FLEXIBILIY ASSESSMENT
FOR HIGH SHARES OF RENEWABLE ENERGY

Thomas Baldauf*[1]
Jens Schmugge[1]
Hans Christian Gils[1]
Jonas Eschmann[1]

1) German Aerospace Center (DLR), Institute of Networked Energy Systems, Curiestr. 4, 70563 Stuttgart, Germany
* corresponding author, thomas.baldauf@dlr.de

Overview

We assess different flexibility options through the lens of a bottom-up energy system model. For this purpose, we filter different flexibility options and power generation technologies in the energy system modeling framework REMix and run a post-processing algorithm on the model output for installed capacities and system costs. The applied data transformation reveals combinations of technologies (rather than single technologies) under different carbon mitigation constraints. As a result, we identify flexibility options which resonate best with the deployment of future power generation technologies. By considering numerous model regions, we systematically capture the interdependence between the composition of the power plant portfolio and the use of different flexibility options.

Methods

The study comprises a two-stage process. In the first stage, a basic model of a highly stylized European power system with sector coupling is set up in REMix as in [1-3]. As we neglect most of the existing infrastructure and do not rely on real-world scenarios, the modeled system is mainly of exemplary nature. This model is optimized for 20 different scenarios that vary in their degree of decarbonization from maximum down to zero emissions in 5% steps. The results from the optimization of these scenarios are fed into the flexibility assessment in the second stage.
REMix is a framework to build energy system models in high spatial and temporal resolution formulated as a linear program that undergoes cost minimization. Its latest development state is described in [4]. The technologies comprised in the model are listed in Table 1, categorized in flexibility options and power generation technologies. In addition to that, a final energy demand for hydrogen is exogenously set. Nuclear power was not included in the generation options.
In order to assess the versatility of different technological solutions of the energy system, we perform a pairwise combination of flexibility options and power generation technologies in the second stage (similar to [5]). We transform all combinations to a two-dimensional feature space of technological replaceability (*flexibility)* and apply a weighting based on the respective system cost impact (*extent*). This allows us to rank all model regions on a quantitative basis (*flexibility score*).

Results

Figure 1 shows a summary of the derived indicators obtained for each model region. Among the model regions considered, we identify the stylized systems of France and Italy as the highest-scoring model regions with regard to flexibility score. We attribute this to their large number of available alternative technology combinations. In contrast, Luxembourg and Switzerland obtain a relatively low flexibility score. This is due to the availability of mainly one single technology with a poor combination possibility with other alternatives.

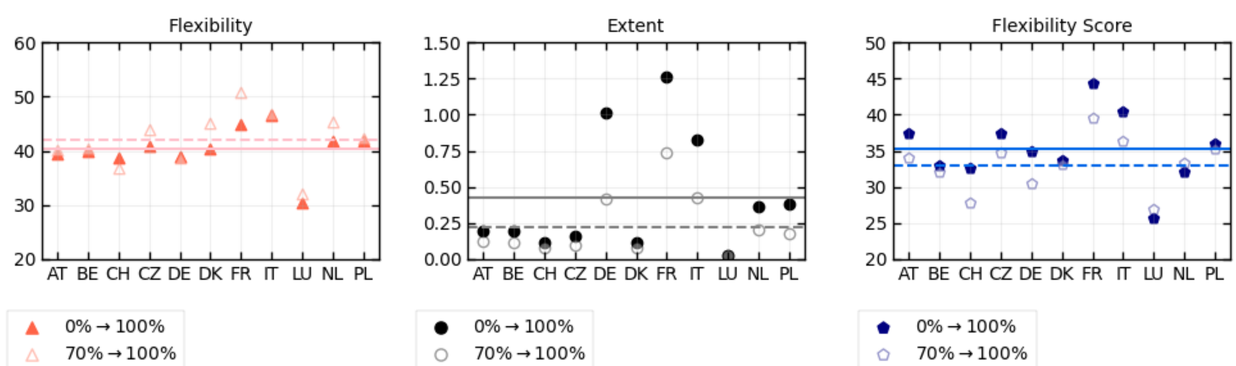

Figure 1: Flexibility, cost extent and flexibility score for the model regions analyzed. Filled symbols show the full range from 0 to 100% emission reduction, open symbols show the values when considering only the last 30% of emission reduction. The solid and dashed horizontal lines indicate the respective sample means.

Considering only the last 30% of emission reduction (open symbols), the differences in flexibility score between the model regions slightly decrease. For some model regions, the degree of decarbonization has only small effects on the flexibility score, indicating a versatile energy system design. The mean flexibility score is slightly decreased in these scenarios with least emissions (dashed horizontal line).

Conclusions

The introduced flexibility score allows for a comparison of model regions with varying renewable energy potentials regarding their adaptability to different decarbonization pathways. It thus for the first time provides a means to evaluate additional costs that arise from lock-in effects due to changing policies towards more ambitious climate targets. In the future, the results could be combined with a normative evaluation procedure to draw conclusions in order to enable resilience assessment and policy recommendations.

Table 1: Overview of the technologies employed in the model.

Battery-electric vehicle	Battery storage
Electrolyzer	Methane-fired combined-cycle gas turbine (CCGT) in local heating grid
Hydrogen salt cavern	Boiler in local heating grid
Hydrogen tank storage	Electric boiler in local heating grid
High-volt. transmission grid	Heat pump for CCGT
Hydro reservoir	Heat storage for CCGT
Natural gas turbine	Heat pump air to water
PV plant	Heat storage for air-to-water heat pump
Offshore wind turbine	Onshore wind turbine

References

[1] Gils et al. (2022a), “Modeling flexibility in energy systems—comparison of power sector models based on simplified test cases.” Renewable and Sustainable Energy Reviews, 158, 111995.

[2] Gils et al (2022b), “Model-related outcome differences in power system models with sector coupling—Quantification and drivers.” Renewable and Sustainable Energy Reviews, 159, 112177.

[3] van Ouwerkerk, et al (2022), “Impacts of power sector model features on optimal capacity expansion: A comparative study.” Renewable and Sustainable Energy Reviews, 157, 112004.

[4] Gils, Gardian, and Schmugge (2021), “Interaction of hydrogen infrastructures with other sector coupling options towards a zero-emission energy system in Germany.” Renewable Energy, 180, 140–156.

[5] Stöckl and Zerrahn (2020), “Substituting Clean for Dirty Energy: A Bottom-Up Analysis” DIW Berlin Discussion Paper No. 1885.