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Policy Framework of Non-Fossil Power Plants in Iran's Electricity Sector by 2030

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ABSTRACT

The Iranian government has set a target of a 20% share of non-fossil fuel electricity generation by 2030, whose main result is reducing Green House Gas (GHG) emissions (about 182 million tonnes in 2017) to achieve the targets pledged under the Paris Climate Accord. So, this paper presents a comprehensive model on the expansion of non-fossil technology to evaluate the impact of increasing their share in Iran's electricity supply system. This analytical approach is based on system dynamics (SD) that was developed based on dynamic behavior of electricity market, with an emphasis on the expansion of non-fossil fuels (solar photovoltaics, wind turbines, expansion turbines, and hydro power) in the supply side of this model by electricity price reformation. For this purpose, we developed four scenarios with different share percent of non-fossil technologies in Iran's electricity system. The findings demonstrate that electricity price must be determined based on the costs of non-fossil technologies, as well as based on fossil fuel prices which are low in the current energy supply system and its value was predicted that increased to maximum of 2.03 cent USD/kWh. In conclusion, in the best scenario, the Paris Climate Accord criteria is achieved with a 20% growth of non-fossil fuels and increasing electricity price to 2.54 cent USD/kWh in 2030 with 0.19 price elasticity of emission.

Keywords:

System Dynamics;
Green House Emission;
Electricity Price;
Modeling;

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1. Introduction

The energy sector plays a major role in global GHG emissions with about a 75-percent share, and there are critical actions in this sector that can make or break efforts to achieve global climate goals aimed at tackling the increasing global average temperatures started since the mid-20th century. Therefore, one of the most important, globally adopted agreements was met in December 2015 called the historic Paris Agreement, which includes GHG mitigation actions covering the period 2020-2030, and its long-term goals include limiting the mentioned temperature rise to well below 2°C and pursuing efforts to limit the rise to 1.5°C [1]. Iran intends to participate by reducing its GHG emissions in 2030 by 4% compared to 2020 based on its Intended Nationally Determined Contributions (INDC).

One of the most important solutions in GHG emissions mitigation is increasing the expansion of non-fossil power plants, such as renewable resources, hydropower, and expansion turbines, in the energy supply system. In 2018, about 2,807 PJ distributed on 86% NG, 8% gas oil and 5% fuel oil was consumed by power plants in the electricity supply system, and because of shortage of natural gas in cold months, this sector had to use gas oil for gas turbines and fuel oil for steam technologies [2]. As a result, about 1,280 Mt of CO_2 equivalent of GHGs were emitted to Iran's atmosphere, which is equal to more than 29% of the total

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Nomenclature

P_t	Electricity price in cent USD/kWh
P_t^I	Electricity price index in cent USD/kWh
AT	Adjustment time in hour
S_r	Reference supply in kWh
D_r	Reference demand in kWh
ES	Effect of price on supply
ED	Effect of price on demand
e_s	Price elasticity of supply
e_d	Price elasticity of demand
EB_p	Effect of demand per supply balance on price
F	Import coefficient
s	Price sensivity of demand per supply balance
λ_i	CO_2 equivalent emission factors in $grCO_2$/kWh
$\lambda_i \cdot_{CO_2}$	CO_2 emission factor in $grCO_2$/kWh
$\lambda_i \cdot_{C}$	Carbon emission factor in grC/kWh
$\lambda_i \cdot_{N_2O}$	N_2O emission factor in grN_2O /kWh
$\lambda_i \cdot_{CH_4}$	CH_4 emission factor in $grCH_4$/kWh
$P_{ceilling_t}$	Price ceiling in cent USD/kWh
α	Variation of price ceiling
CF_i	Capacity factor in %
$Oc_{i.t}$	Operation costs in cent USD/kWh
$Fc_{i.t}$	Fuel costs in cent USD/kWh
$so_{i.t}$	Subsidy of power plants in cent USD/kWh
$ef_{i.t}$	Efficiency of power plants
$T_{i.t}$	Applied tax on power plants in cent USD/kWh
PJ	Petajoules
Mt	Million tonnes

Subscripts

i	Power plants technology number (1 to 13)
t	Time

emissions in the country, demonstrating the importance of the energy supply system for GHG reduction (Fig. 1) [3]. Thus, new energy resources and technologies, such as non-fossil fuels, are required to ensure sufficient energy supply for the growing demand.

The process of implementing Iran's unconditional mitigation of GHG emissions will be facilitated and speeded up with increasing the share of non-fossil fuels in the electricity supply system, and Iran's government intends to achieve a 20% share [4]. This share, as shown in Fig. 2, was 5% in 2018 [2].

This paper describes an analysis performed to assess reaching a 20% share for non-fossil fuels in the electricity supply system for Iran to meet these emission targets pledged in COP21. In particular, it attempts to determine the electricity price such that it enables non-fossil fuel power plants to compete with conventional power plants in gaining electricity market share and to compute the resulting overall costs. So, the main output of this paper is electricity price which determine share percent of non-fossil fuel power plant in Iran's electricity production system. However, energy price reformation has not been effectively pursued in Iran, and therefore, there has not been a successful sensible reduction in utilizing fossil fuels in recent years.

Iran's parliament passed an energy reformation in 2010 and according to it, fossil fuel prices should increase to international prices within five years [5]. Hence, based on changes in fossil prices, share of these fuels should be decreased in Iran's electricity production

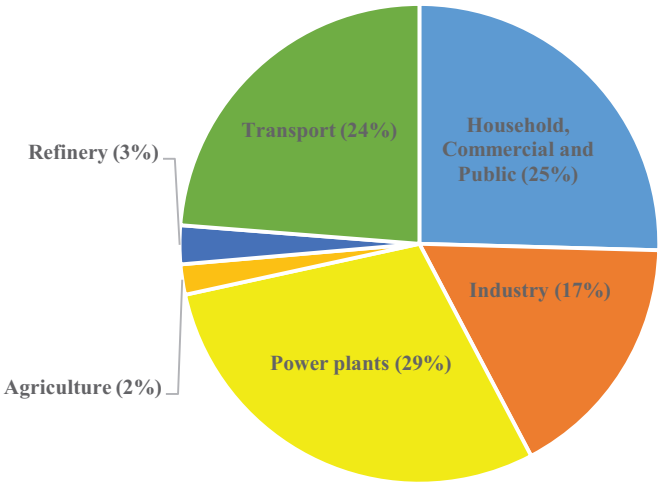

Figure 1: Shares of energy sections in GHG emissions in Iran, 2017 [3]

system, but this share changed only from 95.55% to 91.64% on years between 2010 to 2018 [2]. Indeed, the main concern of this paper is the possibility of electricity prices for the development of non-fossil power plants which, on one hand, can satisfy the growing electricity demand and, on the other hand, can help achieve a 20% share of non-fossil fuels in primary energy by 2030, which can mitigate Iran's GHG emissions according to the Paris Accord targets.

