




# Potentiometry of wind, solar and geothermal energy resources and their future perspectives in Iran

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Received: 30 April 2022 / Accepted: 11 February 2024  
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## Abstract

As a leading exporter and consumer of fossil fuels, it is also attempting to use renewable energy as part of its energy mix toward energy security and sustainability in Iran. Due to the disproportionate rise of GHGs in recent decades, global warming and climate change have necessitated the adoption of suitable measures. Concerning this, the Paris Agreement, which seeks to diminish global GHG emissions, was ratified in 2015 by the UNFCCC to impede the temperature rise. As a signatory to the contract, Iran has pledged to lower its GHG emissions by 2030. The power sector stands out as the primary source of these gas emissions. This study provides a meta-analysis of renewable landscape energies in Iran. In order to do this effectively, the amount of wind, solar, geothermal energy in Iran are identified and estimated. In this paper, the types of renewable energy used in electricity generation in Iran have been studied. Iran also has a much greater potential for utilizing renewable energy. By 2022, Iran has a potential of 43,000 MW use of renewable energies. However, the capacity of renewable power stations constructed in Iran is 1300 MW. Different regions of Iran have high wind, solar and geothermal energy potential, which has not been used enough to meet electricity needs.

**Keywords** Renewable energy · Energy policies · Power plants · Iran

## 1 Introduction

The role of energy in supporting human life is self-evident. (Mousavi et al., 2022). Energy consumption has increased due to population growth and industrial development (Jahangiri et al., 2019). The most important challenge in the use of fossil fuels is their

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GHG emissions during and after their use in addition to their limited and non-renewable resources (Li et al., 2023). Moreover, CO<sub>2</sub> which is the main cause of climate change and global warming, constitutes more than 60% of the world's GHG and is one of the most important gases released from fossil fuels (Molazadeh et al., 2019). Also, with the increase of industrial, urban, and agricultural waste in the world, the use of bioenergy and biomass industries to achieve clean and renewable energy has been more and more under attention (Gao et al., 2023).

Climate change, an internationally significant occurrence with potential ramifications on global climate, is often linked to the potential consequences of increasing levels of GHGs (Mora et al., 2018). It is a prevalent opinion that the burning of fossil fuels is the predominant factor in climate change due to the release of GHGs (Dilmore & Zhang, 2018). This phenomenon is defined by the United Nations as a long-term change in temperature and weather patterns (Wei et al., 2023). It also has some severe effects on the planet, and its inhabitants may face enormous challenges (Zahedi, 2023). In addition to higher temperatures, more intense storms, more droughts, rising sea levels, floods, and wildfires, climate change can also lead to the extinction of species, the rise of poverty, and the displacement of people (Upadhyay, 2020). A variety of health issues may also be adversely affected by climatic shifts, such as asthma, bronchitis, and chest pain because of air pollution, allergies due to the earlier commencement of the grass pollen season, malaria epidemic, hantavirus infection, leishmaniasis, vector-borne diseases, water-related disease, and malnutrition (Shaghghi et al., 2024a). These threats are particularly serious in some vulnerable nations; for instance, it is anticipated that by 2030, climate change will cause a 60% to 80% increase in mortality rates in Africa (Jafino, et al., 2030). A number of sources have purported that global warming, a major contributor to climate change, has grown in recent years (Peng et al., 2020). National Aeronautics and Space Administration (NASA) data from 2019 show that the average global temperature on Earth has risen by 0.98 °C in comparison to average temperatures between 1951 and 1980 (Young & Young, 2021). The harmful effects of climate change as well as the rate of warming have prompted societies to take the appropriate measures (Ge et al., 2020). In this regard, the Paris Agreement, which intends to reduce GHG emissions, was approved at the United Nations Framework Convention on Climate Change (UNFCCC) COP21 in 2015 and came into effect in November 2016 (Kassim et al., 2023). The Paris Agreement is a legally binding international treaty on climate change (Bai et al., 2020). It was adopted by 196 Parties and its overarching goal is to hold “the increase in the global average temperature to well below 2 °C above pre-industrial levels” and pursue efforts “to limit the temperature increase to 1.5 °C above pre-industrial levels.” However, in recent years, world leaders have stressed the need to limit global warming to 1.5 °C by the end of this century (Parikh & Bhavsar, 2023). Over the past few years, the Paris Agreement has received significant political and academic attention in climate diplomacy and this agreement's mitigation efforts revolve around national-scale contributions (Morgan et al., 2019). Regarding this, nations have provided their Intended National Determined Contributions (INDCs) (Nasari et al., 2024).

Alsaleh et al. (2023) investigated what effect will worldwide governance factors and economic growth on the geothermal energy output among the 27 European Countries from the time being 1996 to 2021 (Estelaji et al., 2024). Another study analyzed the effect of factors relating to global competitiveness along with economic growth on the sustainability of geothermal energy among European 27 countries (Wang & Alsaleh, 2023). Alsaleh and Wang also examined what effect ICT, that is, information and communication technology factors with sustainability in the economy, has on geothermal energy output among the considered 27 EU nations within the time frame 1990 to 2021 (Alsaleh & Wang, 2023).

Subsequently, as a signatory to the Paris Agreement and as one of the ten top GHG emitters in the world (Peters et al., 2017), Iran has submitted an INDC to UNFCCC to reduce its GHG emissions. According to Iran's INDC, a reduction of 4% in GHG emissions compared to Business As Usual (BAU) is expected by 2030 for the country. With respect to the termination and nonexistence of unjust sanctions, access to international resources such as financial support and technology transfer, exchange of carbon credits, availability of bilateral or multilateral mechanisms for implementation, transfer of clean technologies, and capacity building, Iran is capable of reducing GHG emissions by up to 8% (i.e. 12% in total both unconditional and conditional) (Shirmohammadi et al., 2020). In terms of GHG emissions, the power sector is one of the most significant contributors. As reported by the International Energy Agency (IEA), the power sector produced more CO<sub>2</sub> in 2022 than any other sector (Shen et al., 2023). It is of importance to note that the power sector accounted for approximately 30% of Iran's emissions in 2020, with transport, residential, and industry sectors constituting 22%, 19%, and 17% of the total, respectively (Shahbazi et al., 2022). As evidenced by this statistic, the electrical sector is of great significance and requires more attention.

Iran is home to one of the biggest fossil fuel resource deposits, and the country has plentiful oil and gas sites (Abbaszadeh et al., 2013). Fossil fuels, owing to their availability, abundance, and affordability in Iran, have long been a mainstay of the nation's energy supply. Likewise, in the power sector, the country is dominated by fossil fuel-based power plants, and approximately 313.5 TWh of electricity was produced by these sources in 2020, representing 91% of the total amount generated (Dinçer & Erdemir, 2023). As the primary contributor to the climate crisis, fossil fuels are also challenged by resource depletion; the depletion of worldwide oil and gas supplies is expected to occur by the mid-twenty-first century (Singh & Singh, 2012), and subsequently jeopardize supply security (Bai et al., 2023). Renewable energy (RE) holds the most promising capability for being fossil fuel's ultimate substitute in the long term (Vakulchuk et al., 2020). RE is widely recognized as a clean and sustainable alternative to traditional sources of energy. By harnessing these resources effectively, we can significantly reduce environmental harm, minimize waste production, and meet the present and future economic and social needs of society (Scheer, 2013).

To predict the energy mix, which includes all kinds of fossil fuel resources and available renewable options, it is necessary to take into account current and future energy demand and key figures relating to current energy resources. This study aims to review the status and current trends in potential resources and to investigate main policies in Iran to suggest some solutions to help the government to achieve its sustainable energy security goals. These suggestions can simplify the application of sustainable inventions, and formally examines how solar, wind and geothermal energies can contribute to the structure of the energy mix in Iran. In this study a review of the previous researches has been done and also the potential of wind, solar and geothermal energies in Iran is measured. The sum of all the 3 mentioned renewable energy power plants capacities is indicated and compared with the potential feasibility of each energy. In following the status of each of these alternative energy sources is reviewed rather in detail. In this article, the capacity of Iran's renewable energy resources has been studied according to the amount of available resources.

