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RESEARCH PAPER

Iranian Natural Gas Production and Trade Behavior under Unconventional Gas Developments: A System Dynamics- Agent-Based Modeling Approach

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Abstract

Forecasting a growth in gas demand in the next 20 years, the Shale gas expansion, and major developments in the gas regional markets, show structural changes in gas trade. The question is whether the U.S. shale production expansion and the emergence of strategic resources in Iran, to increase its gas trade share in the Middle East, can cause a significant change in the world gas trade or not. Accordingly, the aim of this study is a systematic analysis of Iran's natural gas production. The system dynamics-agent-based modeling has been used to achieve this goal due to the dynamic nature of natural gas production and trade in Iran and its global trade in 2015-2035. The results show that the U.S. will become the largest gas trader in North America from 2020 onwards. Iran's share in gas exports of the Middle East gas trade has a trend in the form of a reversed U shape. By continuing the current status, Iran's percentage share will be reduced to less than 5%. This rate in the SD -AB model, which has a higher accuracy than the SD model, can reach over 35% by 2035 through the scenarios of a 75% increase in the exploration rate, a 20% increase in investment in development, and a 5% increase in investment in technology improvement. Based on these results, we can expect important changes in world gas trade during the next two decades.

Keywords: Conventional Gas, Iran, Shale Gas, System Dynamics-Agent Based Modeling, United States.
JEL Classification: C15, D24, F13.

1. Introduction

"Are we entering a golden age of gas?" This is an important question put forward by the International Energy Agency (IEA) in its Special Report "World Energy Outlook (WEO)" in 2011. IEA has reported an increase in world demand for gas from 2030 to 2050. According to WEO reports, gas has been the only fuel, among all fossil fuels, whose production has increased the most since 2011. This has been also noticed by Li et al. (2011).

Another noteworthy point in the IEA report is its attention to unconventional gases, particularly Shale. Based on predictions, U.S. Shale will have accounted for about half of the world's increase in gas production by 2035. Nevertheless, if the worries aroused by the development of Shale are not removed, this issue can put an end to the unconventional gas boom. This has also been discussed in Eker and Van Daalen (2012) in the Netherlands. Despite the Netherlands' emphasis on the replacement of conventional gases with unconventional gases, the study has not addressed environmental issues and challenges. This has been focused on through newer dimensions in Moorlag et al. (2014 & 2015). Comparing the results of Moorlag et al. (2014) and Holz et al. (2008), shale gas expansion has converted the impact on the security of the world energy supply from an unjustifiable one (Holz et al., 2008) into a justifiable one (Moorlag et al., 2014). Moorlag et al. (2014) focused on the expansion of unconventional gases in an attempt to analyze the unconventional gas market through the use of a more precise model than the model used in their previous study.

In WEO (2019) has been pointed out that, according to the question posed in the 2011 report the world might be poised to enter a “Golden Age of Gas”, and now it appears that global gas consumption is very close to those 2011 projections. Since 2010, 80% of growth has been concentrated in three key regions: the United States, where the shale gas revolution is in full swing; China, where economic expansion and air quality concerns have underpinned rapid growth; and the Middle East, where gas is a gateway to economic diversification from oil.

Natural gas continues to outperform coal or oil in both the Stated Policies Scenario (where gas demand grows by over a third) and the Sustainable Development Scenario (where gas demand grows modestly to 2030 before reverting to present levels by 2040). However, the gas industry faces some commercial and environmental challenges as well as some major variations in the storyline in different parts of the world.

According to Figure 1, the share of Europe and North America in world gas production from 1980 to 2019 has a fully downward trend and in contrast, the share of Middle East natural gas production is ascending. In other words, trend lines of gas production shares in the Middle East and two other regions are converging in favor of the Middle East.

The gas production trends in the top 5 countries namely the U.S., Russia, Canada, Iran,[1] and Qatar showed that the highest level of gas production in the world has always belonged to the U.S. and Russia (Figure 2). However, from 2009

[1]. Analysis of natural gas markets in the world based on EIA, IEA and BP reports indicated that, from 2010 to 2019 Iran has become the world's largest gas reservoirs.

until now, the divergence trend in gas production between the U.S. and Russia came into existence in favor of the U.S. The main reason for this is the increase in the production of unconventional gas, especially shale gas in the United States. However, the shale reserves have been in a decline mode with a gentle slope since 2008. The comparison between Iran and Qatar as two neighboring countries (with common reserves in South Pars, the world's largest offshore gas field) is made in Figure 2. Iran until 2010 has always been producing at levels higher than Qatar, from 2011 to 2014, but Qatar has been able to maintain its production at a level higher than Iran. From 2014 to 2019, Iran's natural gas production is higher than Qatar's.

The analysis of the status of world gas (Figures 1 and 2) and according to British Petroleum (2020), indicates a structural change in the world gas production and the movement of it from Europe and North America to the Middle East. Moreover, there have been different trends in the production of gas in the United States and Russia since 2009, which indicates the superiority of the U.S. in gas production over these years. The main reason for this can be an increase in Shale production in the United States.

Another point to consider is the controversy between Iran and Qatar (Figure 2). Until 2010, Iran always had a higher production level than Qatar, but over the years 2011- 2014, Qatar was able to place its production rate at a higher level than Iran. The effects of this on the Iranian gas industry have been assessed by Kiani and Pourfakhraei (2010) and Samadi and Eidizadeh (2013) using System Dynamics (SD) modeling. However, in the last years of the period, Iran had a higher level of production than Qatar.

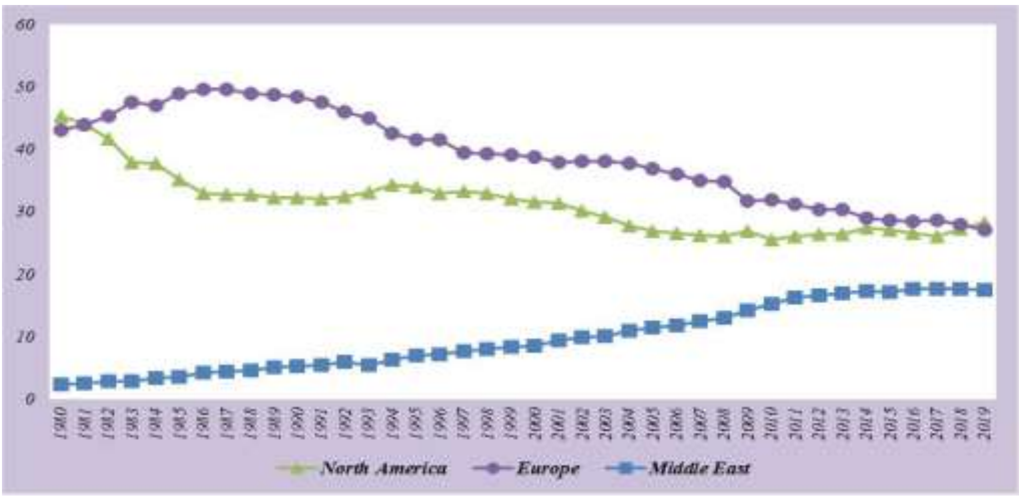


Figure 1. Gas Production Share: 1980-2019 (percent)

Source: BP[1], 2020; IEA[2], 2020.

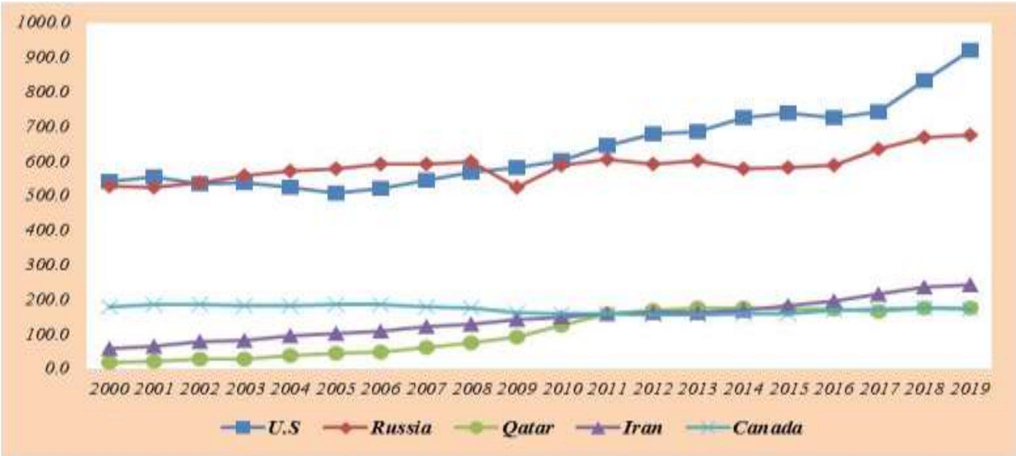


Figure 2. Gas Production in the Five First Countries in the World: 2000-2019 (bm^3)
Source: BP, 2020; IEA, 2020.

Regarding the natural gas industry in Iran, several issues can be mentioned in the context of the development of this industry. First, economic sanctions are challenged in the oil and gas industry. After the JCPOA[3] agreement in 2016, the European Union and the United States also removed many Iranian real and legal entities from the list of sanctioned individuals and entities, especially the U.S. SDN[4] sanctions list. This action led to the conclusion of numerous commercial and investment contracts in the post-JCPOA era, especially in the oil and gas industry (Razavi and Zainaldini, 2017).

According to Figure 3, which has drawn the growth trend of natural gas production for the three countries of Iran, Qatar, and Russia, the downward growth trend of Iran's natural gas production in the years 2016 to 2019 has turned into an upward growth in 2020. However, again in 2021, contrary to the trend of Qatar and Russia, which have experienced an upward trend, the growth trend of gas production in Iran has declined. This could be partly due to the return of economic sanctions on Iran’s oil and gas industry in 2018.