Electricity price has high impact of energy consumption in Iran and is an important input to all demand sectors that were shown in Fig. 1. So, this policy tool could

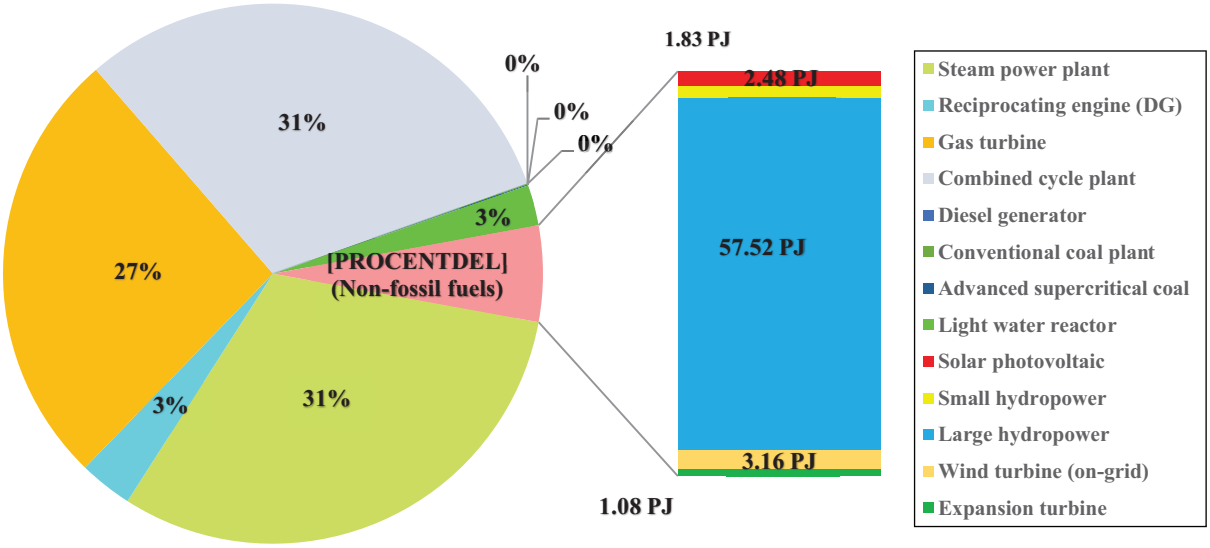

Figure 2: Shares of power plants types in Iran's electricity production system, 2018 [2]

impose to these sectors in changing consumption pattern from fossil resources to their non-fossil types. Because of low electricity price of fossil power plants, supply side do not have incentive to decrease GHG emissions.

Since renewable energy resources have intermittent availability and fossil fuel costs contain uncertainty in their future pricing policy, we analyze the impact of both expansion capacity of non-fossil fuel power plants and fuel costs of fossil power plants on the trend of the expansion of these zero emission resources. So, determination of electricity price that make the most impact on GHG emissions with calculation of emission elasticity (novel parameter) is considered in current study as research gap and this point directly was not investigated in previous papers.

In this paper, we tried to set an energy policy path for an electricity pricing mechanism in Iran's energy supply system for the realization of the Paris Accord targets, for which purpose research and development was done on decreasing GHG emissions based on the proposed method shown in Fig. 3.

This paper is structured as follows. After reviewing previous studies, the methodology and the applications of system dynamics (SD) in an energy supply system were presented. In the continuation of this section, we describe the fuel cost and non-fossil fuel pricing mechanism to derive key electricity pricing components. Therefore, the SD model is constructed, described, and validated in Section 3. Results are discussed in Section 4. The paper finalizes with conclusion and policy implications.

2. Literature Review

In order to understand Iran's future energy consumption and emissions and to investigate the potential utilization of renewable energies, many studies have recently been conducted to simulate various future development pathways. However, they lack an explicit description of how increasing the expansion of non-fossil resources aid in achieving the Paris Accord targets in their analytical model. Some of these articles have proposed analytical models to estimate the overall cost of utilizing renewable resources for emission reduction or have provided general strategies for devising long-term energy policies, but they have not provided a practical and economic method for increasing the expansion of non-fossil fuel technologies in the energy supply system.

Kachoee et al. investigated the current Iranian electricity supply and demand to forecast future generation trends in the power plant sector. Based on their results, this sector will emit about 668.2 Mt of CO_2 equivalent of GHGs in the Business As Usual (BAU) scenario by 2040, which could be reduced to 294.6 Mt by adopting renewable development policies [6]. Setiartiti et al. developed four scenarios for transportation sector of Yogyakarta Province in Indonesia and showed that mitigation scenario could reduce GHG intensity [7].

In 2017, Manzoor and Aryanpur presented a retrospective optimization model for Iran's power sector and showed that demand-side strategies and shifting to renewable supplies are two of the most important key drivers in achieving a low-carbon generation mix [8].

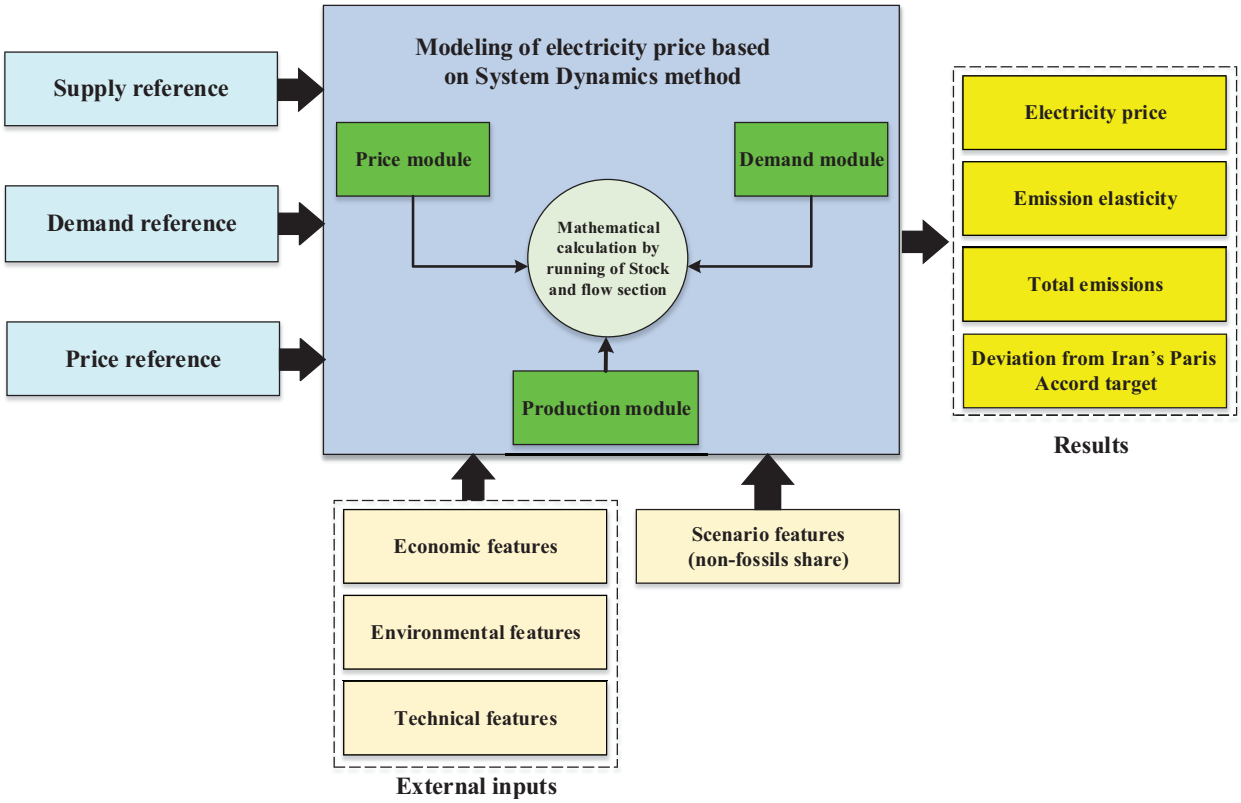

Figure 3: Research methodology flowchart and overall investigation structure

Although fossil fuels still heavily dominate Iran's electricity supply system, especially natural gas, there are great and diverse renewable opportunities that should be considered as distributed generation in different province [9].

This practical solution can lead to the possibility of foreign and domestic investment opportunities. For instance, Shasavari and Akbari focused on potential barriers for promoting solar energy resources and increasing their expansion in the power grid, and claimed that this renewable energy has benefits that can absorb Foreign Direct Investment (FDI) [10]. Studies similar to the mentioned papers have been conducted in other countries, arguing that the cooperative planning framework in the development of non-fossil fuel power plants is capable and possible. Finding the most efficient method based on different incentives in the form of governmental executive scenarios is necessary for increasing the share of renewable resources in meeting the growing future electricity demand [11].

