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Market-Based Analysis of Natural Gas and Electricity Export via System Dynamics

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ABSTRACT

By increasing the extraction of natural gas, its role in the restructured power systems is being expanded, due to its lower pollution. Iran has the second largest reserves of natural gas in the world and exports it to different countries. This paper represents long run analysis of natural gas export from Iran to Turkey as a case study, considering direct transfer and exporting via the power market. In this regard, a system dynamics model is approached for long run analysis of the considered scenarios. The uncertainty of natural gas price is modeled by Markov Chain Monte Carlo (MCMC) for a long run period and four generation technologies including coal-fired, combined cycle gas turbine (CCGT), gas turbine (GT) and wind participate in the power market with a uniform price structure. The published data by energy information administration (EIA) about natural gas charges, costs of electricity generation and export of natural gas and electricity are applied in the simulated models. The results show that exporting the natural gas at real time price is profitable, while its conversion into electricity and exporting at market price is disadvantageous, even by expanding the renewable resources.

1. Introduction

As a clean energy resource, natural gas, despite its price uncertainty, is increasingly consumed in different fields such as electricity generation. Iran is the second owner of the natural gas resources in the world after Russia and can be revealed as an energy hub in the Middle East by exchanging the natural gas and electricity with the other countries.

Exporting natural gas directly or its conversion into electricity is one of the unclear points in a long run decision-making for export. By restructuring the power system in Iran, the role of investors in capacity expansion is increased, because they consider their own profit rather than the cultural and political causes as the only motivation for expanding the capacity; to this end, long run analysis of exporting the electricity from this market to the other countries instead of the natural gas is the other challenge for the investors.

System dynamics is a conceptual tool for long run analysis of social and economic systems. It applies control theories for studying the long run effect of different decisions and policies by recognizing a system, its effective parameters and their mutual relation. The technique is helpful in long run analysis of different decisions, some of which either are not applicable in real world or cause heavy damage to the society.

Scholars have sought long run behavior of different systems via the system dynamics, in which the expansion of generation capacity is one of them. In [1], Shaojie *et al.* have modeled effective factors in launching the capacity via the system dynamics. They have considered effective factors such as advertising, market, transport system, storing, some of which are not applicable in the power market. Based on adjusting the launch scale, they have classified strategies into two categories, namely static strategy for the short term and dynamic strategy for the long term.

Some theorists have employed the system dynamics for analyzing different subjects in restructured power markets. In [2], olsina *et al.* have modeled a free power market by the system dynamics for gaining significant insight into the long run behavior. They have focused on replicating the structure of power markets and the logic of relationships among system components in order to derive its dynamical response, instead of the optimization models. Capacity payment is another topic that is studied by the system dynamics by researchers. In [3], the capacity payment is analyzed in system dynamics. Moreover, the probability density function of the demand is suggested to the market. The authors in [4] have analyzed different policies for capacity payment in Iran electricity market and in [5] system dynamics was used for analyzing different incentives for capacity expansion in Korean electricity market. In [6], the important events in Swiss electricity market such as the retirement of nuclear power plants and integrating with the European Union is analyzed by the system dynamics.

The mutual relation between tradable green certificate (TGC) and the power market is analyzed in [7] & [8]. The authors reconnoitered different factors in each market, their relationship and the reciprocal relations among the markets. Different strategies for the players in the TGC market is considered and the best one for achieving the objective of the players is extracted.

Different patterns of the power plant construction were analyzed through the system dynamics by Ford in [9]- [12]. As a common pattern in industries, he has concluded that timely construction can lead to the economic goals of the investors, while the lag of construction behind the demand growth is led to a boom in the price during the peak load and a dramatic drop after completing the power plant. Ref. [11] has introduced the construction time as a cause of fluctuation in the power market during the over and under supply periods, which is dampened by a constant capacity payment besides the energy premium. Bastidas *et al.* in [12] have implemented first order delays (FODs) and pipe line delays (PLDs), as two types of material delays, in a generic electricity market model in order to assess their effectiveness and adequacy.

Marzooni and Hoseini in [13] have proposed a dynamics system model for analyzing the long run behavior of investment in generation capacity by defining an index for the market power to show the level of competition in the market. The effect of CO_2 emission regulations on the long run behavior of capacity expansion in Australia is analyzed by Chattopadhyay in [14]. He has focused on the coal-fired technology and compared the effectiveness of pursuing the renewable expansion policies instead of the emission limiting rules in this paper. Tang and Rehme in [15] applied a system dynamics approach for analyzing the capacity expansion of renewable resources in Sweden and Norway by considering the renewable producer's electricity certificates and decommissioning decisions. Development patterns of Latvian electricity market and the role of renewable resources in capacity expansion is the main idea in [16], which is done by system dynamics approach.

Eager has modeled the Britain market as control loop for analyzing the long run effect of reliability policies in an energy-only market in [17]. Gary and Larsen have developed a feedback model for analyzing the strategic policies in out-of-equilibrium markets in [18]. Stability of market in autonomous power networks is analyzed by Wittebol *et al.* in [19]. Ref. [20] analyzes the influence of the reliability policy on the price increment in the power market; it has developed a dynamics system model for long run analysis of the capacity expansion in the restructured power market for testing different reliability policies. The results in this article show that continuous policies can decrease the magnitude of the price increment in the energy only market. Hary *et al.* have applied the system dynamics in the study of capacity remuneration mechanisms (CRM) in [21]. Ref. [22] has pointed to the system dynamics as an efficient tool for analyzing different socio-economic problems of power system in sub-Saharan African countries.

