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Modeling of Transition from Natural Gas to Hybrid Renewable Energy Heating system

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ABSTRACT

Global energy demand is increased in recent years due to industrial development and higher standards of living. Currently, fossil fuels, with more than 85%, are the most prominent source of energy in Iran, but it has destructive impacts on the environment and human health. This study models and techno-economically assess renewable energy heating for replacing natural gas in Qazvin city. The natural gas domestic demand is quantified, followed by consumption forecasting for 15 years. Six different scenarios are investigated to assess renewables' potential to meet the city heat demand for the next 15years. The study uncovers that the best practice scenario can reduce natural gas consumption and increase renewable energy sources share. Finally, the proposed scenario is analyzed economically and environmentally. Results revealed that the return on investment would occur in 3 years by exporting the saved natural gas. In addition, Iran can reduce CO_2 emissions by about 1 million tons by the year 2029.

Keywords

Hybrid renewable heating system;
EnergyPLAN;
Energy modeling;
Techno-economic assessment;

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1. Introduction

The positive environmental impact of Renewable Energy Sources (RES) is undoubtedly one of the top reasons which make them favorite resources. Fossil fuel burning emits harmful greenhouse gasses (GHG), which have significant effects on the global warming phenomenon[1,2]. For instance, 28.2 and 26.9 percent of GHG emissions are transportation and electricity production, which directly burn fossil fuels [3].

Using RES would significantly decrease the total amount of GHG emissions, which would help to prevent more intensive climate change impacts. It would also provide new job opportunities and positively affect the economy [4,5]. The number of people employing within the renewable energy industry continues to grow, giving countries like Germany, China, India, Japan, and the USA an excellent opportunity to boost their economies [6,7].

With more emphasis on renewable energy and using domestic RES and distributed generation instead of oil, we would drastically improve our energy security [8]. RES offers various solar, wind, biomass, geothermal energy, and water resources, contributing significantly to our energy needs with its excellent potential for power[9][10][11].

Statistics from 2018 indicate that the highest percentage of energy consumption in the world (85%) is supplied with fossil fuels (Figure 1)[12].

According to the Energy Information Agency (EIA, 2019)[13], worldwide energy consumption is expected to increase by 1.4% annually until 2035, implying that buildings' energy consumption will increase as well. Fossil fuel meets more than 85 percent of energy needs. As the buildings are a large energy consumer, they are also a significant contributor to global carbon emissions and GHG production[14]. Therefore, applying RES in

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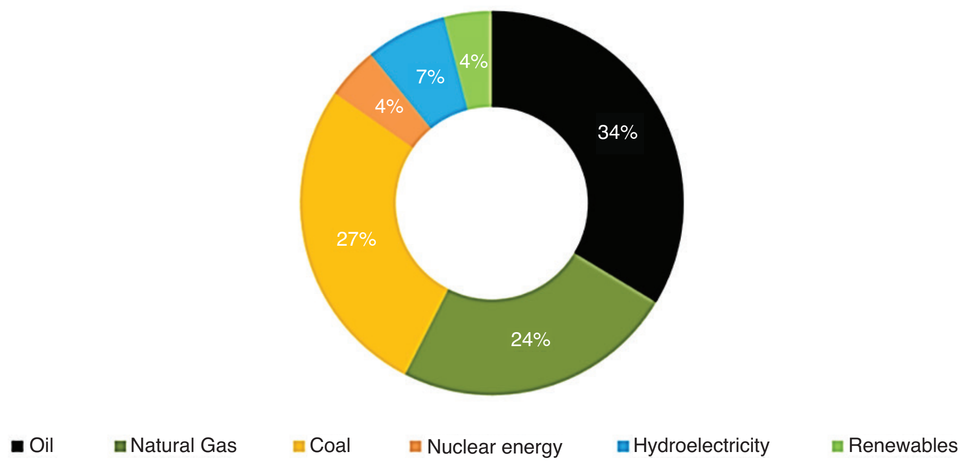

Figure 1: Global energy consumption by fuel in 2018[6]

buildings can reduce total fossil fuel consumption and associated GHG emissions [15][16]. The selection of renewable energy technology is limited by factors such as the availability of renewable energy resources, substantial area for establishing technology, and economic factors[15].

Fernandes and Ferreira[17], in 2014, carried out a study with an approach to a 100% renewable electricity system in Portugal, supported by the application of the EnergyPLAN (EP) model. They investigated technical analyses like cost estimating and CO_2 emission for each scenario. The results revealed that each scenario's cost structure is mainly driven by the low marginal cost of renewable technologies and their high capital costs.

Porubova and Bazbauers [7], in 2011, conducted a study with an approach to 100% RES in Latvia by using domestic energy resources. They presented a potential solution to establish an energy and transport system solely based on the local primary resources for the year 2050.

Bazbauers & Cimdina [18] performed a study to determine whether it is possible to use excess electricity produced by wind power plants during low-demand periods for district heating by using heat pumps in Latvian. The results showed that it is promising to increase the share of RES. Therefore, decrease the use of primary energy sources and reduce CO_2 emissions per unit of energy can be gain by using the surplus electricity produced by wind power in the heat pumps combined with the heat storage system. Cosic et al.[19], in 2012, introduced an approach to 100% renewable energy in Macedonia. They point out that Macedonia's energy sector's most critical problems are an unfavorable energy mix with high dominance of lignite, a strong dependency on energy import, a poor energy system, and inefficiency in energy production. These challenges led this project to investigate the prospects for realizing the 100% renewable energy system in Macedonia by applying the EP model.

Kapica et al., in 2015, reviewed the CO_2 reduction potential by replacing a hybrid solar-wind system [20] with a conventional heating system for a poultry house. The heat requirement for 2400 birds was calculated. They considered simple models for solar collectors, wind turbines, and heat storage tanks, modeled the system in a Matlab/Simulink environment, and analyzed various system configurations for typical climate conditions in central Europe. They varied the solar collector area between 0 and 80 m^2, the wind turbine diameter in the range of 0–20 m, and the number of heat storage tanks from 1 to 4. Apart from the percentage of CO_2 emission reduction, two other indicators are introduced: renewable energy utilization ratio and weighted CO_2 emission reduction. The results indicated that although larger systems provide higher CO_2 reduction, at the same time, the energy utilization ratio will decrease.

Pfenninger and Keirstead [21], in 2015, reviewed the number of scenarios for Britain's electricity system considering the cost, GHG emissions, and energy security. Mitigating climate changes are driving the need to decarbonize the electricity sector. Various possible technological options occur, alongside uncertainty over which options are preferable regarding cost, emissions reductions, and energy security. They compared renewables, nuclear, and fossil fuel technologies (with/without carbon capture and storage). The results indicated that overall costs remain similar across various combinations, which implies that different technical and economic configurations are equally feasible. Brouwer et al. [22] 2016 created three scenarios to reduce CO_2 emissions in Western Europe by 96%, with the shares of 40%, 60%, and 80% electricity production from RES. Results showed a 96% reduction in power sector CO_2 emissions in 2050 compared to 1990 can be reached with either higher shares of RES (80% RES) or a natural gas-fired generation with CCS, nuclear power, and 40% RES.

Kumar et al. [23] 2016 created three scenarios for two countries in South East Asia (SEA) for the year 2050. The focus was on the transition of the electricity sector towards RES to reduce CO_2 emissions. The LEAP energy model is used to develop different renewable energy policy scenarios from 2010 to 2050.

Noorollahi et al. [24] carried out a regional-scale energy-economic mapping for priority assessment of regions, including numerical modeling and optimization of GSHP systems using Genetic Algorithm (GA), regional heating/cooling design load estimation, and spatial data analysis to achieve an economic-based map for 234 cities in Iran. For the first time, Iran's regional shallow geothermal map is presented along with other geographical maps, including air and earth surface's mean temperature, heating/cooling loads; GSHP required operating hours and Iran's climatology. Total Annual Cost (TAC) values were categorized into five equal ranges from CA (the highest priority class) to CE (the lowest priority class), which highlight the convenient regions for shallow geothermal energy use. Finally, Iran's provinces sort according to TAC weighted average values. The presented economic priority maps offered policymakers planning support for GHSP systems subvention and promotion in Iran. In another study in Iran, Noorollahi et al. [25] worked on numerical modeling to techno-economic analysis of heat pump potential provide energy for greenhouses in Alborz province. Both types of research are based on other prior investigations of Iran's biogas production potential and spatial analysis of regional-scale geothermal maps [26][27]. In another study, they examine a solution to replace natural gas with a hybrid renewable energy system. Different scenarios have been investigated, all scenarios lead to a decline in CO_2 emissions equally. They found out, for their study region, and due to the current state of natural gas distribution in Iran, the best scenario is to use solar thermal units besides using the natural gas[28].