According to the CISADA[5], which was activated after the US withdrawal from JCPOA in 2018, the investment ceiling in Iran's oil and gas industry has been reduced from $ 40 million per year to $ 20 million. Given the importance of this issue and its role in creating obstacles to the development of Iran’s gas industry, in

1. British Petroleum
2. International Energy Agency
3. Joint Comprehensive Plan of Action, JCPOA
4. Specially Designated Nationals and Blocked Persons List, SDN
5. The Comprehensive Iran Sanctions, Accountability, and Divestment Act of 2010, CISADA

the scenarios sector, economic sanctions on the oil and gas industry have been considered.

Second, the outbreak of the Russia-Ukraine war in 2022 and the tensions in natural gas exports from Russia to Europe have provided an opportunity for other gas-exporting countries, including Qatar, the United States, and Iran, to expand their gas export markets. However, examining the impact of this issue on the development of Iranian gas exports and other GECF countries, in addition to economic dimensions, also has complex political dimensions that are considered outside the scope of the present study. It is important to note that such an opportunity for Iranian gas exports may be largely offset by the continuation of economic sanctions on the oil and gas industry.

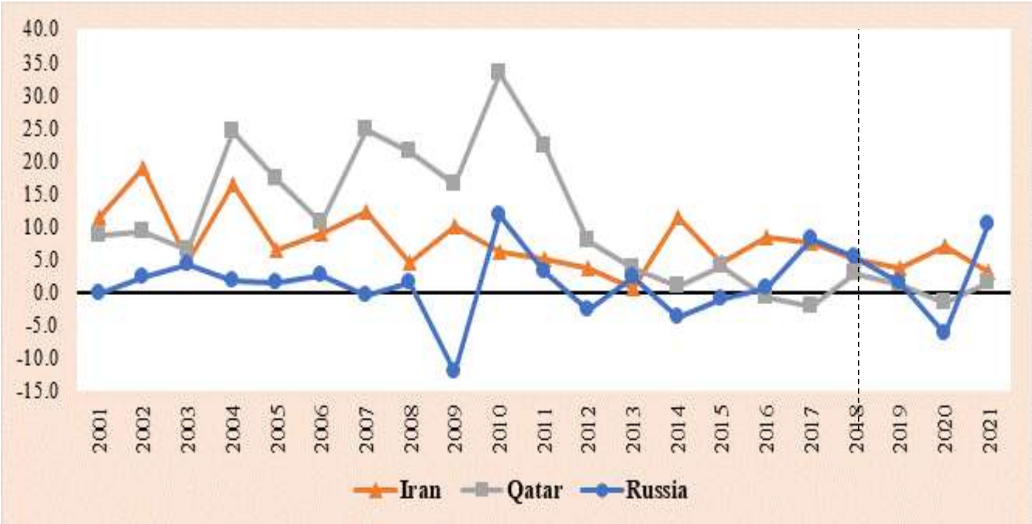


Figure 3. Growth Trend of Natural Gas Production in Iran, Qatar, and Russia: 2001-2021

Source: BP, 2021.

As there are high behavioral complexities in the mechanism of the world gas market, it's required to apply the System Dynamics (SD) approach. However, agent-based (AB) is another model which can be employed complementary to the SD model and which can significantly improve the modeling of the dynamics. Accordingly, the first contribution of this study is to combine SD and AB modeling, i.e., the so-called SD-AB modeling.

According to the Global Energy Reports (IEA and EIA), the most important natural gas events in the world (reality and forecast) can be considered as follows:

1- The beginning of the golden period of natural gas from 2011 onwards,

2- Qatar became the largest LNG exporter in 2015,

3- Allocating more than half of the increase in world gas production by 2035 to US shale gas.

Therefore, since the present study seeks to analyze natural gas in Iran and the impact of US shale gas development on natural gas trade in the Middle East, based on the above events, the period 2015-2035 has been selected as the period of the present study. The simulation of these 20 years can show important points of future developments in the field of natural gas.

Overall, the main purpose of this study is to design the structure of natural gas production and trade in Iran in the context of shale gas development in the United States within the framework of the SD-AB model and to develop scenarios for Providing an increase in Iran's share of gas exports in the Middle East. Accordingly, the most important questions of the present study are as follows:

1. If the current trend of gas production in Iran continues, what will be the forecast of the future situation of gas production until 2035?
2. Considering different scenarios, what will be the share of natural gas exports in Iran by 2035 in the Middle East region?

The rest of this paper is organized as follows: Literature review and methodology are discussed in sections 2 and 3, respectively. In section 4, results (including validation tests, scenarios, and sensitivity analyses) are presented. Section 5 is devoted to discussion. Concluding remarks are presented in the final section.

2. Literature Review

The natural gas market has considerable complexities with various factors that have complex behavioral interactions and mechanisms. Therefore, the use of system dynamics models can help to understand such complexities in predicting the future situation.

Chi et al. (2009) who analyzed several scenarios regarding the British gas industry within the framework of the system dynamics model from 1987 to 2000 can be considered one of the pioneering studies in this field. The results of their study indicate that the management of supply-side policies alone cannot postpone peak consumption, production, and exploration. Also, the dynamics of the main variables, i.e. exploration, production, and consumption, are sensitive to the initial conditions of demand. A low tax policy can encourage exploration and production and ultimately lead to an increase in energy consumption rates. Technological improvements mean lower exploration and production costs, which in the long run keep the dynamic price pattern low.

The expansion of unconventional gas production, emphasizing the high share of the United States and its important role in securing the world's energy supply, is a topic raised by Eker and Van Daalin (2013). These researchers believe that in the Netherlands, unconventional gas sources can be a suitable alternative to conventional gas, which will decrease significantly in the next 25 years. However, there are several uncertainties surrounding the development of unconventional gas in the Netherlands. The main goal of their study is to evaluate the effects of such uncertainties on the production rate of unconventional gases in the Netherlands. To achieve this goal, they have combined the method of modeling and exploratory analysis with the approach of system dynamics. The results of this study indicate that a wide range of possible production rates is provided by introducing various uncertainties into the designed model.

Moorlag et al. (2015) simultaneously deployed System Dynamics and Agent-Based models under deep uncertainty to discover and explore plausible scenarios for the development of shale gas and the effects on regional gas markets and regional import dependency. Among else, it is shown that regional economic growth is likely to have a larger impact on gas import dependency than the actual size of shale gas resources.

Xiao et al. (2017) presented a system dynamics model of the natural gas industry in China. A new system dynamics model for natural gas companies based on reserve exploration and well construction as well as investment dynamics is proposed. They found that the dynamics of the main variables, including gas policy, cost of investment, accounting depreciation, and exploitation technology, are sensitive to the sustainable development of resources. The simulations and results presented here will be helpful for the government to reform policies, and for upstream companies to make decisions.

Feofilovs et al. (2018) established a System dynamics model for natural gas infrastructure with a storage facility in the Latvian context. The results of the statistical analysis performed are reliable and the causal loop diagram explains the construct of the model appropriately. The hypothesis of the study is proved and the SD model presented in this study can be used for research on technological and social aspects of energy policy planning.

Guo and Hawkes (2018) simulated the game-theoretic market equilibrium and contract-driven investment in global gas trade using an agent-based method. The model simulates short-term game-theoretical market equilibrium with a Mixed Complementarity Problem approach. The results indicated that, when the US stays conservative in export expansion, gas supply tightness occurs, leading to continuing European dependence on Russian gas, and a shift to pipeline-based import in the Chinese market. Conversely, when the US invests aggressively, the Middle East and Australia both see significant revenue losses, and Western Europe constructs more regasification plants to provide alternatives to Russian supply.

Meza et al. (2021) applied an agent-based predictive model to the LNG market. The model is validated by comparing simulations with the historical record of the LNG trade in 2016 and 2018, reflecting its accuracy in replicating such real data. Proceeding with the results for the time horizon until 2030, the model represents the preponderance of Qatar as the most competitive LNG supplier, even when new LNG infrastructure comes online everywhere. The US is an emergent competitor with multiple projects finding demand in all the LNG regions, while Australia would still highly depend on the Asian Pacific basin. Other smaller exporters would struggle to find importing markets but collectively would open new regional markets.

In Iran, Samadi and Eidizadeh (2013) and Samadi and Emami (2015) designed the structure of the natural gas industry and the future gas production rate in Iran with different scenarios using the system dynamics method. Also, Nikoui Eskoui et al. (2018) using Agent-based modeling determined Iran's optimal strategy in exporting natural gas. However, there has not been a study that has investigated this issue with the System Dynamics-Agent-based approach. Therefore, the present study in the development of the SD model presented in Samadi and Emami (2015), by adding dynamic behavior to the fixed parameters of the model through Agent-based modeling, tries to reduce the research gap in analyzing Iran’s natural gas industry.

On the other hand, though various studies have been carried out to examine the gas trade, unconventional gases have been focused on in few studies, e. g. Moorlag et al. (2014; 2015) and Eker and Van Daalen (2012) and without taking conventional gases into account. The present study, therefore, fills this gap. Accordingly, the second contribution of the present study is to examine the status of expansion of the US unconventional gases, and development path of the gas industry of Iran, and the way these gas resources of the two countries interact with and influence each other at the world gas markets.

3. Methodology

One of the weaknesses of SD modeling is that the values of some parameters of the model are considered constant. This can affect the simulation results. Assuming a dynamic behavior for such parameters can improve SD, and thus increase the reliability of simulation results. In this regard, the AB model, which is a state chart, can be combined with SD. Such a modeling technique is known as SD-AB modeling.

Another weakness of SD modeling is that some parameters are exogenous and constant. To move the system toward the target, one should determine the best values for the parameters rather than consider them constant. This can enhance the simulation results. One advantage of combining SD and AB is that constant parameters and exogenous variables can act as dynamic processes for them. The combination can eventually improve the dynamics of SD modeling and lead to more realistic and reliable results.

