Short-Term Price and Volume Interactions in an Integrated Gas- and Electricity Market Framework

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Overview

Gas and electricity (G&E) markets are interdependent due to the participation of natural gas fired power plants (NGFPPs) in both markets. Policy makers and regulators require tools to understand the implications of possible technology-, policy-, and economic developments in one market for the operation of the other. Although each market is studied extensively, i.e. by means of a gas market model or an electricity market model, these studies are confined to a certain extent in the sense that G&E market interdependencies are not considered, or at most, only in an iterative manner. In this paper, we propose an integrated G&E market model focussing on short-term interdependencies that relate to price and volume interactions. The short-run **I**ntegrated **EL**ectricity and **GAS** market (I-ELGAS) model is an economic equilibrium model for hourly price and volume interactions, taking into account ramping rates of conventional units, intermittent renewable (I-RES) variability, seasonal- and peak gas storage, and electricity storage. We show that this equilibrium model can be formulated as a Quadratic Program (QP) under the assumption of perfect competition, that allows for solving large-scale systems. The model is applied to a (four-node) test case system to analyse price-volume interactions and the effect of certain drivers, e.g. CO_2 prices, on such interaction.

Methods

The G&E markets are linked via the NGFPPs where the natural gas price is endogenous to the gas market but exogenous to the electricity market, and the natural gas demand of the power sector is endogenous to the electricity market but exogenous to the gas market. The model is formulated using an equilibrium/optimization framework that simultaneously calculates the short-term energy balance and price equilibrium in both G&E markets under a perfect competition assumption (price-taking behaviour). A number of studies exist for modelling interactions between G&E markets, but the available literature is relatively scarce (e.g. [1], [2]). The majority of these models focus on the short-term interactions. Our model is an extension of [1] in the sense that it includes flexibility limitations of conventional power plants (i.e., ramping rates), peak- and seasonal gas storage, electricity storage, and I-RES variability with an hourly resolution and multiple periods. To our knowledge, none of the existing models focusing on short-term interactions differentiates the flexibility properties of different sources in both markets in such detail.

First, a market equilibrium problem for a single year is formulated where it is assumed that none of the market players in both the G&E markets are able to exert market power (i.e. perfectly competitive market assumption). Each market party pursues its own objective (e.g., maximization of its surplus) where at equilibrium, each one's objective is achieved such that they cannot increase their surplus by deviating from the equilibrium solution. This is modeled by formulating the maximization problem for each party and then deriving the first-order (Karush-Kuhn-Tucker, KKT) conditions. Moreover, the market clears at the equilibrium price where supply equals demand for energy. The KKT conditions for all market parties and the market clearing conditions together yields the Mixed Complementarity Problem (MCP) for the entire market. Second, we state a single optimization problem that is equivalent to the MCP, which allows solving larger systems efficiently. Under perfect competition, the market equilibrium represents the least cost solution of the entire system which is optimal for all the market players combined. The model is static, taking the capacities of gas and electricity production and infrastructure as given.

In this study, a scenario-based analysis is performed in order to analyze the price-volume interactions between the G&E markets and the effect of certain drivers on such interaction. In figure 1 the scenario set-up is shown. In the Current 2012 scenario I-RES shares in total generation are relatively low (approximately 10%) as is the price for CO_2. In order to analyse the impact of increasing shares of I-RES, we assume that only the electricity market changes in the 2030 Baseline scenario whereas the gas market is assumed unchanged (e.g. equal production capacities). In the electricity market, I-RES shares in total generation increase (to approximately 32%) while baseload capacities decreases compared to the Current 2012 scenario. Furthermore, no electricity storage is assumed in the Baseline 2030 scenario and the CO_2 price remains relatively low. We further consider four variants of the Baseline Scenario, where the High CO_2 scenario assumes a higher CO_2 price benefiting the competitiveness of NGFPPs compared to coal fired power plants. In the remaining three scenarios, the effect of three types of energy storage technologies is analyzed by comparing the outcomes of these scenarios to the Baseline 2030 scenario.

