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Toward renewable and sustainable energies perspective in Iran

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A B S T R A C T

This paper investigates the potential of renewable energies utilization in detail through three in-house developed strategies to increase the renewable power generation share until the year 2050 assuming either an optimistic 100% or a practical 50% based on the national policies. Solar, wind, and waste energy are the most feasible alternative energy resources in Iran. In the first strategy, power plants are phased out according to their lifetime and replaced by renewable resources in 5-year time steps. The second strategy employs a 3% replacement rate to reach a 100% renewable power generation in 2050. In the third strategy, the national plan of the power ministry is utilized to adopt a more practical pathway for increasing the renewable power generation share up to 50%. Pollution and water shortage crises are also considered within the framework of this study. The following work can lay the foundation for future studies of its kind in Iran as well as other countries all over the world. Developing the presented results can lead to the practical implementation of the study, which will vastly benefit the residents. Moreover, it will provide a great investment opportunity for foreign and domestic companies working on the field.

1. Introduction

Regarding the recent climate changes and the increasing demand for energy all over the world, researchers have been intrigued to investigate and continually optimize both the means and the scenarios of exploiting alternative energy resources [1].

Iran, as one of the major suppliers of oil and gas in the world, is itself highly reliant on fossil fuel sources to provide its energy demand requirements [2]. Statistics indicate that more than 98% of the energy demand in the country is met utilizing fossil energy resources [3]; this has caused several critical issues for the people and decision-makers. Environmental threats are also among the primary concerns of a large urban population that lives in the country; for instance, Tehran, the capital of Iran, tragically experienced only less than one month with clean air in 2017 [4]. The other issue that deserves immediate attention is the water crisis in Iran. The amount of precipitation in the country is less than a third of the global average [5]. Employing renewable energy systems coupled with desalination units can be the ultimate solution to the upcoming water crisis in the country [6,7].

Moreover, the widespread use of fossil fuels is a hazard for underground water sources. In addition to all these, the fossil energy sources are inevitably coming to an end; countries like Iran with this level of dependence on their fossil energy sources must predict and manage the situation in advance. Otherwise, the results will be horrendous. Nevertheless, regarding the solar and wind energies potential of the country, the crisis can be handled with a practical strategy. Considering all these regional and global factors, the necessity of switching to a 100% renewable energy system or at least increasing the share of these green energies in the power grid is beyond any doubt. Previously, several studies have been conducted in this area, which are to be reviewed and discussed briefly.

In 2004, Atabi analyzed how renewable energies can cause socioeconomic growth in Iran, and developed a desirable economic model for the investment of foreign business ventures in the renewable sector [8]. Karbassi et al. studied Iran's energy generation sustainability and concluded that the current system is not only unsustainable but also consumption-oriented. They have also explored the effect of optimizing this system on the reduction of greenhouse gases and the environmental benefits for the country [9]. Fadai in 2007 has developed a plan for utilizing renewable

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energy sources in Iran for power generation. He has also mentioned the positive effect this will have on the environment [10]. In a later study, Ghobadian et al. have reviewed the 4th Socioeconomic and Cultural Development Plan (2005–2010) and reviewed policies and schemes regarding renewable energy technologies in Iran. They have also investigated the private sector share in the upcoming years according to the plan published by the government [11]. Hoseini et al., in 2013, with the importance of renewable energy sources in mind, analyzed potentials of biofuel, hydropower, wind, solar and geothermal energy in Iran and concluded that these potentials are great and deserve a thorough consideration [12]. A comparative study of electricity generation in the Middle East has been conducted by Mostafaeipour and Moastafaeipour, the main focus of the research was Iran renewable potential and the issues existing regarding the matter [13]. In a follow-up study, Ghorashi and Rahimi worked on renewable energy in Iran; their main focus was on technology gaps and the art of know-how [14]. Mostafaeipour et al. mainly worked on wind energy potential in Binalood region in Iran. They also reached the desirable wind turbine implementing financial models. Though very specific and detailed, their idea can be utilized on a larger scale as well [15]. Alamdari et al. have investigated the solar potential in Iran. As they have stated, Iran has about 280 days of sunny days in 90% of its national land, providing a vast potential for energy generation [16]. In the year 2018, Shasavari and Akbari have analyzed the benefits of solar energy for developing countries and the ways of increasing its share in the power grid can help the environment. They have also considered the challenges that must be faced with for promoting this source of energy [17]. A recent study by Shimbar and Ebrahimi involved economic modeling of a waste-to-energy project in Iran. Applying a new methodology in their model, they have concluded that this type of investment can be a profitable scheme for the country [18].

The environmental issues caused by utilizing fossil fuels on this scale were also investigated. In 2018, Kachoee et al. worked on the current carbon emission in the electricity generation sector. According to them, this sector is responsible for 30.2% of Iran current carbon emission. Considering the current policies, this amount will increase to 668.2 million tons by 2040. By adopting renewable energy policies, this amount can be considerably decreased [19].

Manzoor and Aryanpur in 2017 performed a retrospective optimization of Iran power sector. Finding the optimal scenario for the years 1984–2014, they believe they have provided an insight into future developments. According to this study, shifting to renewable supplies is one of the approaches that will benefit the power generation sector of the country [20].

Shakouri and Aliakbarisani have analyzed power scenarios and concluded that shifting to renewable energies is a more sustainable approach for Iran even though due to the abundance of fossil fuel resources in the country, it may not seem profitable at the moment [21].

Studies of the same type have been conducted in other countries. In the year 2003, Stephen Karekezi et al. reviewed the unexploited renewable energy potentials in Africa and found out how vastly it can benefit that continent to utilize these resources [22]. In 2011, Salsabila et al. discussed the issues awaiting Malaysia in future regarding the unreliable future of oil reserves; they offered that transition to renewable energies can be the ultimate solution and to reach that they studied the challenges and potentials in the path of that country to a green, sustainable future [23]. Lund in 2007, performed a similar study about Denmark and concluded that a transition to a 100% renewable energy system is feasible in Denmark [24]. In a later study, Stambouli et al. studied the situation of existing renewable energies and the potential for their development in Algeria [25]. In 2010 Wang and Chen analyzed the impacts of an increase in the share of renewable energies in China and how this can result in a CDM (Clean Development Mechanism) [26]. Junfeng et al. have also done the same type of study for China and reached the same conclusions, according to them, carbon emission of China can decrease significantly using a renewable scheme [27]. One other study in China conducted by Byrne et al. in the year 1998 has investigated the impact of off-grid renewable technologies and found it to be promising [28]. In 2016, Dai devised a plan until the year 2050 for the renewable energy policy in China and developed a strong argument why this will benefit the nation both environmentally and economically [29]. Wang and Huang studied renewable energy generation planning in a single microgrid [30] and also in interconnected microgrids [31] in Hong Kong. Based on the meteorological data, a framework is developed to optimize the investment decisions on solar and wind energy generation and further on the energy storage capacities [30]. Because solar and wind energy generation varies in different locations; developing a cooperative planning framework is necessary [31]. In this study, the interconnected multi grids benefit from the variation of renewable energy in different locations.

Moreover, a numerical case study is conducted which depicts that the cooperative planning framework is capable of reducing the overall cost by 35.9% compared with the non-cooperative benchmark [31]. Jefferson in 2005 explained that the current trend toward renewable energies is not satisfactory and the speed is not sufficiently high [32]. In the year 2006, Doukas et al. investigated the current status of renewable systems in the GCC (Gulf Cooperation Council) and mainly focused on the investment opportunities existing in the region [33]. Dincer in the year 2000 analyzed the interconnection of renewable energy generation and sustainable development. He believed these systems could help to solve a wide range of environmental issues from acid precipitation to the greenhouse gases [34]. One of the challenges governments commonly face in increasing their exploitation of renewable resources is how the public will judge this plan. Addressing this issue in 2006, Patrick Wright, conducted a socio-demographical study in the UK and concluded that the public is supportive regarding renewable energies and even recommended local investment with the public as stakeholders can accelerate the transition to renewable resources [35]. Taking the necessity of increasing the share of renewable resources in the future for granted, Menanteau et al. analyzed different incentives used by governments to find which is the most efficient [36]. In 2001, Painuly explored the barriers on the path of deploying renewable energies, and he developed a framework to find ways for overcoming these barriers [37].

Regarding waste, not much has been done in Iran. Nonetheless, many different countries have begun to use waste to generate electricity or produce synthetic gas. Landfilling is no more an option as the population is growing and a lack of land is turning into a big problem for countries like Japan and China [38]. Technologies employed for waste treatment are also highly dependent on the unique conditions of each country; in developing countries, the significant portion of waste is food, and as a result, the calorific value is low (6 MJ/kg) [38] while in countries like the USA, the calorific value is as high as 10 MJ/kg [39]. The most common method used worldwide for waste-to-energy power generation is grate incinerators since it can handle up to 1200 ton/day of MSW (Municipal Solid Waste) and a complicated pretreatment of wastes is not required. Japan, however, uses gasification mostly because it requires less land and is the best option for Japan which is not a big country [39].

In 2015, a model for switching to a 100% renewable energy scenario was developed by European researchers [40], wherein the energy consumption in Iran till 2050 were estimated and three strategies were developed to replace conventional energy generation methods by the emerging renewable technologies. In the first strategy, a three percent annual replacement rate is considered. Implementing this strategy, Iran will meet 100% of its energy demands by harnessing renewable energy sources in 2050. The second strategy, analyzed, increases the replacement rate to 4%. The third strategy integrates the power generation scheme with water desalination to address Iran water crisis as well. The primary motive and the approach of the article above are invaluable. Nonetheless, due to a lack of access to local information, the results were not immediately applicable, since a great deal of reasoning needed in this model requires the local data.

This paper intends to locally investigate the matter regarding utilization of renewable energy resources in Iran and to provide detailed information that can be used by national decision-makers and those who are interested in investing on the vast renewable potentials in Iran. The method of the study can lay the foundation for future local studies of the same type all over the world.

2. Methodology

2.1. Overview

To reach the objective of developing a renewable power generation scheme for Iran, first, the local data on the current fossil-fuel-based plants and also the real potential for each of the renewable energies are investigated. In this investigation, the availability of these resources is considered. After obtaining the required data, three schemes are discussed and based upon them three strategies are developed. The first scheme is based upon phasing out the existing conventional power plants according to their lifetime and replacing them with the potential in each province. The second scheme proposes a specific constant increase rate in the share of renewable power generation to reach a 100% renewable grid in Iran by the year 2050. The third scheme, however, is based on the national plans suggested by Iran's Ministry of Energy.

Regarding the plan, until the year 2040 the primary objective is to increase the combined-cycle power plants, the scheme developed here will flatten out the conventional power generation share afterward and expand the renewable energy share to 50% till the year 2050. The installations are proposed to be done in each province based upon the life-cycle of currently installed power plants. In order to minimize the replacement costs and also the losses caused by long-distance transmission, the new renewable plants are established in the same regions where the conventional plants are phased out. It has been the authors' intention also to consider the existing technologies and their future progress in choosing the timeline of exploiting different potentials. One advantage of this methodology is that in the first stages of the replacement, there is no need for storage systems as the gradual replacement of the power plants makes using them possible to address the daily and monthly fluctuations.

Furthermore, although the storage scheme is also developed for the early years, as just expressed, in case any problem occurs in implementing the storage scheme, for the first years, there will not be any particular challenge. Because of the abundant fossil fuel resources existing in the country, the meager subsidized prices of these resources and the relatively high expenses of installing the renewable technologies, no short-term economic analysis can justify the current model; therefore, the economic analysis of the model has been deliberately forgone. Alongside its contribution to the sustainable development of the country, there are several other environmental incentives to support the scheme which are thoroughly investigated in the model. Moreover, the schemes formulated in this article can provide further possibilities, like integrating water desalination systems into the grid to address the water crisis, which the country is dealing with currently, and creating business opportunities in the sector. It must also be stressed that since the oil and gas resources are not renewable and will inevitably be finished, shifting into an alternative energy system is a necessity that must be met sooner or later.

2.2. Current grid status

To attain an applicable model, current statistics in the power sector were extracted from a multitude of sources. Current existing power plants including both renewable and conventional fossil-fuel-based plants were analyzed. Name, type, starting date, nominal power generation, actual power generation, fuel consumption and the regional section to which each power plant belongs and can be found in the appendices.

Moreover, using the data for energy consumption in the previous 20 years, the consumption amount was predicted until the year required in the model. This modeling has been done by fitting a linear curve on the existing data. The results are presented in Fig. 1.

This energy consumption was also traced to find the share of each section in the total energy consumption amount as illustrated in the pie chart of Fig. 2. As can be seen, about 34% of the consumption is in the industrial sector, and about 32% is in the household sector, agriculture, and public sectors come next with 16 and 10% respectively. The table of the data used to fit the curve is presented in Appendix A.

Various forecasting methods are suggested for predicting electricity price. These methods are all based on compromising between the offered prices of the suppliers and the existing demand utilizing the equations governing supply and demand economics in the market. In many modern countries, there are mechanisms to resolve the differences to reach a unit price for some time. However, in Iran, since the mechanisms are state-regulated, the aforementioned algorithms are not applicable. To accelerate the development of the power sector, the general policy adopted by the state is to remove the subsidies.

