# Data Wormholes and Speculative Rice Fields: An Infrastructural Politics of Anticipating Greenhouse Gas Emissions

Casper Bruun Jensen, Jean-Philippe Venot

## To cite this version:

Casper Bruun Jensen, Jean-Philippe Venot. Data Wormholes and Speculative Rice Fields: An Infrastructural Politics of Anticipating Greenhouse Gas Emissions. Science, Technology, and Human Values, In press, 10.1177/01622439231215146. hal-04452454

HAL Id: hal-04452454
https://hal.inrae.fr/hal-04452454
Submitted on 2 Mar 2024

# Data Wormholes and Speculative Rice Fields:

# An Infrastructural Politics of Anticipating Greenhouse Gas Emissions

Casper Bruun Jensen[1] and Jean-Philippe Venot[2]

[1] Chulalongkorn University
[2] UMR G-EAU (IRD, University de Montpellier)

**Author version**

**Published in Science, Technology and Human values**

**https://doi.org/10.1177/01622439231215146**

## Abstract

The 2015 Paris declaration obligated international development organizations to assess the climate compatibility of their projects. For irrigation projects, like those negotiated between the *Agence Française de Développement* (AFD), and the Cambodian government in the early 2020s, calculations of estimated greenhouse gas (GHG) emissions have become important requirements. But how to estimate emissions from future rice fields and the effects of irrigation infrastructures that do not exist? To address this issue, emissions calculators have been developed as a means to bridge climate science and development knowledge infrastructures, so that data and forms of calculation from climate science can easily enter the world of development. However, by engaging in an infrastructural inversion, we argue that this understanding is flawed. Drawing on a case study of an irrigation project in Cambodia, we show that heterogeneous data concatenations are continuously transformed in the movement across infrastructures until referentiality breaks down. Emission calculators ~~can~~ operate as a *data wormhole*, emitting extremely uncertain numbers that contribute to a problematic and speculative politics of anticipation. In contrast with the dominant politics of anticipation, which depends on futile efforts to neutralize uncertainty, infrastructural inversion makes it possible to envision a decentered politics attentive to distributed agency.

***Keywords***

Climate, data wormholes, emissions, irrigation, knowledge infrastructure, anticipation

When muddy fields begin to appear after the flood, motorbikes replace boats as the vehicle of choice in the floodplains of Kandal in the Cambodian Upper Mekong Delta. Hundreds of farmers set out to flatten their plots. Standing on wooden planks pulled along by motorized cultivators, they look a bit like surfers. They dig small furrows for drainage and broadcast rice seeds, water the plots and add chemical inputs. Around three months later, combine harvesters are used to harvest paddy. Heavy bags of rice pile up at the roadside, where they are loaded on trucks going to Vietnam for milling. Some farmers keep rice straw to feed cattle or for use as organic supplements. During this time, fields are irrigated regularly, and sprayed with more herbicides, pesticides, and inputs.

Such details are unlikely to be on the minds of officers from the *Agence Française de Développement* (AFD), who are busy negotiating a large US$200 million loan for an irrigation project with government officials in Phnom Penh.[1] But they might be preoccupied with a dilemma. Deep in the floodplains, the building of irrigation infrastructures goes hand in hand with intensified rice cultivation, which is a Cambodian policy priority. However, to get a loan approved in Paris, the project must also be climate compatible, which includes demonstrating that greenhouse gas emissions will be kept to a minimum. Here is a tension because rice cultivation is known to generate a lot of emissions (though *just how much* is contentious).[2] To give away the drama's ending, this project was eventually evaluated as climate compatible and the loan provided in 2018. Technical experts and consultants are now busy building water control infrastructures for Kandal's floodplains. But how was it possible to conclude that a development project entailing the irrigation of rice was climate compatible?

---

[1] French involvement in the Cambodian irrigation sector has a history stretching back to the French protectorate in the 19th century (Venot and Fontenelle, 2016; Venot and Jensen, 2022). The loan under discussion was for US$200 million over an eight-year period; the biggest negotiated by AFD in the Cambodian agricultural sector since support to the government was renewed in the late 1990s after decades of political turbulence. In the early 2020s, investment in irrigation by various donors amounted to more than US$200 million per year. Irrigation systems mostly serve small rice farmers who cultivate a few hectares and derive a net revenue of US$250-500 per hectare per cultivation season.

[2] Rice cultivation is estimated to contribute to 1.2 percent of total anthropogenic GHG emissions, almost equivalent to emissions related to sea-transport (1.8 percent) and more than mining and quarrying (0.8 percent) (WRI, 2023). The contribution of rice cultivation to climate change largely relates to high methane ($CH4$) emissions (9 percent of anthropogenic emissions; IPCC 2021, Table 5.2), after fermentation and manure (e.g., livestock), oil and gas, landfill and waste, and coal burning. Rice is also a significant source of Nitrous Oxide ($N_20$) emissions, the assessment of which probably involves similar dynamics to those we describe here.

Our interest in the relation between this development decision and global climate policy trajectories comes with a history. While the project was negotiated, we were doing our own research in Kandal about knowledge making practices for delta management and experimenting with participatory approaches to influence development practices (Venot and Jensen 2022; Venot et al. 2022; see also https://deltasoutheastasia-doubt.com/ and http://delta.hus.osaka-u.ac.jp/). Jean-Philippe Venot was also involved in an AFD-funded multi-stakeholder network, COSTEA, tasked with generating and sharing irrigation knowledge to inform related projects and policies in countries where the French development bank operates.[3] The challenges faced by AFD staff to internally "justify" irrigation projects given the agency's new climate commitments was a regular topic in this network.

We became interested in how the possibility of funding an irrigation project for rice cultivation emerged at the intersection of climate and development knowledge infrastructures. In this article, we explore this process of emergence, and its consequences, by engaging in an infrastructural inversion (Bowker 1995), which traces how data concatenations from each infrastructure meet, become entangled, and are transformed, radically. One crucial effect is to make it appear feasible to calculate emissions of rice fields that have largely unknown properties, and for these calculations to be used to consider as climate compatible—and thus fundable—various development projects focused on building irrigation infrastructures to support intensified rice production.

From one side, these calculative possibilities are a creative achievement of development experts who, after the 2015 Paris declaration, had to assess project portfolios for climate compatibility[4] while also navigating complex loan negotiations like the one in Phnom Penh. This part of our analysis draws on frequent, informal discussions in the aforementioned network, complemented by formal interviews with AFD officers about climate compatibility assessment, and analysis of available reports and documentation. Our understanding of how rice emissions research expanded and consolidated in the broader climate knowledge infrastructure, before eventually entering development, is based on a review and mapping of the scientific literature on rice emissions. It was followed by interviews with several influential researchers involved in measuring emissions. This story involves Japanese scientists using soil injectors to measure $CO_2$ emissions in the 1960s, U.S. agricultural

---

[3] COSTEA (www.comité-costea.fr/en/) has activities in 15 countries. AFD operates in 150 countries.

[4] The Paris 2015 Agreement calls for "making [development] finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development" (Article 2, UNFCCC 2016).

extension specialists and researchers building closed chambers in experimental rice fields in the 1980s, and the emergence of a distributed research collective around the International Panel on Climate Change (IPCC) guidelines for emissions measurements in the 1990s, eventually crystallizing in equation 5.2 (see Figure 1 below), which made it possible to calculate emissions from any rice field.

