Agent-Based Modeling of Natural Gas Systems

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Abstract

Energy systems models are computational frameworks designed for evaluating effects of different energy policies or regulations on the evolution of energy systems and the broader economy.

Energy systems modeling field is mainly developed by economists. Therefore, similar to other neoclassical economic models, the traditional energy systems models incorporate underlying assumptions about individuals rationality and seek an equilibrium point in the energy market [1]. The natural gas market however, undergone an abrupt change due to rapid development of shale gas industry. Consequently, the natural gas price became much more volatile, and market evolved to a non-equilibrium market in which information is local and market players have bounded rationality. Therefore, traditional natural gas systems models can not capture the growing complexity of the natural gas systems due to their underlying methodological constraints [2].

The goal of this study is to address this methodological gap by developing a natural gas system model using agent-based modeling (ABM) approach. ABM approach offers advantage over traditional methods since it can consider path dependency, infrastructure topology and constraints, and non-equilibrium aspects on the energy market.

Evolution of Natural Gas Market

The U.S. natural gas market is relatively deregulated and liberalized. However, the Federal Energy Regulatory Commission (FERC) plays the major role in structuring the natural gas market through giving permissions to the major natural gas infrastructures such as pipelines, storage, and liquefied natural gas (LNG) export facilities.

The proposed agent-based model aims to assist decisions of FERC by providing insights that is actionable and robust to future uncertainties.

Such a modeling approach can facilitate our understanding about the boom-bust dynamics of natural gas market as well as the path dependency that would be generated by major natural gas infrastructures.

Dynamics of natural gas market emerges from large numbers of interactions among heterogeneous and semi-autonomous agents including supply agents, pipeline agents, storage agents, hub agents, and demand agents that cover all actors involved in the U.S natural gas value chain.

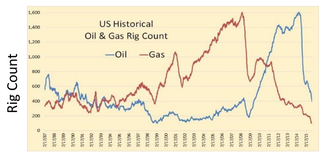

Figure1: Increase of volatility in the US oil and NG rig count (Baker Hughes Rig Count)

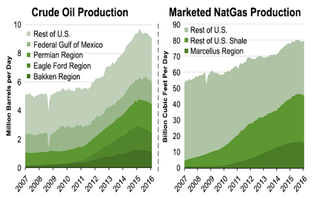

Figure2: The U.S. crude oil and NG production [3].

Modeling Approach

In this model, ***agents*** are geographically explicit and connected to a network of pipelines. Heterogeneity of agents is represented by considering different company sizes, and business models that require different decision-making rules, and behavioral patterns.

Agent's decisions are related to short-term and long term dynamics of the model. Short-term set of decisions determine the quantity and the price for trading natural gas on daily basis. Long-term set of decisions determins agents investment in new projects and infrastructures. EIA, PA DEP, and Bloomberg databases are used to construct and calibrate this model.

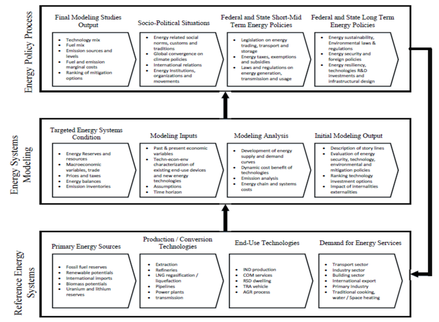

Figure3: The role of Energy systems modeling in Energy policy Formation.

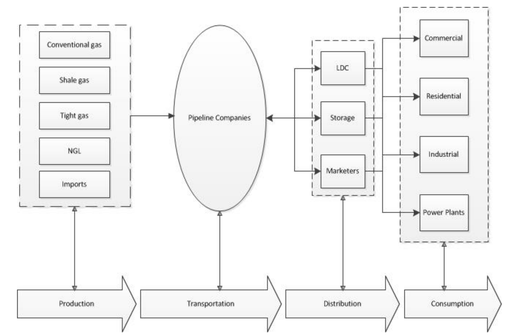

Figure4: A schematic view of a natural gas system.

Variety of methods are integrated in this model including:

- Auction Theory for representing natural gas spot market
- Network modeling used for interconnections of agents through network of pipelines
- Deep First Search (DFS) algorithm is used to find maximum available pipeline routs between a supplier hubs, and demanders.
- Long-term decisions of agents are investment decisions such as investing in new wells using corporate financial modeling approaches.
- Fuzzy variables are used (market is *hot,* or natural gas price is *high)* used to mimic the decision behavior of agents.
- Regression modeling used for forecasting demands
- Embedded optimizer engine in the AnyLogic 8.0 used for model calibration against EIA natural gas market data.

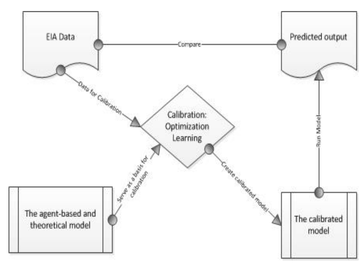

Figure 5: The US North East NG Infrastructures (EIA).

Figure 6: A schematic view of model calibration approach.

Number of Agents :

- 120 Supplier Company Agents
- 5 Pipeline company agents
- 620 Consumer agents of different sectors (Utility, Industrial, Residential and Commercial).
- 61 Storage agents
- 15 Hub agents

Methodology	Pros	Cons
Optimization and Equilibrium models [4].	• Capability to model entire economy – long term scenarios. • Capability of considering detail technological aspects (OR methods). • Prediction of national or international trends.	• Ambiguous large datasets. • Models are too big and weak in computational tractability, repeatability and in transparency. • They are mainly source of possible storylines rather than fundamental truth. • Epistemic uncertainties (arises through imperfect knowledge). • Insufficiency in handling uncertainties (stochastic programming as possible solution). • Old user interfaces. • Only useful from the social planner point of view (not private sector). • Too simplified and unreliable in long term.
Agent-based Modeling	• Capability to capture and explore wide range of behavioral complexity. • Repeatability and traceability • High transparency • Proper for investment planning and operational strategies • Capability in analysis of learning and adaptation • Proper for market design and consumer impact issues (regulators), analyzing strategic issues (private sector).	• Harder to model bigger systems. • Lack of required data. • Hard to code complex behaviors (difficulties of understanding the operation in an energy system). • Hard to validate. • Lack of empirical theories to support assumptions.

Data Integration Approach

This agent-based model is geographically explicit which incorporate latitude and longitude of all agents (e.g. wells, pipelines, storages, and demand nodes). Besides diverse databases of EIA and PA DEP has been used in this model which made the database integration highly challenging. We used Google Map API to populate locations of agents in an interactive fashion.

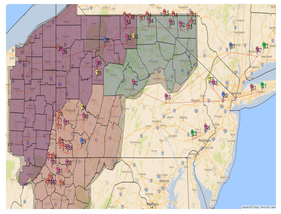

Figure 7: Using Google map to integrate databases.

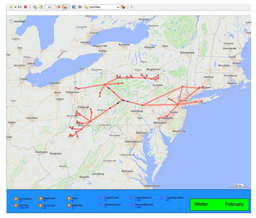

Figure 8: Imported data in the simulation model.

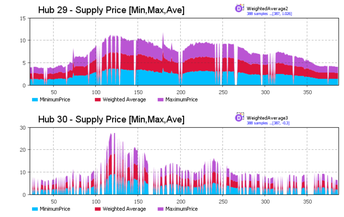

Figure 9: Fluctuation of natural gas price at different hubs.

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References

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