According to Iran's energy policies, by 2029-2030, 20% of the country's energy consumption should be provided by renewable energy [29]. Energy supply in a country like Iran with a vast geography and different environmental conditions such as variations in altitude, climate, and social issues reveals the necessity of careful and detailed energy planning and management [30][31]. Besides the limited natural gas reserves, the unbalanced growth of energy consumption, and about 70% energy dependency of Iran on natural gas could be a threat [32]. With around 616,741 million tons of CO_2 Iran is the first responsible country for climate change in the Middle East, and seventh in the world [33]. Low diversity of energy mix and irregular increase in energy consumption are the main challenges of Iran's energy sector. Hence, careful energy demand management and planning employing energy modeling are necessary [34]. Besides, diversifying the energy basket of a country by using renewable-based systems can improve the energy security, affordability, and reliability in energy supplying of the end-user.

This study's ultimate goal is to find the best method for evaluating the potential of available renewable energy resources (Qazvin city as a case study) for heating. The study investigates how far RES can be replaced with natural gas to supply heat demand by considering economic and environmental conditions. After evaluating renewable energy potential, it is necessary to develop a plan to exploit these energy potentials. In this regard, using different energy modeling methods and tools can be helpful. The rest of this paper is organized as follows: Material and methods are described in Section 2. Results are provided in Section 3. Three different scenarios are assessed and the results are investigated. Conclusions are summarized in Section 4.

2. Material and Methods

2.1. Study area

The solar radiation analysis tools could help to map the radiation and sun's effects the sun over a geographic area for specific periods using ArcGIS. Incoming solar radiation originates from the sun is modified as it travels through the atmosphere and is further amended by topography and surface features[35]. It intercepts the earth's surface as direct, diffuse, and reflected components. One of the solar radiation analysis tools in ArcGIS calculates insolation across a landscape [36,37]. The entire amount of radiation measured for a particular location is provided as global radiation. The computation

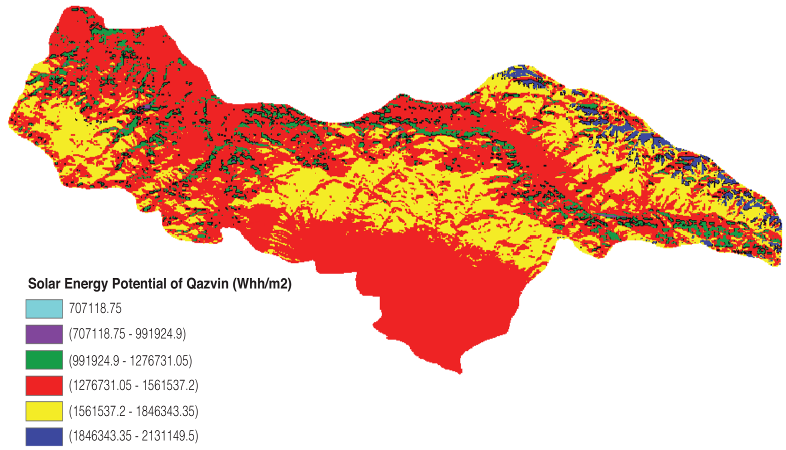

Figure 2: Solar energy potential map of Qazvin (Wh/m^2/year)[28]

of direct, diffuse, and global insolation is repeated for each feature location or every location on the topographic surface. DEM is a digital elevation model that shows the terrain by a cellular network. DEM can be color layed in both two-dimensional and three-dimensional in a GIS environment.

It should be noted that the DEM model is the basis of the analysis in GIS systems to provide the amount of solar radiation after discarding albedo effects. In this study, solar energy potential is calculated using a DEM map. In Figure 2, the solar radiation map is computed from the DEM model. Finally, the estimated potential by GIS is equal to 9641 TWh per year.

2.1.1. Bioenergy Resource in Qazvin

Bioenergy is the energy from organic materials and natural derivatives (except fossil resources). Using this energy will help a lot in protecting the environment from adverse emissions. Therefore, using the data collected from various organizations in the city of Qazvin, the amount of methane emitted from agricultural crop residues, animal manure, landfills (Lya and Mohammadabad), and the city's sewage system have been calculated[38,39]. The total amount of methane emitted from different biomass sources can be found in Table 1 [40].

Since methane's heating value varies from 35.280 to 42,840 kJ/m^3[41]. The average total volume of emitted methane from different biomass sources is equal to 0.05 TWh per year.

2.1.2. Geothermal heat pump

The geothermal heat pump (GSHP) is a device for cooling and heating residential buildings, offices, industrial environments, and supplying hot water for buildings [42].

Table 1: The total amount of methane emitted from bioenergy resources

Emitted methane	Volume (m^3/yr)
Agriculture residue	237,408
Animal manure	1,074,227
Lya landfill	2,450,075
Mohammadabad landfill	330,091
Sewage system	325,495
Total	4,417,296
Total in TWh/yr	0.05

This system's efficiency is higher than the electrical heating and conventional heat pumps, which use air as a heat source [43]. In the depth of several meters under the ground, the soil temperature remains relatively constant over a year. In summer, this temperature is lower than ambient temperature, and in winter, it is higher. Using this temperature difference and a heat exchanger at a depth of several meters and a heat pump at ground level, cooling, and heating of the living environment can be provided.

Figure 3 shows that temperature fluctuations during a year in depths of about 5 meters from ground level are insignificantly different with ambient temperature and constant. Still, the change in air temperature has so many fluctuations. The geothermal heat pump uses this consistent temperature effect for supplying cooling and heating [44].

2.2. Energy modeling and scenarios planning

Energy models are useful tools in the energy planning process. The future energy systems behavior could be predicted using energy models, and due to the importance

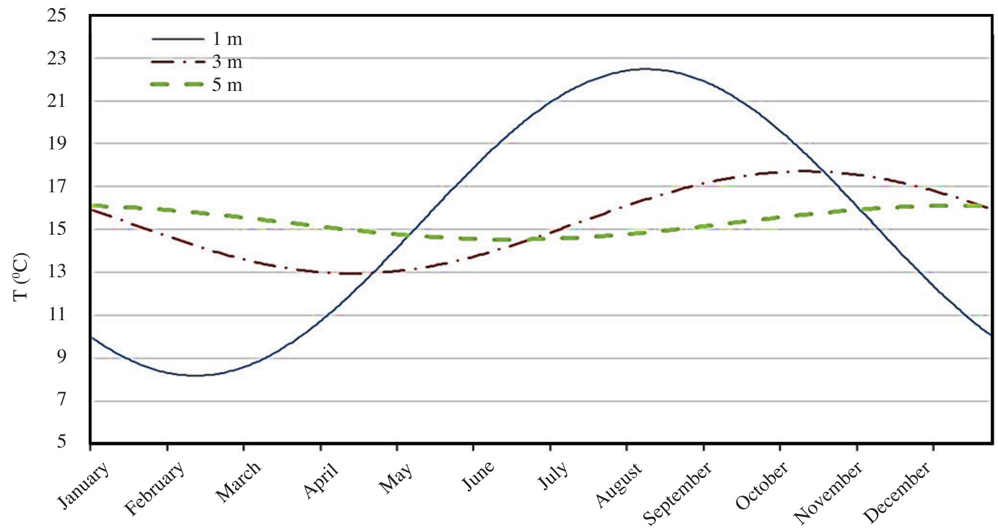

Figure 3: Air and ground temperature curves at different depths during a year in Iran[33].