Emissions calculators that rely on this equation were developed as gateways for making emissions data travel smoothly from climate science into development. Through the infrastructural inversion presented in this article, we show this understanding to be flawed. Heterogeneous forms of data are continuously transformed in the movement across infrastructure, until referentiality finally breaks down. We show the emissions calculator to operate as a *data wormhole*, which emits extremely uncertain numbers that contribute to a problematic, speculative politics of anticipation. And we argue that this situation calls for an infrastructural response, a decentered politics attentive to distributed agency, which conventional critiques of development are unequipped to deliver.

## Where Infrastructures Meet

Scientific knowledge about rice farming Greenhouse Gas (GHG) emissions is shaped by a large, distributed climate infrastructure, which Paul Edwards (2010, 17) defines as a "robust network of people, artifacts, and institutions that generate, share, and maintain specific knowledge about the human and natural worlds," in this case global climate change. As climate change became an urgent matter of concern, this vast machine (Edwards 2010) began to interact with the infrastructure of international agricultural development (cf. Mosse 2005). The relations between these two are partial and problematic. However, compared with conventional physical infrastructures (like roads or waterways), they are similar in some respects. Centrally, the knowledge infrastructures of climate and development are somewhat intangible, diffuse, and dispersed, oriented to the flow of data and information, rather than of people, goods, or energy. They do a lot of work but, as they buzz along quietly in the background, they rarely cause political controversy or protest.[5]

One place where these infrastructures silently meet is in assessments of the GHG emissions of agricultural development projects. This topic has not aroused a great deal of excitement among social scientists, probably because it sits uneasily between different

---

[5] The last decades have seen an explosive growth in infrastructure studies across STS, anthropology, and geography (e.g., Harvey et al. 2017). In STS these came through histories of technological systems, which became coupled with studies of standards and classifications (e.g., Bowker and Star 1999).

research communities. For example, political ecologists have long studied the harmful social and environmental consequences of agricultural (and other natural resource) projects (e.g., Fairhead and Leach 1996), and anthropologists have made powerful critiques of depoliticizing development schemes and their one-size-fits-all ideology (e.g., Ferguson 1990; Li 2007). But since gas emissions are distant from the lived experience of farmers facing development interventions, and are quite indirect and intangible, they are rarely studied.

Others have examined controversies at the interface of climate science and policy. There are, for example, studies of the Intergovernmental Panel on Climate Change (IPCC), which has been characterized as a boundary organization (Hoppe et al. 2013), giving shape to a new "politics of anticipation" (Beck and Mahony 2017) where predictions become scenarios and pathways that, beyond their heuristic value, serve as benchmarks for evaluating climate policies. Focusing on speculative climate geopolitics, those studies are far removed from emissions calculations in sector-specific development projects. But, as we shall see, the latter also involve speculative and anticipatory scenarios.

Here is a bifurcation into different ways of conceiving how STS infrastructure and development studies can speak to one another. If infrastructure studies in a "mode of critique" (Bear 2020) is added to the critique of development as hegemonic structures of power and knowledge, the outcome will be an even more intense critique. From this angle, the usage of information transported from climate infrastructure into development will likely appear to serve little purpose beyond greenwashing. But if one moves closer, foregrounding heterogeneous data concatenations and their progressive entanglements, and raises questions of what they bring into being, a generic view of infrastructures as little more than imprints of power coming from elsewhere loses purchase. In this paper, we follow such a strategy of infrastructural inversion (Bowker 1995; Morita 2017). If all goes well, such entanglements can form an infrastructure of referentiality (Lezaun 2006) through which data and information circulates with apparent ease, though circulation always involves translation (Latour 1999). *But, mostly, things do not go well.* Material frictions (Oui 2022) between various infrastructural segments often obstruct or impede circulation; frictions create gaps, inconsistencies, or pockets of illegibility (Neale 2019; Jensen and Winthereik 2013). The effects of infrastructural entanglements become open questions, which in turn makes available ways of imagining the relations between infrastructure studies and anthropologies of development beyond critique (Venkatesan and Yarrow 2012), which is far from the same as being in love with the status quo.[6]

If we can no longer imagine data as a passive entity that moves through inert channels until properly used or improperly manipulated by human agents (Walford 2007), rice emissions data appear as a lively, “concatenated entity” (Mackenzie 2006, 18) flowing through its “natural electronic habitat” (Haraway 1992, 41). Or rather, several different *entities* that belong to different infrastructures. This creates peculiar effects where they meet. In our case, this meeting happens in inconspicuous devices known as emissions calculators. At first, they appear like simple gateways that make climate data concatenations available for use in climate compatibility assessments in agricultural development. On closer inspection, they start to resemble Donna Haraway’s (1997, 4) technoscientific “wormholes,” through which “the natural and the artificial are transported…to emerge as something quite other” (cf. Jensen and Winthereik 2017). From this wormhole emerges a politics of anticipation as a series of material and speculative effects, which shows problematic patterns for reasons other than deliberate political obfuscation or complete economic overdetermination.

## A Mighty Equation

The 2015 Paris Agreement called for “making [development] finance flows consistent with a pathway toward low greenhouse gas emissions and climate-resilient development” (Article 2, UNFCC 2015). This triggered growing attention to the “climate compatibility” of development projects. But to understand how climate compatibility is assessed today, we must travel back to the early days of the IPCC. In the shadows of its comprehensive Assessments Reports, the organization also publishes “Guidelines for National Greenhouse Gas Inventories” to support accounting of country-level GHG emissions. From the beginning, these guidelines included a section on rice-based emissions.

The first guidelines published in 1995 emphasized various influences on rice-based GHG emissions,[7] and made available an “emission factor” that represented the volume of gas

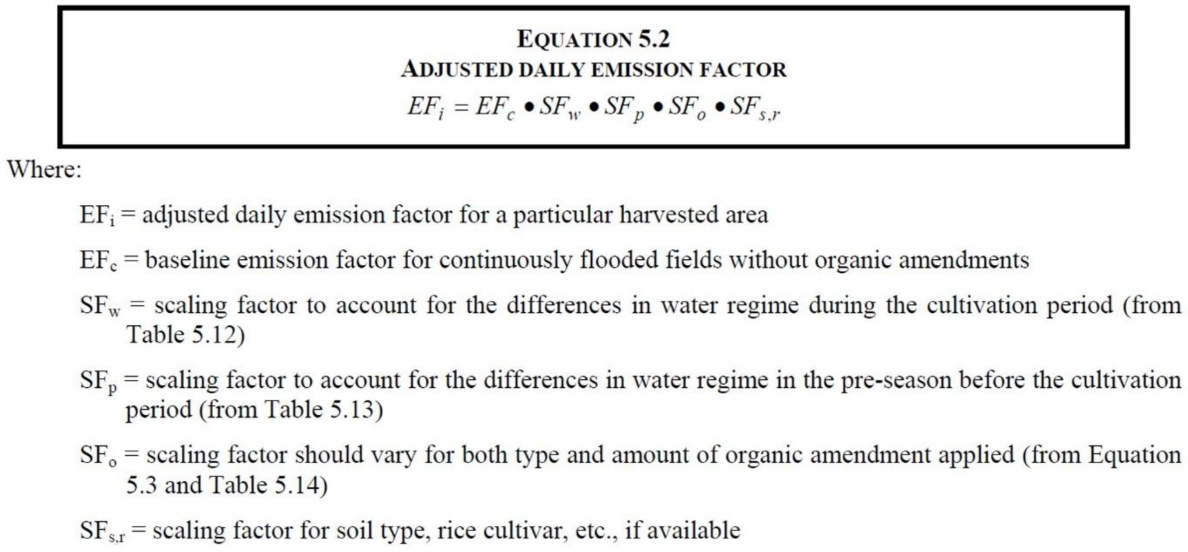
---

[6] By showing how carbon-addicted democracies are effects of battles over oil infrastructures, Timothy Mitchell’s (2011) pathbreaking *Carbon Democracy* shows what can be made visible by conducting infrastructural inversion on a grand scale. Mitchell (2011, 243-4) draws a clear line between (uncertain) oil knowledges shrouded in secrecy and (stable) transparent climate knowledge. Our study of relations between climate and development knowledge infrastructures also indicates differences in the public availability of knowledge, but when it comes to rice emissions calculations in developing countries *both* are haunted by practical difficulties. Similar to how Mitchell (2011, 244) characterizes the uncertainty of oil estimates as a consequence of having to account for unknowable dimensions of “future production,” emissions calculations are also based on scenarios for future rice fields, which generate a speculative politics of anticipation.