Nevertheless, due to the local socio-economic feature of Iran, this is not to be implemented in a short period; according to the 6th Socioeconomic and Cultural Development Plan (2015–2020), a constant increase rate of 9% is devised by the state. As this is the latest announced development plan, it is rational to adopt this increase rate to predict the electricity price for the forthcoming years in the presented model. The results are shown in Fig. 3. It is to be noted that the price axis in the following graph is in logarithmic scale to illustrate the changes better.

To show the improvement in the environment and pollution control the carbon emission of these plants has also been recorded. There is no need to mention that shifting to renewable resources or increasing their share in the power generation, will significantly reduce pollutants and greenhouse gases. This is following Iran policies to reduce its carbon emission, as Iran is one of the signatories of the Paris agreement. This data is provided in Table 1 and Table 2.

2.3. Solar energy in Iran

2.3.1. Solar energy potential

Iran has an excellent potential for solar renewable energy; this is because of the high exposure of the country to sunlight which is 17% higher than the global average [41]. The vertical and horizontal irradiation contours of the land are illustrated in Fig. 4.

Though the radiation rate is approximated on the maps [42], there was no discrete data available on the matter in Iran Renewable Energies Organization. Therefore, an approximation needed to

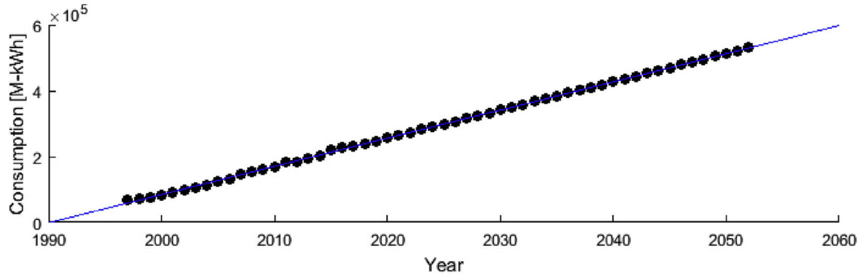

Fig. 1. Estimation of energy consumption until 2050.

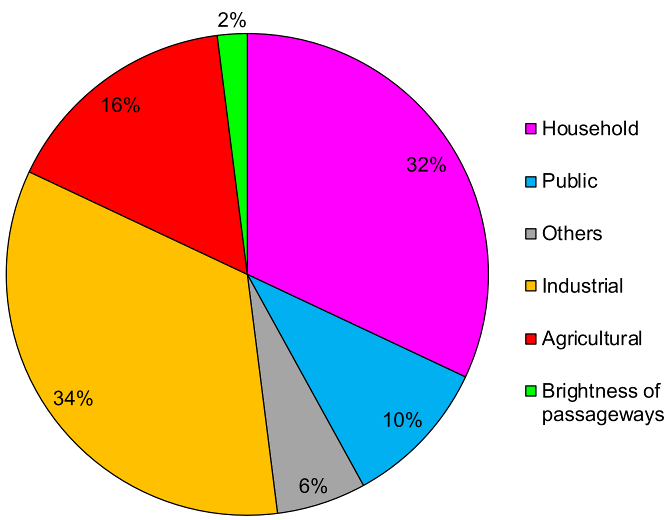

Fig. 2. Energy consumption in different sectors.

be made. As a benchmark for this study, the analysis done by Dr. Besarati is employed [43].

Having the irradiation rate and the area of each province, a sensible percent of that area is considered to have the capability to be utilized for electricity production. This percent has been chosen considering the unique geographical and climatic features of each province. An average of 10 sunny hours for a day is considered. The efficiency of the Photovoltaic (PV) panels has been supposed to be 15% which is pessimistic as will be explained in the following part. It is to be noted that the global horizontal irradiance data has been used to yield a non-optimal amount of available solar energy. However, several optimization methods have been developed in the literature to estimate the optimal tilt angle of the panels [44]. In case these angels are adopted, the harnessed energy will be more than the potential presented. This pessimistic calculation of the potential ensures the practicality of the developed model. As can be seen in Table 3, the total amount of energy produced is 70 times more than what was generated in Iran in 2015.

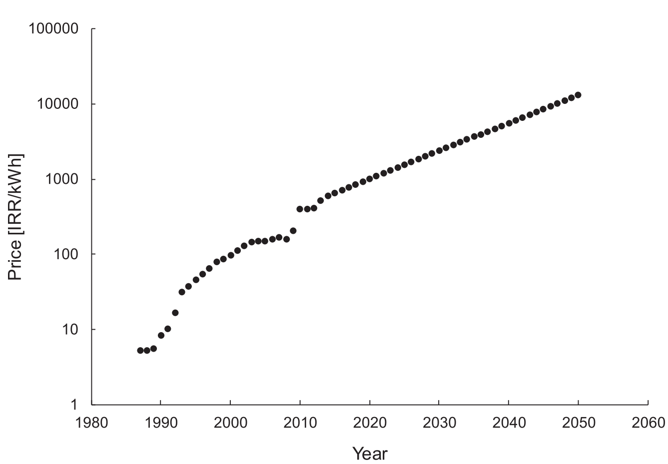

Fig. 3. Estimation of electricity price until 2050.

2.3.2. Solar energy technologies

Between CSP (Concentrated Solar Power) and solar PV, solar PV has proven to be a better alternative since this mode of energy production can well adapt itself to any power requirement from small-scale, home-based production to large-scale production. It is also cheaper than CSP. As this study aims to set the energy policy path for the coming years, research and development being done on this technology, which is to a great extent more than CSP is a crucial factor. However, CSP has one advantage which is storing energy while producing it in the form of heat to be utilized in a later time whereas PVs can only generate electricity and deserve a separate scheme for storage which will be mentioned in the subsequent sections [45]. Based on the data available in Refs. [46,47], the efficiency and price of different existing technologies for solar energy utilization have been compared and crystalline silicon has been chosen as the most appropriate since its efficiency is increasing with an acceptable trend, and its price which is about 0.5 $/kW is decreasing gradually.

The electricity produced by these technologies is bought in Iran by the government with the prices indicated in Table 4 [48].

According to Renewable Energy and Energy Efficiency Organization of Iran, the investment capital expenses might differ depending on the technology and the scale of the solar farm, but on average the cost is estimated to be 1000 $/kW [49].

2.4. Wind energy in Iran

2.4.1. Wind energy potential

Although the amount of this potential is not as much as solar

Table 1
Pollutant and GHG emissions indicators in Iran power plants ton/yr.

Year	NO_x	SO_2	SO_3	CO	SPM	CO_2	CH_4	N_2O
2008	471785	476728	3110	155713	21847	129232000	3013	458
2009	554784	580348	3186	166939	23715	147032000	3299	491
2010	563998	608395	3465	151517	24873	150328000	3345	510
2011	574741	497354	3538	137857	25528	154777000	3522	531
2012	634884	709408	5130	148500	30724	165185000	4087	666
2013	629392	823623	5319	161831	31957	174664000	4273	698
2014	678023	910658	6574	162708	36199	179825000	4725	803
2015	651610	627934	4586	177660	31105	177745000	4243	654
2016	627724	437381	4158	162624	30330	174011000	4201	630

Table 2
Pollutant and GHG emissions indicators in Iran power sector by power plant types for the year 2015 (gr/kWh).

Ownership	Type of Plant	NO_x	SO_2	SO_3	CO	SPM	CO_2	CH_4	C
Governmental Sector	Steam	2.3	7.8	0.03	2.5	0.2	824.9	0.02	225
	Gas	2.4	0.5	0.01	0.1	0.1	849.4	0.02	231.6
	Combined Cycle	2.9	0.3	0.01	0.1	0.1	469.9	0.01	128.2
	Diesel	1.5	4.6	0.1	0.001	0.3	826.4	0.04	225.4
Private Sector	Steam	1.9	3.6	0.02	0.5	0.1	764.9	0.02	208.6
	Gas	2.3	0.8	0.02	0.1	0.1	798.5	0.02	217.8
	Combined Cycle	3.1	0.3	0.01	0.1	0.1	783.9	0.01	132
	Diesel	2.3	0	0	0.5	0.1	1182.7	0.01	322.5

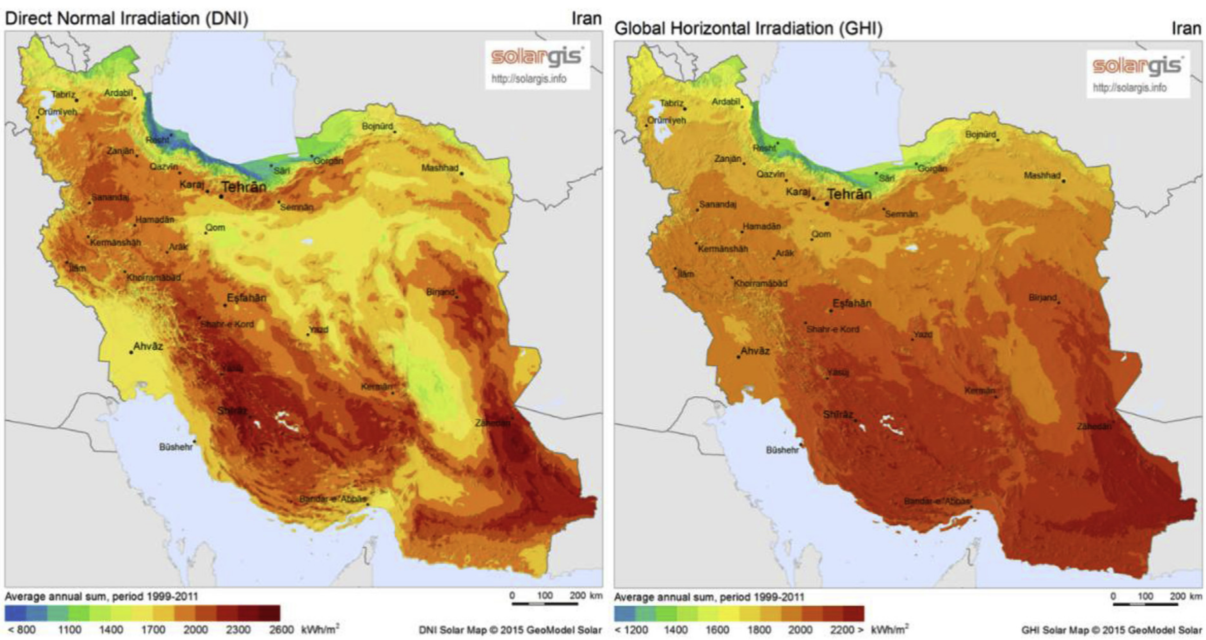

Fig. 4. Direct irradiation contours. left: vertical, right: horizontal [42].

potential, it is still worth considering as the amount is still considerable. The Atlas of wind energy for the Middle East (including Iran) is illustrated in Fig. 5 [50].

Data on wind potentials of Iran are already calculated. These potentials for each province are estimated based on the study conducted by Alamdari et al. and their proposed Atlas as presented in Table 5 [51].

The difference in wind classes does not affect the production rate, but it changes the implemented technologies because of different wind speeds in these classes.

2.4.2. Wind energy technologies

The wind technology trends show that it has reached a stable condition and the changes are not considerable. This is why in each strategy, first the wind potential will be utilized, and then solar panels will be installed. The price line for wind technologies has been quite flattened out, and not much change in price can be expected [52]. Also, the efficiency is proved not to surpass Betz limit which is 59.3%, and currently 50% has been reached [53]. Thus, not much change can be expected in this regard as well. This is the reason for prioritizing wind energy over solar energy in the early time steps of the strategies. Using the existing wind turbine technologies, most of the wind energy potentials of the country could be harvested successfully.

The largest capacity of wind energy that can be harnessed by a single wind turbine using the existing technologies is 9.5 MW. However, in Iran the largest wind turbine that has been produced, and utilized has a capacity of 2.5 MW. So, it is advisable to use this type of technology because of its availability and ease of transportation [54]. This does not prevent decision makers from using larger turbines with higher capacities in the future.

2.5. Geothermal energy in Iran

The potential for geothermal energy exists in some parts of Iran. The atlas of geothermal energy is illustrated in Fig. 6 [55].

Nonetheless, for the following list of reasons, this mode of energy generation has been excluded from the model.

- Requiring high capital cost

This amount has been estimated to be 2500 $/kW which is high compared with other renewable resources [56].

- Requiring high maintenance cost

This amount has been estimated to be between 0.01 and 0.03 $/kW which is more than solar energy [56].

- Requiring Water

Most importantly, this mode of energy production requires large

Table 3
Solar potential estimations in Iran's province.