## 2 Wind energy feasibility

The rise in population has led to increased energy consumption and the growth of factories and industrial units, resulting in higher global pollution due to fossil fuel consumption (Bai et al., 2017). Consequently, there has been a gradual increase in the use of renewable energy (Zahedi et al., 2023a). The sun and wind are two crucial sources of renewable energy. By hybridizing renewable energy sources, their disadvantages can be offset (Fan et al., 2023). During cold seasons, wind speed increases while solar radiation decreases, and vice versa. Hybridizing these two sources allows for a steady and ongoing power output (Haghighatseresht et al., 2023). To address this, it is crucial to create hybrid processes using diverse renewable energy sources. This way, every region can tackle its energy challenges with a variety of renewables.

Renewable energy resources, which are domestically sourced and inexhaustible, encompass biomass, hydropower, geothermal, solar, wind, and marine energies (Tovar-Facio et al., 2022). Due to Iran's location on the Sun Belt of the planet and the presence of wind regions, the country is considered highly abundant in these two sources of energy (Aghahosseini et al., 2018). Based on the high potential of solar and wind energies in Iran, we concentrate on them in this study because they have the best opportunity for mitigating climate change and displacing fossil fuels. Despite gradual growth, less than 10% of Iranian electricity is now supplied by renewable energy sources (Mohsen et al., 2021).

Wind power sites have a nominal capacity of 152,130 KW, 85 suitable sites have already been constructed in 26 regions. Table 1 summarizes the current wind farms and their capacity. According to data extracted from the Energy Balance sheet of Iran in 2010–2015, the available wind potential is not fully utilized. Over the past few years, however, the gap between actual capacity and nominal capacity has narrowed to almost nothing. Figure 1 (Norouzi et al., 2021) shows how the full capacity created is being put to the best possible use.

Manjil, Binalood, and Kahak, respectively, generate the most wind power. A map of Iran's wind potential shows that the country has much room for wind energy. According to available maps, Iran has high potential in terms of wind speed and density. (Fig. 2) (Mortensen, et al., 2017). In a study on multiple production using solar and wind energy,

**Table 1** Wind energy sites with wind features (Zahedi et al., 2022a)

| Wind power site | City     | Wind speed (m/s) | Wind density (W/m <sup>2</sup> ) | Nominal Capacity (KW) |
|-----------------|----------|------------------|----------------------------------|-----------------------|
| Own ebne Ali    | Tabriz   | 8                | 706                              | 1980                  |
| Sarein          | Ardebil  | 6.37             | 302.64                           | 660                   |
| Manjil          | Gilan    | 4–10.5           | 900–1500                         | 92,260                |
| Kahak           | Qazvin   | 6–8.5            | 551                              | 20,000                |
| Binalood        | Khorasan | 7.8              | 550–650                          | 32,380                |
| Khaf            | Khaf     | 9.5–10.8         | 1679                             | 2210                  |
| Soffe           | Isfahan  | 6–8              | 20–70                            | 660                   |
| Mahshahr        | Mahshahr | 3.3–4.2          | 250–495                          | 660                   |
| Babakoohi       | Shiraz   | 5.6–7            | 584–1164                         | 660                   |
| Zabol           | Zabol    | 6.2–7.7          | 257–512                          | 660                   |

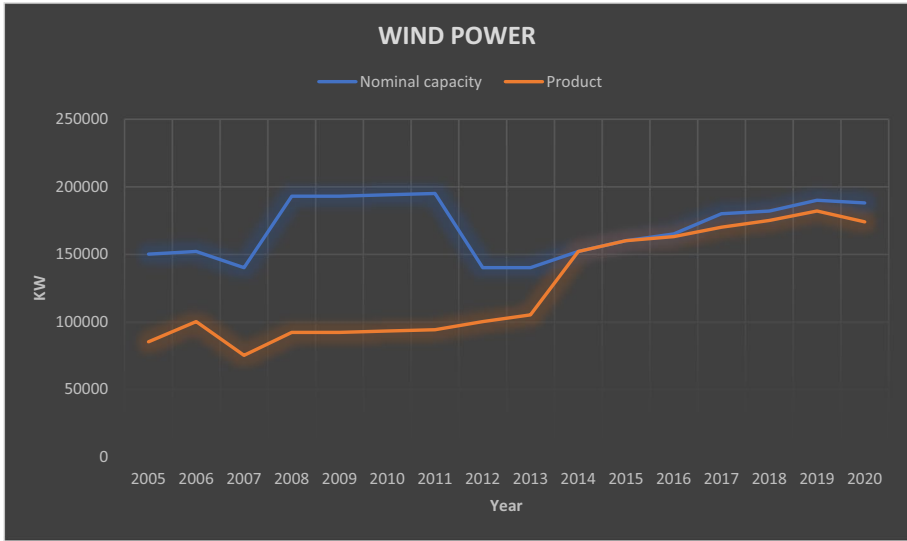


Fig. 1 Difference between the nominal capacity of wind power and generation (Norouzi et al., 2021)

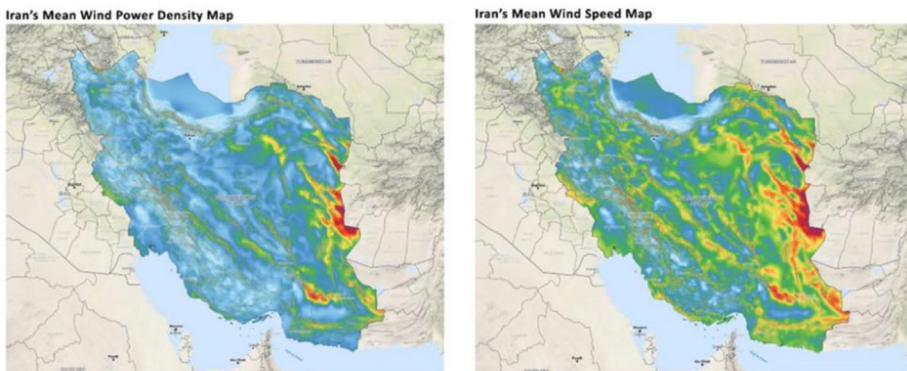


Fig. 2 Iran's wind energy potential, wind speed and power density (Mortensen et al., 2017)

Yapicioglu & Dincer found an energy efficiency of 53.3% and an exergy of 49.8% for this process with a maximum wind speed of 5.95 m/s. The desalination and electrolysis unit has the highest rate of exergy and energy efficiency. The gas turbine experienced the highest exergy destruction (Yapicioglu & Dincer, 2023). Khaled et al. demonstrated the production of electric power, heat, and cold through the use of a wind turbine, CSP collector, and ground heat pump.. The kinetic energy of a mass in motion is expressed as follows (Daneshgar et al., 2022):

$$E = \frac{1}{2}mv^2 \tag{1}$$

The power in the wind is given by the rate of change of energy:

$$P = \frac{dE}{dt} = \frac{1}{2}v^2 \frac{dm}{dt} \quad (2)$$

As mass flow rate is given by:

$$\frac{dm}{dt} = \rho A \frac{dx}{dt} \quad (3)$$

And the rate of change of distance is given by:

$$\begin{aligned} \frac{dx}{dt} &= v \\ \frac{dm}{dt} &= \rho Av \end{aligned} \quad (4)$$

Hence, from Eq. (3), the power can be defined as:

$$W = \frac{1}{2} \rho v^3 AT \quad (5)$$

The value of  $C_p$  is specific to each type of turbine, depending on the wind speed the turbine operates in. Thus, the power extractable from wind is determined as follows:

$$P_{avail} = \frac{1}{2} \rho v^3 AT C_p \quad (6)$$

Numerous studies have been conducted using different methods and approaches to reduce GHG emissions. These studies aim to assist nations in fulfilling their commitments and addressing climate change (Fig. 3).

According to the Table 1, based on current wind energy harnession limitations, Khorasan and Sistan-Baluchestan provinces have the greatest potential for generating wind energy (Daneshgar & Zahedi, 2022). As a result, it appears prudent to invest in these provinces to take advantage of their potential. Wind energy potentials in various Iranian provinces are illustrated in Fig. 4 separately and comparatively. In addition to generating electricity, the wind energy system can be used to beautify the city to attract tourists (Fig. 5). Total of 138.71 MW power has been produced by 244 wind turbines in 2020.

