REALIZING SECTOR COUPLING IN EUROPE AND BEYOND: THE FUTURE ROLE OF ELECTRICITY AND GAS GRIDS

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Overview

The transformation of the energy system requires extensive adjustments to the infrastructure. Due to the geographically different and temporally variable availability of renewable energy sources such as wind, solar and hydro power, future grid infrastructures and temporal balancing through storage and demand flexibility are crucial. This paper focuses on flexible sector coupling, transport networks and their interaction in the future energy system of Europe. The analysis is based on the application of the energy system modeling framework REMix to different future scenarios. The results show the potentials of a conversion of gas grids to hydrogen, but also the high dependency of the infrastructure design on political decisions. This particularly concerns the development of the demand for hydrogen, the preferred power sources as well as the ambition for a high self-supply share.

Methods

The analysis presented here relies on the application of different models derived from the REMix energy system modelling framework (Figure 1). REMix provides the basis for analyzing scenarios of the energy transition in spatial and temporal resolution. Originally limited to the electricity sector [1], the framework has been continuously extended to include the flexible coupling with the heat, gas and transport sectors [2]. REMix provides a multi-node approach where nodes may be connected by different types of transportation infrastructure. Within regions, all units of a technology are aggregated and treated as a single entity. REMix was used to built models of the German and European energy system with different scope and detail [3, 4]. The future potentials of sector coupling were also in the focus of REMix applications for other regions and countries with different conditions, including the Canary Islands [5], Brazil [6] and Australia. REMix is based on a linear cost minimization approach whose objective function includes the annuities and the fixed operation and maintenance costs of endogenously added capacity, the variable operation and maintenance costs of all units, the fuel costs, the optional emission costs, and the penalty costs for unmet energy demand. The REMix framework is implemented in the General Algebraic Modeling System (GAMS). The construction of energy system infrastructures and their hourly operation over the course of a year are integrally optimized in a model run, with perfect foresight and from the perspective of a macroeconomic planner.

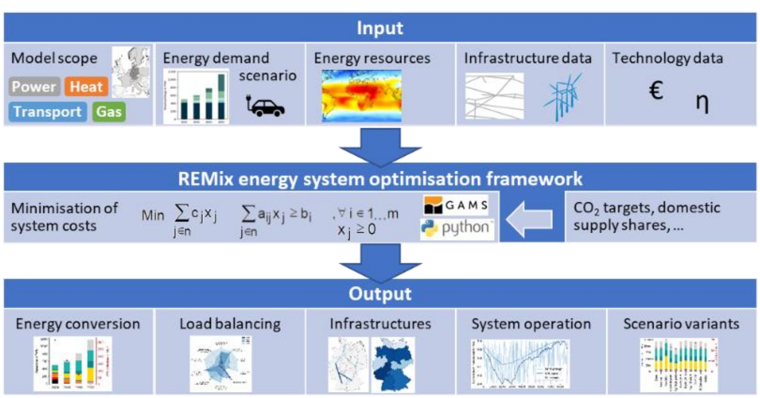

Fig. 1: REMix modelling procedure

The focus of the analysis presented here is the future transmission network infrastructure for electricity and gas in Europe. In particular, the effect of different assumptions on possible grid expansion and import options is examined. The possibility of converting gas pipelines to hydrogen, including the generation and storage of hydrogen, is considered as an important option for flexible sector coupling. In addition, the interaction with other balancing options will be investigated. Building on this, a synthesis of the previous REMix analyses on the future role of flexible sector coupling is provided. It relates the differences in the considered systems to the modelling results in a systematic way to better understand the interaction of energy networks, sector coupling and different renewable energy sources. The differences in the modelled systems especially include their geographical and sectoral scope as well as the spatial detail. All considered REMix models evaluate systems without remaining carbon emissions according to the long-term goals of governments around the globe.

Results

The model results show a high dependence of the infrastructure design on the framework assumptions. This relates in particular to the permitted level of future power grid expansion, but also to the requirements for minimum and maximum power generation of each country, measured against its own demand. The installed capacity of wind and PV plants as well as the electrolyser capacity in Europe prove to be relatively robust (Figure 2). In addition to flexible electrolysis, the flexibilization of heat generation through heat pumps and thermal storage is proving to be particularly effective. Regarding the spatial distribution of electrolysers in Europe, the results show a clear concentration on the Iberian Peninsula, France and the British Isles, driven by the good availability of solar or wind energy (Figure 3). Greater use of flexible sector coupling can compensate for constraints in power grid expansion at relatively low additional cost.

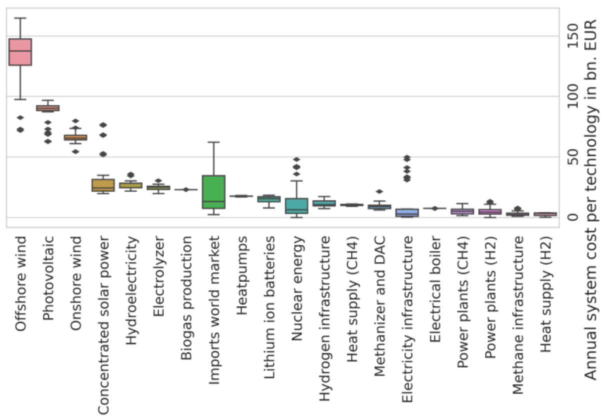

Fig. 2: Contribution of technologies to the system costs

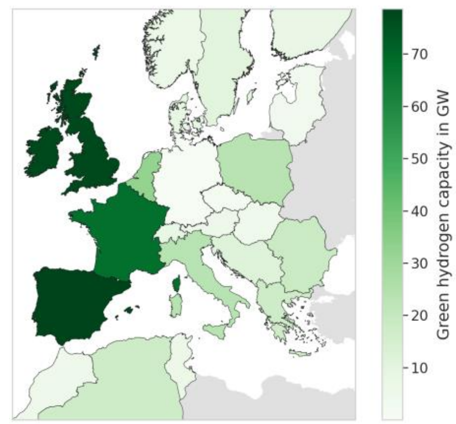

Fig. 3: Spatial allocation of green hydrogen production

Conclusions

The model results underline a high potential for repurposing parts of the existing gas infrastructure in Europe to hydrogen. This especially concerns the connection of regions with good solar and wind availability as southern Europe and the British Isles to the demand centres. In addition, pipeline-based imports from the Maghreb region appear to have high potential. The analysis further more shows that a fully decarbonized energy system profits from hydrogen in the power sector, as it can provide backup power generation with comparatively low demand for additional infrastructure.

The overarching analysis of the REMix model results for different countries shows that the use of sector coupling is on the overall system level cheaper than electrical energy storage. The reductions in system costs made possible by flexible sector coupling are highest for long-term storage and pipelines for hydrogen, as well as by making heat supply more flexible. Moreover, demand side management of battery vehicles, heat pumps and hydrogen electrolyzers notably reduce peak loads. For regions with high heat demand, it can furthermore be observed that the load balancing focus shifts from heat to hydrogen with stronger emission reduction. The model results also indicate that often there is more than one technology option available. Instead, the numerous options available are partly complementary and partly competing. To what extent flexible sector coupling is implemented and which technologies are preferred is to a high degree dependent on the regional renewable power generation potentials and the allowed grid infrastructure expansion.

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