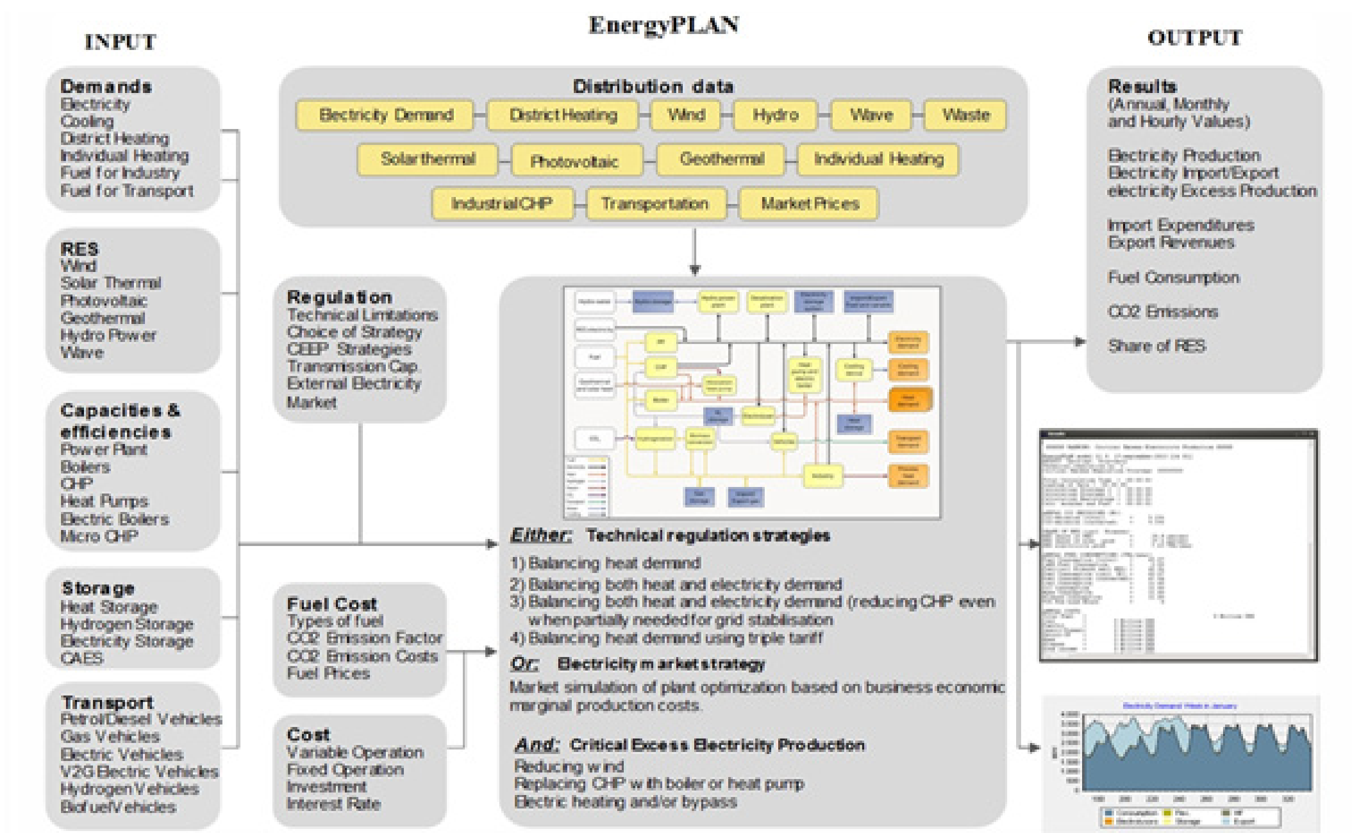

Figure 4: The structure of the EnergyPLAN model[36]

of knowing the future, they are vital analytical tools for energy planning[45].

The EnergyPLAN is developed by Aalborg University and has many key advantages over some other considered energy modeling tools, and has already been used to analyzing many energy scenarios. EnergyPLAN can model all thermal, renewable, storage, conversion, and transport technologies. The model is a deterministic input/output model, and general inputs are demands, RES, energy station capacities, costs, and optional different regulation strategies. Outputs are energy balances and resulting in annual production and fuel consumption. The structure of the EnergyPLAN model is shown in Figure 4. [46,47].

EnergyPLAN is based on analytical programming as opposed to iterations, dynamic programming, or advanced mathematical tools. EnergyPLAN makes the calculations direct and the model very fast when performing calculations. It's an hour-based simulation model instead of a model based on aggregated seasonal demands and productions. Consequently, the model can analyze the influence of fluctuating RES on the system and weekly and annual differences in heat demands. A more detailed description of EnergyPLAN can be found in[48–51].

Currently, heating demand in Qazvin city is just supplied by piped natural gas. Therefore in this study, it is considered to diversify the energy mix of heating systems for this city by entering exploitable RES in different scenarios and analyzing them environmentally and economically to optimize it [48]. Using the natural gas consumption data of Qazvin city for 2015, the hourly distribution is computed and entered into the EP model.

According to the Qazvin energy balance report, the average tariff of each cubic meter of domestic natural gas is equal to 1.79 US$/Gj [52]. The price of carbon dioxide is 12.5 US$/ton[49]. The water heater's final and actual average efficiency is about 45% to 55%, and

Table 2: Modeling results of a current natural gas consumption condition (the year 2015)

Title	Amount
Primary energy consumption (TWh)	8.25
CO_2 emission (MTones)	1.68
CO_2 emission cost (M US$)	21
Natural gas consumption cost (M US$)	53

the average efficiency of the wall-mounted water heater is 75% to 85%. Assuming that most of the buildings in Qazvin use wall-mounted water heaters, the gaseous water heater's efficiency has been entered about 80% to the EP model. By implementing the current condition with this data and using EP, results are shown in Table 2.

In this study, also the amount of natural gas demand for domestic consumption is forecasted, and the result can be found in Figure 5.

The trend is obtained using equation 1. In addition, the results are shown in Table 3.

Table 3: Predicted domestic natural gas demand in Qazvin

Year	2019	2024	2029
Predicted domestic NG demand (TWh)	8.78	10.31	11.83

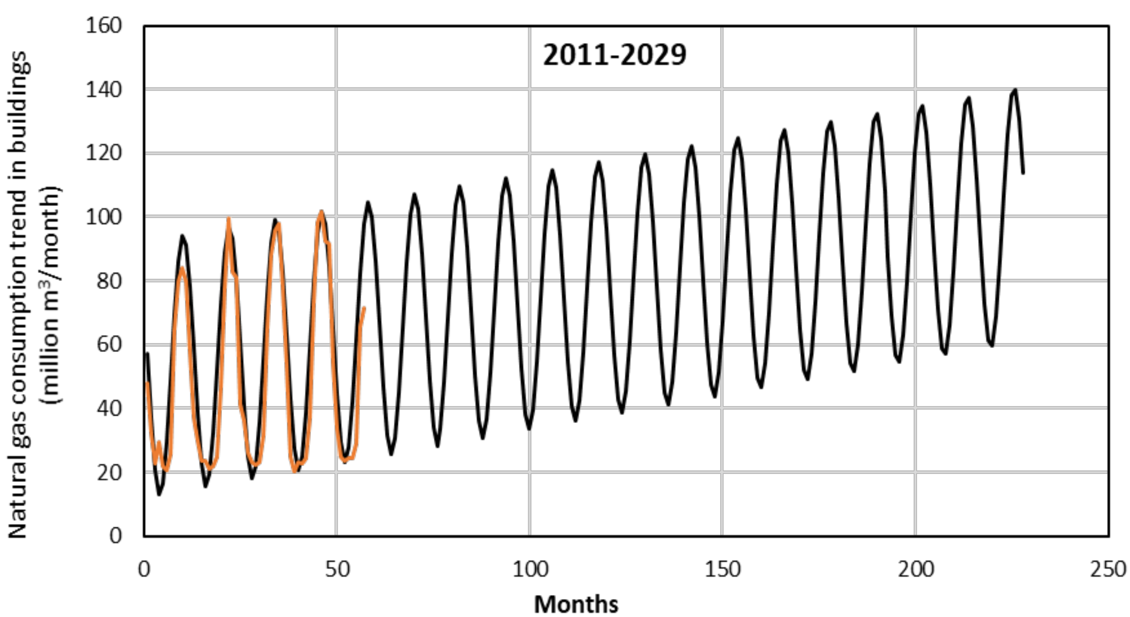

Figure 5: Prediction of natural gas consumption trend in buildings up to the year 2029 (red line is measured, and the black line is simulated)

$$Y = 40.24 \times Cos(0.525 \times X + 0.922064) + (61.346 \times X) / 338.1 \quad (1)$$

Different scenarios have been used to analyze the natural gas consumption in the following years for achieving an optimized model for supplying heat demand in the future. In all scenarios, the number of devoted energies from different resources is entered into EP according to Table 4 [53].

