Modeling Coal and Natural Gas Markets

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Abstract

Coal and natural gas market modeling has seen an impressive upsurge in the last decade. After a long period with a focus on optimization models, complementarity models have been developed since the 1980s and seen a renaissance after 2000. Such models are also called equilibrium models as they allow representing a market game and its equilibrium solution. First versions of complementarity models of the coal and natural gas markets were used to analyze the market structure of the international commodity trade. While they confirmed an oligopolistic market structure in the European natural gas market, the global coal market has been found to be competitive. Moreover, infrastructure analyses are carried out with such models that allow detecting bottlenecks and, in multiperiod models, computing cost-efficient capacity expansions. Other recent advances besides multiperiod modeling are the modeling of multilevel games and stochastic models. Emerging topics are related to computational methods and a better understanding of both energy sectors. Among the challenges to the modeling community are the ongoing shortcomings of publicly available data and an improved understanding of the mathematical modeling and solution approaches by economists. Finally, both sectors are subject to a climate policy constraint which may well lead to a considerable shift in the importance as well as in regional consumption patterns of coal and natural gas and, hence, require improved modeling analysis.

INTRODUCTION

The modeling of coal and natural gas markets has traditionally focused on the international trade of these energy commodities. This relates to trade of natural gas through high-pressure pipeline or in form of liquefied natural gas (LNG), and the trade of steam coal on the seaborne market. In the standard modeling literature of coal and natural gas markets, each sector is investigated on its own, that is with a supply and demand representation of this sector only. These sector-specific models (sometimes also called "partial equilibrium models") have the advantage to represent more complex supply

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structures compared to energy system models where the substitution relation with other energy commodities is included.

More particular, it will be explained in the following that sector-modeling of coal and natural gas trade allows for the analysis of market power, in particular on the supply side. This is a highly relevant feature in markets with very concentrated supply structures. Monopolies, cartels, and oligopolies can be modeled in this framework, as well as perfectly competitive markets.

Other questions than the existence of market power that are being investigated with models of the coal or natural gas markets are supply security and investment requirements in infrastructure, and more recently the interaction with climate policies. A concentrated supply structure is often accompanied by congested infrastructure and even more so in situations of increasing demand (e.g., opening of new markets, increasing energy demand in emerging economies). This leads both to supply security concerns because of few suppliers/supply routes available to supply a certain market and to the necessity to expand transport infrastructure (export ports, pipelines, or import ports). It may be of commercial or public interest to build or expand infrastructure, and the economic modeling provides indications where the investment would be most needed.

The models usually represent the supply chains in a quite detailed manner, although some approximation of the complex technical processes has to be made to deal with solvable models. In the coal sector, the models include the following players:

- producers (combining the activities of exploring, extracting, and preparing/washing the coal in a single supply function)
- exporters (or export ports)
- shippers
- final demand by an importing country, where the demands by various consumers (in general, power producers) are aggregated.

Similarly for the natural gas sector, (a selection of) the following players are represented in the models:

- producers (here, too, combining the activities of exploration, extraction, and processing the natural gas)
- (dedicated) traders (which may be dedicated to a specific producer)
- LNG players: liquefaction, shipment, regasification
- pipeline operators
- storage operators (for seasonal arbitrage over the course of a year)
- final demand (aggregating the national demand from the three sectors using natural gas, namely power generation, industry, and residential/commercial).

This field of research is characterized by an interaction of economists with applied mathematicians from operations research. With the level of detail and the computational methods, the modeling of coal and natural gas markets is part of the same literature in energy economics and applied operations research as electricity market modeling. It has only a lose relation to traditional resource economics which consists mostly in the modeling of a reserve constraint that producers have to respect in the long run.

FOUNDATIONAL RESEARCH

Optimization Modeling

Following the development and wide-spread application of (linear) optimization methods after World War II, this method has also been used in energy economics since the 1960s. Sectoral modeling using linear programming/optimization (LP) solution techniques allows for a great number of technical details to be included in the models, albeit with the simplifying requirement of using linear functions. Such models have found large interest in academia and even more so in the strategy and operational departments of energy companies where they are still widely used today.