Therefore, the SD-AB model can be solved again to approximate the level of some variables to their optimal level. Considering the aforementioned points, the methodology applied in this paper is solving the SD-AB model by considering optimal values for some of the parameters. This section sheds light on the development of SD-AB modeling.

It should be noted that there are two approaches in the combined modeling of System Dynamics and Agent-based models:

1- The basic model is a System Dynamics in which the main structure of variables is designed in its framework. Then, to improve the dynamics of the model, the fixed value parameters of the model can be defined in the form of variable behavior through the flowchart in the ABM modeling. This approach is known as SD-ABM.
2- In another approach, the basic model is the Agent-based model, which is the simulation of a system based on the behavior of agents in the model that some of these behaviors can be designed in the SD model. This model is known as the hybrid model of AB-SDM.

In this study, the first approach is used.

3.1 System Dynamics (SD) Modeling

The designed SD model consists of four general sections: the cycle of gas exploration and production, investment in the gas industry, world gas demand, and world gas trade. The first three sections are inspired by Eker and Van Daalen (2012) on Iran's gas industry and the fourth section is designed. A general description of the four sections has been provided below.

3.1.1 Natural Gas Exploration and Production Cycle

In this section, to assess the development of conventional gases in, the upstream parts of the gas industry, namely exploration and production are considered in the modeling based on the life cycle pattern proposed by Naill (1974). In the CLD of Iran’s natural gas exploration and production cycle (Figure 4), there are three equilibrium loops. In the first loop, an increase in the explored resources leads to an increase in the exploration rate which, in turn, leads to a decrease in the explored resources. This is also applied to undeveloped resources and development rates as well as developed resources and production rates in the second and third loops.

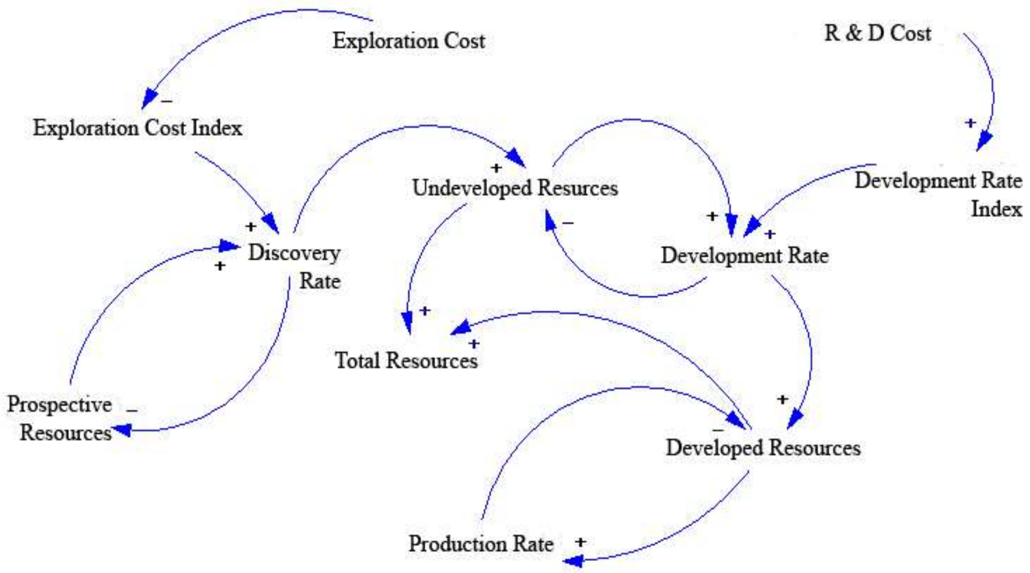


Figure 4. CLD for Natural Gas Exploration and Production Cycle
Source: Research finding.

3.1.2 Investment in Gas Industry

This section models the infrastructure for discoveries and the expansion of the production of conventional sources. The development and expansion of discoveries depend on investment in activities of the target industry. It is assumed that investment is a percentage of cumulative profit. Investment is affected by two factors: *1- Return on investment* (the ratio of gas price to the total cost of the unit of exploration -Chi, Nuttall, and Reiner, 2009; Naill, 1974). This ratio has a positive impact on investment in exploration. *2- Frequency of the resource* (the ratio of total explored resources to demand -Eker and Van Daalen, 2012). This ratio has a negative impact on the rate of investment in exploration.

Investing in the development of developed resources that are ready for gas production is also an efficient factor in technology improvement (Figure 5).

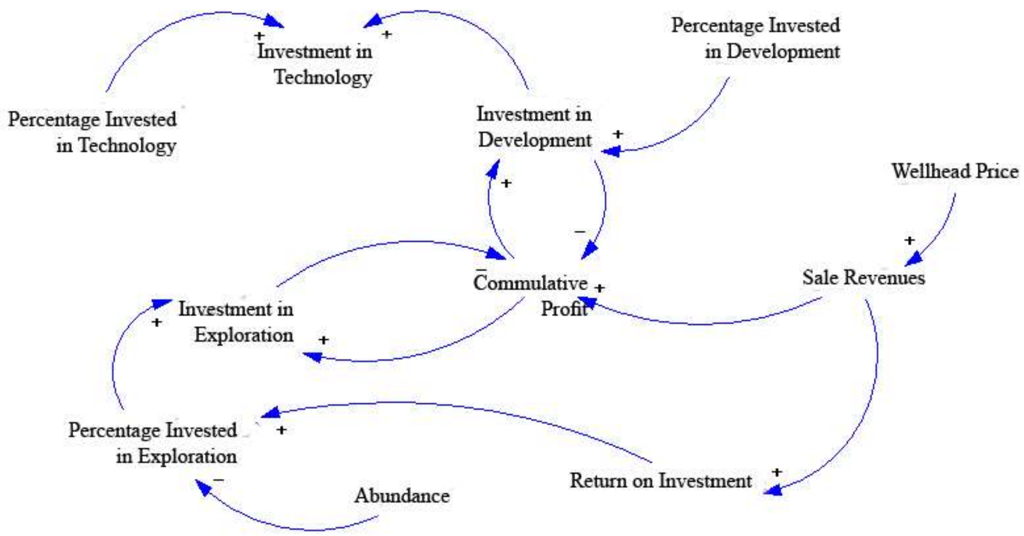


Figure 5. CLD for Investment in the Gas Industry
Source: Research finding.

3.1.3 World Gas Demand and Trade

In this section, the world demand for gas and its modifications are modeled. Figure 6 indicates an equilibrium loop and a positive feedback (reinforcing) loop. In the reinforcing loop, a relative price change has a positive effect on demand shifts. An increase in demand leads to an increase in world gas demand which, in turn, leads to an increase in relative price changes. In the equilibrium loop, an increase in the constant change leads to a reduction in demand. This decline will, in turn, lead to a reduction in world gas demand. Finally, a decline in the world gas demand decreases the constant change. The price elasticity of gas demand is another factor that has been taken into consideration in the diagram. This parameter has a positive effect on the relative price change.

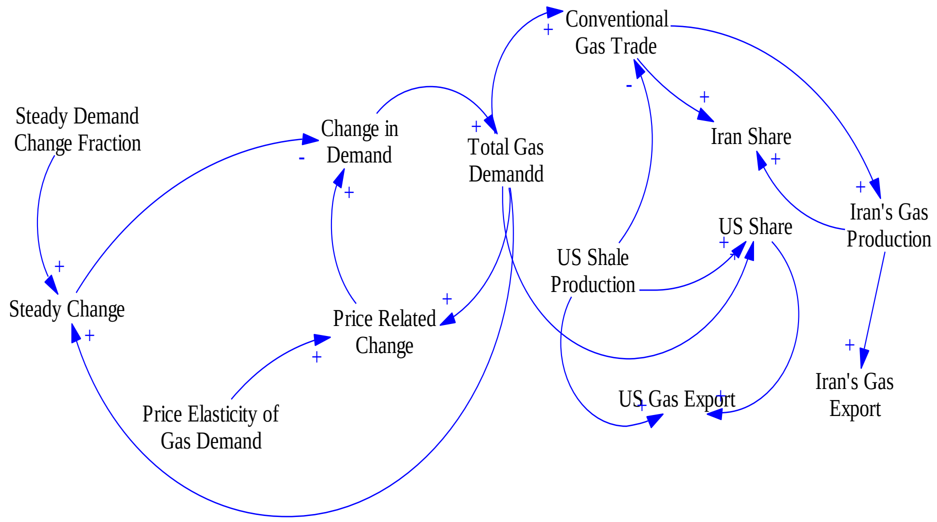


Figure 6. CLD for World Gas Demand
Source: Research finding.

3.1.4 Stock-Flow Diagram (SFD)

The final model has been shown in Figure 7 in the form of an SFD. There are generally six level variables and ten flow variables in the diagram.