Besides the system dynamics and market restructure, natural gas and its relevance to the electricity are studied by researchers. By comparing the investment cost of the CCGT with the coal-fired, Ford has described the importance of natural gas-based technologies in a deregulated power system in [23]. The analysis of different options for investment in a restructured power market was addressed by Zambujal in [24]; the author has suggested the CCGT as a suitable choice for investing in the new structure using Monte-Carlo simulations. Ref. [25] has described the role of natural gas in the future of the electric generation in Spain and introduced the CCGT as tie point between the power and gas systems. In [26] an empirical long run simulation model for the European electricity and natural gas market was described; the authors modeled the markets by dynamic linear programming and analyzed the interrelationship between power generation and gas market. Wang *et al.* in [27] have integrated the electricity and natural gas planning in an expansion co-planning (ECP) model as a mixed-integer linear optimization problem.

Abadie *et al.* in [28] have evaluated energy investment related to the natural gas using the real options method; they have evaluated natural gas combined cycle power plant and a liquefied natural facility and several investment options in a realistic setting. The natural gas price which is an uncertain parameter is estimated by Inhomogeneous Geometric Brownian Motion (IGBM) in this paper. The results of the research show that risks are in the short term and the regulatory changes may have a deeper effect in long term result of an investment.

Ref. [29] has focused on the stochastic models for the spot market of natural gas by including the oil price as an exogenous factor. The authors have shown that associating the natural gas price to the oil price explains its behavior better than other factors such as temperature do. The uncertainty of natural gas price together with the upstream emissions and climate policy was modeled in a two-stage stochastic programming approach in [30]. The results show that climate policies are stronger drivers of greenhouse gas emission trajectories than new natural gas are. Anderea *et al.* in [31] have focused on the pricing of gas swing options by Monte Carlo method in a free natural gas market. They have computed the price of an arbitrarily chosen gas swing option in accordance with the concept of risk-neutral expectations.

Published books by different scholars are helpful in long run analysis of different events in the power market. Sterman has described the concepts of system dynamics and its implementation in different systems in [32]. Ref. [33] is helpful in understanding the concept of power market structure and its design. Stoft has focused on the basic economics and engineering of the power markets such as price spikes, revenue of the firms and reliability. Many advances in random number generation and Monte Carlo methods was incorporated in [34]; Gentle has discussed methods for generation of sequences of pseudorandom numbers in the book. Different technologies for energy extraction from the wind, some techniques for modeling the wind generation and useful data about the operation and maintenance of the wind systems are presented in [35]. Moreover, the published reports by established institutes give useful information about the cost of power generation, life data of different technologies and forecasts of natural gas price [36], [37].

System dynamics was approached by Sterman for analyzing complex systems and system thinking in a practical method. Growing the dynamic complexity in business, industrial and social systems, increases the role of modeling, predicting and analyzing their complex behavior for understanding its reasons. System dynamics is a method for understanding and analyzing the complex behaviors by a set of conceptual tools and modeling methods, which are helpful in simulating the long run behavior of a system in different policies and making better decision. Feedback control theories and nonlinear dynamics found the base of system dynamics. For long run analysis of a system, it is necessary to understand different effective factors and their causal relation. Moreover, identifying feed backs, delays and and other linearity which leads the system to instability and modeling them by stocks and flows is the main art in analyzing a system.

Simulation is the only reliable way for testing the validity of the models because of complexity of relations among different nonlinear parameters, which makes understanding the behavior of the model in a long time period impossible. Without simulation techniques, the system hard behavior can be improved using feedbacks through the real world which is very slow and inefficient due to delays, nonliterary and costs of testing the ideas [32].

This paper applies the system dynamics to analyze exporting the natural gas from Iran to Turkey as a case study. In this regard, two scenarios including direct export of natural gas at real time price and converting into the electricity for exportation at market price is considered. Also, the second scenario studies the effect of renewable expansion. The real time price of natural gas is modeled by Markov Chain Monte Carlo (MCMC), considering the rate of return. Different technologies such as coal-fired, CCGT, GT and wind participate in the market at the second scenario. The research analyzes some parameters such as present profit, profitability index and power market condition. The results are explanatory that exporting the natural gas at real time price not only compensates the costs but also generate profit, while exporting via the power market decreases the profit and cannot make up for investment in transmission lines. Without affecting on exportation, expansion of renewable technologies decreases the total fuel cost.

The rest of the paper is organized as follows. Section 2 describes the developed model; it describes the process of estimating the real time price of natural gas, direct export of natural gas, converting into the electricity and exporting via the power market. Section 2-C models different parts of a restructured power market for analyzing the capacity expansion via the system dynamics. The results are represented and analyzed in Section 3 for different scenarios and are summarized in Section 4 as conclusion. Appendix A represents the detail of MCMC algorithm for estimating the natural gas price.