In 2019, Wahba et al. analyzed the effect of green strategy models on building design in areas with hot and dry climatic zones. They announced that building sector has a big responsibility in 62% of total electricity consumption and around 70% of resultant CO_2 emissions and application of green wall is very powerful way that enhances the ecosystem health [12]. Burciaga et al. implemented Construction and Demolition Waste (CDW) strategies in reducing CO_2 emissions of housing building and found that they can reduce 53% of CO_2 [13]. Khan et al. presented integrated association model of green building rating tool (MyCREST) with Life Cycle Costing (LCC) and its final result was that criteria environmental management plan has lowest costing role in green building projects [14]. In 2018, Darabpour et al. focused on practical approaches toward sustainable construction industry by considering the experts' opinion in Iran [15].

Candia et al. evaluate the flexibility of the Bolivian power generation system in terms of renewable energy and found that 30% participation of solar and wind technology are required for grid reinforcements [16]. At 2020, a comprehensive investigation has been done by European researchers who developed a strategy under a Modern Portfolio Theory (MPT) for replacing conventional electricity generation technologies with renewables

energies when defining efficient portfolios with less risk [17].

Yuan et al. presented a multi-region and multi-period model to explore the carbon and spillover impacts of investments in non-fossil fuel electricity generation and tried to explain how these investments affect CO_2 emissions in China [18]. Atanasoae et al. assessed the employment impact of low capital cost of on-grid power generation on the expansion of renewable energy resources on Romania's electricity supply system [19]. According to their investigation, these production technologies can be profitable at less than 2300 Euro/kWh, depending on the self-consumption share of electricity produced by renewable resources.

In recent years, many papers were published suggesting that an energy policy domain based on System Dynamics (SD) has many advantages in providing a better comprehension of complex interactions between different variables. Furthermore, SD itself can also be combined with other scenario planning methods, which helps obtain solid results from the dynamic behaviors of energy systems such as the electricity supply system [20]. Liu et al. investigated the mobility management policy of Beijing's transport sector and its effects on energy savings and emission reduction using SD approach [21]. Their results show that the effects of energy conservation and emission reduction are two key solutions in comprehensive dynamic policies, and their efficacy is assessed in their study.

The cost-benefit analysis based on SD model has been done on the simulation of energy saving from combining renewable energy and energy efficiency improvements in reference [22]. The results showed that renewable energy has more social benefits than energy efficiency improvements, and every country should introduce appropriate renewable development policies for its emission reduction targets. Shafiei et al. presented an integrated SD model for Iceland's energy system to explore the transition process towards a hydrogen- and biofuel-based market considering both supply and demand sides [23]. They again focused on the application of renewable-based energy system for making this transition pathway.

From the above mentioned papers, it can be understood that the SD method is a suitable way of structuring the causal and indirect relationships with randomness and uncertainty aspects such as electricity price [24]. So, to develop insights into the economic impacts of electricity pricing, we present a dynamic model that provides useful policy implications for Iran's future emission reduction, as there was a substantial increase in the installed capacity of non-fossil fuel technologies in the period under study. Indeed, reducing GHG emissions of power plants by increasing the share of non-fossil energy to 20% is key for Iran to meet its targets in Paris Accord.

3. Model

This section provides a general model representing Iran's electricity pricing that can be applied to the proposed pricing method of power plants owners, and its integrated system dynamics model has three subsystems: production, demand, and price.

In order to understand the effect of technological and economical motivators on the whole electricity sector, it is important for the new non-fossil fuel and conventional capacities to be able to adequately serve the increasing electricity demand of the country. Apart from what is affected by the market, these motivators affect the produced energy and certificate prices. We investigate the effective management of non-fossil fuel power plants expansion in Iran's electricity supply system on its (electricity) pricing mechanism. So, our model is designed by following a principle similar to the one in Klaus-Ole Vogstad's PhD thesis [25] where a complex system is divided for clarifying the sectorial interactions.

Through a review of the existing literature, the causal relationships of electricity pricing considering the share increase of non-fossil resources are presented, and after selecting other causal variables, Causal Loop Diagrams (CLDs) of modules will be constructed. After a qualitative examination of the causal relationships, three modules are derived, and the required data are applied in causal relationships followed by the formulation of these relationships in the next stage. Finally, the integrated stock-flow diagram will be developed. Nevertheless, this study's objective is to investigate the non-fossil fuel certificate policy with the time horizon of 2020-2030 (the Paris Accord timeline).

3.1 Production module

The production module is constructed to model the supply side of electricity energy system associated with fossil and non-fossil resources as shown in Fig. 4.

As can be seen, the new power plant investments are based on investors' expected profitability of the new capacity, which is influenced by price variation, capital

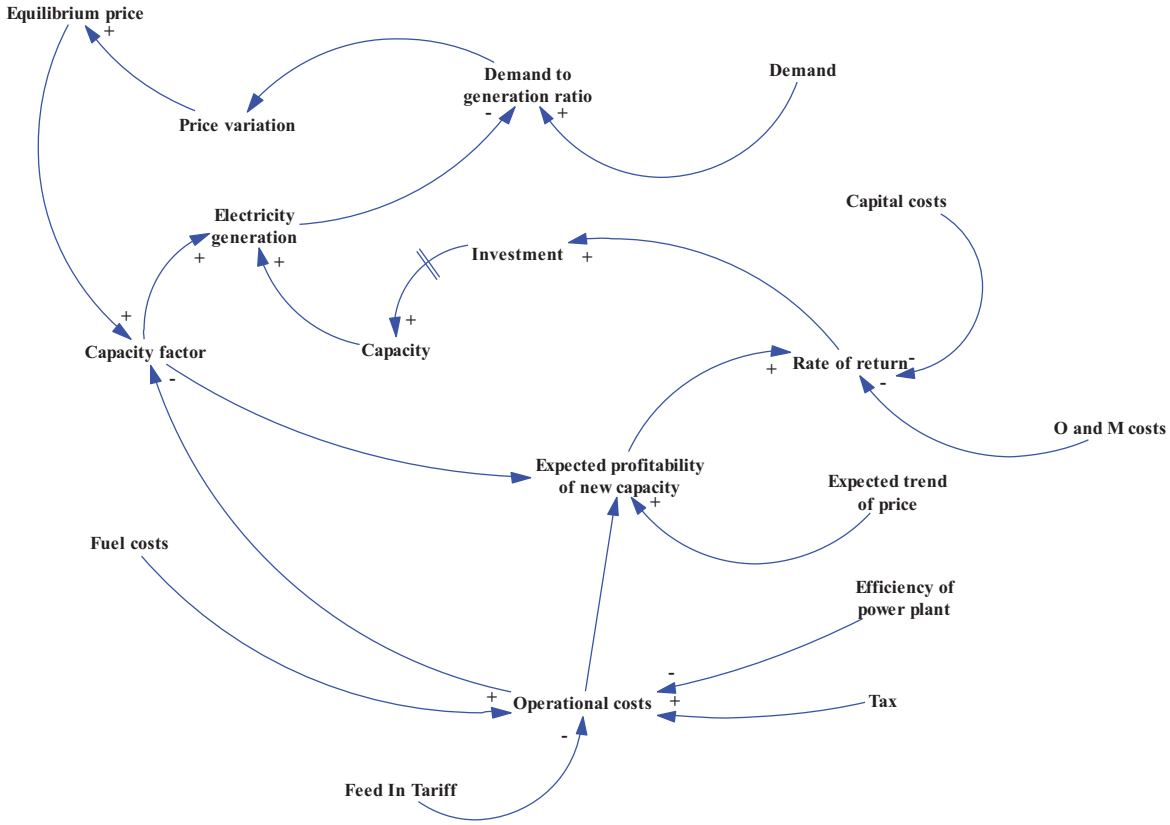

Figure 4: CLD of the electricity production module

costs, O&M costs, fuel costs, and capacity factor. Increasing the expected price and capacity factor soar the expected profit, and conversely, increasing costs decreases it. Variations of profit versus total costs will affect the rate of return and investments of power plants. So, capacity expansion has two delays: 1) Requesting a construction permission, verification, and confirmation receiving, 2) Time required for investing in new power plant capacity. These two mentioned delays have been considered in the proposed CLD of the production module.

Since capacity will grow with investment, the utilization of current and new power plants is a function of capacity and capacity factor, and is in a direct relationship with electricity price and total costs (O&M, capital, and fuel costs at Fig. 3). In this module, we considered 13 various competing generation technologies (see Table 1) which were divided into two categories: fossil and non-fossil fuel power plants. Using the capacity of these technologies depends on their profitability and new investments in capacity.