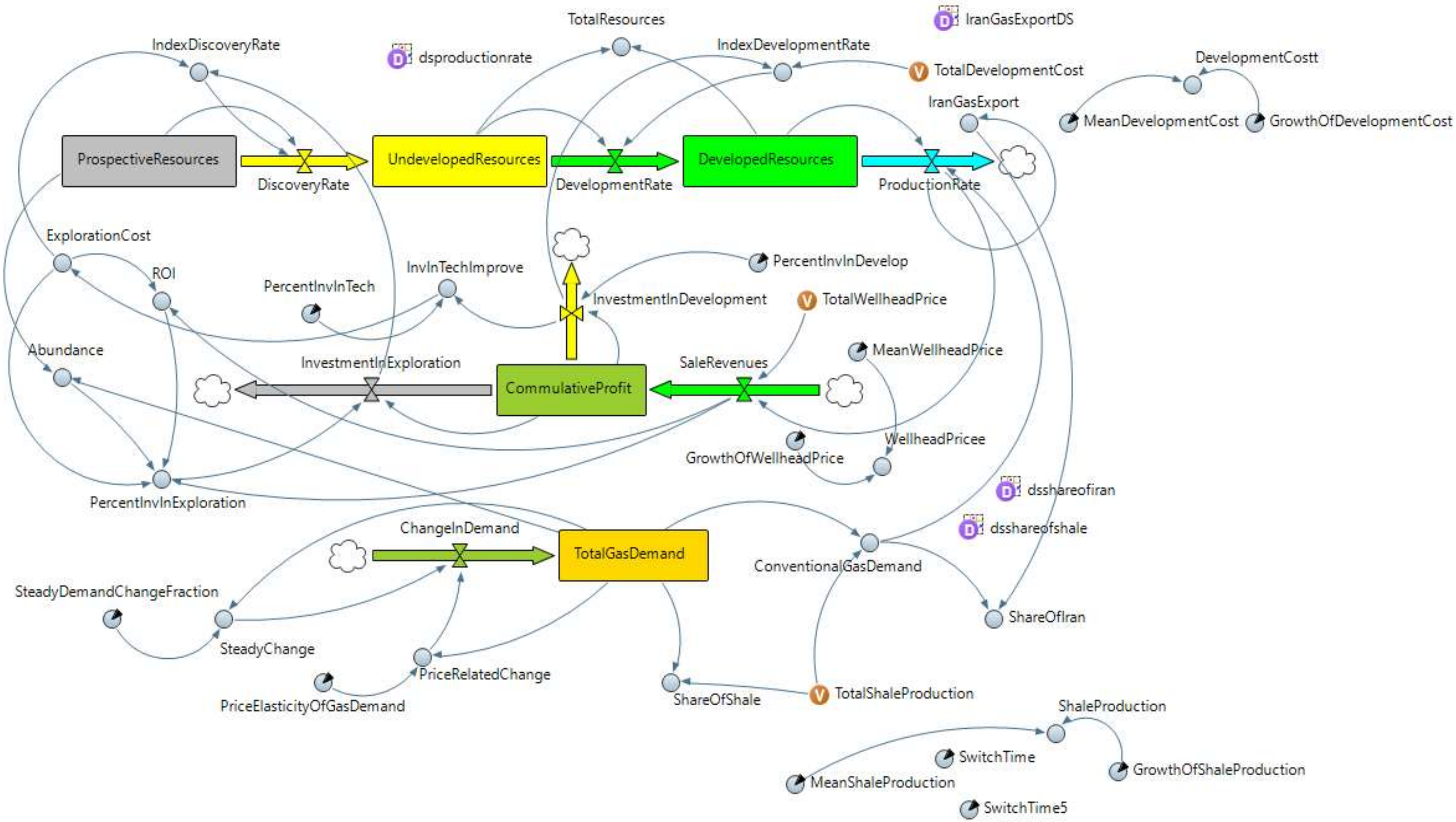


Figure 7. Stock-Flow Diagram

Source: Research finding (AnyLogic Software).

3.2 Agent-Based (AB) Modeling

In this section, state diagrams are described for the United States' shale production, research and development (R&D) in Iran's gas industry, and gas price.

3.2.1 State Chart for the Development of U.S. Shale Gas Production

Shale gas production in the U.S has been quite fluctuation. According to Figure 8, the annual growth of shale gas production in 2008 was about 63%, which has decreased to 10% in 2013 with a completely fluctuating trend. In 2014, this amount increased again to 17%, but with a downward trend until 2017, it reached its lowest level in the last 10 years, reaching 9%. Finally, according to the EIA, the growth of production of this type of unconventional gas in the United States in 2019 has reached less than 16 percent.

Given such fluctuations, in the SD-AB modeling, different statuses have been anticipated through adding a state chart for *U.S.* shale gas production. It is assumed that *U.S.* shale gas production has an average annual growth of about 38% in the base condition. After 12 years, i.e. in 2014, when the U.S. shale gas production growth had stalled, the variable entered the second status. In this status, gas production is assumed to have an average annual growth rate of about 14%. According to IEA, from 2025 onwards, the level of gas resources in Europe and North America will reach its lowest level. Hence, it is assumed that from 2025 onwards, the unconventional gas production growth rate would be equal to that of 2013 to 2015, i.e. about 10%. By accruing this state, unconventional gas production enters the third state (Figure 9a).

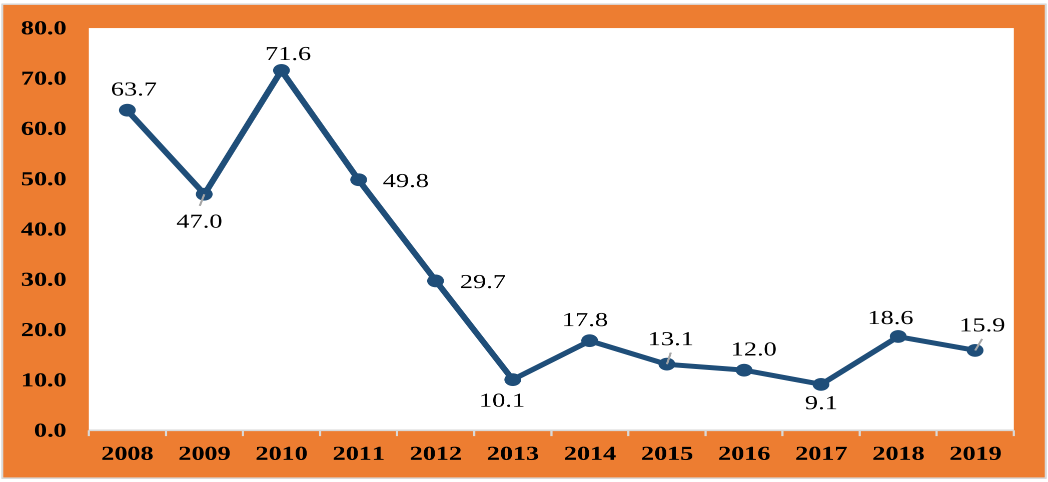


Figure 8. The Trend of U.S. Shale Gas Production Annual Growth Rate: 2008-2019
Source: U.S. Energy Information Administration, EIA, 2020.

3.2.2 State Chart for R&D Expenses

It is assumed that R&D expenses would increase by 1% per annum by 2015. Then, due to plans of Iran's Ministry of Oil for the development of different phases of

South Pars Gas field, the expenses would grow by about 5% and this would continue until 2025. After that, the R&D expenses would enter its third status. In this status, it has been assumed that the average annual growth rate would return to its previous rate (Figure 9b).

2.2.3 State Chart for Natural Gas Price

By 2020, the average annual gas price is expected to grow by 1%. Then, considering IEA's predictions about increasing demand for gas, it has been assumed that, gas prices would increase by 2% per annum on average (Figure 9c).

3.3 Combining SD and AB Models and Simulating them

One of the contributions of the present study is to combine SD (SFD in Figure 7) and AB (State chart in Figure 8) models. Based on the state charts depicted in Figure 9, in doing so, it is necessary that change trends of U.S shale gas production, R&D expenses in Iran's gas industry, and Iran's natural gas price be placed and combined in SD modeling in Figure 7[1].

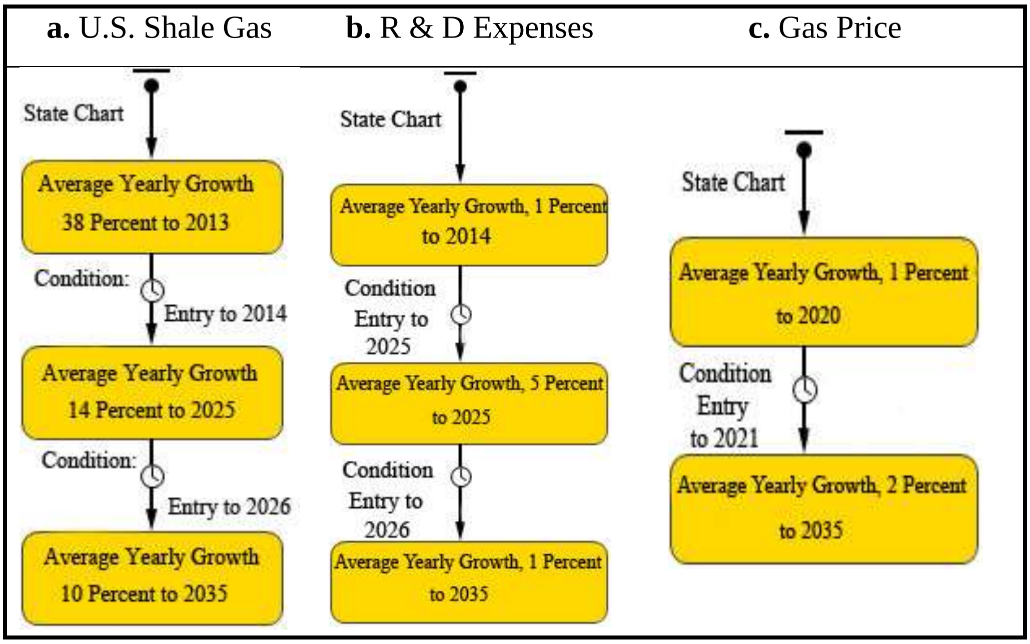


Figure 9. State Chart for Variables U.S. Shale Gas, R & D Expenses, and Gas Price

Source: Research finding.

The final model has been depicted in Figure 10.

[1]. The ***AnyLogic*** Software was used to simultaneously develop SD and AB modeling approaches and to combine them. Using this possibility, the SD model was first designed and, then, the behaviors of the variables were described as state charts. The mathematical structure of the model is presented in appendix.