The investment cost for the assumed powers in each target year and CO_2 emission cost in all scenarios are entered into EP according to the international energy agency (Table 5).

In the first scenario (S1), it is assumed that natural gas is the only supplier of heat demand for the next 15 years (until 2029). To forecast the total amount of energy system cost, CO_2 emission, and primary energy demand for households, the predicted consumption, natural gas price, and CO_2 price [34] are entered into the EP model. The First scenario (S1) modeling results are shown in Table 6. It should be noted that the natural gas price for future years is evaluated according to its price growth rate over the past 10 years using linear regression[54–56].

The second scenario (S2) is based on the assumption that the natural gas consumption is not increased as in 2014 (6.6 TWh/Yr), for the excess heat demand in next

Table 4: Share of different energies for intended scenarios

Year	Energy (TWh)	S1	S2	S3	S4	S5	S6
2014	Natural Gas	6.6	6.6	6.6	6.6	6.6	6.6
2019	Natural Gas	8.78	6.6	6.6	6.6	6.6 (75.2%)	5.94(67.6%)
	Solar	0	1.065	2.18	0	0.53 (6.05%)	0.7 (8%)
	Biomass	0	0.05	0	0	0.05 (0.6%)	0.05 (0.6%)
	Geothermal	0	1.065	0	2.18	1.60(18.15%)	2.10(23.9%)
2024	Natural Gas	10.31	6.6	6.6	6.6	6.6 (64%)	5.28 (51.2%)
	Solar	0	1.83	3.71	0	0.915(8.87%)	1.25(12.1%)
	Biomass	0	0.05	0	0	0.05 (0.5%)	0.05(0.5%)
	Geothermal	0	1.83	0	3.71	2.745(26.6%)	3.73(36.2%)
2029	Natural Gas	11.83	6.6	6.6	6.6	6.6 (55.8%)	4.62 (39%)
	Solar	0	2.6	5.23	0	1.295(10.9%)	1.79(15.2%)
	Biomass	0	0.05	0	0	0.05 (0.4%)	0.05 (0.4%)
	Geothermal	0	2.6	0	5.23	3.885(32.8%)	5.37(45.4%)

Table 5: Economic and technical data used for heat generation technologies

Technology	Investment Cost (US$/MWh)	Operation & Maintenance Cost (US$/MWh)	Fuel Cost		CO_2 Cost	
Natural Gas	–	–	Year	US$/J	Year	US$/T
			2019	6.47	2019	20
			2024	10.4	2024	27.5
			2029	14.33	2029	35
Electricity	–	–	Year	US$/MWh	–	
			2019	36		
			2024	53.6		
			2029	71.2		
Solar thermal	184.68	20.52	–		–	
Biomass	16.416	6.5664	14.036 (US$/MWh)		–	
Geothermal	28.728	6.156	–		–	

Table 6: Modeling results of scenarios

Scenario	S1		S2		S3		S4		S5		S6	
Year	**2024**	**2029**	**2024**	**2029**	**2024**	**2029**	**2024**	**2029**	**2024**	**2029**	**2024**	**2029**
Predicted domestic NG demand (TWh)	10.31	11.83	10.31	11.83	10.31	11.83	10.31	11.83	10.31	11.83	10.31	11.83
Primary consumption of NG & electricity (for a heat pump) (TWh)	12.89	14.79	8.66	9.12	8.25	8.25	9.07	9.99	8.80	9.41	9.14	9.40
Carbon dioxide emission from NG & electricity (for heat pump) (MT)	2.63	3.02	1.88	2.11	1.68	1.68	2.09	2.54	1.95	2.26	1.97	2.07
Carbon dioxide emission cost (M US$)	72	106	51	74	46	59	57	89	53	79	54	72
NG consumption cost (M US$)	483	763	309	426	309	426	309	426	309	425	247	299
Investment cost of renewable energies (M US$)			163	163	288	281	44	44	124	124	29	29
The operation cost of renewable energies (M US$)			3	6			5	11	4	7	8	11
Electrical cost of the geothermal heat pump (M US$)			22	62			44	124	29	83	67	127

year's, firstly the total available amount of biomass has been consumed (0.05 TWh/Yr). The rest of the demand has to be supplied by solar and geothermal energy equally. The model is run for this scenario inputs, and the results are illustrated in Table 6.

In the third scenario (S3), it was assumed that the natural gas consumption would not be increased as its rate in 2014 (6.6 TWh/Yr) and the excess demand in next years would be supplied totally by solar energy. By implementing this scenario, results would be achieved, as shown in Table 6.

In the fourth scenario, it is assumed that the natural gas consumption will be constant and equal to the amount of natural gas consumption in 2014 (6.6 TWh/Yr), the excess heat demand in next years (2019, 2024, and 2029) would be supplied just by the Geothermal energy. By implementing this scenario, results would be achieved according to Table 6.

By comparing the results of the third and fourth scenarios, it can be seen that the investment and operation costs and primary energy consumption are lower when all the share of RES is supplied by geothermal energy.

In the fifth scenario, the share of RES has been distributed with the priority of geothermal energy and then solar energy. Also, the total potential of biomass was consumed.

In scenario five (S5), it is assumed that natural gas consumption would be the same as in 2014 (6.6 TWh/Yr). For the excess heat demand in the next years, the total available biomass amount would be consumed (0.05 TWh/Yr). Due to the particular condition of existing buildings in Qazvin and the impossibility of installing heat pump ground coils, 25% of buildings can be equipped with the heat pump system. Results of implementing this scenario can be found in Table 6. According to this study's primary goal, which is replacing RES instead of natural gas, in the last scenario, the natural gas consumption has a downward trend during the next years to review the environmental and economic impacts of its reduction.

In the sixth scenario, natural gas consumption has been decreased every five years by 10%. For the excess demand in the next years, the total amount of biomass was consumed (0.05 TWh/Yr), 75% of the rest of the demand is supplied by geothermal energy and 25% by solar energy (Table 6).

3. Results and discussion

3.1. Primary energy consumption (PEC)

The total PEC amount in the geothermal heat pump equals the sum of natural gas and electrical energy consumption. According to Figure 6, the PEC for the first

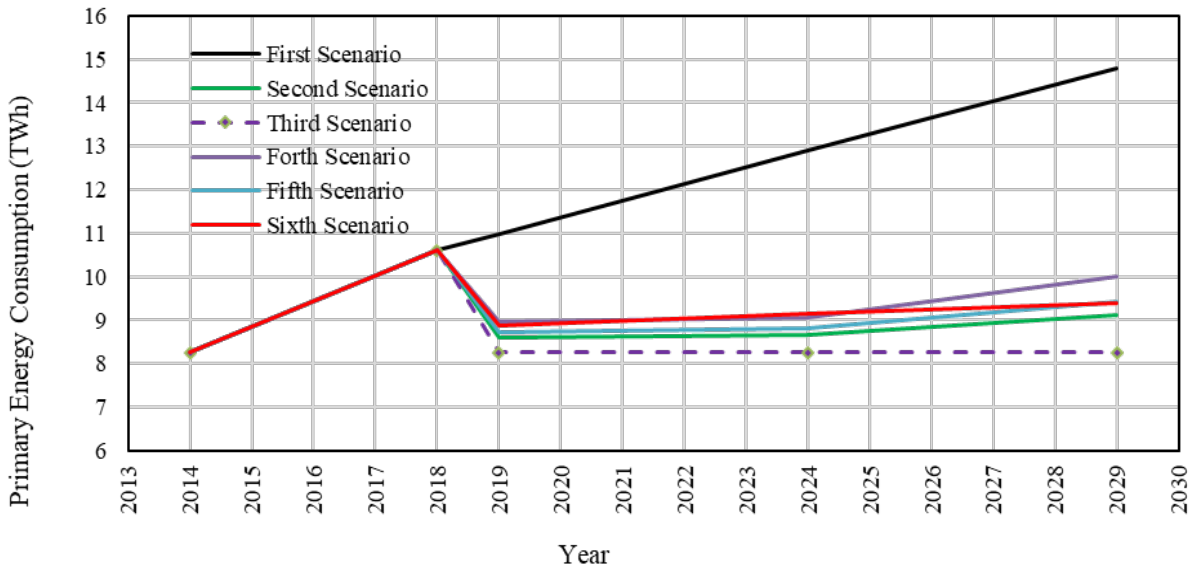

Figure 6: Primary energy consumption trend up to the year 2029 in Qazvin for six scenarios

