THE ROLE OF FLEXIBILITY OPTIONS IN DEEP DECARBONIZATION OF THE EUROPEAN POWER SECTOR

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Overview

The European Union (EU) has formulated ambitious CO2-emission reduction targets in its Fit for 55 package. The aim is to be climate neutral by 2050 with net-zero greenhouse gas (GHG) emissions. As part of the package, the EU set a target of 40% renewable share in total energy consumption by 2030 (Renewable Energy directive, July 2021). The European electricity system is one of the largest contributors to GHG emissions in Europe. In addition, the electricity sector has a potential role in helping the decarbonization of other sectors via the electrification of the energy demand (e.g., electric vehicles, hybrid/electric heat pumps). Therefore, achieving the EU's climate and renewable share targets requires a massive increase in renewable electricity, especially variable renewable energy (VRE) such as wind and solar power, in the EU power system. Flexibility from dispatchable generation, interconnections, storage, and demand side response will be needed to accommodate the growth of electricity production from variable renewable generation sources.

This paper provides insights into different strategies for providing flexibility in the European electricity system with large shares of wind and solar power. We are especially interested in how flexible technologies fill the gap left behind by traditional dispatchable fossil fuel power plants that cannot ramp up and down quickly to compensate the fluctuations in wind and solar generation. To this aim, we analyse the interactions and the trade-offs between different flexibility options such as demand response (shifting demand EV), storage (batteries), cross-border transmission, and dispatchable generation in a 2040 European power market with high shares of variable renewable generation. We use COMPETES, a transmission-constrained optimization model of the European power market, to quantify the optimal flexibility requirements and the role of these flexibility options on the electricity costs, renewable output, and CO2 emissions.

Most of the existing studies analysing flexibility generally do not consider investment decisions in all the flexible options together. This paper adds to the existing literature by modelling the investment and operation decisions in generation, transmission, and storage options, as well as demand-side response, simultaneously. This enables us to assess the optimal mix of these flexibility options. Another contribution of this paper is that we model start-up costs, ramping rates, and minimum load levels of traditional dispatchable power plants, which allows for a better representation of the system flexibility to accommodate the variability of VRE generation. This gives a unique insight into the specific need for flexibility, as not all market models include flexibility limitations of fossil fuel power plants.

Methods

For our analysis, we use an EU-wide transmission-constrained power market model, COMPETES, which we enhanced to simulate generation, transmission, storage investments, and operation decisions, as well as demand-side response (e.g., shifting) whilst accounting for the technical constraints of the generation units and transmission constraints between the countries. COMPETES includes 33 European countries represented by 22 nodes. Transmission in COMPETES mimics an integrated EU network limited by net transfer capabilities (NTC) between countries. By using an EU-wide geographical coverage with cross-border transmission, we can identify not only the interactions between the flexibility options, but also their best locations.

COMPETES is formulated as a relaxed unit commitment model that is well able to capture system flexibility by e.g., including transmission, storage, demand response options and generator's constraints for ramping, minimum up and down times, and the minimum load levels. Our methodology consists of a two-step approach. We first use a long-term planning model to simulate optimal investment decisions in various flexibility options such as generation, transmission, and storage, whilst some part of the demand (i.e., demand from electric vehicles) is flexible. Due to the computational complexity, the investment model is based on twelve representative weeks of the year 2040. Then, we use a day-to-day unit commitment model simulating the operation of day-ahead markets to zoom in on a specific year (i.e., 2040). Both models have constraints that limit ramping up or down (how fast a powerplant can provide maximum power).

We establish a scenario framework to analyse the interactions and trade-offs between the flexibility options (Table 1). We consider market-driven investments in flexibility options such as conventional generation, transmission, and storage capacities. The investments in renewable and nuclear energy are considered to be policy driven and therefore are fixed until 2040.