3.2 Demand module

The demand module aims at clarifying the causal path from the electricity consumers' behavior to factors affecting electricity price that comprise the affordability aspect of the energy market, as shown in Fig. 5.

According to Fig. 5, demand variation in the electricity market is a function of price factors (price ceiling and price elasticity of demand) and real factors in economics (growth rate), with price having a negative effect and real factors having a positive effect on demand.

A rise in demand increases the demand to generation ratio (D/G), leading to electricity price soaring which in turn results in decreasing the demand in the next feedback. Furthermore, demand also relies on external factors such as weather (temperature), which affects the level of generation. On the other hand, price is the main feedback between the demand side and the supply side, which is described through the price elasticity of demand measured on a yearly basis. For modeling future development in our model, a fixed growth rate is considered exogenously for the demand module, which is a representation of Iran's economy

Table 1: Technological features of power plants in electricity supply system [26, 27, 28, 29, 30, 31]

NO.	Technology	Capital cost ($/kW)	Fixed O&M ($/kW)	Variable O&M ($/MWh)	Efficiency (%)	Plant lifetime (year)	Plant factor (%)	Self-consumption (%)	Decreasing rate of investment cost (%/year)	Upper limit on new capacity additions[a] (MW/yr)	Type[b]
1	Steam power plant	1100	9.4	0.48	41.2	30	75	6.8	0	0	F
2	Reciprocating engine (DG)	800	8	5	40–45	10	80	0.7	0	119–811	F
3	Gas turbine	550	4.4	0.64	34.3–38.9	12	70	0.8	0	0	F
4	Combined cycle plant	760	4.3	0.41	50–55	30	80	1.9	0	0	F
5	Diesel generator	550	3.8	0.74	33	10	70	6.5	0	0	F
6	Conventional coal plantc	1600	64	0	35.3	30	85	5.5	0	0	F
7	Advanced supercritical coal	3700	88	0	46–50	40	85	5.6	0.7	0	F
8	Light water reactord	4800	92	0.5	31	40	80	10	0	0	F
9	Solar photovoltaic	4000	50	0	0	25	25	0	3	48–670	NF
10	Small hydropower	2000	14	0	0	40	50	0.5	0	192	NF
11	Large hydropower	1500	10.8	0	0	50	15	0.5	0	1080	NF
12	Wind turbine (on-grid)[e]	1500	48	0	0	20	30	1.4	1.5	3055	NF
13	Expansion turbine	780	30	0.45	0	15	70	0	0	115	NF

[a] An upper limit of a technology for maximum capacity of its power plant that is imposed on the model.
[b] Type of technology is presented that F is related to the fossil fuels and NF is non-fossil power plants.
[c] The country will construct capacity of this technology about 650 MW until 2030.
[d] According to nuclear sanction that were imposed on country, it could be only install 1000 MW capacity of this technology similar to Bushehr's nuclear power plant until 2030.
[e] Based on capacity fluctuations of wind turbine in the country, capacity of this technology will be five time until 2030.

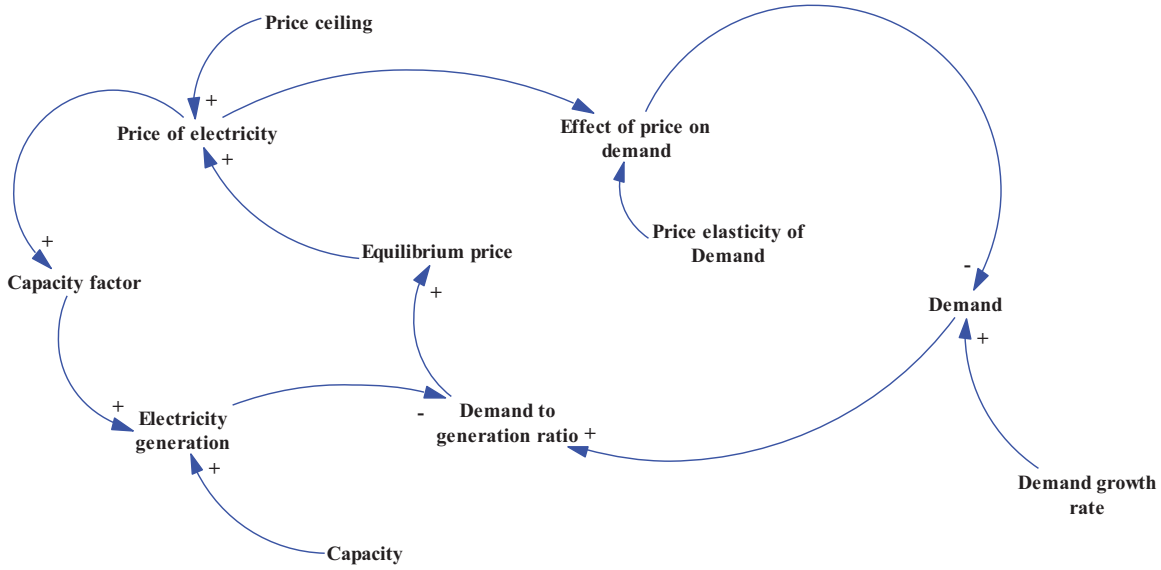

Figure 5: CLD of the electricity demand module

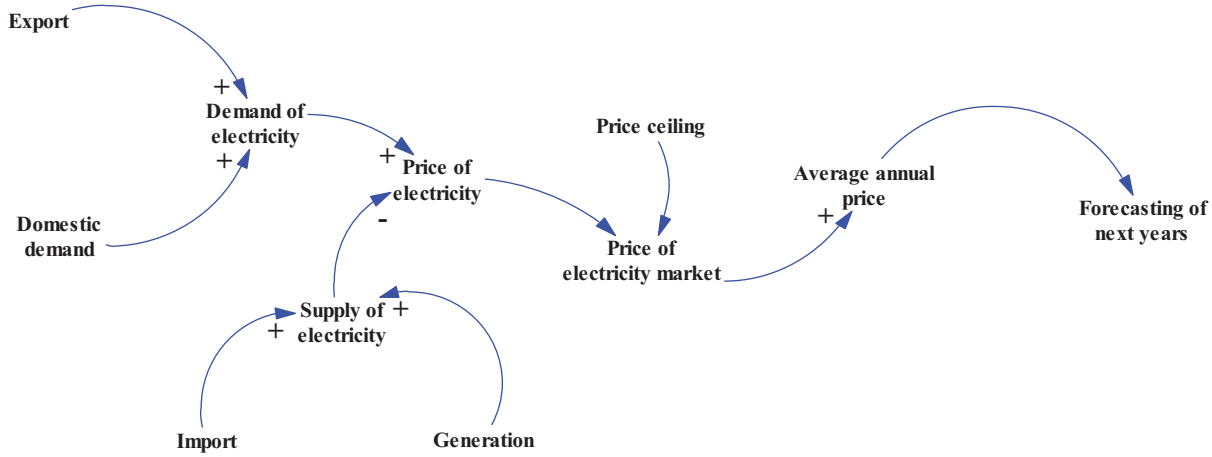

Figure 6: CLD of the electricity price module

3.3 Price module

The price module focuses on management of electricity price formation in the energy market, which includes total demand and total supply with consideration of import and export, as shown in Fig. 6.

Power plants should come up with an accurate estimate of the required power to supply the total electricity demand. On the other hand, offering electricity to the market with a lower price than the real one is a major reason for a rise in the energy consumption rate, with the difference between two prices being paid by the government as subsidy, which is a subject of controversy in Iran. Nevertheless, price variations are not considered as a driving force, and its value is assumed about 6cents/kWh in different scenarios [32]. To determine electricity price, generation scheduling of each unit can be performed as separate optimization tasks, allowing optimization across utilities' production systems, with import being considered as external provision.

3.4 Integrated module

We integrate the three modules into the CLD, and develop the stock and flow diagram as shown in Fig. 7.