An optimization model consists of an objective function that is either maximized or minimized subject to constraints. Typically, the objective function is a total cost function that shall be minimized. A variant with welfare maximization of the specific sector is equivalent to a cost minimization problem given a certain demand level. The constraints are various technical details, for example, maximum production capacity of a mine, maximum throughput capacity of a pipeline. This makes optimization models attractive for companies where they are mostly used today because they are convenient for engineers and helping in day-to-day operational decisions. Generally, these models are static which means that they model one time period. The time period depends on the level of investigation: it can be very short (e.g., 1 h) for an operational analysis (e.g., of a natural gas network) or much longer for strategic analysis (e.g., 1 year). Many models include an optimization of network flows based on graph theory to compute cost-minimal pipeline flows.

The economic assumptions in optimization models are rather simple: with cost-minimization being the objective and the assumption that market prices are equal to the sum of all marginal costs along the value chain (production plus transportation, etc.), these models implicitly assume perfect competition in the markets. In many regions, such as natural gas markets in Europe and Asia, but also coal markets in the US and globally in the 1980s, this assumption has seemed too strong given the small number of suppliers and apparent price levels above (marginal) costs.

Hence, more advanced computational methods have increasingly been used by economists since the 1980s. This was possible with the development of advanced solution algorithms and solvers as well as easily accessible software for economists (namely, GAMS, the standard software used by energy market modelers today). A different class of models than optimization problems is used nowadays: so-called complementarity (or equilibrium) models.

These models consist of the so-called Karush-Kuhn-Tucker (KKT) optimality conditions. The KKT conditions are obtained by deriving the first-order (hence, optimality) conditions of the optimization problem (objective function and constraints) of the players. The Hence, a complementarity model also calculates the optimal solution to an economic problem and follows a similar understanding of the market in question as in optimization models.

However, in contrast to optimization models, in a complementarity model, the optimization problems of several, interdependent players can be solved simultaneously. This allows for a more adequate modeling of a market, with an interaction of supply and demand (i.e., supply functions and demand functions) and with strategic behavior of the suppliers. Hence, perfect competition is not a necessary assumption and one can model a situation with market prices higher than (marginal) costs, for example due to oligopolistic withholding.

This is a strong advantage of complementarity models for the economic analysis of energy markets and has led to an increasing use after 2000. In the 1980s, such models were first developed, in particular for coal markets (US and global markets, e.g., Kolstad & Abbey, 1984) and for natural gas markets (Europe, e.g., Mathiesen, Roland, & Thonstad, 1987). However, the solution algorithms (solvers) and the computer capacities were not yet advanced enough to replace optimization models. Owing to the KKTs, complementarity models have more constraints than optimization models which leads to higher mathematical complexity and computation time.

After some significant advances, in particular with the development of the PATH solver for GAMS, applied complementarity modeling saw a "renaissance" in the late 1990s. While in the 1980s the coal and natural gas sectors triggered the model innovations, it was the electricity sector that was precursor in the late 1990s. The coal and natural gas sectors this time were following behind and modelers of these sectors used model setups and solution techniques that were first used for electricity market analyses.

The early natural gas complementarity models of the 2000s focused on the European natural gas sector and analyzed imports and supply security. European natural gas markets were traditionally segmented with monopolistic national wholesale traders that imported within long-term contracts from a very limited number of suppliers. The import infrastructure (pipelines and import terminal of LNG) was dedicated to sales under long-term contracts. Hence, complementarity modeling was necessary to represent this market appropriately and in order to analyze such questions as infrastructure adequacy.