Province Name	Area (km^2)	Percent of Useable Area	Useable Area (km^2)	Annual Average Irradiation (kWh/m^2)	Absorbed Energy by the Panels (TWh)	Electricity Produced With 15% Efficiency (TWh)	Produced Power (MW)
Kerman	183,193	0.1%	183	2000	366	55	15057
Sistan & Balouchestan	181,785	0.1	182	2200	400	60	16435
Southern Khorasan	140,634	0.1	141	2100	295	44	12137
Fars	122,608	0.1	123	2100	257	39	10581
Razavi Khorasan	118,854	0.1	119	30%: 1900 50%: 2000 20%: 2100	237	35	9720
Isfahan	107,102	0.1	107	50%: 1900 50%: 2000	209	31	8583
Semnan	97,490	0.1	97	1900	185	28	7612
Yazd	73,941	0.1	74	50%: 1900 50%: 2000	144	22	5925
Hormozgan	70,697	0.1	71	2000	141	21	5811
Khouzestan	64,055	0.1	64	1900	122	18	5002
Eastern Azerbaijan	45,650	0.1	46	1700	78	12	3189
Western Azerbaijan	37,411	0.1	37	1700	64	10	2614
Kordestan	29,137	0.1	29	1800	52	8	2155
Markazi	29,127	0.1	29	1800	52	8	2155
Northern Khorasan	28,434	0.1	28	1700	48	7	1987
Lorestan	28,294	0.1	28	1800	51	8	2093
Boushehr	27,653	0.1	28	2100	58	9	2387
Kermanshah	24,998	0.1	25	1800	45	7	1849
Mazandaran	23,842	0.1	24	1200	29	4	1176
Zanjan	21,773	0.1	22	1700	37	6	1521
Golestan	20,367	0.1	20	1400	29	4	1172
Eilam	20,133	0.1	20	1800	36	5	1489
Hamedan	19,368	0.1	19	1800	35	5	1433
Ardebil	17,800	0.1	18	1500	27	4	1097
Charmahal & Bakhtiari	16,332	0.1	16	2000	33	5	1342
Qazvin	15,567	0.1	16	1800	28	4	1152
Kohgiluye	15,504	0.1	16	2000	31	5	1274
Gilan	14,042	0.1	14	1200	17	3	693
Tehran	12,981	0.1	13	1800	23	4	960
Qom	11,526	0.1	12	1800	21	3	853
Alborz	5833	0.1	6	1800	10	2	432
Total						**474**	**129884**

Table 4
Solar energy prices in Iran [48].

Required capacity	Price (IRR/kWh)
100 kW–10 MW	4900
10 MW–30 MW	4000
>30 MW	3200

amounts of water to be injected into the ground, while as shown in the above figure, that amount of water is not available in potential sites since they are located in arid areas. Besides that, due to Iran lack of rainfall and water issues, schemes interfering with the country water provisions are not to be implemented.

2.6. Hydro-power energy in Iran

As the water sources in Iran are threateningly limited, utilizing those to produce electricity is unwise. Thus, this mode of energy generation is considered to remain without change in the model. However, the existing dams can serve as a means of storage. The list of existing dams and hydropower plants are brought in appendix B.

2.7. Waste and biomass energy in Iran

Nowadays, many countries face the problem of waste management as the population grows and more waste is produced. The conventional solution for waste management is landfilling, but pollution and lack of land are the major problems of this method. The new techniques are Gasification and Incineration [57].

2.7.1. Waste energy potential

Based on the data available in the municipalities of major cities in Iran, the waste produced in the seven largest capital cities of provinces in Iran are represented in Table 6 [58]:

2.7.2. Prediction of population

To estimate urban waste produced in each capital city of Iran, existing population data have been used to interpolate and extrapolate the missing year's data [58]. After analyzing different methods and assumptions for extrapolating, it was concluded that calculating the urban population percentage based on the official data is the best way to forecast the population [58]. Prediction of the population in the capital of all provinces in Iran is presented in Table 7. As can be observed, the percentage of urban population will be decreasing in the future for the big cities. The reason behind this decrement is the immigration of the population from these large

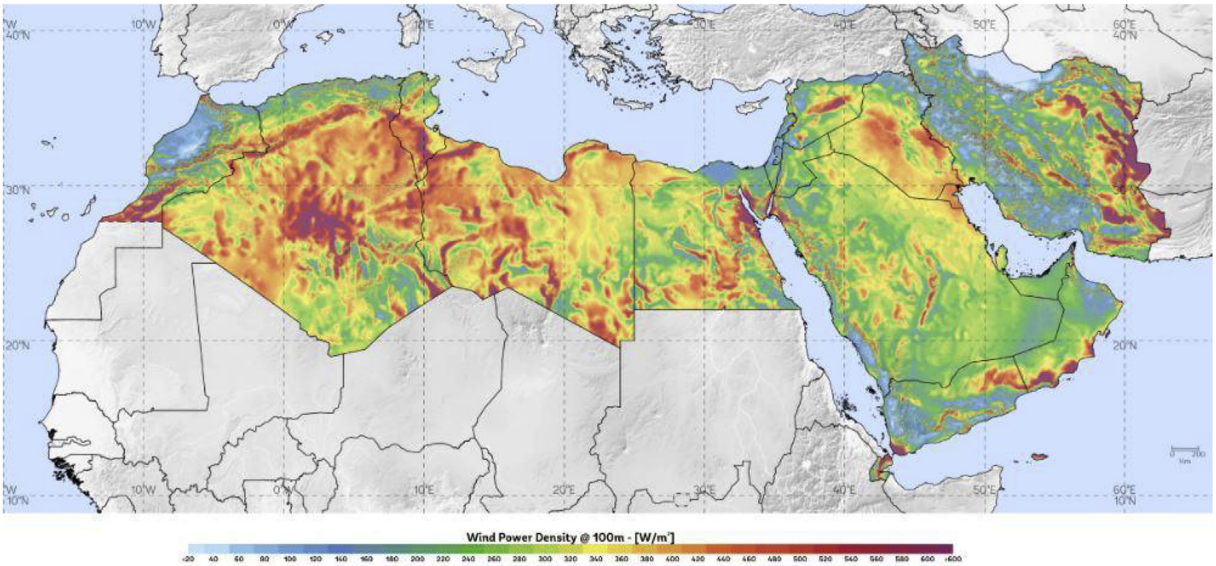

Fig. 5. Atlas of wind energy potential in the Middle East [50].

Table 5
Wind energy potential in Iran's province.

Installable Capacity in Each Province (MW)				
Province	Wind Class 1	Wind Class 2	Wind Class 3	Sum of Capacity (MW)
Eastern Azerbaijan	0	50	700	750
Western Azerbaijan	0	10	400	410
Ardebil	0	0	100	100
Kordestan	0	0	150	150
Zanjan	0	10	350	360
Gilan	200	250	650	1100
Qazvin	0	100	1500	1600
Hamedan	0	0	250	250
Alborz	0	0	200	200
Markazi	0	0	500	500
Qom	0	0	100	100
Lorestan	0	0	20	20
Kermanshah	0	0	250	250
Ilam	0	20	1000	1020
Khouzestan	0	0	600	600
Boushehr	0	0	300	300
Isfahan	0	0	200	200
Yazd	0	0	500	500
Fars	0	0	950	950
Kerman	500	350	2000	2850
Hormozgan	0	0	250	250
Semnan	0	350	1700	2050
Northern Khorasan	0	0	500	500
Razavi Khorasan	500	1000	2000	3500
Southern Khorasan	1000	1500	4000	6500
Sistan	500	2000	4000	6500
Sum of Wind Capacity (MW)	**2700**	**5640**	**23170**	**31510**

major cities to smaller ones due to the gradual development of the other regions.

2.7.3. Prediction of municipal solid waste

Based on data from Ref. [59] the constant Municipal solid waste (MSW) is considered to be 800 gr/person per day for all capital cities except large cities as Tehran, Shiraz, Mashhad, Yazd, Karaj, and Isfahan as presented in Table 8. For a more accurate estimation of these cities, the mentioned constant value for waste production per person was obtained from the average of data from 2012 to 2016.

Based on Iran population prediction, the waste in every capital city was estimated until the year 2050, and it is brought in Fig. 7.

2.7.4. Estimation of net produced electricity

The calorific value of MSW is different in each country. In the USA, this value is as high as 10.5 MJ/kg [39] and in China as low as 6 MJ/kg [38]. The low calorific value for waste is originating in the large portion of food wastes; in developing countries, this fraction is as high as 60% of wastes, so the amount calorific value for Iran is assumed to be 5.5 MJ/kg because of its current developing situation. Then, the total amount of energy that can be obtained from burning

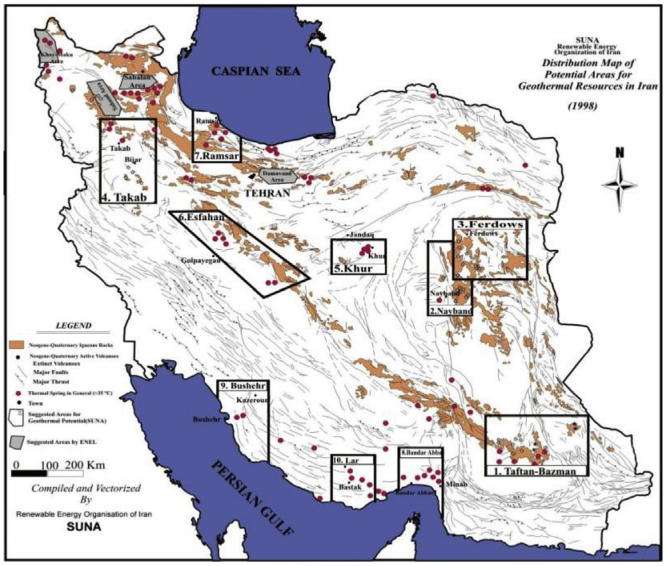

Fig. 6. Geothermal potential sites in Iran [55].

the MSW per ton of waste can be calculated. A 10% heat loss in the furnace and the stack is considered [60]. The turbine efficiency is estimated to be around 28%, and about 15% of produced electricity is considered to be consumed by the plant itself. In the end, it is worth mentioning that only 50% of these wastes are suitable for waste to energy (WTE) plants. The suitable Plant for Iran is grate incinerators because they can burn up to 1200 ton/day of MSW and they do not need pretreatment of wastes. For instance, in the year 2020 in Tehran, 3,038,338 tons of waste is produced annually; the estimated amount of energy that can be extracted from a ton of waste is calculated to be 1.52 MWh/ton. Considering the losses mentioned before, a 0.325 MWh/ton of energy can be supplied to the grid. Considering the fact that approximately this amount of waste can be burnt annually, 57.40 MW can be generated in Tehran.

2.8. Animal waste energy in Iran

Manure, which has been processed, can provide a reliable and clean source of electrical and heat energy. There are three primary pathways for the conversion of organic waste material to energy: Thermochemical, Biochemical, and Physicochemical.

2.8.1. Animal waste potential in Iran

Application and utilization of biogas in Iran have a long history. Sheikh Bahai (1530–1622 BCE) is reportedly the first to use biogas in a bathhouse in Isfahan. In recent years, the first biogas production digester was built in 1975, Niazabad village in Lorestan, a province in the western part of Iran. This digester has a volume of 5 m^3 that uses the livestock waste of the town to produce biogas for providing hot water. Fig. 8 states how this energy is distributed within different sectors [61].

The data provided here are based on the Statistical Center of Iran in 2014 [62]. Table 9 explains the share of animal waste and its energy value in Iran's province.

Table 6
Produced waste in capital cities of provinces in Iran (tons) [58].

City	Year				
	2012	2013	2014	2015	2016
Tehran	3045797	2960704	2861404	3063336	2988272
Mashhad	700372	669547	633552	859604	764981
Tabriz	497495	365365	438000	511000	438000
Karaj	430000	419750	419750	407530	395295
Isfahan	304783	304783	366811	366821	330250
Shiraz	418865	397025	410270	511840	1118475

2.9. The storage scheme

2.9.1. Choosing storage systems

Among the many options available for energy storage systems, battery storages are growing fast. The advantages of these systems are high energy/power density, proper efficiency and high response time [63]. Another influencing parameter in choosing right energy storage for our model is considering topographic conditions and water resources, which is a limitation for pumped-hydro, system development [64], while there is no geographical limitation for batteries. A recent improvement in battery storage systems is that it has reached large-scale utility used worldwide recently (100 MW Li-ion storage in South Australia by Tesla Co. [65]). Another noticeable parameter regarding batteries is the increasing speed of development of them in recent years which has resulted in a 64% reduction in production cost [66]. Among battery systems, Li-ion batteries have more power and energy density, lower self-discharge and better lifetime [67]. Also as discussed in Belderbos et al. [68], these batteries will best suit in a variety of applications including peak replacement, distribution, and microgrid. Accordingly, Li-ion batteries can be considered the best fit for the energy storage system in the proposed strategy, which is developed in this study. Other storage systems such as pumped hydro, compressed air, flywheels, and electro-chemicals are the second priority if the batteries do not meet the conditions or in particular occasions when a pumped-hydro system from the past exists.

2.9.2. Handling fluctuation of energy

Renewable energy systems are divided into two sub-categories of flexible and inflexible. Flexible systems are those who provide the required energy as dictated by the plan. On the other hand, wind and solar energy systems have a time-dependent availability which is the underlying reason to use storage systems for handling fluctuations and the mismatching of energy demand and generation.

In the following part, a typical solar and a wind plant currently-installed in Iran are analyzed to investigate the possibility of handling the challenge of renewable energies availability in case the models presented in the previous parts are implemented. These two sites have been selected to represent the average conditions of solar and wind energy generation in Iran.

First, it is necessary to analyze the consumption patterns in Iran from published statistics of Iran National Energy Ministry [69], the peak monthly demands of the year 2017 are plotted in Fig. 9.

To indicate the daily trend of energy consumption, 23rd of July 2017 which has one of the highest demands in that has been plotted in Fig. 10 [69].

