Unsealing a fossil free energy system by geographical, sector or market coupling. The case of Denmark

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Overview

Denmark is a frontrunner in the green revolution towards a future with a fossil free energy system that focuses on system integration costs, reliability and sustainability. Ambitious climate and decarbonization targets have been set that involve the massive deployment of variable renewable energy such as wind and solar power as well as electrification of various energy and service sectors.

At present wind power is the fastest growing technology being deployed. Denmark has the highest proportion of wind power in the world, which provided 43.4% of total annual Danish electricity consumption in 2017 (Skytte and Grohnheit, 2017). With additional large unused wind and solar power potentials, these shares are expected to increase substantially in the years towards 2050, where the political target is a fossil free (carbon neutral) society.

Integration of large shares of wind energy and other variable renewable energies into power system operations calls for flexibility in the entire energy system (Söder et al. 2018). Denmark is already strongly interconnected to its neighbouring countries. This geographically coupling has until now been the main flexibility provider at the whole sale level. At the same time, district heating with large thermal storage capacities are widely used in Denmark. District heating supplies 50% of the heat demand. A partial electrification of the district heating system could provide large and cheap flexibility options simoultaneously with a decarbonization of the heat sector. Likewise for the gas sector which is also well developed. This calls for a stronger and more flexible coupling between the electricity and other energy sectors in order to utilize the cheap wind energy potentials in the heat, gas and transport sectors to which there today exist a number of barriers (Skytte et al. 2017; Sneum et al. 2018). The current structures of grid tariffs and taxes on electricity use (Bergaentzlé, Jensen, Skytte and Olsen 2018) are important barriers and so are so are a number of restrictions on the heat sector.

A third way of coupling is between markets. Market designs that allow active participation in multiple power and balancing markets increase the flexibility of the system as well as the value of wind energy (Skytte and Bobo 2018). Likewise, smart market coupling between energy and renewable support markets (or similar coherent markets) can increase the flexibility. This call for innovative market and framework designs that facilitate smart market coupling. The Danish support schemes as well as the set-up of the Nordic power exchange NordPool have already been partly adjusted to this which so far have revealed a stable market (Skytte and Grohnheit 2017). However, a stronger market coupling could improve the flexibility.

The main research question in this paper, is to what degree policies should target respectively ***geographical, market,*** or ***sector couplings***. To answer this, this paper discusses possible pathways and the challenges involved in creating a future energy system dominated by variable renewable energy. Four possible scenarios for how the energy system setup might develop are surveyed and discussed with respect to future geographical, market, and sector couplings. The advantages of and barriers for the different kinds of couplings with respect to a flexible energy system are highlighted.

Methods

The current Danish/Nordic experience with large-scale integration of wind energy and in creating framework conditions that facilitate this is surveyed and discussed with respect to further development towards a fossil free energy system.

A taxonomy for the scenarios with different degrees of respectively geographical, sector and market couplings is developed and used in a scenario analysis to discuss and analyse drivers and barriers within framework conditions that facilitate a flexible energy system and thereby the integration of variable renewable energy. Interactions between incentives and barriers are analysed.

The analysis is conducted with a Danish case study. The results are used to discuss how it can be used as an analytical and policy planning tool for other countries. The other Nordic countries are used as references in this discussion. They differ from Denmark in their technology mix, spread of district heating and gas systems as well as in regulatory framework conditions for the use of electricity to heat and gas. Nevertheless, they are part of the same common power market.

Results

The Danish case shows that it is possible to decarbonize the energy system and activate flexibility options that ensure a reliable and suistainble energy system with a large share of variable renewable energy supply. The socio-economic cost and the way you achive the flexibility options depends on the framework conditions and availability of the different couplings.

Present regulatory barriers limit the electrification of the district heating and gas sectors. Under the present framework conditions, our scenario analysis shows that geographical coupling with interconnectors to neighbouring countries will remain the main flexibility provider with investments in additional transmission lines.

With the removal of the main regulatory barriers which implies the redesign of grid tariffs and electricity taxes, our analysis shows that sector couplings and especially electrification of the district heating, reveal large flexibility potentials that provide an economic win-win situation for both system integration of wind energy as well as for heat consumers.

Finally, removing market failures and facilitating better and smarter market coupling is shown to be an efficient and cost-effective way of obtaining more flexibility in the system. *Conclusions*

The developed taxonomy for comparison of respectively geographically, sector and market couplings was shown to be an very usefull tool in the scenario analysis. The results show that unsealing a cost-efficient and reliable fossil free energy system with a large share of variable renewable energy should not have a one-line policy focus.

The analysis reveals that flexibility potentials can be obtained with both geographical, sector and market couplings. Comparing the Danish case with other Nordic countries shows that the socio-economic optimal mix between the different focus areas depends on the each countries' present technology mix and transmission capacities, spread of district heating and gas as well as in framework conditions for use of electricity to heat and gas.

Setting up policy recommendation for a region of different countries therefore implies a more complex but also more robust policy focus. Our taxonomy and scenarios analysis has shown to be fitted for making this kind of recommendations. Overall, this study contributes to the literature in understanding the factors that hinder or facilitate better system integration of variable renewables and that provide flexibility. In particular, it should be of great interest to policy makers looking on how to design policy that address market failures and barriers to sector and market couplings.

References

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