The estimated mean annual capacity factor of these wind parks is 33%. Variation of wind speed potential in different sites is represented in Fig. 5. In (Xie et al., 2010), the authors have studied the challenges of integrating wind turbines into the grid and its solutions. In another study, researchers investigated the technical requirements of the grid code for wind farms (Tsili & Papathanassiou, 2009). In another research work, the authors have focused on the flow control of wind farms by a new algorithm called reinforcement learning (Abkar & Zehtabiyani-Rezaie, 2023). Nacelles in wind turbines are complex machines designed to work in harsh conditions. Thus in Siddiqui et al. (2023), the key challenges in nacelle testing of modern wind turbines are highlighted. Also, in another research work, the authors comprehensively examine the integration of wind power in power grids (Leao et al., 2009). Reference (Liu et al., 2013), reviews recent developments on technical requirements for wind power grid integration. Reference (Hirth, 2012), examines the costs of integration and the value of wind power. Reference (Ghanbari-Ghalehjoughi et al., 2023), uncertainty has been considered in the production of active power of wind turbines and a robust optimization method has been used to deal with the existing uncertainties. In (Erlich & Bachmann, 2005), the requirements of the grid code regarding the connection and operation of wind turbines in Germany

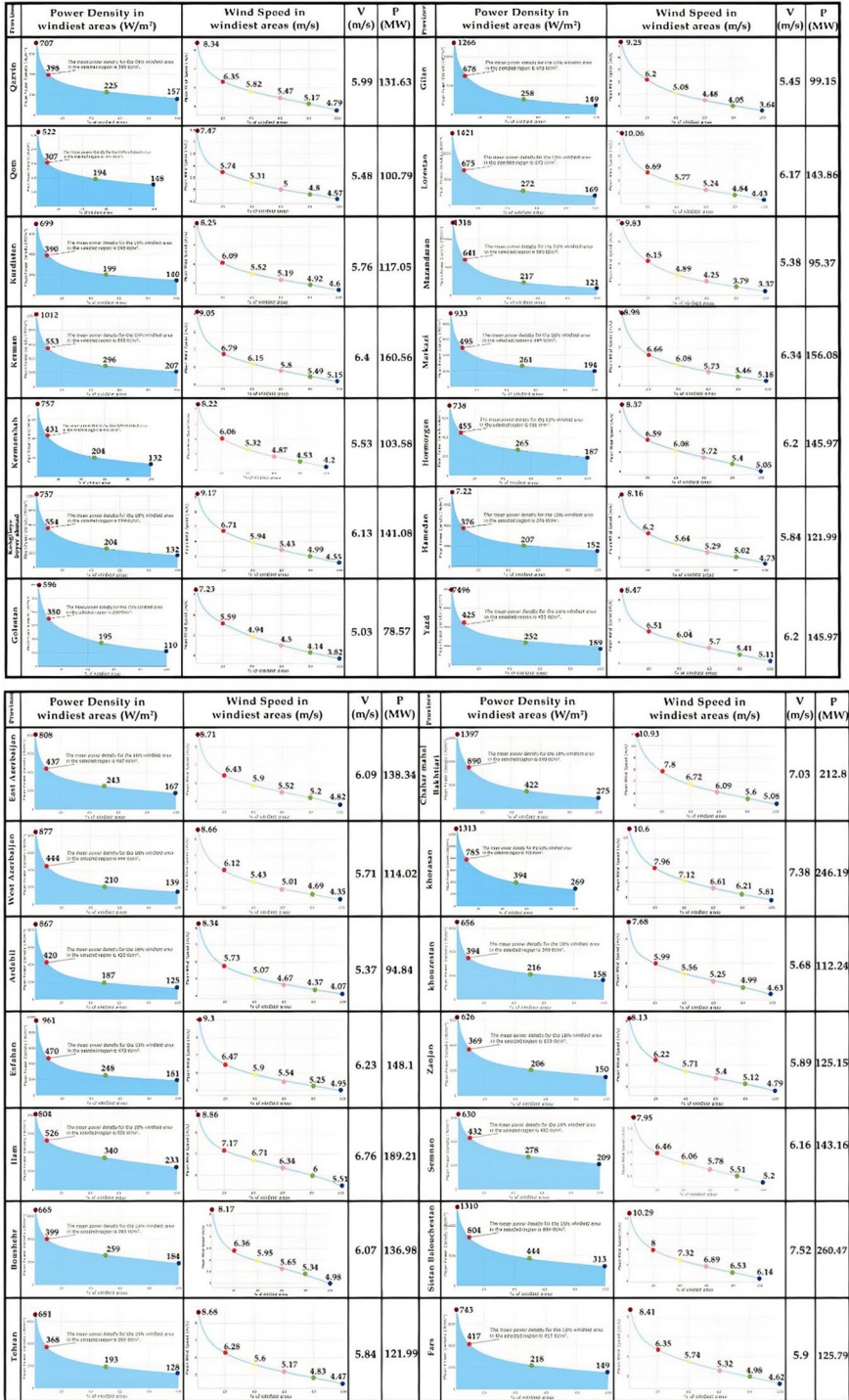
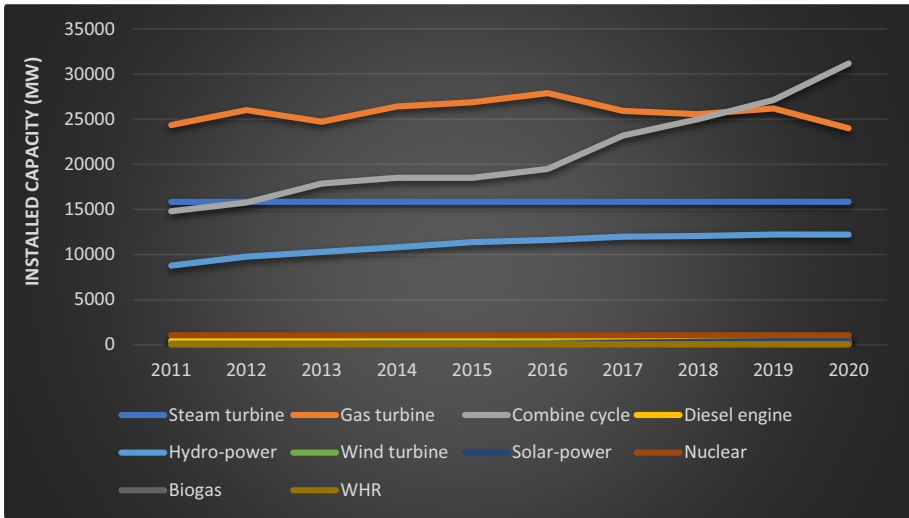
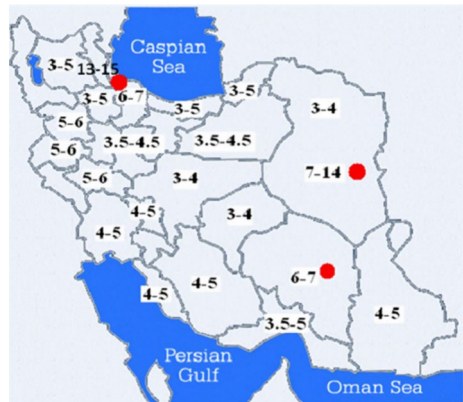


Fig. 3 Analyzing wind potential in various provinces. (Source: Authors; secondary analysis of GWA)



**Fig. 4** Wind and other energy potential of Iran’s power plant capacities (Source: Authors; in accordance with SATBA statistics)

**Fig. 5** Variation of wind speed potential in different site in m/s (Zahedi et al., 2022a)



are examined. Reference (Herbert et al., 2014), analyzes the technical requirements for the development of wind farms. In (Barzegar-Kalashani et al., 2023), the authors focused on the control of small-scale wind turbines under strong wind conditions. In (Zohreh et al., 2023), the authors have focused on the fundamentals of different wind turbines for power generation and their modeling methods using different algorithms. In (Gitifar et al., 2024), the authors investigate different methods of modeling wind turbine with vertical axis.