The solar plant site has been selected to be in the Alborz province which is one of the average sunny provinces in Iran. As mentioned by Shabaniverki [70], for a designed power plant in Shahryar region, normalized power generation of a solar power plant is plotted in Fig. 11:

As it is clearly illustrated in the plots, both electricity consumption and solar power generation follow a similar trend over a year. This implies that seasonal fluctuations are not to be a severe problem in the scheme. On a daily scale, the consumption peak is again simultaneous with the sunny hours. However, utilizing the devised storage systems, the amount of solar power harnessed can simply tackle the daily fluctuations.

Table 7
Prediction of the percentage of urban population in the capital of all provinces.

Capital City	Year										
	1996	2006	2011	2016	2020	2025	2030	2035	2040	2045	2050
Tehran	18.36	15.97	15.20	14.97	13.89	13.26	12.64	12.01	11.39	10.77	10.15
Mashhad	5.18	5.00	5.12	5.43	5.04	5.02	5.00	4.98	4.96	4.94	4.92
Tabriz	3.54	2.86	2.79	2.56	2.37	2.15	1.93	1.70	1.48	1.26	1.04
Karaj	2.66	2.85	3.01	3.11	2.88	2.91	2.94	2.97	3.00	3.03	3.06
Isfahan	3.80	3.28	3.27	3.58	3.32	3.34	3.36	3.37	3.39	3.41	3.42
Shiraz	3.05	2.52	2.72	2.68	2.48	2.39	2.30	2.21	2.12	2.03	1.94
Ahwaz	2.11	1.97	2.00	2.13	1.98	1.95	1.93	1.91	1.89	1.87	1.85
Qom	2.27	2.01	2.07	2.18	2.03	2.02	2.02	2.02	2.01	2.01	2.01
Kermanshah	1.88	1.63	1.59	1.71	1.58	1.57	1.56	1.55	1.53	1.52	1.51
Urmia	1.21	1.20	1.24	1.35	1.25	1.26	1.27	1.28	1.30	1.31	1.32
Rasht	1.25	1.14	1.19	1.21	1.13	1.11	1.09	1.06	1.04	1.02	1.00
Kerman	1.25	1.03	1.00	1.01	0.94	0.91	0.88	0.84	0.81	0.78	0.75
Hamedan	1.14	0.98	0.98	1.00	0.93	0.91	0.89	0.87	0.84	0.82	0.80
Zahedan	1.16	1.15	1.05	1.05	0.98	0.92	0.87	0.82	0.77	0.72	0.67
Sanandaj	0.75	0.65	0.70	0.71	0.66	0.65	0.64	0.62	0.61	0.60	0.59
Ardabil	0.97	0.86	0.90	0.93	0.86	0.84	0.83	0.81	0.79	0.77	0.76
Bojnord	0.47	0.36	0.37	0.43	0.40	0.41	0.43	0.44	0.46	0.47	0.48
Yazd	1.02	0.88	0.91	0.91	0.84	0.81	0.78	0.75	0.73	0.70	0.67
Zanjan	0.79	0.71	0.72	0.75	0.70	0.68	0.67	0.65	0.64	0.62	0.61
Khorramabad	0.74	0.68	0.65	0.65	0.61	0.58	0.56	0.53	0.51	0.49	0.46
Bandar Abbas	0.77	0.76	0.81	0.95	0.88	0.91	0.94	0.97	1.00	1.02	1.05
Arak	1.07	0.91	0.98	0.90	0.84	0.79	0.75	0.71	0.67	0.63	0.59
Qazvin	1.34	0.72	0.71	0.72	0.67	0.65	0.62	0.60	0.58	0.56	0.54
Sari	0.54	0.54	0.55	0.57	0.53	0.53	0.53	0.52	0.52	0.52	0.52
Gorgan	0.57	0.56	0.61	0.65	0.61	0.61	0.62	0.63	0.64	0.64	0.65
Ilam	0.36	0.32	0.32	0.35	0.33	0.33	0.34	0.34	0.34	0.34	0.35
Bushehr	0.41	0.34	0.36	0.38	0.35	0.34	0.33	0.32	0.31	0.31	0.30
Yasuj	0.16	0.20	0.20	0.26	0.24	0.25	0.27	0.28	0.30	0.31	0.33
Shar-e Kord	0.54	0.26	0.30	0.37	0.35	0.38	0.41	0.44	0.46	0.49	0.52
Birjand	0.36	0.33	0.33	0.36	0.33	0.33	0.32	0.32	0.32	0.31	0.31
Semnan	0.33	0.26	0.29	0.31	0.29	0.28	0.28	0.27	0.27	0.26	0.26

Table 8
MSW per person in a day for six major cities of Iran.

City	MSW per person per day (gr)
Tehran	977
Mashhad	699
Tabriz	811
Karaj	707
Isfahan	500
Shiraz	1049

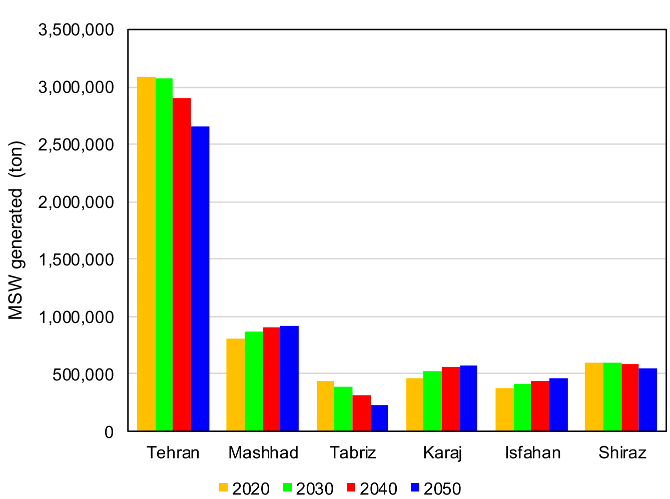

Fig. 7. Prediction of waste products for the capital city of provinces in Iran (ton).

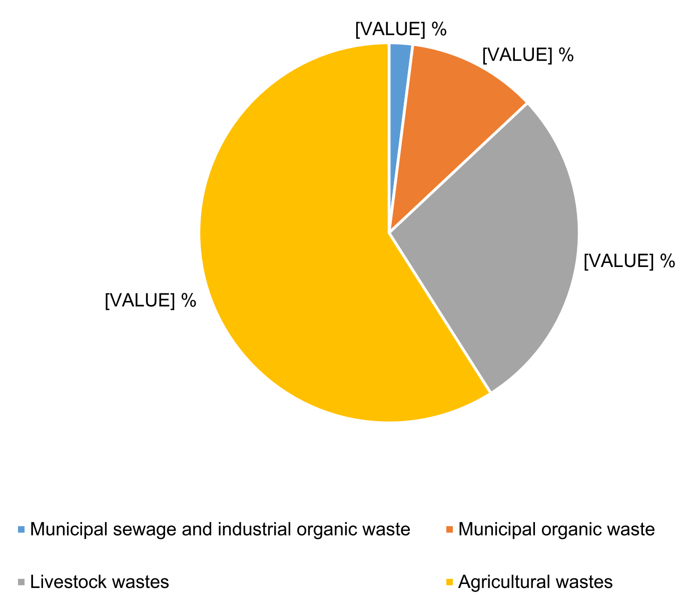

Fig. 8. The share of biogas production resources in Iran [61].

To address the wind power fluctuations, the Kerman province was selected. Kerman is a dry city in the central arid area of Iran; therefore, it can well represent an average city in Iran regarding wind energy. A study done by Mostafaeipour et al. [71] has revealed the wind power density throughout one year in Shahrbabak, and it has been plotted in Fig. 12.

The daily fluctuations of wind speed are directly linked with wind power generation capability in the speed range of the site [72].

Table 9
Statistics of animal waste and its energy value in Iran's provinces.

Provinces	Energy (MW/year)	Waste volume (m^3)	Total waste (kg × 10^6)	Number of goats	Number of lambs	Number of cows
East Azarbayjan	294	163352	368	313941	2307463	346304
West Azarbayjan	301	167400	377	217253	2520155	315741
Ardabil	158	88018	198	176609	1228352	192350
Isfahan	175	97409	219	329675	1169196	255798
Alborz	33	18490	42	20742	229476	74852
Ilam	81	45077	101	252886	559033	27679
Boshehr	61	34036	77	428577	179417	24779
Tehran	115	63812	144	79385	673637	343050
Charmhal &Bakhtiari	83	46254	104	261935	541229	51363
South khorasan	130	71972	162	607669	708068	29328
Razavi khorasan	412	229082	515	481506	3537424	222891
North khorasan	125	69358	156	147303	1100294	43870
Khozestan	315	175250	394	1155008	1797342	264180
Zanjan	90	49993	112	109280	716854	87682
Semnan	121	67207	151	220050	969348	57459
Sistan & balochestan	210	116898	263	1338833	744690	88659
Fars	384	213374	480	1864625	1920053	175923
Ghazvin	78	43518	98	45362	591306	139549
Ghom	30	16874	38	46659	189348	62439
Kordestan	102	56518	127	129730	811422	93607
Kerman	299	165979	373	1474333	1462592	142286
Kermanshah	119	66310	149	171577	979896	73600
Kohkeloye & Boyerahmad	103	57028	128	675010	360279	28801
Golestan	125	69703	157	147433	982365	139150
Gilan	80	44303	100	42231	412211	290584
Lorestan	185	102639	231	480777	1316333	102584
Mazandaran	136	75682	170	62692	988795	285426
Markazi	112	62238	140	81946	948013	108025
Hormozgan	74	41301	93	665394	76503	26904
Hamedan	114	63582	143	60892	1023725	85514
Yazd	66	36520	82	243962	375749	51617

This trend is plotted in Fig. 13 [71].

As depicted in the plots, wind speed varies largely both over a year and during a day. To handle this fluctuation, battery storage systems must be utilized as a long-term storage device. It is noteworthy that the basic load of the grid in the presented model is to be supplied through solar energy generation and as the solar energy generation pattern is congruent with the consumption pattern, the load on the storage is not much and can be tackled using the storage system recommended.

In the following part, an economic analysis for the 2nd strategy which adopts a constant increase rate is conducted. The reason for undertaking this economic analysis is that battery storage systems are one of the greatest technical and commercial challenges of the model [73]; hence, an economic model is considered to be essential to the integrity and practicality of the current study. The same procedure can be taken for the two other strategies.

2.9.3. Evaluating costs of energy systems

After choosing the operating energy storage system, the total cost of this new system needs to be estimated. To do this, applying the levelized cost of energy storage (LCOS) is required. There are many metrics defined under the name of LCOS, with different formulas in the literature [68]. In this case, LCOS, independence of charging cost has been used. The same attitude has been adopted by World Energy Resources report [67]. To obtain a reasonable estimation of utility Li-ion batteries, the future capital cost of these batteries are analyzed, and LCOS is predicted accordingly. Regarding Schmidt et al. [74], the cost of battery systems is predicted and shown in Fig. 14.

According to World Energy E-Storage report [75], the LCOS ($/kWh) is defined by Eq. (1).

$$LCOS = \frac{I_o + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}} \quad (1)$$

Where:

$\boldsymbol{I_o}$: Investment costs ($)
$\boldsymbol{A_t}$: Annual total costs ($)
$\boldsymbol{M_{el}}$: Produced electricity in each year (kWh)
$\boldsymbol{n}$: Technical lifetime (years)
$\boldsymbol{t}$: Year of the technical lifetime (1, …, n)
$\boldsymbol{i}$: Discount year - Weighted-Average Cost of Capital (WACC) in %

In Eq. (1), the effect of capital cost is much greater than annual costs (>1000 times) and the lifetime of Li-ion batteries is about 15 years [63], consequently, the summation of annual costs during the lifetime will be still much lower than the capital cost, as a result we can estimate the LCOS for Li-ion batteries by considering the change in capital costs up to 2040.

According to *Lazard report* [76], the current average LCOS of utility Li-ion battery system is about 331 $/MWh for grid uses (peak replacement, distribution, micro-grid).

As shown in Table 10, the capital cost of Li-ion systems is 1148 USD/kWh and this value at 2020, 2025, 2030, 2035, and 2040 will be 825, 600, 476, 428, and 390 USD/kWh respectively. So the change in capital costs to reach LCOS estimation can be analyzed:

Thus, by fitting a curve on the estimated LCOS, a reasonable estimation of yearly values until 2040 can be obtained. Results are presented in Fig. 15.

3. Results and discussion

Considering the obtained data, the two feasible technologies

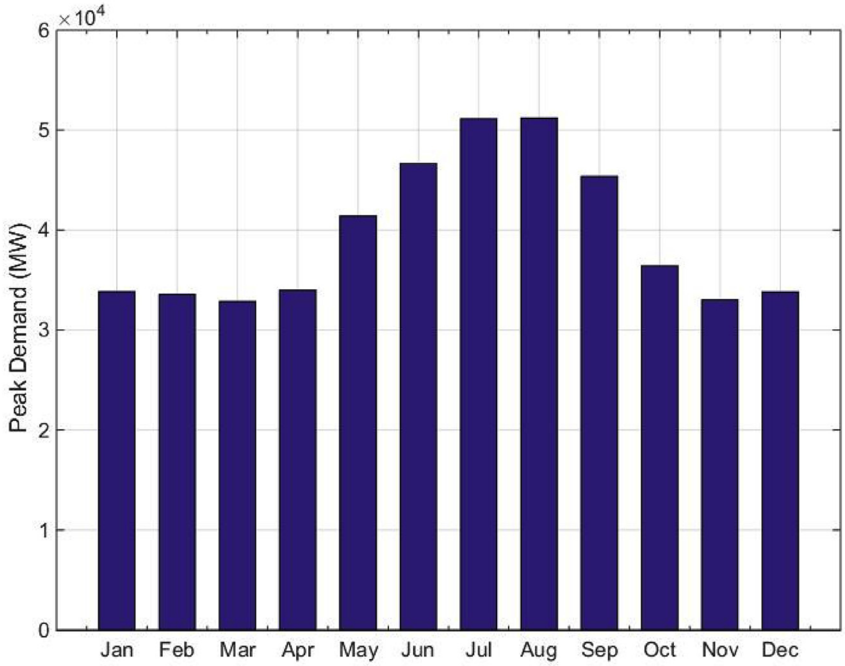

Fig. 9. Monthly consumption demand of the year 2017.