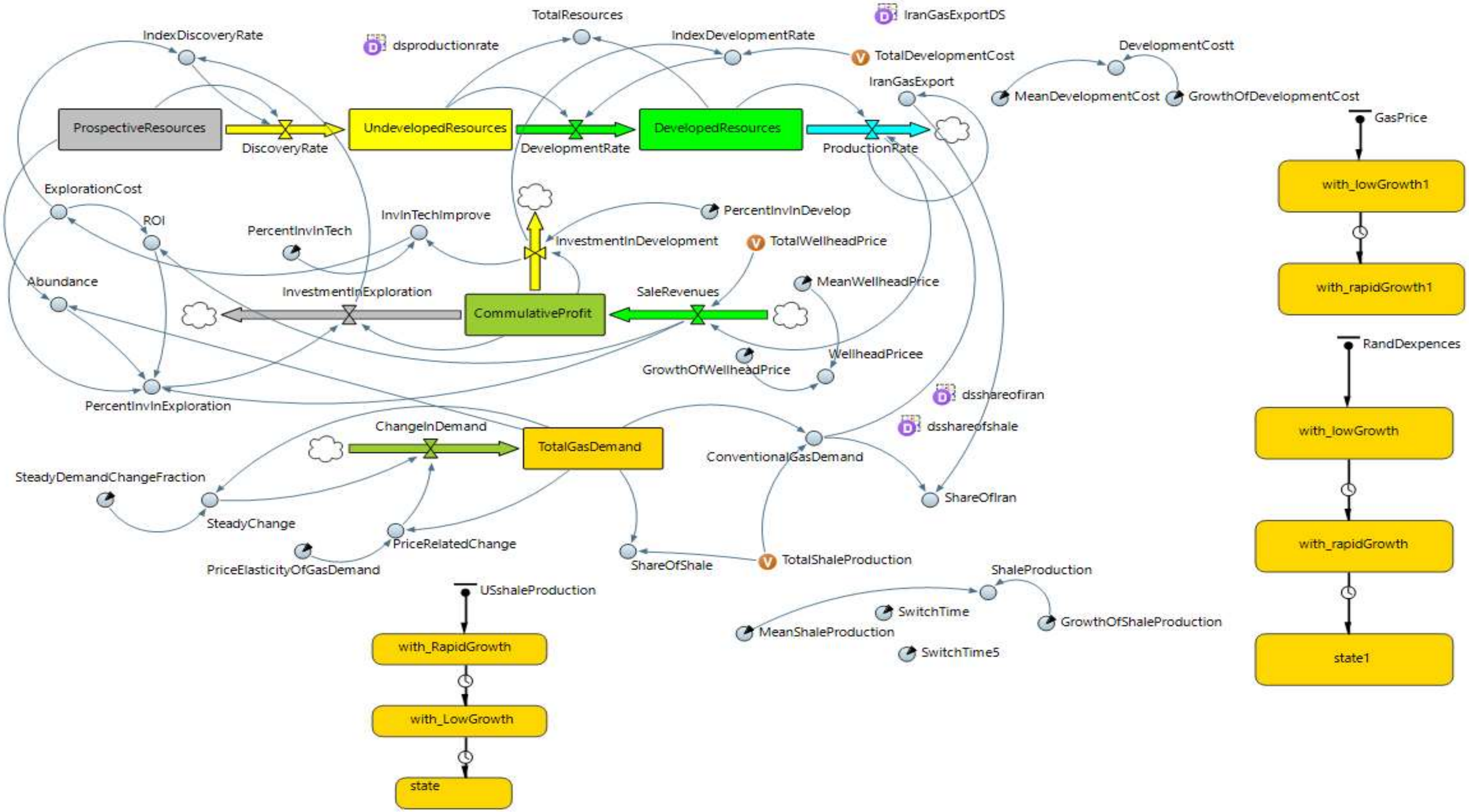


Figure 10. SD-AB Combined Model
Source: Research finding (AnyLogic Software).

4. Simulation

In this section, the simulation results of the SD-AB model and the scenarios for U.S. shale gas production as well as the expansion of Iran's gas production and its share in the Middle East are presented. Before presenting the results, the validity of the designed model will be examined.

4.1 Model Validation

In this paper, Root Mean Square Percent Error (RMSPE), Theil’s Inequality (TI), Roots Error, and behavior reproduction tests are used. The results of the error tests have been presented in Table 1. The findings show that the error values are desirable. Also, 15 years, from 2001 to 2021, have been considered for the behavior reproduction test (Figure 11).

Table 1. The Amount of Errors for Some Variables in the SD-AB Model

Variables	RMSPE (Percent)	TI	Roots Error		
			U^m	U^s	U^c
Iran’s Natural Gas Production	9.53	0.05	0.37	0.54	0.09
Iran’s Natural Gas Consumption	9.70	0.06	0.45	0.44	0.10
Iran’s Natural Gas Exports	20.16	0.11	0.05	0.03	0.91

Source: Research finding

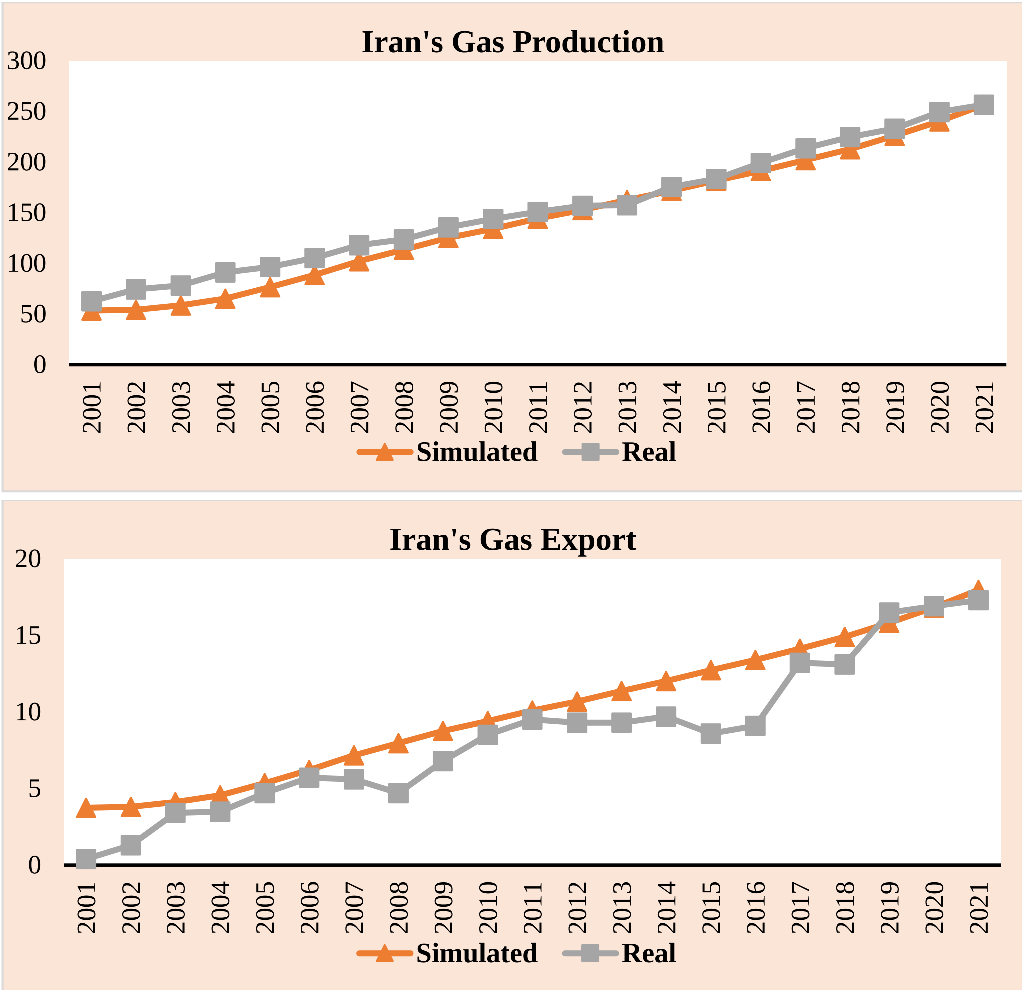


Figure 11. Behavior Reproduction Test
Source: Research finding.

Figure 11 shows that the trend of simulated variables has the same direction as the actual variables' trend. Therefore, we can trust the simulation results of the model.

In general, the results of the SD-AB show that some model outputs have matched with the observed data. The match can be explained via external input functions and feedback loops. Gas exploration and production feedback loops in Iran and world natural gas trade feedback loop have led to the match between dynamics of simulations and the observed data.

Concerning Iran's natural gas production loop, the initial volume of prospective resources and extraction costs are considered as the most significant values and external input functions which affect model output and exploration rate index. Furthermore, the share of Middle East gas trade, which can externally affect gas production rate in Iran, can influence this process. Concerning the world natural gas trade loop, such external input functions as the primary level of natural gas trade in the different regions and the U.S. gas export function, play an important role, too.