scenario in the target year will be 4.8 to 6.54 TWh more than other scenarios. In all scenarios, except the first and sixth scenarios, the amount of natural gas consumption is almost the same. They would have the same PEC, and the difference is because of electricity consumption due to the heat pump. The third scenario has the lowest PEC due to the absence of a geothermal heat pump because of the electricity consumption by the heat pump provided by electricity from the national network.

3.2. Carbon dioxide emission

As shown in Figure 7, the CO_2 emission for the first scenario in the target year will be 16 to 44% more than other scenarios due to more primary energy consumption. In the third scenario, the CO_2 emission has the lowest amount due to not using a geothermal heat pump. In the sixth scenario, there is a decreasing rate of CO_2 emission due to the assumed decreasing trend for natural gas consumption, but then it has an upward trend because of the increase in electricity consumption; nevertheless, it has a slower increasing rate than other scenarios. It should be mentioned that carbon emissions from biomass burning will be neutralized by reducing this biomass decomposition and preventing releasing its carbon dioxide into the atmosphere. According to Figure 8, the cost of CO_2 emission is more than in other scenarios due to more CO_2 emission in the first scenario. In the third scenario, the CO_2 emission is constant due to constant natural gas consumption (6.6 TWh), and the increasing rate of that is because of the rising CO_2 cost during future years. In the sixth scenario, the natural gas consumption has been decreased for the next years, the increasing rate of CO_2 emission has a more gradual slope than other scenarios. It is due to the growing cost of CO_2 emission from electricity consumed by the geothermal heat pump and natural gas consumption.

3.3. Cost of natural gas consumption:

According to Figure 9, increasing natural gas costs during the years affects the charts' increasing slope. The sixth scenario's gradual slope is due to decreased natural gas consumption during the years and is 61% lower than the first scenario in 2029. The sharp slop of the first scenario is because of supplying the total heat demand by natural gas. In other scenarios, the natural gas consumption is the same during the years (6.6 TWh), and just the cost of that is increased during the years.

3.4. Renewable energies investment cost

According to Figure 10, there is no investment cost for the first scenario due to supplying the total heat demand just by natural gas. In the third scenario, the investment cost is 28% to 86% more than other scenarios due to supplying the RES share for heat demand just by solar energy. In all scenarios, from the year 2019 (the first year of starting to provide a portion of heat demand by RES), the investment cost reduces and approximately remains constant, which is due to the further use of RES for the increasing demand during years. According to Figure 10, the sixth scenario's investment cost in years

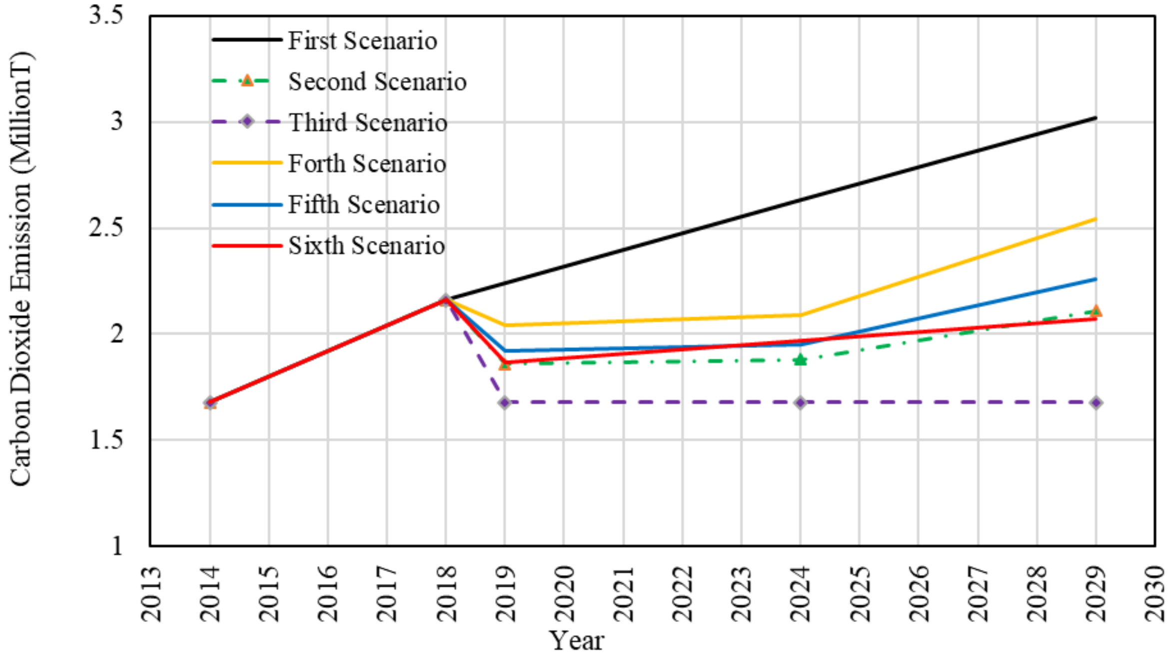

Figure 7: Carbon dioxide emission trend up to the year 2029 in Qazvin for six scenario

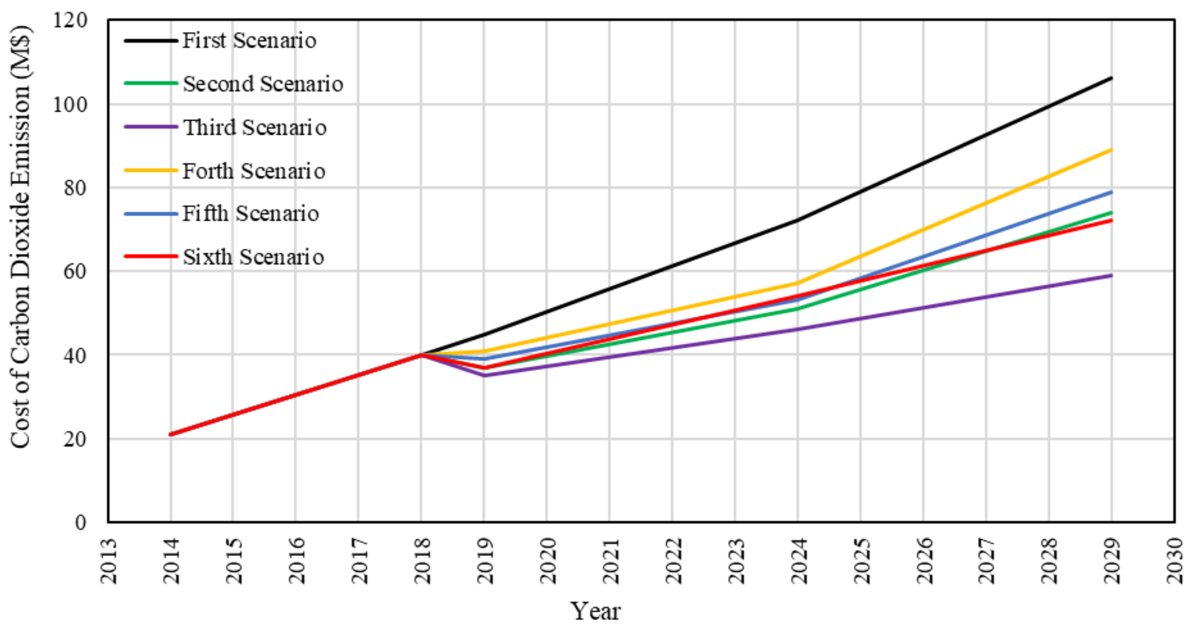

Figure 8: Cost of carbon dioxide emission trend up to the year 2029 in Qazvin for six scenario

after 2019 is less than other scenarios and is equal to 29 million dollars.