2. Model Description

A model is developed for analyzing the long run behavior of exporting the natural gas by Iran using the concept of system dynamics. Two different scenarios, namely export of natural gas at real time price and converting into electricity for export via the power market is considered in the paper. The real time price of natural gas is estimated by MCMC method. The second scenario studies the effect of renewable expansion in the market. The export of natural gas to Turkey is chosen as a case study and is analyzed using the published reports by EIA about the export targets and its costs [39], [40].

A. Natural Gas Price

Natural gas price is a source of uncertainty in the power system [25]. Markov chain is a sequence of random variables such that for a given X_t, the distribution of X_{t+1} is independent from $X_{t-1}, X_{t-2}, \ldots$.

There are various ways of using a Markov chain to generate random variables from some distributions related to the chain. Such methods are called Markov Chain Monte Carlo, or MCMC. Following engineering terminology for sampling sequences, the techniques based on these chains are generally called samplers. The objective in the Markov chain samplers is to generate a sequence of auto correlated points with a given stationary distribution. Appendix A describes the process of MCMC method in creating samples.

For estimating the future price by the Metropolis-Hastings sampler, the initial price of natural gas and its variance is chosen from Ref. [38], summarized in table 3. The price is estimated for 400 months by using Normal distribution for the target stationary distribution of natural gas price, ρ_X, and Uniform distribution for the proposal distribution, $g_{Y(t+1)|Y(t)}$, in the flowchart (fig.11). Figure 1 shows the natural gas price, Γ_{NG}, during the studied time horizon that increases with a constant rate of return according to table 3 [37].

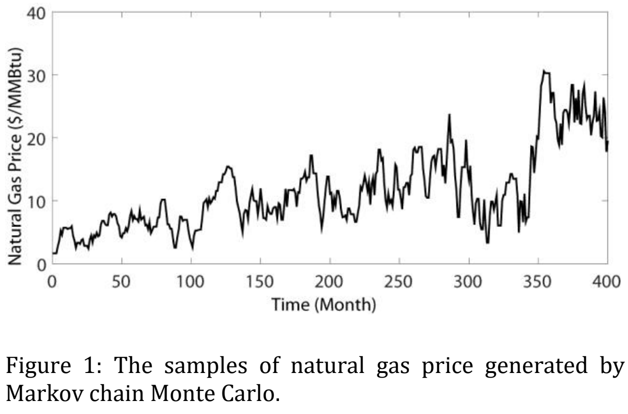


Figure 1: The samples of natural gas price generated by Markov chain Monte Carlo.

B. Direct Export of Natural Gas

The first scenario analyzes the direct export of natural gas at real time price as shown in Fig. 2. Due to its profit in the present situation expressed by Eq. (1), investment on transfer of the specified amount of gas from Iran to Turkey [39] has decreased. Table 3 summarizes the information on the direct export of natural gas such as amount and costs.

$$\Pi_{NG}(\tau) = \int_0^t (\Phi_{NG}(\tau).\Gamma_{NG}(\tau)) \times (1+rr)^{-y} \, d\tau - \Upsilon_{NG} \qquad (1)$$

C. Export of the Converted Natural Gas via the Power Market

In the second scenario, the natural gas is converted into the electricity and is exported at the price of power market. The expansion of capacity for supplying the demand, including the exported energy, is influenced by the profit that is made by active firms in the liberalized power market. Four technologies including coal-fired, CCGT, GT and wind turbine compete in the power market and the natural gas-based technologies allocate a part of their capacity to the exported electricity.

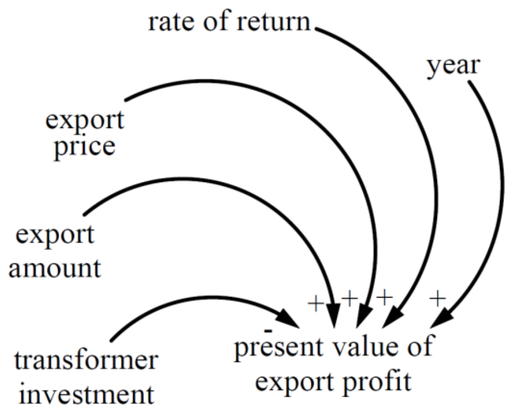


Figure 2: The causal procedure of natural gas direct export.

Figure 3 illustrates the process of capacity expansion in a restructured power market in this scenario. In order to clear the price and amount of generation, the firms offer their marginal cost to the market, which have uniform price structure. The market determines the profit of each firm considering the investment costs and capacity payment. The profit affects decision about the investments by firms and creates the generation capacity by passing the construction time. The capacity is offered to the market, which forms the main feedback loop in this process; it is retired after its life time and changes the investment rate in the expansion process. The market price determines the profit of the export based on the amount of planned export and investment in infrastructure for transmission of electricity.