### 3 Solar energy feasibility

As a vast country with an average solar radiation of 4.5 kWh per square meter, Iran offers excellent prospects for initiating and utilizing solar systems, and in particular, solar power plants for the generation of electricity. Iran indeed has a favorable geographical location for harnessing solar energy due to its position on the solar radiation belt. With over 300 sunny days per year in 90% of its territory, Iran benefits from a high potential for utilizing this natural resource (Fan et al., 2024). The estimated amount of solar radiation in various regions of Iran ranges between 1800 and 2500 kWh/m<sup>2</sup> annually, surpassing the global average (Almutairi et al., 2021). Figure 6 illustrates the average global horizontal irradiation in Iran between 1999 and 2018 (Naserpour et al., 2020). Also the annual average of total monthly sunshine hours, as an important parameter for installing solar equipment and power generators using solar energy, in Iran was obtained to be about 250.8 h (Jahangir et al., 2023).

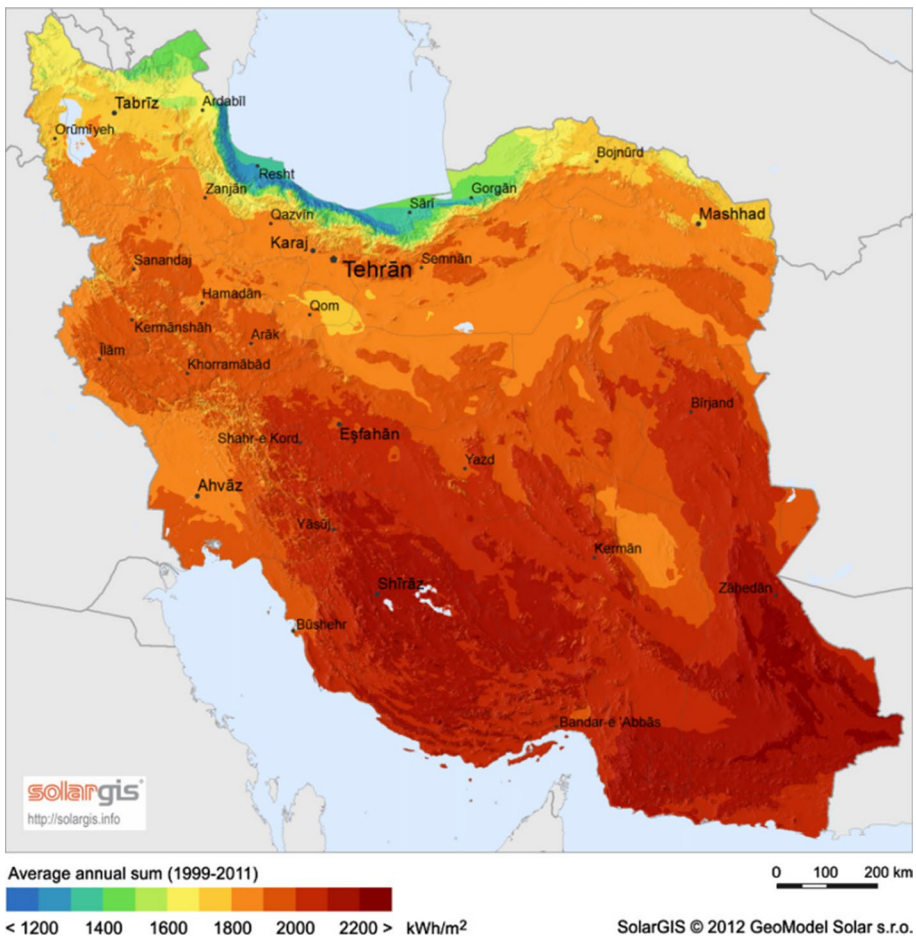


Fig. 6 The map of annual average KT at the provincial scale (Norouzi et al., 2021)

Although Iran has a considerable amount of solar energy potential, the report of the Iran Energy Yearbook in 2020 indicates that this energy is not being utilized effectively. According to this report, the share of solar power generation in Iran compared with other power sources is about 0.17% with 583.9 GWh of power generation per year and an installed capacity of 402.5 MW until the end of 2020 (Shaghaghi et al., 2024b). Figure 7 shows that the value of DSR decreases from southern to northern Iran.

Solar rays that reach the panel directly from the sun are called "direct radiation." This type of radiation belongs to the rays that hit the module in a straight path (Zhang et al., 2023). Direct radiation is one of the most important parameters for evaluating and optimizing the performance of solar panels (Sun et al., 2022). When the sun's rays hit the Earth's atmosphere, some of it is scattered, depending on various factors such as air concentration, cloudiness, fine dust, and air humidity. Part of this scattered light has less power and is radiated to the surface of the module in different ways. This type of radiation is called "scattered horizontal radiation." In other words, radiation scattered horizontally. The amount of radiation received per unit area does not reach the surface of the panel in a direct path from the sun. For example, on a cloudy day, light mainly consists of scattered radiation. Iran's annual average decreasing solar radiation map was evaluated and depicted in Fig. 8, in accordance with the average solar radiation in different seasons (Ghodusinejad et al., 2022).

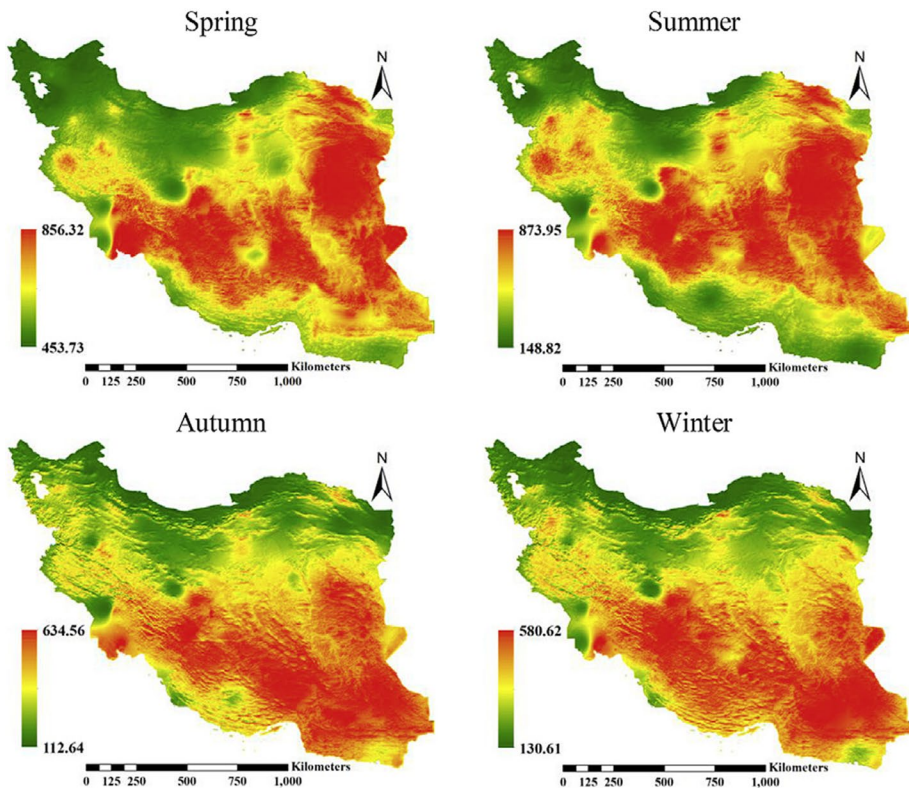


Fig. 7 Iran's seasonal mean DSR ( $W m^{-2}$ ) (Norouzi et al., 2021)

**Fig. 8** Iran's yearly mean DSR ( $\text{W m}^2$ ) (Zahedi et al., 2022b)

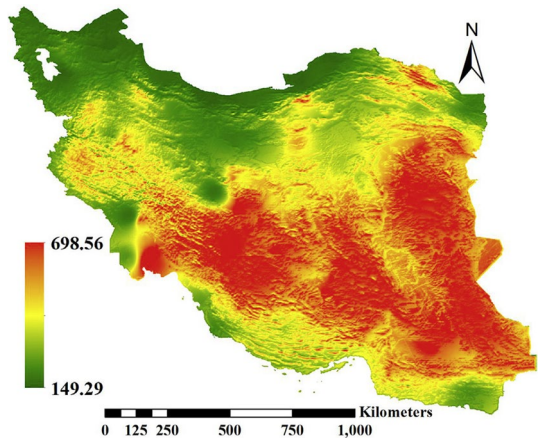


Table 2 shows the installed nominal capacity (MW) for various types of power plants from 2014 to 2023.