3.5. Renewable energies operation cost

According to Figure 11, there is no operation cost for the first scenario due to not using RES. Besides, there is no operation cost in the third scenario due to providing the renewable energy share for heat demand just by solar energy. In other scenarios, the operation cost has an increasing rate due to more use of RES. Its value for the second, fourth, fifth, and sixth scenarios are 6, 11, 7, and 11 MillionUS$ respectively, by 2029.

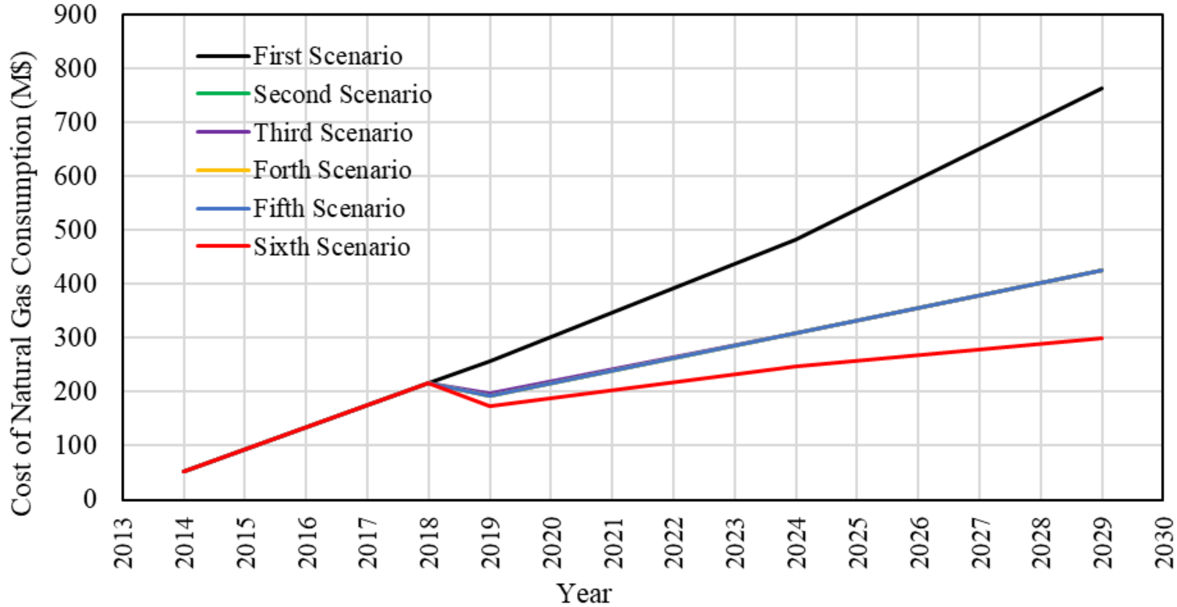

Figure 9: Cost of natural gas consumption trend up to the year 2029 in Qazvin for six scenario

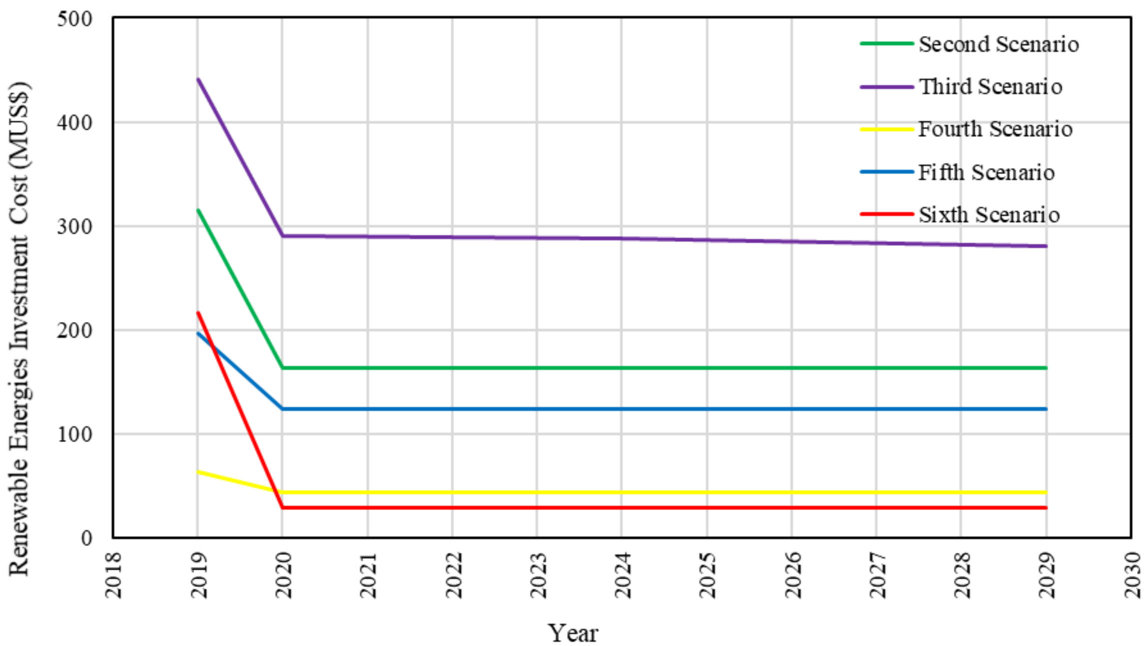

Figure 10: Renewable energies investment cost trend up to the year 2029 in Qazvin for six scenario

3.6. Possibility of using solar energy by S6 scenario

According to the 2011census, the population of Qazvin is 381,597, and the growth rate is about 17.2% from 2006 to 2011 [35]. This study assumes that the population is increased with this rate every five years until the year 2029. By dividing the community by the number of family members (typically 4.2), the number of families living (homes) in Qazvin has been evaluated. The heat demand of each family is calculated using the total heat demand in this city in kWh. Multiplying this amount to the part of need that has to be supplied by solar energy and using a solar water heater [36], the number of water heaters that each family needs was evaluated and shown in Table 7.

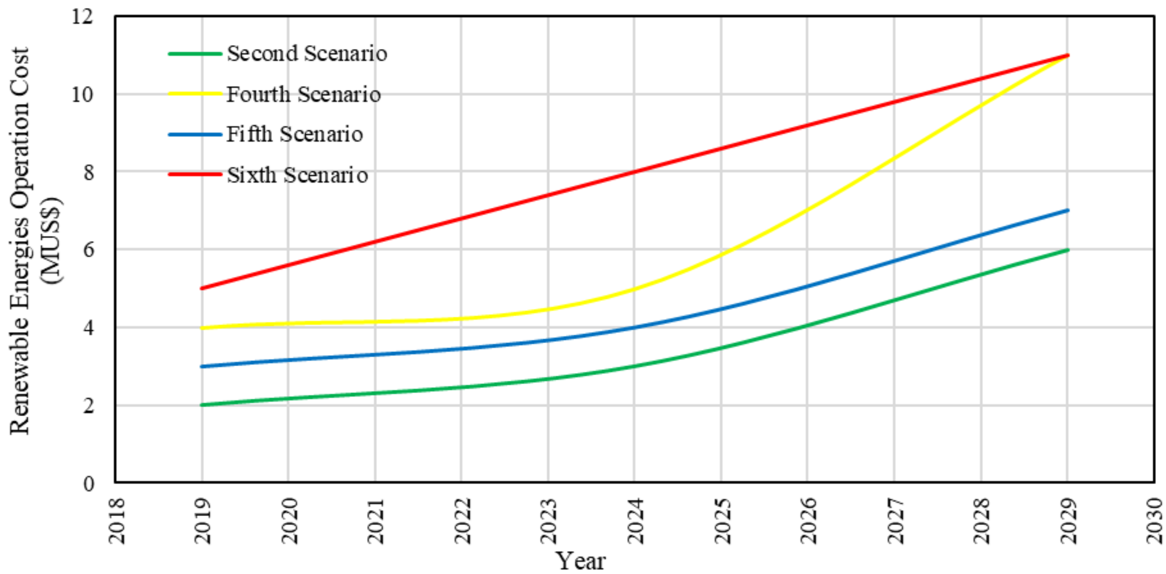

Figure 11: RES operation cost trend up to the year 2029 in Qazvin for six scenario