The first modeling teams were based in countries with a strong interest in a better understanding of international natural gas trade, namely Norway and the Netherlands (producing countries) as well the United States (a prospective large importer at the time). In Norway, Lars Mathiesen *et al*. were at the forefront of natural gas modeling; Rolf Golombek *et al*. developed a cost function approach that is still widely used in the natural gas and oil modeling literature (Golombek, Gjelsvik, & Rosendahl, 1995). In the Netherlands, Maroeska Boots and Wietze Lise developed and used the GASTALE model to which Benjamin F. Hobbs contributed (Boots, Rijkers, & Hobbs, 2004; Lise & Hobbs, 2008). Ruud Egging, together with Steven A. Gabriel, developed the European Gas Model (Egging & Gabriel, 2006; Egging, Gabriel, Holz, & Zhuang, 2008) which was later extended to the World Gas Model (Egging, Holz, & Gabriel, 2010). More recently, the Institute of Energy Economics at the University of Cologne in Germany moved from optimization modeling to complementarity modeling of natural gas (Hecking & Panke, 2012).

In complementarity models, too, a flow optimization in a network can be implemented. The modeling approach has the advantage, compared to optimization models, to allow for the implementation of a simultaneous, concurrent use of an (pipeline) arc by several players or even types of players. Moreover, in a complementarity model, the dual variable of a capacity constraint can directly be used in the equations of the model. The dual (or shadow) variable gives an economic value to an additional unit of the constrained capacity, for example, the implicit economic valuation of a marginally higher pipeline capacity. The information on the value of a constrained arc can, for example, directly be used in the pricing formulae of the arc transportation.

The resurgence of coal modeling came some years after that for natural gas and followed some few empirical analyses. The international steam coal market seems to be characterized by a less complex institutional structure, in particular because of lower asset specificity of the export/import infrastructure (ports, ships), and a more diversified supply structure. However, increasing concentration of producing companies in the last decade has raised the interest of economists, too. Hence, first modeling efforts were directed at market structure analysis and market power detection, for instance with the Coalmod-Trade model by Haftendorn and Holz (2010) and for more recent years by Trüby and Paulus (2012). For both, coal and natural gas markets, there is a strong limitation of data availability: because company information, for example on costs, is hardly available, most models use country data. However, price and quantity results give an acceptable approximation and allow to detect if there is exertion of market power.

CUTTING-EDGE RESEARCH

The first complementarity models of natural gas and coal markets that are mentioned above were static one-period analyses with perfect competition or Cournot competition (i.e., one-stage games). They served for market structure analysis or the identification of infrastructure bottlenecks. Cutting-edge research today goes in three main directions:

- multiperiod modeling with endogenous investment decisions (usually in transport infrastructure),
- stochastic modeling,
- multilevel games with sequential decisions, for example, Stackelberg games, and other games with joint constraints by several players (Generalized Nash equilibrium problems).

MULTIPERIOD MODELS

Multiperiod models of coal and natural gas markets are usually based on a net present value optimization by rational players with perfect foresight. These models go beyond the identification of bottlenecks in infrastructure. Their results also show which infrastructure will be economic to be built, as a result of a complex interaction of minimization of investment costs and variable costs of infrastructure utilization, for an endogenously computed level of transportation and commodity demand in each period. Computing such settings with several optimization problems and market equilibrium while having a relatively large number of endogenous variable types is a strength of the complementarity approach.

Several such much models of the European or global natural gas markets and of global coal markets are currently in use. A state-of-the-art example in natural gas market modeling is the World Gas Model (Egging, Gabriel, & Holz, 2010); for coal markets, the COALMOD-World (Haftendorn, Holz & Hirschhausen, 2012) was the first of its kind. The models usually cover time periods until 2030 or 2050 in 5-year steps. An increase in the number of time steps more than proportionally increases the computation time (often exponentially); hence, the relatively small number of model periods.