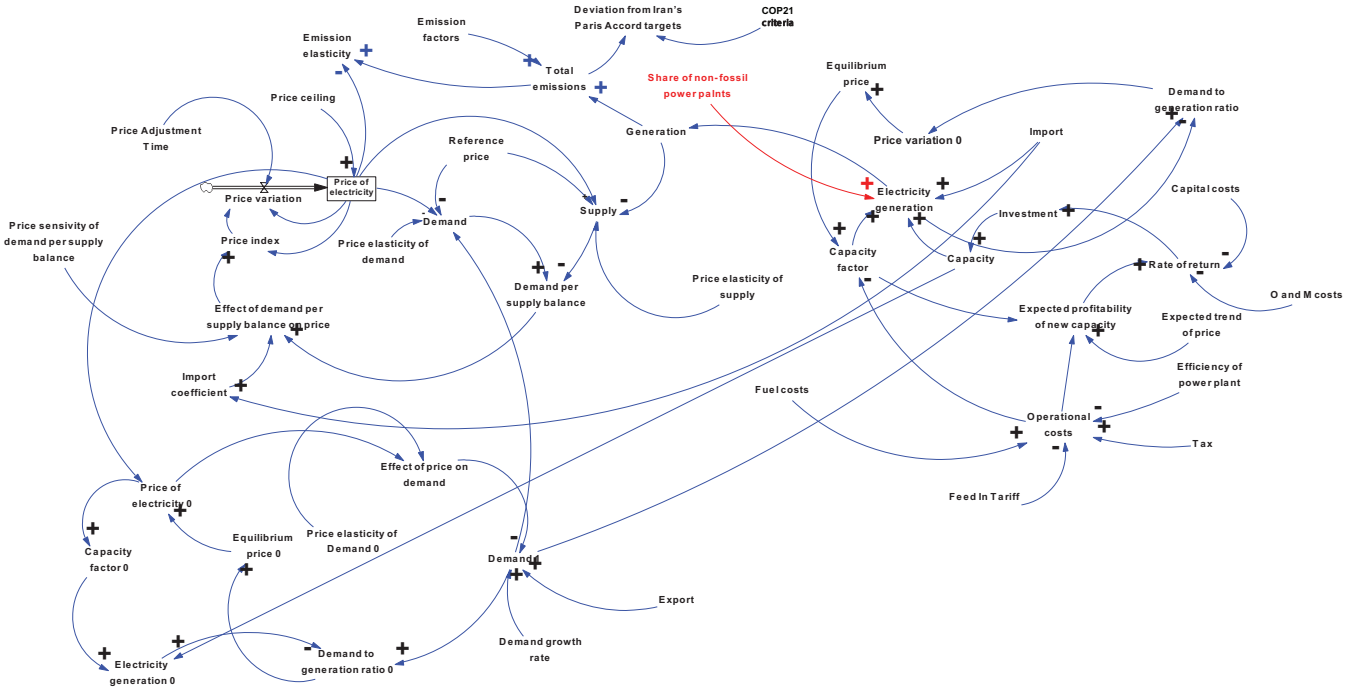

Figure 7: Stock and flow diagram of the integrated model

In order to check the structural consistency and validity of the model, verification tests and some new important causal paths are utilized to explain the real electricity pricing mechanism. After the addition of the new causal paths, the final structure of the model is presented according to these modifications.

Commonly, reviews show that price adjustment time, price index, and demand to supply ratio should be inserted into a balanced loop between supply and demand for electricity pricing. Electricity demand has a direct impact on the demand of non-fossil fuel energies, as well as to some extent on the demand of oil, coal, natural gas, and nuclear energy. Furthermore, we considered a certain share of non-fossil fuel power plants in electricity generation for modeling the exogenous effect of these energies on the final electricity price.

Attracting private investors is a very crucial issue in electricity market. The government should provide sufficient support through allocation of incentives to attract them to constructing power plants, especially non-fossil fuel ones, to cope with the growing electricity demand in the future. These investment motivators are considered in the "Feed-in Tariff", "fuel costs", and "tax" parameters whose values will affect both operational costs and expected profitability of new capacities.

3.5 Greenhouse gas emissions

In this paper, GHG emissions are evaluated based on CO_2 equivalent concept estimated by the Eq. 1:

$$\lambda_i = \alpha\lambda_{i.CO_2} + \beta\lambda_{i.C} + \gamma\lambda_{i.N_2O} + \delta\lambda_{i.CH_4} \quad (1)$$

where $\lambda_{i.CO_2}$, $\lambda_{i.C}$, $\lambda_{i.N_2O}$, and $\lambda_{i.CH_4}$ are emission factors of CO_2, Carbon, N_2O, and CH_4, respectively. Eq. 1 is a measure of how much energy the emission of one tonne of a certain gas will absorb over 100 years relative to the emissions of one tonne of CO_2. Moreover, in Eq. 1, relation factors α, β, γ, and δ are 1, 3.7, 265, and 28, respectively [33].

In this paper, the mentioned emission factors in Eq. 1 have been valued based on real data collected from various installed power plants in Iran (as shown in Table 2).

Our model has a nonlinear and complex structure that will cause some difficulties for investigators in describing demand, production, and pricing principles of the above modules. Therefore, we implement our model in Vensim software [34]. The details of the models and principle equations are presented in Appendix A.

3.6 Validation

In order to test the model, we examine how the model output fits the historical data by performing the behavioral reproduction test. As shown in Fig. 8 and Fig. 9, for two modules (production and demand) from 2007 to 2018, our model-simulated behavior well matches the behavior of the real system. Also, by comparing the data in the time horizon mentioned above, statistical error values, such as Mean Average Error (MAE) and Root Mean Square Percentage Error (RMSPE), were evaluated in our model based on Eq. 2 and Eq. 3.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\frac{|R_i - S_i|}{R_i} \quad (2)$$

$$RMSPE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{R_i - S_i}{R_i}\right)^2} \quad (3)$$

where R_i and S_i represent real value and the simulated value of i, respectively, and n represents the quantity of the data.

The values of MSE and RMSPE for the production module are 3.38% and 3.59%, respectively, with their values for the demand module being 4.37% and 4.54%, respectively. Our model has good conformity to historical trends.

All efforts in R&D, competition of technologies, and government's laws in the energy sector are reflected as changes in electricity demand and production. Indeed, if

Table 2: Pollutant and GHG emission factors in Iran power sector by power plant types for the year 2017 (gr/kWh) [3]

Ownership	Type of Plant	CO_2	C	N_2O	CH_4
Governmental Sector	Steam	684.874	186.784	0.002	0.015
	Combined Cycle	493.708	134.648	0.001	0.010
	Gas	832.395	227.017	0.002	0.016
	Diesel	811.159	221.225	0.007	0.033
Private Sector	Steam	680.974	185.720	0.001	0.012
	Combined Cycle	497.376	135.648	0.001	0.011
	Gas	752.758	205.298	0.002	0.015