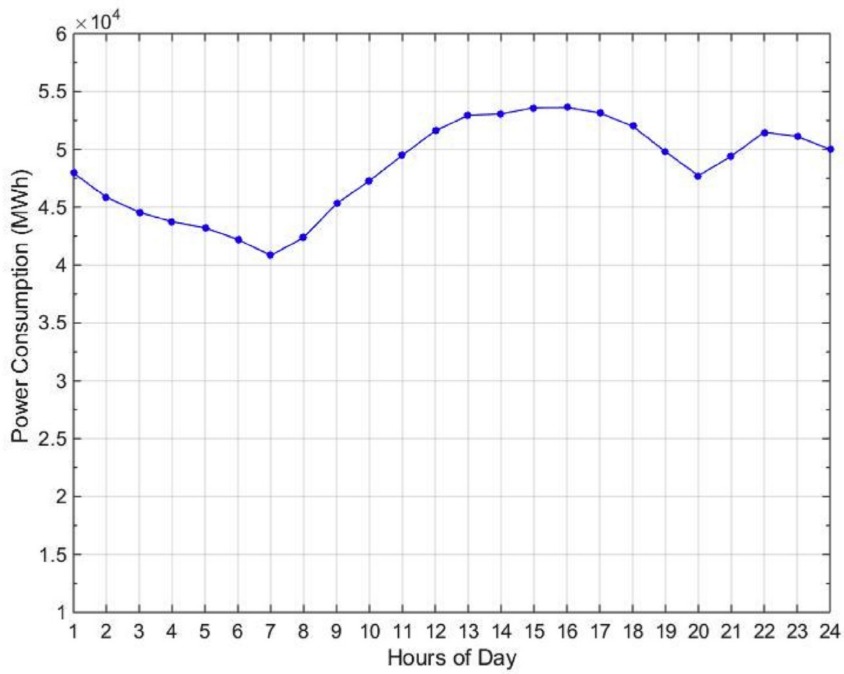

Fig. 10. Daily trend of energy consumption.

that can be used to develop a renewable grid are solar PVs and wind turbines. Three strategies are developed to reach the desired objective. This first strategy, which is based on phasing out power plants according to their lifetime, is aimed at a 100% switch to renewable resources in 35 years. In the second strategy, a constant amount of renewable energy is added to the grid to reach the 100% renewable scheme until 2050. This strategy requires a 3% increment rate in renewable sources annually. The third strategy is based on an existing plan presented by Iran's ministry of energy, as policymakers have planned to replace steam and gas cycle power plants with combined cycle power plants, reaching a 100% renewable scheme is not feasible but it is recommended to increase the share of renewable sources after that year till 2050 as much as possible.

3.1. First strategy

This strategy is based upon phasing out power plants. It is

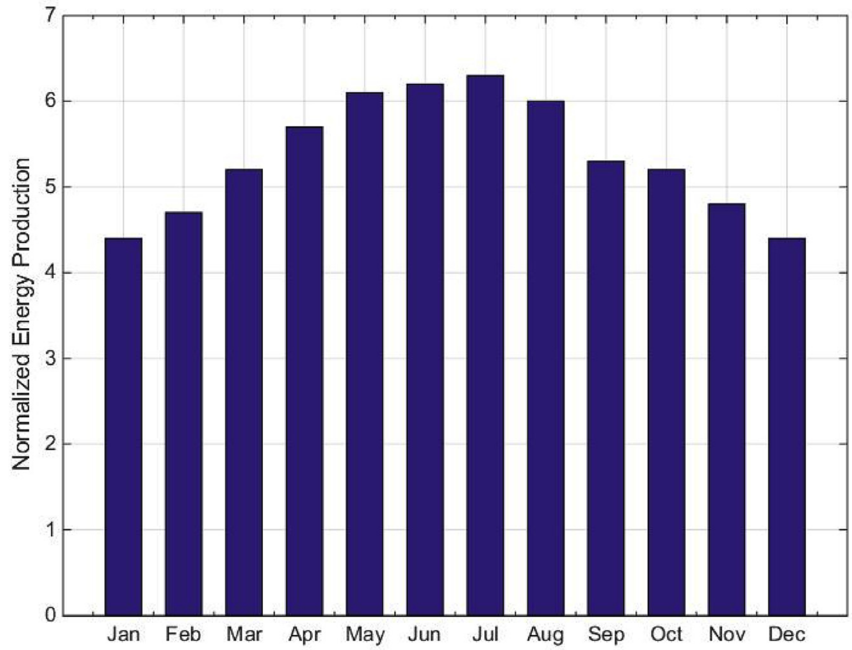

Fig. 11. Normalized power generation of a solar power plant.

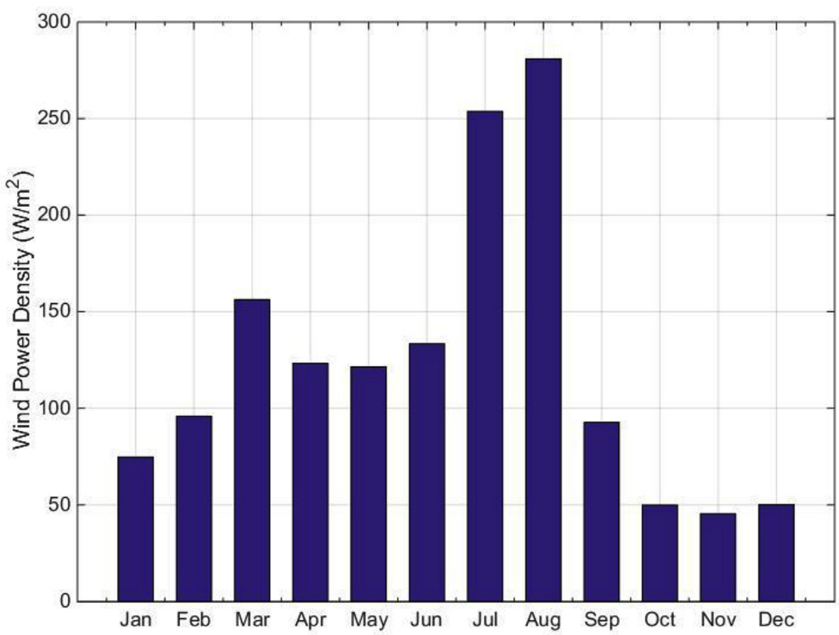

Fig. 12. Wind power density over one year.

assumed that no conventional power plant will be added to the Iranian power grid in the forthcoming years. Two factors of increasing consumption due to development power plans and population growth and phased-out power plants are considered in the model. It has been tried to produce electricity locally to reduce transmission costs and loss of efficiency due to transmission. The phase-out charts brought here contain only the regional sections and the reduction in power production; the detailed charts can be found in Appendix B.

3.1.1. Calculating the consumption for each 5-year time step

Phase out, and plant installation schemes are brought in tables of the following part. The increase in consumption in comparison with the previous period according to the prediction for future consumption for the first five years:

(Consumption in 2022) − (Consumption in 2017) = 273052.61−230282.72 = 42769.89 M-kWh.

This amount equals 4882.4 MW if divided by the number of hours in a year.

The total capacity of replaced renewable plants must equal 6288.56 MW.

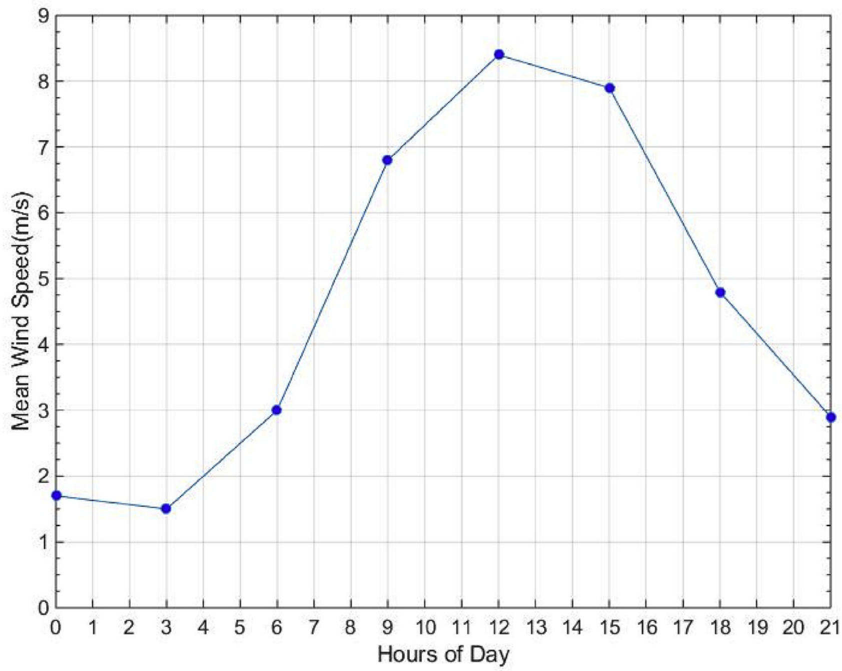

Fig. 13. Daily fluctuations of wind speed.

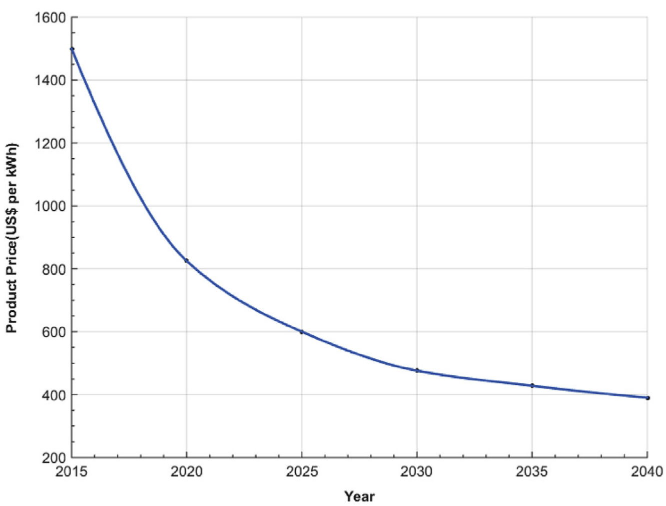

Fig. 14. Cost estimation of utility-scale Li-ion batteries.

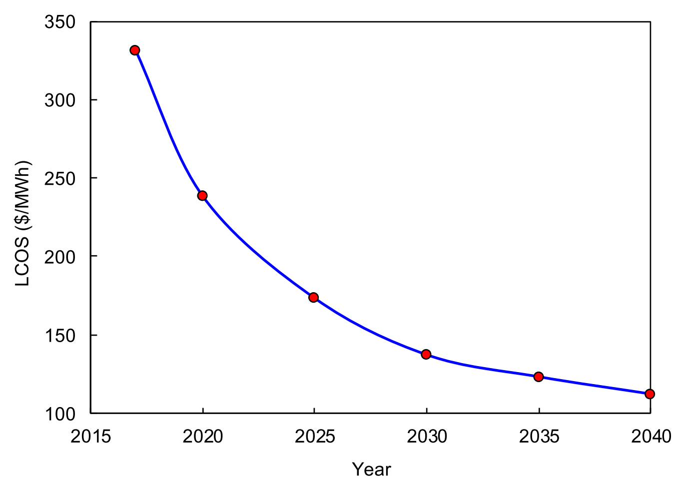

Fig. 15. Estimation of LCOS up to the year 2040.

Table 10
Estimation of LCOS using capital cost trend of Li-ion.

Year	Capital cost estimation (US$/kWh)	Reduced estimation (%)	Estimation for LCOS by capital cost trend ($/MWh)
2017	1148	–	331
2020	825	−28	238
2025	600	−27	173
2030	476	−21	137
2035	428	−10	123
2040	390	−9	112

For the other time steps, the same procedure is carried out, and the results are reported in Table 11.

The amount of replaced energy, doing the unit conversion, is 4882.4 MW in every five years and this amount added to the phased-out capacity yields the total required renewable energy installation, which is brought in the last column of Table 11.

3.1.2. Phase-out plan of existing power plants

The details of phase-out plan for the existing power plants in the 30-year period is presented in Table 12.

Table 11
The required increase in the amount of renewable capacity in each five years.

Time interval	First-year consumption (k-MWh)	Last-year consumption (k-MWh)	Increase in consumption (k-MWh)	Total necessary renewable installation (MW)
2017–2022	230282.72	273052.61	42769.89	6288.5
2022–2027	273052.61	315822.5	42769.89	7522
2027–2032	315822.5	358592.38	42769.88	9639.28
2032–2037	358592.38	401362.27	42769.88	8085
2037–2042	401362.27	444132.16	42769.88	17300
2042–2047	486902.05	444132.16	42769.88	14976.88
2047–2052	529671.94	486902.05	42769.88	13217.3

Table 12
Detailed phase-out plans for 5-year time steps.

