses pour la prise de décision en matière d'adaptation et contribuer à renforcer le système de suivi et d'évaluation de l'adaptation au Viet Nam.

- 4] Élargir la portée de la couverture des impacts sectoriels dans le modèle macroéconomique, en intégrant les impacts sur le tourisme, les autres secteurs agricoles, les impacts des événements extrêmes à court terme et les impacts relatifs au Viet Nam par rapport au reste du monde.
- 5] Évaluer les stratégies d'adaptation au niveau macroéconomique via des proxys basés sur des scénarios construits avec une approche adaptative et collaborative.
- 6] Étudier comment les résultats sont affectés par les nouveaux scénarios climatiques et socio-économiques issus du dernier rapport du GIEC.

Chapter 11

Climate change Adaptation Policies in Viet Nam from national perspective to local practices

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Abstract

Chapter 11 looks at various legislation, policies and programmes that have fostered climate change adaptation over the last two decades in Viet Nam. We aim to introduce fundamental guiding principles for adaptation policies, and address the achievements and limitations in their implementation. Many significant results have already been attained in strengthening resilience and enhancing the adaptive capacity of communities, economic sectors and ecosystems; proactively responding to natural disasters, reducing natural disaster risks, and damage due to climate change. However, several critical limitations in policy implementation need to be addressed. For example, the findings of our case studies in the North, the Centre and the Mekong Delta indicate a significant lack of technical and financial resources, capacity-building, and an integrated institutional scheme dedicated to climate change. Consequently, short-term reactive responses often override proactive and preventive strategies, while only a few actions address structural drivers of vulnerability. To advance the translation of adaptation policies into practice, we recommend the following actions: developing a system-based approach that integrates vulnerability and risk assessment as well as climatic and socio-economic uncertainty considerations into adaptation decision-making; adjusting adaptation policies to more sufficiently reflect both local context and the needs of vulnerable groups; mainstreaming adaptation into sectoral and local development planning; establishing an appropriate adaptation monitoring and evaluation system; promoting a holistic application of hard and soft adaptation measures; and strengthening the capacity of, and increasing financial and technical support for, all stakeholders.

Tóm tắt

Chương 11 tổng quan các luật, chính sách và chương trình khác nhau nhằm thúc đẩy thích ứng với biến đổi khí hậu ở Việt Nam trong hai thập kỷ qua. Chúng tôi đưa ra các nguyên tắc cơ bản mang tính định hướng đối với chính sách thích ứng và phân tích những thành tựu và hạn chế trong quá trình thực hiện các chính sách đó. Một số kết quả quan trọng đã đạt được trong tăng cường khả năng chống chịu và nâng cao năng lực thích ứng của cộng đồng, các thành phần kinh tế và hệ sinh thái; chủ động ứng phó với thiên tai, giảm thiểu rủi ro thiên tai và thiệt hại do biến đổi khí hậu. Tuy nhiên, vẫn còn tồn tại một số hạn chế trong quá trình thực thi chính sách cần được giải quyết. Ví dụ, kết quả từ nghiên cứu điển hình của chúng tôi ở miền Bắc, miền Trung và Đồng bằng sông Cửu Long chỉ ra rằng các định hướng chính sách quốc gia chỉ được thực hiện một phần do thiếu hụt đáng kể về nguồn lực kỹ thuật và tài chính, thiếu các hoạt động nâng cao năng lực và thiếu một khung thể chế tích hợp dành riêng cho biến đổi khí hậu. Do đó, các hành động có tính chất phản ứng ngắn hạn thường được ưu tiên thực hiện hơn các hành động mang tính chiến lược và chủ động phòng

ngừa. Rất ít hành động thích ứng ở cấp địa phương giải quyết được vấn đề cấu trúc của tính dễ bị tổn thương. Để thúc đẩy đưa các chính sách thích ứng vào thực tiễn, chúng tôi đề xuất một số hành động sau: áp dụng cách tiếp cận hệ thống tăng cường tích hợp các đánh giá về tính dễ bị tổn thương và rủi ro cũng như xem xét sự không chắc chắn về khí hậu và kinh tế xã hội vào quá trình ra quyết định thích ứng; điều chỉnh các chính sách thích ứng để phản ánh đầy đủ hơn bối cảnh địa phương và nhu cầu của các nhóm dễ bị tổn thương; lồng ghép thích ứng vào quy hoạch phát triển ngành và địa phương; thiết lập một hệ thống giám sát và đánh giá thích hợp đối với các hoạt động thích ứng; thúc đẩy áp dụng toàn diện các biện pháp thích ứng cứng và mềm; và tăng cường năng lực và tăng cường hỗ trợ tài chính và kỹ thuật cho tất cả các bên liên quan.

Résumé

Le **chapitre 11** examine les diverses législations, politiques et programmes visant à favoriser l'adaptation au changement climatique au cours des deux dernières décennies au Viet Nam. Il introduit les principes de ces politiques et présente les principales réalisations ainsi que les limites dans leur mise en œuvre. Des résultats significatifs ont déjà été obtenus dans le renforcement de la résilience et l'amélioration des capacités d'adaptation des communautés, des secteurs économiques et des écosystèmes ainsi que dans la mise en place d'initiatives proactives visant à réduire les risques et les dommages liés aux aléas climatiques. Cependant, la mise en œuvre des politiques d'adaptation rencontre certaines difficultés majeures. Par exemple, les résultats de nos études de cas dans le Nord, le Centre et le delta du Mékong témoignent d'un manque important de ressources techniques et financières, de la faiblesse des actions de renforcement des capacités et de l'absence de dispositifs institutionnels dédiés au changement climatique. Il en résulte que les réponses à court terme pour faire face aux effets du changement climatique supplantent les initiatives proactives, les mesures préventives et les actions visant les facteurs structurels de vulnérabilité. Pour améliorer la mise en œuvre des politiques d'adaptation, nous recommandons les actions suivantes : développer une approche systémique qui intègre l'évaluation de la vulnérabilité et des risques, améliorer la prise en compte des incertitudes climatiques et socio-économiques; ajuster les politiques d'adaptation afin qu'elles correspondent davantage aux contextes locaux et aux besoins des groupes vulnérables ; intégrer l'adaptation dans les plans de développement sectoriel et locaux ; mettre en place un système de suivi et d'évaluation des programmes d'adaptation ; promouvoir une approche holistique des mesures d'adaptation; renforcer les capacités des agents en charge de l'adaptation et accroître le soutien financier et technique.

1. Adaptation policies in Viet Nam

1.1 National adaptation policies in Viet Nam

Over the last two decades, Viet Nam has enacted various legislation and plans to foster climate change adaptation (see [Table 11.1](#)). The submission of the Viet Nam Initial National Communication to the United Nations Framework Convention on climate change (UNFCCC) in 2003 was an important milestone, further accelerating climate actions in Viet Nam. A fundamental component of these documents is fostering climate change responses in line with the socio-economic development plans of Viet Nam. Since then, a significant number of important policies have been developed and approved. Some of the most important policies are:

- ▶ The National Target Program to Respond to Climate Change (NTPRCC) was first approved in 2008 and then updated in 2012 for the period up to 2015. In 2016 the Green Growth component was added to the 2016–2020 NTPRCC that became the National Target Program to Respond to Climate Change and Green Growth (NTPRCC-GG). The key adaptation-related tasks under these programs include: developing and updating climate change and Sea Level Rise scenarios (CC&SLR); developing, updating, and implementing national, sectorial, and provincial level action plans to respond to climate change; and building capacity and rising awareness about climate change responses.
- ▶ The National Strategy on climate change (NSCC) endorsed in 2011 by the Prime Minister is one of the most important adaptation

policies, as it sets key principles, visions, and objectives to be followed in other policies. Key principles of the Strategy are promoting climate change adaptation and greenhouse gas mitigation through strengthening people's and natural systems' adaptability to climate change, and thus developing a low-carbon economy in order to protect and improve quality of life, guarantee national security and sustainable development in the context of global climate change, and proactively work with the international community in protecting the earth's climate system.

- ▶ The National Action Plan on climate change (NAPCC) was first approved in 2012 for the 2012–2020 period, and updated in 2020 for the 2021–2030 period to concretize actions to implement the strategic tasks defined in the NSCC;
- ▶ The National Plan for the Implementation of the Paris Agreement (PIPA) was approved in 2016 by the Vietnamese government to execute Viet Nam's commitments under the Paris Agreement. Adaptation is one of the five main components of the PIPA. Another important task of this plan is to establish and operate a M&E system (*i.e.* monitoring and evaluation – M&E) to monitor and evaluate adaptation efforts. This M&E system is expected to play a very important role in planning, tracking, and governing adaptation activities. Currently, the M&E system is under development;
- ▶ The Law on Environmental Protection (LEP) was approved in 2020 by the National Assembly of Viet Nam. The climate change adaptation stipulated in this law includes assessment of impacts, vulnerabilities, risks, losses and damage from climate change; implementation of adaptation activities; and the development of a M&E system for climate change adap-

[Table 11.1]

Matrix of climate change related policies

Level	Document	Adaptation	Mitigation
National	Resolution	The Resolution No.24-NQ/TW of Viet Nam's Central Committee of the Communist Party of Viet Nam on proactively responding to climate change, strengthening natural resources management and environmental protection (2013) The Resolution No.134/2016/QH13 of the National Assembly on adjusting the national land-use master plan to 2020 and the land-use plan for the final period 2016–2020 (2016) The Resolution No.36-NQ/TW of the Conference No.8 of the Communist Party's Central Committee, Legislature XII on the Strategy for sustainable development of Viet Nam's marine economy until 2030 with a vision to 2045 (2018) The Resolution No.76/NQ-CP on natural disaster prevention and control (2018) Resolution No.120/NQ-CP of the Government on sustainable and climate-resilient development of the Mekong Delta (2017)	
	Law	The Land Law (2013) The Law on Environmental Protection (2014 & 2020) The Law on Water Resources (2014) The Forestry Law (2017) The Law on Fisheries (2017) The Law on Planning (2017) The Law on Crop Production (2018) The Law on Animal Husbandry (2018) The Biodiversity Law (2018) The Law on Marine and Island Resources and Environment No.82/2015/QH13 (2018) The Law on Natural Disaster Prevention and Control (2013) The Law on Hydro-Meteorology (2015) The Law on Irrigation (2017)	
	Decree	The Decree No.119/2016/ND-CP of the Government issuing several policies on the management, protection and sustainable development of coastal forests to respond to climate change (2016)	
	Strategy	Decision No.2139/QD-TTg dated 2011 on the National Strategy on Climate Change Decision No.1939/QD-TTg dated 2012 on the National Green Growth Strategy	
	Plan	National Action Plan on Climate Change (NAPCC) for the period 2012 to 2020 (2011) Plan for the Implementation of the Paris Agreement on Climate Change (PIPA) (2016) National Action Plan for the Implementation of 2030 Agenda for Sustainable Development (2017) Viet Nam's National Climate Change Adaptation Plan (NAP) (2020)	
	Program	The National Target Program to Respond to Climate Change (Decision No.158/2008/QD-TTg dated 2008 and Decision No.1183/QD-TTg dated 2012 for the period 2012–2015, concerning the implementation of the Program); The Science and Technology Program for Climate Change Response for the period 2016–2020 (2016) Support Program in Response to Climate Change (SP-RCC) (Decision No.2044/QD-TTg dated 2017 for the period 2016–2020) The Target Program for Climate Change Response and Green Growth for the period 2016–2020 (Decision No.1670/QD-TTg dated 2017) The National Action Program REDD+ to 2030 (2017) The 2016–2020 Science and Technology Program for Natural Disaster Prevention and Control and Environmental Protection (2018) The Overall Program for Sustainable and Climate-Resilient Agriculture Development of the Mekong River Delta to 2030 with a Vision to 2045 (2020) Updated version of Nationally Determined Contribution (NDC) (2020)	

tation activities. The law also stipulates the integration of climate change responses into strategies and plans.

The 2020 update of Viet Nam's Nationally Determined Contribution [VN's NDC, 2020] was submitted to the Secretariat of the UNFCCC in September 2020. To internalize commitments related to adaptation in the updated NDC 2020 and adjust for more suitable policies in the new development context of Viet Nam, Viet Nam has introduced three new policies on adaptation and response to climate change, namely the National Adaptation Plan for the 2021–2030 period, with a vision through to 2050 (NAP) (Decision No.1055/QĐ-TTg dated 20/7/2020), the post-2020 NSCC and the National Action Plan to Respond to Climate Change (NAPRCC) for the 2021–2030 period (draft versions of the NSCC and NAPRCC were available when writing this report; they are expected to be submitted to the Prime Minister by the end of 2021).

The NAP is the first national policy to focus solely on adaptation. The overall objective of this plan is to reduce vulnerability and risks to the impacts of climate change on communities, economic sectors, and ecosystems. The NAP explicitly requires the assessment of vulnerability and risk during adaptation planning processes. The plan also promotes the integration of climate change adaptation into development strategies and planning. The NAP's objectives are translated into three groups of actions, including (i) strengthening resilience and enhancing adaptive capacity; (ii) mitigating the risk and damage of climate change-related disasters and enhancing preparedness to respond to extreme weather and natural disasters; and (iii) strengthening national adaptive capacity through institutional improvement, capacity building, securing re-

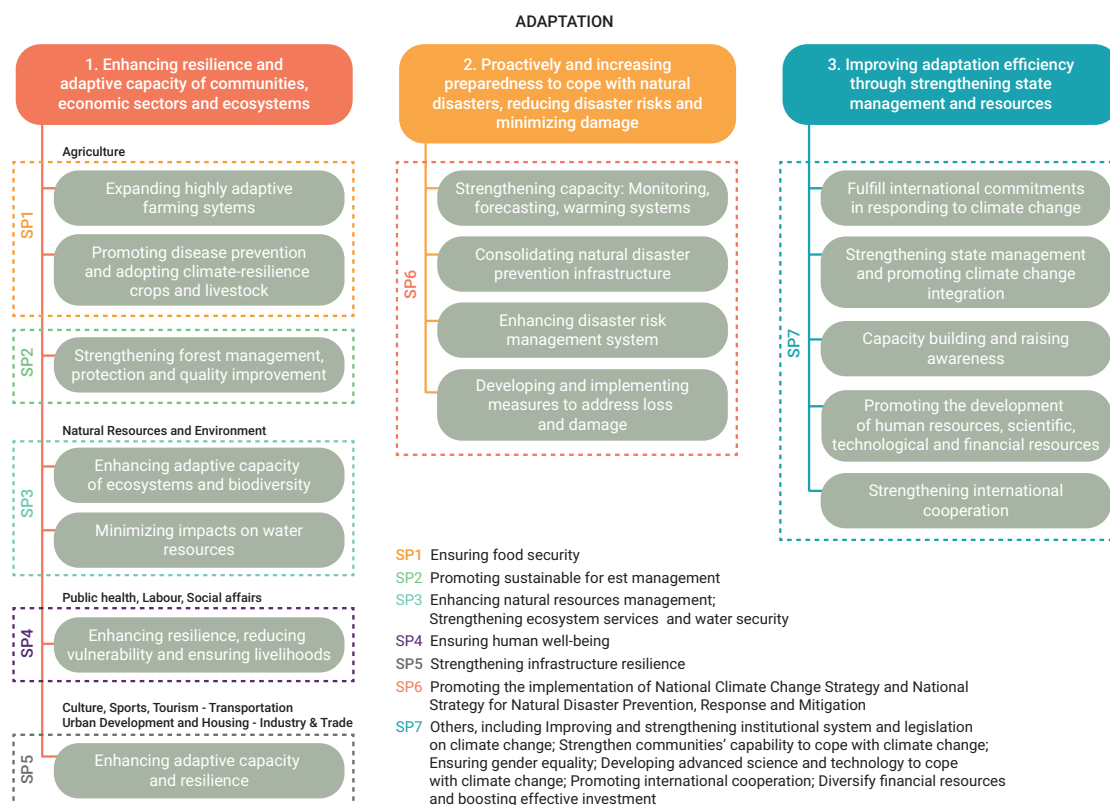
sources, promoting international cooperation, and implementing international obligations.

The Draft National Action Plan on Climate Change (NAPCC) for the period 2021–2030 gives specific directions for ministries, sectors, and localities to continue developing and implementing climate change adaptation actions, in line with the socio-economic development plan corresponding to their authorities. Implementing the NAPCC for 2021–2030 will also contribute to achieving the goals set out in Resolution No.24-NQ/TW, the National Climate Change Strategy, and the National Adaptation Plan, by consolidating and enhancing the achievements in response to climate change over the previous period. Key strategic priorities (SP) identified in the draft NAPCC are presented in [Figure 11.1](#).

1.2 Regional, sectoral, and provincial level adaptation policies

In the light of national adaptation policies, ministries and provincial-level governments have developed specific adaptation policies at their respective levels. The two significant national adaptation policies that have been concretized to implement at the sectorial and provincial levels are the National Action Plan to Respond to Climate Change (NAPCC) and the National Plan for the implementation of the Paris Agreement (PIPA). In addition, there are two special adaptation-related policies, including Resolution No.120/NQ-CP dated 15/11/2017 of the central government on the sustainable development of the Mekong Delta adapting to climate change, and the national scheme on urban development responding to climate change.

[Figure 11.1]
Key strategic priorities in Viet Nam's adaptation policies



■ Source: based on MoNRE, 2020.

► Following the NTPRCC and NAPCC, ministries and provincial level authorities developed their Action Plan to Respond to Climate Change (CAP). To date, these plans have been updated multiple times, according to guidelines provided by the Ministry of Natural Resources and Environment (MoNRE). Recently, ministries and provinces/cities have formulated their CAPs for the 2021–2030 period, with a vision through to 2050;

► Following Decision No.2053/QĐ-TTg of the Prime Minister regarding the approval of the PIPA, provinces and ministries have developed

their PIPAs up to 2030 based on the guidelines provided by MoNRE through the Document No.4126/BTNMT-BDKH dated in 2017. The main contents of the sectorial and provincial PIPAs are closely linked to the national PIPA;

► Resolution No.120/NQ-CP on the sustainable development of the Mekong Delta adapting to climate change is the first adaptation policy that focuses on the regional level. This document sets out visions, strategic direction, overall solutions, and specific tasks for the future development of the Mekong Delta, with relation to climate change adaptation. From the adap-

tation perspective, Resolution 120 highlights some important principles, such as the need to promote nature-based solutions; to put people at the centre of development models; and to apply an integrated and holistic approach to socio-economic development, with a focus on inter-sectorial and inter-regional links;

► The scheme on urban development responding to climate change is the most important adaptation policy to focus on the urban area in Viet Nam. This policy was first approved in 2013 for the period 2013–2020 (Decision No.2623/QĐ-TTg), and was recently extended for the 2021–2030 period (Decision No.438/QĐ-TTg). The main objectives of this policy are to integrate climate change into urban development policies, planning and investment, to ensure that Vietnamese cities have the capacity to respond effectively to climate change. The programme covers urban systems nationwide, but focuses on the provinces and cities most affected by climate change.

1.3 Adaptation and key principles defined in adaptation policies

One of the main objectives of this chapter is to examine how adaptation policies are implemented. In doing so, it is important to understand how adaptation is defined in existing policies. There are multiple definitions of adaptation, and multiple terms that are associated with the adaptation concept, such as resilience, vulnerability, and adaptive capacity.

According to the Intergovernmental Panel on Climate Change (IPCC), adaptation is defined as the process of adjustment to actual or expected climate change and its effects. In human systems, adaptation seeks to moderate or avoid harm, or exploit beneficial

opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate change and its effects [IPCC, 2014]. This IPCC approach has been adopted in adaptation policies in Viet Nam.

In addition to this definition, key national adaptation policies also define important principles that need to be applied, such as: the need to apply an integrated and systems-based approach (NSCC, NTPRCC, NAP, Resolution No.120/NQ-CP, LEP, NAPCC); to take into account uncertainties (NAP, NAPCC); to apply proactive strategies (NSCC, NCAP, NAP, NAPCC); to address vulnerability and risk (PIPA, NAP, LEP, NAPCC); to mainstream adaptation into development planning and policies; to actively mobilize and engage all relevant stakeholders (NSCC, NACC, NAP, LEP, NAPCC); to promote multi-benefit actions, soft measures, and ecosystem-based and community-based adaptation measures (NAP, LEP, NAPCC); and to develop and implement a monitoring and evaluation system for climate change adaptation (LEP, PIPA, NAP, NAPCC).

These principles indicate the high quality of adaptation policies, which aim to promote integrated, holistic, and inclusive approaches, and account for the interrelationships between sectors and regions, short-term and long-term actions, and climate change uncertainties. Given the complexities of vulnerability and risk that Viet Nam is facing at temporal, spatial and sectorial scales, and the uncertainty associated with future climate change and future development, these principles may be considered to be highly appropriate (see [Chapter 12](#)). In the following sections, we will discuss how adaptation policies and the guiding principles mentioned above are implemented and applied in practice, in different sectors and at provincial and lower levels.

1.4 Adaptation policy implementation: achievements and limitations

Achievements

For decades, the Government of Viet Nam has established various programmes, policies, and legislations to adapt to climate change, as well as to take advantage of climate change opportunities to achieve the country's sustainable development goals. Subsequently, many significant results were attained in strengthening resilience and enhancing the adaptive capacity of communities, economic sectors and ecosystems, in proactively responding to natural disasters, and in reducing natural disaster risks and damage due to climate change [MoNRE, 2020]. There is a long list of results and achievements to be mentioned. Some examples are presented below for indicative purpose.

- ▶ All 63 provinces and most national ministries have completed and started to implement their Action Plan to Respond to Climate Change. The majority of provinces have also developed their Plan for the implementation of the Paris Agreement;
- ▶ Climate change has been integrated into important policies, such as the national socio-economic development plan of the 2016–2020 period and the 2017 Law on Planning;
- ▶ The Department of climate change was established at the national level while a division for hydro-meteorology and climate change was organized in 18 provinces. In some provinces and cities such as Ho Chi Minh, Can Tho, Ben Tre, and Binh Dinh, a climate change office was established and is fully dedicated to climate change response and coordination;
- ▶ Out of 65 major programmes/projects identified in the 2012–2020 National Action Plan on Climate Change, 26 focusing specifically on adaptation were implemented;
- ▶ Many science and technology programs, with a large number of research projects, have been implemented;
- ▶ Awareness-raising and capacity-building activities with a focus on community-based disaster risk management have been implemented in 1,900 communes out of 6,000 communes frequently affected by climate-related hazards;
- ▶ The effective implementation of adaptation and disaster risk reduction policies has led to major results. For instance:
 - The average number of dead and missing people per year in the last 10 years was reduced by 38% compared to the average of the 10 previous years, even though typhoons are becoming more destructive;
 - Property damage in the period 2008–2017 (688 million USD/year) decreased by 29% compared to the period 1998–2007 (967 million USD/year) [MoNRE, 2020];
 - Several new varieties and production processes – which can increase productivity by 10% for high economic value crops such as rice, maize, and soybean – have been tried out in the provinces of Lao Cai, Yen Bai, Son La and Dien Bien. Fifteen new rice varieties have been successfully bred in the Red River Delta and the Mekong Delta [DCC, 2020];
 - A number of other important outcomes have been achieved in food security (see Chapter 4), water security (see Chapter 9), energy security (see Chapter 5), environmental protection, job creation, along with other socio-economic benefits [MoNRE, 2020].

– Several successful community level adaptation models have also been developed and replicated, such as flood-resistant housing in many provinces in the Central region, and a small-scale seawater desalination system and domestic wastewater treatment in Ca Mau province [DCC, 2020].

Limitations

Although important progress has been made, there are still a number of limitations in the implementation of adaptation policies, and in translating the guiding principles defined in these documents into practice. Some important limitations are discussed below.

► **Guiding integration among adaptation policies:** Although almost all adaptation policies are in line with each other, several policies address the same issue at the same level and the same period, for example, PIPA, NAP and NAPCC. Official guidelines for integrating these policies are highly desirable to avoid overlapping implementation and the risk of double-counting in evaluation;

► **Integrated and system-based approach in addressing vulnerability and risk:** Although the country has made good progress, there are still important gaps in disaster risk reduction and adaptation planning. For example, climate change response and disaster planning practices are still fragmented and sector-oriented. In addition, there is a limited number of effective and practical assessment and decision-support tools to assess vulnerability and risk in a holistic and systemic manner; identify root causes of vulnerability and risk; integrate assessment results into planning processes; and store data and keep track of how vulnerability and risk changes over time¹. This may be the reason for the widespread lack of vulnera-

bility and risk assessment in adaptation and disaster planning, although it recently became a legal requirement (see the NAP and the 2018 guidelines developed by the Viet Nam Disaster Management Authority on developing sectorial and local level disaster risk prevention and control plan). As a result, there is often a vague or poor connection between adaptation actions identified in provincial level CAPs, and vulnerability and risk [Nam *et al.*, 2014];

► **Consideration of uncertainties:** According to NDC 2020, the system of legal documents on climate change response is still not consistent, and should be reviewed and adjusted. For example, adaptation policies require the consideration of future climate change uncertainty, and the integration of climate change into development including infrastructure planning. On the other hand, building technical infrastructure such as roads, drainage systems, dykes, and embankments needs to follow existing technical standards, which are often managed by ministries other than MoNRE and were developed without properly taking climate change uncertainty into account. As a result, infrastructure is often designed based on fixed standards and historical data, and provides little or no room for redundancy, flexibility and for accommodating unexpected situations. For example, according to a recent study by the World Bank, much of the Viet Nam's road network (over 400,000 km) was not built to withstand extreme climatic hazard scenarios [Oh *et al.*, 2019]. Given the non-stationary nature of future climate,

1. Several practical tools have been developed and applied internationally and locally in Viet Nam such as the City Climate Resilience Framework (by the 100 Resilient Cities Program), City Climate Resilience Index, and the Community Flood Resilience Assessment Framework by the Zurich Alliance on Flood Resilience. These frameworks and tools have been applied at the project level but can provide good lessons and examples if Viet Nam plans to develop its own tools.

this infrastructure is eventually likely to lead to substantial losses, when extreme events become more frequent and stronger than the protection level;

► **Mainstreaming adaptation into sectorial and local development planning** has been identified as a legal requirement in many national and provincial level policies. Many studies have indicated that the cost of investing in adaptation by taking climatic risk into account is much smaller than the damage caused by climate-related hazards [Chinowsky *et al.*, 2015; Hill *et al.*, 2019]. However progress has been slow, and many sectors and localities are reluctant to integrate climate change response into development plans for sectors, provinces and cities. In most cases, adaptation mainstreaming stays at the policy (and not the implementation) level. This limitation is caused by multiple factors such as:

- Lack of staff with sufficient capacity and knowledge about climate change adaptation at different specialized ministries and departments;
- Lack of practical and concrete tools and guidelines for mainstreaming. According to NDC (2020), guidance for integrating climate change issues into national and sectorial strategies and plans, and into plans for socio-economic development, is still inadequate. Some guidelines such as Circular No.05/2016/TT-KHDT of the Ministry of Planning and Investment have been developed. However, according to provincial level officials, available instructions are often too general and abstract²;
- Lack of financial rules and mechanisms to support the implementation of adaptation actions/tasks integrated within sectorial plans and policies (see [Chapter 12](#));

– According to a recent study by the Asian Development Bank, many technical standards in Viet Nam are often out-dated and overlook future climate risk, focussing on protecting targeted infrastructure rather than the resilience of services provided and of entire systems [ADB, 2020]. This technical gap is also an important barrier to integrating climate change into infrastructure development planning;

► **Dominance of hard measures and lack of attention to soft measures:** efforts to respond to climate related hazards often focus on short-term emergency actions and recovery, with limited attention paid to long-term prevention and proactive response activities. In addition, there has been an important focus on hard structural infrastructure measures such as concrete dykes and embankments. Soft measures that may be more cost-effective such as integrated and risk-informed urban planning and green infrastructures have not received enough attention [PIPA, Phuong *et al.*, 2018; World Bank, 2015];

► **Limited implementation of adaptation policies at the sectorial and local level:** Although most national ministries and provinces have developed and even updated their CAPs, the implementation of these plans has been very limited. Many provinces such as Dien Bien, Bac Kan, Ninh Thuan failed to effectively implement their CAPs [Bac Kan PPC, 2015; Dien Bien PPC, 2015; Ninh Thuan PPC, 2015]. These plans do not exist at the district and commune level, where there are no agencies or even staff responsible for climate change response. In addition to the financial gap that has often been used to justify this situation (see [Chapter 12](#)), there may be many other reasons, such as a lack of capacity and personnel (see Human capital gap below), the

2. Interviews with officials from DPI and DONRE in several provinces/cities such as Can Tho, Binh Dinh, and Bac Kan.

appropriateness of the approach used to develop these plans, or the lack of an effective mechanism for climate change coordination and response. Therefore, to improve the implementation quality of sectorial and provincial level CAPs, it is extremely important to carefully investigate the factors that contribute to the poor implementation of these plans, and identify ways to address these factors;

► **Human capital gap:** Although many capacity building activities have been organized in the last 10 years, the knowledge and awareness of local staff in charge of climate change response is still limited. Many of them are not professionally trained in climate change adaptation, and often focus on the adverse physical effects of climate change [Nguyen *et al.*, 2017] without fully acknowledging the bigger picture of adaptation planning, the complexity underlying vulnerability and risk, and the uncertainty associated with future climate change. Since the capacity of government staff plays an important role in the quality of policy implementation, it is urgent to expand the scope and improve the quality of capacity building activities by taking the guiding principles defined in national policies into account;

► **Lack of monitoring and evaluation system (M&E):** a comprehensive and practical M&E system (see Box 11.1) plays an important role in planning, tracking, and governing adaptation activities. Developing and implementing this system is also one of Viet Nam's commitments under the Paris Agreement, but this system has not been put in place. Therefore, establishing a monitoring and evaluation (M&E) system for adaptation is a mandatory task, and a prominent solution to enhance Viet Nam's post-2020 adaptation policies [DCC, 2020];

► **Financial gap:** the insufficient financial resources available for climate change response are one of the key reasons for the limited implementation of adaptation policies (see Chapter 12). Among other factors, this problem may be attributed to the lack of incentive and effective mechanisms to engage with and mobilize resources from the private sector, and the limited use of existing resources allocated to socio-economic and sectorial development for adaptation, due to the poor integration of climate change into development policies and sectorial planning;

► **Lack of stakeholder participation** in adaptation planning and implementation is another critical gap. For example, consultation activities organized during the development of provincial CAPs often remain at a superficial level. According to our interviews with local officials in several provinces such as Lao Cai, Can Tho, and Binh Dinh, the local climate change action plans were mainly prepared by consulting firms from elsewhere, and consultations with technical departments (other than DONRE) was often of poor quality. Moreover, the engagement of local communities or even commune-level government is even more limited. Lack of commitments and of an appropriate system to safeguard consultation processes is a significant barrier to effective participation. For instance, there is currently no mechanism to verify and report how and to what extent the comments and contributions of consulted actors have been taken into consideration. In addition, many local agencies (other than DONRE) overlook the importance of climate change, and thus often provide only general comments, or send junior staff to consultation events.