D. Electricity Generation Cost

Marginal and investment costs are the main expenses for generating the electrical energy. Some costs such as fuel, pollution and operation, presented in [36], [37], form the marginal cost of the firms, which shows the cost of electricity generation per MWh. The marginal cost increases with constant rate of return every year as expressed in Eq. (2); the HR_j denotes the required thermal energy for generating electric energy by a certain technology in Btu/kwh and decreases every year [37]. The natural gas based technologies pay the Γ_{NG} for fuel cost.

$$MC_j = (F_j.HR_j + OM_j + CO_j)(1+rr)^y \tag{2}$$

The investment cost is paid over the construction period and must be recovered during the operation of the firms. Recovering the investment cost is important for providing the reliability in the uniform price markets, especially about the peak technologies [20], [33]. The firms cannot add the investment costs to their offers, while these costs are recovered due to the market pattern and capacity payment to the firms that have not the fortune of generation [33].

E. Electric Demand

The electric demand is modeled by load duration curve (LDC) for the base, middle and peak sections of the demand, which are supplied by coal-fired, CCGT and GT, respectively. The demand grows in each section with a constant growth rate every year and its average, expressed in Eq. (3), is offered to the market. The planed export demand is added to the interior demand, which is supplied by the natural gas based technologies at first. The total of interior and exported demand forms the market demand in Eq. (3).

$$D(t) = \sum_{i=1}^{k} \delta_i .L_i .e^{gy} + E_d \tag{3}$$

F. Power Market

In this paper, it is assumed that the market structure is uniform. Thus the price and generation of each firm is determined based on the minimum cost criterion. The firms bid their marginal cost in Eq. (2) and the offers are sorted from low to high for specifying the market price by the last bid that supplies the demand completely.

The investment cost does not influence the bid of the firms directly, but it must be recovered during the operation period. Wining the high bids is profitable for the firms with lower marginal cost, and the reliability of the power system is provided by capacity payment to the losers or free capacities [33].

G. Profitability

Clearly, the market specifies generation of firms, which can be used for computing their costs and profits. Total generation cost is the sum of expenses paid by the firms for generating electrical energy until the studied time, expressed by Eq. (4).

$$GC_j(t) = \int_0^t \Phi_j(\tau).MC_j(\tau)d\tau \tag{4}$$

As expressed in Eq. (5), income of firms is calculated by subtracting the generation and investment cost from their income, where $\Phi_j.MC_j$, $CP_j.I_j$ and $\Phi_j.\Omega_j$ are generation cost, investment cost and income of firms respectively.

$$\Pi_j(t) = \int_0^t \Phi_j(\tau).\Omega_j(\tau) - \Phi_j(\tau).MC(\tau) - CP_j(\tau).I_j(\tau)d\tau \tag{5}$$

The profit of firms can be normalized to the same quantity by defining the profitability index as the ratio of the profit to the generation cost, defined by Eq. (6) [32]. This parameter is helpful in decision about investing in a technology.

$$PI_j = \frac{\Pi_j}{GC_j} \tag{6}$$

H. Capacity Expansion

The PI of firms is converted into the investment rate by the S-shaped curves as defined by Eq. (7), which limits the rate of variation and the final value [26]. Each technology has different amounts of $m_{j\max}$, α_j and β_j, but the m_j is equal to 1 for $PI_j = 1$ in all the firms. The coefficient m_j is influenced by the reliability policy and the profitability for providing enough capacity.

$$m_j = \frac{m_{j\max}}{1+e^{-(\alpha_j PI_j - \beta_j)}} \tag{7}$$

The investment rate in each technology is a function of demand growth rate and the retirement rate of the firms, which is weighted by the coefficient m_j as indicated in Eq. (8).

$$IR_j = m_j.(\dot{L}_i + R\dot{E}_j) \tag{8}$$

The reliability policy in Eq. (9) is an internal loop in launching process, named as launch scale [1] that changes the rate of investment in each technology for holding the ratio of the reserve to the demand at a proposed level.