Regional Sections	Nominal Power (MW)	Average Actual Power (MW)
FIRST 5 YEARS (2017–2022)		
Azerbaijan	96	73
Bakhtar	180	130
Fars	323	225.9
Gilan	932	683.8
Isfahan	97	80
Kerman	97	73
Khoozestan	128	82
Sistan & Baloochestan	60	41
Tehran	110	76.5
Yazd	33	21
TOTAL	**1958.6**	**1406.2**
SECOND 5 YEARS (2022–2027)		
Azerbaijan	347.5	288
Fars	64	50
Gilan	87.6	65
Isfahan	998.4	797
Kerman	328	256
Khorasan	495.6	454
Tehran	832.5	730.8
TOTAL	**3153.6**	**2640.8**
THIRD 5 YEARS (2027–2032)		
Azerbaijan	24	14
Fars	165	132
Hormozgan	75	45
Isfahan	390.2	273.3
Kerman	1280	1280
Khoozestan	290	255
Kish Water & Power Co.	835	830
Mazandaran	120	84
Sistan & Baloochestan	1779.6	1714.6
Yazd	183.8	129
TOTAL	**5142.6**	**4756.9**
FOURTH 5 YEARS (2032–2037)		
Azerbaijan	4.2	3
Bakhtar	954	715.8
Fars	2442	2236.6
Hormozgan	1004	768
Isfahan	2662	2357
Khoozestan	789	631
Khorasan	1815	1555.6
Mazandaran	954	763
Tehran	285	253
TOTAL	**3843**	**3202.6**
FIFTH 5 YEARS (2037–2042)		
Bakhtar	1444	1406.7
Fars	2296	1976
Gilan	324	280
Hormozgan	640	640
Isfahan	349	276
Kerman	648	550
Khoozestan	100	81.5
Mazandaran	1305.6	1183
Semnan	435	402
Sistan & Baloochestan	2170.8	1769
Tehran	2536	2393.1
West	1632	1460
TOTAL	**13880.4**	**12417.3**
SIXTH 5 YEARS (2042–2047)		
Azerbaijan	2811.8	2259.8

(*continued on next page*)

Table 12 (*continued*)

Regional Sections	Nominal Power (MW)	Average Actual Power (MW)
Fars	1628	743.4
Isfahan	1372	1111
Kerman	954	720
Khoozestan	1912	1451.2
Khorasan	3528	2853.1
Yazd	1208.8	956
TOTAL	**13414.6**	**10094.5**
SEVENTH 5 YEARS (2047–2052)		
Fars	968	795
Gilan	324	259
Isfahan	956	769
Kerman	1456	1149
Khoozestan	986	912.9
Khorasan	888.6	726
Mazandaran	150	120
Semnan	50	35
Tehran	2868	2234
West	332	269
Yazd	1308	1030
Zanjan	47.4	36
TOTAL	**10334**	**8334.9**

Table 13
Detailed installed plants in 5 years periods.

Type	Province	Amount (MW)
FIRST 5 YEARS (2017–2022)		
Wind	Eastern Azerbaijan	500
Wind	Hamedan	250
Wind	Fars	500
Wind	Gilan	800
Wind	Isfahan	200
Wind	Kerman	200
Wind	Sistan & Baluchestan	500
Wind	Yazd	500
Wind	Khorasan Razavi	1050
Solar	Qom	850
Solar	Tehran	950
Total		**6300**
Second 5 YEARS (2022–2027)		
Wind	Western Azerbaijan	400
Wind	Gilan	300
Wind	Kerman	500
Wind	Southern Khorasan	1500
Wind	Alborz	200
Solar	Isfahan	1000
Wind	Qazvin	1500
Wind	Ilam	1000
Wind	Khuzestan	600
Solar	Zanjan	1000
Solar	Bushehr	1000
Total		**7500**
Third 5 YEARS (2027–2032)		
Wind	Hormozgan	250
Wind	Kerman	2000
Wind	Bushehr	300
Wind	Sistan & Baluchestan	2000
Solar	Yazd	1000
Solar	Markazi	2000
Solar	Semnan	1000
Solar	Isfahan	1000
Wind	Qom	100
Total		**9650**
Fourth 5 YEARS (2032–2037)		
Wind	Markazi	500
Wind	Fars	450
Wind	Khorasan Razavi	2000
Wind	Northern Khorasan	500
Solar	Mazandaran	1000
Solar	Hamedan	1200
Solar	Fars	2500
Total		**8150**

Table 13 (*continued*)

Type	Province	Amount (MW)
Fifth 5 YEARS (2037–2042)		
Solar	Lorestan	2000
Wind	Semnan	2000
Wind	Sistan & Baluchestan	2000
Wind	Kermanshah	250
Wind	Kurdistan	350
Solar	Kermanshah	1700
Solar	Eastern Azerbaijan	1500
Solar	Ardebil	1000
Solar	Gilan	600
Solar	Kerman	2000
Solar	Southern Khorasan	2000
Solar	Sistan & Baluchistan	2000
Total		**17400**
Sixth 5 YEARS (2042–2047)		
Wind	Ardebil	100
Wind	Eastern Azerbaijan	650
Wind	Southern Khorasan	2000
Wind	Khorasan Razavi	1500
Wind	Sistan & Baluchestan	2000
Solar	Alborz	400
Solar	Khuzestan	2000
Solar	Kerman	2000
Solar	Isfahan	2000
Solar	Yazd	2000
Solar	Golestan	400
Total		**15050**
Seventh 5 YEARS (2047–2052)		
Solar	Sistan & Baluchestan	3000
Solar	Kerman	2000
Solar	Southern Khorasan	2000
Solar	Charmahal Bakhtiari	1200
Solar	Kohgiluye Buyerahmad	1200
Solar	Kurdistan	1500
Solar	Isfahan	1500
Solar	Hormozgan	1000
Solar	Khorasan Razavi	1000
Total		**13400**

Table 14
Detailed installed plants in 5 years periods.

Type	Province	Amount (MW)
FIRST 5 YEARS (2017–2022)		
Wind	Eastern Azerbaijan	500
Wind	Hamedan	250
Wind	Fars	500
Wind	Gilan	1100
Wind	Isfahan	200
Wind	Kerman	200
Wind	Sistan & Baluchestan	500
Wind	Yazd	500
Wind	Khorasan Razavi	1050
Solar	Qom	850
Solar	Tehran	950
Solar	Zanjan	1000
Solar	Bushehr	1000
Wind	Southern Khorasan	1500
Solar	Isfahan	1000
Total		**11100**
SECOND 5 YEARS (2022–2027)		
Type	**Province**	**Amount (MW)**
Wind	Western Azerbaijan	400
Wind	Sistan & Baluchestan	2000
Wind	Kerman	2500
Solar	Semnan	1000
Wind	Alborz	200
Solar	Isfahan	1000
Wind	Qazvin	1500
Wind	Ilam	1000
Wind	Khuzestan	600
Solar	Yazd	1000
Total		**11200**
THIRD 5 YEARS (2027–2032)		
Type	**Province**	**Amount (MW)**
Wind	Hormozgan	250
Wind	Khorasan Razavi	2000
Wind	Bushehr	300
Wind	Northern Khorasan	500
Solar	Fars	2500
Solar	Markazi	2000
Solar	Mazandaran	1000
Solar	Isfahan	1000
Wind	Qom	100
Solar	Eastern Azerbaijan	1500
Total		**11150**
FOURTH 5 YEARS (2032–2037)		
Type	**Province**	**Amount (MW)**
Wind	Markazi	500
Wind	Fars	450
Solar	Lorestan	2000
Wind	Semnan	2000
Wind	Sistan & Baluchestan	2000
Solar	Hamedan	1200
Solar	Kerman	2000
Solar	Ardebil	1000
Total		**11150**
FIFTH 5 YEARS (2037–2042)		
Type	**Province**	**Amount (MW)**
Wind	Southern Khorasan	2000
Wind	Sistan & Baluchestan	2000
Solar	Alborz	400
Wind	Kurdistan	350
Solar	Kermanshah	1700
Solar	Gilan	600
Solar	Southern Khorasan	2000
Solar	Sistan & Baluchistan	2000
Total		**11050**
SIXTH 5 YEARS (2042–2047)		
Type	**Province**	**Amount (MW)**
Wind	Ardebil	100
Wind	Eastern Azerbaijan	650
Wind	Kermanshah	250
Wind	Khorasan Razavi	1500
Solar	Khuzestan	2000
Solar	Kerman	2000
Solar	Isfahan	2000
Solar	Yazd	2000
Solar	Golestan	400
Total		**10900**
SEVENTH 5 YEARS (2047–2052)		
Type	**Province**	**Amount (MW)**
Solar	Sistan & Baluchestan	3000
Solar	Kerman	2000
Solar	Southern Khorasan	2000
Solar	Charmahal Bakhtiari	1200
Solar	Kohgiluye Buyerahmad	1200
Solar	Kurdistan	1500
Solar	Isfahan	500
Solar	Hormozgan	1000
Solar	Khorasan Razavi	1000
Total		**12900**

3.1.3. *Installation plan*

Table 13 summarizes the details of plants to be installed in the 30-year period.

3.2. *Second strategy*

If the lifetime of the plants is not considered, to have an equal increment rate annually, a 3% increase of the renewable energy share must be met. Based on the calculations in the first strategy, the total renewable energy required to be installed is 77450 MW. As presented in Table 14, every five years, about 11100 MW of renewable energy capacity must be exploited, and the existing power plants can be phased out following the increasing installed renewable capacity.

3.3. *Third strategy*

This strategy has been devised considering the plan of the power ministry of Iran, in the year 2040, 60% of power consumption will be supplied by combined cycle plants. According to the prediction of power consumption in the current work, this will be about 266479 M-kWh.

To develop a more practical strategy to be adopted by the state, it is considered that till the year 2040 no change of policy will occur and the starting point of the third strategy is then (see Table 15). Though unlike the previous two strategies, this one does not reach a fully renewable grid; it is more practical and has higher probability to be implemented by the government. Without phasing out these combined cycle power plants, till 2050 about 263193 M-kWh needs to be replaced by renewable resources. This amount is equal to 30045 MW. In two 5-year periods, this amount can be installed, in each of them, a potential of 15000 MW can be exploited.

3.4. *Storage scheme*

One of the basic challenges in all renewable energy major schemes is storage. As discussed in the previous section, the battery has been chosen for storage, and it has been economically modeled in the following part. Having the estimated LCOS, the ratio of storage output to electricity demand should be analyzed. From the available data in the study performed by Ghorbani et al. [40], this ratio is obtained and plotted in Fig. 16.

In the last step, the total cost is estimated using the information acquired in the preceding parts and brought in Table 16; the results are also illustrated in Fig. 17.

Another potential alternative to be exploited for storage as a secondary to the primary scheme is utilizing Iran existing dams for the pumped-hydro storing method. Having the shortage issue of

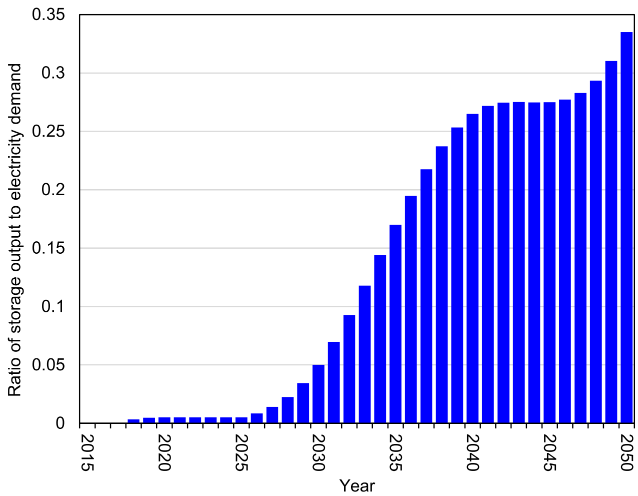

Fig. 16. The ratio of storage output to electricity.

Table 15
Detailed installed plants in 5 years periods.

Type	Province	Amount (MW)
FIRST 5 YEARS (2042–2047)		
Wind	Ardebil	100
Wind	Eastern Azerbaijan	650
Wind	Southern Khorasan	2000
Wind	Khorasan Razavi	1500
Wind	Sistan & Baluchestan	2000
Solar	Alborz	400
Solar	Khuzestan	2000
Solar	Kerman	2000
Solar	Isfahan	2000
Solar	Yazd	2000
Solar	Golestan	400
Total		**15050**
SECOND 5 YEARS (2047–2052)		
Type	**Province**	**Amount (MW)**
Solar	Sistan & Baluchestan	3000
Solar	Kerman	2000
Solar	Southern Khorasan	2000
Solar	Charmahal Bakhtiari	1200
Solar	Kohgiluye Buyerahmad	1200
Solar	Kurdistan	1500
Solar	Isfahan	1500
Solar	Hormozgan	1000
Solar	Khorasan Razavi	1000
Solar	Zanjan	1000
Solar	Bushehr	1000
Total		**15400**

Iran's water resources, this can only be possible if the long-term policies for supplying water does not interfere with it.