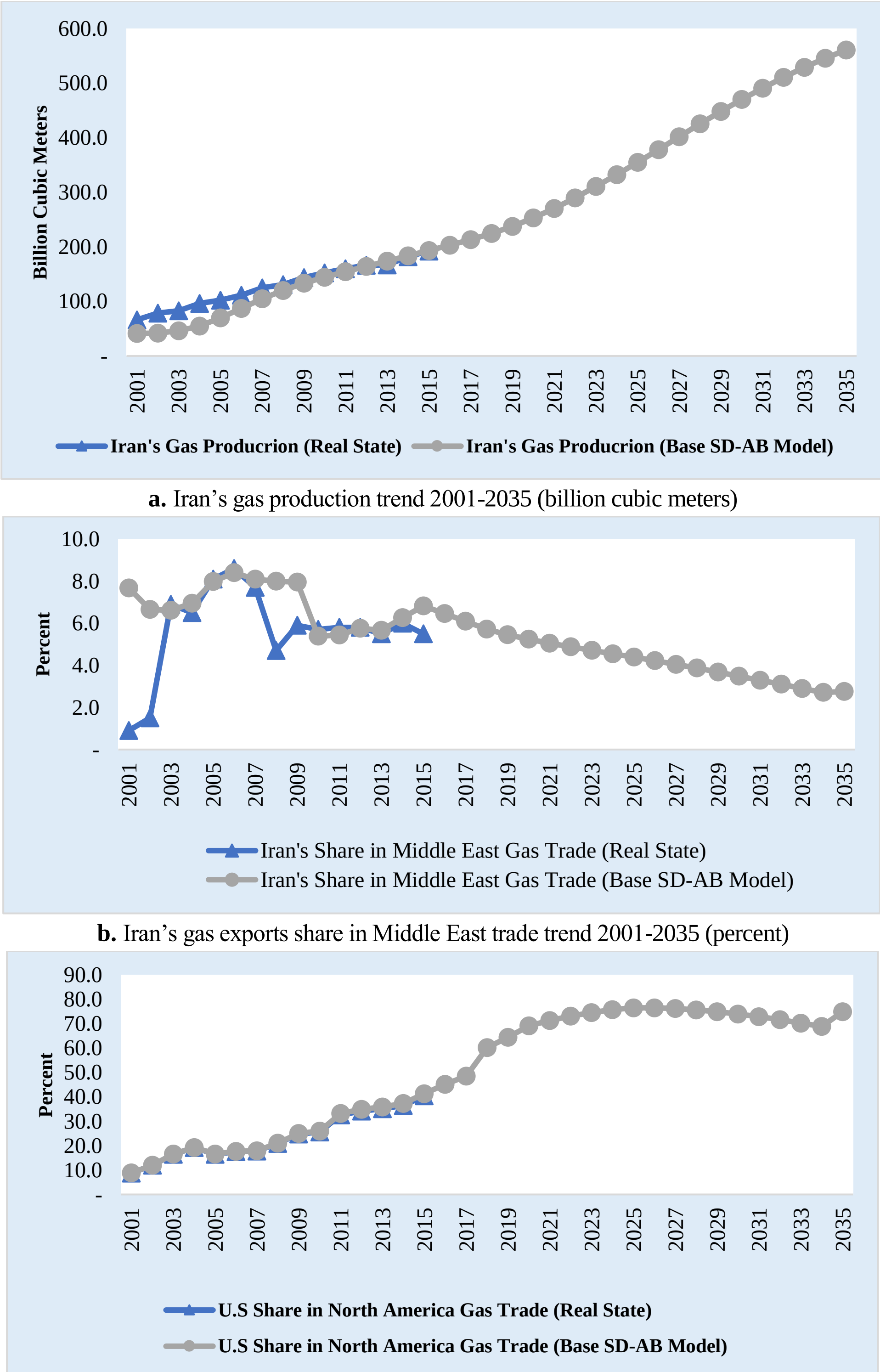
4.2 Benchmark

Since the main objective of the present study is to examine the expansion trend of unconventional gases and the share of Iran's conventional gas production in the Middle East, the findings concerning simulation of the three variables of gas production in Iran, the share of Iran in gas exports of the Middle East, and the share of the U. S. in gas exports of North America are presented in this section.

The amount of gas produced in Iran has been 192.5 mm^3 in the base year of 2015. As Figure 12a indicates, the simulated value in this year has been 193.43 mm^3. In 2035, based on the SD-AB model, the predicted gas production of Iran will reach over 560 mm^3.

According to the SD-AB base model, the percentage share of Iran's gas exports in the Middle East gas trade (Figure 12b) has been about 5.5% in 2016, and its simulated value is close to 6.8. Nevertheless, as the model predicts, Iran's percentage share will be reduced to 4.4% in 2025. It will also be reduced to less than half in 2035.

Also, the trend of changes in share of U.S. in gas exports of North America gas trade (Figure 13c) shows a sharp increase. Based on the simulation results, the U.S. will be the largest gas exporter in North America from 2020 onwards. A large part of this share can be due to the expansion of shale production in the U.S.



a. Iran's gas production trend 2001-2035 (billion cubic meters)

b. Iran's gas exports share in Middle East trade trend 2001-2035 (percent)

c. U.S. gas exports share in North America 2001-2035 (percent)

Figure 12. Iran's Gas Production, Exports Share in Middle East Trade and U.S. Gas Exports Share in North America Trade Trend: 2001-2035

Source: Research finding.

One of the issues that can affect the development of Iran's gas industry is economic sanctions in the oil and gas industries, which was explained in the introduction section. Due to the high importance of this issue, according to the CISADA, the investment ceiling in Iran's oil and gas industry should be reduced by 50%. Based on this, in a separate scenario, it is assumed that the amount of investment in development will be reduced up to 50%. In Figure 13, the trend of Iran natural gas production in the case of applying this scenario is drawn along with the production process in the case of applying the previous scenarios. The results show that the amount of gas production in Iran will reach about 450 billion cubic meters by 2035. This value is about 16% lower than the base model and 33% lower than the all scenarios-based model. Also, in the long time period, this gap can increase even more.

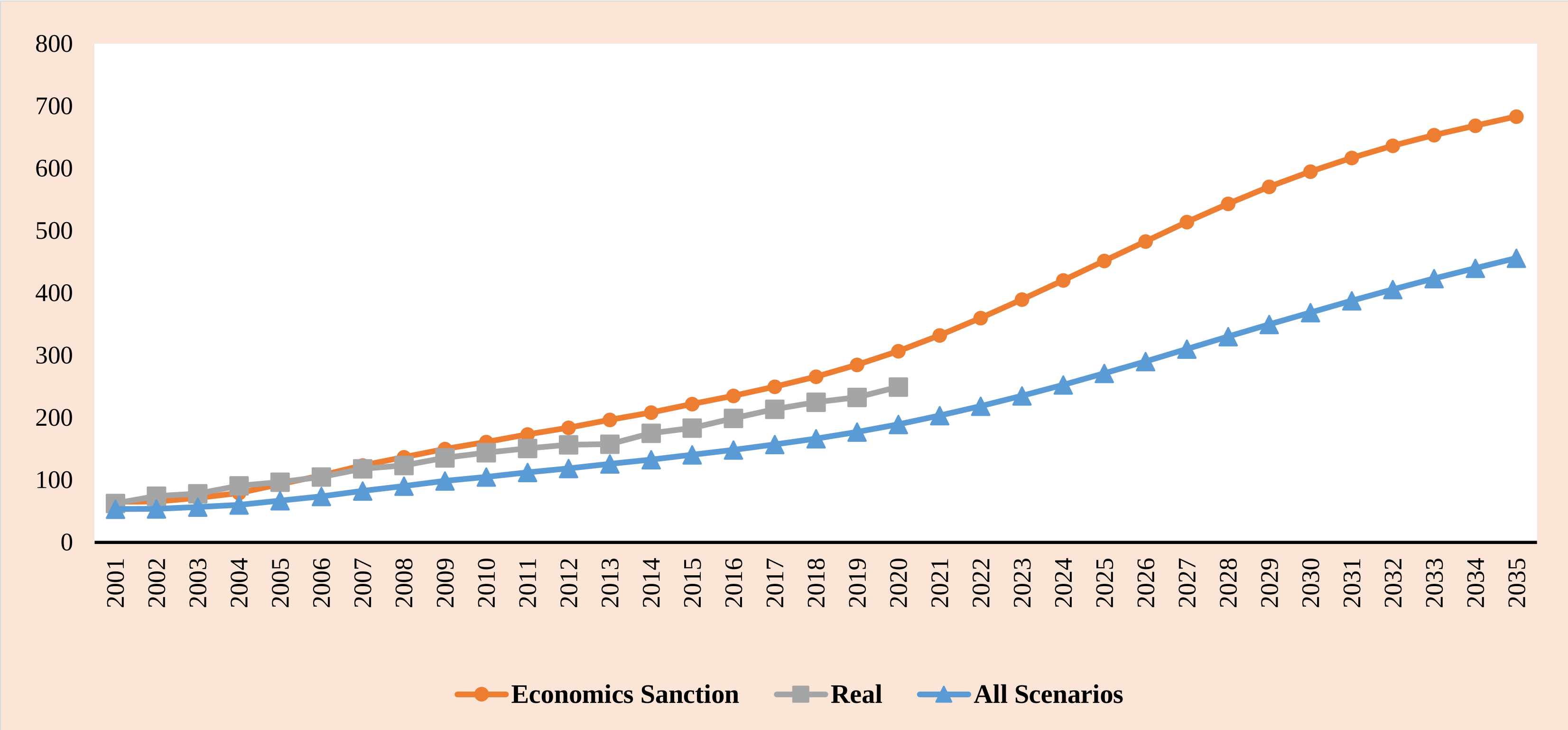


Figure 13. Iran's Gas Production Trend in Two Cases; Economic Sanction and all Scenarios Model: 2001-2035

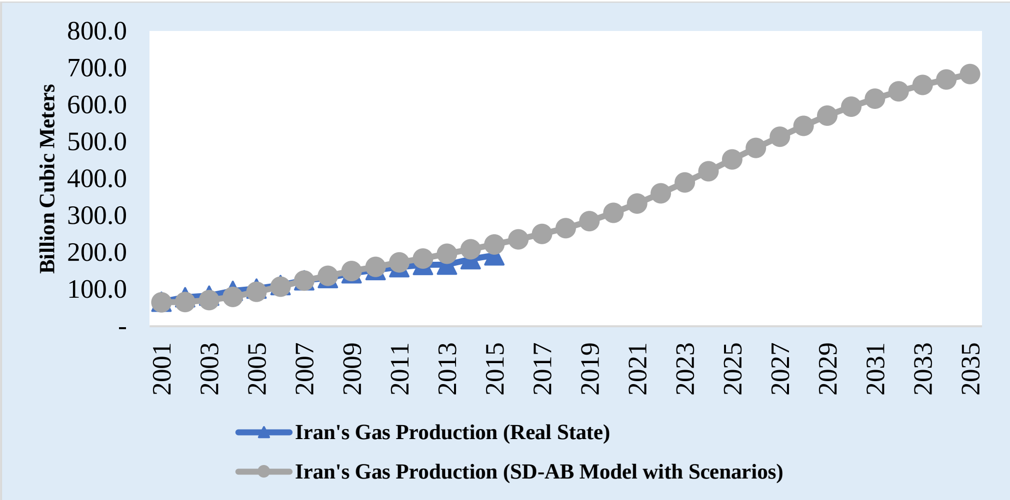
Source: Research finding.