[Box 11.1]

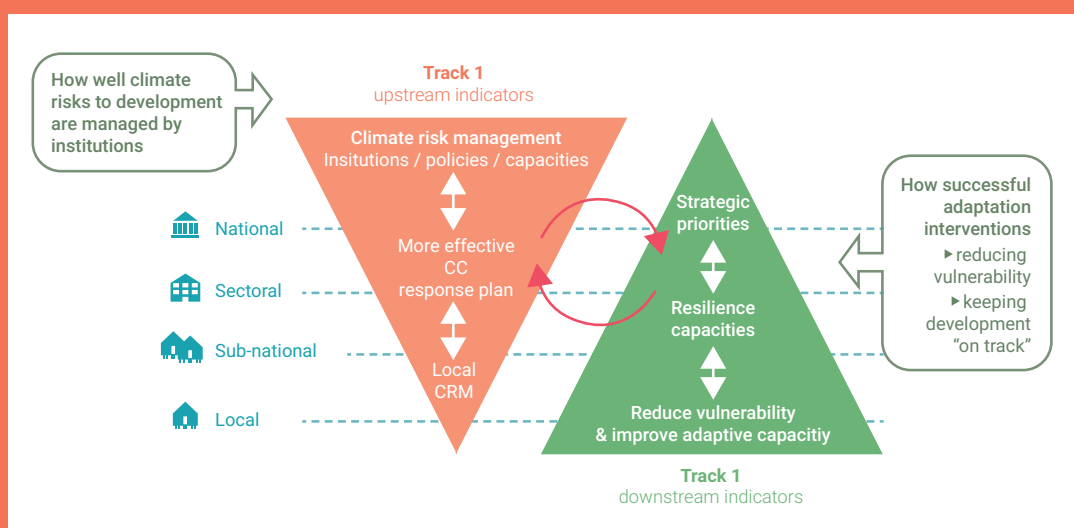
Introduction to the adaptation monitoring and evaluation (M&E) approach in Viet Nam

Monitoring and Evaluation (M&E) systems for adaptation are indispensable and powerful tools that can enhance stakeholders' understanding of climate change risks and vulnerabilities: by conducting periodic climate risk assessments, by reviewing whether or not adaptive interventions are achieving their goals, by taking stock of the lessons learned from actions taken to inform and strengthen adaptation planning and future implementation [Spearman & McGray, 2011]. So far, climate change impacts have gradually become more pronounced as shown in this report throughout chapters 3, 4, 5 and 6. As the number of national adaptation activities and strategies increases in Viet Nam, establishing a monitoring and evaluation system has become an urgent requirement for the country to ensure the efficiency and appropriate allocation of capital to implement climate change adaptation actions.

Regarding the post-2020 adaptation policy in Viet Nam (section 1.3), a proper M&E framework for Vietnamese adaptation should ensure that it provides useful information with regard to how enhanced adaptive capacity and resilience are achieved, the degree of improvement in disaster risk management and damage reduction, and the extent of contributions to national development goals. A report on the development of an M&E system for adaptation in Viet Nam indicates that Tracking Adaptation and Measuring Development (TAMD) can be considered a suitable M&E framework for the adaptation process in Viet Nam [Tran *et al.*, 2021].

TAMD is a twin-track framework developed by IIED to support evaluating adaptation success, based on how widely and how well countries or institutions manage climate risks (Track 1), and how successful adaptation interventions are in reducing climate vulnerability (Track 2) [Brooks and Fisher, 2014]. The principal M&E approaches in TAMD include [Figure 11.2]:

- M&E Track 1 (top-down) - evaluating 'upstream' climate risk management (CRM) interventions: improving climate risk management (CRM) at the national level leads to better CRM at the sector/field level, thereby enhancing resilience, and building the adaptive capacity of institutional systems, the environment, the economy,
- M&E Track 2 (bottom-up) - evaluating 'downstream' vulnerability and development outcomes: a theory of change is proposed by Rai, Smith, and Brooks (2019) to describe the logical and reciprocal relationships between local adaptation outcomes and how they contribute to overall development goals. Accordingly, the assessment framework can be defined along the path of the impact of adaptation activities, starting from those activities to outputs, outcomes and their contribution to national strategic priorities [Figure 11.1].



■ **Figure 11.2** Evaluation orientation of the TAMD (based on Brooks *et al.*, 2013; Brooks & Fisher, 2014).

Four types of indicators need to be assessed as follows [Rai, Smith, and Brooks 2019]:

- Process indicators: assess how a country's institutions and governments are managing climate risks, particularly institutional processes and governance mechanisms that directly address climate risks, or influence how people and systems respond to them;
- Output indicators: measure the quantity and efficiency of goods and services delivered by an adaptation intervention;
- Outcome indicators: assess how the actions of a country's institutions and governments influence the vulnerability, resilience and adaptive capacity of people and systems on the ground;
- Long-term development impact indicators: measure the success of adaptation in the longer term, in particular regarding the extent to which it helps secure development goals, and maintains and improves human and ecological well-being, in the face of climate change that would otherwise undermine both.

Accordingly, several adaptation M&E criteria sets for Viet Nam are being researched and considered based on two approaches [Tran *et al.*, 2021]: 1) Top-down approach, including (i) Criteria set for evaluating climate change adaptation activities at the national level; (ii) Criteria set for evaluating the effectiveness of national-level adaptation for strengthening adaptive capacity at the provincial level; 2) Bottom-up approach includes: (i) Criteria set for evaluating the results of climate change adaptation activities at the provincial level; (ii) Criteria set for evaluating the effectiveness of provincial-level activities in achieving the national adaptation goal; and (iii) Criteria set for evaluating the effectiveness of project-level climate change adaptation. Specific indicators can be synthesized and selected for Viet Nam from the Set of indicators to evaluate the effectiveness of climate change adaptation in Viet Nam [Huynh and Ngo, 2018] and GLZ's Repository of Adaptation Indicators [Hammill *et al.*, 2014]. These indicators are broadly divided into four categories, including (i) Climate parameters - information about observed climatic conditions; (ii) Climate impacts - Information about the observed impacts of climate variability and change on socio-ecological systems; (iii) Adaptation action (implementation) - Information to help track the implementation of adaptation strategies; and (iv) Adaptation results (outcome) - Information to help monitor and evaluate the outcomes of adaptation strategies.

A national M&E system for the NAP is in preparation, and will be submitted to the Prime Minister by October 2021. This system is the first national M&E system for Vietnamese adaptation that moves towards a more holistic and comprehensive upcoming M&E system. The Ministry of Natural Resources and Environment (MoNRE) will be the focal point of this system.

2. From policy to local response to climate-related hazards: insight from the ground

While climate change adaptation policies are set by national or provincial authorities, the implementation of adaptation actions at the local level (commune, household and individual) is strongly context specific. In this section, we will examine how local practices

of adaptation, in particular climate-related hazard responses, reflect national and provincial level policies and their guiding principles (see Section 1.3), as well as the lessons and insights that may inform policy improvement.

Our findings indicate that adaptation developed in localities is indeed shaped by many drivers that can reinforce, divert or contradict the principles and objectives of national adaptation policies. Moreover, many of these adaptation actions are not directly driven by adaptation policies, but occur “spontaneously” after a climate-related stress, and through iterative and *ad hoc* daily adjustments framed by

[Figure 11.3]
Location of case study areas



interaction between individuals, households, local authorities, private sector actors and market forces. In these conditions, it seems important to provide contextual understanding and grounded insights into the various local-level adaptation practices, to illuminate how different factors can interact and affect the capacity of a community, households and individuals to cope and adapt. It is noteworthy that while it is difficult to prove that the climatic hazards faced by inhabitants are a direct result of climate change, those kinds of climatic stresses are typical of climate change-induced events, and might be exacerbated with climate change. Therefore, we assume that the study of local responses contributes to possible adaptations to future climate change.

Our analysis is supported by data and evidence collected from several case studies in rural areas in the Northern Mountainous Region (Lao Cai), the Central Region (Thua Thien-Hue) and the Mekong Delta (Ben Tre)³ [Figure 11.3]. Based on a socio-anthropological perspective that grants a central place to micro-localized in-depth ethnographic fieldwork, the data collection combined immersion in local life (agricultural activities, ceremonies, official meetings, festivities, etc.), direct observation of practices, micro-quantitative census, local

3. The villages where we conducted our case studies are all inhabited by Kinh people, which is the main ethnic group in Viet Nam, but also, in the northern case, by Tày and Dao people, and, in the central case, by Pa Cô, Tà Ôi, Cơ Tu (Katu) people, who are so-called "ethnic minorities", even if they are the most numerous where they live.

official and private written sources, informal talks, and semi-structured interviews.

2.1 Description of the climatic hazard context at three study sites

The historic flash flood in Lao Cai

The first case study takes place in a commune located in Viet Nam's northern uplands (Lao Cai Province). The commune consists of 16 hamlets mainly inhabited by Tay (97%) with some Kinh and Dao. Villagers combine small-scale semi-subsistence farming (wet

rice, husbandry, aquaculture, garden, fruit trees, non-timber forest product) along with cash crops on hillsides (corn, cassava, agroforestry, tea, etc.) and off-farm activities (trading, laborers, masons, factory worker, etc.).

In November 2018, an unprecedented flash flood combined with a landslide devastated the commune. The flood affected 704 households and 222 houses, and destroyed many shops, roads and bridges [Figure 11.4], some sections of the irrigation system, w electric system and the water supply system, as well as gardens (20 ha), rice fields (61 ha), crops (corn, trees, cassava) on the hillsides (88 ha), and fishponds (14 ha). The economic damage was



[Figure 11.4] Bridge destroyed by flash flood in November 2018

Bao Yen district, Lao Cai

Photo credit: ©Phan Thi Kim Tam



[Figure 11.5] Landslide threaten house

A Luoi district, Thua Thien-Hue

Photo credit: ©Nguyen Cong Thao

estimated at over VND 20 billion (870 000 \$) by the commune⁴. This event has been locally classified as “the historic flood”.

Historic flood in Thua Thien Hue

The second case study takes place in a commune located in the centre of Viet Nam (Thua Thien-Hue Province), near the Laos border. The commune consists of 11 villages mainly inhabited by Ta Oi and Co Tu people (90%), with some Kinh and Pa Co households. Farming is the dominant economic activity in this commune. Wet rice, cassava and acacia are

the three most popular crops, while buffalo, oxen, pigs and fish ponds also bring important cash for households. Most of the forest area in the commune is classified as Protection Forest, and put under management of the district ranger forces.

While local people have experienced many climate-related hazards in the past, they consider 2020 as the most “unusual” year of the last 30 years. This is mainly because of the series of consecutive tropical low-pressure systems, and extreme typhoon and flooding events, among which the historic floods in October were considered the most dangerous. According to the local community, they were unprepared, and their responses were generally passive and reactive.

4. According to the official data on damage from the People's Committee of the commune and the “Situation socio-economic report of the commune for 2019”.

The historic flooding event occurred in 2020, while extreme cold in early 2021 caused serious damages to the local community [Figure 11.5]. For example, 44% (108 ha) of the commune's wet rice area was partly or completely damaged by landslide or land erosion triggered by flooding. About 25% of households in the commune lost part of their acacia tree areas. Though no houses were completely destroyed, about 300 households reported that their houses were damaged. Moreover, due to the heavy rain, severe flooding and unusual cold, many chickens and cattle died. It should be emphasized that pigs, cows and buffaloes are very important social, symbolic and economic assets for the local people.

Climatic hazards in Ben Tre

The third case study takes place in Binh Dai district in the Mekong Delta of Viet Nam. This district promotes agricultural, industrial and fishery extension activities, and applies production models focused on safety, efficiency, and sustainability. Cropping coconut, vegetables, fruit trees, shrimp, and fish farming account for a substantial proportion of the local agriculture sector. In the aquaculture sector, shrimp farming largely dominates in Binh Dai. There is a trend for shrimp farming development in the intermediate zone of the district, although coconut cultivation practices remain predominant [Figure 11.6].



[Figure 11.6] Shrimps and coconut production: a market-oriented agriculture

Binh Dai district, Ben Tre

Photo credit: ©Olivier Tessier

Salinization is of the main hazards facing Binh Dai district in general, and Long Hoa commune in particular. In the last decade, saline intrusion has become more severe and frequent, thus causing serious impacts on the local community (see Chapter 9). For example, a 20-day saline intrusion period in 2016 led to significant drops in rice production. Farmers and local authorities blame this event for the drastic decline in the rice area, from some 100 hectares to 3 or 4 hectares after 2016. The event in 2020 lasted even longer (from February to April) and was more destructive. The 2020 salinization affected 90% of households in Long Hoa commune, caused a 30-50% drop in coconut production along with smaller nuts, and a 50 to 70% decrease in fruit production.

In addition, shortages of freshwater supply due to salinization has become a growing concern in Ben Tre. Serious freshwater shortages for drinking and other domestic usages were recorded, especially during the salinity intrusion period in 2020. As a result, many households had to buy freshwater (but not drinking) from private suppliers at very high prices (*i.e.*, 200 to 250,000 VN/m³, or 12 to 15 times more expensive than in Ho Chi Minh city).

The area has also been affected by landslides and bank erosion, which are caused by rising sea levels and decreasing river flows (see detail in Chapter 7). This process is the result of complex dynamics that are secondarily linked to climate change in the short term [Chapter 9]. In Ben Tre, the coastline is eroded over a total length of about 19.4 km, including Binh Dai district. In some communes, severe landslides have a length of about 3,000 m, and penetrate deep into the mainland about 30 m each year, destroying people's productive land, along with coastal protection and special-use forests.

2.2 Local responses to climatic-related hazards: policy insight from the ground

Short-term responses versus long-term proactive and preventive strategies

The national and provincial adaptation policies promote both short- and long-term proactive and preventive strategies [Figure 11.1]. However, evidence from our study sites indicates that actions taken at the community level in response to climate-related hazards often focus on immediate responses, emergencies and short-term recovery. For example, in the case study in northern uplands area, after the 2018 flash flood, the local government was very active in mobilizing the support and contribution of multiple actors in activities such as cleaning and clearing of communal and private areas. Moreover, the electric network and domestic water supply system was rapidly restored, and the province provided funds to hire machines to clear destroyed housing and agricultural areas in the centre of the commune.

At the household level, people also took action to repair and improve their houses [Figure 11.7], or to move to a safer location. Farmers whose rice fields could not be restored shifted their agricultural practices from rice cultivation to cash crops such as corn, cassava, banana trees, or to planting mulberry and raising swarm (sericulture) [Figure 11.8]. However, little has been done to invest in longer-term preventive solutions, such as improving the limited flash flood early warning system, strengthening coordination and information sharing between communes – in particular between upstream and downstream and between sectors – and improving the resilience of critical infrastructure such as bridges and irrigation systems [Figure 11.1 - SP6 & SP7].

[Figure 11.7]
Housing adaptation: improving and rebuilding new concrete houses



Bao Yen district, Lao Cai.
Photo credit: ©Phan Thi Kim Tam

[Figure 11.8]
Post flood cropping changes

04/2019 From rice → 07/2020 Bananas, corns, fish pond, vegetable, etc. sericulture



Bao Yen district, Lao Cai.
Photo credit: ©Phan Thi Kim Tam



[Figure 11.9] New wooden house building in upper location after flood

A Luoi district, Thua Thien-Hue

Photo credit: ©Nguyen Cong Thao

In the second case study in Central Viet Nam, the popular strategies used to deal with typhoon and flooding include: placing sand bags on the roofs of houses (popular among poor households), moving houses to safer locations [Figure 11.9], or raising the house floor to a higher level. However, local people admit that most of these measures were only reactive, temporary and insufficient to protect them from big floods or severe typhoons. In addition, in the upland area, replacement of cassava with acacia has been the most popular practice for 10 years. However, it has not helped them to alleviate poverty and climate hazard vulnerability, as the land is degrading

and becoming more barren, and it is likely that this crop will not be viable in the future.

Concerning livestock, an important change consists of increasing pig to the detriment of buffalo and cow. It is reported that the pig population has increased by about 10%, while buffalo has decreased by about 60% in the whole commune over the last 5 years. Unstable weather conditions are among the key causes of this transition, with a decrease in grazing land in relation to land allocation, and an increase in cultivated areas to the detriment to common land. Findings from interviews indicate that there has not been much signifi-

cant adaptation in livestock raising techniques. Cages were not yet popular, and the free wandering method was still practiced. However, in recent years, instead of the free wandering method, people started assigning one family member to collect grass for cattle or to take care of cattle during the day. Food reservation for rainy and the cold days is more popular than before. Finally, farmers who have bigger herds and large upland field areas built cages for their buffaloes or cows in the upland fields.

Our study results also suggest that most actions taken at the household level in this commune are spontaneous adaptation. Support from external actors, including local government, on long-term strategic solutions

and measures to address root causes of problems like forest protection and reforestation seems to be limited [Figure 11.1 - SP2]. Moreover, investments also need to take other short- and long-term measures into account, such as building concrete dyke systems alongside streams and concrete walls in hill-bottom areas, where there is high risk of landslide [Figure 11.1 - SP6]; enhancing irrigation systems, introducing new rice varieties with shorter life cycles and higher resistance to floods; and supporting post-disaster cultivation recovery [Figure 11.1 - SP1]; reforming transport infrastructure; applying new technologies, and using sustainable materials with high resistance to climate change for construction [Figure 11.1 - SP5].



[Figure 11.10] Using plastic socks to store fresh water at the bottom of ditches and furrows

Photo credit: ©Olivier Tessier



[Figure 11.11] Individual reservoir to stock rainwater

Binh Dai district, Ben Tre

Photo credit: ©Olivier Tessier

To respond to drought and salinization, local communities in our third case study (Ben Tre) have applied a number of short-term measures such as: switching from three to two rice seasons per year, or even to one season followed by a second season combining rice and shrimp farming; planting new drought/salt-resistant rice and fruit tree varieties; adopting new agriculture water-saving techniques (using water-fern to preserve soil moisture, applying drip irrigation systems, storing water in plastic socks placed at the bottom of ditches and furrows, see [Figure 11.10](#)), improving small-scale storage capacity for domestic water use (rainwater storage tanks from 10 m³

to 25 m³ per household, see [Figure 11.11](#)), increasing the storage capacity of fresh water in ponds and diversifying water sources to include rainwater storage and water transportation from surrounding areas.

Despite the significant efforts made, local people are still struggling with the impact of salinization. Interviewees in the study area explained that many measures applied in agricultural activities are often ineffective, and agricultural productivity has still decreased [[Chapter 4](#)].

In this context, the government has provided significant support to the local communities



[Figure 11.12] Dam sluice gate on the Ba Lai River to block saltwater intrusion

Binh Dai district, Ben Tre

Photo credit: ©Olivier Tessier

by investing in hard infrastructure projects such as dykes, dams, and reservoirs, increasing the capacity of water treatment plants and extending and densifying freshwater supply networks. Dam sluice gates (removable gates), which block the rise of saltwater downstream and build up freshwater reserves upstream, is the type of structure which the province focuses on [Figure 11.12]. After constructing the dam on the Ba Lai River, several structures of this type are under construction and should be completed during the 2021–2023 period, notably with the completion of the Ben Tre Province Water Management Project (JICA3).

Although some positive results have been observed, water shortage for agriculture and domestic usages remains a major concern in the region. In addition, it was also found that some infrastructure such as the Ba Lai dam built to prevent saline intrusion in Ba Lai River have increased salinization in other local rivers, and exacerbated the salinization and freshwater shortage risks in the downstream areas of the dam.

Our findings in Ben Tre indicate that existing hard infrastructure is not enough to fully address the drought and saline intrusion challenge. Many other solutions are required

but as yet missing, to contribute to long-term benefits and to address drivers of vulnerability: they include developing and applying an integrated surface and ground water management system at the river basin scale, integrated farming systems and water-efficient irrigation models, investing in agronomic research programmes to develop more saline-resistant plants [Figure 11.1 - SP1 & SP6], restoring and developing protection and mangrove forests [Figure 11.1 - SP2], and developing and applying a salinization monitoring and warning system [Figure 11.1 - SP6]. In addition, a system-based and holistic approach is urgently required in designing adaptation measures.

Traditional knowledge vs uncertainty

Our study in Thua Thien - Hue exposed an important issue related to weather forecasting and climate uncertainty raised by local farmers. About 20 years ago, local elders could guess the coming climate trends through their observation of their surroundings. For instance, if it rains a lot at the beginning of the year, severe floods will come in the end of the year; if it is cloudy, the trees stand still, and there is no wind, these are signals of coming heavy rain; if the wind from the west (Lao wind) is strong during May – June, floods will come in October – November. It is reported that traditional knowledge in weather forecasting now no longer works well, due to the changing climate.

Unstable climate conditions have led to several inappropriate cultivation decisions by farmers who often rely on their past experience and on the historic trend of disasters. As a result, although an alert about the historic hurricane and flood in 2020 was sent out several days before the event, local people did not think the situation would be that serious, and no precau-

tions were taken. The evidence from our case study in Thua Thien - Hue suggests the need for local communities and policy-makers to consider the change in the frequency and intensity of climatic hazards and the unpredictability of future events, and prepare for unexpected situations while designing adaptation interventions at the community level. Improving the weather forecasting and warning system can provide reliable inputs for the decision-making process [Figure 11.1 - SP6]. It is also important to invest in raising local awareness on capacity-building for local government and communities, to better deal with climate uncertainty [Figure 11.1 - SP7].

The importance of social network and social capital in local adaptation

Results of our case studies indicate the very significant role that social capital plays in advancing disaster responses at the community level. In our case studies in Northern and Central Viet Nam, families affected by the historic floods received support from their relatives, friends, and other community members in a number of ways, such as evacuating to safer places, getting food, agricultural input access via credit, cleaning rice fields, rebuilding houses and getting financial capital to restore their livelihoods. In Binh Dai district, there are currently 66 cooperative groups in the fields of agriculture and fisheries, which can foster collective action to connect to the market and develop risk-sharing mechanisms.

The role of social capital in adaptation and disaster risk reduction is most visible in case study in northern uplands. Our research indicates that local communities get significant financial and material support during and after disasters from their interpersonal relationships involving kinship, lineage, neighbour-

hood and friends in various forms, such as monetary gifts, loans with or without interest, credit purchase, informal rotative savings and credit groups, and labour exchange practices. As in many place in Viet Nam, these networks of personal relationships provide people with access to a wide range of resources needed to implement their responses to shocks in general and climate-related risks in particular [Fischer *et al.*, 2011; McElwee, 2010; Delisle & Turner, 2016; Son & Kingsbury, 2020].

The above findings have some policy implications. First, they suggest that social capital should be better recognized in existing policies. Particular attention should be paid to not undermining the web of local solidarities and interpersonal obligations, and more effort is required to promote and strengthen both formal and informal networks and collaborative mechanisms at the community level. Second, if these local forms of support are necessary, especially to recover after the shock, they are not sufficient to foster long-term adaptation, they are not efficient in the case of covariant shocks, and they cannot endure repeated extreme events. Finally, the fact that local people have to rely mainly on their personal networks and relationships indicates the lack of financial capacity of community actors, and of support from the government. Therefore, more adaptation resources should be allocated at this level, where people often suffer the most.

Mobilization of contributions from multiple actors

As indicated in the 2020 NDC report, state resources can only meet about 30% of the financial needs for climate change response. Therefore, national adaptation policies call for the engagement and contribution of other

stakeholders, including the private sector and societal actors. Evidence collected from our study sites indicates an active contribution of various actors to community disaster response and climate change adaptation. For example, apart from state resources, affected households in our case study in northern uplands received support from other actors such as “charitable donations” from individuals, public or private organizations, material and immaterial resources from interpersonal relationship networks (social capital), personal bank loans, and emergency supplies such as food and water. Similarly, a local church in Ben Tre installed a desalination-treatment system to provide free fresh water to local communities. A private donor from Ho Chi Minh City supported the cost of this system, while the church financed the installation and operation costs. Local branches of VietBank also helped poor households to build individual tanks (2 to 4 m³) to store water.