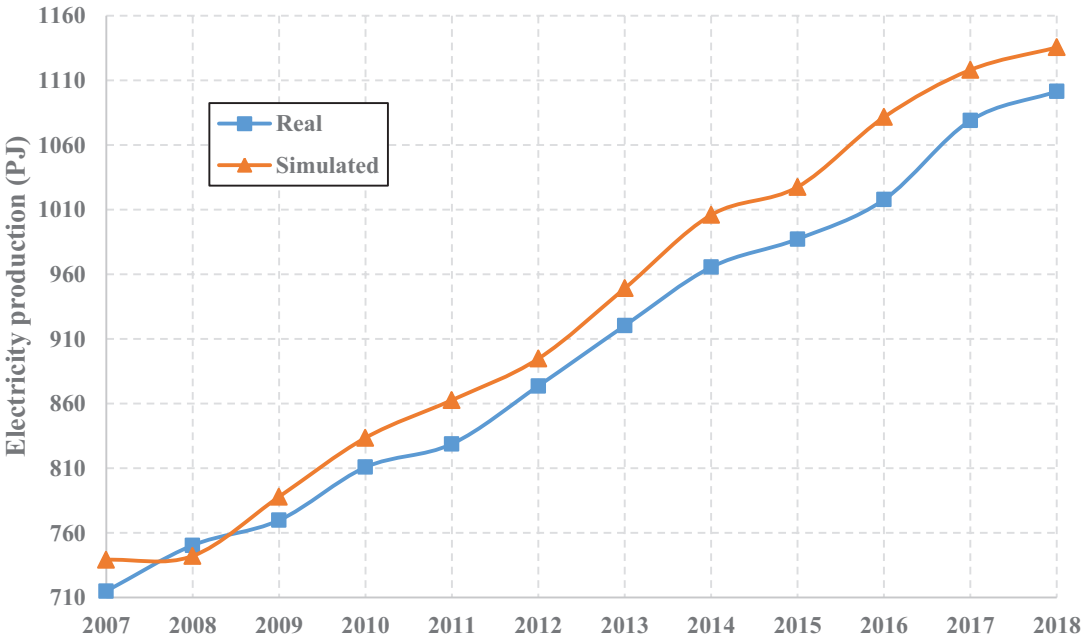

Figure 8: Simulated and real electricity production in Iran's energy system

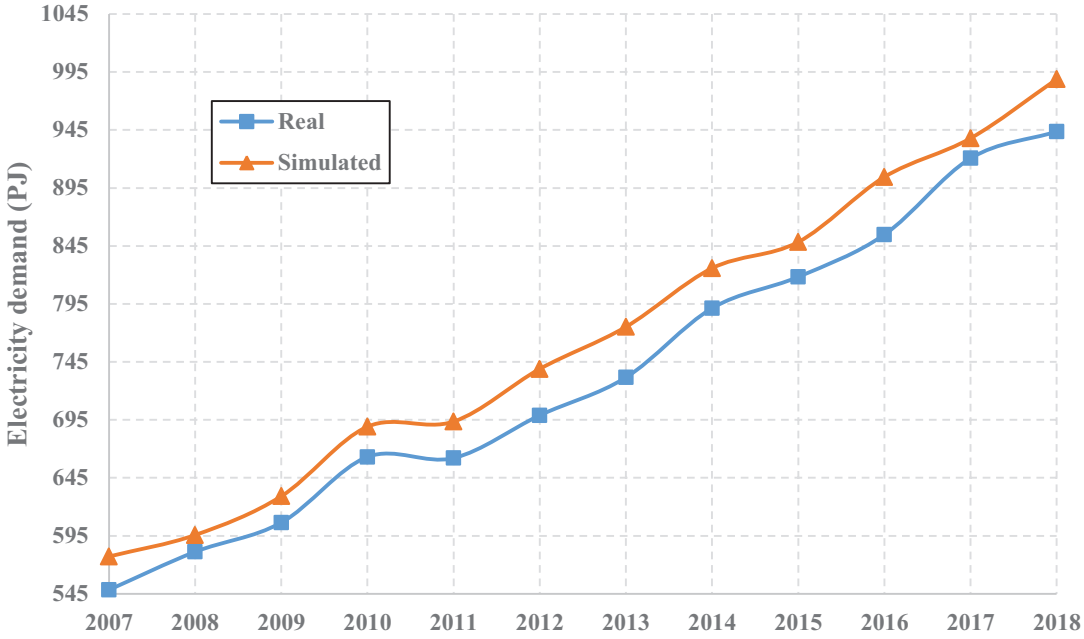

Figure 9: Simulated and real electricity demand in Iran's energy system

behaviors of these module outputs are reproduced by the final model, this model passes the behavior-reproduction test [35]. Error values obtained by this test confirm the validity of the results.

4. System simulation and results

One of the main weaknesses of the existing system dynamics models in the literature is the unstructured process of policy scenario development. Through a structured process, we can apply a common view of the future of non-fossil fuel power plants to finding the plausible combination of modules, and then to developing scenarios [36].

Electricity producers are managing two types of electricity production: traditional (fossil) and renewable (non-fossil) resources. Based on electricity market price, the capacity mix of non-fossil fuels and traditional resources will be defined. Since a simple relationship between electricity production, demand, and price cannot be obtained, we tried to derive such a relationship by considering two performance measures: First, promoting non-fossil fuels to reduce GHG emission from electricity production. Second, bringing the attention of electricity producers to the economic gains of renewable generation.

According to the environmental and economic factors of developing Iran's electricity supply system and to determine the conditions under which the electricity production system meet the Paris Accord target by 2030, four possible[1] scenarios defined by varying share percent of non-fossil fuel power plants.

Wide range of share percent is chosen in order to assess electricity price in increasingly GHG emissions models. The reference scenario has a 5% share of non-fossil resources in the power plant sector, describing the Iran's energy system status quo (In 2018). The "Non-Fossil Fuels 1 (NFF1)" with a 10% share presents a low growth of non-fossil fuels in the electricity production system. Such an ineffective policy and unfavorable conditions would exacerbate energy efficiency and the state of infrastructure.

"Non-Fossil Fuels 2 (NFF2)", the medium scenario, corresponds to the average of share percent, NFF3 scenario corresponds to the upper limit of share percent, and NFF1 scenario corresponds to the lower limit of share percent. In NFF2 scenario, non-fossil fuels have a 15% share of the electricity supply. Moreover, "Non-Fossil Fuels 3 (NFF3)", where non-fossil fuels have a 20% share, demonstrates a high growth in electricity production and it is an optimistic scenario that can be applied to Iran's future energy supply system. Almost all foreseeable scenarios for the futures fall between the NFF1 and NFF3 scenarios. An overview of the four mentioned scenarios is presented in Table 3.

[1] In this paper, the base year, time of scenario implementation, and time horizon are selected at 2017, 2020, and 2020-2030, respectively.

In fact, we have set up a method to simulate the energy system for achieving the long-term goals of Iran's Paris Accord targets, which consists of economic, environmental, and social goals. In short, the investment policy will change energy prices which are considered constant (or compounded with inflation) in applying investment decisions. So, in this paper, we integrate long-term investment decisions and short-term operational features. If we try to estimate the electricity price in the future with the reference scenario, where non-fossil fuels have a 5% share, we can see that between 2020 and 2030, the price is stable and has a routine profile in each year (Fig. 10).

As shown in Fig. 10, the electricity price peaks in the 5th month (August) of each year due to the rise in demand in this month, with a growth rate of about 3% for each year. Conversely, the electricity price has reached its lowest in the 8th month (November) of each year that has the lowest electricity demand. However, after this month, the price witnesses a sharp increase, with its variation also substantially increasing, which happens because the increased demand must be supplied. This pattern is repeated through years between 2021 to 2030. Also, this estimation is done for the other scenarios, and the result are shown in Fig. 11.

As shown in Fig. 11, the reference scenario has lower electricity prices than other scenarios, but does not mitigate the increase in prices in the time horizon. This trend can also be viewed in other scenarios, with the maximum value of electricity price occurring in NFF3 scenario which is 2.54 cent USD/kWh at 2030. The growth in price indicates redundancy in supply capacity (increase in wind, hydro, solar and expansion turbine), therefore reducing the usage of fossil fuels. This happens because the share of the mentioned non-fossil technologies has been increasing in the period under study, and GHG emissions will probably have lower values in different scenarios compared to the reference scenario.