In game-theoretic terms, the multiperiod models today are open-loop models based on a perfect foresight assumption. In the open-loop approach, the decisions for all periods are taken at once in a single intertemporal optimization over the entire model horizon. All players are assumed to have perfect and complete information on the outcomes of all (current and future) periods. This is a strong assumption, which is necessary to remain in the framework of (non-) linear complementarity modeling in which the KKT optimality conditions give the unique solutions. Open-loop models have the advantage of a limited solution space that ensures unique equilibrium results (under some conditions). Hence, they can be solved numerically in the mixed complementarity format (cf. Gabriel, Gabriel, Conejo, Fuller, Hobbs, & Ruiz, 2012).

After market structure analyses were in the focus of economic studies with static market models, multiperiod models are used to study the long-term perspectives of the resource markets, in particular under climate policy constraints. Hence, scenario analyses are current contributions to the literature with multiperiod natural gas or coal market models. Such climate policies can be varying levels of CO_2 prices, export taxes on fossil fuels, or (mandatory) consumption reductions (see e.g., Haftendorn, Holz, Kemfert, & Hirschhausen, 2013).

Not all functions of the models in use are well-founded, both in their functional form and the data input. This is a problem both on the demand and the supply side. On the supply side, cost functions for production, transportation, and investment must be included in the model. They are often assumed to be linear to ensure convexity of the optimization problem. More complex functional forms than linear functions are possible and could potentially enrich the models. Only for production costs, an alternative curve has become a standard assumption in the European literature: it is assumed that (marginal) costs are increasing, with a strong rise close to the production capacity constraint (the often called "Golombek cost function", mentioned above). However, this cost function still has to be introduced in multiperiod models that allow for endogenous investment decisions in the production capacity. Huppmann (2013) has paved the way for this model extension.

Stochastic Modeling

Another stream of literature at the current research frontier is stochastic modeling. While this approach has not been applied for coal market models yet, there have been a few applications to natural gas markets (e.g., Zhuang & Gabriel, 2008). As for deterministic models, the availability of perfect and complete information is assumed. The stochasticity consists in having multiple possible realizations of a variable. The realizations are predetermined and are assigned a known probability of occurrence.

Computing the outcome of a stochastic model has the advantage to include the reaction of the players to uncertainty. This can lead to a different outcome than in a deterministic model and it is also different from the average of the outcomes of the equivalent deterministic models of each stochastic scenario. Similar to (deterministic) multiperiod models, the number of nodes in the scenario tree cannot be extended at will due to the more than proportional increase of computation time.

Multilevel and Coupled Constraint Models

A third advance in the recent literature of coal and natural gas modeling deals with the application of multilevel and coupled-constraint games. Even in a relatively simple market setup with sequential decisions as a Stackelberg game with one leader and a few Cournot-playing followers, there can be more than one solution. A Stackelberg game describes a sequential "leader-follower" problem and can be used to describe market structures with a high concentration in market power by just a few of players (e.g., OPEC in the oil market).

In general, if the feasible set of a player type depends on the decisions taken by other players, multiple solutions are possible and numerical algorithms face problems. Hence, there is a challenge to reduce the solution space to the only reasonable solution(s). This challenge is even greater with more complex models, for example with several leaders competing in addition to the game between the followers. Multilevel complementarity models are either mathematical programs with equilibrium constraints (i.e., optimization problem of one player in the first stage) or equilibrium problems (e.g., game of several players in the first stage) with equilibrium constraints (MPEC or EPEC, respectively). Clearly, they are a generalization of static game complementarity models.

KEY ISSUES FOR FUTURE RESEARCH

Several topics have recently emerged in the coal and natural gas market research. They would promote this field of research both in the complementarity modeling stream and with other modeling methods. In the following, the emerging topics will be discussed first, before presenting some major challenges for current and future research.

Emerging Topics in the Coal and Natural Gas Market Modeling

One major advance currently under research are new solution methods for computationally large problems, that is, multiperiod models, stochastic models, or multilevel models. In these large models, it can often be helpful to reduce the solution space in order to decrease the model running time to a feasible duration (or in some cases to obtain a solution at all). Branch-and-cut or decomposition methods have been experimented with in the natural gas modeling literature so far. Other methods may emerge in the future.