produced by rice fields (in kg/ha). The guidelines also provided a “simple formula” to calculate country-level emissions by multiplying a seasonal “average emission factor” with data on rice harvested areas. The average emission factor (“default data”) was based on just 12 studies. In response to calls to collect more data, the guidelines published the following year drew on 58 additional experiments and 35 additional studies conducted in 10 countries. The 1996 guidelines also introduced two other kinds of numbers. One was “scaling factors” used to adjust calculations for specific modalities of water management. The other was error ranges for each of the “default numbers,” which can go as high as 30-40 percent even for measurements taken under similar conditions (most recently, IPCC 2019).

A seemingly innocuous but crucial modification occurred with the 2006 guidelines, which formalized the relation between a “baseline emission factor” (EFc) and several scaling factors (SFw, SFp, SFo, SFs,r) in “equation 5.2” (Figure 1). Gone were the long tables showing rice harvested areas by country that used to fill pages of the earlier guidelines. Instead, equation 5.2 offered a generic method for calculating the emissions of any rice area. Obviously, this is a mathematical reduction because emissions from all the world’s chaotic and diverse rice fields are represented in a single line, but it is also a speculative expansion that makes it possible to conjure any possible scenario and act from a distance.

Figure 1. The IPCC (2006, Vol 4: page 5.28) equation for calculating methane (CH4) emission from rice



**EQUATION 5.2**
**ADJUSTED DAILY EMISSION FACTOR**

$$EF_i = EF_c \bullet SF_w \bullet SF_p \bullet SF_o \bullet SF_{s,r}$$

Where:

$EF_i$ = adjusted daily emission factor for a particular harvested area

$EF_c$ = baseline emission factor for continuously flooded fields without organic amendments

$SF_w$ = scaling factor to account for the differences in water regime during the cultivation period (from Table 5.12)

$SF_p$ = scaling factor to account for the differences in water regime in the pre-season before the cultivation period (from Table 5.13)

$SF_o$ = scaling factor should vary for both type and amount of organic amendment applied (from Equation 5.3 and Table 5.14)

$SF_{s,r}$ = scaling factor for soil type, rice cultivar, etc., if available

---

[7] Identified by earlier research: the history of water levels across the cultivation season, soil type, temperature, agricultural practices and organic amendments, and cultivars.

While this seemed to give the equation universal reach, issues with uncertainty were highlighted in the same process. The authors of the first guidelines had already observed that "as more factors are identified, more categories need to be included. Inclusion of additional factors does not, however, lead to an automatic improvement of the total emissions [assessment] since errors propagate and may create large uncertainties" (IPCC 1995, vol. 3: page 4.55). Yet, despite awareness of the problem and the pointed disclaimer—additional factors and data will not automatically improve the situation—research has consistently focused on adding more data from different kinds of rice fields. The 2006 guidelines, for instance, rely on approximatively 10 times the number of measurements used for the 1996 guidelines. The 2019 guidelines use twice as many measurements as the 2006 guidelines and, for the first time, default data is also disaggregated by "region" (IPCC 2019, Vol 4: page 5.53).

Here, we seem rather close to a "post-plural" situation, as characterized by the anthropologist Marilyn Strathern (1989, 63; see also Jensen and Winthereik 2013, 161), where the act of generating new data or knowledge does not get one closer to any whole picture, because it is accompanied by awareness of yet more gaps that need filling. To solve this conundrum, the many factors of the equation have been equipped with uncertainty ranges, and climate scientists are now confident that piling up more studies is unlikely to significantly modify the global methane budget. But aggregate data does not solve the problem of assessing rice emissions under specific conditions, which is the prime concern of development agents. Emission measurements would have to be conducted in an endless process for every single rice field, which is obviously impossible. Thus, ~~on the one hand,~~ data concatenates and extends infrastructure, while this process continuously threatens referentiality with error propagations, fresh gaps to fill, and other destabilizations. Down the line, where the IPCC equation is built into emissions calculators used to assess the emissions of development projects this has surprising consequences. But before we can understand them, we must visit the rice fields where emissions data and scaling factors were originally obtained.

## A Collective and a Device

In the 1960s, a few Japanese analytical chemists and soil scientists mixed dried soils with water and organic compounds in "soils injectors" and used gas chromatography to measure emissions (Yamane and Sato 1963; Koyama 1964—left panel Figure 2).[8] Two decades later, the atmospheric scientist Ralph J. Cicerone and colleagues covered rice plants with saran bags and glass-carboy collectors at an experimental rice field at the University of California, Davis (Cicerone and Shetter 1981; Cicerone et al. 1983—middle panel Figure 2). A few years later, the German soil scientists and chemists H. Schütz, H. Rennenberg, and R. Conrad measured rice emissions using "static boxes" installed in the Po River delta (Holzapfel-Pschorn and Seiler 1986). The soil scientist K. Minami from Tsukuba University, Japan and the chemist M. X. Wang from the Chinese Academy of Science in Beijing studied rice emissions in East Asia. Meanwhile, the theoretical physicist M. A. K. Khalil and his botanist colleague R. A. Rasmussen produced some of the first global methane budgets, which highlighted the anthropogenic causes of rising atmospheric $CH_4$ concentrations. They also demonstrated that rice cultivation was a significant contributor to global $CH_4$ levels (Khalil and Rasmussen 1982; personal communication).

Khalil and Minami coordinated the rice section of the first IPCC guidelines published in 1995. The 1996 update was led by the chemist R. L. Sass (Texas University) and the agricultural scientist K. Yagi (Tsukuba University). Figure 2 shows various research clusters and indicates that a research boom took place in the early 1990s in the wake of the first guidelines. [9] This is corroborated by interviewees who described a gradual convergence of previously dispersed communities.[10] During this period, the Philippines-based International Rice Research Institute (IRRI)[11] also emerged as a key actor, alongside the North American, European, Chinese, and Japanese universities that had spearheaded emissions measurements in the 1980s.

