IMPACTS OF LARGE-SCALE INTERMITTENT RENEWABLE ELECTRICITY - HOW TO INTEGRATE THESE INTO THE ENERGY SYSTEM WITH A MARKET-DRIVEN APPROACH?

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Overview

A shift towards low-carbon electricity generation is prevalent in OECD countries. Particularly the intermittent renewable energy sources of wind and photovoltaics form the main pillars of future electricity generation. This unpredictable renewable infeed comes along with distinctive challenges for technical and market integration. This is especially valid for countries with strong wind and photovoltaic capacity development e.g. Germany, Denmark and China. A key issue is to find reasonable use for excess intermittent renewable electricity generation and avoid curtailment of renewables with close to zero short-term marginal costs.

One promising approach is to provide flexibility from the demand side by linking the electricity market to the heat market. This market linkage can be reached by using electricity for heat production. This holds great promise for addressing the vexing challenge of matching an increasing infeed of intermittent renewable energy with an inelastic energy demand. The objective is to find out whether there is an intrinsic micro-economic benefit for consumers and producers to shift electricity consumption for heating purposes in dependency of the momentary requirements and market signals. The chosen approach combines focus areas of current scientific research: system integration of intermittent renewables, market coupling, flexibility on the demand side and market-based operation.

Methods

1st, the study draws on empiric data of the electricity market for Germany. Following current scientific knowledge a reproducible model based on the residual load is applied. This multivariate short-term price model, which includes a deterministic and a stochastic part, is developed to reflect the functional correlation of electricity prices and intermittent renewable electricity generation. **2nd**, heat demand is modelled in high resolution using empiric data for residential and district heating as well as with empiric process data from a paper and a chemical company. At the end, two models are combined: The model of price formation in the electricity market and the decision model for the heat producer. The combination of two models and the essential use of empiric data are distinctive for this paper.

The work draws on a market-driven operation of power to heat. From a micro-economic perspective, the electricity demand for heating purposes must compete with conventional heat production cost in the sectors. Short-run marginal cost curves for heat production are calculated for conventional and power to heat systems. A short-run marginal cost curve represents the relation between incremental cost in the short-run of a good and the quantity of output produced. Hourly specific spread patterns for 22 years for diverse applications in three sectors are processed.

Results

First, the paper discusses technical feasibility for heat production with electricity in the different sectors for system integration of large-scale intermittent renewable energy. Despite technical complexity is highest for the industry sector the corresponding economy of scale effect decreases the average specific investment cost. The specific investment cost reach its lowest value with 49,47 €/kW$_{el}$ for the chemical industry. Specific investment cost with 63.30 €/kW$_{el}$ are higher for district heating despite modest technical requirements.

A trans-sectoral comparison with micro-economic focus is completed in the second section. The question is addressed how to integrate large-scale intermittent renewable electricity into the energy system in a market-driven way. Analysis show that in all application fields the levelized cost of heat (LCoH) produced with intermittent renewable electricity are competitive with the conventional heat production cost. E.g. taking a moderate electricity price scenario and a life-cycle of 10 years into account the LCoH is 8.98 €/MWh$_{th}$ for the chemical industry. However, these results are restricted to the exclusion of state-induced price components. In Germany, the benefits in electricity use for heating purposes will be small, if the full extent of the taxes level of approx. 200 €/MWh$_{el}$ on electricity consumption is considered. Under current market framework in Germany the economic operation to integrate intermittent renewable electricity is limited to the paper and chemical company due to prevalent tax exceptions for energy intensive industries.

The third section addresses the CO_2-emissions reduction by using intermittent renewable electricity for heat production rather than gas as fossil energy source. Final energy reduction per installed power to heat capacity is almost equal for paper producing company and district heating with around 12 $MWh_f/kW_{el}\cdot$year. However, yearly CO2-emission reduction is highest for the paper producing company with 3.210 t $CO_2/kW_{el}\cdot$year. A CO_2-emission price of 5 €/t CO_2 is implemented in the simulation model reflecting the current price level. For large-scale gas operating plants the merit of CO_2-emission reduction is between 1.12 €/MWh_f and 1.35 €/MWh_f. Incentives for CO_2-emission reduction cannot be derived from this low values.

Fourth section of the paper discusses macro-economic consequences and describes market interaction effects by using large-scale intermittent renewable electricity to produce heat. Flexible demand interacts with the electricity market and has an electricity price stabilizing effect. Higher electricity prices inhibit the economic efficiency of heat production with electricity that accompany a self-stabilizing effect. With a power to heat capacity of 10 GW_{el} in the market simulation for the moderate price scenario indicate that the yearly average electricity price will increase in 2024 from 23.87 €/MWh_{el} to 35.76 €/MWh_{el} (increase of 49.8 %) and in 2034 from 15.04 €/MWh_{el} to 23.32 €/MWh_{el} (increase of 55.1 %). This will reduce the marginal revenues of the investigated chemical company on average over the life-cycle period by 11 % for 2 GW_{el} demand side installed capacity.

Conclusions

Among the key findings is that intermittent renewable electricity can be technically integrated into the energy system. However, economic performance for heat production with electricity strongly depends on the regulatory framework. Matching a flexible infeed with a fixed structure of state-induced components is not adequate. Policy-relevant conclusion is that government intervention will be required to reach an optimal level which incorporate social issues e.g. address the burden of low-income households. To reach cost efficient system stability regulatory intervention is advised to establish a time-variable tax structure and a transparent electricity market price. This will help to overcome barriers for renewable market integration in countries with large-scale intermittent renewable energy infeed.

Focus on macro-economic criteria shows that distinctive advantages come along by integrating intermittent renewable electricity into the heat market. **1st**, the use of intermittent renewable electricity generation is increased, **2nd**, this leads to higher short-term electricity prices, **3rd**, and a solution for the strong fossil fuel dependency of the heat market is promoted.

References

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