Science Policy Brief: a climate variability viewpoint on renewable energy and electricity systems

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COMPLEX
Knowledge Based Climate Mitigation Systems for a Low Carbon Economy

SCIENCE-POLICY BRIEF: A CLIMATE VARIABILITY VIEWPOINT ON RENEWABLE ENERGY AND ELECTRICITY

Solar PV farm of Les Mées,
Alpes de Haute Provence, France
(Photo: J.-D. Creutin)

Background

This Science-Policy brief is about the influence of climate, weather and Earth's surface waters on the integration of renewables in electricity systems. It specifically refers to wind, solar and hydropower production of electricity in a future European system that is massively based on these three sources of energy. They are here named 'Climate-Related Energies'.

Following the main outcomes of the FP7 COMPLEX research project (2012-2016), this document highlights research achievements in the best interest of policy-makers, stakeholders and society, through a set of six key messages.

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Introduction

Sources of Climate-Related Energies (CRE) are found everywhere. The availability of CRE resources, however, depends on atmospheric and hydrologic variations in space and time. Additionally, the integration of CRE in electricity systems affects energy production and consumption, transport, storage and backup, as well as markets and policy. CRE integration is thus a multifaceted challenge for science and innovation in the transition to a low-carbon society.

From the scientific perspective, the multiscale analysis of CRE resources is a nascent research field, acknowledged also by the Intergovernmental Panel on Climate Change (IPCC). This new body of knowledge, together with the growing deployment of renewable energy technologies, opens up new prospects to support innovation and services in the energy sector.

The research supporting this Science-Policy brief focused on three sources of CRE: wind, solar and hydropower. Run-of-the-river hydropower is considered to capture the natural variability of water flowing through streams and rivers. The crucial role of hydropower in balancing supply and demand through energy storage in water reservoirs is nevertheless also recognized. The point of view is that of climate variability affecting CRE integration. To allow a clear view and understanding, other physical or economic factors are dismissed, although these are also relevant in renewable energy systems.

The results draw attention to the diversity in the variability features of the different CRE sources at both short and long term. This controls the exploitability of these energies, i.e., their ability to match the demand in quantity and timing. European regions or countries have uneven exploitability conditions, which are expected to change in a transition to 100% renewable energy.

Today, the EU Energy Roadmap explores ambitious decarbonisation scenarios of the European energy systems, with a high share of renewables in energy and electricity consumption by 2050 (greater than 75%). Understanding the variability and impacts of the climatic drivers of CRE sources is a relevant step towards fostering the needed transformations in a cost-efficient way.

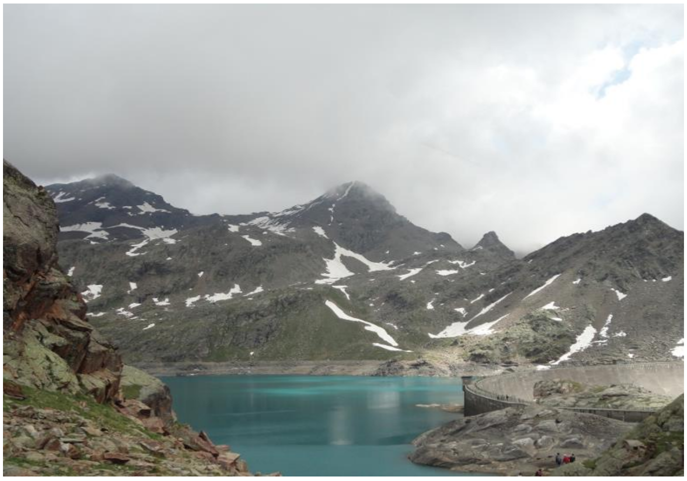
1. Atmospheric and hydrologic variability governing CRE

Potential energy production from solar, wind and hydropower follows the natural fluctuations of wind velocity, solar radiation and river flow at all scales in space and time.

At short time scales (up to about one hour), production is governed by patterns of weather variability that show distinct behaviour for wind, solar radiation and rain. Atmospheric water, in the form of clouds, makes solar radiation and rainfall fields more variable and less predictable than wind fields. Catchments transform rainfall into runoff. They are integrators of water flow, which smooths out river flow variability.