Figure 2. Emissions research clusters (The Authors)

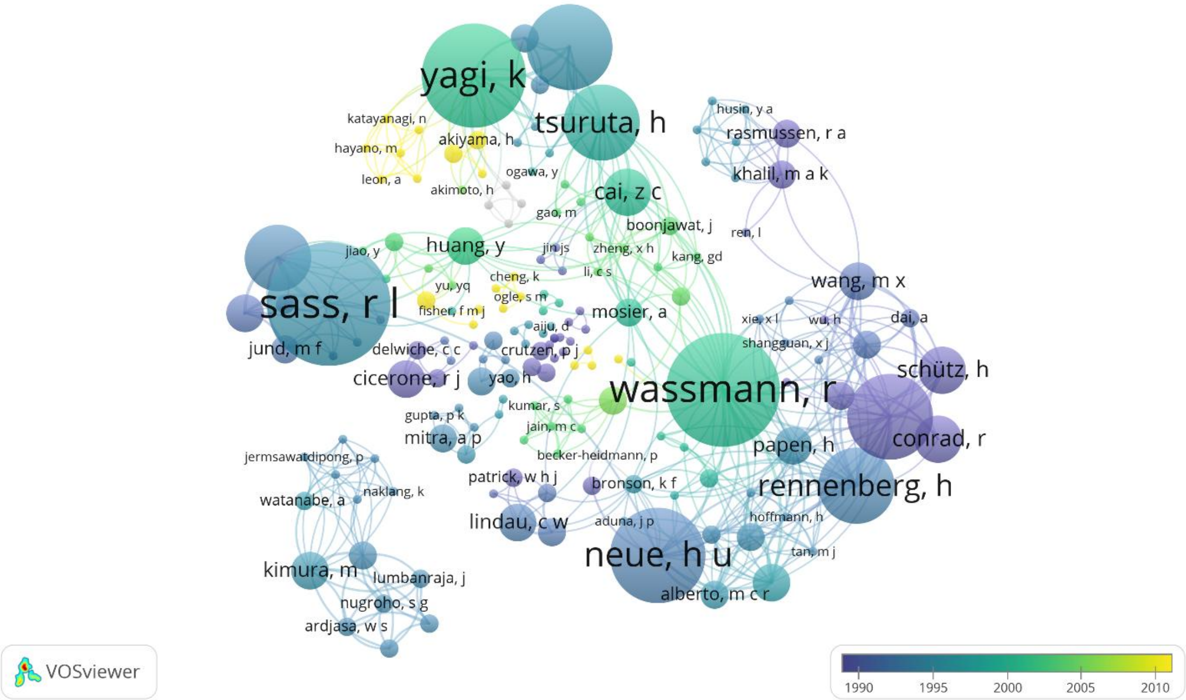
---

[8] These studies refer to experiments conducted on "swamp rice soils" as early as the 1910s.

[9] Figure 2 identifies different research clusters based on a compilation of the complete set of 130 references in support of the rice sections of the 1995, 1996, 2006 and 2019 IPCC guidelines. Each node in Figure 2 represents a single author. The size of the circles is proportional to the number of times the name of the specific author appears in the database. The lines show co-authorship relations, and the colour of the circle gives an idea of the period when each author was active based on publication dates. The relative weight of research conducted after 2006 is under-represented because IPCC (2019) refers to a single review article (Wang et al. 2018). This article references 85 studies conducted after 2006 that are not in our database.

10 Two events organized in Portland, The United States in 1991 (Khalil, 1993) and Amersfoort, The Netherlands (van Amstel, 1993) laid the ground for the early international exchanges.

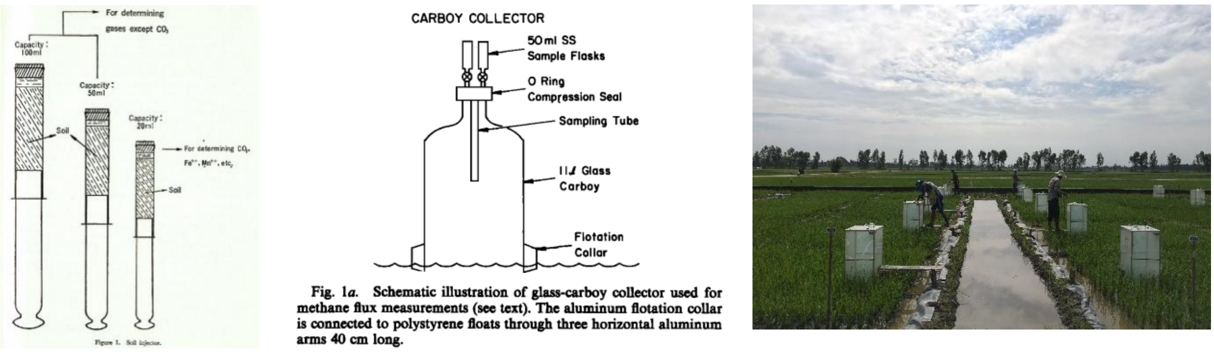
[11] IRRI is a member of the Consortium of International Agricultural Research Centers (CGIAR). In the 1990s, it was headed by the German agronomist Klaus Lampe and hosted several German researchers.



Since the 1990s, emission research has been facilitated by an experimental device known as the closed chamber; a descendant of the saran bags used by Ralph C. Cicerone in the early 1980s (Sander and Wassmann 2014; Minamikawa et al. 2015; right panel Figure 3).

Schematically, closed chambers are plastic or glass boxes of approximately 1m$^3$ with instruments for collecting gases and measuring temperature. Due to (relative) ease of use, the closed chamber functions much like a portable mini laboratory for collecting emissions data from all kinds of rice fields, which are thereby made comparable. The spread of the chambers also led to the expansion of research agendas. While early research aimed to assess rice emissions to improve global atmospheric methane budgets (which is important to understand climate), attention progressively turned to understanding the physiological processes that impacted rice emissions (Schütz et al. 1989). As more studies took place outdoors and stretched over the entire cultivation period, it became clear that emissions related to plant growth and were influenced by many things aside from soil, including water management regimes, organic amendments, and types of cultivars. Those influences were later embedded as scaling factors in the IPCC equation.

Figure 3. Experimental devices for measuring rice-based GHG emissions. Left: Early soil injectors used by Koyama (1964). Center: An early representation of chamber for measuring rice-based GHG emission (Cicerone and Shetter 1981). Right: closed chambers at an IRRI experimental station in the 2000s (Credit: IRRI).



Closed chambers helped consolidate the dispersed research collective and extend the infrastructure of referentiality for rice emissions data, but they also introduced potential destabilizations. Some had to do with the materiality of the chambers, which were more complex and variable in design than soil injectors, and subject to many disturbances in hot, humid rice fields. In the “anthropogenic wild,” emission research also raised numerous protocol and methodological questions about issues ranging from the positioning of the chambers to the sampling and transport of gas (Sander and Wassman 2014).

To safeguard the data referentiality of this infrastructure, those sources of error and uncertainty had to be brought under control. This was undertaken in documents like the 80-page “Guidelines for Measuring $CH_4$ and $N_2O$ Emissions from a Rice Paddies by a Manually Operated Closed Chamber Method” published by the Japanese National Institute for Agro-Environmental Sciences in 2015 (Minamikawa et al. 2015). A veritable encyclopedia of possible threats to rice emissions measurement, this document meticulously considers everything from chamber design and problems with pseudo replication to diurnal gas sampling variations and how to build scaffolding to avoid disturbance and artificial $CH_4$ ebullition. The outcome is a rice field that is ideally suited for measurement because and to the extent that it is in a totally pristine condition. That field is, of course, only an ideal, but one on which the IPCC equation relies.

Data is collected from specific Californian, Southern European, and East Asian rice fields. It is aggregated and delocalized—as scaling factors and uncertainty ranges—in the generic equation. This equation will feed emissions calculators that are used in climate compatibility assessments for development projects like the one in Kandal. But these rice fields do not relate in the same way to the global equation as the experimental rice fields equipped with gas chambers. For one thing, they are not pristine. For another, they do not yet exist. Instead of conduits that simply extend referentiality, the calculators come to operate as wormholes that break and redistribute it in preparation for new data concatenations. We now take a close look at how this happens.