Table 7: Calculation of required solar water heaters for each home in the sixth scenario

Year	2019	2024	2029
Predicted domestic NG demand (TWh/Yr)	8.78	10.31	11.83
Population	446468	522368	611171
Number of households	106301	124373	145517
Domestic thermal energy consumption (kWh/day)	226	227	223
Domestic consumption of solar thermal according to S6 (kWh/day)	18.08	27.47	33.90
Capacity of each solar water heater (kWh/day)	16.5	16.5	16.5
Number of solar water heater	1.10 ≈ 1	1.70 ≈ 2	2.10 ≈ 3

Table 8: Calculating the number of families (home) that can use biomass in the Sixth Scenario

Year	2019	2024	2029
Predicted domestic NG demand (TWh/Yr)	8.78	10.31	11.83
Population	446468	522368	611171
Number of households	106301	124373	145517
Domestic thermal energy consumption (kWh/day)	226	227	223
The total amount of biomass potential (MWh/yr)	50000	50000	50000
Number of households that can use biomass	606	603	614

According to the above calculations, installing the above-calculated number of solar water heaters for each home is logical. The rest of each home's heat demand can be supplied by natural gas or a combination of natural gas and geothermal heat pump.

3.7. Using biomass as a heat source by the sixth scenario

The heat demand for the total number of families (home) supplied by biomass has been calculated in Table 8, about 600 families (home). The mentioned houses should be concentrated in a specific region to use anaerobic digestion and reduce the transfer cost.

3.8. Environmental analysis of the sixth scenario

The costs of environmental emissions are external costs created through the devastating effects of pollutants on crops, ecosystems, and human health. Greenhouse gases are the most critical environmental pollutants, which cause climate changes and global warming phenomenon. The World Health Organization estimations indicate that annually about 800 thousand premature deaths occur in the world because of air pollution-related diseases [37]. Air pollution in cities has the largest share of environmental damages related to pollution effects on human health.

Carbon dioxide as a greenhouse gas has an essential role in the environment and sustainable development discussions and has been detected as the leading cause of global warming. This gas is directly linked to energy consumption which is crucial worldwide [38] — so estimating the CO_2 emission cost caused by fossil fuels such as natural gas is of great importance in economic parts in planning strategies and policy recommendations for the control of environmental pollutants. In this section, the interest in reducing CO_2 emissions in this energy planning has been calculated.

In the first scenario, the O_2 emission and its cost are calculated, assuming that the total heat demand would be supplied by natural gas. The benefits of carbon dioxide emissions reduction for 2019 to 2029 have been analyzed according to the natural gas consumption in the sixth scenario in Table 9.

In addition to the carbon dioxide emission from natural gas consumption, some carbon dioxide emission occurs due to geothermal heat pumps' power consumption. Referring to the 2013 energy balance sheet, the country's power sector's greenhouse gas emissions Index for carbon dioxide is equal to 496 g/kWh [29]. The cost of carbon dioxide emission is calculated using this data and the total electricity consumption each year. Carbon dioxide emission in the first and sixth scenarios for 2019 to 2029 is illustrated in Figure 12. As can be seen, up to one million T per year of CO_2 emission can be avoided by applying the sixth scenario.

3.9. Economic analysis of the scenarios

In the first scenario, the cost of natural gas consumption calculated assuming that in the next 15 years, heat demand would be supplied by this energy. In the sixth scenario, the cost of natural gas consumption estimates that it will decrease by 10% every five years. Due to the increase in

Table 9: Calculation of CO_2 emission reduction profit between the first and the sixth scenario

Year	**2014**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
CO_2 emission of S1 (MT)	1.68	2.24	2.32	2.40	2.47	2.55	2.63	2.71	2.79	2.86	2.94	3.02
Cost of CO_2 Emission S1 (M **US$**)	21	45	50	55	61	66	72	79	85	92	99	106
CO_2 emission of S6 (MT)	1.68	1.52	1.48	1.45	1.41	1.37	1.35	1.32	1.28	1.27	1.26	1.18
Cost of CO_2 emission S6 (M **US$**)	21	30	32	33	35	36	37	38	39	41	41	41
CO_2 emission reduction (%)	0	16.5	19	20.4	22.3	23.9	25.1	26.2	27.9	28.3	28.6	31.5
CO_2 emission reduction profit (M **US$**)	0	15	18	22	26	30	35	41	46	51	58	65
CO_2 emission from NG & electricity (MT)	0	0.35	0.40	0.46	0.51	0.57	0.62	0.68	0.73	0.78	0.84	0.89
Cost of CO_2 from NG & electricity (M **US$**)	0	7	9	11	13	15	17	20	22	25	28	31
Total emitted CO_2 in S6 (MT)	1.68	1.87	1.88	1.91	1.92	1.94	1.97	2	2.01	2.05	2.10	2.07

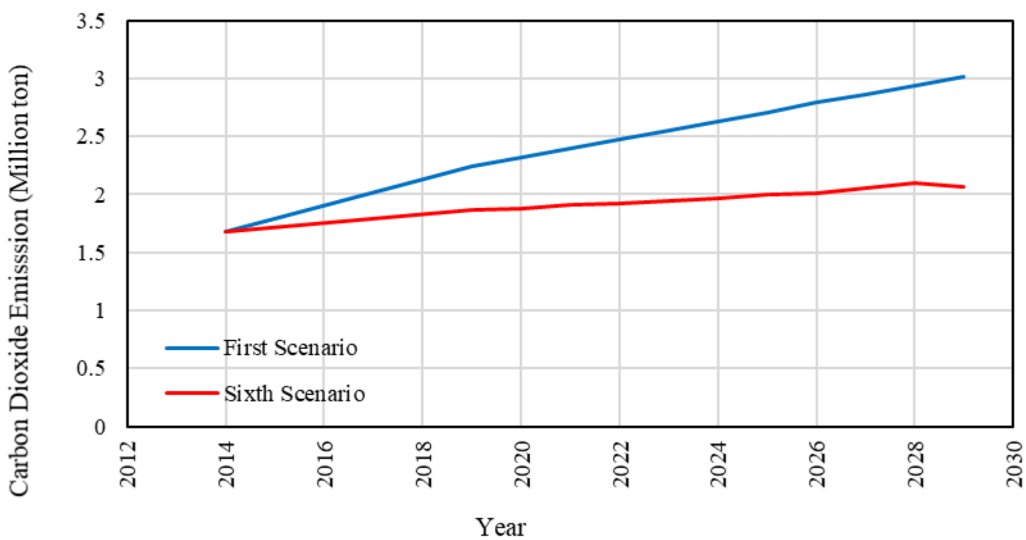

Figure 12: Comparison of the CO_2 emission of the first and sixth scenario

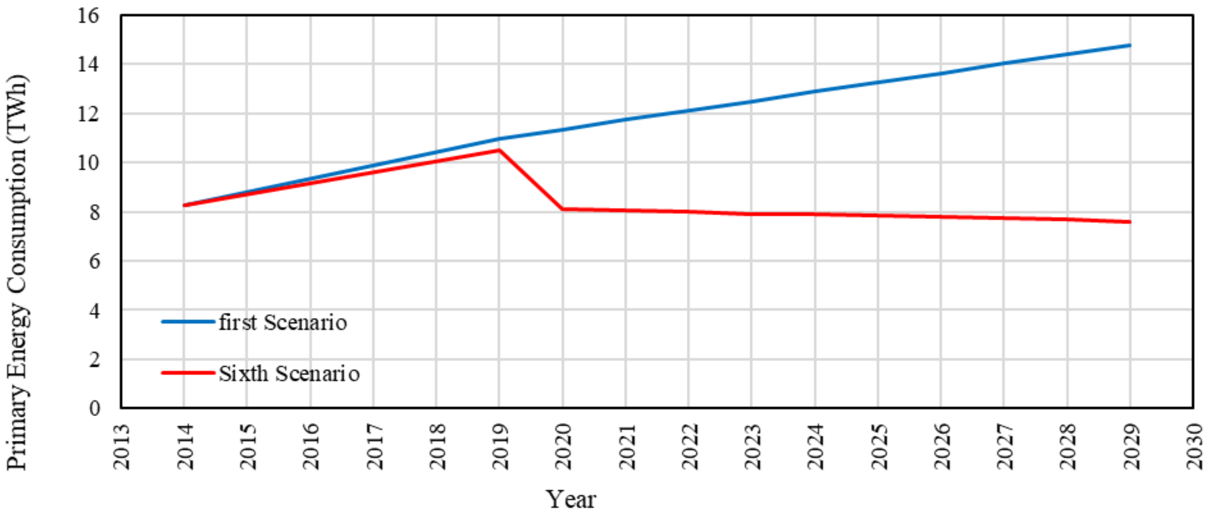

Figure 13: Comparison of the primary energy consumption of the first and sixth scenario 2019 - 2029