It is also important to note that support mobilized from non-government actors involves not only financial and material resources (such as money, land, equipment), but also immaterial forms (such as labour exchange between farmers, technical support, training, information). In addition, some resources were mobilized to contribute to disaster risk reduction and adaptation objectives, but not classified under the climate change funding label. For example, as part of an economy-focused effort, a private sector service cooperative helped local communities in our study site in northern uplands – with the support of district authorities – to improve and diversify their income by shifting from rice cultivation to mulberry plantation and silkworm rearing. This project has proven effective, not only in terms of generating higher income, but also in coping with future climate events, especially flood and drought.

Our findings suggest the need to apply an integrated and inter-sectorial approach to climate change adaptation in general and adaptation finance in particular, to improve the mobilization of resources from various sectors, and to design more holistic policies to better support the integration of adaptation, and socio-economic development and environmental protection objectives [Figure 11.1 - SP7].

Finally, we found that most resources mobilized at the community level have been mainly used for emergency response during disaster and short-term recovery. In addition, the mobilization of resources for adaptation is often spontaneous, and lacks effective structure and organization. The limited coordination of emergency support during disaster periods, such as in the case of the 2020 flood in some areas of the Central region of Viet Nam, is a pertinent example. Therefore, it is important to develop new incentives and coordination mechanisms to promote the more active contribution of public and private actors, not only for short-term response but also for longer-term actions [Figure 11.1 - SP6].

The importance of local context in policy implementation to support vulnerable groups

Supporting vulnerable groups is one of the top priorities identified in national and provincial adaptation policy. Although significant support has been provided to these groups there are still some limitations. Following extreme flooding events, the most affected households – as well as the poor and vulnerable households – are allowed to borrow money at low rates from the Viet Nam Bank for Social Policies, for recovery purposes such as repairing or rebuilding houses, or improving or changing their livelihood activities. For instance, in our study site in

Central Viet Nam, people can borrow up to VND 50 million for 2 years at an annual interest rate of 5%. In the case study in northern uplands, after the flood, households whose houses had been swept away could borrow VND 100 million (USD 4300) for 10 years at a low interest rate (0,65%/month) to rebuilt new improved houses or relocate to a safer place. In addition, they received substantial state support ranging from VND 20 million (USD 870) to VND 40 million (USD 1,700). Households whose houses had not been destroyed but were considered at risk also received support (VND 20 million) to move their houses. According to local stakeholders the national criteria established to define who is eligible for state support and low-interest loans from the Bank for Social Policy do not reflect the needs of vulnerable groups. Only 30 percent of seriously-affected households received significant support from the government. However, others who are also highly vulnerable and suffered serious damage as a result of the 2018 historic flood received very little or nothing, because their houses were not classified as “washed-away” and therefore, according to official criteria, they were not eligible for the support.

More generally, with the exception of this specific post-disaster support focussed on very few households, borrowing money from banks is not easy for everyone, since people need to provide guarantees in the form of owned assets. For the poorest and most vulnerable, who often have low and unstable incomes, it is very difficult to meet the bank's requirements. They often have recourse to informal credit, sometimes with high interest rates. As a result, this group faces significant challenges in developing sustainable adaptive strategies to prepare for and recover from disasters, and thus remains vulnerable, or even becomes more so. In our case study in Central

region, there are 172 households of this kind. These families have had to stay in vulnerable areas after the 2020 floods, and will likely experience severe damage from landslides, flooding and typhoons in the coming years.

Finally, our case studies highlight that debt within the formal and informal sectors remains the dominant solution for recovering from the shock and developing adapting strategy. But it can strengthen inequality as a result of unequal access to credit, and can lead to over-indebtedness for the most vulnerable. Under these conditions, the State must define appropriate policies to facilitate access to low-interest-rate credit for vulnerable households, to support the informal credit sector by limiting usurious practices, and thus avoid spirals of over-indebtedness. For the most vulnerable

populations, the introduction of free or subsidized insurance schemes for a set of risks – ranging from natural to economic – may be a relevant solution, alongside capacity building, job creation and awareness-raising.

The findings presented above suggest that existing adaptation-related policies should be improved by taking the local context and the specific needs and characteristics of intended beneficiaries into account. **Box 11.1** represents how the theory of change approach can facilitate identifying proper adaptation interventions based on local context towards expected outcomes, and how the M&E system for adaptation enables and promotes their achievement. New special policies may also need to be developed to provide adequate support to the poorest and most vulnerable groups.

3. Conclusion

Climate change adaptation is one of the top priorities of policy-making in Viet Nam. The Government of Viet Nam has enacted various legislation, policies, programmes and plans to foster climate change adaptation over the last two decades. Regarding post-2020 adaptation policy in Viet Nam, adaptation interventions are classified into three categories corresponding to three main adaptation targets, including: (i) strengthening resilience and enhancing adaptive capacity; (ii) mitigating risk and damage from climate change-related disasters, and enhancing preparedness to respond to extreme weather and natural disasters; and (iii) strengthening national adaptive capacity through institutional improvement, capacity-building, securing resources, promoting international cooperation, and im-

plementing international obligations. The fundamental requirement for adaptation in this period is that the overall goals and orientation of adaptation interventions should promote integrated, holistic and inclusive approaches to adaptation, while being consistent with sectorial development priorities and the country's sustainable development goals.

As we have shown at the national and provincial levels, although important progress has been made, there are still a number of barriers to translating the guiding principles into practices. Several key issues need to be considered, including official guidelines for integrating adaptation policies; the need for adaptation and disaster planning to be based on vulnerability and risk assessment; consideration of uncertainties; mainstreaming adaptation into sectorial and local development planning; paying more attention to soft measures; en-

hancing the implementation of adaptation policies at the sectorial and local levels; strengthening capacity-building; enacting a monitoring and evaluation system; employing incentives and effective mechanisms to engage with and mobilize resources from the private sector; improving stakeholder participation in adaptation planning and implementation.

Our evidence-based insights into local post-disaster responses and adaptations illustrate the strong capacity of local communities to cope with natural hazards, but also show that people respond more than they adapt: short-term reactive adaptation often overrides proactive and preventive strategies. We argue that in a context of uncertainty over future climatic events, this ability to mobilize various endogenous and exogenous resources to restore and implement everyday pragmatic adjustments, and to develop multiple options (e.g. multiple sources of income) to cope with shocks and stresses, reveals a high degree of flexibility at the local level that can foster adaptive capacity and reinforce resilience. But it is not sufficient to face the impacts of climate change. More preventive and planned adaptation via a system-based and holistic approach is still required to implement the core principles and objectives of adaptation policies.

In this vein, the findings from our case studies indicate that national adaptation policies have partially addressed needs in the local context, but that the lack of technical and financial resources and capacity-building, along with the absence of an integrated institutional scheme dedicated to climate change issues, remain crucial challenges. Furthermore, strengthening weather forecasts and early warning systems, and raising awareness on adaptation is still needed to improve preventive and proactive actions. Moreover, very few actions address

the structural drivers of vulnerability, although it is well known that climate change vulnerability and adaptive capacity is not only a question of climate risk or exposure reduction, but is also rooted in socio-cultural-economic-institutional systems [Adger *et al.*, 2005; Klein *et al.*, 2007, McElwee, 2010, 2017; Adaptation Knowledge Platform, 2013]. Unless these factors are taken into consideration in a meaningful way, adaptation objectives as designated in policy are unlikely to be achieved. Practical achievements also demonstrate that social capital, collective actions, the mobilization of contributions from multiple actors (community, NGOs, private sector, state organization, civil society), as well as local knowledge can play an essential role in successfully implementing adaptation policies that take each local and specific context into consideration, alongside the core principles of adaptation and resilience policies.

Last but not least, existing adaptation policies should be more local-specific, and focus on the needs and characteristics of their intended beneficiaries. Consequently, employing the theory of change approach to identify adaptation interventions based on local context towards expected outcomes, and enacting an M&E system that can enable and promote adaptation performance and effectiveness, are highly recommended.

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Chapter 12

Financing climate change adaptation in Viet Nam: A perspective from the field

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Abstract

This chapter investigates the financial aspect of climate change adaptation in Viet Nam. While providing a general overview of global climate finance, it focuses on the structure, main actors, flow, and use of adaptation finance in Viet Nam, and highlights the challenges that the country faces in effectively mobilizing and using resources for adaptation. This paper mainly draws on studies of adaptation policies and in-depth qualitative field research, as conducted by the authors throughout Viet Nam over the last seven years.

The results indicate an important gap in tracking adaptation spending and measuring the impact of adaptation finance. A monitoring and evaluation system is therefore needed. This system needs to track not only formal financial flows, but also various resources that are often mobilized for adaptation at the local level. This chapter also reveals a significant financial gap at the provincial, and especially the community level, and calls for urgent national and international commitment to support local adaptation. This gap is partly explained by the limited integration of adaptation into development planning and state budget regulations, as well as by the weak engagement of the private sector. In addition, a concern is raised regarding how to better harmonize development objectives with the adaptation agenda. Moreover, climate adaptation projects often target the reduction of hazard exposure through hard infrastructure, rather than reducing social and economic vulnerability. This may come with adverse effects with regard to long-term adaptation. Therefore, in addition to the lack of funding dedicated to adaptation, the way funding is used and monitored also appears to be a crucial issue.

Tóm tắt

Chương 12 phân tích vấn đề tài chính liên quan đến công tác thích ứng với Biến đổi khí hậu (BĐKH) ở Việt Nam. Bên cạnh việc cung cấp một bức tranh tổng thể về tài chính khí hậu trên thế giới, báo cáo này tập trung xem xét hệ thống tổ chức, các bên liên quan chính, các nguồn vốn và cách thức sử dụng và phân bổ ngân sách về thích ứng với BĐKH ở Việt Nam cũng như làm rõ những thách thức liên quan đến việc huy động và sử dụng hiệu quả các nguồn lực dành cho công tác thích ứng. Chương này được xây dựng dựa trên các phân tích về chính sách và kết quả của một số nghiên cứu định tính chuyên sâu được thực hiện bởi các tác giả trong 7 năm vừa qua. Kết quả nghiên cứu cho thấy một lỗ hổng quan trọng trong việc theo dõi và đánh giá hiệu quả của các hoạt động tài chính cho thích ứng. Vì thế, việc xây dựng một hệ thống theo dõi và đánh giá là hết sức cần thiết. Hệ thống này cần theo dõi không chỉ các nguồn tài chính chính thức mà cả các nguồn lực khác nhau thường được huy động cho hoạt động thích ứng ở cộng đồng. Báo cáo này cũng chỉ ra sự thiếu hụt nghiêm trọng về nguồn lực tài chính ở cấp tỉnh và đặc biệt là cấp cộng đồng và kêu gọi sự cam kết mạnh mẽ của chính quyền cấp quốc gia và các nhà tài trợ quốc tế nhằm hỗ trợ cho công tác thích ứng ở các địa

phương. Sự thiếu hụt về tài chính cho công tác thích ứng một phần là do sự hạn chế trong lồng ghép thích ứng với BĐKH vào các quy hoạch phát triển và vào các quy định về ngân sách của nhà nước cũng như mức độ tham gia hạn chế của khu vực tư nhân. Bên cạnh đó, nghiên cứu của chúng tôi nhấn mạnh sự cần thiết phải cân bằng và kết hợp giữa các mục tiêu về tăng trưởng và thích ứng. Ngoài ra, hiện nay các nỗ lực về thích ứng thường tập trung vào việc giảm thiểu mức độ phơi nhiễm với hiểm họa thông qua các giải pháp công trình thay vì giảm thiểu tính dễ bị tổn thương về xã hội và kinh tế. Điều này có thể tạo ra những tác động bất lợi về lâu dài với công tác thích ứng. Vì vậy, bên cạnh sự thiếu hụt về tài chính thì cách thức nguồn vốn cho thích ứng được sử dụng và giám sát cũng là một vấn đề hết sức quan trọng.

Résumé

Le **chapitre 12** aborde les aspects financiers de l'adaptation au changement climatique. Après un aperçu des modes de financement à l'échelle internationale, il présente les structures, les principaux acteurs ainsi que les flux du financement de l'adaptation au Viet Nam tout en soulignant les principaux défis auxquels le pays fait face pour mobiliser et allouer ces ressources. Ce chapitre s'appuie sur plusieurs recherches de terrain qualitatives menées à travers le Viet Nam au cours des sept dernières années.

Dans un contexte où le suivi des fonds dédiés à l'adaptation et l'évaluation de l'impact du financement de l'adaptation présentent d'importantes lacunes, ce chapitre souligne la nécessité de la mise en place d'un système de suivi et d'évaluation. Ce système doit suivre non seulement les flux financiers officiels mais aussi les diverses ressources en dehors des flux officiels mobilisées pour l'adaptation au niveau local. Face à l'insuffisance du financement de l'adaptation au niveau des provinces et des communautés locales, les auteurs appellent également à un engagement national et international fort et urgent pour soutenir l'adaptation au niveau local. Ces insuffisances s'expliquent en partie par une prise en compte limitée de l'adaptation dans les plans de développement, par le mode de fonctionnement du budget national, ainsi que par la faible implication du secteur privé. Un enjeu majeur réside dans la combinaison des ambitions de développement avec les objectifs d'adaptation. Enfin, les projets d'adaptation au changement climatiques tendent à privilégier la réduction de l'exposition aux aléas climatiques au moyen de lourdes infrastructures, au détriment des mesures de réduction de la vulnérabilité sociale et économique. A long terme, cette tendance risque d'être contre-productive en termes d'adaptation. Nous estimons pour conclure qu'en plus des manques de fonds dédiés à l'adaptation, la manière dont les fonds sont utilisés et contrôlés s'affirme comme un enjeu central.

Note: This chapter is partly based on a previous published work: Pannier, E., Vu, T. C., Espagne, E., Puliat, G., & Nguyen, T. T. H. (2020). The Three Dialectics of Adaptation Finance in Viet Nam. *Sustainability*, 12(18), p. 7691. <https://www.mdpi.com/2071-1050/12/18/7691>

1. Introduction

Adapting to climate change is probably one of the biggest challenges facing Viet Nam today, and in the near future. As shown in the previous chapters of this report, even if the Paris Agreement's goals are met and global warming remains below the 2°C line – eventually falling to 1,5°C – the country will experience strong consequences from climate change, and from sea level rise, temperature increases and changing rain patterns in particular. Thus, while pursuing the goal of an economic development pattern that minimizes the greenhouse gas (GHG) emissions, the country is still seeking to foster a development path that contributes to adaptation and reduces climate change vulnerability.

In the field of climate change, adaptation is defined as the process of adjustment to actual or expected climate change and its effects [IPCC, 2014]. It refers to all actions undertaken to better cope with the effects of climate change, and to moderate or avoid harm to human systems. Specifically, adaptation concentrates on reducing human systems' vulnerability to potential impacts and therefore includes a wide range of actions, such as changing agricultural practices to less climate sensitive crops or transforming housing settlements. At the international level, the first priority has been mitigation, in order to maintain global warming below the 2°C line. But adaptation is being given growing scrutiny, as it appears that adapting to a changing environment is also crucial for addressing ongoing climate change. Therefore, an increasing share of international climate change finance is expected to target adaptation.

At the local level, several adaptation actions have already taken place. From relocating

houses to mitigate exposure to floods to changing livelihoods towards less climate-sensitive sources of income, several types of actions and projects are helping to foster adaptation (see [Chapter 11](#)). These adaptation actions are funded through multiple channels. With the increasing attention being paid to adaptation by policymakers, it is expected that more funding will be available to strengthen adaptation actions and initiate new projects. At both international and local level, adaptation funding exists to specifically foster such actions. However, there is not a precise overlap between adaptation practices that take place on the ground, and the adaptation funding available at different levels (from international to local).

Viet Nam provides an interesting situation to study adaptation finance. The country receives international funding through various agencies, including for instance the Green Climate Fund, the World Bank or Japan International Cooperation Agency (JICA), and allocates its own resources to climate change adaptation. However, it is not always easy to follow up and trace the adaptation actions that have been funded through these channels: at the global as well as the national scale, there is no standardized system of reporting [Sancken, 2020; Roberts and Wiekman, 2017]. Meanwhile, a wide range of adaptation actions are taking place on the ground that may be funded either by these adaptation funds, or by other funding sources that are not specifically targeted towards adaptation, but which nonetheless contribute to adaptation policies. Therefore, in this chapter, we intend to unfold how adaptation finance works in practice in Viet Nam, looking from both perspectives:

► How does international and national funding flow, from the top to the scale where climate actions are implemented?

► Meanwhile, on the ground, what adaptation actions are being identified and reported as such? How are these actions funded, and via which funding channels?

This research is based on first-hand data gathered in different locations in Viet Nam and on an analysis of climate-related reports and official data. This chapter also discusses the question of adaptation finance at the larger scale, to provide the background to the Vietnamese case.

After presenting the datasets and methods that we use, the chapter will present the international background of climate adaptation finance, then our results in the Vietnamese case study. A discussion on the use of adaptation funding follows.

2. Sources and data

The data and analysis provided in this chapter are based on a combination of document review¹, semi-structured interviews and direct observation of the implementation of adaptation projects and local responses to climate-related hazards.

Our investigation shows that quantitative data reporting how adaptation funding is used is

currently lacking in Viet Nam — as well as at a larger scale [Roberts and Weikmans, 2017]. An exhaustive assessment of adaptation funding is therefore difficult, due to the current state of the reporting mechanism (or lack thereof). We nonetheless mobilize quantitative assessments based on official documents that were provided by MoNRE and the Department of climate change (DCC), and provincial level reports on the implementation of both the national target program to respond to climate change and similar action plans. There are several limits to the use of such quantitative data for our purpose. First, a share of Official Development Aid (ODA) funding from international donors is integrated into the national budget and allocated for various projects that are either directly focused on climate change, or related to environmental issues, disaster risk reduction, agriculture, or infrastructure projects that are linked to adaptation but for which climate change adaptation is not the main goal. Therefore, using the available data, it is impossible to distinguish between international and national funds, nor to identify the respective share of funds coming from each channel that are used for each project. Secondly, the DCC's data include only information related to projects under their management, and do not cover projects and initiatives managed by other ministries, provincial governments, or initiated by NGOs. Thus, it only provides a partial picture of what is taking place in the field.

Our primary goal is to depict and analyse the actual process of climate change adaptation in the field: a qualitative approach is therefore required to allow us to examine the mechanisms at play beneath the implementation of adaptation actions. Our main dataset is thus based on semi-structured interviews. We have used semi-structured interviews and obser-

1. The document review consists of academic articles on climate change in general and adaptation finance in particular (in Viet Nam as well as at the international scale), official reports from different governmental, non-governmental (NGOs, research institutions, etc.) and international (UNFCCC, Green Climate Fund, WB/MPI, GIZ/Adelphi, etc.) organizations, and projects related to climate change adaptation policy and its implementation. We also reviewed documents related to Viet Nam's policies and plans, such as the national target program on climate change, provincial level action plans to respond to climate change, etc. This review allows us to depict the general landscape of adaptation policy in Viet Nam, and its wider international background.

vations that were conducted between 2016 and 2021, via a set of field-surveys in various provinces of Viet Nam (Ha Noi, Lao Cai, Bac Kan, Ha Nam, Thua Thien Hue Binh Dinh and Can Tho) with a wide range of interviewees at different levels (central, province, district, and commune). The main groups of interviewees we interacted with include: (i) national government agencies under the Ministry of Natural Resources and Environment (MoNRE), the Ministry of Agriculture and Rural Development (MARD), and the Ministry of Construction; (ii) provincial and district level agencies in charge of climate change, disaster risk management, urban development, planning, and investment and finance; (iii) international and Vietnamese NGOs; (iv) mass organizations; (v) local communities; and (vi) research institutions.

In addition to these interviews, we conducted in-depth ethnographic fieldwork between 2019 and 2021 in rural communes in the Northwest upland, Central Viet Nam (Thua Thien Hue) and the Mekong Delta River (Ben Tre), where populations had recently suffered from extreme events (such as flash flood, landslide, salinization, drought). We studied their experience of the climate hazard, their risk perception and their responses. We paid particular attention to the various material and immaterial resources they mobilized – ranging from state support to interpersonal social networks, banks and private donations – to restore and adapt after the disaster (see details of the method and results in [Chapter 11](#)).

3. Adaptation finance: the global landscape

3.1 A climate justice concern

A specific issue of global climate change finance relates to the “common but differentiated responsibility” regarding climate change. It refers to the fact that, historically, some countries have greatly contributed to the anthropogenic emissions of GHG – and are therefore the main contributors to global warming – while other countries, which have sometimes been marginal contributors to such emissions, are expected to be highly impacted by global warming’s environmental consequences. This principle was adopted under the Kyoto Protocol and reaffirmed in the Paris Agreement; it implies that developed countries must provide financial assistance to developing countries to achieve UNFCCC

goals. The international flow of climate finance contributes to this principle.

This idea is based on a principle of justice. Because some countries are more responsible for current and future climate impacts, they should contribute more to correcting such impacts. Meanwhile, countries that are more vulnerable to climate impacts need to be compensated for the harm they suffer. This is a principle of compensatory justice [Khan *et al.*, 2020]. But enforcing climate justice at the global scale is challenging. The climate timescale induces a significant gap between the release of GHGs into the atmosphere and their adverse effects on human systems. Negotiations involve countries and national entities, while spaces and populations within countries are unevenly impacted by climate change. Additionally, a certain level of uncertainty remains as to the expected impacts of future climate changes (see [Chapter 1](#) in the case of Viet Nam). All these dimensions come

together to blur the assessment of a fair level of compensation between the parties.

Nonetheless, adaptation finance flows at the global scale are a means of contributing to compensatory justice. Grasso (2009) defines adaptation finance justice as a fair process of raising adaptation funds according to responsibility for climate impacts, and of allocating those funds with priority given to the most vulnerable. However, within the climate arena, parties tend to pursue their own interests and try to minimize their own contributions to the global climate cost. Do vulnerable countries receive a fair share of global climate finance to compensate for the harm they undergo, and to adapt to climate change? Do they receive enough support to foster an adequate adaptation strategy?

To answer these questions, it is first crucial to identify the climate finance flows that target vulnerable countries, and assess whether these flows enable actual adaptation to climate change.

3.2 The landscape of adaptation finance at global scale

According to the UNFCCC, climate finance refers to “local, national or transnational financing — drawn from public, private and alternative sources of financing — that seeks to support mitigation and adaptation actions that will address climate change”. What it embeds is therefore very broadly defined. Global climate finance, according to this definition, totals some USD 500 billion per year, and is mostly spent domestically (81% of global climate finance was spent domestically in 2015–2016 according to Padraig, Clark, and Meattle (2018)). However, most of it goes to mitigation,

especially investments in renewable energies. Adaptation finance is estimated at USD 22 billion per year (2015–2016), although the lack of reporting makes it difficult to establish a clear picture of the trends. According to these estimates, adaptation represents only some 5% of global climate finance.

Following the Paris Agreement, the global budget allocated to adaptation is likely to increase, since the international climate organizations and conferences have stated that adaptation and mitigation were equally important in addressing the challenges brought about by climate change. The UNFCCC has long stated that mitigation and adaptation funding should be balanced, with a specific focus on adaptation for countries considered to be highly vulnerable to climate change impacts, such as Small Islands Developing States. But no clear guidance or commitments have been established to this end [Roberts and Weikmans, 2017].

According to Padraig, Clark and Meattle (2018), in 2016 — and at global scale — the private sector provided 63% of climate finance flows, while the public sector provided 37%. The public channels are diverse, including the UNFCCC and Paris Agreement mechanisms, but also other channels such as development banks, multilateral, regional and national funding [Sancken, 2020]. As for international public funding, the main agencies are the Global Environment Facility (GEF) and the Green Climate Fund (GCF), which manage funding provided by donors. The GEF also manages two extra funds: the Special climate change Fund (SCCF) and the Least Developed Countries Fund (LDCF). Additionally, the Adaptation Fund (AF) was set up under the Kyoto Protocol in 2001, and contributes to adaptation projects in developing countries that are particularly vulnerable to climate change. Since its

foundation in 1994, the GEF has transferred USD 14.7 billion to beneficiaries. The Green Climate Fund, which started to operate in 2014, began with a budget of USD 7.1 billion for its initial resource mobilization – a figure that has expanded to reach USD 10.3 billion as of July 2020, provided by 49 countries, regions and cities.

3.3 The follow-up of climate adaptation projects

Despite the increasing attention to adaptation policies, following up adaptation actions remains challenging. There are several reasons for this situation. First, adaptation to climate change is often not the only goal pursued by a specific project. In particular, projects that are funded through bilateral ODA (Official Development Assistance), for example, may include several goals including climate adaptation – but adaptation would not be the primary goal of the project. Hence, to what extent should these kinds of composite projects be considered to be adaptation actions? Weikmans (2018) expresses concern because part of international adaptation funding has been integrated into general development aid (ODA), and because some countries report some ODA-funded projects as adaptation contributions even though they are only loosely related to climate goals. This can result in over-estimation of adaptation finance.

Second, there is no standardized reporting system for adaptation finance. Sources of finance are various: there are international agencies and bilateral agreements as well as national funding, alongside both public and private sources. This makes it difficult to gather data regarding the funds that contribute to adaptation policies. Some private fun-

ding may not be published [Sancken 2020] since reporting is not mandatory, even if they do contribute to adaptation. Additionally, adaptation projects are spread over various sectors, such as energy, transportation, agriculture or other sectors. Because there are typically several budget lines for adaptation projects, identifying specific adaptation finance requires a detailed breakdown that may not be available. To date, the tools to assess adaptation finance consistently at the global scale are lacking.

In addition to assessing the level of adaptation finance, it is not always easy to measure the effectiveness of adaptation policies, and thus the impact of adaptation finance in climate change response. While mitigation can be reasonably well measured by tons of GHG that were either avoided or sequestered, it is much more difficult to measure the harm that was avoided thanks to adaptation actions, especially in a context of high uncertainty. As opposed to mitigation, in which GHG emissions are used as a metrics to measure achievements, no such metrics exists for adaptation. It is therefore likely that the funding of policies that only contribute marginally to adaptation may be counted as adaptation finance, simply because they were funded through such channels and regardless of the actual result. Conversely, several actions that foster adaptation (for instance, changes in agricultural practices) are not identified as such and are funded through other channels (such as agricultural policies).

Climate finance has primarily targeted mitigation, and adaptation has only recently emerged as equally important. While several countries have defined national targets for GHG emissions, especially since the Kyoto protocol, there are no clear goals for adaptation. While

the need for adaptation will be linked to the actual climate changes, and therefore to mitigation efforts, no clear milestone has been defined so far. Moreover, international agreements on climate change state that adaptation funding must be “new and additional” to existing international development aid. This is a critical aspect of the compensatory justice that frames the international climate response. To date, due to the lack of consistency in reporting systems and the lack of clear and systematic distinction between ODA for general development and the international adaptation aid that flows through ODA, it is difficult to assess whether the latter is actual-

ly “new and additional”, or whether some ODA has simply been reoriented from general development towards adaptation actions. While ODA is useful to foster adaptation, it remains critical that funding of the extra costs resulting from climate change is met by international climate response, in supplement to general ODA. Overall, the urgency of climate adaptation implies that adaptation should be mainstreamed in development policies in general. It is crucial that the paths of development that are fostered today through international financial flows systematically address climate adaptation in the short- as well as long-terms, especially in the most vulnerable areas.