## Emissions Calculators and the Emergence of Speculative Rice Fields

While scientists built closed chambers, standardized protocols, took measurements, and fed results into increasingly elaborate IPCC guidelines, private companies, consultancy firms, and research institutes were busy designing emissions calculators. They are basically digital spreadsheets used to assess the GHG emissions of a project, a sector, or a company.

Like other development agencies such as the World Bank or the Asian Development bank, AFD started using carbon footprint tools in the 2000s (AFD 2017). At the time, they were used to assess project impacts in high-emission sectors like energy and transport. After the Paris agreement, the climate compatibility of the entire portfolio had to be assessed, including many agricultural projects that had not previously been considered through a climate lens. The explosion in climate assessments created a host of practical problems over the life cycle of development projects, for example how to assess the impact of building future irrigation infrastructures and future farming practices on rice fields emissions, and led to a treasure hunt for the right tools to solve them (Clarke and Fujimura 1992).

Emissions calculators based on equation 5.2 complete with reference numbers and emissions factors were among those tools. Leveraging the scientific credentials and authority of the IPCC, they confer legitimacy upon climate assessments. Calculators also seem *neutral*, nothing but conduits for extending gas emissions referentiality from the climate infrastructure into the world of development. Nevertheless, they embody a tension because the users are technical experts working for development organizations rather than climate scientists working for research institutions.

As explained by Reiner Wassmann, a German rice emissions scientist, the design of the calculators "has been driven by the desire to provide a readily available tool for users—especially those who may not have high familiarity with the IPCC approach" (Wassmann et al. 2019, 81, and personal communication). Similarly, Richards et al. (2006, 1, emphasis added) describe calculator development in the agricultural sector as driven by "the demand for tools to *rapidly* assess greenhouse gas impacts from policy and technological change," which is possible because they rely on "*simple* accounting approaches...to calculate GHG emissions with *minimal* input data." Thus, the popularity of calculators is due to their ability to integrate scientific accuracy and practical expediency. In brief, they are the right tools for the job because they make it possible to carry out credible emissions calculations, by simply selecting options from a drop-down menu that materializes IPCC knowledge.

Simplicity is nevertheless unlikely to be what first springs to mind when you encounter an emissions calculator. To the contrary, the large number of options can seem daunting. For example, the EX-ACT calculator offers six choices of water management regimes during the cropping season, which can be combined with three water management regimes prior to cultivation, and seven forms of organic amendments, a total of 126 combinations. It is also possible to vary the duration of cultivation and the amount of expected fertilizer, and even the IPCC default numbers can be replaced with more context-specific data as available. These many options provide the calculator with the flexibility necessary to tackle any conceivable rice field. But while that might be beneficial to climate science, it can make the calculators appear frustratingly complex to the experts tasked with making project assessments. If "numerous entities are considered," we read, manual entry becomes "cumbersome and time-consuming" (Wassman et al. 2019, 81). So why are emissions calculators still widely viewed as simple and convenient? The answer is that easiness is the effect of a *particular form of usage* crucially shaped by three factors: the technical experts are very busy, they often have limited knowledge of local farming practices, and there are few incentives for them to deepen their understanding of the latter.

Some choices are straightforward. There is little difficulty in choosing between "irrigated" or "rainfed" rice fields for a project in Kandal, since anybody can tell you they are all irrigated. But others are confusing. For example, what to do with "water management practices during the cropping season," when those practices can vary from one field to another, or year by year? Moreover, it is impossible to follow IPCC's sage advice to replace general reference numbers with accurate local data, when specific information about the conditions of rice cultivation, so called "activity data," is routinely missing (Colomb et al. 2013; Richards et al. 2016). Given this mix of light and shadow, the easiest way to calculate is to begin with what is obvious and string together more or less random assumptions about the rest. When a scenario has been constructed in this way, there is rarely any reason to subject it to further tests.

The combined input requirements of calculators and busy schedules of experts conspire to generate *speculative rice fields* with half-imagined properties, which are inherited by the emissions calculations that are fed into project assessments. In this way, GHG calculators prepare the grounds for wild uncertainties to reverberate largely unnoticed through climate compatibility frameworks until funding decisions are made. The calculators thus contribute to a *politics of anticipation* where numbers operate as phantasmatic signs of objectivity.

The AFD's climate assessment of irrigation project in Cambodia aptly illustrates these dynamics because, unusually and contingently, two very different scenarios were actually produced. A first calculation had concluded that the project would increase emissions by 300,000 tCO2-eq per year. Although, for reasons to be discussed shortly, the project was still assessed as climate compatible, this was not a happy result. A follow-up assessment after the funding decision was made, conducted by experts involved in designing the EX-ACT calculator, found the project would instead *decrease* emissions by 35,000 tCO2-eq per year.[12] This much more appealing number was reached by changing several assumptions: the project would lead to higher carbon sequestration in the soil due to changing land-use patterns and lower fertilizer use, and it would promote new water management practices. Note that we are not pointing fingers at the second assessment for manipulating assumptions or even for being too optimistic (though it probably is). The point is that radically different scenarios can appear equally plausible or implausible, because we are dealing with unknown properties of future rice fields.[13]

From a climate science perspective, the calculators are roughly comparable to closed chambers: both are meant to support more or less accurate assessments of gas emissions. Seen from this angle, the calculators seem to be botching the job. But from the side of development, accurate assessment is at best a partial job description. Just as importantly, the calculators must contribute to data concatenations appropriate to project funding assessment. At this point, the decomposition of referentiality accelerates.

## The Sustainable Development Analysis Framework

As part of the agricultural development infrastructure, emissions calculations are enmeshed in a different data concatenation with its own subtleties. Within AFD, the calculations become input for a "climate selectivity grid" used to "avoid financing projects with high

---

[12] This second evaluation was carried out as part of a broader initiative to test the feasibility of including GHG assessment in the formulation phase of AFD's projects.

[13] Even so, these totally different results were never compared, since the first (negative) assessment had lost relevance immediately after its usage as part of the (positive) climate compatibility assessment.

emission levels" (AFD 2018b). In the grid, each project is scored between -2 and +3 depending on estimated emission levels.[14] This links the calculated emissions with a "sustainable development analysis framework" used to "facilitate cross-cutting inclusion of sustainable development concerns in AFD interventions" and inform funding decisions (AFD 2018b; Figure 4).

The "sustainable development analysis framework" consists of seven indicators, two of which relate to climate. While rice emissions researchers can study Minamikawa et al.'s 80-page guidelines to learn how to set up closed chambers and measure gas emissions, AFD's technical experts can consult an internal 80-page methodological guide (AFD 2018a) to assess how well projects support a "transition to a low carbon pathway" and "climate change resilience" while contributing to "social well-being and reduc[tion of] social imbalance" and ensuring "gender equality" (Figure 4).

This data concatenation, which makes incongruent issues (from gender equality to biodiversity conservation and greenhouse gas emissions) comparable by scoring them on a scale of -2 to +3, must look almost meaningless to climate scientists. However, things look quite different to development experts for whom it is a given that projects respond to multiple objectives and must be assessed to account for diverse factors. They are indeed often *baffled* by the uncertainty of scientific emissions calculations, which instead of delivering clarity and a sense of direction, complicate the issues. In comparison, the vague scale that defers to their expertise is more useful. It enables conversion of irresolvable problems with scientific uncertainty into a workable format where unapologetically subjective indicators can move projects forward.