Optimization and complementarity models depict market settings that are well-founded in economic theory, namely perfect competition and Cournot competition, sometimes also a bilevel Stackelberg market or monopoly. However, the player's optimization problems in real world are more complex than in the abstract economic theory and richer formulations may reveal new insights in the players' behavior and the market structure. For example, many companies in the natural gas market are entirely state-owned and are operated under different premises than standard profit maximizing, such as an objective of revenue maximization or employment maximization. Alternatively, a regulated player may also have to obey to rules that are not covered by the standard perfect competition model, for example, certain pricing rules. It is not straightforward to include such deviant objectives in a standard optimization or complementarity model and other modeling techniques can more easily accommodate them. In particular, agent-based modeling is a promising approach to include complex objectives. This method has, however, the drawback of a lack of theoretical foundation of its economic relations.

For any modeling approach to be used, a considerable improvement of the understanding and modeling of reserves is needed. This entails several aspects: first, the mechanism how (uneconomic) resources become (economically exploitable) reserves needs better understanding in order to derive a general relation that can be included a model. Second, the impact of reserve depletion on the production cost function is hardly taken into account in the models so far. One can assume that low-cost reserves are produced first and that higher-cost ones remain in the ground for longer, but that at the same time a variety of types of basins are in production. Hence, one can assume an upward shift of the cost function over time. A seminal contribution by Haftendorn (2012) to long-term coal market modeling gives an example of an integration of reserves in the cost function. Third, unconventional resources need to be included in the models, for example shale gas. The models usually only include information on the reserves, but not on the resources. Obtaining this information is hard for most types of resources, but for some such as shale gas more and more information has become available.

Challenges to Coal and Natural Gas Market Modeling

The availability of data is one of the major challenges for coal and natural gas market modeling. In particular access to supply side data, such as production costs, is very limited for the scientific community. It is somewhat better for companies of the energy industry (utilities, consultants). However, statistical information by the International Energy Agency (OECD) and the Energy Information Administration (U.S. Department of Energy), as well as organizations close to the industry (e.g., IEA Clean Coal Centre for coal, Observatoire Méditerranéen de l'Energie for natural gas) and recent research efforts (e.g., the Global Energy Assessment) provide a satisfactory basis for sound academic research.

Another major challenge for the further development of coal and natural gas market models, in particular the complementarity models is the increasing mathematical complexity of the modeling and solution techniques. An improved understanding by economists of the advanced mathematical modeling is needed and requires more and more involvement of mathematicians in addition to economists and engineers in the modeling community.

If more complex and nonstandard objectives and constraints are to be included in the models, a better understanding of the real-world players' behavior and optimization problems is needed. Experimental economics has started to investigate some aspects of energy markets (e.g., auctioning of transportation capacities), but there remain plenty of topics to be examined. This will also be a valuable input for nonstandard models such as agent-based models of the natural gas or coal markets.

Last but not least, the looming transformation of the energy systems under climate change and climate policy pressure may well lead to a strong reduction of the consumption of coal and natural gas, hence to a disappearing object of analysis of natural gas or coal market modeling. Owing to different carbon intensities, fossil fuels are presumably differently affected by climate policies due to differing carbon intensities. This calls for using models of the entire energy system, ideally in the same modeling format as the state-of-the-art coal and natural gas market models (i.e., complementarity modeling) which allows for the representation of market power in order to be able to investigate the effects of systemic changes on coal and natural gas markets. A first such modeling step was suggested by Egging and Huppmann (2012) in a multifuel complementarity model.

In conclusion, the modeling techniques and experience of coal and natural gas modeling are potentially relevant for modeling other (nonenergy) resource markets, for example, metals and rare earths.

