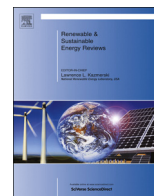




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# A system dynamics analysis of technology, cost and policy that affect the market competition of shale gas in China



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## ABSTRACT

In order to ease environment pressure and alleviate the scarce problem of energy, Chinese government has begun to exploit and develop shale gas (SG) since 2009. However, the formation of competitive market is bristled with difficulties, due to its infancy, imperfect and lack of standardization. This paper firstly analyzes the status quo of technology, policy, cost, and competition of SG industry in China. Then a system dynamics (SD) model is built to show various trends of Chinese SG industry under different scenarios, which shows that technology, policy and cost all have effects on competitiveness. At last, the simulations reveal that the number of competitors in Chinese SG industry will arrive at its peak from 2019 to 2020. The corresponding recommendations have been presented: Chinese government should pay more attention on the perfection of laws and regulations of SG industry. And competitors should focus on increasing R&D investment.

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## 1. Introduction

As a coal-dominated energy structure country, China is suffering from serious environmental problems. It has become a significant energy strategy for China to develop clean energy. Natural gas, a type of clean energy, is becoming increasingly popular. Gas consumption increases year after year. However, China's conventional natural gas reserves fail to meet the increasing demand of gas. Therefore, reliance on imported natural gas poses a great energy security threat to China. More than 31.6% of the gas consumption relied on foreign supplies according to statistics in 2013 [1]. Energy security in China will become more serious over time. Fortunately, China has huge reserves of shale gas (SG) which is a type of unconventional natural gas [2–4]. It will be expected to effectively alleviate above problems when SG begins to be commercially exploited to a certain extent. Many scholars having studied the SG industry believed that SG development is an energy revolution which will have a great influence on the world energy landscape [5–7]. Many regions around the world like European countries, Australia and China begin to research or exploit SG after the US.

Chinese SG industry has been in the forming stage since 2009 and SG market is easily monopolized, which is unfavorable for technology progress, cost reduction and market competition. Competition benefits to realize efficient use of energy resources and low extraction cost. Therefore, healthy and competitive SG market is particularly important to China energy strategy. In fact, SG market is affected by complex technology, cost and policy factors in China because of deeper burial depth and more complex geological conditions [8–11] and further, these factors have significant influence on the competition of SG market [12]. Some scholars qualitatively listed several key factors affecting the SG industry competition: technology, cost and policy [13–19]. Hu and Xu [15] advocated that the increase of researches on SG exploitation and government subsidy might benefit SG industry development. However, the influence mechanism between these factors and their influence on SG market is lack of quantitative research in detail. This paper aims to analyze these factors affecting the competition of SG market and corresponding influence on competition. Qualitative and quantitative methods are applied to ensure comprehensive and sufficient argumentation.

We try to choose a system-analysis model that can analyze complex system to study the above issues. Estimating the influencing mechanism in an industrial section is a complex problem due to the presence of multiple technological limitations, feedback processes among subsystems, and various kinds of delays. System dynamics is a suitable approach to such a complex model. System dynamics (SD) approach, established by Forrester [20], has been widely used in socio-economic studies. Many researchers developed SD models to analyze industry in various districts all over the world [22–24]. SD also has wide application in energy field. Feng, Chen and Zhang developed a model to study the energy consumption and CO<sub>2</sub> emission trends of Beijing from 2005 to 2030 [25]. Naill presented an SD model of gas industry dynamics in the United States. He demonstrated technological, physical, economic and political factors that might alter the gas industry [26]. Movilla, Miguel and Blázquez [27] used SD to analyze the behaviors of the photovoltaic sector in Spain and its expectations in some possible scenarios. Ansari and Seifi studied energy consumption and CO<sub>2</sub> emission in Iranian cement industry under various production and export scenarios based on SD model [28]. Kiani and Ali presented a system dynamic model which considers the feedback between supply and demand and oil revenue of the existing system in Iran considering different sectors of the economy [29]. Chyong, Nuttall and Reiner presented an SD model of the indigenous natural gas industry in the UK [24]. Therefore, advantages of using SD model to

analyze the influences of complicated factors on industry competition are obvious from the published literatures mentioned above.

In conclusion, it is very important to form a healthy market in an orderly and efficient way because of the strategic importance of SG. Through literature comparison, we find that SD model is a feasible method to analyze the competition of SG industry. In this paper, we build the SD model and analyze the influence of technology, cost and policy on the SG industry. The results and conclusions will be helpful for government to formulate policies, and for enterprises to make decisions.

## 2. System dynamics method

SD method was originally developed to help corporate managers to improve the understanding of industrial processes [20]. SD focuses on describing endogenous feedback structure of a system. The word “endogenous” means growing from a system. An endogenous structure generates the dynamics of a system through the interaction of variables and actors represented in the model [30]. It is an important method to learn and solve problems of complex system. It emphasizes to take a view angle to treat the research issues systematically and objectively.

Through modeling feedback structure, one can better understand dynamic complexity that can be found in situations where the same action has different effects in the short and the long run, and where an action has one set of consequences locally and a different set of consequences in another part of the system. It has been argued that real leverage in many management and economy situations lies in understanding dynamic complexity. System dynamics has been widely utilized to study dynamic behaviors of various social systems, and has been applied in policy formulation and analysis both in the public and private sectors.

To be specific, the SD model mainly includes the following steps:

- 1) Analyzing system structure to understand elements of the system and relationships among them. This step allows researchers to get a clear boundary of a system and find out the systematic characteristics and structures macroscopically.
- 2) Establishing flow diagram to further describe logical structure of the system. The modeling elements can be divided into level variables, rate variables and auxiliary variables. They reflect the nature of the analyzed object correctly with standard symbols.
- 3) Constructing the equation for these variables in a flow diagram to analyze the quantitative relationships between them clearly. The essence of SD equations is taking a differencing treatment towards a series of differential equations. On the one hand, it describes the relationships between the variables in mathematical form. On the other hand, it also reflects the recursive relationships between the variables. The construction of equations makes it easy to analyze a complex system with computer simulation.
- 4) Entering these flow charts and equations into computer simulation environment to simulate, debug, and examine the model so that we can adjust control variables in the model to study the influences of different factors on the system.

## 3. System dynamics model of SG industry

### 3.1. Structure analysis of competition system

The exploitation of SG calls for high level of technology. When technology barriers decline or even disappear, market competition may become fierce for the reason that more companies acquiring

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