The discrepancy between the certainty expected from climate science (via the calculators) and the very uncertain results actually obtained generate tensions between science and policy decisions. Those tensions are flexibly resolved by development agents, but in contradictory ways. In one direction, the authority of the IPCC can be emphasized, as when an AFD project officer told us that even a "bad number is better than no number." He meant that no matter how bad they are (in the sense of *uncertain*), scientific numbers are still required to make decisions, hence an uncertain estimate is better than nothing. But a number can be bad not only because it is uncertain, but because it points to *high emissions*. In that case it can be dismissed *despite its scientific basis* because it is too uncertain. This tactic is on

---

[14] The thresholds are +/- 10.000, 100.000, 500.000 and 1.000.000 tCO2-eq/year. Projects expected to emit more than 1.000.000 tCO2-eq/year are scored "-2" and only eligible in certain countries. Projects expected to lead to a decrease of more than 500 000 tCO2-eq/year are scored +3 (AFD 2014).

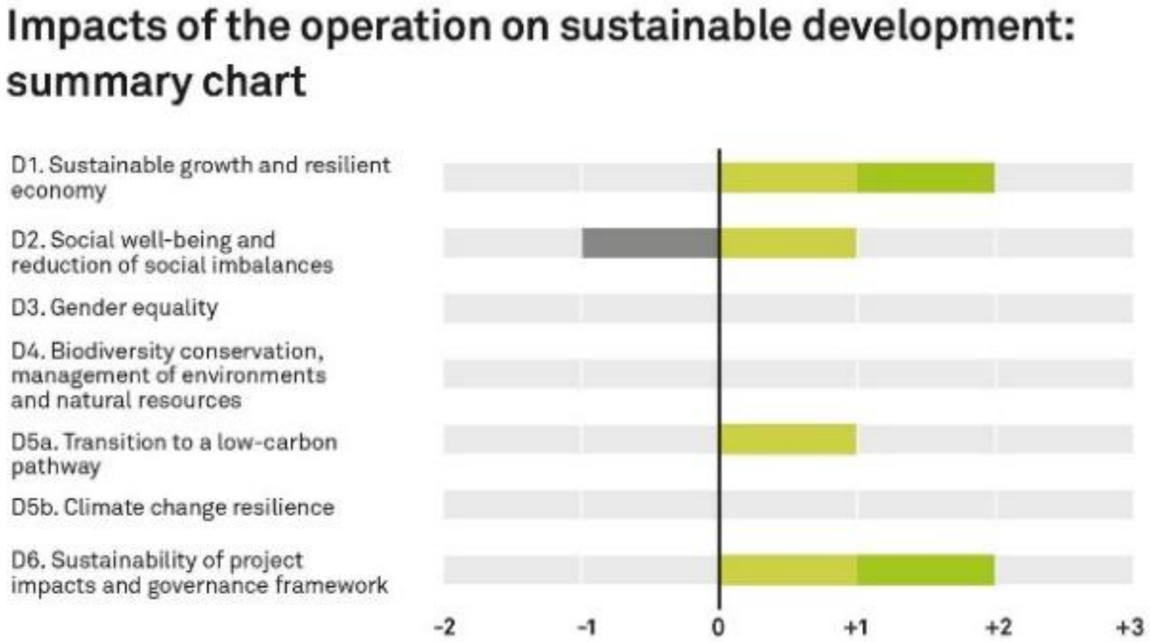
display as another officer explains why the very large emissions calculation discussed above did not disqualify the Cambodian project from being climate compatible:

> We decided, after internal discussion, to classify this project 100 percent with adaptation co-benefits (hence "climate") despite the fact that it will likely lead to increased GHG emissions (and without stressing the very high numbers we generated). If we wanted to do a real analysis, we would need to look at current and future infrastructure, water management, farming practices...but also the whole value chain...and compare things with a baseline scenario without project. We make the recommendation that…mitigation needs to be considered to steer decisions within the project framework.

This officer negatively compares the uncertainties of the actual assessment of future project emissions—the one that was ultimately carried out, and which resulted in high numbers—with another analysis, which would be real—in the sense of properly tackling uncertainty—but will never actually be carried out. This supports the conclusion that it would be reckless to disqualify the project, which might turn out to be much better than suggested by the highly uncertain calculation. The finesse is to acknowledge that rice cultivation contributes to emissions in general, but plead uncertainty about this particular situation where things might be different, while emphasizing that irrigation, in general, enhances climate change adaptation, again without being specific about how it works in the concrete case. In this way, it becomes feasible and indeed unremarkable to incorporate rice-intensive farming in a fully climate-compatible project.

In a mode of critique, this situation can easily be denounced as a form of greenwashing where sound climate science is tweaked to keep emissions-heavy rice projects on track. This is certainly an explanation, but one that comes with significant costs and leaves infrastructural dynamics in the dark. First, it depends on a view of the technical experts as either corrupted by development and completely indifferent to climate effects, or naive with respect to the games of power into which they are spun unaware. Both images fit poorly with most experts we have come across. But second, there is the assumption that greenwashing would not occur *if only development projects used climate science properly*. That might be the case if it was possible to calculate emissions with a high degree of certainty, but as we have seen this is far from the case.

Figure 4: The sustainable development analysis framework applied to a hypothetical project (D5a and D5b relate to climate; AFD 2018b).



## Data Wormholes and Politics of Anticipation

By now, the list of development projects plagued by controversies is very long. They often have conventional infrastructural dimensions: just think of the well-documented adverse impacts of dams, canals, or irrigation systems (WCD 2000). Here, we have taken a step to the side, to inspect the knowledge infrastructures that support the materialization of such agricultural development projects and, in doing so, join and shape a worldwide development monitoring movement (Jensen and Winthereik 2012). Diverse forms of climate science and development practice were brought into closer proximity by the 2015 Paris Agreement. But only in the abstract. It was left to the development practitioners and scientists to invent tools with which to concretize the point of contact. Among these tools were emissions calculators imagined as conduits for the smooth movement of data between climate infrastructures used to assess rice-based GHG and development infrastructures used to evaluate the climate compatibility of agricultural projects, like the large Cambodian irrigation project that has held our attention.

Our infrastructural inversion has shown that image to be misleading. The imagined infrastructural trajectory assumes an unambiguous relation between equation 5.2 as a global formalization derived from a set of ideal, pristine, reference fields, and rice fields everywhere. But while the scaling factors and uncertainty ranges work well as knowledge devices for stabilizing global estimates of GHG emissions, their relations with specific rice fields are far more ambiguous. From the moment closed chambers are placed in experimental rice fields and until they enter the calculator wormhole and are radically reconstituted in the sustainability matrix, there are continuous data transformations.

The flawed image of smooth infrastructural transmission from climate to development is widely shared, yet it leads to mutually reinforcing blind spots. From the side of climate science, it affirms the erroneous notion that equation 5.2. makes it possible to maintain referentiality across the infrastructures—with the caveat that appropriate activity data should be ideally added by users. On the development side, technical experts are tasked with conducting sound climate compatibility assessments to inform funding decisions. Unsurprisingly, they turn to the IPCC, which promises robust calculations of rice emissions. The calculator appears as the right tool for the job, except for one small problem: the required activity data is missing. However, there is no good alternative, and to the eyes of distant managers and funders a halo of objectivity still shimmers around the calculator. Thus, the experts proceed as if the missing activity data is not such a big deal, because the calculators are supposed to be more or less sufficient in themselves. Fed with speculative rice fields and scenarios, the calculator becomes a data wormhole: it emits extremely uncertain results that are taken as unremarkable.