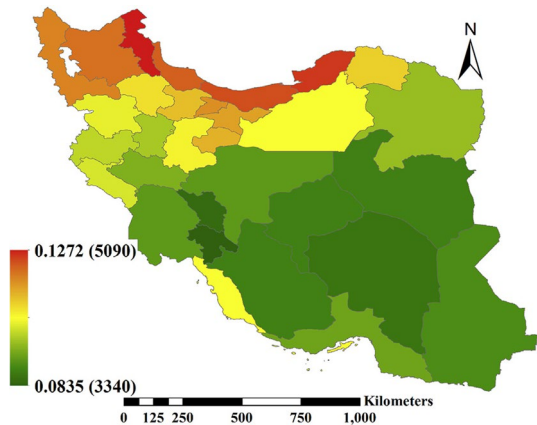
According to Fig. 9, Kohgiluyeh and Boyer Ahmad Provinces receive the most DSR, with an annual average total of around  $578.6 \text{ W m}^2$ . Ardabil Province, on the other hand, ranks last with  $380.1 \text{ W m}^2$  (Heydari, et al., 2023). A solar fraction equal to one means that all the energy requirements of an appliance are met by solar technology. On the other hand, when the solar fraction is zero, it means the appliance uses no solar energy. Due to the nature of the panels and existing errors and other conditions, it is natural that this value is never equal to 1.

Nowadays, solar energy has gained interests due to its numerous uses in desalination, power & electricity generation and steam production for processes (Khan & Arsalan, 2016). The steam production for; hydrogen, electricity, house heating & cooling, and seawater desalination can all be conducted using solar thermal energy (Shi et al., 2020). Also, Iran has very high irradiation and potentials for solar energy to be used. Some of its cities during spring and summer have high irradiation and it reaches up to  $1200 \frac{\text{W}}{\text{m}^2}$ . The irradiation can be trapped and converted to thermal energy by central dish, parabolic through collectors (PTC) (Ahmad et al., 2024), linear Fresnel collectors (LFC) (Häberle, 2022), and solar towers (Platzer et al., 2021). LFCs & PTCs reflect solar irradiation to a linear center called receiver and it converts to solar thermal energy with some industrial application and purposes (Khan et al., 2023). In addition, LFCs & PTCs are cheaper to construct in term of production cost compared with the cost for converting thermal energy, trapped energy in receiver, into electricity (Lillo-Bravo et al., 2018). In LFCs & PTCs, the heat from the sun transfers and uses by increasing the temperature of the heat transfer fluid (HTF). About 85%, 7% and 6% of all PTCs commonly used are thermal oil fluids, molten salts and directly produced steam, respectively. Chantasirivan in a study for a 50 MW power plant determined while direct steam is produced in collector 3.48% less area of the collector is required compared to when HTF is first heated and then the steam is produced in an oil–water exchanger (Chantasiriwan, 2022). The capacity of solar resources in Iran is shown in Table 3.

**Table 2** Installed nominal capacity (MW) for various types of power plants from 2014 to 2023

|      | Steam turbine | Gas turbine | Combine cycle | Diesel engine | Hydro-power | Wind turbine | Solar-power | Nuclear | Biogas | WHR  |
|------|---------------|-------------|---------------|---------------|-------------|--------------|-------------|---------|--------|------|
| 2014 | 15,821.6      | 24,341.7    | 14,779.5      | 408.4         | 8746.2      | 98.2         | 0.07        | 1020    | 6.7    | –    |
| 2015 | 15,829.2      | 26,002.8    | 15,743.5      | 439.4         | 9746.1      | 106.2        | 0.1         | 1020    | 6.7    | –    |
| 2015 | 15,829.2      | 24,714.7    | 17,849.1      | 439.4         | 10,266.4    | 110.2        | 0.1         | 1020    | 6.7    | –    |
| 2017 | 15,829.2      | 26,412      | 18,493.1      | 439.4         | 10,789.3    | 153.6        | 0.55        | 1020    | 11.6   | –    |
| 2018 | 15,829.2      | 26,870      | 18,493.1      | 439.4         | 11,354.3    | 158.6        | 9.2         | 1020    | 11.6   | –    |
| 2019 | 15,829.2      | 27,890      | 19,469.1      | 439.4         | 11,579.8    | 191          | 39.6        | 1020    | 11.6   | 13.6 |
| 2020 | 15,829.2      | 25,919.2    | 23,165.1      | 439.4         | 11,951.9    | 263.3        | 177.1       | 1020    | 11.6   | 13.6 |
| 2021 | 15,829.2      | 25,551.3    | 24,995.1      | 439.4         | 12,027      | 284.8        | 299.3       | 1020    | 11.6   | 13.6 |
| 2022 | 15,829.2      | 26,180.2    | 27,129.1      | 439.4         | 12,188.2    | 302.3        | 368.2       | 1020    | 11.6   | 13.6 |
| 2023 | 15,829.2      | 23,990.4    | 31,178.1      | 439.4         | 12,188.7    | 302.9        | 402.5       | 1020    | 11.6   | 13.6 |

**Fig. 9** Optimal FIT for PV Power Purchase (US \$ (Rials)) (Zahedi et al., 2022c)



#### 4 Geothermal energy feasibility

The RE Organization of Iran (Zahedi et al., 2023) conducted subsequent exploration studies in 1996–1999, finding ten additional zones, they are shown in Fig. 10. In 1995, first Iran’s geothermal power generation project began at Sabalan geothermal area, where five promising areas had been identified through a series of exploration and feasibility studies (Noorollahi et al., 2019). The NW Sabalan geothermal field (Seyedrahimi-Niaraq et al., 2017) was chosen out of the five for exploration drilling. Mud pools, hydrothermal alteration, and hot springs are examples of geothermal energy. Table 4 (Yousefi et al., 2019) shows the electricity generation (GWh) for various types of power plants from 2014 to 2023. The information collected from the Iran Energy Yearbook in 2020 was used to display electricity generation for various power plants from 2014 to 2023.

Alsaleh et al. (Alsaleh et al., 2022) evaluated how the research will look at the impact of geothermal energy production on the quality of the subterranean in the 27 European nations from 1990 to 2021. Another study also investigated the effect of geothermal energy output on carbon dioxide emissions among the European countries (EU) classified as EU27 states, within the time frame 1990 to 2021 (Alsaleh et al., 2023).

Alsaleh et al. (Alsaleh & Abdul-Rahim, 2023a) examined the impact of geothermal energy on agri-food supply among the 27 European countries (EU27), within the time frame 1990 to 2021. Another study also examined what influence geothermal energy will have on land use changes among the considered 27 states in the European Union from the time being 1990 to 2021 (Alsaleh & Abdul-Rahim, 2023b).

#### 5 Forecasting based analysis

If only one independent variable is used to identify and predict the dependent variable, the model is called "Simple Linear Regression." The form of a simple linear regression model is as follows:

