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Space-time dependence between energy sources and climate related energy production

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The European Renewable Energy Directive adopted in 2009 focuses on achieving a 20% share of renewable energy in the EU overall energy mix by 2020. A major part of renewable energy production is related to climate, called "climate related energy" (CRE) production. CRE production systems (wind, solar, and hydropower) are characterized by a large degree of intermittency and variability on both short and long time scales due to the natural variability of climate variables. The main strategies to handle the variability of CRE production include energy-storage, -transport, -diversity and -information (smart grids). The three first strategies aim to smooth out the intermittency and variability of CRE production in time and space whereas the last strategy aims to provide a more optimal interaction between energy production and demand, i.e. to smooth out the residual load (the difference between demand and production). In order to increase the CRE share in the electricity system, it is essential to understand the space-time co-variability between the weather variables and CRE production under both current and future climates. This study presents a review of the literature that searches to tackle these problems. It reveals that the majority of studies deals with either a single CRE source or with the combination of two CREs, mostly wind and solar. This may be due to the fact that the most advanced countries in terms of wind equipment have also very little hydropower potential (Denmark, Ireland or UK, for instance). Hydropower is characterized by both a large storage capacity and flexibility in electricity production, and has therefore a large potential for both balancing and storing energy from wind- and solar-power. Several studies look at how to better connect regions with large share of hydropower (e.g., Scandinavia and the Alps) to regions with high shares of wind- and solar-power (e.g., green battery North-Sea net). Considering time scales, various studies consider wind and solar power production and their co-fluctuation at small time scales. The multi-scale nature of the variability is less studied, i.e. the potential adverse or favorable co-fluctuation at intermediate time scales involving water scarcity or abundance, is less present in the literature.Our review points out that it could be especially interesting to promote research on how the pronounced large-scale fluctuations in inflow to hydropower (intra-annual run-off) and smaller scale fluctuations in wind- and solar-power interact in an energy system. There is a need to better represent the profound difference between wind-, solar- and hydro-energy sources. On the one hand, they are all directly linked to the 2-D horizontal dynamics of meteorology. On the other hand, the branching structure of hydrological systems transforms this variability and governs the complex combination of natural inflows and reservoir storage.Finally, we note that the CRE production is, in addition to weather, also influenced by the energy system and market, i.e. the energy transport and demand across scales as well as changes of market regulation. The CRE production system lies thus in this nexus between climate, energy systems and market regulations. The work presented is part of the FP7 project COMPLEX (Knowledge based climate mitigation systems for a low carbon economy; http://www.complex.ac.uk)