4.3 Scenarios

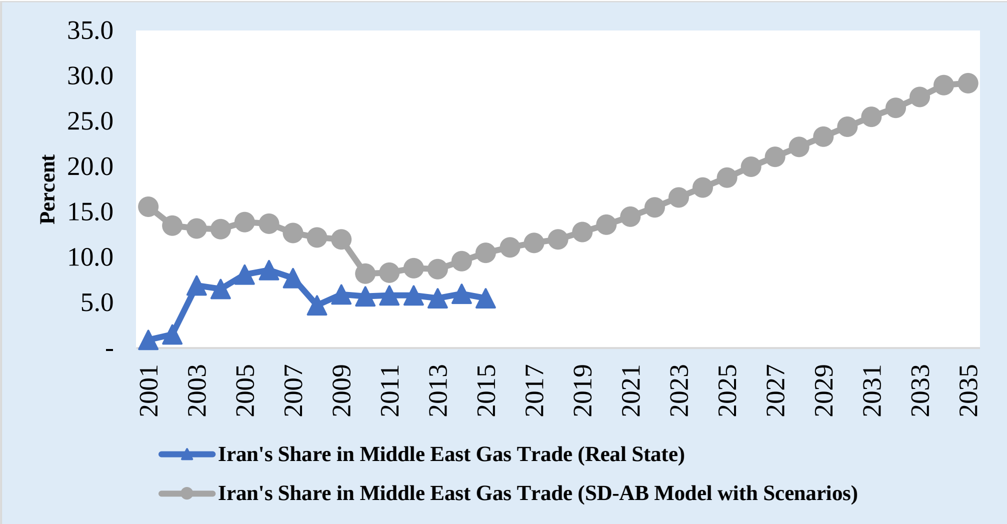
In this section, the scenarios of a 75% increase in the exploration rate (from 0.017 to 0.02975), a 20% increase in investment in development (from 0.40 to 0.48), and a 5% increase in investment in technology improvement (from 0.05 to 0.0525) have been considered. Based on Figure 13a, the rate of Iran's gas production in 2035 will reach 650 mm^3. This is three times the country's current rate of gas production.

Iran's percentage share in gas exports of the Middle East trade can be 30%. In the current status, Iran's largest share of trade in the region has been related to the year 2006 (about 9%). Therefore, by 2035, Iran's share will increase three times more than the country's share in 2006 (Figure 14b).

It should be noted that scenarios concerning gas industry in Iran have not affected the U.S. share in gas exports of North America over a long period of time. In other words, with the expansion of shale production in the U.S., the country will become the largest exporter of gas in North America under all scenarios. This is why the diagram related to the share of the U.S. has not been presented.



a. Iran's gas production 2001-2035 (billion cubic meters)



b. Iran's share of trade in Middle East 2001-2035 (percent)

Figure 14. Iran's Gas Production and its Share of Trade in Middle East Trend in Model with Scenarios

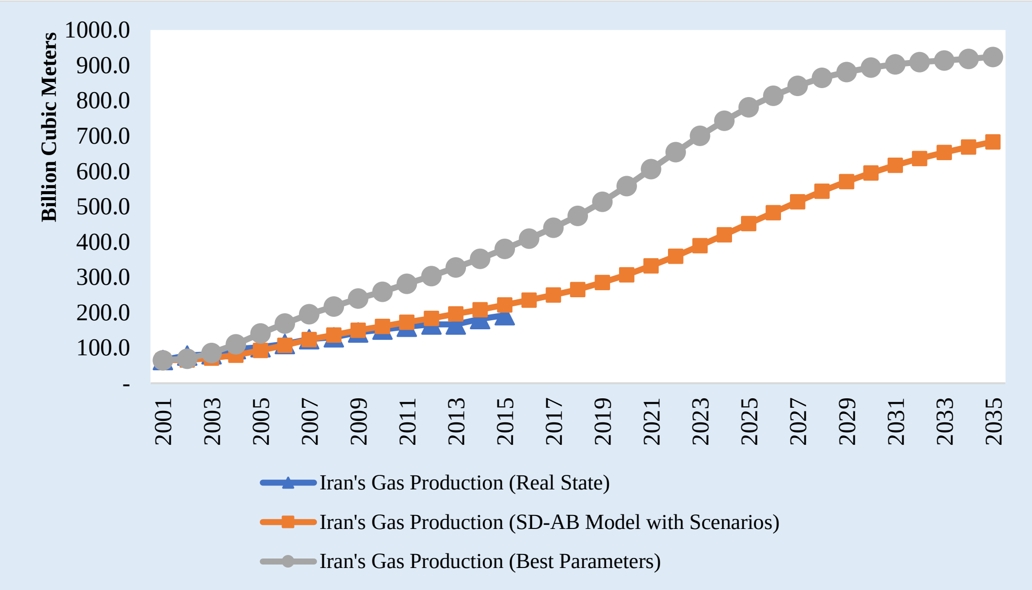
Source: Research finding.

4.4 Best Values for Parameters

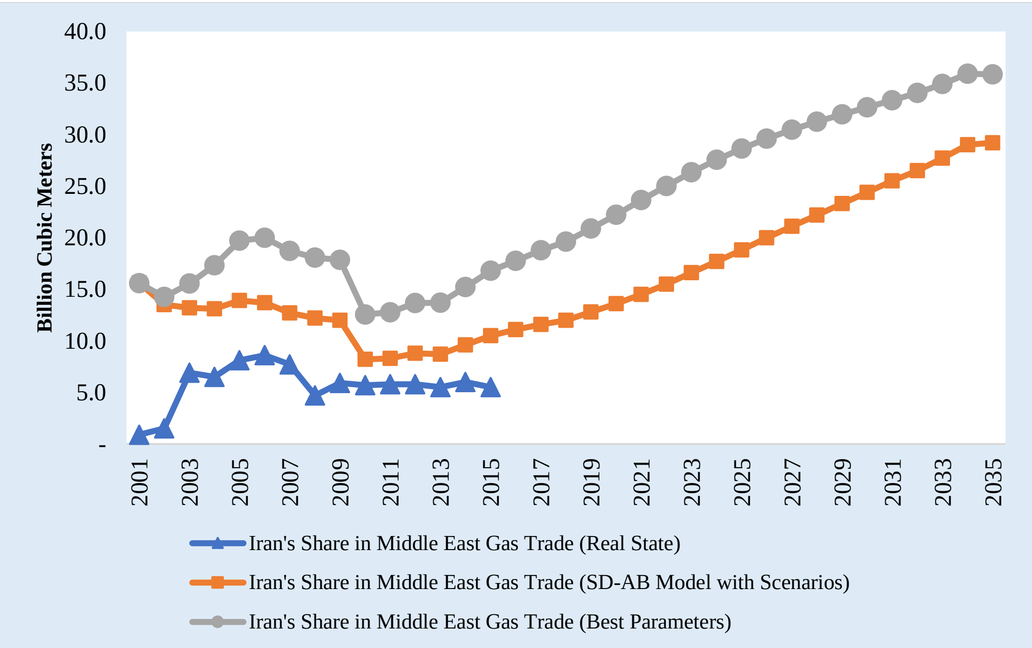
Based on the findings presented in the previous section, if Iran's gas production level reaches 1,000 mm^3 a year in 2035, the country can take a significant share in the Middle East gas trade. The simulation results concerning the scenarios with the aim of achieving a level of gas production near to 1000 mm^3 in 2035 and minimizing R&D expenses in Iran have been presented in this section.

Based on the objectives of the present study and with regard to the limitations, the best value for a growth in R&D expenses and the percentage of investment in development is 10%. However, in the scenarios, the percentage of investment in development is set at 20%. This is because of the fact that the variables have non-linear relationships in the SD model. Moreover, an increase in R&D expenses and in the percentage of investment in development do not necessarily lead to an increase in gas production. Therefore, only a certain level of increase in these variables can lead to an increase in gas production in Iran.