$$Y = \beta_0 + \beta_1 X + \epsilon \tag{7}$$

**Table 3** The capacity of solar resources in Iran (Gorjian et al., 2019)

| Number | Consulting Co                       | Province                  | Location           | Capacity (MWJ) | Date of Operation |
|--------|-------------------------------------|---------------------------|--------------------|----------------|-------------------|
| 1      | Arrian Persian                      | Tehran                    | Malard             | 0.514          | 2014              |
| 2      | Pak Bana                            | Qom                       | Qom                | 1              | 2016              |
| 3      | Aftab Mad Rahe Abrisham             | Hamedan                   | Qahavand           | 7              | 2016              |
| 4      | Aftab Maad Rahe Abrisham            | Hamedan                   | Aq Bolagh-e Latgah | 7              | 2016              |
| 5      | Negin Setare Marzi Taybad Shayan    | Razavi Khorasan           | Taybad             | 5              | 2016              |
| 6      | Ayandeh Sazan Sayareh <b>Sabz</b>   | Isfahan                   | Kashan             | 1              | 2016              |
| 7      | Tara Moshaver                       | Alborz                    | Shams Abad         | 0.23           | 2017              |
| 8      | Ghadir Energy Investment Co.  GE CJ | Isfahan                   | Jarghoyeh          | 10             | 2017              |
| 9      | Toseeye Faragire Jaask              | Kerman                    | Mahan              | 10             | 2017              |
| 10     | Solar Energy Arka                   | Kerman                    | Mahan              | 10             | 2017              |
| 11     | Mehrad Energy Arvand                | Kerman                    | Rafsanjan          | 1.2            | 2017              |
| 12     | Pejvak Omran Kish                   | Yazd                      | Ardakan            | 10             | 2017              |
| 13     | Aftab Taban Kavir Part              | South Khorasan            | Khusf              | 10             | 2017              |
| 14     | Sarzamin Abi Do Qeshm               | Hormozgan                 | Qeshm Island       | 10             | 2017              |
| 15     | Behnad Energy Pars Lian             | <b>Fjrs</b>               | Sarveslan          | 4.6            | 2017              |
| 16     | Gostareh Energy No Ajiyeh           | Sistan & Baluchestan      | Zahedan,           | 10             | 2017              |
| 17     | Gostareh Energy No Ajiyeb           | Yazd                      | Ashkezar           | 10             | 2017              |
| 18     | Aftab Maad Rahe Abrisham            | Hamedan                   | Kerdabad           | 7              | 2017              |
| 19     | Aftab Maad Rahe Abnsham             | Hamedan                   | Qahavand           | 8.9            | 2017              |
| 20     | Aftab Maad Rahe Abrisham            | Hamedan                   | Famenin            | 8.6            | 2017              |
| 21     | Shahrekord Cement Industries        | Chaharmahal and Bakhtiari | Share-Kord         | 1.5            | 2017              |
| 22     | ABO wind                            | Semnan                    | Syed Abad-Damghan  | 1.313          | 2017              |
| 23     | Taban Energy Envelopment            | <b>Fars</b>               | <b>Eqlid</b>       | 10             | 2018              |
| 24     | Taban Energy Envelopment            | <b>Fars</b>               | Abadeh             | 10             | 2018              |
| 25     | Nika-Energy                         | Fars                      | Slnrai             | 10             | 2018              |

**Table 3** (continued)

| Number | Consulting Co  | Province           | Location           | Capacity (MWJ) | Date of Operation |
|--------|--|--------------------|--------------------|----------------|-------------------|
| 26     | Tose-e Maksan Dehshir                                | Yazd               | Dehshir            | 3.5            | 2018              |
| 27     | Iran Tablo   | Alborz             | Nazarabad          | 0.628          | 2017              |
| 28     | Pars Ray Energy Bahar                                | Tehran             | Shahr-e-Ray        | 10             | 2017              |
| 29     | MahdTejarat Costaran Attar                           | <b>Fars</b>        | Abadeh             | 10             | 2017              |
| 30     | Mohandesi Moshaver Tajdidpazir Soheil                | Tehran             | Damavand           | <b>8.4</b>     | 2017              |
| 31     | Taban Energy Mehr Afarin                             | Tehran             | Tehran             | 0.02           | 2017              |
| 32     | Tose-e Khorshidi Mehriz Ghadir                       | Yazd               | Mehriz             | 10             | 2018              |
| 33     | Tose-e Energy Sabz Shafagh                           | South Khorasan     | Boshruyeh,         | 1              | 2018              |
| 34     | Energy Sabz Kavir Kish                               | Kerman             | Mahan              | 10             | 2018              |
| 35     | Khorshid Derakhshan Kavir                            | Yazd               | Chahak             | 10             | 2018              |
| 36     | Tose-e Energy Khorshidi Ghadir Qom                   | Qom                | Qom                | 10             | 2018              |
| 37     | Mapna  | <b>Qazvin</b>      | Kahak              | 2              | 2018              |
| 38     | Installed PV Power Plants by Electricity Subscribers | Across the Country | Across the Country | 4.701          | –                 |
| 39     | Small-scale Solar Power Plants                       | Across the Country | Across the Country | 7.9            | –                 |

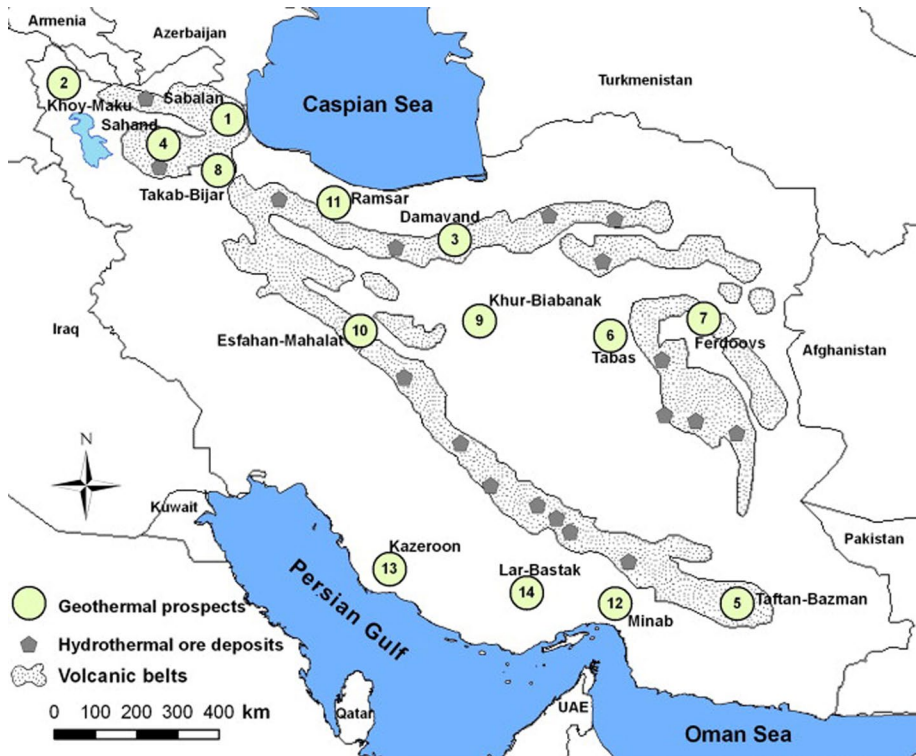


Fig. 10 Iran's geothermal potential areas (Seyedrahimi-Niaraq et al., 2017)

If used to identify and predict the dependent variable only from an independent variable, they call the model " simple linear regression " (Simple Linear Regression). The form of a simple linear regression model is as follows: As shown in this equation, above Eq is a line that is added, including the fault, or the same  $\epsilon$ . The parameters of this linear model are the width of the source ( $\beta - 0$ ) and the line slope ( $\beta - 1$ ). The line slope in the simple linear regression model indicates how much the dependent variable depends on the independent variable. It means that by increasing one unit to the value of the dependent variable, the dependent variable will change. The width of the origin also represents a value of the dependent variable, which is calculated as the value of the independent variable equal to zero. In other words, a fixed amount of origin can be considered as the dependent variable's mean value on the independent variable's return. Thus, if the value of the independent variable is zero, the dependent variable value must also be considered zero. This model is considered when the researcher is confident that the regression line must cross the origin of the coordinates.

The linear relationship in the regression model is between the coefficients, not between the independent variables. For instance, this model  $y = \beta_0 + \beta_1 \times 2 + \epsilon y = \beta_0 + \beta_1 \times 2 + \epsilon$  can also be considered linear while they  $y = \beta_0 x = 1 + \epsilon y = \beta_0 x$  is no longer linear and is known as the exponential model. To estimate the parameters of the simple linear regression parameters, minimizing the least-squares error function is sufficient. In