Just as the critique of development for relying on simple, transportable schemes would predict, emissions calculations lack context. In a mode of critique, it is now easy to see the calculations as greenwashing. Their function is simply to manipulate uncertainty in the desired direction of positive climate compatibility assessment and project funding. The only problem with this verdict is that the decontextualization at hand was introduced by climate science rather than development. It was a feature (not a bug) of equation 5.2., which precisely promised *to work everywhere regardless of context*. In other words, the technical experts are deferring to science as they have been encouraged. If the equation is indeed generic and universal, shouldn't it work—at least tolerably—even in the absence of complete data?

Curiously, this deference to science appears to be shared by those who criticize the development experts. We see this in the tendency to explain away problematic recommendations and decisions, blaming them on vested interests. This embeds the assumption that if decisions were based on IPCC and real climate science, the outcomes couldn't possibly be problematic. Behind it, we discern the flawed idea of context-free scientific knowledge that can be transported through infrastructure without transformation, and used wherever it ends up without any loss.

There are plenty of differences between climate scientists and development experts, and their respective data concatenations, but we should not lose sight of a certain similarity. Both rely on forms of procedural objectivity assumed to be guaranteed by numbers. While the climate scientist says, “accept the rice emissions data” and “just use the equation,” the development expert says, “accept the emissions calculations” and “just follow the climate compatibility framework.” In the realm of development, this generates a politics of anticipation, which is both infrastructural and highly speculative: funding decisions are informed by extremely uncertain assessments. We are faced with a politics that neutralizes uncertainty by hiding it in plain sight. We are also at the far end of precaution: if a project can’t be decisively proven to do harm—as it practically never can—one might as well forge ahead, eyes closed and come what may.

That there are many uncertainties is not a problem but a *fact* in the context of development interventions. The problem is that those uncertainties are intolerable to existing procedures of accountability and transparency. So, what would a politics of anticipation that does not take uncertainty as an enemy would look like? Undoubtedly, it would be decentered: beginning with attentiveness to distributions of knowledge and agency among “networks of people and things” (Star 1995, 115). It would take heterogeneous data concatenations as a given. The risk of propagating uncertainties arising from ongoing infrastructural traffic between those concatenations would remain problematic. But those risks and uncertainties would be taken as worthy of attention, rather than as something to be papered over. Fully aware of the necessity of acting while adrift in a sea of uncertainties, meaningless single digits would be discarded as a basis for making difficult decisions.

In a development world informed by this alternative politics of anticipation, statements like “a bad number is better than no number” would not roll off the tongue so easily. Yet there would still be room for speculative scenarios. They would be part of an *art of consequences*, where missing data, gap filling, and imagined properties are activated as topics for collective learning about how to proceed under uncertain conditions.

## Biography

Casper Bruun Jensen is an anthropologist of science and technology whose work focuses on climate, environments, and infrastructures. Holding a position as professor at Chulalongkorn University, he is the author of *Monitoring Movements in Development Aid* (with Brit Ross Winthereik) (2013, MIT) and the editor of *Infrastructures and Social Complexity* with Penny Harvey and Atsuro Morita (Routledge, 2016).

Jean-Philippe Venot is director of research at the French National Research Institute for Sustainable Development (IRD). He has an interdisciplinary profile and is committed to critically examine and reshape discourses and daily practices of water governance.

## Acknowledgments

We thank the scientists and experts who taught us about the practicalities of measuring greenhouse gas emissions from rice fields, and of using emissions calculators. We are also grateful to the editors and anonymous reviewers for their insightful comments. This paper benefited from earlier research conducted as part of the Deltas' Dealings with Uncertainty (DoUbT) and COSTEA projects.

## References

AFD (Agence Française de Développement). 2014. *Methodology Guide to the "Sustainable Development Opinion" Mechanism* (Paris: AFD).

AFD (Agence Française de Développement). 2017. *The AFD Carbon Footprint Tool for Projects* (Paris: AFD).

AFD (Agence Française de Développement). 2018a. *Dispositif Analyse et Avis Développement Durable: Guide méthodologique* (Paris: AFD).

AFD (Agence Française de Développement). 2018b. *The Sustainable Development Analysis: Raising Questions and Integrating Project Sustainable Development Issues Upstream* (Paris: AFD).

Bear, Laura. 2020. "Speculations on Infrastructure: From Colonial Public Works to a Post-Colonial Global Asset Class on the Indian Railways 1840-2017." *Economy and Society* 49, no.1: 45-70.

Beck, Silke, and Martin Mahony. 2017. “The IPCC and the Politics of Anticipation.” *Nature Climate Change* 7: 311-313.

Bowker, Geoff. 1995. “Information Mythology: The World of/as Information.” In *Information Acumen: The Understanding and Use of Knowledge in Modern Business*, edited by Lisa Bud-Frierman, 231-247. London: International Thomson Publishing.

Bowker, Geoff, and Susan Leigh Star. 1999. *Sorting Things Out: Classification and Its Consequences*. Cambridge, MA & London: MIT Press.

Cicerone, Ralf J., and James D. Shetter. 1981. “Sources of Atmospheric Methane Measurements in Rice Paddies and a Discussion.” *Journal of Geophysical Research* 86: 7203-7209.

Cicerone, Ralf J., James D Shetter, and Constant C Delwiche. 1983. “Seasonal Variation of Methane Flux from a California Rice Paddy.” *Journal of Geophysical Research* 88: 11022-11024.

Clarke Adele, and Joan Fujimura. Eds. 1992. *The Right Tools for the Job: At Work in Twentieth-Century Life Sciences*. Princeton, NJ: Princeton University Press.

Colomb Vincent, Ophélie Touchemoulin, Louis Bockel, Jean-Luc Chotte, Sarah Martin, Marianne Tinlot, and Martial Bernoux. 2013. “Selection of Appropriate Calculators for Landscape-Scale Greenhouse Gas Assessment for Agriculture and Forestry.” *Environment Research Letters* 8 (2013): 015029.

Edwards, Paul. 2010. *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*. Cambridge, MA & London: MIT Press.

Fairhead James, and Melissa Leach. 1996. *Misreading the African Landscape: Society and Ecology in a Forest-Savanna mosaic*. Cambridge: Cambridge University Press.

Ferguson, James. 1990. *The Anti-Politics Machine: “Development,” Depoliticization, and Bureaucratic Power in Lesotho*. Cambridge: Cambridge University Press.

Haraway, Donna. 1992. “When Man is on the Menu.” In *Incorporations,* edited by Jonathan Crary, Jonathan, Sanford Kwinter, 38-43. New York: Zone.

Haraway, Donna. 1997. *Modest_Witness@Second_Millennium.FemaleMan© Meets_OncoMouseTM: Feminism and Technoscience*. New York: Routledge.

Harvey, Penny, Casper Bruun Jensen, and Atsuro Morita. Eds. 2017. *Infrastructures and Social Complexity: A Companion*. London & New York: Routledge.

Hoppe, Rob, Anna Wesselink, and Rose Cairns. 2013. "Lost in the Problem: The Role of Boundary Organisations in the Governance of Climate Change.*" WIRE's Climate Change* 4: 283-300.