3.5. Waste to energy

Energy from solid waste is primarily not a very economical way to produce electricity but the environmental advantages it can provide, underlie the logic on why to establish these plants.

In Tehran, which has the most MSW produced in a year, a plant, which can burn around 190 tons of waste hourly and produce about 493.71 GWh electricity yearly can be established. Two plants, one in western and the other in the eastern part of Tehran are suggested, with each of them possessing two parallel furnaces capable of burning up to 50 ton of MSW hourly.

In Mashhad, a plant with two parallel furnaces with a capacity of 25 tons of MSW/hour is suggested. This plant will be able to produce up to 122 GWh of electricity annually.

In cities like Shiraz and Ahwaz, plants with a capacity of 25 tons hourly which produce up to 90 GWh of electricity yearly can be established. In other cities which are small, plants with a capacity of 15 tons of MSW hourly and a capacity of around 30 GWh hourly can

Table 16
Financial results of storage systems.

Year	Estimation of LCOS (US$/ MWh)	Electricity demand estimation (TWh)	The ratio of storage output to electricity demand (%)	Electricity demand × LCOS × storage ratio (Million US$)
2017	331	286	0.00	0
2018	293	293	0.33	281
2019	262	300	0.48	375
2020	238	307	0.50	365
2021	219	315	0.50	344
2022	203	322	0.50	328
2023	191	330	0.50	316
2024	182	338	0.50	307
2025	173	346	0.50	299
2026	165	353	0.83	486
2027	157	361	1.40	793
2028	149	369	2.25	1241
2029	143	378	3.43	1850
2030	137	386	5.00	2650
2031	133	395	6.98	3665
2032	130	405	9.28	4865
2033	127	415	11.79	6208
2034	125	424	14.40	7644
2035	123	435	17.00	9115
2036	122	445	19.48	10553
2037	120	455	21.74	11891
2038	118	465	23.72	13053
2039	116	476	25.34	13956
2040	112	487	26.50	14509
2041	112	499	27.17	15232
2042	112	511	27.47	15769
2043	112	523	27.52	16190
2044	112	536	27.48	16571
2045	112	550	27.50	16998
2046	112	564	27.72	17566
2047	112	578	28.28	18378
2048	112	593	29.33	19547
2049	112	608	31.03	21199
2050	112	623	33.50	23468

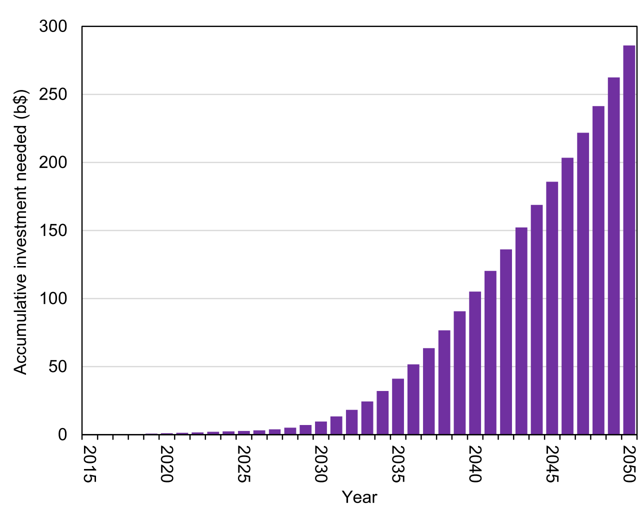

Fig. 17. Financial results of storage systems.

be used.

Heat for the local district can also be produced besides electricity to reach better efficiencies. The lifetime of a waste-to-energy plant is around 20 years. The data of waste modeling can be found in the appendix.

4. Conclusion

Iran, a country in one of the arid regions of the world, is one of the major suppliers of fossil fuel around the globe. This country is internally highly reliant on its non-renewable energy resources. As a result, this country is dealing with severe environmental pollution of its air and water resources and also is vulnerable in case its energy resources come to an end; this will inevitably happen in the future. This country also has excellent potential for wind and solar renewable energy resources, but unfortunately, these resources are not being utilized in the country, and they only play a minor secondary role in the power generation sector.

In this article, the renewable energy potentials of the country were investigated, and several strategies have been developed to switch the state to 100% renewable supplies of energy or at least increase the amount of these energies in the current existing policies. Three strategies were developed to increase the share of the renewable generation. The storage problem was also addressed. One further possibility exists that is to address the garbage-monitoring problem, a crisis in some areas including the beautiful northern landscapes of the country.

If the current article is used by the significant policy-makers of the country, there is a hope to solve some of the most pestering daily challenges of the Iranian people. This work also lays the foundation for further studies in each of the investigated fields to provide more and more detailed and accurate designs, which can be implemented more simply.

Declarations of interest

None.

Appendix A

Table A.1 shows the consumption of electricity in different sectors from 1997 to 2052 in Iran.

Table A.1
Consumption in M-kWh

Consumption							
Year	Household	Public	Others	Industrial	Agricultural	Brightness of Passageways	TOTAL
1997	23993	6595	7622	22925	5731	2805	69671
1998	26523	6727	8160	23661	6009	2278	73358
1999	28686	7077	8484	24140	6782	2477	77646
2000	29754	10622	5567	26504	8019	4190	84656
2001	31266	11271	5991	28937	9147	3754	90366
2002	32891	11951	6394	30739	11079	4117	97171
2003	34946	12630	6925	33469	12435	4671	105076
2004	37967	13714	7461	36951	13859	4672	114625
2005	40564	15021	7863	40343	15489	5188	124466
2006	44108	16350	8542	43123	16469	4305	132898
2007	48085	18329	9320	46590	17666	4608	144598
2008	50777	19648	9953	49772	17670	4510	152330
2009	52896	20428	10742	52110	21179	4091	161446
2010	55630	21827	11015	54887	21405	3674	168438
2011	60908	21308	12727	61483	24189	3568	184182
2012	56774	16751	12664	63944	30020	3752	183904
2013	61351	17810	12599	67107	31647	3635	194148
2014	64379	17833	13378	70733	33126	3765	203215
2015	71163	19767	15404	74456	35188	3837	219814
2016	76103	22196	16680	72227	36089	4017	227311
2017	73927.02	23533.67	14947.36	77359.54	36264.33	4251.44	230282.72
2018	76545.00	24309.00	15430.49	80326.63	37940.94	4285.32	238836.70
2019	79162.98	25084.33	15913.62	83293.72	39617.55	4319.19	247390.67
2020	81780.96	25859.66	16396.75	86260.82	41294.16	4353.07	255944.65
2021	84398.95	26634.99	16879.88	89227.91	42970.77	4386.95	264498.63
2022	87016.93	27410.31	17363.00	92195.01	44647.38	4420.83	273052.61
2023	89634.91	28185.64	17846.13	95162.10	46323.99	4454.71	281606.58
2024	92252.89	28960.97	18329.26	98129.19	48000.60	4488.58	290160.56
2025	94870.87	29736.30	18812.39	101096.29	49677.21	4522.46	298714.54
2026	97488.86	30511.63	19295.52	104063.38	51353.82	4556.34	307268.52
2027	100106.84	31286.95	19778.64	107030.48	53030.43	4590.22	315822.50
2028	102724.82	32062.28	20261.77	109997.57	54707.04	4624.09	324376.47
2029	105342.80	32837.61	20744.90	112964.66	56383.65	4657.97	332930.45
2030	107960.78	33612.94	21228.03	115931.76	58060.26	4691.85	341484.43
2031	110578.77	34388.27	21711.16	118898.85	59736.87	4725.73	350038.41
2032	113196.75	35163.59	22194.28	121865.95	61413.48	4759.61	358592.38
2033	115814.73	35938.92	22677.41	124833.04	63090.09	4793.48	367146.36
2034	118432.71	36714.25	23160.54	127800.14	64766.70	4827.36	375700.34
2035	121050.69	37489.58	23643.67	130767.23	66443.31	4861.24	384254.32
2036	123668.68	38264.90	24126.80	133734.32	68119.92	4895.12	392808.30
2037	126286.66	39040.23	24609.93	136701.42	69796.53	4929.00	401362.27
2038	128904.64	39815.56	25093.05	139668.51	71473.14	4962.87	409916.25
2039	131522.62	40590.89	25576.18	142635.61	73149.75	4996.75	418470.23

(*continued on next page*)

Table A.1 (*continued*)

Consumption							
Year	Household	Public	Others	Industrial	Agricultural	Brightness of Passageways	TOTAL
2040	134140.60	41366.22	26059.31	145602.70	74826.36	5030.63	427024.21
2041	136758.59	42141.54	26542.44	148569.79	76502.97	5064.51	435578.19
2042	139476.57	42916.87	27025.57	151536.89	78179.58	5098.38	444132.16
2043	141994.55	43692.20	27508.69	154503.98	79856.19	5132.26	452686.14
2044	144612.53	44467.53	27991.82	157471.08	81532.80	5166.14	461240.12
2045	147230.51	45242.86	28474.95	160438.17	83209.41	5200.02	469794.10
2046	149848.50	46018.18	28958.08	163405.27	84886.02	5233.90	478348.07
2047	152466.48	46793.51	29441.21	166372.36	86562.63	5267.77	486902.05
2048	155084.46	47568.84	29924.33	169339.45	88239.24	5301.65	495456.03
2049	157702.44	48344.17	30407.46	172306.55	89915.85	5335.53	504010.01
2050	160320.42	49119.50	30890.59	175273.64	91592.46	5369.41	512563.99
2051	162938.41	49894.82	31373.72	178240.74	93269.07	5403.28	521117.96
2052	165556.39	50670.15	31856.85	181207.83	94945.68	5437.16	529671.94

Appendix B

Power plants detailed phase-out scheme for the first developed strategy is presented in Table B.1.

Table B.1
Detailed phase-out charts

Name	Type	Start of Operation	Ownership	Nominal Power (MW)	Average Actual Power (MW)	Regional Sections	Consumed Fuel	Life Time (Year)	Phase Out Year
FIRST 5 YEARS (2017–1400)									
Zarjan Gas Plant	Gas	1976	Private Sector	128	82	Khoozestan	Gas	12	1988
Razi Petrochemical Gas Plant	Gas	1976	Big Industries	70.0	60.0	Bakhtar	Gas/Gasoline	12	1988
Zob Ahan Gas Plant	Gas	1976	Big Industries	26.0	13.0	Isfahan	Gas	12	1988
Dorood Gas Plant	Gas	1978	Governmental Sector	60	33.3	Bakhtar	Gas/Gasoline	12	1990
Shahid Beheshti Gas Plant	Gas	1978	Governmental Sector	120	96.66	Guilan	Gas/Gasoline	12	1990
Mes sarcheshmeh Gas Plant	Gas	1978	Big Industries	130.0	80.0	Kerman	Gas	12	1990
Shahid Firouzi Steam Plant	Steam	1960	Governmental Sector	50	40	Tehran	Gas/Gasoline	30	1990
Kenarak Gas Plant	Gas	1979	Governmental Sector	142.5	105.9	Sistan &; Baloochestan	Gasoline	12	1991
Rey Gas Plant	Gas	1979	Governmental Sector	931.7	683.8	Tehran	Gas/Gasoline	12	1991
Yazd Gas Plant	Gas	1979	Governmental Sector	97	80	Yazd	Gas	12	1991
Yazd Shahid Zanbagh	Gas	1980	Private Sector	97	73	Yazd	Gas/Gasoline	12	1992
Oroumieh Gas Plant	Gas	1981	Governmental Sector	60	41	Azerbaijan	Gas/Gasoline	12	1994
Shiraz Gas Plant	Gas	1981	Governmental Sector	60.8	40.5	Fars	Gas	12	1994
Boushehr Gas Plant	Gas	1981	Governmental Sector	50	36	Fars	Gas	12	1994
Shiraz Petrochemical Steam Plant	Steam	1964	Big Industries	12.6	9.0	Fars	Gas/Gasoline	30	1994
Tractor Sazi Gas Plant	Gas	1984	Big Industries	20.0	12.0	Azerbaijan	Gas	12	1996
SECOND 5 YEARS (1400–1405)									
Mashhad Gas Plant	Gas	1985	Private Sector	195.6	167	Khorasan	Gas/Gasoline	12	1997
Soufian Gas Plant	Gas	1985	Governmental Sector	100	72	Azerbaijan	Gas/Gasoline	12	1997
Be`sat Steam Plant	Steam	1966	Governmental Sector	247.5	216	Tehran	Gas/Gasoline	30	1998
Tabriz Gas Plant	Gas	1990	Private Sector	64	50	Azerbaijan	Gas	12	2002
Hesa Gas Plant	Gas	1990	Governmental Sector	87.6	65	Isafahan	Gas/Gasoline	12	2002
Montazer Ghaem Combined Cycle	Combined Cycle	1972	Private Sector	998.4	797	Tehran	Gas/Gasoline	30	2002
Bandar Imam Petrochemical Gas Plant	Gas	1991	Big Industries	328.0	256.0	Fars	Gas/Gasoline	12	2003
Shahid Beheshti Steam Plant	Steam	1974	Governmental Sector	240	240	Guilan	Gas/Gasoline	30	2004
Zarand Steam Plant	Steam	1974	Governmental Sector	60	47	Kerman	Mazut	30	2004
Ghaen Gas Plant	Gas	1992		75	49.8	Khorasan	Gas/Gasoline	12	2004

Table B.1 (*continued*)