Table 10: Calculation of the revenues of exporting saved natural gas

Item	2014	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Primary energy consumption by S1 (TWh)	8.25	10.98	11.35	11.74	12.12	12.5	12.89	13.26	13.65	14.02	14.41	14.79
Primary energy consumption S6 (TWh)	8.25	10.51	8.12	8.06	7.99	7.91	7.89	7.83	7.78	7.75	7.71	7.61
Difference in primary energy consumption between S1 & S6 (TWh)	0	0.47	3.23	3.68	4.13	4.59	5.00	5.43	5.87	6.27	6.70	7.18
Amount of NG saving (Mm^3)	0	47	33	37	42	46	50	54	59	63	67	72
Interest of exporting the saved NG (M$)	0	22	156	179	200	222	242	263	284	304	325	384

Table 11: Calculation for the cost of the Sixth Scenario

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Electricity cost of the geothermal heat pump (M **US$**)	25	29	40	48	57	67	77	89	101	114	127
Investment cost of renewable energies (M **US$**)	216.5	29	29	29	29	29	29	29	29	29	29
Renewable energies' operation cost (M **US$**)	5	5	6	7	8	8	9	9	10	11	11

population and 30% reduction of natural gas consumption during these 15 years, the extra demand would be supplied by RES. According to the sixth scenario abroad, Iran's natural gas company can export the saved natural gas due to decreased natural gas consumption (e. g. Turkey) (Figure 15).

According to the price of exporting natural gas to Turkey in 2014, which is 48 cents/m^3 [35] and the amount of saved natural gas consumption by applying this scenario, the revenues of exporting that amount were calculated, and results are indicated in Table 10. Regarding these calculations, the amount of saving in natural gas consumption will reach 72 million m^3, and the revenues of exporting will be 384 million USD. Also, Table 11 shows the calculation for the cost of the Sixth Scenario.

Table 12: Calculation of return on investment of the plan

Year	2019 (0)	2020 (1)	2021 (2)	2022 (3)	2023 (4)	2024 (5)	2025 (6)	2026 (7)	2027 (8)	2028 (9)	2029 (10)
Cost (M **US$**)	–253.5	–72	–86	–97	–109	–121	–136	–149	–165	–182	–321
Revenues (M **US$**)	37	174	201	226	252	277	304	330	355	383	413
Difference (M **US$**)	–216.5	–114.5	0.51	129.5	272.5	428.5	596.5	777.5	967.5	1168.5	1260.5

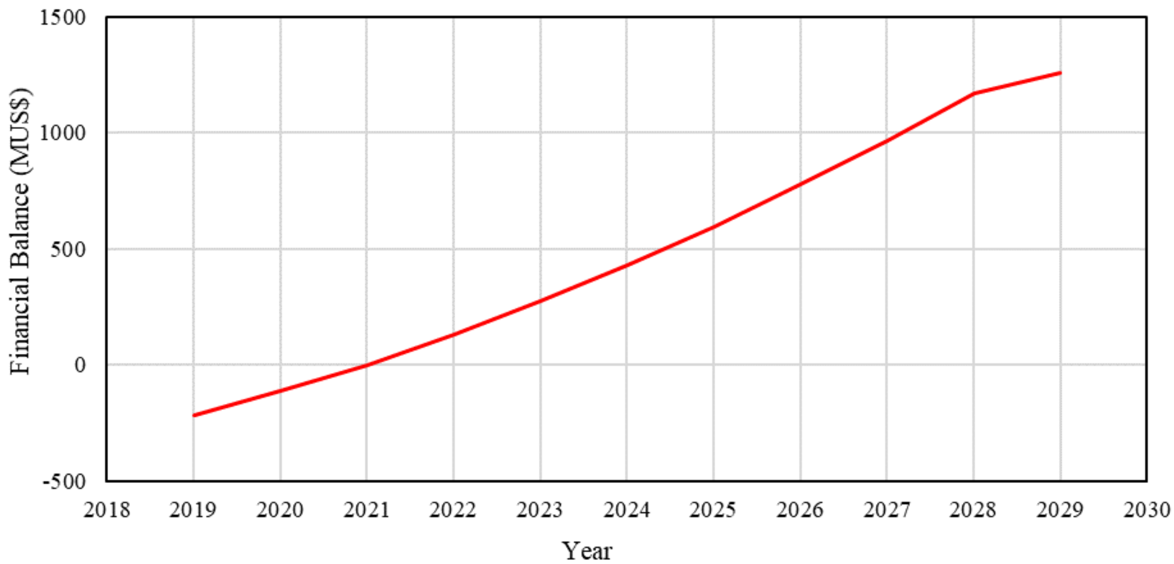

Figure 14: Return on investment of the plan from the year 2019 to 2029

3.10. Return on investment (S6)

The operation cost for each year and calculated revenues of the selected scenarios, which are the sum of revenues due to natural gas export and carbon dioxide emission reduction, the return on investment of the proposed plan was calculated and presented in Table 12.

According to the calculations in Table 12 and considering the saved environmental expenses and exporting the saved natural gas, the return on investment will be achieved in 3 years. Figure 14 indicates the financial balance of the proposed scenario.

Due to the gradual development trend of RES in the country, it is predicted that the share of RES in Qazvin would not be more than the amount provided in this plan until 2019. Therefore, this amount of renewable energy replacement with natural gas consumption is sufficient for this study.

4. Conclusion

The study's primary goal is to compute a new model that is economically and technically investigates the feasibility of a proposed scenario to replace RES instead of natural gas consumption in Qazvin city. Six different scenarios are analyzed to evaluate renewables' potential for city heat demand over the next 15 years. The result shows that the optimal scenario (Scenario Sixth) reduces natural gas consumption and increases RES. The sixth scenario results indicate that this plan's investment cost is significantly efficient than other scenarios. Also, the cost of natural gas consumption due to its decreasing trend is less than in other scenarios.

Economic and environmental analysis indicated that such a plan is feasible due to its 3-year return on investment. Also, the emission reductions of 35% by 2029 and the plan's investments are achievable. This plan will help fulfill Iran's commitments to reduce carbon dioxide emissions up to 12 percent until 2030. Also, it would allow Iran to achieve its agreement in COP 21 to reduce greenhouse gasses. Qazvin's solar radiation map indicates that most of the areas have a high potential for harnessing solar energy in the home. Besides, according to studies in this plan, using solar water heaters is reasonable and can be used on houses' roofs. Economic analysis indicated that this plan is noteworthy according to the shares allocated to each renewable energy in the sixth scenario.

Regarding the current energy system based on fossil fuels and the absence of RES, the initial cost of establishing and using renewable resources is very high. The increasing eagerness of the scientific community and public authorities towards RES will be competitive with fossil fuels. By implementing this plan, the savings in natural gas consumption in 2029 will be about 72 million cubic meters, and CO_2 emission reduction will be approximately 31.5%.

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6. Data Availability

The study area's solar energy resource map is available, and it can be delivered by contact with the corresponding author.

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