**Table 4** Electricity generation (GWh) for various types of power plants from 2014 to 2023

|      | Steam turbine | Gas turbine | Combine cycle | Diesel engine | Hydro-power | Wind turbine | Solar-power | Nuclear | Biogas | WHR  |
|------|---------------|-------------|---------------|---------------|-------------|--------------|-------------|---------|--------|------|
| 2014 | 95,901.1      | 58,715.3    | 72,749.1      | 61.7          | 12,058.3    | 217          | 0.05        | 327.1   | 21.9   | -    |
| 2015 | 91,788.3      | 67,364.1    | 80,534        | 65.6          | 12,446.6    | 206.6        | 0.1         | 1847.3  | 22.6   | -    |
| 2016 | 89,664        | 66,038.9    | 87,135.1      | 71.1          | 14,583.9    | 375.6        | 0.1         | 4545.8  | 20.8   | -    |
| 2017 | 85,623.8      | 73,340.3    | 96,823        | 83            | 13,864.5    | 185.7        | -           | 4472.1  | 47     | -    |
| 2018 | 86,968.2      | 75,423.8    | 100,935.6     | 65.6          | 14,092.7    | 221          | 0.8         | 2913.9  | 14.4   | -    |
| 2019 | 85,091.9      | 76,778.3    | 103,859.5     | 46.2          | 16,421.1    | 250.4        | 4.4         | 6620.2  | 23.6   | -    |
| 2020 | 90,337.6      | 79,477.1    | 115,078.8     | 94.3          | 15,395.6    | 307.1        | 86.2        | 7450.5  | 38.1   | 41.3 |
| 2021 | 85,654.5      | 70,319.6    | 129,200.7     | 81.2          | 15,765.1    | 518.2        | 339.6       | 7245.9  | 21.6   | 28.8 |
| 2022 | 85,115.4      | 71,216.3    | 131,149.5     | 39.5          | 31,087.5    | 615.6        | 672.8       | 6756.7  | 18.6   | 32   |
| 2023 | 84,789.5      | 71,429.4    | 157,185.9     | 58.6          | 22,075.5    | 754.3        | 583.9       | 5526.6  | 23.6   | 33.4 |

order to do so, the following steps should be taken, Calculate the sum of the power of the second error (Zahedi et al., 2023b):

$$\sum (Y_i - (\hat{\beta}_0 + \hat{\beta}_1 x_i))^2 \quad (8)$$

Derivative of the sum of squares of error in terms of parameters  $\hat{\beta}_0 \hat{\beta}_1$ :

$$\sum (-y_i + \hat{\beta}_0 + \hat{\beta}_1 x_i) \quad (9)$$

Find the root for the resulting equation in terms of  $\hat{\beta}_0 \hat{\beta}_1$ :

$$\hat{\beta}_0^n = \bar{y} - \hat{\beta}_1 \bar{x} \quad (10)$$

Derivative of the sum of squares of error according to the parameter  $\hat{\beta}_1 \hat{\beta}_1$ :

$$\sum (-2x_i y_i + 2\hat{\beta}_0 x_i + 2\hat{\beta}_1 x_i^2) \quad (11)$$

Place  $\hat{\beta}_0 \hat{\beta}_0$  and find the root for the resulting equation in terms of  $\hat{\beta}_1$ :

$$\hat{\beta}_1 = \sum (x_i - \bar{x})(y_i - \bar{y}) / \sum (x_i - \bar{x})^2 \quad (12)$$

In this way, the estimation of the parameters of the linear model will be as follows (Ghoshchi et al., 2022):

$$\hat{\beta}_1 = \sum (x_i - \bar{x})(y_i - \bar{y}) / \sum (x_i - \bar{x})^2 \quad (13)$$

$$\hat{\beta}_0 = \bar{y} - \hat{\beta}_1 \bar{x} \quad (14)$$

For ease of calculation, the  $\hat{\beta}_1 \hat{\beta}_1$  estimate can be written in another form:

$$\hat{\beta}_1 = n(\bar{x}y - \overline{xy}) / (n-1)\sigma^2_x \quad (15)$$

If  $\hat{y}$  is the estimated value for the dependent variable, we can consider it as the average of the observations for the dependent variable for the constant value of the independent variable. So assuming that the average error sentence is also zero, we will have the following:

$$\hat{y} = E(Y|X = x) = \hat{\beta}_0 + \hat{\beta}_1 x \quad (16)$$

On the other hand, the variance of the error sentence according to the initial hypotheses for the regression model should be constant and equal to  $\sigma^2 \sigma^2$ . The variance estimate for the error sentences is as follows

$$\sigma^2 = \sum (y_i - \hat{y}_i) / 2n - 2 \quad (17)$$

Test related to the model and its parameters:

After performing the regression steps, using the "Analysis of Variance" table, the model's accuracy and efficiency can be measured. The analysis of the variance of the variable depends on two parts, the part of the change or scatter that can be represented by the regression model and the part that is determined by the error sentence. So the following relation can be written accordingly

$$SST = SSR + SSE \tag{18}$$

Each of these is defined as follows:

$$SST = \sum (y_i - \bar{y})^2 \tag{19}$$

The value of SST can be considered as the sum of the squares of the difference between the observations of the dependent variable and their mean, which is the form of the variance fraction of the dependent variable. This quantity can be divided into two parts. It is worth mentioning that the SSE value is also called the sum of squares of error, which was obtained in the regression model by minimizing the model parameters. The following section is also shown with SSR:

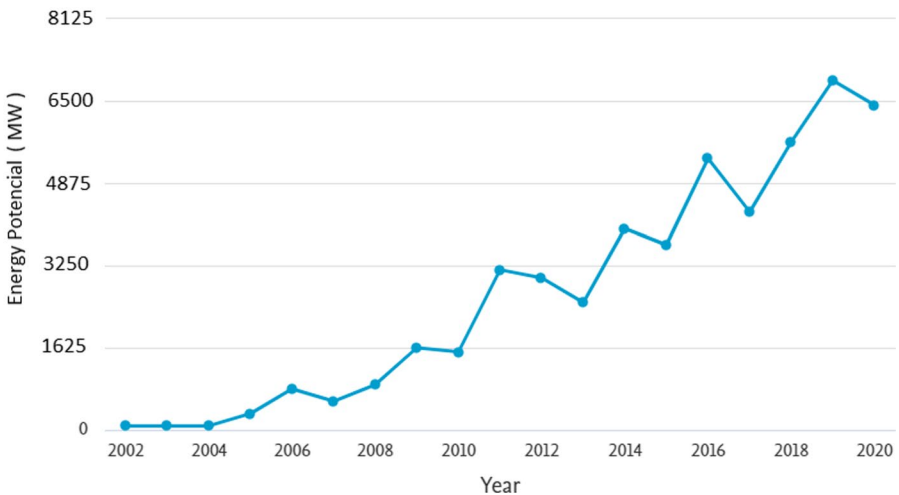
$$SSR = \sum (\hat{y}_i - \bar{y})^2 \tag{20}$$

## 6 Results and discussion

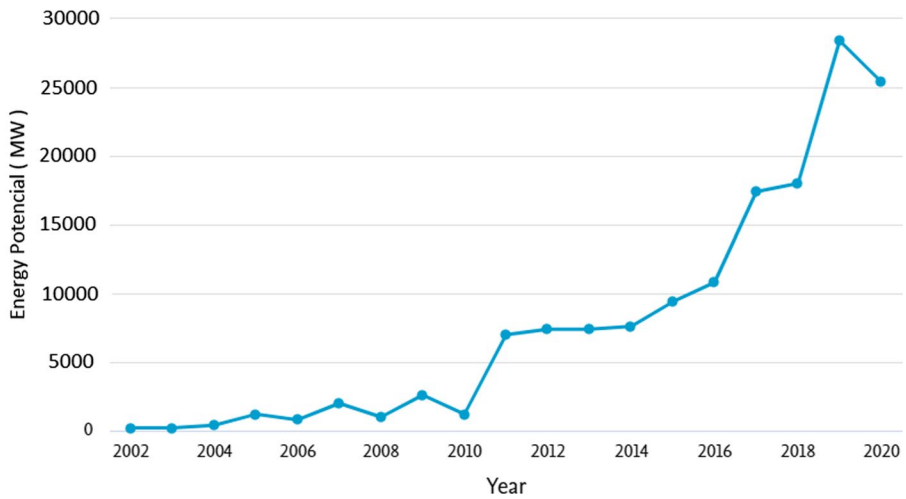
Due to the exact unanalyzability of most energy resources, international communities should turn to received accurate estimation to supply their resources. The purpose of this article was to examine the amount of admission resources to advance this important goal. The important goal was to evaluate the potential of resources received in Iran. Nowadays, the development of renewable energy is limited by Research and development (R&D) and investment cost. In addition there has been some problem related to investment risk and unreliable return and long term design.