4. Adaptation Finance in Viet Nam

As already extensively emphasized in the previous chapters of this report, Viet Nam is considered a country that faces major impact from expected global warming and climate change. In particular, its deltas and coastal areas are expected to undergo substantial consequences: according to the National Adaptation Plan² for instance, 39% of the Mekong Delta could be flooded by 2100 if nothing is done. The forecast may be even more serious if we combine sea level rise dynamics with subsidence and salinity intrusion dynamics, as shown in Chapter 9. But even with a drastic reduction of GHG emissions at global scale, sea level rise will already significantly affect the low-lying areas of the country. Therefore, alongside mitigation plans to limit the amplitude of global warming and future changes, adaptation actions are essential and

require significant funding. This section first describes the channels of adaptation finance in Viet Nam, then the practical flows of adaptation funding, and finally discusses the actual use of adaptation resources on the ground.

4.1 Adaptation finance actors in Viet Nam

International organizations

As a country that is highly vulnerable to climate change, Viet Nam has received significant international financial support. It often takes the form of Official Development Assistance (ODA) provided by bilateral and multilateral institutions such as the World Bank, the Asian Development Bank (ADB), the Japan International Cooperation Agency (JICA), the French Development Agency (AFD), USAID, or the Kreditanstalt für Wiederaufbau (KfW) together with the German Corporation for International Cooperation (GIZ). ODA funding is transferred directly to and managed by the central government. Most ODA takes the

2. <https://www.greenclimate.fund/sites/default/files/document/readiness-proposals-Viet-Nam-undp-adaptation-planning.pdf>

form of loans; however, these organizations also provide some grants. Viet Nam has also been supported by United Nations (UN) agencies such as UNDP and UN-Habitat. These agencies work directly with national agencies, which are subsequently in charge of implementing the adaptation actions. For instance, UNDP often mobilizes resources and acts as a direct recipient from financial institutions such as the Green Climate Fund or Adaptation Fund, and then works with national ministries such as the Ministry of Natural Resources and Environment (MoNRE) and the Ministry of Agriculture and Rural Development (MARD), to implement adaptation projects at the national and provincial scale. To date, five projects have been funded by the GCF in Viet Nam. In 2020, the Adaptation Fund approved a project targeting the Mekong delta for a total amount of USD 6.3 million. In addition, international non-governmental organizations (NGO) also provide funding for adaptation projects; but a major difference is that NGOs often focus on

working locally with local communities, rather than at the national scale.

Government actors

At the national level, the Ministry of Natural Resources and Environment (MoNRE) is assigned to lead and coordinate climate change policy development and implementation in Viet Nam. The ministry has been leading the implementation of major programs and policies. These programs include the National Target Program to Respond to climate change – NTPRCC (2011–2015), the National Target Program to Respond to climate change and on Green Growth – NTPRCC-GG (2016–2020), the Support Program to Respond to climate change (SPRCC), the National Strategy on climate change, and the National Adaptation Plan. MoNRE works closely with the Ministry of Finance and the Ministry of Planning and Investment to coordinate, allocate and manage funding mobilized for adaptation.

[Table 12.1]

Examples of adaptation projects funded by GCF in Viet Nam

FP013	Cross-cutting	Improving the resilience of vulnerable coastal communities to climate change related impacts	\$29,523,000	\$11,006,625	30/06/2016	60	\$40,529,625
FP071	Mitigation	Scaling Up Energy Efficiency for Industrial Enterprises	\$86,300,000	\$410,900,000	01/03/2018	60	\$497,200,000
FP125	Adaptation	Strengthening the resilience of smallholder agriculture to climate change-induced water insecurity in the Central Highlands and South-Central Coast regions of Viet Nam	\$30,205,367	\$126,087,475	12/03/2020	72	\$156,292,842

■ Source: GCF Website.

A major field of action in terms of adaptation relates to disaster risk management, to mitigate the adverse effects of future hazards. As the national state management bodies for disaster risk management, the Ministry of Agriculture and Rural Development (MARD) and its Disaster Management Authority are responsible for developing and implementing natural disaster risk management policies, projects, and programs. As such, during the 2010–2015 period, MARD was the largest recipient of adaptation funding compared to other ministries [World Bank, 2015b], because the agricultural sector is considered key for adaptation.

MoNRE and MARD work closely with the Ministry of Planning and Investment (MPI) and the Ministry of Finance (MoF) to review and plan climate change adaptation and/or disaster risk management budgets. MPI is responsible for socio-economic development strategies, planning and investment at the central level, and for attracting, coordinating and managing ODA, concessional loans and foreign non-governmental aid. The ministry is also in charge of coordinating public development investment. In the process of project review and selection, MPI plays a very important role, since it is responsible for managing the appraisal of investment portfolios and portfolio-balancing capability in relation to proposed projects. The appraisal results serve as the basis for relevant ministries, agencies, and local authorities to revise project proposals, and complete pre-feasibility study reports before submitting them to the Prime Minister for approval. MoF is the state management body for finance management, budget allocation, and tracking of government budget spending. Specifically, MoF works closely with MPI to formulate annual and medium-term plans for public investment, to determine the total funds from different sources for these plans,

to assess the capital and ability to balance the capital of relevant projects, and to guide local financial authorities to balance the regular budget in order to pay for the corresponding expenditures. MoF is also in charge of reporting the disbursement and finalization of the plans, programmes and projects to the central Government.

At the provincial level, the Department of Natural Resources and Environment (DoNRE), the Department of Agriculture and Rural Development (DARD), the Department of Planning and Investment (DPI) and the Department of Finance (DoF) play similar roles to their respective superior agencies at the national level. However, at the district and commune levels, there is currently no organizational structure or staff dedicated specifically to climate change adaptation. As a result, district Division for Agriculture and Rural Development and district and commune level Steering Committees for Natural Disaster Prevention and Control and Search and Rescue are often involved when an adaptation project takes place. However, although a regular budget, both from recurrent and investment sources, is planned for disaster risk management (often for disaster recovery), district and communal governments have rarely allocated funding exclusively for adaptation activities. Most adaptation projects implemented at the district and commune level have been directly funded and managed by the national and provincial agencies. There is therefore a discrepancy between the adaptation actions that take place at a local level, and the long-term management of adaptation policies at that level, as there are — to date — no dedicated bodies for climate action.

Local Non-Governmental Organizations and socio-political organizations

In addition to government agencies, mass associations such as the Red Cross, Women's Union, Farmer's Association, and Youth Union are important actors. These associations often operate under the aegis of the Fatherland Front. Present at all levels, mass associations serve as a relay (for information or resources) between the community and governmental levels. They are often mobilized to implement projects to support local communities, to mobilize and distribute financial resources for community-level disaster recovery, and sometimes for adaptation-related projects.

Last but not least, many Vietnamese NGOs have also played an important role in mobilizing funding — often from international sources — for adaptation. These organizations mainly work at the district, commune, and community level. They are also often directly involved in implementing adaptation projects.

4.2 Adaptation funding flows and mechanism

Tracking adaptation funding in Viet Nam — as in many other countries — is particularly challenging, as funding for climate change response is not clearly integrated into the existing planning and state budgeting system [World Bank, 2015b]. In addition, there is no specific system and tool to monitor and track adaptation spending in a comprehensive manner. Specifically, funding channelled through, and managed by, MoNRE is often well recorded. However, according to a national officer, there is no mechanism to track all adaptation projects managed by other minis-

tries and the provincial government. In addition, a clear definition of what constitutes an adaptation intervention is not yet available. As a result, development projects without a climate change label may increase resilience and reduce vulnerability, but are not systematically counted. On the contrary, implemented climate change projects may have low or marginal benefit with regards to climate change response [World Bank, 2015b].

According to McElwee (2017), the country has received more than USD 7 billion for climate change response, mainly from major bilateral and multilateral institutions. ODA funding has played a major role in helping Viet Nam to implement climate change policies. It is expected that 94% of the funding required for implementing the National Strategy on climate change (NSCC) and the NTPRCC-GG will come from international sources [GoV, 2017]. During the 2016-2020 period, nearly VND 15,000 billion (or around USD 652 million) was mobilized from ODA sources for projects under the NTPRCC-GG. In addition, various NGOs have provided significant financial support to Viet Nam, which could have an important impact at the local scale. For example, during the 2010–2015 period, Hai Phong city was able to mobilize nearly VND 113 billion (or around USD 4.9 million) from these organizations for climate change adaptation activities [Hai Phong PPC, 2015]. It has funded projects for mangrove restoration, climate awareness, coastal resource management, sustainable livelihood development, etc. It is important to note that, although the Vietnamese government has made a significant effort to mobilize funding for climate change responses, the budget required to implement climate policies and plans is far more ambitious than the resources which the country has available [Phuong *et al.*, 2018].

The most important financing mechanism to manage climate change-related ODA funding is the SPRCC, the Support Program to Respond to climate change. This program was created in 2009 to mobilize financial support from development partners for implementing major national policies and programs, especially the NTPRCC and NTPRCC-GG. A policy matrix that identifies priority projects is used as the basis for mobilizing international support, and for allocating funding for climate change interventions. During the first phase (2009–2015), the SPRCC program raised nearly USD 1 billion in ODA support from bilateral and multilateral international donors, and expects to raise up to USD 1.2 billion for the second phase (2016–2025) [GoV, 2016]. International financial support to SPRCC is directed to the central budget, before being distributed to climate change projects under NTPRCC and specific SPRCC priority projects. The remaining funding could be integrated into the general state budget for other uses. According to a recent report, only around 35 percent of the resources mobilized under the SPRCC has been directly spent on climate change initiatives [ECORYS, 2018].

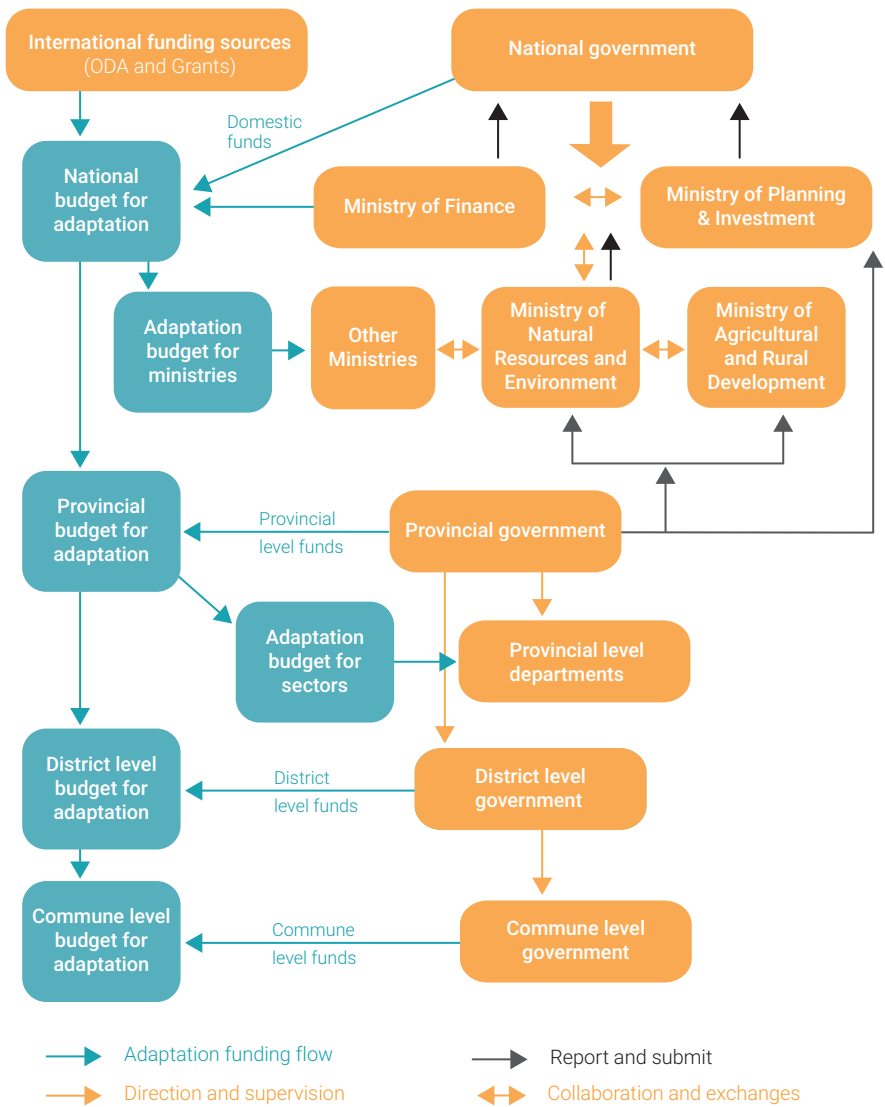
The funding received is managed and controlled according to the financial rules and regulations of the Vietnamese government. The central government generally merges its own resources with international funding. At the local level – in most projects funded via the SPRCC – there is also some contribution from the provincial government in the form of a counterpart fund. Figure 4.1 describes the process for allocating adaptation funds³.

Provinces and national ministries submit their proposals once a year to MoNRE. MoNRE then reviews, evaluates, and selects prioritized projects, with the support and guidance of the National Committee on climate change. Proposals developed by provinces and ministries must nonetheless be consistent with the list of prioritized actions identified in national policies (such as the NTPRCC-GG, National Strategy on climate change, the plan for the implementation of the Paris Agreement, and the SPRCC). MoNRE then sends the list of selected projects to the Ministry of Planning and Investment (MPI) and the Ministry of Finance (MoF) for review. The most prioritized projects identified by MPI will be submitted to the Prime Minister for approval. The MPI allocates funding for selected projects from the national budget, then the MoF disburses the approved funding to provinces and ministries. A similar process is applied at the provincial level, where the district governments and provincial departments submit their proposals annually to DoNRE, which collaborates with the Department of Planning and Investment and the Department of Finance to review, select, and allocate funding (see Figure 4.1). The main difference is that no adaptation funding from bilateral and multilateral organizations is transferred directly to the provincial government.

At commune level however, the adaptation finance flow and mechanism do not follow any single rule, and are often quite complex (see Figure 4.2). As stated previously, practically no formal financial resources are allocated exclusively for adaptation by commune-level government. However, resources (financial and non-financial) for disaster risk reduction and, in part, for adaptation at the community level may come from different sources, through different actors and networks, and in both formal and informal forms. For example,

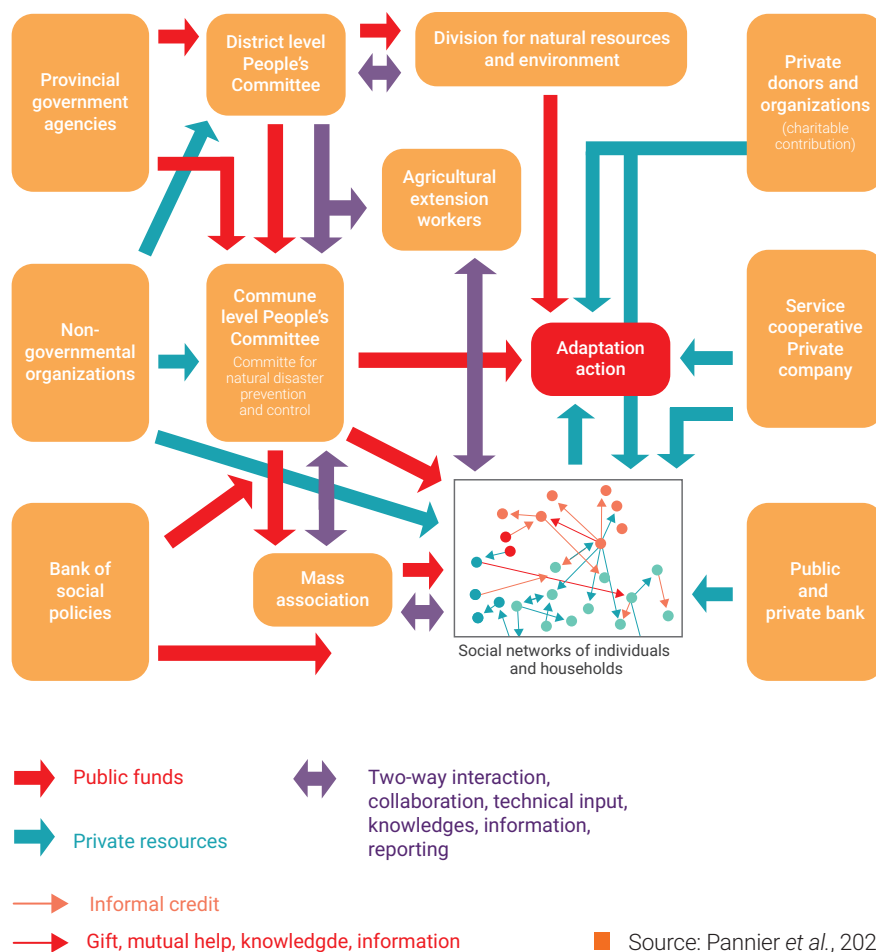
3. By national budget and provincial budget for adaptation we mean budget for adaptation at the national and provincial levels. It includes both investment and recurrent budget.

[Figure 12.1]
Formal adaptation financial flow



■ Adapted from Pannier *et al.*, 2020.

[Figure 12.2]
Adaptation resource flow at the community level



vulnerable communities may receive funding or other support in the forms of information, knowledge, techniques, and agricultural inputs (seeds, fertilizer, crop protection products, etc.) that help improve agricultural practices in the face of climate change impacts [Pham *et al.*, 2019; Tran & Rodela, 2019]. Such support may come from commune, district and even provincial governments, as well as from non-governmental and mass organizations. Vulnerable communities can also access

loans from public and private banks, or receive external support from private actors in the form of charitable contributions after disaster events. These resources are used for post-disaster recovery, and also to implement new adaptation strategies, such as changing housing structures or applying new crop systems and practices (see Chapter 11). All these resources contribute to climate adaptation, and can therefore be considered as part of climate finance.

Additionally, alongside this formal system, the “shadow system” [Stacey, 1996] – defined here as the set of interpersonal exchanges and arrangements occurring outside but in connection with the official institutions [Tran & Rodela, 2019] – also constitutes an important source of resources for adaptation. The review of existing studies and our research findings in Lao Cai suggest that local communities have access to different types of resources for small-scale adaptation activities. These resources come through informal local loan systems, local rotating savings and credit groups, informal safety nets, as well as labour exchange practices, land arrangements, and a strong flow of gifts and mutual services [Adger, 2000; McElwee *et al.*, 2010; Delisle & Turner, 2016; Fischer *et al.*, 2011; Pannier & Pulliat, 2016; Son & Kingsbury, 2020]. An event that we studied during our field research illustrates these informal finance flows and how they support adaptation. In 2018, a historical flash flood and landslide caused serious damage to local houses, infrastructures and livelihood in a Tày Commune in Lao Cai Province. As a result, many households decided to move their homes to a safer place or to rebuild higher and stronger houses in the same location. These actions were funded via five sources: (i) local government support ranging from VND 4 million to 40 million per household; (ii) “voluntary contributions” from individuals and public or private organizations, ranging from VND 500000 to VND 8 million; (iii) bank loans (from VND 50 million to 100 million); (iv) funds from the market, such as extra-agricultural activities or other salaries, sale of agricultural produce etc.; and (v) resources obtained from interpersonal relationship networks in various forms, such as monetary gifts, interest-free or low-interest loans, material support (building materials, food for workers, etc.), credit when buying building materials, in-kind support (e.g.

help for the construction work). We estimate that the last category contributed between 30% and 85% of the budget required to relocate or rebuild the houses. Hence, it reveals that interpersonal interactions, arrangements, and exchanges, framed by both the logic of indebtedness and of mutual help, and regulated by a strong sense of moral and social obligation [Delisle & Turner, 2016; Pannier & Pulliat, 2016], may significantly contribute to the implementation of climate change adaptation actions at the local level. Such essential financial sources are often overshadowed in climate finance.

4.3 The uses of resources for adaptation in practice

What does adaptation finance actually fund? What are the kinds of adaptation actions that occur in practice in the field? At all scales, the main approach for climate adaptation actions has been a technical one. The main use of climate finance is for large-scale infrastructure that aims at reducing the adverse effects of environmental hazards, such as building dykes against floods. The importance of disaster risk reduction and of strengthening the physical assets to make infrastructure more climate-resilient is underlined by international donors, such as the IMF in its latest report regarding climate change in Asia-Pacific region. While it requires very high funding, it has been given priority in Viet Nam.

At the national level, a study examining the climate change expenditure of five ministries (MoNRE, MARD, MOT, MOIT, and MOC) during the period before 2015 states that a major part of adaptation funding was used for large-scale infrastructure [GoV, 2016; World Bank, 2015b]. Specifically, MARD and MOT

[Table 12.2]

Local adaptation funding allocation for hard and soft measures

	Quang Nam	Ca Mau	Hai Phong
Funding planned for hard infrastructure solutions (%)	97%	90%	89,5%
Funding planned for soft measures (%)	3%	10%	10,5%

■ Source: Ca Mau PPC, 2020; Hai Phong PPC, 2020; Quang Nam PPC, 2020.

have the largest share of funding for climate change response, and the majority of their resource was used for irrigation systems, disaster-specific infrastructure and transportation projects [World Bank, 2015b]. Only a small portion of climate change funding was allocated to the improvement of climate-response governance, or to the design and effective implementation of adaptation policies. More specifically, little funding was dedicated to the development of sectorial and provincial climate adaptation plans (CAP) [World Bank, 2015b]. As a result, the quality of these plans and their implementation are rather limited [PEAPROS, 2012; Priambodo *et al.*, 2014].

The findings of this World Bank study are still relevant today. According to the list of projects under the National Target Program on climate change and Green Growth for the 2016–2020 period, nearly 80% of the total budget allocated to provincial government is used for “hard” infrastructure. The remaining funding is spent on soft measures, with the focus on forest plantation, protection, and restoration. In addition, there have been a limited number of projects aimed at addressing social, institutional, and environmental drivers of vulnerability. Vulnerability assessment was not even a legal requirement until recently, and thus was

not a common practice in climate change adaptation planning processes.

At the provincial level, large-scale hard infrastructure is also the dominant approach for climate change response (see Table 4.2). For example, nearly 97% of funding for implementing the Quang Nam CAP for the 2021–2030 period is earmarked for “hard” measures, such as river embankment, dykes and pumping stations [Quang Nam PPC, 2020]. Nonetheless, overall actual funding to implement the provincial CAP remains relatively limited. Most provinces have to rely on financial support from the national level and external sources. In some cases, support from international organizations (in the form of grants) to provinces is much higher than from the national government. For example, during the 2010–2015 period, Can Tho received only VND 1.8 billion from the national government, while accessing some VND 27 billion from international donors [Can Tho PPC, 2016]. Similarly, 95% of funding needs for climate change activities in Da Nang over the same period was met by international organizations [Da Nang PPC, 2015].

The budget for adaptation actions implemented by local authorities often comes from the national government, and has mainly been used to develop infrastructure and large-scale adaptation projects. In several provinces, a small portion is allocated by the provincial government budget in the form of a counterpart fund. For instance, An Giang and Ben Tre provinces received VND 165 billion and VND 152 billion from the national government during the 2010–2015 period, and contributed around VND 47 billion and around VND 19 billion respectively from their own budget [An Giang PPC, 2015; Ben Tre PPC, 2015].

However, this situation is not the same across the country: many other provinces do not have access to this level of support. In many areas, there is no local finance to add to the national funding. For instance, Bac Kan, Ninh Thuan, and Dien Bien provinces received only VND 1 billion from NTPRCC and SPRCC funding, and could not mobilize local funding for climate change response activities over the same period [Bac Kan PPC, 2015; Dien Bien PPC, 2015; Ninh Thuan PPC, 2015]. In other words, there has been a significant financial gap to implement provincial climate adaptation plans (CAP). According to the reports on the implementation of the NTPRCC program at the provincial level during the 2010–2015 period, most provinces reported that they failed to fully implement their CAPs due to lack of financial resources. An officer from DoNRE said that: “Our department has received very limited funding to work on climate change. We got some support from the central government to develop the action plan to respond to climate change. However, most of the actions identified in this plan have not been implemented due to the lack of funding...” Similarly, a senior former government officer stated that: “There is a huge funding

gap for adaptation at the provincial level, not to mention the district and commune levels.” According to provincial reports on the result of the implementation of the NTPRCC for the 2010–2015 period in many provinces, very few actions identified in the provincial-level CAP for the 2010–2015 period were actually implemented. For example, none of the projects listed in the climate change action plans of Dien Bien, Ha Nam and Bac Kan provinces, and only one out of 16 priority projects of the Ninh Thuan CAP, were implemented by 2015 [Bac Kan PPC, 2015; Dien Bien PPC, 2015; Ha Nam PPC, 2015; Ninh Thuan PPC, 2015]. At the district and commune level, the situation is even more critical, since there are no or very limited financial resources for proper adaptation interventions.

At the community level, a large number of disaster risk management projects have been implemented. However, the focus is often on emergency response, short-term recovery and reactive actions, rather than interventions that address fundamental drivers of vulnerability and risks [McElwee *et al.*, 2017; McElwee *et al.*, 2010] (see [Chapter 11](#)), and longer-term and preventive solutions that are well informed by future climate change projections [Oxfam International, 2008]. For instance, only 2% of the funding planned for climate change and disaster responses was used for enhancing governmental capacities, and only 1% for developing adaptive capacity of communities and smallholder farmers [Phuong *et al.*, 2018; World Bank, 2015a].

Overall, at the provincial level, the current environmental governance does not enable full implementation of climate-response policies [Pulliat, 2019]. The priority given to costly large-scale infrastructure may result in an inadequate scaling of infrastructure, in parti-

cular in a context of high uncertainty regarding the magnitude of future events. Meanwhile, less costly measures — in particular regarding population preparedness — appear overlooked in the current pattern of climate adaptation finance.

Nonetheless, adaptation actions take place alongside and in addition to policies and climate-adaptation plans. There are cases in which development-oriented projects contribute to local adaptation. For example, in our case study in Nghia Do (in Lao Cai province),

local communities have shifted from rice production to planting mulberry for raising silkworms. This project was initiated and implemented by a cooperative that had mobilized private and state funds to help improve local farmers' incomes. However, it has been proved that the project also contributes to helping local communities adapt better to climate change-related hazards, especially flooding. There is therefore a discrepancy between expected climate finance flows, implementation of planned climate policies, and actual adaptation actions that take place on the ground.

5. Towards effective mobilization and use of funding for adaptation

The lack of financial resources is often seen as a major challenge for adaptation in Viet Nam. However, in addition to attracting more financial support from international donors, it is important to investigate: (i) why there is not enough funding for climate change adaptation; (ii) how to ensure sustainable mobilization of funding for climate change response; and (iii) whether existing funding for adaptation has been used in an effective manner.

5.1 Adaptation and/or Development?

Regarding the first two questions, our study suggests that adaptation funding has mainly come from the support of international organizations earmarked for climate change; it is

difficult to use existing development funding for purposes of adaptation. Climate change is often seen as a separate issue, under the responsibility of the natural resources and environment sector, as opposed to a development challenge, although climate-related disasters have caused significant damage to different sectors in Viet Nam, with annual economic losses estimated at 1.5% of the country's GDP [GoV, 2015]. In addition, proposed adaptation actions in sectorial and provincial climate action plans are often no more than a list of independent measures that are neither fully in line with, nor integrated into sectorial and socio-economic development plans. As a result, while the need for incorporating climate change into development planning has been highlighted in several national policies, including in the Law on Environmental Protection approved in 2020, climate change adaptation is currently poorly integrated both into the socio-economic development plan and those of other sectors, and into the regular State budgeting process and regulations.

