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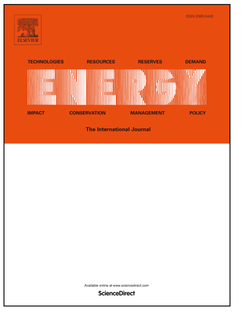

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Synergies of sector coupling and transmission reinforcement in a cost-optimised, highly renewable European energy system

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Abstract

There are two competing concepts in the literature for the integration of high shares of renewable energy: the coupling of electricity to other energy sectors, such as transport and heating, and the reinforcement of continent-wide transmission networks. In this paper both cross-sector and cross-border integration are considered in the model PyPSA-Eur-Sec-30, the first open, spatially-resolved, temporally-resolved and sector-coupled energy model of Europe. Using a simplified network with one node per country, the cost-optimal system is calculated for a 95% reduction in carbon dioxide emissions compared to 1990, incorporating electricity, transport and heat demand. Flexibility from battery electric vehicles (BEV), power-to-gas units (P2G) and long-term thermal energy storage (LTES) make a significant contribution to the smoothing of variability from wind and solar and to the reduction of total system costs. The cost-minimising integration of BEV pairs well with the daily variations of solar power, while P2G and LTES balance the synoptic and seasonal variations of demand and renewables. In all scenarios, an expansion of cross-border transmission reduces system costs, but the more tightly the energy sectors are coupled, the weaker the benefit of transmission reinforcement becomes.

Keywords: energy system design , large-scale integration of renewable power generation , sector coupling , power transmission , CO_2 emission reduction targets

1. Introduction

It has been established in many studies that the integration of high shares of renewable energy in the European electricity sector is both technically feasible and affordable [1–8] (see also the review [9]). Typically, these studies show that the most cost-effective solutions are dominated by wind generation and require the expansion of a pan-continental transmission network, which enables the exploitation of the best renewable production sites and smooths out the variations from weather systems on the synoptic scale (~ 600–1000 km) as they pass over the continent. Without an expansion of the transmission network, more expensive electricity storage solutions are needed to balance the variability of renewables in time [10–14].

However, focussing on the electricity sector means not only neglecting the significant greenhouse gas emissions from other energy demand sectors, such as heating and transport, but also ignoring important sources of flexibility in these sectors. In what some authors term 'smart energy systems' [15], demand from, for example, battery electric vehicles or intelligent heating systems can be brought forward or delayed to reduce system costs, and low-cost long-term storage can be provided either chemically, using power-to-gas units to produce synthetic fuels such as hydrogen and methane (so called 'electrofuels'), or thermally [16]. Long-term storage can smooth out both the seasonal variations of renewables and the synoptic variations (~ 3-10 days in the time dimension).

Modelling all energy sectors in high spatial and temporal detail is computationally demanding. In order to maintain computational tractability, previous sector coupling studies have either focused on just a few demand sectors, or sacrificed spatial or temporal resolution.

Studies of a few sectors have either considered just electricity and heat, electricity and transport, or electricity and gas. For example, in [17, 18] the possibility of using excess renewable electricity in the