Flexibility Demand Meets Flexibility Supply - The influence of the future renewable energy portfolio on the optimal investment in flexibility options

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Overview

The extension of renewable energies leads to a transformation of the energy systems. With an increasing share of variable renewable energy (VRE) sources the balancing of electricity consumption and generation becomes more challenging (Huber, et al., 2014). Additionally to the flexibility of conventional power plants, new flexibility options are necessary in future energy systems (Evans, et al., 2012). With an increasing share of VRE on total demand, the different generation characteristics of the weather dependent energy sources photovoltaic (PV), wind onshore and offshore have an increasing influence on the flexibility need. Thus, the chosen VRE extension path can lead to very different energy systems. To observe the influence of the variability in VRE generation, a few studies analysed cost minimal VRE shares (Rodriguez, et al., 2015; Huber, et al., 2014) as well as different solar-to-wind ratios (Gils, et al., 2017; Lund, 2006). The present papers analysis the uncertainty of future PV and wind capacity extensions by setting up two scenarios with different solar-to-wind ratios in a VRE portfolio with an overall share of 80 % in total demand. To integrate the resulting variable generation it is further of high importance to assess the required types and capacities of flexible technologies, since different available options may become more appropriate when pursuing different VRE extension paths. Therefore the impact of different flexibility needs on optimal investments in flexibility options is analysed. By including a broad range of flexible technologies (on electricity supply and demand side as well as electricity shifting technologies) with different applications possible synergies and competitions will be analysed in an isolated view as well as in a combined approach. Therefore a coupled linear cost-minimizing investment and a dispatch energy system model is used, to calculate endogenously required capacities and system cost. The question evaluated is: how does a varying flexibility need, resulting from uncertain solar-to-wind ratios, interact with a cost-optimal flexibility provision?

Methods

In a first step the flexibility need is calculated and analysed in VRE portfolio scenarios. The solar-to-wind ratio is calculated from the theoretical annual power generation of PV and wind. For the analysis of the uncertain solar-to-wind ratio two scenarios are developed with a PV-share of 20 and 80 % respectively. The weather and base year for the scenario data is 2014. VRE and demand data is based on ENTSO-E data (2018). The model region includes the EU 15 countries[1] plus Norway and Switzerland. For this region a theoretical overall VRE share of 80 % on electricity consumption is assumed. While the electricity demand is kept constant on 2014 level the extension of VRE in the different countries is based on the mean of the full load hours (FLH) of the years 2006 to 2016. This includes the assumption, that the distribution of PV and wind is proportional to their power production potential, reflecting cheaper cost for higher potentials.

The above presented scenarios are used to find optimal investments in power plants and further flexible technologies. Therefore ELTRAMOD, a linear European electricity transhipment market model, is used as basis and extended by equations constraining the investment and dispatch of the included flexibility options. In general the basic version of ELTRAMOD cost minimizes the power plant dispatch per region. The regions (here 17 countries) are treated as one node each, connected by Net Transfer Capacities (NTC), while the electricity grid within one country is neglected. The main restriction is the energy balance defining to meet the residual load in each time step and region. Further constraints of the basic version limit the output of power plants by upper bounds for capacity and availability as well as load change costs. As a first extension the endogenous investment in conventional power plants is introduced. With this modification ELTRAMOD becomes a greenfield approach model. This is reasonable regarding the long-term scenarios. Furthermore equations concerning model-endogenous investments in NTC, demand-side-management (DSM) processes, storages as well as so called Power-to-X technologies are introduced. Regarding the DSM applications seven aggregated processes (for both load reduction as well as load increase) are represented including their technical constraints, temperature dependencies (if existing) as well as resulting country specific yearly and hourly potentials as data input. Furthermore three storage types (namely hourly, daily and seasonal storages) and their corresponding techno-economical characteristics are included in the presented model.

[1] Austria (AT), Belgium (BE), Czech Republic (CZ), Germany (DE), Denmark (DK), Spain (ES), France (FR), Great Britain (GB), Ireland (IE), Italy (IT), Luxemburg (LU), Netherlands (NL), Poland (PL), Portugal (PT), Sweden (SE)

The Power-to-X technologies include electric boilers and heat pumps in combination with heat storages as well as electrolyzers.

To reduce the computational time the presented model is divided in an investment model with reduced time frame (representative weeks selected by a hierarchical clustering algorithm) and a dispatch model in hourly resolution for a full year. The investment model is used to calculate optimal capacity investments and the corresponding costs. The dispatch model calculates resulting dispatch costs as well as further results like curtailed VRE and emissions for the two scenarios. The presented model can be used to analyse optimal investments in a single technology or in different combinations (e.g. only electricity shifting technologies) to give insights in the interplay between available flexibility options.

Results

Regarding the flexibility requirements it can be noted in general, that with high wind shares longer periods with surplus energy out of VRE can be observed. Nevertheless in comparison to a PV-dominated energy system other residual load parameters (in the present paper residual load is defined as difference between the load and the electricity generation out of PV, wind -onshore and –offshore) are less extreme. This is due to both, the lower availability as well as the higher daily (and seasonal) variability of PV compared to wind. With an increasing share of PV in the solar-to-wind ratio in particular electricity surplus peaks on midday combined with corresponding residual load gradients become very huge.

In general the optimal investments in flexible technologies show a strong sensitivity to the flexibility needs. In the following the results for a combination of all included flexibility options is presented briefly. While in a wind-dominated energy system NTC extensions are the major source of flexibility provision, this is true for storages and gas power plants in a PV-dominated energy system. Additionally seasonal storages are more beneficial with high installed wind capacities to balance longer periods of VRE surplus or deficits. In contrast there are higher installed capacities of daily storages with a high PV-share in the observed region. Besides further results in a PV-dominated energy system less Power-to-X capacity is optimal with a higher share of heat-pumps compared to the high wind-share scenario.

Conclusions

The presented approach combines analyses on both sides of the future flexibility challenge in energy systems. On the one side the VRE extension in Europe as crucial uncertainty is observed. Resulting from the dissimilar availabilities and generation characteristics of solar and wind energy, the uncertainty regarding a future VRE portfolio can lead very different flexibility needs. On the other side this flexibility need is used to analyse optimal flexibility provision. The presented model set-up including the holistic as well as extensive representation of flexible technologies allows to answer to a broad range of questions regarding the competition of flexibility options to meet the flexibility demand. The results show a close interaction between these two sides. It can be shown, that the optimal combination of flexibility options differs strongly between wind- and PV-dominated energy systems.

References

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