Holzapfel-Pschorn, Anette, and Wolfgang Seiler. 1986. "Methane Emission During a Cultivation Period from an Italian Rice Paddy." *Journal of Geophysical Research* 91 (D11): 11803-11814.

IPCC (Intergovernmental Panel for Climate Change). 1995*. IPCC Guidelines for National Greenhouse Gas Inventories -Volume 3: Greenhouse Gas Inventory Reference Manual* (Geneva: IPPC Secretariat).

IPCC (Intergovernmental Panel for Climate Change). 1996. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 3: Reference Manual* (Geneva: IPPC Secretariat).

IPCC (Intergovernmental Panel for Climate Change). 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories - Volume 4: Agriculture, Forestry and Other Land Use* (Geneva: IPPC Secretariat).

IPCC (Intergovernmental Panel for Climate Change). 2019. *Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories -Volume 4: Agriculture, Forestry and Other Land Use* (Geneva: IPPC Secretariat).

IPCC (Intergovernmental Panel for Climate Change). 2021. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge & New York: Cambridge University Press).

Jensen, Casper Bruun, and Brit Ross Winthereik. 2013. *Monitoring Movements in Development Aid: Recursive Partnerships and Infrastructures*. Cambridge, MA & London: MIT Press.

Jensen, Casper Bruun, and Brit Ross Winthereik. 2017. "Audit Loops and Audit Implosion" In *Redescribing Relations: Strathernian Conversations on Ethnography, Knowledge, and Politics*, edited by Ashley Lebner, 155-181. New York: Berghan.

Khalil, M.A.K., and R.A. Rasmussen. 1982. “Secular Trends of Atmospheric Methane (CH4)”. *Chemosphere* 11: 877-883.

Khalil, M.A.K. 1993. Methane Cycle: Sources, Sinks, Distributions, and Role in Global Change. NATO ASI series. Series I, Global environmental change; vol. 13. Springer Verlag: Berlin.

Koyama, Tadashiro. 1964. Biogeochemical Studies on Lake Sediments and Paddy Soils and the Production of Atmospheric Methane and Hydrogen. In *Recent Researches in the Fields of Hydrosphere, Atmosphere and Nuclear Geochemistry*, edited by Yasuo Miyake, Tadashiro Koyama, 143-177. Tokyo: Maruzen.

Latour, Bruno. 1999. *Pandora’s Hope: Essays on the Reality of Science Studies*. Cambridge, MA & London: Harvard University press.

Lezaun, Javier. 2006. “Creating a New Object of Government: Making Genetically Modified Organisms Traceable.” *Social Studies of Science* 36, no. 4: 499-531.

Li, Tania M. 2007. *The Will to Improve: Governmentality, Development, and the Practice of Politics*. Durham, NC: Duke University press.

Mackenzie, Adrian. 2006. *Cutting Code: Software and Sociality*. New York: Peter Lang.

Minamikawa Kazunori, Takeshi Tokida, Shigeto Sudo, Agnes Padre, and Kazuyuki Yagi. 2015. Guidelines for Measuring CH4 and N2O Emissions from Rice Paddies by a Manually Operated Closed Chamber Method. Tsukuba: National Institute for Agro-Environmental Sciences.

Mitchell, Timothy. 2011. *Carbon Democracy: Political Power in the Age of Oil*. London & New York: Verso.

Mosse, David. 2005. *Cultivating Development: An Ethnography of Aid Policy and Practice*. London: Pluto.

Morita, Atsuro. 2017. “Multispecies Infrastructure: Infrastructural Inversion and Involutionary Entanglements in the Chao Phraya Delta, Thailand.” *Ethnos* 82, no.4: 738-757.

Neale, Timothy. 2019. “A Sea of Gamba: Making Environmental Harm Illegible in Northern Australia.” *Science as Culture* 28, no.4: 403-426.

Oui, Jeanne. 2022. “Commodifying a ‘Good’ Weather Data: Commercial Meteorology, Low-Cost Stations, and the Global Scientific Infrastructure.” *Science, Technology, and Human Values* 47 (1): 29-52.

Richards, Meryl, Ruth Metzel, Ngonidzashe Chirinda, et al. 2016. “Limits of Agricultural Greenhouse Gas Calculators to Predict Soil N2O and CH4 Fluxes in Tropical Agriculture.” *Scientific Reports* 6: 26279.

Sander, Bjoern Ole, and Reiner Wassmann. 2014. “Common Practices for Manual Greenhouse Gas Sampling in Rice Production: A Literature Study on Sampling Modalities of the Closed Chamber Method.” *Greenhouse Gas Measurement and Management* 4, no.1: 1-13.

Schütz, Helmut, Peter Schroder, and Heinz Rennenberg. 1991. Role of Plants in Regulating the Methane Flux to the Atmosphere. In *Trace Gas Emissions by Plants*, edited by Thomas D. Sharkey, Elisabeth A. Holland, Harold H. Mooney, 29-63. New York: Academic Press.

Star, Susan Leigh. 1995. The Politics of Formal Representations: Wizards, Gurus, and Organizational Complexity. In *Ecologies of Knowledge: Work and Politics in Science and Technology*, edited by Susan Leigh Star, 88-119. Albany, NY: SUNY Press.

Strathern, Marilyn. 1989. “Between a Melanesianist and a Deconstructive Feminist.” *Australian Feminist Studies* 10: 49-69.

United Nations Framework Convention on Climate Change. 2016. *Paris Agreement* (Paris: United Nations).

van Amstel, Andre R. 1993. Methane and nitrous oxide: methods in national emissions inventories and options for control. Proceedings RIVM report no. 481507003. International IPCC Workshop, Amersfoort, 3-5 February 1993.

Venot, Jean-Philippe, and Jean-Philippe Fontenelle. 2016. Irrigation policy in Cambodia: history Achievements and challenges of AFD’s interventions. COSTEA: Paris.

Venot, Jean-Philippe, and Casper Bruun Jensen. 2022. “A multiplicity of prek(s): Enacting a socionatural mosaic in the Cambodian upper Mekong delta.” *EPE Nature and Space* 5, no. 3: 1446-1465.

Venot, Jean-Philippe, Casper Bruun Jensen, Etienne Delay, and William’s Dare. 2022. “Mosaic glimpses: serious games, generous constraints, and sustainable futures in Kandal, Cambodia.” *World development* 151(2022) 105779.

Walford, Antonia. 2017. “Raw Data: Making Relations Matter.” *Social Analysis* 61, no. 2: 65-80.

Wang, Jinyang, Hiroko Akiyama, Kazuyuki Yagi, and Xiaoyiuan Yan. 2018. “Controlling Variables and Emission Factors of Methane from Global Rice Fields.” *Atmospheric Chemistry and Physics* 18: 10419-10431.

Wassmann, Reiner, Richard Pasco, J Zerrudo, Duc Minh Ngo, T.B.T Vo, and Bjoern Ole Sander. 2019. “Introducing a New Tool for Greenhouse Gas Calculation Tailored for Cropland: Rationale, Operational Framework and Potential Application.” *Carbon Management* 10, no. 1: 79-92.

WCD (World Commission on Dams). 2000. *Dams and development: A new framework for decision-making* (London, UK: Earthscan).

World Resources Institute (WRI). 2023. Climate watch data portal. https://www.climatewatchdata.org/ (accessed 23/01/2023)

Yamane, Ichiro, and Kazuo Sato. 1963. “Decomposition of Plant Constituents and Gas Formation in Flooded Soil.” *Soil Science and Plant Nutrition* 9, no. 1: 28-31.