$$\mathrm{Res}.Rat = \frac{TCP - D(t)}{D(t)} \tag{9}$$

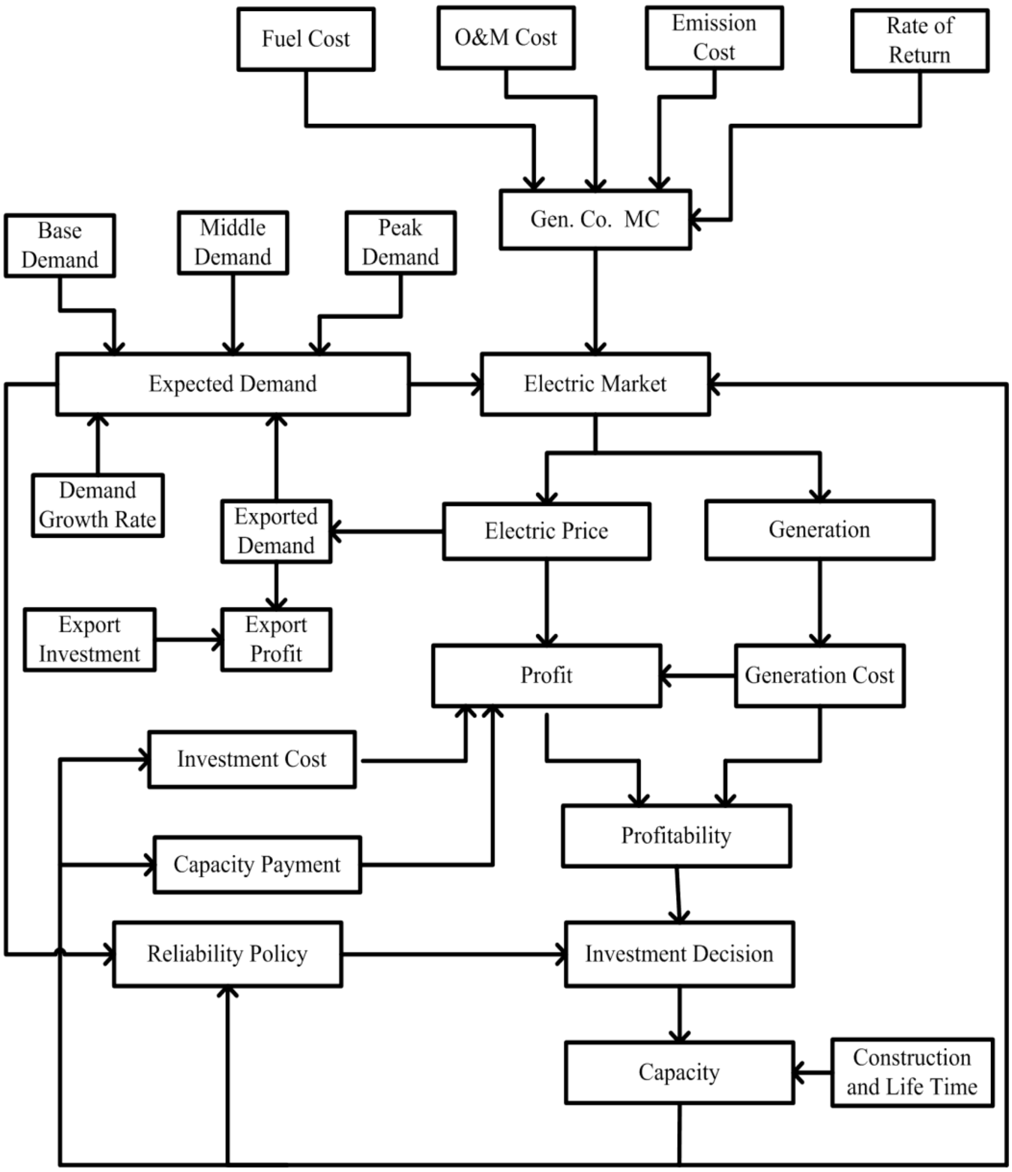


Figure 3: Export of the converted natural gas via power market.

The investment rate is converted into the under construction capacity during the construction time in Eq. (10), which is the difference between the investment rate and the construction rate in each technology. The capacity in operation is the difference between the constructed and the retired capacity in Eq. (11). The exploited capacity is declared to the market and creates the main feedback loop in this process; besides, it is used for providing the reliability as an internal loop.

$$UC_j = \int_0^t IR_j(\tau) - IR_j(\tau - CT_j)d\tau \tag{10}$$

$$CP_j(\tau) = \int_0^t CN_j(\tau) - CN_j(\tau - LT_j)d\tau \tag{11}$$

I. Wind Technology

The wind technology participates in the market besides the thermal technologies. Different effective factors such as generation and investment costs, construction time and life time are considered for analyzing the long run behavior of the wind technology in the market [36], [37]. The output power of the wind technology is perturbed by the wind speed, which is modeled by the Weibull probability distribution function in Eq. (12).

$$V_w(t) = \frac{\gamma}{\eta}.(\frac{t}{\eta})^{\eta-1}.e^{-(\frac{t}{\eta})^{\gamma}} \tag{12}$$

The wind generation in Eq. (13) is affected by the wind perturbation and the restriction of the infrastructures in low and high wind speeds, which eliminates the generation from the nominal amount [35]. The GT increases its income by compensating the lack of planed generation by wind, due to its fast response and free capacity [25].

$$G_{\omega}(V) = \begin{cases} 0 & V < V_{ci} \\ \left(\frac{V}{V_r}\right)^3 C\,\mathrm{P}_{\mathrm{r}\omega} & V_{ci} \le V < V_r \\ C\,\mathrm{P}_{\mathrm{r}\omega} & V_r \le V < V_{co} \\ 0 & V \ge V_{co} \end{cases} \tag{13}$$

3. Simulation and Results

This section studies two presented situations in section 2 for exporting the natural gas from Iran to Turkey during 400 months as a case study. The results are obtained using the published reports by EIA about the natural gas and the costs of electricity generation summarized in table 3 [37]-[40]. The analyses consider the export of natural gas at real time price, Γ_{NG} , and electricity at the market price, Ω .

Figure 4 represents the present profit of exporting the planned amount of natural gas in table 3 at real time price. The final profit is 2.1×10^11$, which recovers the investment costs during 1 year.

By restructuring of the power system the price of electricity is determined in a competitive market, which can be applied to the exported electricity. Figure 5 presents the market price, which grows with a constant rate of return and is influenced by the natural gas price, Γ_{NG} ; the coal-fired technology determines the lower limit of the price in this figure.

