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What is the cost of energy autonomy? — Assessing import independence for a multi-modal, climate-neutral European energy system

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Overview

As stated in the Paris Agreement, the energy systems worldwide need to be climate-neutral in the foreseeable future. In Europe, this currently results in a significant scale-up of renewable energies and a corresponding integration of the electricity, gas, heat and transport sectors for a complete decarbonisation until 2050. Envisioned by many as the key vector for this transition to a sustainable energy system is hydrogen. The general opinion is that this is going to be accompanied by a significant amount of hydrogen imports from outside Europe.

In view of recent past developments, most notably the issues with natural gas-based energy imports that a lot of European countries faced after the start of the Ukraine war, questions concerning the energy security of the continent can be raised for such a future. This is why this contribution aims to analyse what a prospective energy autonomy of Europe would mean for its energy system. To do so, two future energy systems of Europe are compared, one that allows hydrogen imports from outside the regional scope based on cost estimates from other studies, and a second scenario with no supply with energy carriers from outside Europe. A special focus is on the comparison of infrastructure requirements and system costs for a sufficient energy supply.

Methods

A sector-integrated linear optimisation model of the European energy system is used for the analysis of the transformation to a cost-minimal and climate-neutral energy system in the target year 2050. The hourly-resolved model is built within the open-source energy system optimisation framework REMix. It includes around 100 technologies from the electricity, gas and heat sector, with a particularly high resolution of almost 50 different technologies for the latter. The regional granularity with more than 50 nodes is also high and chosen in a way that in areas with higher demand, generation and energy transfer requirements, the density of nodes is higher. The optimisation is executed on the basis of existing power plant, electricity and natural gas grid capacities. Two scenarios are calculated: one with high hydrogen import costs and almost no resulting imports, the other with low hydrogen import costs and forced imports of cumulated 300 TWh via Mid-Eastern and Northern-African pipeline import routes.

Results

The optimisation results underline the significant ramp-up of renewables required to meet the climate neutrality goal for the target year. This is needed to substitute fossil fuels in all sectors as well as the electrification of the heat, transport and industry sectors. Hydrogen is produced in large scale across Europe to serve local demands and provide flexibility to the power system. Large-scale hydrogen caverns are an important part of the system and act as seasonal storage whereas thermal energy storage and batteries are used for short to mid-term flexibility. The option to repurpose existing natural gas infrastructure for the transmission of hydrogen is commonly used between regions with high renewable potentials and demand centres.

Our analysis indicates that an import-independent European energy system results in greater requirements to build up energy system infrastructure, most notably renewables to supply the electricity demand, electrolyser capacities to supply the evolving hydrogen demand, and seasonal and short-term storage capacities to bridge periods with fewer sun and wind hours. In our analysis, the overall system costs for the two presented systems with hydrogen-import autonomy and forced hydrogen imports differ only by an annual amount of 2 billion €. This indicates that other considerations might take precedence instead rather than pure costs.

Conclusions

Necessity for energy infrastructure changes significantly between a system with and without hydrogen imports for some technologies. Hydrogen transfers via repurposed pipelines commonly occur, whereas the construction of new dedicated hydrogen pipelines is only a rarely-chosen option.

For the assumptions made, the overall system costs of an import-independent Europe do not differ a lot from the system with large shares of hydrogen imports. With regards to energy security, it can be questioned if this measure is actually appropriate or just shifting security concerns towards imports of technologies and/or resources instead of energy carriers themselves. These also mostly come from outside Europe.

References

Wetzel et al. (2024). REMix: A GAMS-based framework for optimizing energy system models. *Journal of Open Source Software*, *9*(99), 6330. https://doi.org/10.21105/joss.06330.