So, in order to encourage investments in renewable capacity and sustain the development of traditional capacity in the electricity generation sector, it is essential to reform the current electricity price and apply the following price pattern (Fig. 11) which will develop a proper business model for electricity producers. However, choosing between NFF1, NFF2, and NFF3 patterns is also dependent on GHG emission reduction

Table 3: Scenario features and their assumptions

Scenario	Growth grade	Share percent variations as driving force	Time horizon
Reference	–	No change from 5%	2020–2030
NFF1	low	5% – 10%	2020–2030
NFF2	medium	5% – 15%	2020–2030
NFF3	high	5% – 20%	2020–2030

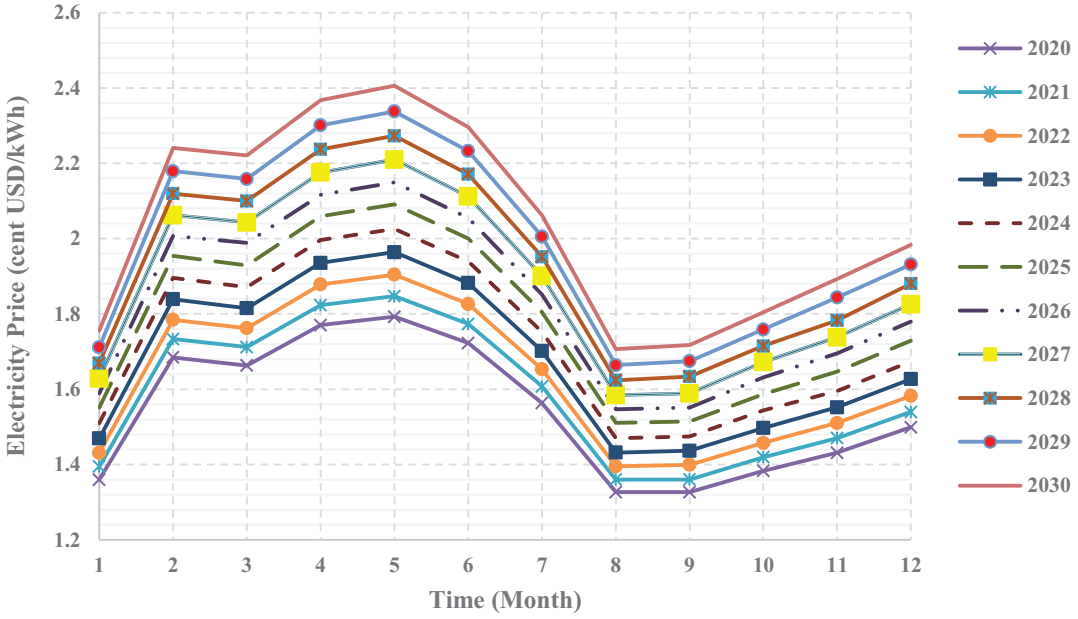

Figure 10: Electricity price variations in Reference scenario on monthly basis

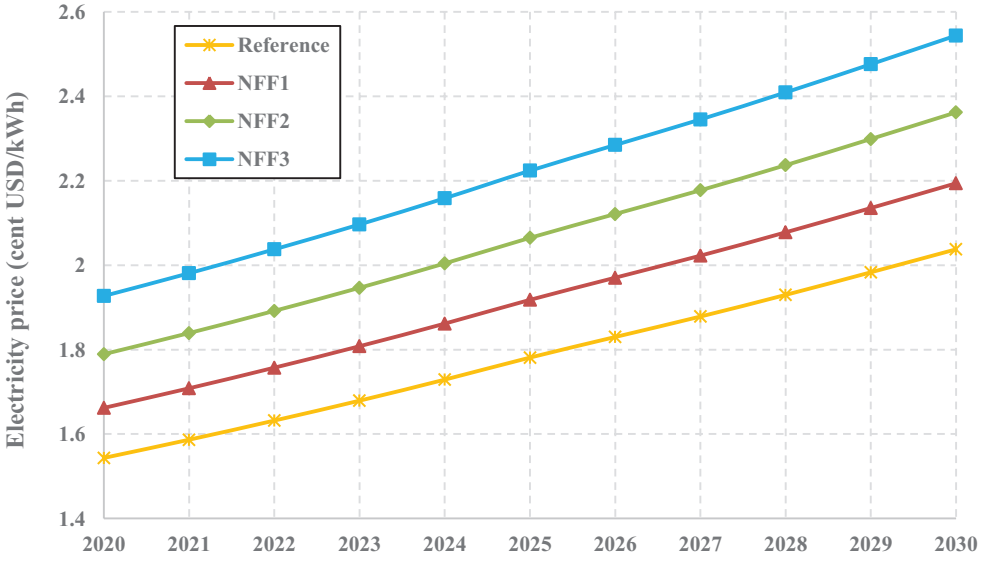

Figure 11: Average electricity price variations in different scenarios on monthly basis

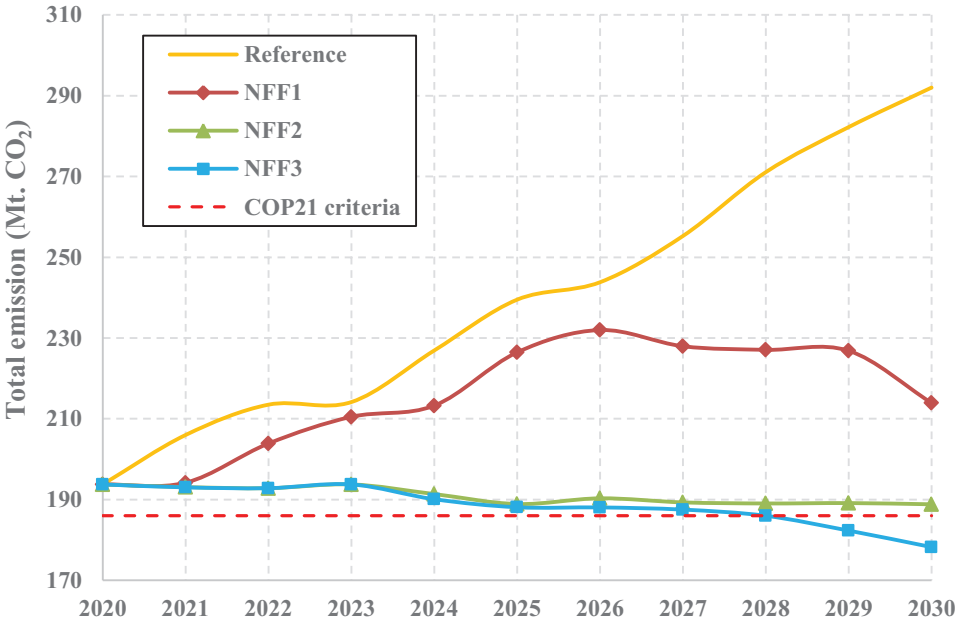

Figure 12: The total GHGs emission in different scenarios

for attaining the Paris Accord targets. The variations of this reduction are presented in Fig. 12.

In the beginning of the time horizon (2020), the amount of greenhouse gas emission is 193.75 Mt of CO_{2eq}. In the reference scenario, it will reach 292.01 Mt of CO_{2eq} with an average growth rate of 4.2% until 2030. Thanks to GHG emission reduction policies, by increasing the share of non-fossil fuels, it is expected that GHG emissions plummet to 213.92, 188.83 and 178.23 Mt of CO_{2eq} in NFF1, NFF2, and NFF3 scenarios, respectively. As a result, if the government adopts NFF3 scenario, realizing the Paris Accord targets would be feasible.

Based on Fig. 12, GHG emission in the reference scenario is increasing substantially over time due to the large share of fossil fuels in electricity production. Moreover, in this scenario, the deviation from COP21 criteria is about 106.01 Mt of CO_{2eq}, which signifies the

importance of focusing on decreasing the share of pollutant technologies, such as steam power plants, and increasing the share of combined cycle and non-fossil resources.

In NFF1 scenario, GHG emission deviation has decreased to 27.92 Mt of CO_{2eq}, but has not met COP21 criteria. Indeed, applying a 5% increase in the share of non-fossil technologies in electricity production in this scenario could decrease emissions of high GHG-emitting power plants but is not sufficient for satisfying the Paris Accord targets. However, GHG emissions have followed an upward trend after 2026 and the gradual growth the share of non-fossil fuels falls short of controlling this increase. In NFF2 scenario, the deviation optimistically falls to 2.83 Mt of CO_{2eq} above COP21 criteria, and it is proven that increasing the share of non-fossil resources in electricity production is necessary for GHG emission mitigation, thus contributing to achieving the Paris Accord targets. However, total emissions start rising after 2028, therefore stopping the government from realizing COP21 criteria in the Accord deadline using this scenario.