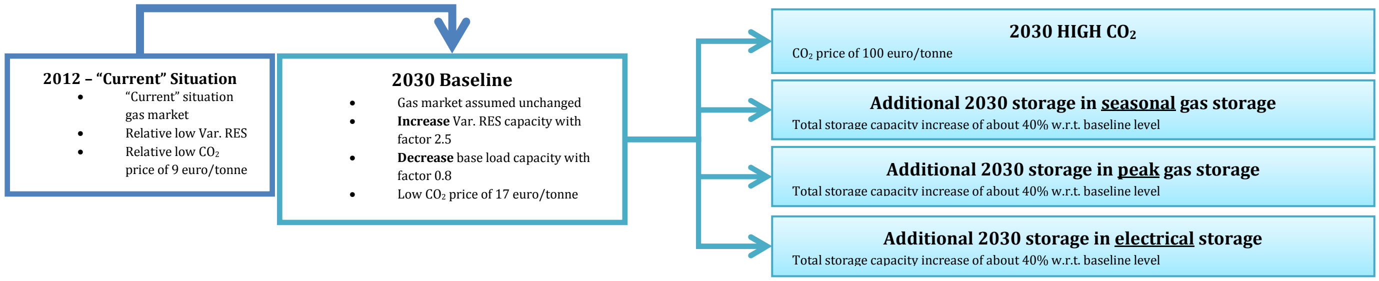

Figure 1.Set of test case scenarios modelled with I-ELGAS.

Results

An important determinant for the level of the gas demand in the power sector is the residual demand, i.e. electricity demand minus I-RES generation. Thus, the higher the generation from I-RES, the lower the residual demand and the lower the need for more expensive generation such as coal or gas. However, due to the variable characteristic of I-RES generation, flexible back-up capacities like NGFPPs are still needed in times of low I-RES generation. Even though total gas demand from the power sector is decreasing in Baseline 2030 compared to Current 2012 scenario, the level of I-RES generation is becoming a more important determinant for the level of the gas demand from the power sector. Under a high CO_2 price, the competitiveness of NGFPPs increases, hence increasing its dispatch and gas demand from the power sector. In this case, the correlation becomes even stronger. Furthermore, under higher I-RES shares the volatility of electricity prices increases, with price spikes and prices close to zero, depending on the level of I-RES generation. Although I-RES generation and gas demand from the power sector are correlated, gas price volatility is moderated by gas storage. Gas storage optimizes the availability of gas throughout the year depending on the volatility of gas demand. In this respect, seasonal storage which is restricted to inject in warm seasons and to extract in cold seasons is suitable to accommodate seasonal gas demand variability. Opposed to seasonal storage, peak gas storage has higher operational costs but its main advantage is that it is not restricted to seasons, plus it has faster extraction and injection rates. Hence, peak gas storage is better able to accommodate volatility of gas demand that is related to I-RES levels that does not necessarily have a seasonal pattern. Our results show that with increasing shares of I-RES and additional seasonal storage capacity, the gas demand from the power sector is not affected while the impact is significant with additional peak storage capacity which increases the gas demand from the power sector. With additional electricity storage, extreme events due to I-RES can be directly accommodated within the electricity market, reducing the need for flexible generation of NGFPPs.

Conclusions

The electricity and gas markets are interdependent due to NGFPPs operating in both markets. This brings forward the necessity to analyse the two markets in an integrated fashion. In this study, an integrated G&E market model is formulated that is able to analyse short-term price and volume interactions in the G&E market on an hourly basis while also considering ramping rates, peak and seasonal gas storage, electricity storage, and I-RES variability. To our knowledge, none of the existing integrated G&E market models that can model the short-term interactions differentiates the flexibility capabilities of different sources in both markets on this level of detail. Furthermore, we introduce a single optimization problem which finds the market equilibrium of the integrated G&E market assuming that the G&E markets are perfectly competitive. Thereby, computational time has been improved significantly allowing for solving large-scale systems. The analysis presented in this study shows that the price-volume interaction between the G&E markets becomes stronger with increasing I-RES generation. Furthermore, the availability of flexible gas supply (i.e., peak gas storage) in the gas market becomes more important to determine the competitiveness and the future role of gas power plants in the electricity market. Although the conclusions cannot be generalized yet to the European system since the results are derived from a test case, our modelling approach allows for a more detailed analysis of energy systems on a large geographical and temporal scale. In the future, the model will be extended to a European scale including all hours in a year so that we can analyse important issues such as the future role of gas in the European electricity market under increasing shares of I-RES generation.

References

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