As shown in Figure 15a, the gas production rate in Iran always is higher than the rate of gas production which are shown in the previous model. Accordingly, the level of gas production in the country will reach over 900 mm^3 in 2035. Additionally, Iran's share of gas exports will be significantly higher than that indicated by the previous model between the years 2001 and 2035, and it can increase and reach to 35% in the Middle East trade in 2035 (Figure 15b).



a. Iran's gas production 2001-2035 (billion cubic meters)



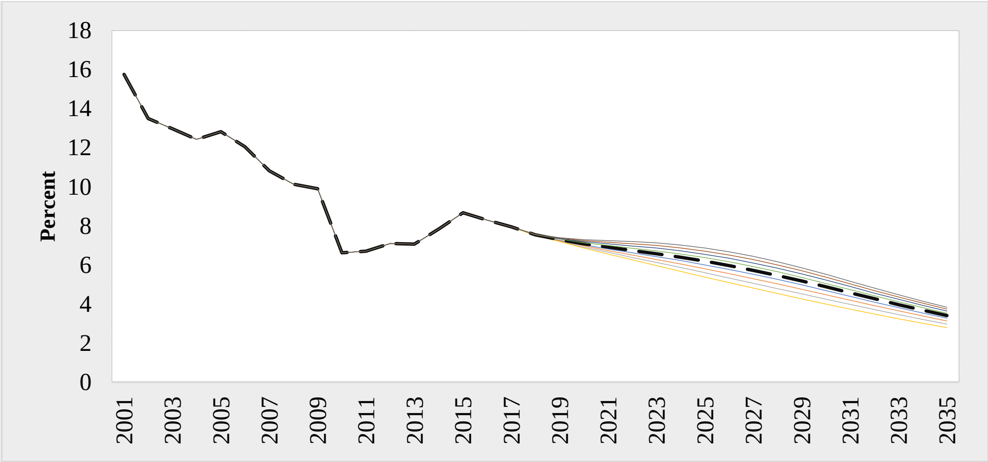
b. Iran's share of trade in Middle East 2001-2035 (percent)

Figure 15. Iran's Gas Production and its Share of Trade in Middle East in Model with Best Values for Parameters

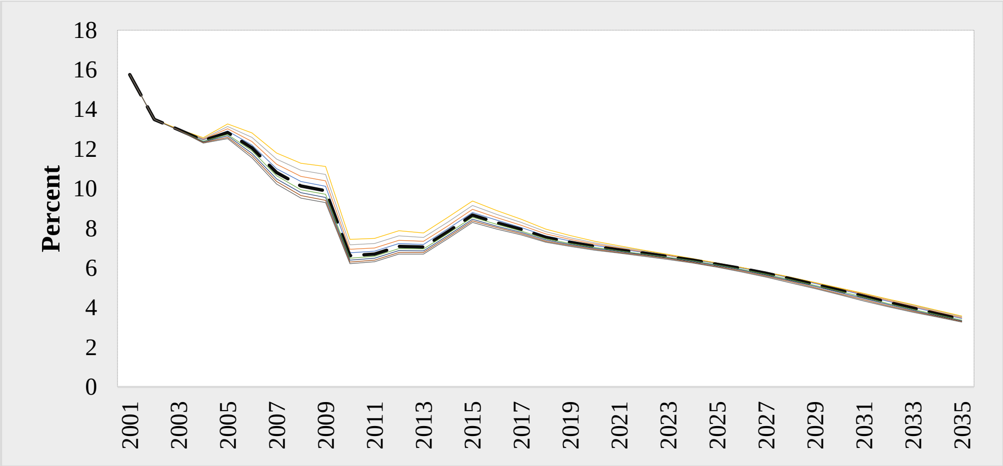
Source: Research finding.

3.5 Sensitivity Analysis

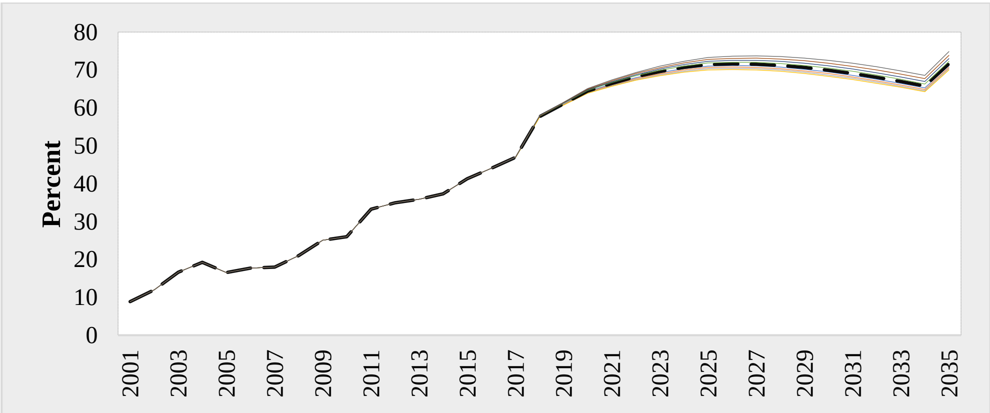
In the designed model, three status diagrams related to the expansion of shale production in the U.S., the trend of R&D expenses in Iran's gas industry, and Iran's gas price have been added to the SD model. Sensitivity analysis has been employed to check the sensitivity of the system to changes in these variables. Here, the sensitivity of the model to a 5% level of change is examined in these variables. As shown in Figure 16, a 5% level of change in the expansion of shale production in the U.S. will not have a significant effect on the simulation results.



a. Iran's gas exports share in Middle East trade due to changes in Iran's gas industry R & D expenses



b. Iran's gas exports share in Middle East trade due to changes in Iran's gas price growth



c. U.S. gas exports share in North America trade due to changes in shale production development

Figure 16. Sensitivity Analysis

Source: Research finding.

This is also true with regard to the increase in R&D expenses and gas prices and concerning its impact on Iran's share in gas exports of the Middle East. Therefore, it can be said that the designed model has an acceptable level of reliability.

5. Discussion

Significant developments have taken place in world gas markets over the years 2010-2015. These developments include the emergence and expansion of shale gas in the U.S., Qatar becoming the world's largest exporter of Liquid Natural Gas, Russia’s loss of power over the gas market in Europe, and the emergence of strategic resources in Iran, as a world potential player. These events have paved the way for world energy markets to enter a golden era of gas industry. Therefore, the IEA's prediction that the world can enter a golden era of gas industry can actually happen over 2010-2035.

In the present study, the gas industry in Iran and various scenarios for expanding Iran’s share in the Middle East gas trade have been addressed. The results obtained under various scenarios show that Iran is able to increase its share in gas trade in the region from about 5% to 40% by 2035. However, it can occur under certain conditions. Accordingly, it has been assumed that the main rivals of Iran, such as Qatar and Russia, do not have a particular behavioral change. Additionally, the Gas Exporting Countries Forum (GECF) have not been included in the analyses. If the GECF has cartel behaviors, it may stop expansion of unconventional gases and significantly increase the share of its members. In other words, based on the findings of this study, if a cartel is formed, Iran's share will be more realizable. The Russia’s gradual loss of power over Europe gas trade can move Iran towards Asia-Pacific markets. However, Iran should not overlook Asia-Pacific markets, and in particular, the Japanese gas market and Japan's its geopolitical position in relation to both European and Asia-Pacific markets. In this market, Qatar as the largest gas exporter, will be a rival to Iran. The most important factors which should be taken into consideration by Iran are managing the exploitation of resources the country has in common with Qatar through increasing foreign investments and using new technologies.

Based on the results of the present study, seeking to expand its gas production out of its unconventional resources and in particular its shale resources, the U.S., with a percentage share of about 90%, will become the largest exporter of gas in North America by 2035. Nevertheless, it seems that such challenges as environmental issues, which led to a halt in production of these gases in 2014 and 2015, restarting the production of unconventional gas after Trump became the President of the U.S., and the possibility of GECF forming a cartel to maintain the power of unconventional gases create the major barriers facing expansion of these gases in North America.

Regarding what was stated before, it can be understood that, at least over the next three decades, a complex gas competition will take place in world energy markets. In this game, the winner will be the country which will rely on its strategic resources and move toward sustainable gas markets. In other words, the policy of reducing dependence on gas imports, which have been implemented by some regions, including Europe, during the last 5 years will be of great importance.

6. Conclusion

Generally, the simulation results of all the models indicate that, from 2020 onwards, the U.S. will become the largest exporter of gas in North America under various conditions of the expansion of gas production out of unconventional resources. The U.S. percentage share in North America gas trade will reach over 70% by 2035.

Iran's share in gas exports of the Middle East gas trade has a trend in form of a reversed U shape. By continuing the current status, Iran's percentage share will be reduced to less than 5%. However, if the process of gas trade in other parts of the Middle East pursue the same trend as during 2010-2015, and by the application of all scenarios, Iran's percentage share can reach 15% in 2035. This rate in the SD -AB model, which has a higher accuracy than the SD model, can reach over 25%.

The proposed policy of the present study is, therefore, related to Iran's gas industry. Iran can increase its current share in the Middle East gas trade six times and to nearly 36% by 2035 through increasing its exploration rate, R&D expenses in the gas industry, investment in development, investment in technology improvement, and through allocation of gas production in the country for gas exports by 75, 10, 10, 20 and only 2%, respectively.

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Appendix:

Mathematical Structure of Model

$$Discovery\ Rate = DELAY1(Index\ of\ Discovery\ Rate, 4.5) * 0.017 * Prospective\ Resources \quad (1)$$

$$Development\ Rate = DELAY1(Index\ \ of\ Development\ Rate, 1) * (0.3 * Undeveloped\ Resources) \quad (2)$$

$$Production\ Rate = 0.014 * Developed\ Resources + 0.09 * Middle\ East\ Gas\ Trade \quad (3)$$

$$Cumu\ Profit = INTEG(Sales\ Rev - Invest\ in\ Development - Invest\ in\ Explor, Initial\ Value) \quad (4)$$

$$Inv. in\ Dev. = \max(Comulative\ Profit * Percentage\ Invested\ in\ Development, 0) \quad (5)$$

$$Inv. in\ Exp. = max(Comulative\ Profit * Percentage\ Invested\ in\ Discovery, 0) \quad (6)$$

$$Percen\ of\ invest\ in\ Exploration = ((0.0686 * ln(Return\ on\ Investment)) * (-0.99 * ln(Abundance)) * (-1.4 * Exploration\ Cost) + (0.005 * Sale\ Revenues))/Exploration\ Cost \quad (7)$$

$$Total\ Demand = INTEG(Change\ in\ Demand, Initial\ Value) \quad (8)$$

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