REFERENCES

Boots, M. G., Rijkers, F. A. M., & Hobbs, B. F. (2004). Trading in the downstream European gas market: A successive oligopoly approach. *The Energy Journal*, *25*, 73–102. doi:10.5547/ISSN0195-6574-EJ-Vol25-No3-5

Egging, R. G., & Gabriel, S. A. (2006). Examining market power in the European natural gas market. *Energy Policy*, *34*, 2762–2778. doi:10.1016/j.enpol.2005.04.018

Egging, R., Holz, F., & Gabriel, S. A. (2010). The World Gas Model: A multi-period mixed complementarity model for the global natural gas market. *Energy*, *35*(10), 4016–4029. doi:10.1016/j.energy.2010.03.053

Egging, R., Gabriel, S. A., Holz, F., & Zhuang, J. (2008). A complementarity model for the European natural gas market. *Energy Policy*, *36*(7), 2385–2414. doi:10.1016/j.enpol.2008.01.044

Egging, R., & Huppmann, D. (2012). *Investigating a CO_2 tax and a nuclear phase out with a multi-fuel market equilibrium model*. 9th International Conference on the European Energy Market (EEM) 2012 IEEE, Florence. 10.1109/EEM.2012.6254690

Gabriel, S. A., Conejo, A. J., Fuller, J. D., Hobbs, B. F., & Ruiz, C. (Eds.) (2012). *Complementarity Modeling in Energy Markets* (pp. 1–629). Springer. doi:10.1007/978-1-4419-6123-5

Golombek, R., Gjelsvik, E., & Rosendahl, K. E. (1995). Effects of liberalizing the natural gas markets in Western Europe. *Energy Journal*, *16*(1), 85–111. doi:10.5547/ISSN0195-6574-EJ-Vol16-No1-6

Haftendorn, C. (2012). *Evidence of market power in the Atlantic steam coal market using oligopoly models with a competitive fringe*. DIW Discussion Paper 1185, Berlin. 10.2139/ssrn.2006496

Haftendorn, C., & Holz, F. (2010). Modeling and analysis of the international steam coal trade. *The Energy Journal*, *31*(4), 205–229. doi:10.5547/ISSN0195-6574-EJ-Vol31-No4-10

Haftendorn, C., Holz, F., & Hirschhausen, C. V. (2012). The end of cheap coal? A techno-economic analysis until 2030 using the COALMOD-World model. *Fuel*, *102*, 305–325. doi:10.1016/j.fuel.2012.04.044

Haftendorn, C., Holz, F., Kemfert, C., & Hirschhausen, C. V. (2013). Global steam coal markets until 2030: perspectives on production, trade and consumption under increasing carbon constraints. In R. Fouquet (Ed.), *Handbook on Energy and Climate Change*. Cheltenham, England: E. Elgar.

Hecking, H., & Panke, T. (2012). *COLUMBUS—A global gas market model*. EWI Working Paper 12/06.

Huppmann, D. (2013). Endogenous investment decisions in natural gas equilibrium models. *European Journal of Operational Research*, *231*(2), 503–506. doi:10.1016/j.ejor.2013.05.048

Kolstad, C. D., & Abbey, D. S. (1984). The effect of market conduct on international steam coal trade. *European Economic Review*, *24*(1), 39–59. doi:10.1016/0014-2921(84)90012-6

Lise, W., & Hobbs, B. F. (2008). Future evolution of the liberalised European gas market: Simulation results with a dynamic model. *Energy*, *33*(7), 989–1004. doi:10.1016/j.energy.2008.02.012

Mathiesen, L., Roland, K., & Thonstad, K. (1987). The European natural gas market: Degrees of market power on the selling side. In R. Golombek, M. Hoel & J. Vislie (Eds.), *Natural Gas Markets and Contracts, Contributions to Economic Analysis*. Amsterdam, The Netherlands: North-Holland.

Trüby, J., & Paulus, M. (2012). Market structure scenarios in international steam coal trade. *The Energy Journal*, *33*(3), 91–123. doi:10.5547/01956574.33.3.4

Zhuang, J., & Gabriel, S. A. (2008). A complementarity model for solving stochastic natural gas market equilibria. *Energy Economics*, *30*(1), 113–147. doi:10.1016/j.eneco.2006.09.004

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