Existing state budget regulations and processes contain neither a formal definition of

climate finance nor a classification of climate change funds. Climate change adaptation may be integrated into development policies, but no budget line is specifically dedicated to climate change adaptation in the state budget regulations, resulting in a lack of implementation of these policies. This is one of the main reasons for the lack of funding for adaptation at the local level, and for the implementation of provincial level action plans to respond to climate change. Therefore, we argue that in order to increase and sustain funding for climate change adaptation, available resources allocated for development programs should be mobilized for adaptation, and used in ways that meet both development and adaptation objectives. For this to happen, a detailed and clear legal foundation and guidelines must be in place. According to the Department of climate change, a decree guiding the implementation of the climate change mainstreaming requirement of the Environment Protection Law will be soon developed, and is thus expected to facilitate the use of development resources for climate and disaster risk-informed development, and thus for adaptation. However, a strong enforcement mechanism will be required to ensure the proper implementation of this decree.

5.2 Hard infrastructure vs soft solutions – reducing exposure vs. reducing vulnerability

With regards to the third question, we argue that although Viet Nam will need more financial resources for adaptation, it is important to make sure that available funding is allocated and used in an effective manner. As reported in Section 4.3, hard infrastructure has been used as the dominant approach for adaptation. Although hard infrastructure may be cri-

tical for tackling future climate changes and contributing to development objectives, it may barely contribute to adaptation [Eckardt *et al.*, 2016] or risk being maladapted [Balboni, 2019] if not carefully designed and planned. For example, some new and upgraded roads and dykes in Quy Nhon contributed to making flooding worse in the city during the historic flood in 2009 [DiGregorio & Van, 2012]. Similarly, a system of large dykes and sluice gates was built in the Mekong Delta to protect people living inside the dyke, at the expense of people outside the dykes [Schwab, 2014]. A study conducted by the World Bank and MPI revealed that many climate-related infrastructures projects of MARD and MOT are considered as having marginal climate change relevance [World Bank, 2015b]. In addition, hard infrastructure such as river dykes and embankments may modify the usual dynamics of hazards, and local ecosystems and services; their existence may induce a feeling of protection among the population, and lead to increased exposure combined with reduced preparedness when a major hazard occurs (such as centennial floods).

Moreover, we also found that costly climate-related infrastructure is often designed in ways that rarely take future climate change-related uncertainty into account [Lindegaard, 2013; Toan Vu, 2017]. Given the non-stationary nature of future climate change uncertainty [Milly *et al.*, 2008], this approach is no longer appropriate [Hallegatte, 2009; Lempert *et al.*, 2004], as the lock-in effect associated with large-scale and rigid infrastructure often lasts for decades, and may cause substantial losses when extreme events are more frequent and stronger than the design protection level [Hallegatte, 2009]. This infrastructure may also limit the scope for future adaptation [Dessai & Wilby, 2011; Lindegaard, 2013],

and even reduce Viet Nam's ability to effectively adapt to future climate change [Fortier, 2010], since the option value of a different climate scenario is no longer available. According to Schwab (2014), relying on defensive infrastructure is probably inefficient in a context of increased major hazards. This is not to deny the important role of hard infrastructure in some cases. However, as Viet Nam is expected to face more severe and unpredictable future climate change, and large-scale hard infrastructure often lasts for many decades, infrastructure investments are also the riskiest kind, since they are prone to unexpected and irreversible social and ecological impacts, potentially leading to maladaptation. As climate science tends to move fast, there is often no room to accommodate unexpected changes. In this context, climate change responses – flood risk management strategies and interventions, for instance – should prioritize flexible, reversible and robust options [Hallegatte, 2009; Wilby & Dessai, 2010], since these allow for adjustment under changing future climate conditions and for the ability to adapt to surprise in even extreme and unexpected situations [Klinke & Renn, 2002].

It is now generally accepted that adaptation efforts should focus on reducing vulnerability, and on supporting vulnerable populations [Awolala & Ajibefun, 2015; Barrett, 2015; Pickering, 2012]. However, decisions on adaptation finance distribution are seldom based on the level of vulnerability [Barrett, 2015; Hall, 2017]. According to Jeff Baum and colleagues (2015), at the global scale, addressing vulnerability is not clearly articulated in 66% of adaptation-labelled projects reviewed. The case of Viet Nam is no exception. Indeed, focusing on hard infrastructure solutions means that little funds have been allocated to other types of measures. The results of our study

indicate a significant lack of funding for soft adaptation measures, and for actions aimed at addressing the social, cultural, economic, and institutional drivers of vulnerability. This finding is consistent with other adaptation studies in Viet Nam, such as Lindegaard's (2013) and Nguyen's and colleagues (2017). Meanwhile, the availability and capacity of local government officials – crucially important for the successful implementation of climate adaptation plans – have received limited attention. According to a national government climate change officer, despite significant funding for climate change response in Viet Nam over the last 10 years, the capacity of government staff working on climate change at the local level is still very limited. Our interviews with DoNRE's staff assigned to work on climate change in Ha Nam and Bac Kan provinces in early 2021 reveal that they are not trained on climate change adaptation planning. Moreover, in Ha Nam DoNRE, there are only two staff members working on climate change, and their responsibilities also cover water resource management, hydrology and meteorology. Similarly, at the commune level, there are no staff dedicated to climate change issues, and local authorities in charge of disaster risk management do not have any specific training on climate change risk and adaptation options (see Chapter 11 and Puliat, 2019). These examples and further field study evidence suggest that the ways the funding is used may be equally or even more important than its quantity.

5.3 More funding for local adaptation

We have highlighted the critical funding gap for climate change adaptation at the provincial level, and especially for community level

actions. This problem can be attributed to the large share of adaptation funding dedicated to large-scale infrastructure projects that are often directly managed by national and provincial agencies, and by the limited integration of climate change adaptation into development planning, and budgeting processes and regulations. Therefore, more adaptation funding should be allocated at the community level and for community adaptation actions, and new rules need to be in place to facilitate the use of resources for development that supports local adaptation. At the global scale, the call for more funding at the local level has also been raised [Ayesha & Colleen, 2019; Ben Soltoff *et al.*, 2015; Fenton *et al.*, 2014; Soanes *et al.*, 2017]. The target of reaching USD 100 billion annually for all developing countries was set following the Paris Agreement, for both adaptation and mitigation actions [Soanes *et al.*, 2017]. However, there is a serious lack of international commitment to allocating adaptation funds to local communities [Fenton *et al.*, 2014], and thus climate finance rarely reaches the local level [Ayesha & Colleen, 2019]. Indeed, less than 10% of mobilized climate finance reaches local communities [Soanes *et al.*, 2017]. Therefore, a clear and strong national and international commitment is urgently needed. Otherwise, vulnerable communities will continue to suffer not only from climatic hazards, but also from the existing top-down and centralized approach of adaptation finance [Fenton *et al.*, 2014]. In addition, even when this commitment is in place, a strong mechanism needs to be developed to ensure that vulnerable groups receive support [Ben Soltoff *et al.*, 2015], and that they are the direct beneficiaries and actors in designing and implementing adaptation interventions [Soanes *et al.*, 2017].

5.4 Two financing bridges between local and national adaptation strategies

Viet Nam is characterized by a unique network of 18 subnational development banks (SDBs) [AFD, 2020], which could enable the government to better monitor local needs and the specificities of adaptation to climate change in its different regions and provinces. In order to understand the precise role these SDBs could play to facilitate climate adaptation, we need to picture the broader arrangement of the Vietnamese banking system.

Since 1988, the State Bank of Viet Nam (SBV) has played the role of the country's central bank, the financial regulatory agent and the guardian of monetary reserves. Simultaneously, state-owned commercial banks have seen their role enhanced. The SBV delegates its banking activities to four newly created state-owned commercial banks (SOCBs), each targeting a different segment of the economy: the Viet Nam Industrial and Commercial Bank – Vietinbank (industry and commerce); the Bank for Agriculture and Rural Development – Agrinbank (agricultural and rural development); the Bank for Foreign Trade of Viet Nam – Vietcombank (international trade), and the Bank for Investment and Development of Viet Nam – BIDV (infrastructure). Since the 2008 crisis, a new major banking reform has been implemented, separating commercial bank activities from development banking activities. As a result, Viet Nam has three national-level development banking institutions, namely the Viet Nam Bank for Social Policies (VBSP), Viet Nam Development Bank (VDB), Viet Nam Russia Joint Venture Bank (VRB), as well as eighteen local development investment funds, considered as non-financial institutions.

Through these local institutions, the government encourages the decentralization of infrastructure investments at the provincial level: “[...] as commercial bank financing and bond issuance did not prove to be the appropriate solution for the Provincial People’s Committees (PPC) during this period, the Local Development Investment Fund model was considered more appropriate in this context” [AFD, 2017]. Although Local Development Funds are exempt from regulatory control by the Central Bank, they can use standard international financing market procedures. They serve as channels to mobilize resources from multilateral development banks, establishing partnerships with private local funds and becoming shareholders of private enterprises [Kiet, 2018; Hà, 2019].

This existing network of sub-national development institutions could provide the seeds for financial integration between local and national adaptation strategies. With its intimate knowledge of local adaptation needs, it would also be able to raise international funding targeted towards climate-related projects, dependent on climate-mainstreaming its operations. As an example, the Ho Chi Minh City Finance and Investment Corporation (HFIC) has certified its credit portfolio to become a climate bond issuer. In 2016, when the Viet Nam Ministry of Finance approved a pilot project for issuing sub-sovereign green bonds, the municipal People’s Committee decided that the Ho Chi Minh City Finance and Investment State Owned Company would issue a VND 523.5 billion (USD 23 million) 15-year green bond, whose proceeds would be allocated to 11 projects related to the water, adaptation and infrastructure sectors [CBI, 2018].

In parallel, it is also argued that public financing institutions may not be sufficient to face

the expected damage from current climate scenarios. It is true that Viet Nam has recently been constrained by its self-inflicted public debt ceiling of 65% of GDP. In this case, the argument goes, it is necessary to involve the private sector in financing the climate change National Adaptation Plan (NAP) process, notably through public-private partnerships. This strategy aims at harnessing available savings on the international financial markets, and driving them towards climate-virtuous investments in the countries which need them most. That strategy is sometimes called the Wall Street consensus [Dafermos *et al.*, 2021], as it combines private financial actors seeking returns on new climate-related financial assets with de-risking activities from public development institutions, to guarantee a predictable flow of returns for private investors. Although it may allow the faster deployment of financing, it also carries a risk of hidden costs for local and national public budgets if the public guarantee is suddenly called.

5.5 Monitoring and tracking adaptation spending

A system set up to track the finance flows and adaptation spending across sectors and levels, as well as a practical framework to evaluate how adaptation projects contribute to reduce vulnerability and build climate resilience, are important to ensure the effective and transparent use of adaptation funding. It is also an important factor to attract more external funding. These systems and frameworks will also help determine financial gaps and adaptation needs, deficits as well as barriers to public and private investments for adaptation. In 2016, the Viet Nam national plan for the implementation of the Paris Agreement set up the tasks to establish a Monitoring,

Reporting, and Verification (MRV) system for climate change adaptation activities at national and provincial levels, and to develop guidelines to monitor spending for responding to climate change.

Recently, some institutions under MoNRE have been working on financial monitoring and adaptation evaluation. For example, IMHEN has conducted research into developing climate change indicators to assess, notably, the effectiveness of adaptation projects (see [Chapter 11](#)). The Department of climate change also plans to develop a tool to track and monitor adaptation-related finance flows and spending. However, in over 10 years since the first NTPRCC was approved, such systems and frameworks are still not in place. A national government officer stated that there

is neither a comprehensive tool for tracking and monitoring adaptation-related finance flows, nor an accounting system to specifically manage adaptation spending. But Viet Nam is not the only country that is facing this challenge. At the global level, there has not been a consensus over approaches and methodologies to determine adaptation finance and adaptation projects [Hall, 2017]. In addition, the distinction between finance for adaptation and for development is not always clear, so it is difficult to track the exact funding allocated to adaptation [Banhalimi-Zakar *et al.*, 2016; Trabacchi & Buchner, 2017]. It has even been said that there is an “absence of an internationally agreed definition of what qualifies as adaptation finance” [Trabacchi & Buchner, 2017, p. 6].

6. Conclusions

This chapter has presented the complex landscape of adaptation finance in Viet Nam, and analysed the way resources for adaptation circulate. It is clear that Viet Nam has made a great effort in responding to climate change in general, and climate change adaptation in particular. A significant level of funding has been mobilized. However, many important gaps and challenges related to the access to, and effective use of, adaptation funding are still present, and Viet Nam needs to implement breakthrough solutions to overcome these challenges.

Firstly, adaptation resources have mainly been spent on large-scale hard infrastructure, which is often designed without full recognition of the systemic nature of the risks and

uncertainties associated with future climate change. These exposure-reduction and pure optimization strategies may lead to a perception that the future climate is predictable, and that adaptation is simply a technical problem. This perception is considered no longer appropriate to deal with a context of uncertain climate change. Some infrastructure is still necessary, but some may also increase existing risks or create new ones. Therefore, it is important to shift the main focus of the adaptation approach from exposure reduction and building hard infrastructure to reducing vulnerability, risk mitigation, and adaptive capacity building. When needed, hard infrastructure should be planned and designed using open, robust and flexible approaches that enable current and future climate-related risks to be accommodated. In addition, by putting more emphasis on nature-based solutions and lowering potential climate impacts on new

general infrastructure, investments will contribute to sustainable economic development and also adaptation outcomes.

Secondly, this chapter indicates a major funding gap for adaptation between the national and local levels, and especially at the community level. There is no single solution to this problem, which requires interventions at multiple scales. On the one hand, government agencies should be better prepared, with the capacity and eligibility to access more funding both from global adaptation-related resources and from the private sector. On the other hand, breakthrough measures should be taken to ensure the effective use of available funding. Specifically, instead of focusing on hard infrastructure and on reducing exposure, more funding should be allocated to other measures that target social, institutional, and economic dimensions of vulnerability and adaptation, especially at the local level. In addition, instead of relying on external support and on resources specifically designed for adaptation, available funding for development should be mobilized and used in ways that support adaptation, and at the same time ensure resilient and risk-informed development. In doing so, a strong legal foundation and practical guidelines need to be in place, to ensure full integration of adaptation into Socio-Economic and Sectoral Development Plans, and into the annual and medium-term budget planning process at the national, provincial and lower levels. More importantly, a monitoring, reporting, and verifying system should be placed at the core of Viet Nam's adaptation strategy. Without good statistical information, it remains difficult to assess the state and dynamics of adaptation finance. In addition, it is urgent to develop and apply comprehensive and practical frameworks and indicators, to assess how adaptation projects contribute to reducing

vulnerability and increasing resilience. Finally, at the global level, a strong international financial commitment to directly support local vulnerable communities is also required.

Adaptation funding will be a key issue for Viet Nam in the next decades as climate change worsens. The landscape of adaptation finance today gives us insights into the types of adaptation projects that may be financed, which carry some risks. Breakthrough policy solutions will be required to overcome the many challenges, as described in this chapter. Finally, it is important to highlight that while Viet Nam will need more resources for adaptation, it is not only the level of and access to funding that matter, but also the ways in which available resources are used and allocated, and adaptation interventions are designed.

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Chapter 13

The macroeconomics of climate change and adaptation in Viet Nam

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Abstract

We propose an economy-wide assessment of the social and economic effects of climate impacts on the Vietnamese economy as a whole using an integrated macroeconomic framework. Our integrated assessment framework involves the following steps. First, we apply a monetary valuation of direct damages by sector (agriculture, energy and health) by using the key quantitative results from the Chapters 3, 4, 5, 6. Mainly, we focus on the impacts on rice yields, hydropower supply and electricity demand, infectious diseases and mortality, labor productivity and total factor productivity. Then, we construct the sectoral damage functions which represent the losses in each sector conditional on Viet Nam mean surface temperature (VNMST) change. Summing across sectoral direct impacts as a function of VNMST change 2020–2099 relative to the pre-industrial period 1851–1900, we found that expected annual GDP loss is 1.8% relative to the baseline scenario at +1°C of warming. This loss becomes 4.5% for a 1.5°C increase, 6.7% for a 2°C increase and up to 10.8% for a 3°C increase. The cross-sectoral and macroeconomic effects of these sectoral impacts by 2050 lead to average losses which are larger than direct damages by around 30%. In addition, we estimate the annual GDP losses due to typhoons in the period 1992–2013 at 2.4%. Uncertainties remain about the future impacts of typhoons combined with climate change scenarios. Finally, because export-oriented activity clearly supports the country's growth, we specifically account for the potential international damage spillovers that may be incurred by changing trade patterns. Evidence is given that climate change through international spillover damages is expected to reduce Viet Nam's long-run growth rate over the next 40 years.

Tóm tắt

Chúng tôi đề xuất một đánh giá các tác động kinh tế và xã hội của biến đổi khí hậu trên toàn bộ nền kinh tế Việt Nam bằng cách sử dụng một khung vĩ mô tích hợp. Khung đánh giá tích hợp của chúng tôi được xây dựng theo các bước sau. Thứ nhất, chúng tôi áp dụng lượng giá bằng tiền đối với thiệt hại trực tiếp theo ngành (nông nghiệp, năng lượng, y tế và năng suất lao động) bằng cách sử dụng các kết quả định lượng chính từ các chương 3, 4, 5, 6. Chúng tôi tập trung vào một số ảnh hưởng tới sản lượng lúa, thủy điện, tiêu dùng điện, các bệnh truyền nhiễm, tử vong, năng suất lao động và năng suất nhân tố tổng hợp. Sau đó, chúng tôi xây dựng các hàm thiệt hại theo ngành tương ứng với sự thay đổi nhiệt độ bề mặt trung bình của Việt Nam (VNMST). Bằng cách cộng tổng các tác động trực tiếp theo ngành như một hàm theo sự thay đổi của nhiệt độ Việt Nam giai đoạn 2020–2099 so với thời kỳ tiền công nghiệp 1851–1900, chúng tôi nhận thấy rằng tổn thất GDP hàng năm dự kiến khoảng 1,8% so với kịch bản cơ sở khi nhiệt độ tăng lên 1°C. Tổn thất này sẽ là 4,5% khi nhiệt độ tăng 1,5°C, 6,7% khi nhiệt độ tăng 2°C và 10,8% khi nhiệt độ tăng 3°C. Tác động kinh tế vĩ mô và

xuân ngành đến năm 2050 có thể lớn hơn thiệt hại trực tiếp khoảng 30%. Thêm vào đó, chúng tôi tiến hành ước lượng thiệt hại hằng năm GDP do bão trong giai đoạn 1992–2013 là khoảng 2.4%. Hiện nay, rất khó dự đoán các cơn bão trong tương lai với các kịch bản khí hậu khác nhau. Cuối cùng, do đặc điểm tăng trưởng của Việt Nam chủ yếu dựa vào các hoạt động xuất khẩu, chúng tôi đặc biệt nghiên cứu các tác động ảnh hưởng từ quốc tế có thể thay đổi cấu trúc thương mại của nước ta. Bằng chứng cho thấy biến đổi khí hậu thông qua các tác động ảnh hưởng từ quốc tế sẽ có thể làm giảm tốc độ tăng trưởng lâu dài của Việt Nam trong vòng 40 năm tới.

Résumé

Nous proposons une évaluation des effets sociaux et économiques du changement climatique en utilisant un cadre macroéconomique intégré. Notre cadre d'évaluation comprend les étapes suivantes. Tout d'abord, nous appliquons une évaluation monétaire des dommages directs par secteur (agriculture, énergie et santé) en utilisant les principaux résultats quantitatifs des chapitres 3, 4, 5 et 6. Nous nous concentrons principalement sur les impacts sur les rendements rizicoles, l'offre et la demande d'électricité, les maladies infectieuses, la mortalité, la productivité du travail et la productivité totale des facteurs. Ensuite, nous construisons des fonctions de dommages sectoriels qui représentent les pertes dans chaque secteur en fonction du changement de la température moyenne de surface du Viet Nam (VNMST). En additionnant les impacts directs sectoriels en fonction du changement VNMST 2020–2099 par rapport à la période pré-industrielle 1851–1900, nous constatons que la perte annuelle de PIB attendue est de 1,8% par rapport au scénario de référence lors d'une augmentation de +1°C. Cette perte devient 4,5% pour une augmentation de 1,5°C, 6,7% pour une augmentation de 2°C et jusqu'à 10,8% pour une augmentation de 3°C. Les effets transsectoriels et macroéconomiques, d'ici 2050, sont en moyen supérieurs aux dommages directs d'environ 30 %. En outre, nous estimons à 2,4% les pertes annuelles de PIB dues aux typhons pour la période 1992–2013. Des incertitudes subsistent quant aux impacts futurs des typhons combinés aux scénarios de changement climatique. Enfin, étant donné que l'activité particulièrement orientée vers l'exportation du Viet Nam soutient clairement la croissance du pays, nous tenons compte spécifiquement des retombées potentielles des dommages internationaux qui peuvent être encourus par la modification de la structure des échanges. Le changement climatique, par le biais des dommages internationaux, devrait réduire le taux de croissance à long terme du Viet Nam au cours des 40 prochaines années.).

1. Introduction

In previous chapters, we have presented updated and more spatially-disaggregated climate scenarios, different types of sectoral analysis, and an in-depth look at national adaptation strategies and local adaptation dynamics. Indeed, we have investigated how climate change might affect health [Chapter 3], the agricultural sector [Chapter 4], the energy sector [Chapter 5] and households [Chapter 6], while also considering the complex dynamics of climate and more local environmental impacts in the Mekong region (Chapters 7, 8, 9). Yet it remains essential to understand the cross-sectoral and cumulative effects of climate change, not only within Viet Nam, but also in relation with its main trade partners. In this chapter, we propose a new economy-wide assessment of the social and economic effects of climate change on the Vietnamese economy as a whole, using an integrated macroeconomic framework.

In addition, existing studies on the evaluation of the impacts of climate change in Viet Nam are usually focused on specific sectors or specific regions, as shown in the different meta-analysis and sectoral assessments in the second part of this report. Few studies seek to assess the economy-wide effect of climate change. UNU-WIDER and CIEM (2012) are to our knowledge the most recent study to evaluate climate impacts on economic growth and welfare in a dynamic CGE model, via three principal mechanisms: crop yields, hydropower production and regional road networks. This latest study provides insights into the potential macroeconomic effects of different climate scenarios from the previous IPCC report.

Contrary to standard CGE models, the macroeconomic model that we have specifi-

cally developed combines real side variables with financial balance sheet effects. Indeed, over the last three decades, the Vietnamese economy has been integrated into the world economy and undergone an important financialization process. Increased integration with other countries has contributed to income growth, but also to economic vulnerability in the context of rising trade tensions. The global financial crisis of 2008, the ensuing Vietnamese banking crisis of 2011, along with the recent COVID-19 pandemic – all mostly macroeconomic shocks coming from the financial side – have had significant impacts in real terms as well. They have thus revealed the critical need to pay more attention to the integration of the financial sector (*i.e.* money, debt, and assets/liabilities) and the real economy within a single framework, to gain a proper understanding of the dynamics at hand. This more coherent approach is key for any comprehensive macroeconomic analysis and forecast in the short term, and necessary to public policies for a sound development process and macroeconomic stability in the longer term.

Furthermore, Viet Nam is a very open economy, whose international position might also be affected (for better or for worse) by differentiated climate impacts across key trading partners. Within this chapter, we will investigate them independently by using the theory of Balance-of-Payments-Constrained Growth (BPCG).

Beyond this introduction, this chapter has five other sections. Section 2 highlights the integrated framework that has been built within this project to assess climate impacts and adaptation. It should be borne in mind that this platform remains open to incorporate further studies on specific impacts of climate change

on specific sectors. We thus do not pretend to offer an exhaustive assessment of the economic costs of climate change through to 2050, but rather to build transparent empirical scenarios of what could happen in very specific and contingent circumstances. Section 3 thus builds an aggregate damage function based on different sectoral assessments. Section 4 integrates this assessment into the stock-

flow coherent macroeconomic model of Viet Nam. Section 5 treats the specific case of the relative climate impacts of Viet Nam with respect to its main trade partners, which can act as a constraint on the long-term equilibrium growth rate of the Vietnamese economy. Section 6 concludes with some more policy-oriented recommendations and avenues for further research.

2. Towards an integrated framework to assess climate impacts and adaptation

Our methodological approach in this chapter builds on the integrated assessment approach of Hsiang *et al.* (2017) who have attempted to assess the economic cost of climate change in the US via a combination of multiple climate scenarios, quantitative meta-analysis of sectoral and social impacts based on existing studies, and aggregation and integration within a macroeconomic model.

Our integrated assessment framework involves the following steps:

- Valuation of direct damage by sector: in order to aggregate over each individual sector to obtain a total economic response to climate forcing, we first apply a monetary valuation to each individual sector, namely agriculture, energy, health, labor productivity, and total factor productivity. We use the key quantitative results from Chapters 3, 4, 5, 6. The choice of studies as well as the valuation for specific sectors is discussed below. For all direct da-

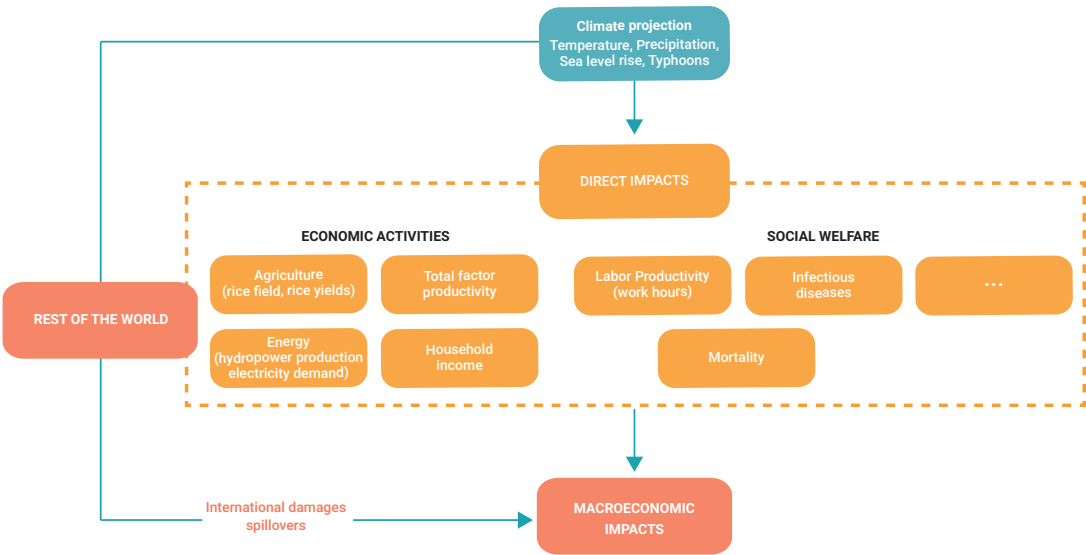
mage, values are presented as a proportion of Vietnamese Gross Domestic Product.

