Storage and Investments in a Combined Energy Network Model

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(1) Overview

Throughout the world a transition of existing energy systems is supposed to take place in the coming decades. Industrialized countries aim for a switch from fossil based to more renewable energy fueled systems and in developing regions of the world a significant increase of energy demand will occur. Both developments will require a large amount of investments in energy production and transport infrastructure (IEA (2011a) estimates investment needs of ca. 38 trillion $ till 2035). As energy markets are interlinked with each other due to the substituting character for specific utilizations (eg. heating oil/gas vs. heating with biomass vs. electricity) and the direct usage of energy fuels in downstream markets (eg. coal, oil and gas as fuel input for electricity) the relations between markets need to be accounted in estimates of future developments. In addition energy markets often rely on network structures which add a spatial layer to the problem.

This interaction of energy markets is particular relevant for natural gas and electricity systems. The increasing importance of emission reductions raises the need for a shift from coal based to natural gas fired units. Similar the increased utilization of intermitted renewable generation units raises the need for more flexible generation units as back-up capacities which are mainly assumed to be gas fired. These developments will likely increase demand for natural gas in the electricity sector which can raise the need for investment in gas infrastructure. On the supply side the development of unconventional gas and further increases in the LNG infrastructure can lead to shifts in the global natural gas market prices (IEA, 2011b) which in turn will have an impact on the dispatch order of existing electricity units and influence investment incentives.

The objective of this paper is to develop a representation of coupled natural gas and electricity markets focusing on investment options while accounting for the network characteristics of both markets. The underlying model is an extension of the static market representation in Abrell and Weigt (2010) by including time dimensions and investment. Dynamic aspects are important issues in both markets: First, in the short run, the two markets clear a different time scale, i.e. wholesale electricity markets usually clear at an hourly basis and natural gas on a longer time scale. Second, storage plays an important role in both markets. Third, with an increasing reliance of electricity generation on natural gas investment in production capacities and transmissions become increasingly interdependent. We extend the static approach by incorporating those dynamic restrictions and an investment representation to evaluate the interaction between both markets under realistic market conditions and transmission grid restrictions.

(2) Methods

Our approach is based on the static model of Abrell and Weigt (2010). Electricity transmission is depicted using the DC load flow approach (Hobbs, 2001), i.e. loop flows in the electricity grid are considered. Natural gas transmission occurs via two different networks. Oversee natural gas resources are connected to Europe using Liquefied Natural Gas vessels. This transmission option is restricted by available liquefaction and regasification capacities. Within Europe natural gas is transported via directed pipelines which are restricted by the available pipeline capacities. Natural gas transmission is modeled as a multi-commodity network flow problem which allows not only analyzing production, demand, and congestion in natural gas transmission but also bilateral trade flows between regions. Assuming perfect competition, the model is formulated as an equilibrium model using the Mixed Complementarity format.

The static approach is extended by firstly incorporating the time dimension: The natural gas market is largely characterized by seasonal patterns whereas the electricity market is defined by daily load levels which require a matching of the two time frames. Second, the storage options for the two markets are included as storage operators: seasonal storage for natural gas and pumped hydro for electricity. Given this short- to mid-term dynamic setting, investment options are included. The investment options include the extension of natural gas and electricity network capacities as well as storage facilities in both markets and investment in new natural gas generation capacities.

The dynamic model is applied to a stylized representation of the European market, i.e. each European country is represented by one node in the respective network. Furthermore, we include major natural gas suppliers on a global level. We analyze he interaction of the two markets with a special focus on investment by conducting several scenarios with varying frame conditions, e.g. RES development, emission restrictions and global natural gas supply conditions.

(3) Results

Fig. 1 shows the impact of increased emission prices on the European generation dispatch by load segments and season. As expected increased emission prices lead to a decrease in coal based power generation which is substituted by increased natural gas based generation. Furthermore, due to the resulting increase in electricity prices, a slight decrease of electricity demand can be observed and, due to increased natural gas demand the natural gas price rises.

Concerning investments, the increased need for natural generation leads to additional investment in gas fired power plants. However, investment in transmission capacity only takes place in the electricity market. Additional capacities are constructed towards Italy and from Germany towards Poland and France. These results show that it is more efficient to construct natural gas plants close to existing pipeline supply structures like the German Russian connection and shift the electricity supply pattern instead. This extension of the electricity grid is interpreted as a substitution pattern between the transmission options.

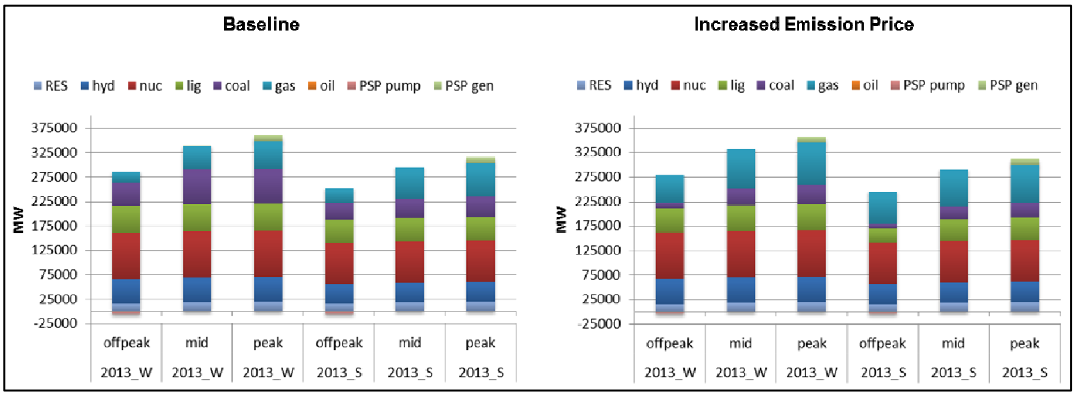

Fig. 1: European Generation Dispatch

(4) Conclusions

We presented the extension a static model of combined electricity and natural gas market with a special emphasis on transmission networks to a dynamic setting. The extensions include a matching of different short-run demand pattern and the inclusion of storage facilities in both markets. In particular, we allow for investment in electricity power plants and transmission capacities in both markets. The model is implemented for a stylized representation of European markets including oversea natural gas producers via Liquefied Natural Gas shipments. We consider an increase in carbon emission prices for fossil fuel based electricity generation. The scenario results highlight the importance of considering an integrated modeling approach of natural gas and electricity markets. In particular, we show that there substitution pattern between the extensions of the electricity grid and generation on the one hand and the natural gas pipeline system on the other hand.

References

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