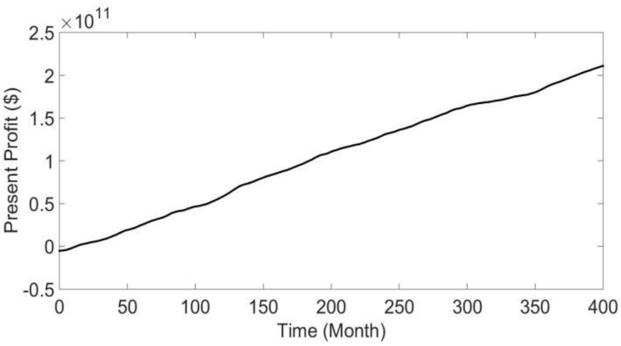


Figure 4: The present profit of natural gas export.

The profitability index of the firms, changes by the variation of natural gas price as indicated in Fig. 6. As the greatest value, the PI of CCGT is about 0.4; it is due to fact that the efficiency of energy conversion in this technology is comparatively high. On the other hand, the high marginal cost of GT reduces its efficiency, leading to the lowest PI for this technology in the market. High price natural gas increases the PI of the coal-fired due to higher electricity price and increases the costs of the GT and CCGT, which decreases their profitability in Fig. 6.

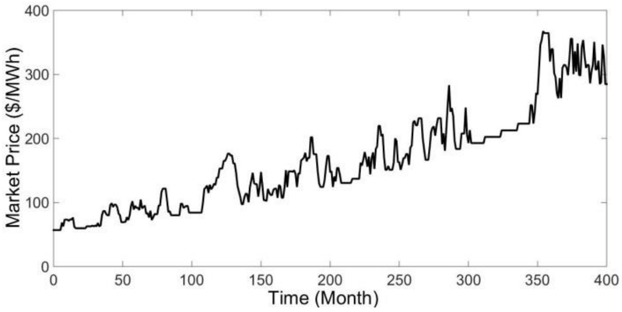


Figure 5: The market price of the electricity.

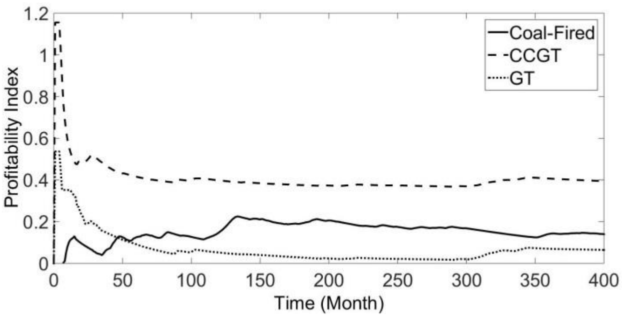


Figure 6: The profitability index of the thermal technologies in the power market.

The present profit of electricity export at the market price for different firms is summarized in table 1. The CCGT earns the most profit and operates at the full capacity in comparison to other firms. Electricity exportation at the market price does not recover the invested resources in transmission and causes loss as the income from market is 6.2×10^8$.

Table 1
The Present Profit of the Firms and Electricity Export Via the Market

Firm	Profit ($)
Coal- Fired	1.9×10^8
CCGT	3.2×10^8
GT	0.26×10^8
Exportation	-21.8×10^8

The variation of natural gas price and the profitability affects the pattern of capacity expansion by the firms as shown in Fig. 7. Increasing the natural gas and market prices provides the opportunity for capacity expansion by the coal-fired to the maximum capacity of 13.8×10^4 MW. The rate of capacity expansion by the CCGT and GT is less than the coal-fired and their capacity is 7.5×10^4 MW and 6.4×10^4 MW at the end of the period, respectively. The power market provides the reliability of domestic and foreign demand as indicated in Fig. 8, in which the ratio of power system reserve remains about 20%.

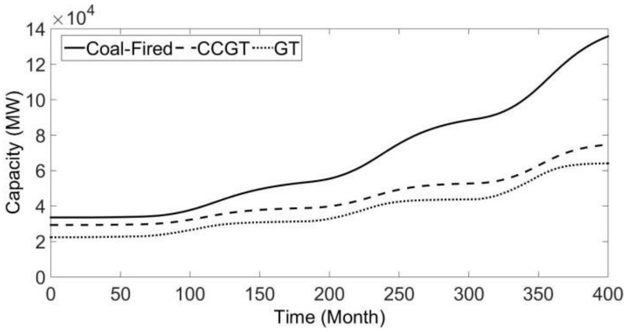


Figure 7: The capacity of the thermal technologies in the power market.

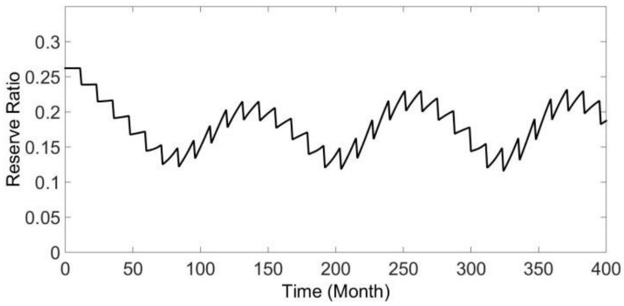


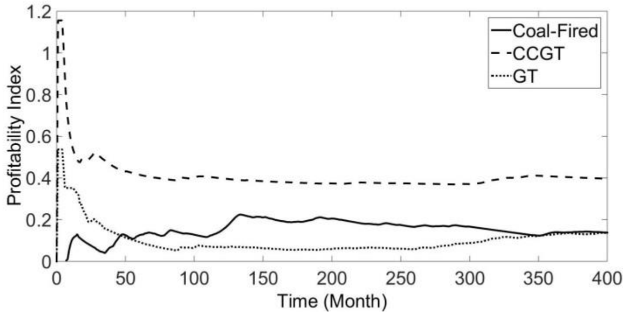
Figure 8: The reserve ratio of the power system.