- Sectoral damage function calculation: constructing sectoral damage functions requires that losses in each sector be represented as conditional on Viet Nam mean surface temperature (VNMST) change. We estimate summaries of these relationships by regressing the impact value (for all realizations) on these temperatures. As in Hsiang *et al.* (2017), we consider that the results are not weighted, because the likelihood of states of the world is not relevant to the description of the damage function.

- Aggregate national-level damage function:
 - Summing sectoral damage functions across the spectrum of possible temperature increases to obtain cumulative direct impacts;
 - Applying the direct damage impacts to the stock-flow coherent macroeconomic model of Viet Nam, in order to assess the intersectoral and aggregate effects.

Independently of this framework, we assess the impact of typhoons on Vietnamese GDP, using night-time light data to get a better spatial approximation of their economic costs. Because we could not work on the impacts of climate change on the increased frequency of

[Figure 13.1]
An open integrated framework to assess climate damage in Viet Nam



The integrated framework used in this report allows for the measure of direct impacts on key socio-economic variables and their macroeconomic effect. It remains open to additional sectoral impacts, more detailed specifications of climate scenarios (including uncertain future tipping points), as well as probabilistic assessments considering different sources of uncertainties.

typhoons under different climate scenarios, we did not integrate typhoon impacts into the general framework at this stage, although this will be done in future developments of the model. We also assess the impact of international spillover impacts independently of this framework, as this assessment involves a refined representation of Viet Nam's trading partners as well as their own climate impacts, that would have been too complex to integrate within the already-complex SFC model used for the general assessment of climate impacts.

We thus end up with three parallel evaluations of climate impacts, mainly the direct climate impacts on socio-economic variables in the face of temperature increase, changing preci-

pitation patterns and sea level rise; the climate impacts on GDP due to typhoons; and the relative climate impacts on growth due the changing external position of Viet Nam, in different climate scenarios. This chapter thus builds an open platform to progressively incorporate different aspects of climate change impacts on Viet Nam in more detail. It should be noted that the empirical assessment of climate damage costs is a very difficult and sometimes hazardous exercise [Keen *et al.*, 2021]. This specific application to Viet Nam tries to be as transparent as possible with regard to the inevitable unknowns and uncertainties surrounding these types of assessments.

3. Direct climate damages

Total damage in each sector, and sometimes daily projections from the relevant chapters (mainly Chapters 3, 4, 5 and 6), are valued in monetary terms, aggregated nationally, and completed with a meta-analysis of selected studies. For the meta-analysis, climate models and scenarios may be different from the simulations developed in Chapter 1 of the report. We have included them nonetheless in order to build a theoretical response function, which will then be applied to the complete set of Chapter 1 scenarios. Indeed, each of these aggregate outcomes can be indexed against the change in average temperature in the corresponding climate realization across the four Representative Concentration Pathways (RCP), or their equivalent in the previous form, or the most recent one from the incoming Intergovernmental Panel on Climate Change (IPCC) report. Values are presented as a proportion of Vietnamese GDP. As such, the relative weighting of each sector follows the weighting anticipated by the Vietnamese government up to 2050 and defined in the baseline scenario (see the next section on the macroeconomic model). By being expressed as a percentage change, this direct damage would scale with the expansion of the economy while holding the structure of the economy unchanged compared to the baseline.

3.1 Agriculture

Since the entire Vietnamese population depends on agriculture for food, and agricultural labor still accounts for a significant proportion of total labor (33% in 2020), agriculture remains one of the most important sectors. Climate change has important impacts on

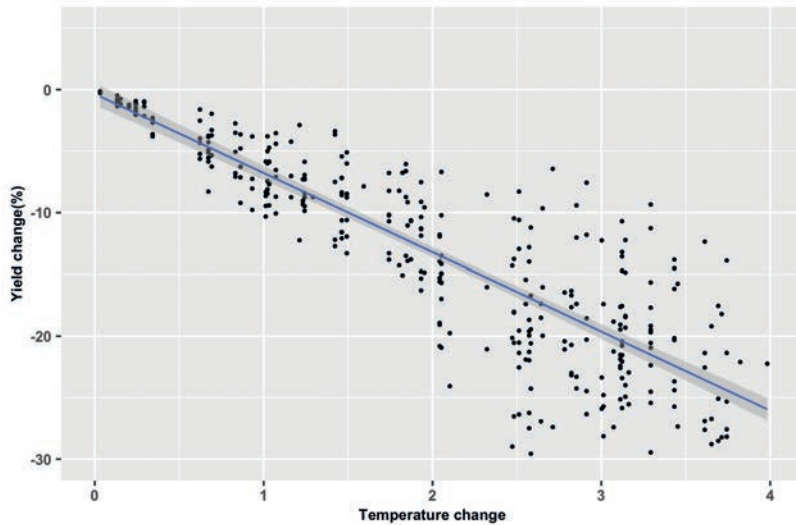
the agricultural sector via both direct (temperature, precipitation, sea level rise, etc.) and indirect mechanisms (water resource, saline intrusion, drought, floods, impacts on labor productivity, etc.). Despite the expected restructuring of agriculture from predominantly rice production towards higher-value products – such as coffee, rubber, fishing, etc., rice is still one of the most important crops in Viet Nam (see Chapter 4 of this report). In addition, Viet Nam is one of the largest exporters of rice (top 5 rice exporting countries in 2020).

In our study, agricultural yield impacts are represented as changes in rice yields. We base our analysis purely on a meta-analysis of a set of key existing studies to develop the sector-specific damage functions for agriculture, namely Yu *et al.* (2010), Li *et al.* (2017), Kontgis *et al.* (2019), Deb *et al.* (2015), Shrestha *et al.* (2016) (see Chapter 4 for a more detailed assessment of these references). Then, we assume that a given change in rice output results in a proportional change in the value of that agricultural sector's gross output in the baseline scenario. In this sense, we do not consider possible endogenous adaptation strategies at this stage and estimate an upper threshold for the corresponding damage function. However, we may also under-estimate damage since non-linear tipping points of the climate system are not accounted for, even if we complete this assessment by taking sea level rise into account in the case of rice. With these limitations in mind, the direct impact of climate change on rice could affect yields by up to 30% beyond a 2°C increase in temperature relative to 1997–2019.

3.2 Energy

The energy sector is a crucial component in any development dynamics, but is affected

[Figure 13.2]
Rice damage function



Average yield change over the period 2020–2099 as a function of VNMST change 2020–2099 relative to 1997–2019. Dots indicate the distribution of direct damages corresponding to VNMST change in each combination of climate models and scenario projection. Black line represents the linear regression of damage values on VNMST change.

by climate change both in terms of energy supply and demand [Auffhammer & Mansur, 2014; Yalew *et al.*, 2020]. The direct costs and benefits of climate-driven change in energy were assessed in Chapter 6, including the forecasted development of the Viet Nam Power Development Plan 8 (PDP8).

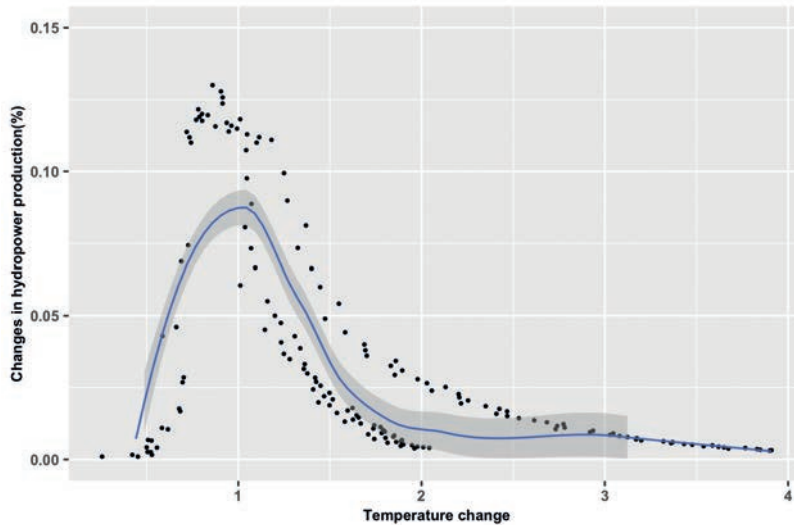
On the supply side, changes in precipitation and temperature can affect energy production capacity, the transmission systems, or the infrastructure itself [World Bank, 2011; Ciscar & Dowling, 2014; Perera *et al.*, 2020]. In this report, given the current dominant role of hydropower in total Vietnamese electricity production (37.7% in 2019) despite a planned reduction to 18% by 2030 and to 9% by 2045 (PDP8), we study the climate impact on hydropower production. Figure 13.4 shows that the case of hydropower is more complex,

as it induces an initial surplus of production (with a maximum at a 1°C increase of temperature) because of increased precipitation. Beyond a 2°C increase however, there is not much change compared to a baseline without further climate change. It should be noted here, as suggested in Chapter 5, that we do not consider other impacts on energy supply and demand due to lack of data, and that we cannot consider the impact of the multiple use of water from the hydropower sector.

On the demand side, the rising temperature and weather extremes in recent years have strongly affected residential electricity demand (27% of total end-use consumption in 2016). The main use of electricity in households is for air conditioners, refrigerators, and electric fans. In Chapter 5, we project changes in residential and commercial

[Figure 13.3]

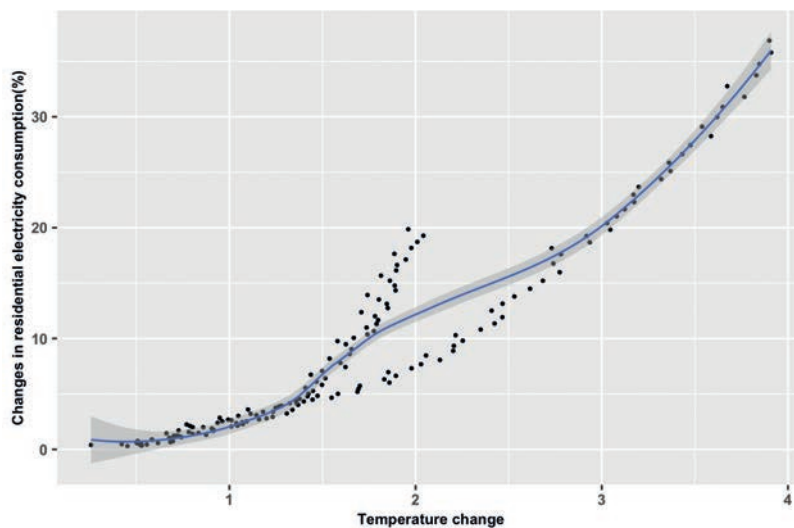
Hydropower production damage function



Average change in hydropower production over the period 2020–2099, as a function of VNMST change 2020–2099 relative to 1997–2019. Dots indicate the distribution of direct damages corresponding to VNMST change in each combination of climate models and scenario projection. Black line represents the polynomial regression of damage values on VNMST change.

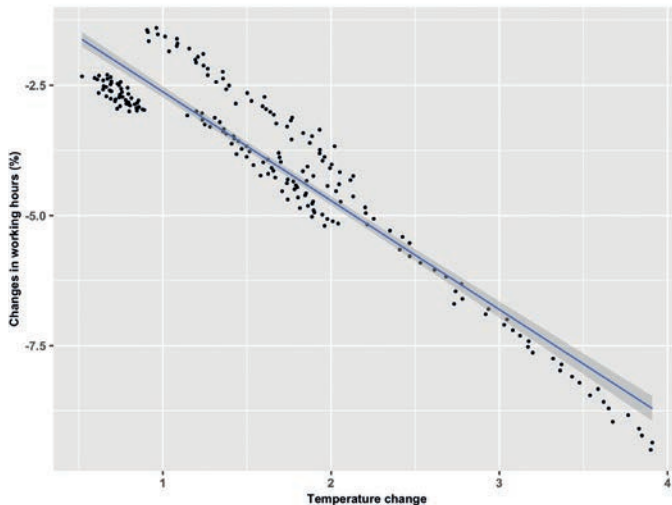
[Figure 13.4]

Electricity demand damage function



Average residential electricity demand changes over the period 2020–2099 as a function of VNMST change 2020–2099 relative to 1997–2019. Dots indicate the distribution of direct damages corresponding to VNMST change in each combination of climate models and scenario projection. Black line represents the non-linear regression of damage values on VNMST change.

[Figure 13.5]
Labor productivity damage function



Average working hours lost over the period 2020–2099 as a function of VNMST change 2020–2099 relative to 1997–2019. Dots indicate the distribution of direct damages corresponding to VNMST change in each combination of climate models and scenario projection. Black line represents the linear regression of damage values on VNMST change.

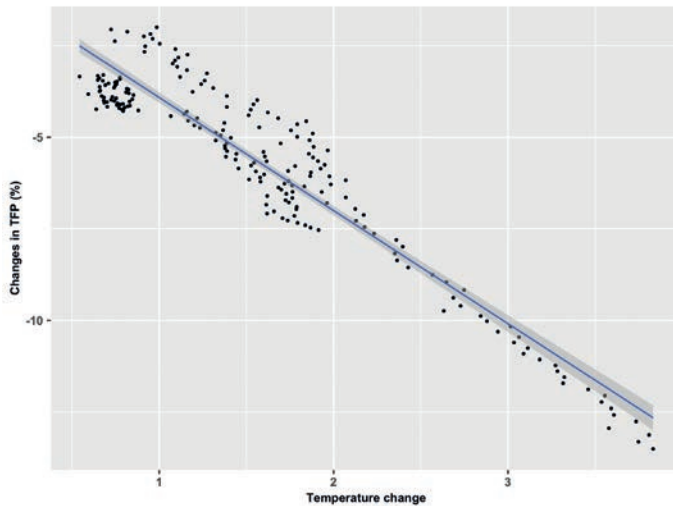
electricity demand, residential and commercial total energy expenditure, and electricity generating capacity. The response functions are derived from the outputs of LEAP in 2040, under a range of temperature scenarios from [Chapter 1](#). These responses are then mapped to regional changes in climate variables in each period (2020–2039, 2040–2059 and 2080–2099). Beyond a 2°C increase in temperature, electricity demand could increase by as much as 12%, and by more than 20% above a 3°C increase.

3.3 Labor productivity

Several studies show that heat stress can have negative impacts on human health as well as worker productivity [Orlov *et al.*, 2020; ILO, 2019; ILO, 2016; Kjellstrom, 2009]. Kjellstrom *et al.* (2012) describe how in the

case of South-East Asia, heat stress reduces work capacity leading to lower economic output. Dao *et al.* (2013) found that in Da Nang, the rise in temperature has particularly affected the working conditions of low-income outdoor workers. Opitz-Stapleton (2014) demonstrates the heat stress induced by climate change will increase the occupational heat exposure of workers. Kjellstrom *et al.* (2014) emphasize that in 2030, heat loss could represent 5.7% of Viet Nam's GDP. In our case, we consider the results of [Chapter 6](#) to quantify an impact function in terms of working hours lost. A 1°C rise in temperature is associated with a decrease of 2.5% in working hours. The value of labor productivity impact is calculated by multiplying the equivalent number of workers which is proportional with the working hours lost by GDP per worker.

[Figure 13.6]

Total factor productivity damage function

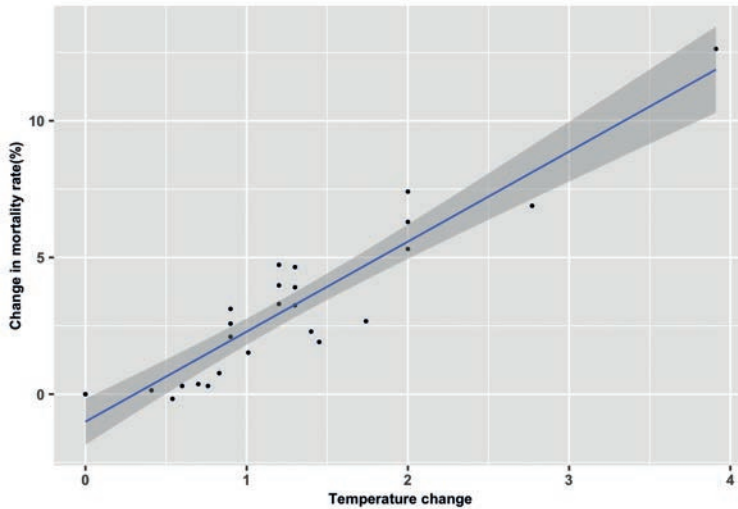
Change in TFP over the period 2020–2099 as a function of VNMST change 2020–2099 relative to 1997–2019. Dots indicate the distribution of direct damages corresponding to VNMST change in each combination of climate models and scenario projection. Black line represents the linear regression of damage values on VNMST change.

3.4 Total factor productivity

The total factor productivity (TFP) plays an important role for the long-run economic growth. In Viet Nam, according to GSO data, TFP has contributed 43.5% to the national economic growth in 2018. In addition, the approved National Assembly's resolution for Viet Nam's socio-economic development indicates that the TFP is expected to contribute 45–47% of GDP growth during coming years. Several studies in the recent literature found a negative impact of climate change on total factor productivity. Letta & Tol (2016), by using macro TFP data from the Penn World Tables, examine the relationship between annual temperature shocks and TFP growth rates in the period 1960–2006. They found only a negative relationship in poor countries but indistinguishable from zero in rich coun-

tries. Dietz & Stern (2015) marginally change the DICE model of William Nordhaus and test the macroeconomic impacts when TFP is hit. Moore & Diaz (2015) test a modified DICE model, calibrated on Dell *et al.* (2012) and obtain increased impacts. Another theoretical study of Moyer *et al.* (2014) also has hypothesized a future impact of global warming on TFP growth. Chapter 6 in the report found that an increase in temperature would reduce the total factor productivity. Specifically, an increase of average temperature of 1°C leads to a 3.6 per cent decline in the TFP. The value of total factor productivity impact is calculated through their impact on GDP growth which is then translated to the changes in GDP level.

[Figure 13.7]
Mortality damage function



Change in mortality rate over the period 2020–2099 as a function of VNMST change 2020–2099 relative to 1997–2019. Dots indicate the distribution of direct damages corresponding to VNMST change in each combination of climate models and scenario projection. Black line represents the linear regression of damage values on VNMST change.

3.5 Health

Most studies show negative impacts of climate change on health outcomes (e.g. physical health, mortality, infectious diseases, mental health, dietary outcomes) [Rocque *et al.*, 2021]. In this report, [Chapter 3](#) investigates the effects of climate variability (temperature, rainfall, wind speed, heatwaves) on infectious diseases (i.e., water-borne, airborne, and vector-borne) and on mortality. They found that the effect of a heat wave on the mortality rate is more significant and of greater magnitude compared with a cold wave. There is also a strong impact of temperature on vector-borne and water-borne disease. The effect of weather changes on the incidence of major diseases differs by climate region. Provinces located in the South and Southern Central Coast appear to have a higher sensitivity to infections at 15°C–18°C temperature.

Mortality

Regarding the effect on mortality, Gasparri *et al.* (2017) investigate the projections of temperature-related excess mortality under climate change scenarios, assuming no adaptation or population changes. This study shows the negative impacts of climate change, which potentially produces an increase in mortality in most regions. Guo *et al.* (2018) projected excess mortality in relation to heatwaves in the future under each RCP scenario, with or without adaptation and with three population change scenarios (high variant, median variant, and low variant). They found that if there is no adaptation, heatwave-related excess mortality is expected to increase the most in tropical and subtropical countries/regions. WHO (2014) shows climate change-attributable heat-related deaths by world region. They find that the relative increase in excess

deaths from 2030 to 2050 is large in some regions, including South-East Asia. In addition, the countries with high populations and pre-existing disease burdens will be more vulnerable to the health impacts of climate change. Another study by Vicedo-Cabrera *et al.* (2018) suggests that the Paris Agreement's commitment to hold warming below 2°C could prevent an increase in temperature-related mortality. Based on these above studies, we obtain the damage function represented in the Figure 13.7.

To value mortality damage in monetary terms, several methods exist and we do not necessarily want to engage in a theoretical decision about them, as this should be the choice of policy-makers. As a practical solution, despite the problems on both theoretical issues of interpretation and difficult problems of measurement of the Value of Statistical Life [Ashenfelter, 2006], we use the Value of Statistical Life (VSL) from a study of Ohno *et al.* (2012) on measurement of Value of Statistical Life by Evaluating Diarrhoea Mortality Risk due to Water Pollution in Viet Nam. VSL has been calculated as 65,726–209,660 US\$ for Viet Nam. Concerning the impact channel in the macroeconomic model, it is possible to consider an impact on population growth, which in turn affects aggregate demand, the labor supply and thus economic growth.

Infectious diseases

Climate change increases the risk of many infectious diseases. Chapter 3 investigates the effect of infectious diseases on the macro-economy through loss in labor productivity. The results suggest a negative influence of infectious diseases on labor productivity, which is represented as the average hourly wage of workers. Specifically, a 1% increase in disease

infections leads to a decrease in the average hourly wage of approximately 0.049%. Based on the projection of changes in the number of infections under RCP4.5 and RCP8.5 of Chapter 3, we develop the damage function of infectious diseases [Figure 13.8]. The average provincial incidence of infection will increase by 29% by 2050 under both RCP4.5 and RCP8.5 without adaptation, and by 36% by 2100 under RCP8.5 without adaptation.

3.6 Typhoons and sea level rise impacts

We know from Chapters 4 and 9 that sea level rise in the Mekong Delta will induce a loss in rice production due to salinization [Nguyen *et al.*, 2018]. In the particular case of the Mekong Delta (see Chapter 9), sea level rise dynamics are due to a combination of climate change and subsidence dynamics from human-induced and natural causes [Minderhoud, 2020]. In our chapter, we use the Ministry of Natural Resources and Environment (MoNRE) flood maps for three scenarios of sea level rise in 2050: 30cm (RCP2.6/RCP4.5), 60 cm (RCP6.0) and 90 cm (RCP8.5). We then include rice fields lost by submersion [Table 13.1] in the macroeconomic model.

Given its location in the Northwestern Pacific Basin, the most active tropical cyclone zone on earth, and its extensive coastline, Viet Nam is prone to meteorological disasters, particularly storms and typhoons. With one-minute sustained wind speeds that can reach more than 64 knots, typhoons are intense storms accompanied by heavy rainfall. When they make landfall, typhoons cause flooding and trigger landslides. With additional climate change, typhoons have more impact because of sea level rise. In order to assess this aspect, we have selected past typhoons above

130 knots, which are supposed to re-occur every century in the current climate while generating an important storm surge. Sea level rise tends to make this type of storm surge

more frequent. We use the calculation of the economic impact [Box 13.1] of this particular type of typhoon to assess the associated GDP losses in affected grid cells.

[Table 13.1]

Rice submersion assessment

Province	Rice planted areas (k.ha)	Rice planted areas lost (%) - Scenario		
		30 cm	60 cm	90 cm
Quang Ninh	21	49%	55%	58%
Thai Binh	82	11%	23%	66%
Hai Phong	38	3%	8%	53%
Nam Dinh	76	8%	29%	68%
Ninh Binh	42	1%	7%	21%
Quang Binh	30	21%	33%	58%
Phu Yen	25.3	0%	0.70%	1.10%
Ninh Thuan	16	0%	0%	0.20%

[Box 13.1]

Assessing typhoon impacts on GDP using satellite imagery

Global damage caused by typhoons has steadily increased in recent decades [OFDA, 2010], due to a combination of accelerated economic development [Takagi, 2019] and ongoing climate change [Stocker *et al.*, 2013]. The economic impacts of typhoons have notably been estimated at the global scale [Felbermayr *et al.*, 2018], in the US [Strobl, 2009], China [Elliott *et al.*, 2015], and the Philippines [Blanc and Strobl, 2016], among others.

We estimate the GDP impact of typhoons in Viet Nam using satellite data as a proxy for localized GDP. We avoid using ex-post collected data on damage, deaths, and/or the affected area such as EM-DAT [Noy and Vu, 2010; Thomas *et al.*, 2010; Trung, 2015; Arouri *et al.*, 2015], which suffers serious drawbacks: reliability, endogeneity, and sample selection bias. In the end, the higher the affected country's GDP per capita, the more likely a disaster with a given natural intensity will be reported. When it comes to developing economies such as Viet Nam, this leads to the under-inclusion of events and their spatial extents, while overestimating the impact.

Night-time light imagery was adopted to investigate economic activity as early as Croft (1978). It is indeed a good proxy for economic activity both at the country [Chen and Nordhaus, 2011; Henderson *et al.*, 2012] and subnational levels [Hodler and Raschky, 2014; Donaldson and Storeygard, 2016]. A large volume of literature studying the consequences of extreme events has already applied night-time light luminosity [Strobl, 2012; Bertinelli and Strobl, 2013; Elliott *et al.*, 2015; Felbermayr, 2018], although never in Viet Nam.

As stated in Noy (2009), heterogeneity in institutional and socioeconomic characteristics results in different ex-post disaster impacts.

The International Best Track Archive for Climate Stewardship (IBTrACS) Version ibtracs.WP.list.v04r00 provides information on 6-hourly central locations of the Western North Pacific's storms, with their respective maximum sustained wind speed in conjunction with details such as direction, forward velocity, central pressure, etc. It is worth noting that interpolated 3-hourly data are also available. Some measurements across different World Meteorological Organization (WMO) Regional Specialized Meteorological Centres (RSMC) cannot be directly compared due to varying units. Therefore, we use data from different agencies when appropriate.

Typhoons are tropical cyclones that reach a 1-minute sustained wind of 64 knots according to international standards. As weaker storms may also be devastating due to the associated extreme rainfall, the results of this study should be treated as the lower bound of damage caused by tropical cyclones. We consider wind speed data from the U.S. Department of Defense Joint Typhoon Warning Center (JTWC), which are given with a 1-min averaging period. We use RSMC Tokyo wind radii at a 30-knot threshold to define if a pixel is affected by a typhoon. Figure 13.8 illustrates all the typhoons used for analysis.