As can be seen from the diagrams of wind, solar and geothermal energy potentials in the above figures(Figs. 11, 12 and 13), in general, with technological advances and the

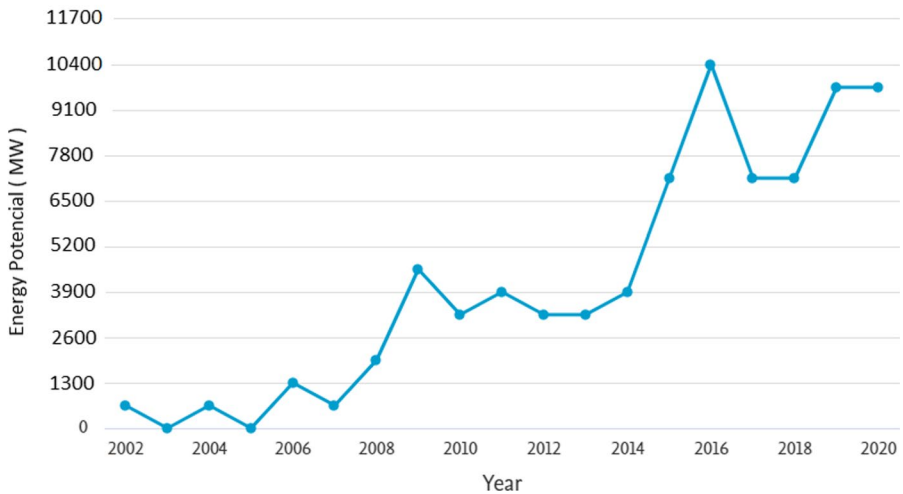
**Wind Potencial Analysis by Year**



**Fig. 11** Iran’s wind energy utilization potential regarding economic feasibility

**Solar Potential Analysis by Year**

**Fig. 12** Iran's solar energy utilization potential regarding economic feasibility

**Geothermal Potential Analysis by Year**

**Fig. 13** Iran's geothermal energy utilization potential regarding economic feasibility

possibility of exploiting these energies and creating demand for them and causing their transition from reserves to resources and as a result, the potential for energy resource estimates has been rising over the years. Since 200 BC, Iranian windmills have been designed and manufactured due to the existence of wind regions (Ragheb, 2017). As a result of Iran's unique geographical location, being situated in a low-pressure area along with high-pressure areas in the north and northwest, it generally experiences winds that blow in winter from the Atlantic Ocean to the Mediterranean and Central Asia and winds that blow in

the summer from the Indian Ocean and the northwest to Iran throughout the winter and summer months (Mohammadpour et al., 2021).

In 2002, the New Energy Organization of Iran initiated a project to assess the potential for wind energy and create a comprehensive wind atlas for the country. This project was completed in 2009 and involved the installation of over 130 wind synoptic stations throughout Iran. These stations collected wind data every 10 min, taking into account the impact of thunderstorms and turbulence on the wind flow. As a result, the wind atlas is a reliable and freely available reference tool. The atlas covers 26 regions and 45 sites in Iran. According to the findings, these 20 sites alone have a wind energy potential equivalent to 6500 MW, while the estimated total wind energy capacity for the entire country is around 20,000 MW. Despite Iran’s significant wind energy potential, the report of the Iran Energy Yearbook in 2020 indicates that the installed capacity of wind turbines is about 302.9 MW which produced 754.3 GWh in this year. This amount of electricity is just 0.22% of the total electricity generation of the country.

The chart below (Fig. 14) indicate the new operation of the total number of power stations built each year and have a cumulative nature. As we are aware, surplus electricity production, also known as Critical Excess Electricity Production (CEEP), poses a significant challenge within the energy system, specifically for renewable sources like solar and wind energy. It occurs when there is an abundance of electricity generated compared to the current demand in a particular location and timeframe (Shaghghi et al., 2023). Unlike the other scenarios, the energy network will experience this CEEP in the NSP scenario. It is the ambitious goals of this scenario that are responsible for this excess electricity production, and if the Iranian government implements the plans of this scenario, it should have a specific plan for handling this situation. Next comes the BAU scenario, which contributes 7.6% of the country’s total electricity production to renewable sources. Finally, there is the RES scenario, even though this is our proposed scenario in this study, with 7.2% of electricity production derived from RES. This low share of renewables in BAU and RES scenarios demonstrates the country will be continuously reliant on fossil fuels in the power

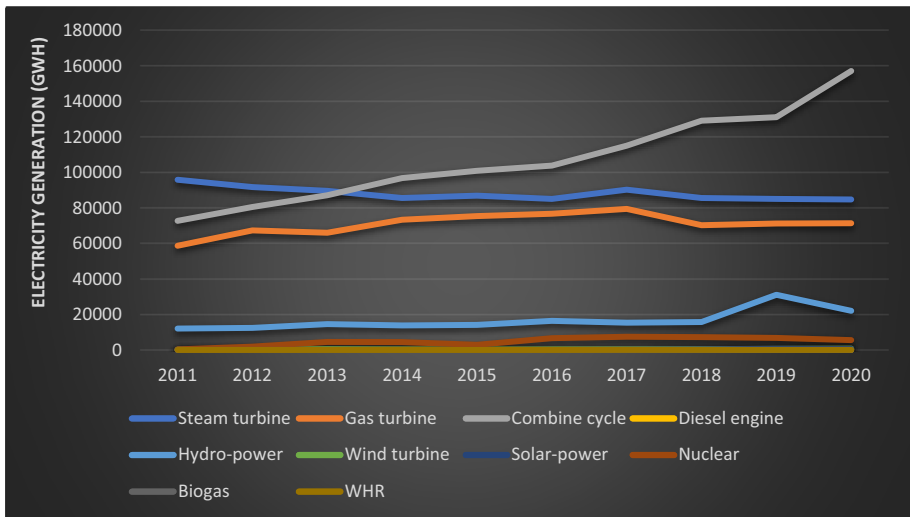


Fig. 14 Total operating capacity of wind farms, solar, geothermal and other Iran’s power plant generations in each year

sector. As a flexible resource, wind turbines in power systems can help improve the performance and efficiency of these systems while reducing dependence on fossil energy.

## 7 Conclusion

Iran's development trends illustrate that in 18 years, renewable energies have supplied 1.17% of Iran's electrical energy demand. The total wind, solar and geothermal potential in 2020 for Iran are estimated at 6500, 25,300 and 9700 MW, respectively. However, the total capacity of the wind, solar and geothermal power stations constructed are 305, 367 and 76 MW, respectively, until now. According to Iran's national development plans, electricity produced by renewable energies should be 5% of Iran's total electricity production energies by the year 2035. Government approvals for the production of new energies must be noted and pursued to achieve this aim.

While this study has analyzed a number of possible solutions, the proposed "RES scenario" is the only feasible one that will meet all of Iran's commitments, both unconditional and conditional, under the Paris Agreement. In this scenario, solar and wind power capacities have been expanded simultaneously with rising thermal power plants efficiency. As a result of this scenario, GHG emissions from Iran's electricity sector will reach 202.325 megaton CO<sub>2</sub> equivalent in 2030, which will meet all of Iran's obligations, whether unconditional or conditional. It is clear that this expansion of solar and wind is going to require a substantial amount of investment, and it will be difficult to achieve it without an effective policy framework. Consequently, to drive toward a sustainable future far away from environmental concerns, the following findings and organizational measures are recommended.

- (1) Regarding solar energy, Iran has extensive barren lands exposed to solar radiation of great intensity most days; therefore, many appropriate locations are available for the development of solar energy, including Tehran, Yazd, Semnan and Shiraz.
- (2) Regarding geothermal energy, Iran enjoys favorable conditions for the formation of geothermal fields, and the sector is seeing renewed activity with the approval of a 55 MW geothermal power plant in Meshkinshahar
- (3) To create a clean and healthy environment, renewable energy must be used. Among the renewable energies, solar energy has more economic justification for Iran and should be the first priority of the macro-energy planning in the country.

A country with many fossil fuel resources needs appropriate policies and guidelines for the future of renewable energy development and reduced international barriers to the use of advanced technologies and the experiences of other countries in the use of renewable energies. Therefore for future studies, it is suggested that the use of crude oil export revenues to make a significant investment in various and high potential renewable energies for the future without fossil energy resources at local levels be studied in more detail.

**Funding** The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

**Data availability** Datasets analyzed during the current study are available and can be given following a reasonable request from the corresponding author.

## Declarations

**Conflict of interest** The authors have no relevant financial or non-financial interests to disclose.

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