The presence of the wind technology besides the thermal firms changes the pattern of generation without influence on the market price and profit of the exportation. Figure 9 represents the profitability index of the firms by the presence of the wind turbines in the market. The PI of the coal-fired and CCGT does not change, but the PI of GT increases compared with Fig. 6, due to compensation of the difference between generated power and nominal power. Free capacity of the GT and its fast start up and fast response to the changes made the GT suitable for making up the wind lack. Table 2 summarizes the profit of the firms and electricity exportation via the power market beside the wind technology. The present profit of the coal-fired and CCGT decreases as compared with table 1, while the present profit of GT is increased through compensating the lack of wind generation.

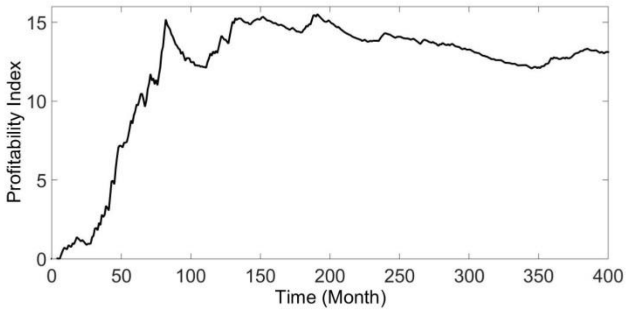
The wind participation in the market changes the generation pattern as shown in Fig. 10. The capacity of the thermal firms reduces to 10.2×10^4 MW, 5.9×10^4 MW and 5.2×10^4 MW for the coal-fired, CCGT and GT, respectively as the wind capacity gets to 2.7×10^4 MW.

TABLE 2
THE PROFIT OF ELECTRICITY EXPORT VIA POWER MARKET FOR DIFFERENT FIRMS IN THE PRESENCE OF WIND TURBINES

Firm	Profit ($)
Coal- Fired	1.6×10^8
CCGT	2.9×10^8
GT	0.7×10^8
Wind	0.69×10^8
Exportation	-21.7×10^8



(a) Thermal firms



(b) Wind

Figure 9: The profitability index of the firms with the presence of the wind.

The new generation pattern decreases the total fuel cost of electricity generation from $2.34\times10^7$$ to $1.93\times10^7$$.

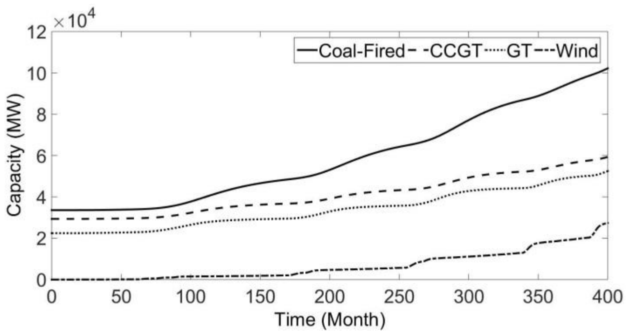


Figure 10: The capacity of different technologies with the participation of the wind.

4. Conclusion

In this paper, the long run export of natural gas was analyzed by the system dynamics method. In this regard, the exportation from Iran to Turkey was studied using the published data by the EIA about the natural gas price and its forecast, the situation of natural gas resources around the world and the costs of electricity generation. The real time price of natural gas is estimated by the Markove Chain Monte Carlo, considering the present price and variation and rate of return.

Two different scenarios was considered for transferring the energy including direct export of natural gas at real time price and conversion of natural gas into electricity for export via the power market with considering the renewable resources. Direct export of natural gas in the real time price creates profit at the amount of 2.1×10^{11}\$, which recovers the investment in transfer infrastructure during 1 year. Export of electricity in the real time price was investigated in the second scenario. The electricity price is cleared in the power market with uniform price structure. The firms including coal-fired, CCGT and GT technologies supply the demand and export electricity, given that they expand their capacity according to the earned profit from the market. Exporting via the market price loses amount -21.8×10^{8} \$ and does not recover the investment in transmission. Therefore, the costs of transmission in this scenario have to be appropriately considered by planning for transmission right. Participation of the exported electricity besides the demand in the market can be provided by the capacity expansion of the firms for keeping the reliability of the power system. The profit of coal-fired, CCGT and GT in this scenario is 1.9×10^{8}\$, 3.2×10^{8}\$ and 0.26×10^{8}\$, respectively.