Name	Type	Start of Operation	Ownership	Nominal Power (MW)	Average Actual Power (MW)	Regional Sections	Consumed Fuel	Life Time (Year)	Phase Out Year
			Governmental Sector						
Montazer Ghaem 2 Combined Cycle	Steam/ Combined Cycle	1974	Private Sector	625	548	Tehran	Gas/Gasoline	30	2004
Mashhad Steam Plant	Steam	1975	Private Sector	132.5	133	Khorasan	Gas/Gasoline	30	2005
THIRD 5 YEARS (1405–1410)									
Zargan Steam Plant	Steam	1976	Private Sector	290	255	Khoozestan	Gas/Gasoline	30	2006
Mes Sarcheshmeh Steam Plant	Steam	1978	Big Industries	24.0	14.0	Kerman	Gas/Gasoline	30	2008
Zob Ahan Steam Plant	Steam	1979	Big Industries	165.0	132.0	Isafahan	Gas/Gasoline	30	2009
Tabriz Petrochemical Gas Plant	Gas	1998	Big Industries	75.0	45.0	Azerbaijan	Gas/Gasoline	12	2010
Kangan Gas Plant	Gas	1998	Governmental Sector	164	116.5	Fars	Gas	12	2010
Zahedan Gas Plant	Gas	1998	Governmental Sector	226.2	156.78	Sistan &; Baloochestan	Gasoline	12	2010
Bandar Abbas Steam Plant	Steam	1981	Governmental Sector	1280	1280	Hormozgan	Gas/ Gasoline/ Mazut	30	2011
Isfahan Steam Plant	Steam	1981	Governmental Sector	835	830	Isafahan	Gas	30	2011
Yazd Gas Plant	Gas	1999	Governmental Sector	120	84	Yazd	Gas	12	2011
Shahid Salimi (Neka) Steam Plant	Steam	1981	Governmental Sector	1779.6	1714.6	Mazandaran	Gas/Mazut	30	2012
Kish Gas Plant	Gas	2002	Governmental Sector	183.8	129	Kish Water &; Power Co.	Gas/Gasoline	12	2014
FOURTH 5 YEARS (1410–1415)									
Bandar Abbas Gas Plant	Gas	2003	Governmental Sector	50	33	Hormozgan	Gas	12	2015
Farg Darab Gas Plant	Gas	2003	Governmental Sector	4.2	3	Fars	Gas	12	2015
Shahid Mohammad Montazeri Gas Plant	Gas	2004	Private Sector	954	715.8	Isafahan	Gas/Gasoline	12	2016
Toos Steam Plant	Steam	1986	Private Sector	600	600	Khorasan	Gas/ Gasoline/ Mazut	30	1394
Khalij Fars Gas Plant	Gas	2005	Governmental Sector	990	870.6	Hormozgan	Gas/Gasoline	12	2017
Foulad Mobarakeh Gas Plant	Gas	2005	Big Industries	108.0	100.0	Isafahan	Gas	12	2017
Fajr Petrochemical Gas Plant	Gas	2006	Big Industries	585.0	546.7	Fars	Gas/Gasoline	12	2018
Southern Isfahan (Chehelsotoon) Gas Plant	Gas	2007	Private Sector	159	119.3	Isafahan	Gas/Gasoline	12	2019
Parand Gas Plant	Gas	2007	Private Sector	954	735	Tehran	Gas/Gasoline	12	2019
Tabriz Steam Plant	Steam	1990	Private Sector	736	650	Azerbaijan	Gas/ Gasoline/ Mazut	30	2020
Asalouyeh Gas Plant	Gas	2008	Private Sector	954	826	Fars	Gas/Gasoline	12	2020
Ramin Steam Plant	Steam	1990	Governmental Sector	1903	1823	Khoozestan	Gas	30	2020
Golestan Gas Plant	Gas	2008	Private Sector	972	881	Mazandaran	Gas/Gasoline	12	2020
Rood Shoor Gas Plant	Gas	2008	Private Sector	789	631	Tehran	Gas/Gasoline	12	2020
Pars Jonoubi Gas Plant	Gas	2009	Big Industries	954.0	855.6	Fars	Gas/Gasoline	12	2021
Mobin Gas Plant	Gas	2009	Big Industries	861.0	700.0	Fars	Gas/Gasoline	12	2021
Ferdowsi Gas Plant	Gas	2009	Private Sector	954	763	Khorasan	Gas/Gasoline	12	2021
Eilam Gas Plant	Gas	2010	Big Industries	75.0	63.0	Bakhtar	Gas/Gasoline	12	2022
Foolad Mobarakeh Steam Plant	Steam	1992	Big Industries	210.0	190.0	Isafahan	Gas/Gasoline	30	2022
FIFTH 5 YEARS (1415–1420)									
Chabahar Gas Plant	Gas	2011	Private Sector	414	338	Sistan &; Baloochestan	Gasoline	12	2023
Eilam Gas Plant	Gas	2011	Big Industries	120.0	100.0	Bakhtar	Gas/Gasoline	12	2023
Fars LNG	Gas	2011	Big Industries	324.0	306.7	Fars	Gas/Gasoline	12	2023
Shahid Rajaee Steam Plant	Steam	1993	Governmental Sector	1000	1000	Tehran	Gas/ Gasoline/ Mazut	30	2023
Hafez Gas Plant	Gas	2012	Private Sector	972	716	Fars	Gas/Gasoline	12	2024
Bastami (Shahrood) Gas Plant	Gas	2012	Governmental Sector	324	260	Semnan	Gas/Gasoline	12	2024
Shahid Mofatteh Steam Plant	Steam	1373	Governmental Sector	1000	1000	Bakhtar	Gas/Mazut	30	2025
Damavand Petrochemical Gas Plant	Gas	2013	Big Industries	324.0	280.0	Tehran	Gas/Gasoline	12	2025
Bistoon Steam Plant	Steam	1995	Governmental Sector	640	640	West	Gas/Mazut	30	2025

(*continued on next page*)

Table B.1 (*continued*)

Name	Type	Start of Operation	Ownership	Nominal Power (MW)	Average Actual Power (MW)	Regional Sections	Consumed Fuel	Life Time (Year)	Phase Out Year
Bampour Gas Plant	Gas	2014	Governmental Sector	324	258	Sistan &; Baloochestan	Gas/Gasoline	12	2026
Khark Gas Plant	Gas	2015	Governmental Sector	25	18	Fars	Gasoline	12	2027
Aisin Gas Plant	Gas	2015	Governmental Sector	648	550	Hormozgan	Gas/Gasoline	12	2027
Islam Abad Gharb (Shian) Gas Plant	Gas	2015	Governmental Sector	100	81.5	West	Gas/Gasoline	12	2027
Gilan Combined Cycle	Combined Cycle	1998	Private Sector	1305.6	1183	Guilan	Gas/Gasoline	30	2028
Shahid Salimi Combined Cycle	Combined Cycle	1998	Governmental Sector	435	402	Mazandaran	Gas	30	2028
Shahid Rajaee Combined Cycle	Combined Cycle	1998	Governmental Sector	1042.8	836	Tehran	Gas/Gasoline	30	2028
Qom Combined Cycle	Combined Cycle	1999	Private Sector	714	595	Isafahan	Gas/Gasoline	30	2029
Mahshahr Gas Plant	Gas	2017	Governmental Sector	664	555.1	Khoozestan	Gas/Gasoline	12	2029
Shahid Mohammad Montazeri Steam Plant	Steam	2000	Private Sector	1616	1592	Isafahan	Gas	30	2030
Iranshahr Steam Plant	Steam	2000	Governmental Sector	256	246	Sistan &; Baloochestan	Gas/ Gasoline/ Mazut	30	2030
Shazand Steam Plant	Steam	2001	Governmental Sector	1300	1215	Bakhtar	Gas/ Gasoline/ Mazut	30	2031
Goharan Gas Plant	Gas	2019	Private Sector	332	245	Kerman	Gas	12	2031
SIXTH 5 YEARS (1420–1425)									
khooy Combined Cycle	Combined Cycle	2003	Private Sector	349.3	288	Azerbaijan	Gas/Gasoline	30	2033
Fars Combined Cycle	Combined Cycle	2003	Private Sector	1035.3	794	Fars	Gas/Gasoline	30	2033
Shariati Combined Cycle	Combined Cycle	2004	Private Sector	346.8	291	Khorasan	Gas/Gasoline	30	2034
Nishabour Combined Cycle	Combined Cycle	2004	Private Sector	1040.4	856.8	Khorasan	Gas/Gasoline	30	2034
Chadormalo Combined Cycle	Combined Cycle	2004	Big Industries	40.0	30.0	Yazd	Gas/Gasoline	30	2034
Sahand Combined Cycle	Steam	2005	Governmental Sector	650	650	Azerbaijan	Gas/Mazut	30	2035
Shirvan Combined Cycle	Combined Cycle	2006	Governmental Sector	954	723.36	Khorasan	Gas/Gasoline	30	2036
Khorasn Petrochemical Steam Plant	Steam	2007	Big Industries	24.0	20.0	Khorasan	Gas/Gasoline	30	2037
Kazeroon Combined Cycle	Combined Cycle	2008	Private Sector	1372	1111	Fars	Gas/Gasoline	30	2038
Jahrom Combined Cycle	Combined Cycle	2008	Private Sector	954	720	Fars	Gas/Gasoline	30	2038
Kerman Combined Cycle	Combined Cycle	2008	Governmental Sector	1912	1451.2	Kerman	Gas/Gasoline	30	2038
Sabalan Combined Cycle	Combined Cycle	2009	Private Sector	960	834	Azerbaijan	Gas/Gasoline	30	2039
Khoramshahr Combined Cycle	Combined Cycle	2009	Private Sector	972	817.8	Khoozestan	Gas/Gasoline	30	2039
Shahid Kaveh Combined Cycle	Combined Cycle	2009	Governmental Sector	636	477.32	Khorasan	Gas/Gasoline	30	2039
Oroumieh 1 Combined Cycle	Combined Cycle	2010	Private Sector	960	772	Azerbaijan	Gas/Gasoline	30	2040
Oroumieh 2 Combined Cycle	Combined Cycle	2010	Private Sector	960	786	Azerbaijan	Gas/Gasoline	30	2040
Kashan Combined Cycle	Combined Cycle	2010	Private Sector	324	255	Isafahan	Gas/Gasoline	30	2040
Yazd Combined Cycle	Combined Cycle	2010	Governmental Sector	884.8	701	Yazd	Gas/Gasoline	30	2040
SEVENTH 5 YEARS (1425–1430)									
Damavand Combined Cycle	Combined Cycle	2012	Private Sector	2868	2234	Tehran	Gas/Gasoline	30	2042
Genaveh Combined Cycle	Combined Cycle	2013	Private Sector	484	415	Fars	Gas/Gasoline	30	2043
Zavvareh Combined Cycle	Combined Cycle	2013	Private Sector	484	380	Isafahan	Gas/Gasoline	30	2043
Qods (Semnan) Combined Cycle	Combined Cycle	2013	Private Sector	324	259	Semnan	Gas/Gasoline	30	2043
Sanandaj Combined Cycle		2013	Private Sector	956	769	West	Gas/Gasoline	30	2043

Table B.1 (*continued*)

Name	Type	Start of Operation	Ownership	Nominal Power (MW)	Average Actual Power (MW)	Regional Sections	Consumed Fuel	Life Time (Year)	Phase Out Year
	Combined Cycle								
Shirkooh Combined Cycle	Combined Cycle	2013	Private Sector	484	395	Yazd	Gas/Gasoline	30	2043
Sadooq Yazd Combined Cycle	Combined Cycle	2013	Private Sector	324	254	Yazd	Gas/Gasoline	30	2043
Soltanieh Combined Cycle	Combined Cycle	2013	Private Sector	648	500	Zanjan	Gas/Gasoline	30	2043
Ouz Combined Cycle	Combined Cycle	2014	Governmental Sector	18	12.9	Fars	Gas/Gasoline	30	2044
Pareh sar Combined Cycle	Combined Cycle	2014	Private Sector	968	900	Guilan	Gas/Gasoline	30	2044
Kahnooj Combined Cycle	Combined Cycle	2014	Private Sector	75	52	Kerman	Gas/Gasoline	30	2044
Abadan Combined Cycle	Combined Cycle	2014	Private Sector	813.6	674	Khoozestan	Gas/Gasoline	30	2044
Shariati Combined Cycle	Combined Cycle	2014	Private Sector	150	120	Khorasan	Gas/Gasoline	30	2044
Shams Sarakhs Combined Cycle	Combined Cycle	2014	Private Sector	50	35	Khorasan	Gasoline	30	2044
Shohadaye Pirouz (Behbahan) Combined Cycle	Combined Cycle	2015	Private Sector	332	269	Khoozestan	Gas/Gasoline	30	2045
Shoubad (Kahnooj) Combined Cycle	Combined Cycle	2017	Private Sector	484	391	Kerman	Gas/Gasoline	30	2047
Samangan Combined Cycle	Combined Cycle	2017	Private Sector	332	245	Kerman	Gas	30	2047
Chadormalo (Sarv) Combined Cycle	Combined Cycle	2017	Private Sector	492	394	Yazd	Gas/Gasoline	30	2047
Noshahr Combined Cycle	Combined Cycle	2019	Private Sector	47.4	36	Mazandaran	Gas/Gasoline	30	2049

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