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INTERCONNECTION VS. ENERGY SYSTEM COUPLING: A SOCIO-ECONOMIC ANALYSIS OF FLEXIBILITY BENEFITS

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Overview

With expected future penetration of Variable Renewable Energies (VREs) arises the question of how to maximise the utilisation of large shares of cheap energy resources. The traditional way to address this is to export energy surpluses, thereby using interconnectors as flexibility solution. This study explores the benefits for Denmark of engaging into an electrification strategy of its District Heating (DH) system to unlock and expand thermal storage capacities. Energy system coupling activates low cost flexibility capable of complementing other flexibility technologies at the power sector, while contributing to decarbonise the heat sector. We address the following research questions: What is the socio-economic value of the smart electrification of the heat sector in Denmark and what are the distribution effects generated by the integration of both sectors as compared to "traditional" flexibility strategy, embodied by flexible generation capacities, interconnections and possibly curtailment?

Background

Denmark is a leading country in terms of transition to low carbon energy. With a constant increase of renewable energy sources, driven by a strong penetration of wind energy, Denmark has already achieved its 2020 30% renewable energy target. In 2017, Variable Renewable Energies (VREs) wind and solar, accounted for 46% of total consumed electricity. This represents more the double of VRE's share in annual electricity demand 10 years before. The central location of Denmark reflects in it interconnection to the rest of Europe and notably to Norway, which gives Denmark access to large hydropower capacities providing flexibility services, and allowing the trading of abundant cheap electricity across countries. Another asset to Danish energy transition is its DH sector. DH supplies 50% of total Danish heat consumption, of which, 70% is provided by Combined Heat and Power (CHP) plants, thereby completing the flexibility spectrum at the power system.

In previous works, Skytte et al. (2017) identify the regulatory framework conditions in DH in the Nordic and Baltic countries that either distort or limit flexibility signals from the Nord Pool power market and limit the flexible operation of Power-to-Heat (P2H) technologies in DH. For the most, these conditions take the form of volume-based electricity grid tariffs and taxes, and subsidy schemes granted to some polluting resources in DH. Møller Sneum et al. (2018) investigated how taxes and subsidies impact the use of flexible CHPs in the Baltic countries. Bergaentzlé et al. (2019) demonstrated how current electricity grid tariffs and tax system dampen the electrification and flexibility in Danish DH and assessed how alternative grid tariffs increase flexibility in a Danish DH test case. Kirkerud et al. (2016) or Sandberg et al. (2018) modelled the impact of flexibility-friendly tariffs using a Nordic perspective and further demonstrate the relationship between lack of flexibility signals, tariffs and business case for flexible power-to-heat technologies.

Method

This paper builds on the past findings relative to the barriers to flexibility in DH. We introduce flexibility-friendly tariffs and taxes that support the flexibility signals sent by the wholesale market and ultimately improve the business case for flexible power-to-heat technologies in Danish DH. We look at the horizon 2050 and compare this flexibility scenario to an increased interconnection scenario that leaves unchanged the tested regulatory framework conditions. We use Balmorel (http://www.balmorel.com/) as a partial equilibrium modelling tool to estimate and compare the socio-economic effects of sectors coupling to the extended transmission capacities scenario in terms of increase of VRE capacities; electricity spot prices; system cost; congestions; electricity exchange balance; total CO_2 emissions and heat prices.

Results

Our results show that the adoption of appropriate regulatory policies designed to reap the synergy benefits of energy sectors coupling has the clear potential to fasten the clean, reliable and competitive transition across energy sectors. Our results show that the electrification of the heat sector with flexible power-to-heat technologies further supports the penetration of VRE at the power sector, contributes to decarbonize the heat sector and has a positive impact on final heat prices.

The electricity price increase as a result of the electrification of the heat sector is moderate and decreases with the continuous penetration of low marginal cost power generation. The reason for that is the competition effect between energy resources in the DH sector, where electricity as input competes with other relatively low cost resources such as biomass. It is therefore the cost of biomass that limits the use of P2H in periods of time where the electricity price on the wholesale market reflects the largest share of VRE.

Increased coupling reduces the overall CO_2 emissions in both the electricity and the heat sector. It lowers total system cost to integrate VRE and completes the traditional flexibility sources with thermal storage.

The comparison with the interconnection scenario shows that distribution effects take place between Denmark and the neighbouring countries. The electrification of the Danish heat sector results in a limited average wholesale price increase in interconnected countries and contributes to reduce congestion effects.

Conclusions

The electrification of the heat sector in Denmark has the potential to play a critical part into the transition strategy but requires policy makers to implement policy instruments tailored to support the value of flexibility without distorting market competition. Integrated energy systems would benefit the society in accelerating the transition with limited and positive impacts on electricity and heat prices respectively. The comparison between the energy system coupling scenario and the extended transmission capacities scenario show substitution effects where the use of power-to-heat in DH reduces the congestion rents at the interconnector when Denmark is in situation of VRE surpluses. At last our results are relevant for the coupling of electricity and heat but could also be extended to any energy systems coupling involving Power-to-X technologies. Our scientific approach is consequently not limited to countries with DH, but is also relevant in the prospect of developing power-to-gas and in a context of electric vehicles penetration.

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