At intermediate time scales (days to months), the fluctuation of all CRE sources is controlled by patterns of large-scale systems of air circulation in the atmosphere, such as cyclonic perturbations that are found in the middle latitudes. CRE variability at short and intermediate scales has received the most of the attention over the last years.

At large time scales (years and more), climatic drivers of wind and solar power show much less intra-annual to multi-decadal variability than drivers of hydropower. Expected climate changes are likely to modify CRE potential, especially for hydropower. Confidence in the projected modifications depends on the ability of General circulation models (GCMs) to simulate the climate of the last decades.



The Pian Palù Lake in Peio, Italy – glacier and micro-hydropower (Photo: M. Borga)

2. Role of energy transport, storage and mix on CRE variability

Energy transport and storage as well as the mix of different CRE sources facilitate CRE integration. Transport smooths out CRE variability in space, while storage copes with fluctuations in time. The energy mix exploits the complementarities of the space-time variability of different CRE sources. These aspects act together to minimize the adverse effects of CRE variability. With the spread of CRE production in space, the typical logic of an asymmetric grid, where a centralized production feeds clusters of consumers, is disturbed. A new paradigm arises to take into account a decentralized and mixed renewable energy production. Each CRE source requires storage features that are adapted to its variability. As a consequence, CRE integration calls for enhanced knowledge on CRE variability for the benefit of new technologies and solutions for grid structure and storage management.

3. Matching production and consumption: a matter of CRE integrability

Electricity systems require, in permanence, a balance between production and consumption. The more the energy sources are coexistent in space and synchronous in time with the demand, the larger is the amount of supplied energy that can be directly used. This also means lesser needs for backup, storage and transport.

Statistics of the production/consumption balance are needed to assess the integrability of CRE sources and evaluate the easiness of CRE integration. The average behaviour of the balance measures the penetration of a CRE source or a mix of sources. The fluctuations of the balance characterize the needs in terms of flexibility of the backup and storage. The space and time units to be considered to study the balance and assess CRE integrability are chosen according to transport and storage issues – both supposedly solved inside these units. Under these considerations, CRE integrability is more informative than the classic assessment of the potential CRE abundance, which is given by statistics of available energy from individual CRE sources and ignores the features of the demand.

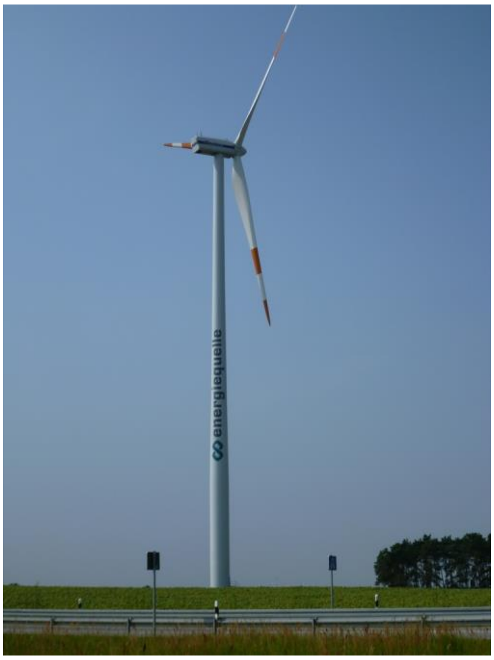
4. European regions are not equal in terms of CRE abundance and easiness of integration

The abundance of CRE broadly shares Europe into a windy Atlantic façade, a sunny Mediterranean South and the snowy mountainous areas in Scandinavia and the Alps. These areas concentrate the potential of wind, solar and hydropower resources, respectively.

The easiness of CRE integration is more heterogeneous across Europe. Comparatively to Northern Europe, the Mediterranean area has the potential to directly use higher amounts of energy supplied by CRE and Southern Europe needs lower backup and storage to compensate for CRE variability.