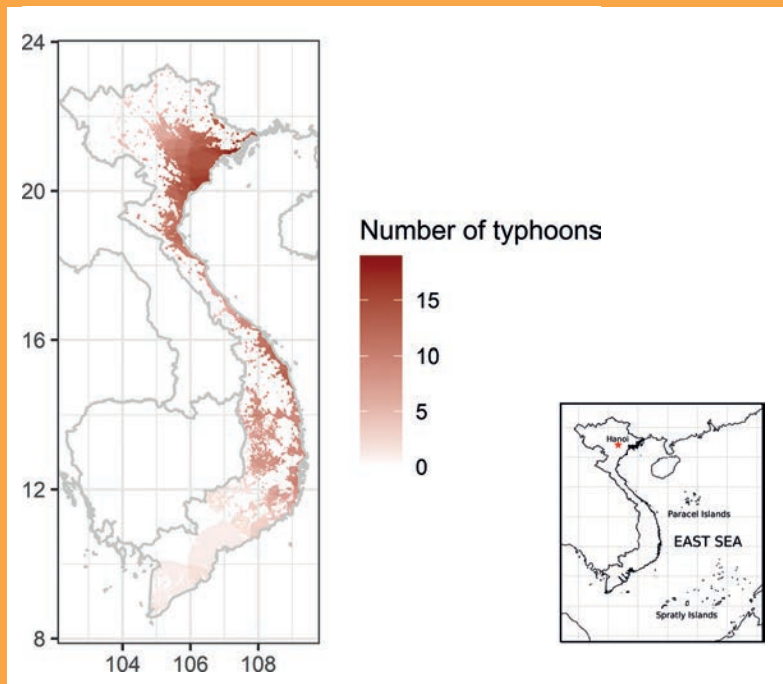
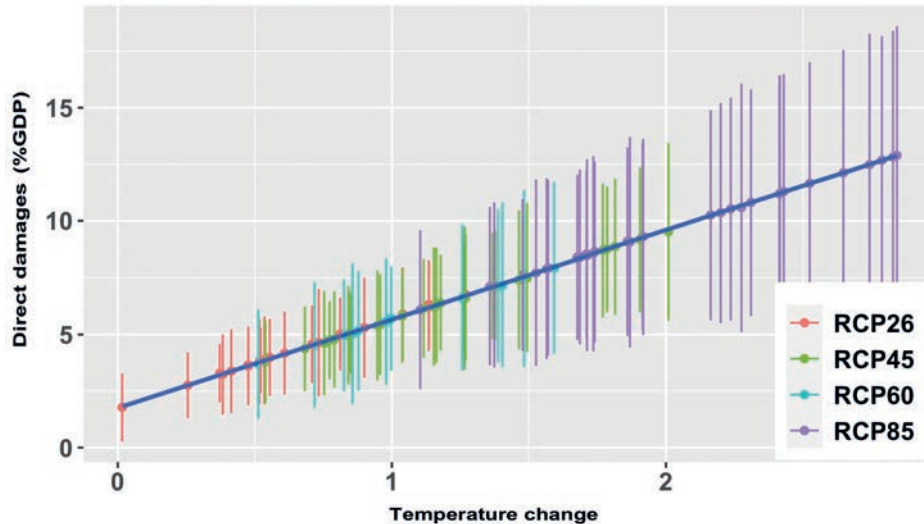


Figure 13.8 Typhoon impacts during 1992–2013

Night-time light data come from the Defense Meteorological Satellite Program (DMSP) and have been processed for the general public by the National Oceanic and Atmospheric Administration (NOAA), with records dating back to 1992 [Elvidge, 2001] and up to 2013. Only pixels in mainland Viet Nam and sizable islands are used for analysis. This is since lights at sea may be affected by typhoons differently and come from mobile and temporary sources such as oil rigs, fishing boats, etc. On average, for pixels with a large value of nightlight intensity, being stricken once in a year leads to a reduction of local economic activities of 4.6%. Given that a 1% change in NL is approximately equivalent to a 0.633% change in GDP, this corresponds to 2.4% GDP loss annually due to typhoon impacts in Viet Nam between 1993–2013.

[Figure 13.9]
Estimates of total direct damage under RCPs



Total direct damage to the Vietnamese economy summed across different sectors as a function of VNMST change 2020–2099 relative to 1997–2019. Dots indicate the distribution of direct damages corresponding to VNMST change in each combination of climate models and scenario projection. Black line represents the linear regression of damage values on VNMST change.

Aggregate direct damage function

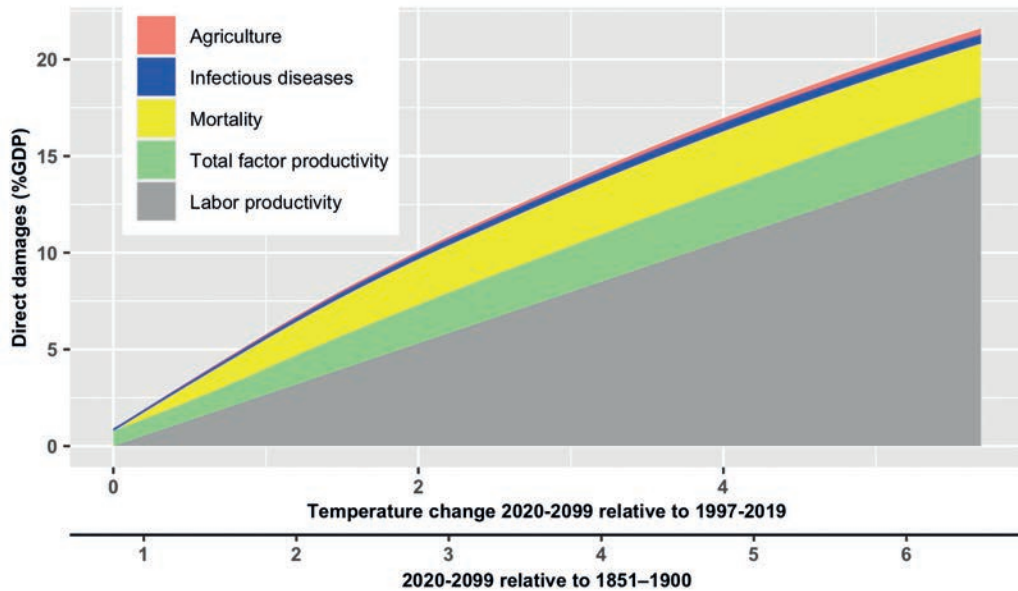
Based on the sectoral damage functions described above, we can build an aggregate damage function for the Vietnamese economy by applying the different functions to the climate scenarios of [Chapter 1](#). [Figure 13.9](#) gives us a hint of the aggregate direct damage in different RCPs, considering the uncertainty from the different climate scenarios (but not from the socio-economic side). It shows that direct damage can reach up to a 12% loss in annual GDP relative to the baseline scenario in the case of a temperature increase above 2.5°C. Remaining below a temperature increase of 1°C allows for a minimal loss of up to 6% of GDP compared to the baseline scenario.

It should be noted that this assessment takes into account some uncertainty on the climate side, but not on the socio-economic side, where strong non-linearities in the reaction to non-marginal climate changes might emerge. Some important impacts have not been taken into account, such as typhoon impacts, which we show independently because their dynamics in relation to climate scenarios is not yet clear.

[Figure 13.10](#) shows a break-down of total direct damage into its sectoral components, using the mean value of climate scenarios. We found that the greatest direct damage from the increasing of VNMST is the impact of labor productivity. The economic damage on agriculture is relatively small mainly due to the Vietnamese economic restructuring in the

[Figure 13.10]

Estimates of total direct damages by sectors



Total direct damage to the Vietnamese economy by different sectors as a function of VNMST change 2020–2099 relative to 1997–2019 (contemporary climate) and relative to 1851–1900 (pre-industrial climate). The temperature of the pre-industrial period is estimated from observation dataset and HadCRUT5 (with a coarse resolution of 5°x5°).

coming years. Indeed, the agriculture share of GDP by 2045–2050 tends to decline.

The macroeconomic simulations we propose in this chapter try to tackle the complexities of a rapidly developing economy such as Viet Nam. At this stage, they do not capture international trade effects. This is the reason why we have completed them with a specific exercise of simulation of the relative impacts of climate change on Viet Nam's trade partners with the hypothesis that the Thirlwall law is verified. This gives us a hint over the reallocation effect of activities at the international level. These results need to be confirmed by a full integration into the main macroeconomic

model. At this stage also, we do have not capture reflected the effect on migrations, both within and outside Viet Nam, either. In the end, we have deliberately admitted that impacts and adaptation strategies are also a question of governance [Chapter 12] and cooperation [Chapter 8], especially for the Mekong region [Chapter 7], which might even involve historically grounded-based perceptions of the natural environment and a social memory of past climate events [Chapter 2]. Although prospective scenarios provide useful and transparent tools for informed strategic discussions, they must be put in context, which is the purpose of the resolutely trans-disciplinary approach of this project.

4. Macroeconomic impacts

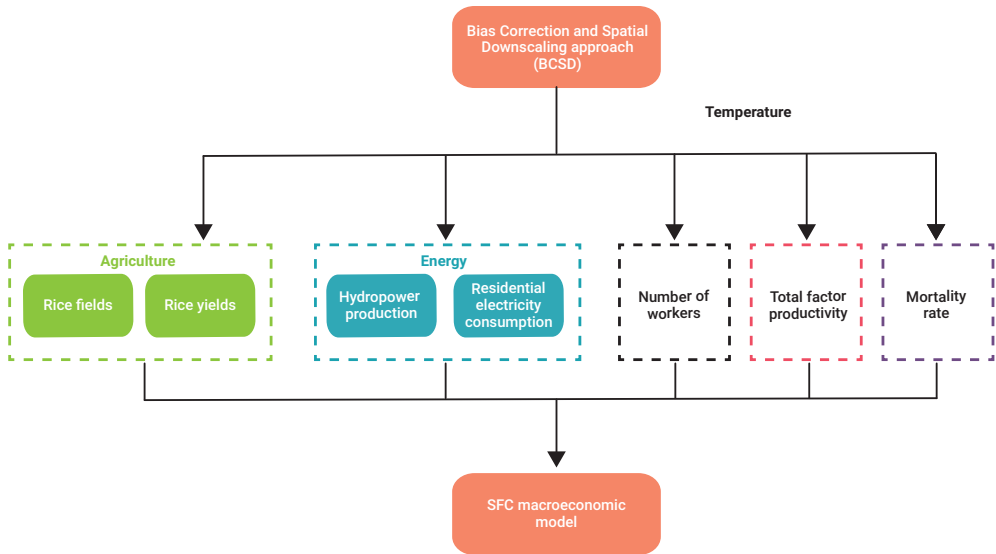
In this part, we develop the different steps necessary to evaluate macroeconomic climate damage at the national level [Figure 13.11]. Indeed, given the complex relations between sectors in the economy, climate impacts cannot be summarized by the sum over the direct impacts. As soon as they affect a specific sector or economic agent, they disturb the whole set of relations within societies, leading to reallocations in the forms of production. Thus, these estimated damage functions build on the work done in the second part of the report at the sectoral level. In our case, several climate impact channels are considered: how climate change might affect health (from

Chapter 3), the agricultural sector (from Chapter 4), the energy sector (from Chapter 5) or labor productivity and total factor productivity (from Chapter 6), while also considering the complex dynamics of climate impacts in the Mekong region (Chapters 7, 8, 9). They will then be implemented within the GEMMES Viet Nam macroeconomic model in order to assess the macroeconomic effects of different climate change scenarios.

4.1 An empirical stock-flow consistent macroeconomic model for Viet Nam

Vietnamese government institutions, research institutes and universities use different types of macroeconomic models for forecasting and

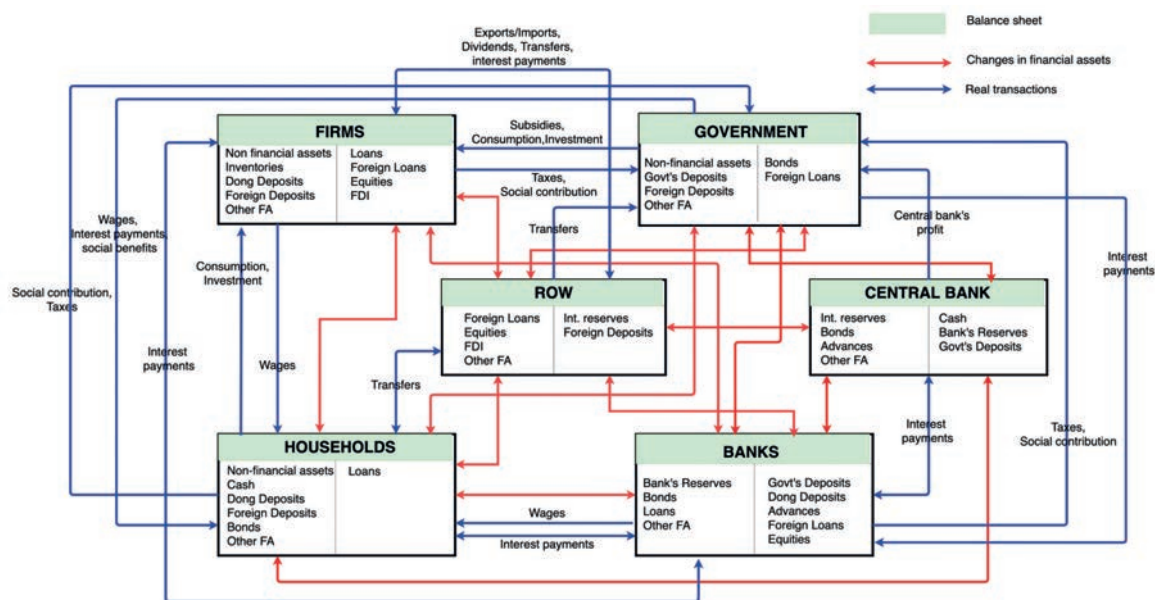
[Figure 13.11]
Macroeconomic impacts framework



Macroeconomic impacts from climate change scenarios via different channels in the macroeconomic model.

[Figure 13.12]

Circular flow of the economy and balance sheet structure



Transactions of the real economy (in blue) and financial flows (in red) between sectors. Balance sheet structure of each sector with assets on the left and liabilities on the right of each institutional sectoral account.

modelling the Vietnamese economy, as well as policy analysis. They include input-output (I-O) models, regression-based econometric models, time series models and Computable General Equilibrium (CGE) – an accounting-based macroeconomic modelling approach. However, overall, there is a lack of attention paid to the financial sector/system in these models. Stock-flow consistent (SFC) models, although marginalized during the period of the so-called great moderation, assume that financial and real variables should be integrated together within the same framework and analysed as a whole in the same model. They are therefore best-suited to address the challenges posed by the recent crisis. The SFC literature has emerged from the post-Keynesian school [Godley and Lavoie, 2007], itself a product

of discussion around James Tobin (1969). The SFC approach relies on two main basic principles: accounting consistencies (i) flow consistency, (ii) stock consistency, (iii) stock-flow coherence, and (iv) quadruple entry) and post-Keynesian closure/behavioural specifications, which explain how economic agents determine and finance their expenditure, and allocate their wealth among different non-financial and financial assets (See Figure 13.12). In this chapter, we thus use the first empirical stock-flow coherent model for the Vietnamese economy¹.

1. The model is fully described in an incoming AFD Working Paper. This chapter only highlights its key characteristics and presents the main results of the climate impact simulations.

Our model is multi-sectoral in order to assess the cross-sectoral effects of different types of climate impacts. Although a few studies have tried to integrate the SFC approach with the I-O approach, notably to address environmental issues [Jackson *et al.*, 2014], or energy issues [Berg & Hartley & Richters, 2015], it is among the first empirical multi-sectoral models of this sort.

The macroeconomic specificities of a developing economy experiencing massive structural change with a plurality of possible futures play a key role in assessing prospective climate impacts. Indeed, despite rapid economic growth and transformation, much of Viet Nam's population still depends on agriculture. At the same time, a rapidly expanding energy sector puts key infrastructure at risk of being stranded by changing climates and climate policies, while adaptation pathways are facing the difficulties of rapid structural change. We thus need to make some hypotheses on the future structural transformations experienced by Viet Nam by mid-century. We also use key macroeconomic features from the simple open-economy model of Yilmaz and Godin (2019), and more generic features from the seminal book by Godley & Lavoie (2007).

We assume that there is one single good, domestically produced or imported, that can be used for intermediate consumption, final consumption, export and investment purposes. It is itself produced using agricultural, energy and industrial services, and financial and government production. Firms decide to produce based on adaptive expectations. They invest and accumulate physical capital by using retained profits, borrowing from banks or abroad, issuing equities or attracting foreign direct investment. Climate change affects the agricultural and energy sectors via rice yields,

electricity demand and the hydropower sector. They also affect firms' productivity in general via an impact on total factor productivity.

The State Bank of Viet Nam (SBV) determines the refinancing rate as a monetary policy tool, provides advances to the commercial banks and manages international reserves. The SBV does not directly purchase government bonds but indirectly from commercial banks (mainly in repos contract) if commercial banks are in need of liquidity. However, we simplify in our model that the central bank buys the bulk of remaining government bonds. We assume that all the central bank's profits are transferred to the government. In 2016, Viet Nam changed its exchange mechanism by daily determining the central exchange rate and allowing commercial banks to transact within bands of $\pm 3\%$ of this rate. For the sake of simplicity and following IMF (2019), we consider the exchange rate as the result of supply and demand of foreign exchange, with an active intervention of the central bank to the foreign exchange market through reserve stock to respond to the evolution of the exchange rate.

Commercial banks provide credits to firms and households, but they also impose credit rationing on firm and household loans, based on loan-to-value (LTV) and debt-to-income (DTI) respectively. They decide both the lending rate and the deposit rate based on a premium over the central bank's interest rate. Commercial banks also hold part of the government's bonds.

Households use their disposable income to consume, invest and accumulate financial assets in the form of deposits, government bonds, firms' equities or other financial assets. Households can also borrow from commercial banks to meet their financing needs.

Households are impacted by climate change through different channels: the number of working hours they can dedicate to firms; their productivity decreases if they catch an infectious disease; the aggregate mortality rate of the population.

The government collects taxes, receives other transfers or payments, and then consumes and invests. The public deficit can be financed by issuing bonds or borrowing from abroad. The rest of the world contributes to financing the domestic economy through foreign direct investment, portfolio investment or foreign loans.

The macroeconomic model for Viet Nam is estimated using the data from 1996 to 2019. We check the model's performance in replicating past data. Then, we simulate it to create a baseline scenario broadly aligned with current Vietnamese Green Growth and NDC strategies in 2030, as well as the socio-economic development trends of Viet Nam and the world.

4.2 Baseline scenario

Firstly, the agricultural contribution to GDP is projected to fall during the period 2020–2050². The rate of population growth is taken from the United Nations population projections for Viet Nam. It represents a downward trend. The capital depreciation rates are projected to remain constant at their current value [IMF, 2018]. Due to the large share of informal and self-employment in the Vietnamese economy and the low level of unemployment in the past, we assume that the unemployment rate will remain constant at the 2019 value [IMF, 2018]. The ratio of public investment to GDP, and public current expenditures to GDP are respectively 6.8% and 5.9%, taken from Viet Nam's Debt Sustainability Analysis (DSA) (IMF, 2018).

2. Projections are taken from the GDP growth baseline projection of Viet Nam Green Growth Strategy.

[Table 13.2]

Main assumptions for exogenous variables

Variables	Projections
Sectoral contribution to GDP	Agriculture (8.7%), Industry (45.6%), Services (45.7%) in 2045
Population	United Nations projections (109 million in 2050)
Unemployment rate	2% (Value in 2019)
Capital depreciation	Value in 2019
Public expenditures	5.9% GDP
Public investment	6.8% GDP
Growth rate of world GDP	SSP's projections (SSP5)
Imports of trading partners	OECD's projections
US interest rate	FED's forecasts for interest rate

Several variables reflect the dynamics of the rest of the world. For the growth rate of world GDP, we take the quantitative projections of the so-called Shared Socioeconomic Pathways (SSP5) to facilitate the integrated analysis of future climate impacts and adaptation policies in the second step of the simulation exercise of the model. The demand for real imports by trading partners is based on the OECD's projections.

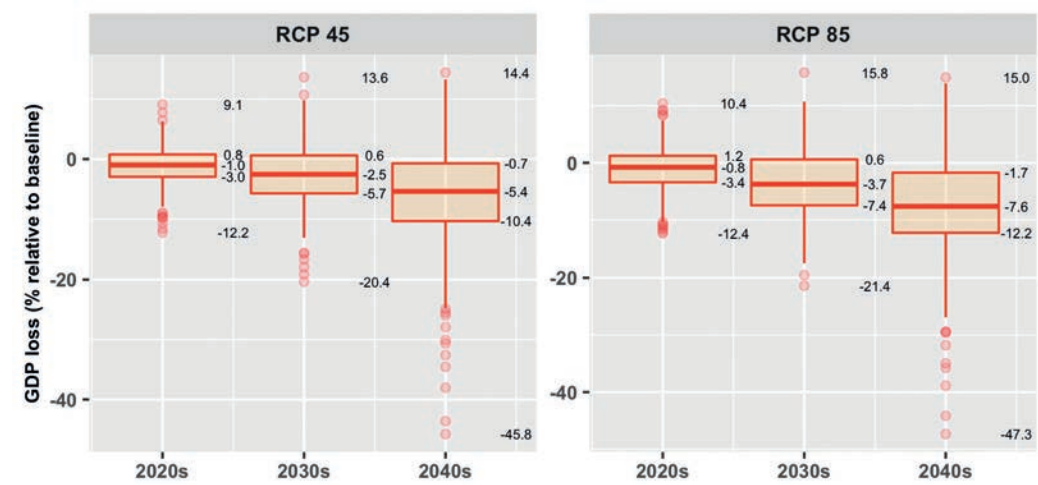
Regarding the financial side of the model, we follow the most recent behaviour of key variables. We follow the projection of the Federal Reserve's interest rate forecasts for the short term and the longer term.

4.3 Climate impacts at the macroeconomic level

Figure 13.13 shows the damages within the macroeconomic model by decade (2020s, 2030s, 2040s) in the simulation where all sectoral damages (agriculture, energy, labor productivity, total factor productivity, mortality) are integrated simultaneously. By the 2040s, averaged losses ranged between 0.7 and 10.4% under RCP4.5 and between 1.7 and 12.2% under RCP8.5.

Then, we consider the climate impacts when the GWLs 1.5°C and 2°C are reached for RCP8.5 in 2023 and 2039 respectively. [Figure 13.14].

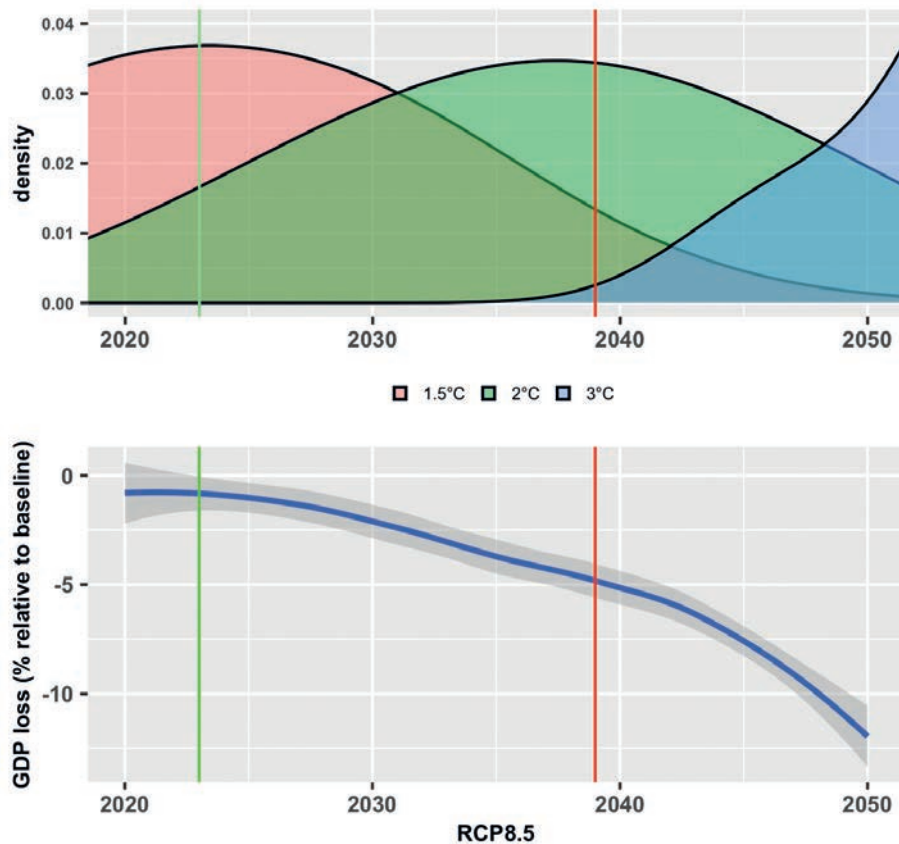
[Figure 13.13]
Macroeconomic damage as a percentage of GDP loss relative to baseline scenario



Boxes = interquartile range (25th (Q1) and 75th (Q3) percentile); Black line = median value; Dots = outliers (maximum = Q3 + 1.5 * interquartile range (IQR: 25th to the 75th percentile), minimum = Q1 + 1.5 * interquartile range (IQR: 25th to the 75th percentile). Damage functions (agriculture, energy, labor productivity, total factor productivity, mortality) are taken into account.

[Figure 13.14]

Macroeconomic damage when the GWLs 1.5°C and 2°C are reached for RCP8.5



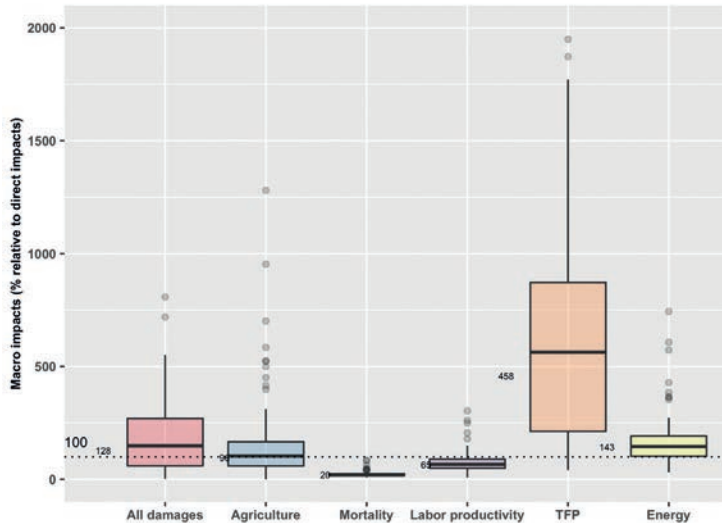
The top graph is the distribution of 1.5°C, 2°C and 3°C VNMST change in RCP8.5 according to the different climate models. The bottom graph represents the average macroeconomic damage relative to the baseline scenario up to 2050 in RCP8.5. The vertical green line indicates the median date when the GWL 1.5°C is reached. The red line indicates the median date when the GWL 2°C is reached. The median date for the GWL 3°C threshold appears after 2050, but there is still an increasing probability to cross it between 2040 and 2050.

We also compare macroeconomic adjusted losses with direct damage losses. Figure 13.15 shows that the direct damages of one sector in the macroeconomic model can be larger or smaller than the corresponding direct damages valuation, depending on the sector. The case of mortality, it is much smaller in the macroe-

conomic model due to the way of valuation of mortality by using VSL. In the case of TFP, the macro impact is much larger due to the role of TFP in the model, which contributes to the production decision, the investment decision. Overall, the macroeconomic impacts losses are larger than direct damages by around 30%.

[Figure 13.15]

Distributions of GDP loss in the macroeconomic model compared with direct damages



■ Boxes = interquartile range (25th and 75th percentile); Black line = median value; Dots = outliers.

5. Viet Nam's external climate constraint under the Thirlwall's law stability condition

Viet Nam is one of the most open economies in the world, with trade in merchandise reaching 196% of GDP in 2018. Yet the country may both export to and import from climate-sensitive countries. In the long term, there will be a differentiated impact on countries' export and import growth rates, and this impact varies over time and across different groups of exporting and importing countries. If we consider the fact that the country is highly open, this implies that climate change may indirectly impact Viet Nam's economy through chan-

ging trade patterns. Because export-oriented activity clearly supports the country's growth, we need to address climate-related challenges by taking into account potential "international spillover damages". Ultimately, climate change is a global externality, meaning that Viet Nam could be further affected by climate damage incurred by its trading partners, and that an adjustment in trade patterns could increase the burden of climate impacts. By ignoring such "international spillover damages", the Vietnamese government may misjudge the climate shock on the domestic economy.