The expansion of renewable technologies in the power market does not affect the continuity of export. Although the expansion of renewable energy decreases the costs of fossil fuel from 2.34×10^{7}\$ to 1.93×10^{7}\$ during the studied period, it does not make a profit for export, due to its high investment in transmission and the loss of export is still about 21.8×10^{8} \$. The profit of coal-fired and CCGT decreases to 1.6×10^{8}\$ and 2.9×10^{8}\$ by the expansion of renewable resources, while GT increases its profit to 0.7×10^{8}\$, equal to wind technology, by Compensating the deviation of wind generation from the nominal amount beside power generation.

All in all, export of natural gas at real time price recovers the invested resources in transmission and makes profit, while exporting via the power market doesn't compensate the costs of transmission and is disadvantageous. So, the electricity must be exported at a suitable forward price.

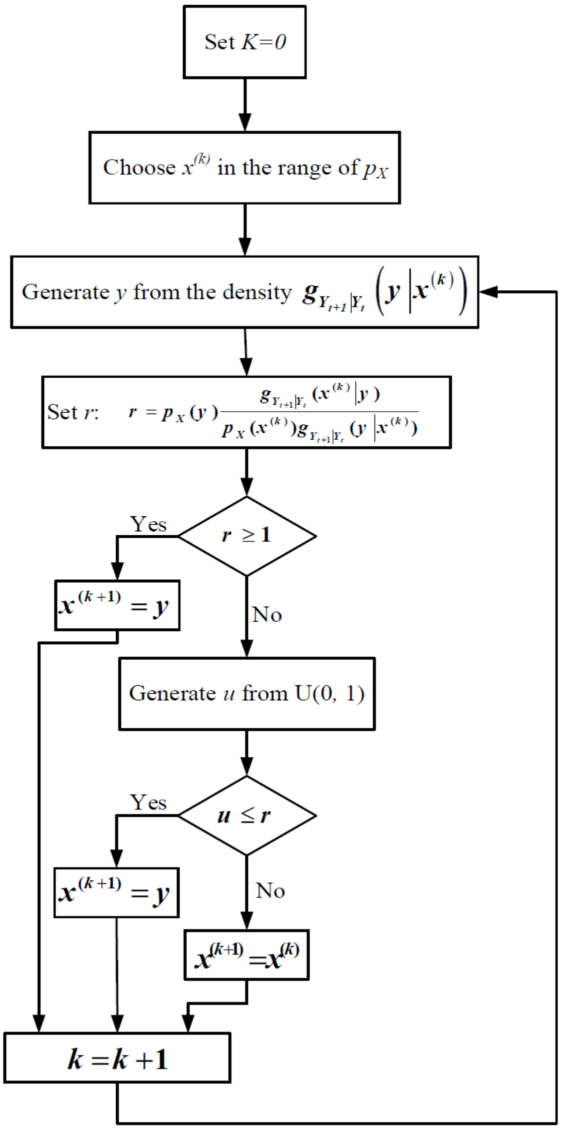


Figure 11: The flowchart for estimating the natural gas price.

5. Appendix A

Inequality (14) expresses the criterion for acceptance or rejection of a sample in a distribution with the density ρ_X , which generates the walk moves from the point y_i to a candidate point $y_{i+1}=y_i+s$, where s is a realization from U(-a, a) and u is an independent realization from U(0, 1).

If the new point is at least as probable (that is, if $\rho_X(y_i+1)\geq\rho_X(y_i)$), the condition (14) implies acceptance without the need to generate u [34].

$$\frac{\rho_X(y_i+1)}{\rho_X(y_i)}\geq u \qquad (14)$$

The Metropolis-Hastings sampler uses a more general chain for the acceptance/rejection step, instead of just basing the decision on the probability density ρ_X as in the inequality (14). The Hastings technique uses deviates from a Markov chain with the density $g_{Y_{t+1}|Y_t}$ for generating deviates from a distribution with a probability density ρ_X as flowchart shown in figure 11.

6. APPENDIX B

Table 3 summarizes the applied data in the simulation, borrowed from [37]- [40].

TABLE 3
THE PARAMETERS OF THE SIMULATION [37-40]

Parameter \ Technology	Coal Fired	C.C.G.T	G.T	Wind
Fuel Cost	65 ($/ton)	Γ_{NG}	Γ_{NG}	-
Heat rate (Btu/KWh)	9200	6752	9289	-
O&M costs ($/MWh)	7.7	3.3	4.3	3.4
CO_2 costs ($/MWh)	24	10.5	16	-
Investment costs ($/KW)	1923	877	604	1797
Construction time (months)	48	36	24	6
Life time (months)	720	360	360	240
Planned amount of natural gas export (MMBtu/Month)	112.5×10^6			
Natural gas transfer investment ($)	5.1×10^9			
Planned amount of electricity export (MW)	23000			
Electricity transfer investment ($)	2.8×10^9			
Rate of return (%/year)	5%			
Peak demand (MW)	52000			
Peak duration	0.2			
Middle demand (MW)	40000			
Middle duration	0.6			
Base demand (MW)	28000			
Base duration	0.2			
Demand growth rate (%/year)	5%			
Rated wind speed (m/s)	7			
Product wind speed (m/s)	4			
Cut out wind speed (m/s)	13			

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BIOGRAPHIES

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