Table 1 Overview of flexibility scenarios

	Flexibility options			
Scenarios	Expansion in generation capacity	Expansion in transmission capacity	Expansion in battery capacity	Shifting of EV demand (within 6 hours)
Baseline	X			
Transmission only	X	X		
Transmision+ Battery	X	X	X	
Transmission + Smart EV	X	X		X
All flex options	X	X	X	X

Results

Our analysis shows that transmission is a dominant flexibility option regardless of the availability of other options (Figure 1). It mainly complements other options by allowing countries to share their flexibility. On the other hand, generation, batteries, and smart EV compete. As the cheapest flexibility option, smart EV is more attractive and thus substitutes battery and generation. Without demand response, battery is more attractive, partly substituting generation.

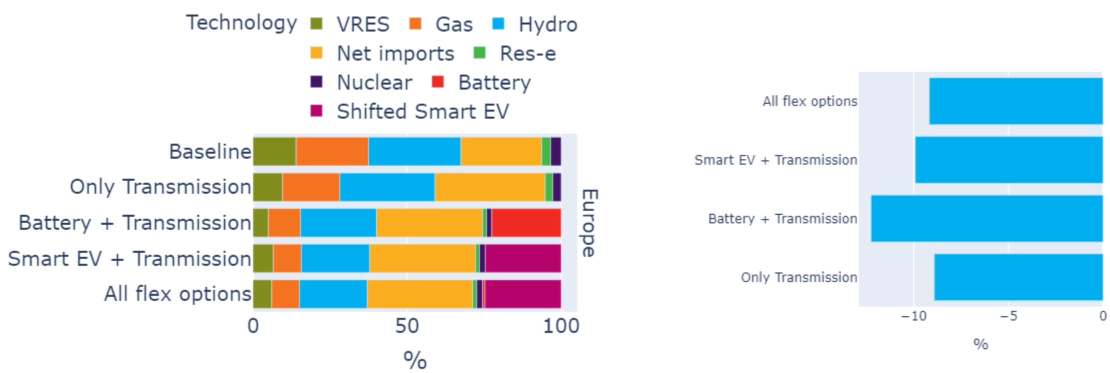

Figure 1 a) Percentage of the total flexibility supply for ramping up in EU electricity system in 2040 b) Avoided CO2 emissions compared to baseline

In addition, we look at system costs and emissions under different flexibility scenarios. The *All flex options* scenario results in the lowest system cost. Interestingly, the *All flex options* scenario is not necessarily the cleanest one. The *transmission+battery* scenario results in the highest CO_2 emission reduction. This scenario uses the largest amount of batteries, which are more flexible compared to smart EVs and hence result in less curtailment of wind and solar generation.

Finally, we perform sensitivity analyses on some of the important model assumptions, such as CO_2 price, battery costs, and the availability of EV smart charging. Our main conclusions still hold under a low CO_2 price level. With 50% higher battery costs, the battery investments decrease by 61% and flexibility supply from batteries decrease by 12.5%, which is to a large extent substituted by increase in flexibility supplied by both renewable and conventional generation (11.5%) and somewhat by transmission (1%). In case the flexibility from EVs is limited with half of the EVs participating with a maximum delay of 3 hours instead of 6 hours, the decrease in flexibility from EVs is substituted by increase in flexibility from generation and storage.

Conclusions

This paper compares the role of flexibility options such as transmission, batteries, and smart EV in filling the gap left behind by traditional fossil fuel power plants that cannot ramp up and down quickly to compensate the fluctuations in wind and solar generation. Our analysis show that cross-border transmission is an important option which complements other options by sharing their flexibility supply among neighbouring countries. On the other hand, batteries and smart EV compete with each other, as well as with generation within a country. They both substitute the flexibility from conventional generation which would help reduce the dependency on fossil fuels such as gas. While smart EV is an attractive option because of its lower costs, it provides limited flexibility compared to batteries. Batteries provide more flexibility than smart EV and hence result in lower CO_2 emissions.

Overall, these results highlight the important role of storage and demand response in providing flexibility and reducing the need for fossil-fuel generation. Reduction in storage costs and more consumer participation for demand response options are important factors that help increase their share in the electricity system and facilitate the de-carbonization of the EU power sector.