Accordingly, the present section aims to measure the consequences of climate change on Viet Nam's patterns of trade and the related competitive position. In that respect, the theory of Balance-of-Payments-Constrained Growth (BPCG) is a particularly well-suited approach to our purpose. Originally proposed by

Thirlwall (1979), this theory broadly appeals to external demand-side constraints in explaining long-term growth. It allows us to analyse how, and through which transmission channels, the changing geography of international trade resulting from climate damage would impact the evolution of Viet Nam's external constraints and growth rates in the long term.

Our analysis on the projected costs of climate change is measured in comparison with a baseline scenario absent climate considerations. Because of cross-country linkages through bilateral trade, there are two channels through which "international damage spillovers" occur. First, we can easily trace the dynamics of partners' growth in the two alternative scenarios (with and without climate damage) to project future trends in Viet Nam's volume of exports. Second, since the domestic impact of climate change may be heterogeneous across countries, there will be a differentiated impact on export and import market shares. Both terms play a critical role in summarising behavioural parameters that are likely to shift relative competitive positions.

5.1 Analytical framework

The impact of climate change is likely to vary considerably across countries at different levels of economic development and trade openness. If climate change had homogeneous impacts across trading partners and Viet Nam, there would be no change in the country's relative competitiveness; but if instead Viet Nam was negatively affected by climate damage while its trading partners were more severely impacted, then the country's relative competitiveness would be improved. Therefore, we need to understand not only the impact of climate change on potential domestic disruptions of economic

activity in Viet Nam, but also the projected impacts on trading partners and their positions relative to Viet Nam.

In this context, we propose to examine how trade interrelations are channels through which climate impacts are transmitted into the Vietnamese economy. With projections on the implications of climate change for its main trading partners, these interlinked impacts labelled "international spillover damage" will allow us to measure the effect on Viet Nam's relative competitiveness and long run growth rate. To our knowledge, Gassebner *et al.* (2010) and Oh and Reuveny (2010) were the first to highlight the significant effects of natural disasters on bilateral flows by using a trade gravity analysis. Although research on the trade effect is in its infancy, a multi-country setting is still lacking to assess the indirect effects of climate change. The OECD (2015) and Dellink *et al.* (2017) embraced climate-related issues by providing a DCGE modelling approach to climate damage through to 2060. Specifically, Dellink *et al.* (2017) used the OECD's ENV-Linkages model to explore the long-term impacts of climate change on international trade, diving much deeper into the consequences for competitiveness, specialization, and changes in international trade patterns.

This paper builds on the OECD's ENV-Linkages model simulations to highlight geographic disparities in the indirect consequences of climate change. While an aggregated model of the domestic economy is assumed, a multi-country setting is required to simulate the effects of climate damage on the international geography of trade. Given that domestic growth depends on the growth rate of other countries, it is clear that the relative impact in a country compared to its trading partners matters more for growth predictions than the absolute size of damage.

[Box 13.2]

A multi-country or disaggregated version of Thirlwall's law

Thirlwall's law postulates that the growth rate of an open economy which is consistent with its Balance-of-Payments (BP) equilibrium defines the maximum rate that it can reach in the long run [Thirlwall, 1979]. In its original version, this growth rate is determined by the ratio of the growth rate of aggregate exports (which is, in turn, determined by the exogenously given growth of world income) to the income elasticity of import demand. In practice however, an individual country trades with numerous partner countries and each bilateral trade relation may have different outcomes. Since the economic growth of a country depends on the growth rate of other countries through the BP constraint, this mutual interdependence should be reflected in a model, with multilateral trade relations between the individual country and blocks of countries. Accordingly, our analytical framework relies on Mania *et al.* (2021), who apply a multi-country specification initially developed by Bagnai *et al.* (2016).

Let's assume that a given country i has n trading partners. Equations (A1) and (A2) feature the conventional demand functions for imports and exports respectively, and equation (A3) sets an equilibrium condition for the BP on the current account as follows:

$$M_{ij} = \left(\frac{P_i}{E_{ij}P_j} \right)^{\psi_{ij}} Y_i^{\pi_{ij}} \quad (\text{A1})$$

$$X_{ij} = \left(\frac{E_{ij}P_j}{P_i} \right)^{\eta_{ij}} Y_i^{\varepsilon_{ij}} \quad (\text{A2})$$

$$P_i \sum_j X_{ij} = \sum_j E_{ij} P_j M_{ij} \quad (\text{A3})$$

where P_i are country i export prices, X_{ij} is the real demand of partner j for country i exports, E_{ij} is the bilateral nominal exchange rate, P_j are export prices in j , and M_{ij} are country i imports from partner j , $\psi_{ij} > 0$ and $\pi_{ij} > 0$ are respectively the price and income elasticities of country i imports from partner j , $\eta_{ij} > 0$ and $\varepsilon_{ij} > 0$ are respectively the price and income elasticities of country i exports to partner j .

Taking the growth rates in (A4) we obtain (where dots denote the growth rates):

$$\dot{P}_i + \sum_j v_{ij} \dot{X}_{ij} = \sum_j \mu_{ij} (\dot{E}_{ij} + \dot{P}_j + \dot{M}_{ij}) \quad (\text{A4})$$

With:
$$v_{ij} = \frac{X_{ij}}{\sum_j X_{ij}} \quad \mu_{ij} = \frac{E_{ij} P_j M_{ij}}{\sum_j E_{ij} P_j M_{ij}}$$

v_{ij} and μ_{ij} are respectively the market shares of partner j in country i total exports (in volume) and in country i total imports (in value).

Solving for the growth rate of country i and assuming that relative prices are not trending (namely, the ratio of domestic to foreign prices expressed in domestic currency), we obtain a multi-country or disaggregated version of Thirlwall's law:

$$\dot{Y}_{i,BP} = \frac{\sum_{j=1}^n v_{ij} \varepsilon_{ij} \dot{Y}_j}{\sum_{j=1}^n \mu_{ij} \pi_{ij}} \quad (\text{A5})$$

It defines the maximum growth rate (also the BPCG rate) that an economy i can reach in the long run. In our disaggregated law, the numerator features a volume effect (a weighted sum of real export growth where export market shares intertwine with the income elasticities to magnify partners' income growth). The denominator instead features an "appetite for imports" (a sum of bilateral income elasticities of imports weighted by the corresponding market shares).

Assuming its heavy reliance on foreign-based determinants, a break-down of Viet Nam's long-term growth into different factors from different sources has been undertaken. In that respect, we apply a multi-country specification of Thirlwall's law (see Box 13.2). The changing geography of international trade can shape the evolution of the BP constraint, as the elasticity ratio is rooted in different patterns of production and trade. Taking into account the BPCG model, a country's long-term predicted growth is based on trading partners' growth on the one hand, and on the country's relative competitiveness on the other. Yet both factors are identified as the two key international spillovers through which country i may be affected by the long-term effect of climate change abroad, namely: the changing volume of exports and market shares in country i total exports (in volume) and total imports (in value).

Applied to Viet Nam, our approach consists in evaluating the impact of climate change on the BPCG rate, and assumes no mitigation actions are taken during the period considered. To do this, we use data results from Dellink *et al.* (2017), where two scenarios are projected for 2060: a no-damage baseline which simulates overall change in the world economy without taking into account damage caused by climate, and another scenario where climate impacts are integrated into the model³. In the implementation of the BPCG model, we aggregate the 25 regions considered in the OECD's ENV-Linkages model by selecting ten key individual countries or blocks of countries that are Viet Nam's major trading partners. Box 13.3 presents the list of partner areas and the 11th group will cover the rest of the world. In our trade statistics, these ten partner

areas accounted in 2017 for 90% and 91% respectively of Viet Nam's exports in volume and imports in value.

Moreover, we rely on Mania *et al.* (2021) who constructed the average growth rates predicted by the BPCG model for Viet Nam over the period from 1990 to 2017. The long-term elasticities of bilateral exports and imports featuring the BP constraint are used here to construct the BPCG rate corresponding to the two scenarios, namely: a no-damage baseline (with $Y_{VN,BP}(Baseline)$) and a scenario with climate damage (denoted $Y_{VN,BP}(CC)$). The objective here is twofold: first, we compare both predicted rates. If $Y_{VN,BP}(Baseline) > Y_{VN,BP}(CC)$, this indicates that climate damage will tighten Viet Nam's BP constraint and reflect a deteriorating trade position relative to partners (and vice-versa). Second, we examine how, and through which transmission channels, the changing trade patterns resulting from climate damage would impact the evolution of Viet Nam's external constraint in the long run.

Before going into an analysis of our results, it is worth mentioning from Equation A5 that three key elements are of interest in comparing our predicted BPCG rates. On the one hand, climate change will hurt partners' income growth and modify Viet Nam's volume of exports (Y_j); on the other hand, the domestic impact of climate change in each partner j over time will have a differentiated impact on Viet Nam's export ($v_{ij}\varepsilon_{ij}$) and import ($\mu_{ij}\pi_{ij}$) competitiveness relative to partner j . In our analysis, we consider that change in the country's relative competitiveness arises exclusively through change in the related export and import market shares ($\Delta v_{ij}\Delta\mu_{ij}$), given that long-term income elasticities are unaffected by climate damage (in line with a "business-as-usual" benchmark). In addition,

3. See Dellink *et al.* (2017) for a description of the model and damage that is taken into account.

[Box 13.3]

Viet Nam's trading partner group

CHN	China (including Hong-Kong, SAR)
JPN	Japan
KOR	Rep. of Korea
IND	India
USA	United States of America
RoA	Rest of Asia
OTPP-HI	Other Trans-Pacific Partnership-High Income countries (Australia, Canada, New Zealand)
EU-28	European Union
AFR	Africa
LA	Latin America
RoW	Rest of the World

the multi-country setting cannot be decomposed in bilateral terms, *i.e.* we cannot define something as a “BoP-constrained-by-partner- j -growth rate”. However, it allows us to assess separately the contribution of each partner j 's variable to changes in the aggregate BP constraint. Therefore, our multi-country version will allow us to break down the overall impact in relation to the evolution of Viet Nam's trade position *vis-à-vis* each partner j .

5.2 The impact of climate change on Viet Nam's international trade position

A global assessment

In this subsection, we first compare the average growth rates predicted by our disaggregated law in the two scenarios. Table 13.3 shows our results over the period 2020–2060, and separately for the two sub-periods 2020–2040 and 2040–2060. We observe that $Y_{VN,BP} (Baseline) > Y_{VN,BP} (CC)$ whatever the time span considered. Thus, climate change leads to a tightening of Viet Nam's BP constraint.

This overall impact is reflected in a 0.13 point reduction in the average growth rate over the period 2020–2060 (*i.e.* a 2.5% reduction). Note that the climate-induced impact on Viet Nam's BPCG rate is non-linear, as the decline is deeper in the second sub-period (-3.2% vs -2.1%). The gap is not excessively large because, as growth is a cumulative process, the reductions in GDP levels as a result of climate change translate into small reductions in average annual GDP growth rates over the simulation period. In order to capture the scale and implications of this gap, it can be evaluated that if Viet Nam's actual future growth rates matched the BPCG predicted ones, the fractional loss would be 4.84% of GDP in 2060⁴.

Viet Nam's competitiveness in relation to its main partners

What is now interesting is to analyse the contribution of each explanatory variable and partner area to the tightening of the BP

4. In 2060, the loss attributed to climate change would be equal to $\left(1 - \frac{(1.05)^{40}}{(1.0513)^{40}}\right) \cdot 100$

[Table 13.3]

Viet Nam's BPCG rates by sub-periods, with and without climate damage

	$Y_{VN,BP}(Baseline)$	$Y_{VN,BP}(CC)$	Difference in percentage
2020–2060	5,13%	5,00%	-2.5%
2020–2040	6,17%	6,04%	-2.1%
2040–2060	4,11%	3,98%	-3.2%

constraint between the two scenarios. By decomposing the Equation (A5) down linearly through a Taylor series expansion, it is possible to disaggregate the BP constraint development into three components:

i) **A partner growth effect.** Climate change will hurt partners' income growth and by modifying Viet Nam's volume of exports, it will subsequently affect the external constraint. A positive sign associated with this component explains the tightening of the BP constraint.

ii) **An export market share effect.** When climate change increases the relative size of Viet Nam's volume of exports on partner j market, it will reflect improvement in the country's relative competitiveness and soften the constraint tightening. This favorable effect is then associated with a negative sign.

iii) **An import market share effect.** When climate change increases the relative size of Viet Nam's import value from partner j , it will reflect deterioration in the country's relative competitiveness on its domestic market. The unfavorable effect explains the tightening of the BP constraint and is therefore associated with a positive sign.

By aggregating over partner areas, we get the decomposition by effect of the overall BP

constraint tightening (shown in the last line of Table 13.4), which allows us to gauge the relative importance of the different mechanisms at work. We observe that the deterioration in the BP constraint is accounted for at 34.8% by the negative impact of climate damage on partners' growth (mainly China and the USA), at 37% by a reduction in export market shares (particularly vis-à-vis the USA and EU28) and at 28.1% by Viet Nam's import market shares. Unsurprisingly, all trading partners' growth will be negatively affected by climate change, and this explains Vietnam's BP constraint development. But this channel intertwines with the export market share effect to magnify the tightening. When looking at the import market share effect, a contrasting picture emerges between China (whose share in Viet Nam's total imports is diminishing) and India with South Korea (whose growing shares in Vietnimports reflect deterioration in the country's relative competitiveness).

If instead we aggregate over the three effects, we get the decomposition by partner area (reported in the last column of Table 13.4). Another contrasting picture is revealed between China on the one hand, and India and the US on the other hand. Indeed, climate-induced damage leads to improving Viet Nam's competitiveness relative to the former (it should be recalled that China is the country's

[Table 13.4]

A full breakdown of the overall decrease in Viet Nam's BPCG rate by effect and by partner area (in %)

	Partner growth	Export market share	Import market share	Total by area
CHN	12,7	-13,3	-30,6	-31,3
JPN	-0,1	6,6	6,6	13,1
KOR	0,8	-4,8	22,4	18,4
IND	3,2	4,6	25,5	33,2
RoA	3,7	-7,0	9,7	6,4
USA	6,1	30,7	4,1	40,9
OTTP-HI	0,0	-2,2	2,4	0,2
EUR28	2,1	21,6	-4,8	18,8
AFR	1,1	0,8	-3,8	-1,9
LA	2,5	6,4	2,6	11,5
RoW	2,7	-6,2	-5,9	-9,3
Total by effect	34,8	37,0	28,1	100,0

Table 13.4 presents the result of our linear decomposition by effect and by partner area. To get a better understanding of their relative weights, the contributions of each effect and partner area are expressed as a percentage of the overall decrease in the predicted growth rate $Y_{VN,BP}(CC)$.

main trading partner), while the opposite occurs in relation to the US and India.

Putting all the information together by crossing the partner/effect level, we observe that the largest positive effects (*i.e.* main explanations for the overall tightening of Viet Nam's BP constraint) are the export market share effect relative to the US (30.7%) and EU28 (21.6%), and the import market share effect relative to India (25.5%) and South Korea (22.4%). Symmetrically, a sizable negative effect (*i.e.* main explanation in mitigating the overall tightening) is the import (-30.6%) and export (-13.3%) market share effect relative to China. In other words, China contributes to alleviating the im-

pact of climate damage on Viet Nam's long-term growth (-31.3% as shown in the first line, last column) because of a joint increase in the export market share and decrease in the import market share (*i.e.* improvement in Viet Nam's relative competitiveness with respect to this partner). In contrast, because the US is the second leading individual market for Viet Nam's exports, the unfavourable evolution of the bilateral export market share deeply affects the BPCG rate in the climate damage scenario. It reveals that Viet Nam would lose competitiveness vis-à-vis its competitors in the US market.

All in all, our decomposition exercise clearly shows that international damage spillovers

may indirectly impact Viet Nam's economy through changing trade patterns. By looking simply at predicted changes in the country's

BP constraint, these outcomes result from the composition of very different individual behaviors.

6. Conclusion

6.1 Main results

Our results provide a new economy-wide assessment of the social and economic effects of climate change on the Vietnamese economy as a whole, using an integrated macroeconomic framework and based on empirical analyses of climate impacts and available regional and global climate models. Summing across sectoral direct impacts as a function of VNMST change 2020–2099 relative to the pre-industrial period 1851–1900, we found that expected annual GDP loss is 1.8% relative to the baseline scenario at +1°C of warming. This loss becomes 4.5% for a 1.5°C increase, 6.7% for a 2°C increase and up to 10.8% for a 3°C increase. The cross-sectoral and macroeconomic effects of these sectoral impacts by 2050 lead to average losses which are larger than direct damages by around 30%. In addition, we estimate the annual GDP losses due to typhoons in the period 1992–2013 at 2.4%. Uncertainties remain about the future impacts of typhoons combined with climate change scenarios.

Finally, because export-oriented activity clearly supports the country's growth, we specifically account for the potential international damage spillovers that may be incurred by changing trade patterns. Evidence is given that climate change through international damage spillovers is expected to reduce Viet Nam's long-run growth rate over the next 40 years.

This national estimate is built using the first empirical stock-flow coherent macroeconomic model of the Vietnamese economy. In that sense, growth is demand-driven, while production capacities are affected by the direct impacts of temperature increases on agriculture, energy, labour productivity and health (mortality and infectious diseases), and by the indirect impacts of sea level rise and typhoons on capital stock and agriculture. This estimate will certainly not be the last, as multiple known sectors of the Vietnamese economy for which no suitable studies exist have been omitted from the analysis so far. We could mention the impacts of climate change on tourism, forestry management, aquaculture and fisheries, the informal sector, and biodiversity losses, to name a few. We will complete the work in some of those directions over the remaining duration of the project. But more generally, the GEMMES Viet Nam architecture is designed to be open to contributions from rigorous future studies, which would quantify climate impacts in these "missing sectors". Our approach therefore allows for updates based on new econometric/sectoral modelling results or climate model projections.

The macroeconomic simulations we propose in this chapter try to tackle the complexities of a rapidly developing economy such as Viet Nam. At this stage, they do not capture international trade effects. This is the reason why we have completed them with a specific exercise of simulation of the relative impacts of climate change on Viet Nam's trade partners with the hypothesis that the Thirlwall law is

verified. This gives us a hint over the reallocation effect of activities at the international level. These results need to be confirmed by a full integration into the main macroeconomic model. At this stage also, we do have not capture reflected the effect on migrations, both within and outside Viet Nam, either. In the end, we have deliberately admitted that impacts and adaptation strategies are also a question of governance [Chapter 12] and cooperation [Chapter 8], especially for the Mekong delta region [Chapter 7], which might even involve historically grounded-based perceptions of the natural environment and a social memory of past climate events [Chapter 2]. Although prospective scenarios provide useful and transparent tools for informed strategic discussions, they must be put in context, which is the purpose of the resolutely trans-disciplinary approach of this project.

6.2 Integrating adaptation

Adaptation has been only partially treated in this intermediary report, at least in quantitative terms. The different field studies and models from Chapters 10 and 11 have shown how complex and multifaceted adaptation could be on the ground. Chapter 12 has investigated the financial aspect of adaptation projects and underscored the lack of consistent data, as well as the difficulties in tracing adaptation financing throughout the budgeting process. These difficulties make it hard to implement adaptation pathways in an empirically consistent way within a macroeconomic model.

However, because the empirical results that we use describe how populations have responded to climatic conditions in the past, our damage estimates capture numerous forms of adaptation to the extent that populations have previously employed them. In that way,

we can already obtain sectoral estimates of specific adaptation strategies or costs, and how much they have allowed to mitigate sectoral damage in the past. This has been done specifically in the case of agriculture and health and will be expanded beyond them in a future stage of the project, although there might well be thresholds of climate changes beyond which certain adaptations might be less effective.

Good adaptation strategies in the future also depend on the incorporation of no-regret situations in the face of unexpected climate situations. In this regard, the full assessment of climate uncertainties calls for dynamic adaptive policy pathways, which would strengthen the resilience of physical assets. A recent study by Dabbla-Norris *et al.* (2021) estimates the costs of both upgrading new projects and retrofitting existing assets for a number of countries in the Asia-Pacific region. Upgrading new investment projects involves choices in design and materials: for example, new roads could incorporate drainage to sustain heavier rainfall, or be built on more-elevated terrain to reduce risk of flooding. Retrofitting existing assets involves modifying existing capital stock exposed to natural hazards, and as such is typically much more expensive. It is thus essential to be able to build this dynamic adaptive policy design to minimize costly retrofitting strategies, especially in the Mekong Delta, as illustrated in Chapters 9 and 10.

6.3 Policy implications

Even if not all effects have been accounted for, the loss could possibly reach up to about 12.2% GDP relative to the baseline scenario by 2050 under RCP8.5. This could prevent Viet Nam from achieving her development target which is set at about 7% GDP growth annually

during 2021–20230 and become an industrialized country by 2045. This urges Viet Nam to pay more attention to climate change adaptation strategy in order to improve resilience, mitigate possible negative impacts and achieve the country's development targets. Viet Nam is currently quite active in responding to climate change.

The recently revised Environmental Protection Law, unlike the previous version, dedicates a separate article on climate change adaptation with concrete regulations on climate change impact assessment, adaptation activities, monitoring and responsibilities. In the National Adaptation Plan during 2021–2030, a vision to 2050, Viet Nam is preparing for a separate Law on climate change. These provide a basic framework for planning, designing and implementing climate adaptation. The macroeconomic simulation results in this chapter suggest some policy recommendations on more effective adaptation:

First, adaptation strategies should be designed in a way to combine both bottom-up and top-down approaches. The bottom-up approach has been widely applied in Viet Nam and has helped to identify the climate change impacts on specific sectors or areas and then formulate the relevant adaptation activities accordingly. The top-down approach on the other hand will allow us to take into account the climate change aggregate effects of multi-sectors and help to prioritize resources for more effective adaptation strategies. Measuring aggregate impacts through an integrated modelling framework in this chapter is an example of such a combination approach and should be followed up and improved overtime.

Second, as pointed out in the chapter, the economic damage of climate change can be signi-

ficant in some sectors such as agriculture or energy or can impact across sectors through labor productivity or total factor productivity loss. Therefore, climate change adaptation will be more effective if it is mainstreamed into master plans. Viet Nam is at the beginning of master planning for the period of 2021–2030 and vision to 2050. All master plans, ranging from national to sectoral, regional and provincial master plans are currently being drafted. The climate change impacts should be taken into account in these plans. Although this has been regulated in the new Environmental Protection Law, the guidance for this mainstreaming needs to be made available soon to be in line with the master planning process.

Third, agriculture and energy sectors are the sectors which have potential for green house gas mitigation as shown in Viet Nam's NDC. This suggests a possibility to combine between mitigation and adaptation measures of these two sectors in order to better mobilize financial resources.

Fourth, as shown in this chapter, climate change is expected to reduce Viet Nam's long-term growth rate over the next decades through "international spillover damages". In this regard, the Ministry of Industry and Trade of Viet Nam is assigned to prepare a report in 2022 to assess the international trade policies, technical barriers related to climate change and propose response solutions. The "international spillover damages" identified in this chapter should be taken into account carefully in this report in order to lead to relevant measures to mitigate the negative impacts of trade.

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ABBREVIATIONS

ACMECS	Ayeyawady-Chao Phraya-Mekong Economic Cooperation Strategy	ILSSA	Institute of Labor and Social Affairs
ACSC/APF ASEAN	Civil Society Conference/ASEAN Peoples' Forum	IMHEN	Vietnam Institute of Meteorology, Hydrology and Climate
ADB	Asian Development Bank	INRAE	Institut National de Recherche pour l'agriculture, l'alimentation et l'environnement
ADMER ASEAN	Agreement on Disaster Management and Emergency Response	IPCC	Intergovernmental Panel on Climate Change
APAEC ASEAN	Plan of Action for Energy Cooperation	IRD	Institut de Recherche sur le Développement
ART-Dev	Acteurs, Ressources et Territoires dans le Développement	IREEDS	Institute of Research in Economics, Environment, and Data Science
ASEAN	Association of Southeast Asian Nations	ISSET	Institute for Social and Environmental Transition
AWGWRM	Working Group on Water Resources Management of ASEAN	IWRM	Integrated Water Resources Management
BAU	Business As Usual	JC	Joint Committee of the MRC
BCSD	Bias Correction Spatial Disaggregation	JSPS	Japan Society for the Promotion of Science
CERD	Centre d'Etude et de Recherche sur le Développement International	JWG	Joint Working Group on Water Resources Cooperation of the MLC
CESBIO	Centre d'Etude Spatiale de la Biosphère	LASTA	Laboratoire d'Analyse des Sociétés Transformations Adaptations
CIEM	Central Institute for Economic Management	LEAP	Low-Emission Analysis Platform
CMIP5	Coupled Model Intercomparison Project Phase 5	LEP	Law on Environmental Protection
CSO	Civil Society Organisation	LFS	Labor Force Survey
CTU	Can Tho University	LMI	Lower Mekong Initiative
DTI	Debt To Income	LNMCs	Laos National Mekong Committee Secretariat
ECARES	European Center for Advanced Research in Economics and Statistics	LTV	Loan To Value
EE	Energy Efficiency	LUCAS	Land Use Change for Adaptation Strategies
EFEO	Ecole Française D'Extrême Orient	MARD	Ministry of Agriculture and Rural Development
EGAT	Electricity Generating Authority of Thailand	MDRI	Mekong Development Research Institute
EVN	Viet Nam Electricity	MLC	Mekong-Lancang Cooperation
GCM	Global Climate Model	MOISA	Marchés, organisations, institutions et stratégies d'acteurs
GDP	Gross Domestic Product	MoNRE	Ministry of Natural Resources and the Environment
GHG	Greenhouse gas	MRC	Mekong River Commission
GLOBEO	Globa Earth Observation	MUSP	Mekong-US Partnership
GMS	Greater Mekong Sub-region	NAPCC	National Action Plan on Climate Change
GSO	General Statistics Office of Viet Nam	NGO	Non-governmental organization
GWL	Global warming levels	NSSC	National Strategy on Climate Change
HFMD	Hand Mouth Foot Disease	NTPRCC	National Target Program to Respond to Climate Change
HNUE	Hanoi National University of Education		
ICED	Institute for Circular Economy Development		
IE	Institute of Energy		

PALOC	Patrimoines Locaux, Environnement et Globalisation
PDSI	Palmer Drought Severity Index
PIPA	Plan for the Implementation of the Paris Agreement
PSE	Paris School of Economics
PV	Photovoltaic
RBO	River Basin Organizations
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
REMOSAT	REmote sensing and MOdelling of Surface and ATmosphere
ROK	Republic of Korea
RSF	Regional Stakeholder Forum
SENS	Savoirs, Environnement, Sociétés
SFC	Stock-Flow Coherent
SOE	State-Owned Enterprise
SSP	Shared Socio-economic Pathway
SWAT	Soil and Water Assessment Tool
TNMCS	Thai National Mekong Committee Secretariat
TSE	Toulouse School of Economics
ULB	Université Libre de Bruxelles
UMMISCO	Unité de Modélisation Mathématique et Informatique des Systèmes Complexes
UMR	Unité Mixte de Recherche
UQ	University of Queensland
USSH	Université des Sciences Sociales de Hanoï
USTH	University of Science and Technology Hanoï
UU	Utrecht University
UW	University of the West of England
VBD	Vector Born Disease
VHLSS	Viet Nam Household Living Standard Survey
VNSC-STAC	Viet Nam National Space Center - Space Technology Application Center
VMD	Vietnamese Mekong Delta
WBD	Water Born Disease
WG	Wageningen University



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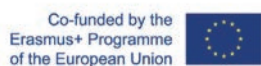
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