The government is aware of the challenges and is seeking a number of reforms in electricity price to improve the performance of non-fossil power plants, including private sector in the generation of green electricity and implementation of a power pool in a competitive market. Based on 2.36 cent USD/kWh of electricity price in NFF2 scenario in 2030, formation of this market can effect on decrease of GHG emissions. Although, attain 15% share of non-fossil power plants that will cause to emit only 2.83 Mt of CO_{2eq} above COP21 criteria, is acceptable in this environmental accord. As a result, in the final scenario, NFF3, the deviation from COP21 criteria drops to 7.77 Mt of CO_{2eq} under Iran's Paris Accord targets, following a declining trend until 2030.

So, by adopting the policies for reaching a 20% share of non-fossil technologies, Iran can meet its Paris Accord targets, and this achievement will be sustainable even after 2030 (the Paris Accord deadline) and tackle rising GHG emissions with 2.54 cent USD/kWh of electricity price.

Furthermore, price elasticity of emission is one of the main indicators of the amount of GHG emission relative variation versus electricity price relative variation, presenting the amount of GHG that would be emitted for increasing the electricity price to improve the share of non-fossil fuels. It is evaluated according to the following equations.

$$\varepsilon_E = \frac{\Delta E / \overline{E}}{\Delta P / \overline{P}} \tag{4}$$

where ε_E, ΔE, ΔP, $\overline{E}$, and $\overline{P}$ are price elasticity of emission, emission variation, price variation, emission average, and price average in the calculation period, respectively. This equation is applied to different scenarios, and the results are presented in Table 4. In the reference scenario, the share of non-fossil fuels did not change, so the calculation of ε_E is undefined.

Based on Table 4, the average values of ε_E for NFF1, NFF2, and NFF3 are 0.1, 0.17, and 0.19, respectively. In fact, NFF3 scenario has both the highest variation in the share of non-fossil resources in electricity production and the price elasticity of emission. Nevertheless, ε_E should increase in this scenario compared to the two previous ones, meaning that it is possible to achieve Iran's reduction target (according to its INDC) as stated in the Paris Accord. It should be noted, however, that the difference between NFF1 and NFF2 scenarios is larger in terms of ε_E mainly due to the high expansion of non-fossil technologies. Thus, one unit change of electricity price in NFF3 scenario leads to a 190,000 tonnes of CO_{2eq} decrease in GHG emissions. So, by considering only the environmental efficacy of the energy supply improvement by non-fossil resources, it is fair to conclude that Iranian price policies are effective for emission reduction.

Another notable finding is the higher emission elasticity of Iran's electricity market in NFF3 scenario that can diffuse more share of non-fossil resources in the market. Indeed, after 2027 (Table 4), ε_E increases and the tendency of the electricity market to change price for emission reduction soars. In 2027, electricity price in NFF3 scenario will reach to 2.34 cent USD/kWh that is near to

Table 4: Price elasticity of emission in different scenarios at various time periods

Scenario	2020–2021	2021–2022	2022–2023	2023–2024	2024–2025	2025–2026	2026–2027	2027–2028	2028–2029	2029–2030
NFF1	0.01	0.06	0.10	0.03	0.09	0.10	0.27	0.03	0.24	0.14
NFF2	0.17	0.13	0.31	0.17	0.14	0.07	0.10	0.20	0.28	0.19
NFF3	0.30	0.20	0.22	0.11	0.19	0.10	0.22	0.06	0.20	0.28

this price in NFF2 scenario at 2030. According to higher emission elasticity in NFF3 rather than NFF2, increasing of electricity price in NFF3 cause to decrease GHG emissions between 2027 and 2030 and COP 21 criteria will available for Iran. But because of less value of ε_E, this action will not occur in NFF2 and decreasing of GHG emissions will stop at 2.83 Mt of CO_{2eq} above COP21 criteria.

This approach puts emphasis on proposing appropriate policies contributing to the competitiveness of non-fossil resources, considering ε_E, that leads to the environmentally sustainable development of the electricity supply system, which can be done through reforming the current electricity market price.

5. Conclusion and policy implications

This study investigates the expansion policy of non-fossil fuels and its impact on GHG emission reduction and the electricity market to meet Paris Accord targets. For analyzing the practicality of this method and its implications, four scenarios with various growth rates of non-fossil technologies were presented: reference, NFF1, NFF2, and NFF3.

If the private sector could be encouraged to invest in these low-carbon power plants by reforming the electricity price, NFF2 scenario with a 5%-15% expansion of non-fossil technologies is suitable for the mid-term development of the power plants for GHG emission reduction and electricity price must be increased to 2.36 cent USD/kWh by 2030. Although GHG emissions in this scenario is about 10.60 Mt of CO_{2eq} over COP21 criteria, the average value of emission elasticity in this scenario is 0.17 and the policy maker can decrease 170,000 tonnes of CO_{2eq} with a single unit increase in electricity price in each year (between 2020-2030). In NFF3 scenario electricity price will increase to 920 IRR/kWh that is about 0.18 cent USD/kWh over NFF2 in 2030.

On the other hand, NFF3 scenario with a 5%–20% expansion of non-fossil technologies decreases GHG emissions to 178.23 Mt of CO_{2eq} (7.77 units lower than COP21 criteria) which will keep its downward trend in the long run even after 2030, and the government is assured that the Paris Accord targets would certainly be achieved. As a result, a 15% share of non-fossil fuels is considered as the driving force to decrease GHG emissions (in NFF2), but it individually fails at decreasing emissions for successful achievement of the Paris Accord targets. The share of non-fossil fuels must be increased to 20% (NFF3), especially while emission elasticity in this scenario is higher than NFF1, NFF2, and the reference scenarios.

However, there are many barriers to the successful implementation of NFF3 scenario, the main ones being underpricing the input fuel for power plants and low FITs for renewable energies. Therefore, the government must modify the performance of the generation sector by reforming electricity price and developing a competitive market in order to attract the private sector to invest in the expansion of non-fossil technologies as low-emission power plants. Without tackling these issues, the impact of reform attempts is temporary, and after a while, GHG emissions start following a rising trend. Based on the presented results, the policy makers must decide to apply energy price reform to Iran's electricity market to develop a suitable plan for reducing the emission of the power plant sector.

On the other hand, in the current dynamics model, the uncertainty of fuel prices is not considered, which can be added to the relevant equations in future works. Furthermore, other pollutant sectors such as transport and industry (see Fig. 1) can be investigated by similar approaches.

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Appendix A

The main equations that describe system dynamics model used in this papers, are presented below:

$$P_{t+1} = P_t + \int Price\ change_t\ dt \quad \text{Eq. A 1}$$

$$Price\ change = \frac{P_t^I - P_t}{AT} \quad \text{Eq. A 2}$$

$$S = S_r * ES = S_r\left(\frac{P}{P_r}\right)^{e_s} \quad \text{Eq. A 3}$$

$$D = D_r * ED = D_r\left(\frac{P}{P_r}\right)^{e_d} \quad \text{Eq. A 4}$$

$$P_t = P_t^I * EB_p \quad \text{Eq. A 5}$$

$$EB_p = F\left(\frac{D}{S}\right)^s \quad \text{Eq. A 6}$$

$$P_{t+1} = \left(P_t + \int Price\ change_t\ dt\right) \le P_{ceiling_t} \quad \text{Eq. A 7}$$

$$P_{ceiling_{t+1}} = (1+\alpha)P_{ceiling_t} \quad where \quad 0 < \alpha \le 1 \quad \text{Eq. A 8}$$

$$Input\ matrix = \left[S_{12*12}.D_{12*12}.P_{12*12}\right]_{@2018} \quad \text{Eq. A 9}$$

$$Output\ matrix = \left[P_{12*12}\right]_{@2019-2030} \quad \text{Eq. A 10}$$

$$CF_{i.t} = \frac{P}{Oc_{i.t}} \quad \text{Eq. A 11}$$

$$Oc_{i.t} = \frac{Fc_{i.t} - so_{i.t}}{ef_{i.t}} + T_{i.t} \quad \text{Eq. A 12}$$