The mix of CRE sources that best satisfies the consumption also varies across European regions. For instance, the share of solar power increases when moving towards South.

In addition to estimating the abundance of CRE, measuring the easiness of integration is a critical step for the design of a mixed CRE system that directly depends on local climate variability. Dependencies on the scales must be considered: hourly and daily optimal mixes can be quite different and differences can also be seen from one place to another.



Wind turbine (Photo: J. Sauterlete)

The Nigardsbreen Glacier in Norway
(Photo: J. Sauterlete)

5. Transition to "100% renewables" is not a smooth process

Transition trajectories to 100% renewable energy are marked by two phases of uneven easiness of CRE integration. Up to 50% renewables, any mix of CRE production is absorbed by the consumption (full penetration), and has the same moderate influence on the stability of the electricity system. Between 50% and 100% renewables, part of the CRE production cannot be consumed and time sequences of CRE supply greater than the demand appear. The easiness of integration decreases and clearly diverges for different strategies of production: it is more efficient when a mix of sources is considered comparatively to a strategy based only on a single CRE source. Overproduction, beyond 100% renewables, further improves penetration and reduces backup and storage needs. However, such achievement largely depends on new technological solutions (e.g., export and curtailment) and economic constraints.

Transition means evolving conditions for transport, storage and demand behaviour, all of which improve CRE integration. The balance between transport and storage needs to be further studied with regard to the mosaic of territories, which is designed by policies, markets and equipment acquisition by industries and privates. Demand flexibility also deserves more attention as it can be a central game changer concerning CRE integration and the achievement of a transition to a 100% renewable energy.

6. The present state and the potential development of hydropower deserve particular attention

With its ability to both produce and store energy, hydropower holds a specific status in the context of energy transition and renewable energy targets. The natural run-of-the-river variability governing hydropower production facilitates the integration of other CRE sources at all scales across Europe. Run-of-the-river power production is already a reality in many national energy systems. Hydropower also plays a crucial role in effectively balancing demand with supply through the storage of energy in water reservoirs. Hydropower storage capacity offers the higher storage flexibility needed with the growing development of variable renewable energy sources.

The development of hydropower is however challenged by its intrinsic characteristics, as well as current technical limitations and environmental issues. Hydropower cannot be exploited everywhere, but at specific locations along river networks. Besides, energy production and storage is only one particular use of water. It often coexists with other water uses for agriculture, industry, freshwater supply or tourism. Water management in hydropower systems must also be compatible with strategies for river ecosystems conservation. Tensions among water uses may be particularly critical in regions such as Southern Europe, where water resources are expected to decrease with climate warming.

Climate changes may also modify the role of large reservoirs and be key drivers of changes in the way water and power plants are managed today. Adaptation may include the setup of new management strategies at different time horizons (e.g., daily to seasonal inflow management), the revision of the design characteristics of existing power plants, and the development of pumped-storage hydropower facilities to explore the overproduction capability of other variable renewable energy sources.

Summary

From a policy perspective, the European energy directives recognize the variability of climate-related energies (CRE) and the needs to analyse the potential of renewable energy resources at the country level as a starting point for the energy transition. At each level, from the local to the EU-wide level, questions remain about how and where to produce, transport, store, complement, sell and buy these renewable energies. Answers to these questions need to be guided by a robust knowledge that informs where and how climate-related energy is available.

Driving the decarbonisation of the European electricity systems is a complex process. On the one hand, it is embedded in multi-level legislations, market rules and functioning, economic and technological constraints, private initiatives and public interests. On the other hand, it must also consider the multiscale climate and environmental variability governing CRE resources, the easiness of CRE integration in the energy mix and the potential conflicts with regard to land and water use as well as environmental regulation.

The concept of water-energy-food nexus, as highlighted by the Food and Agriculture Organization of the United Nations, recalls that low-carbon energy developments cannot be designed without the other non-energy sectors. Climate variability and change is also a relevant component of the nexus. It sheds light on interdependencies in space and time of CRE sources, on regional exposure to CRE resources and on the potential interlinkages to be explored in the routes to decarbonisation.

Authors

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