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Energy-Economic-Environmental assessment of solar-wind-biomass systems for finding the best areas in Iran: A case study using GIS maps

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ABSTRACT

According to the existing capacities of solar and wind in Iran and given this fact that, to reach a proper economic growth, Iran needs to increasing its capacity in the generation of power, and also noting that there is a severe water shortage in Iran and Iran is required to produce power without water consuming, present paper attempts to find the minimum price of electricity production by hybrid wind-biomass-solar configurations in the 103 station of Iran, using NASA website data and hybrid optimization model for multiple energy resources (HOMER) software. Forasmuch as building sector counting for 45% of energy using in Iran, the goal of present study is supplying the electricity for off-grid/on-grid in homemade scale. The outcomes showed that in on-grid mode, the cost of generating electricity is less than that of the off-grid. In the off-grid biomass generator-based system, Bandarabbas and Jask with 0.519 $/kWh and 0.385 $/kWh, are the most suitable stations for wind turbine applications and solar cell applications, respectively. For on-grid mode, these prices are reduced by 65 to 80%. As a general result, it can be said that Bandarabbas, Jask and Bandarabbas stations are the most suitable for wind, solar and wind-solar hybrid respectively.

Introduction

The amount of energy that buildings consume is high and responsible for about 45 % of world energy use that produces and releases a considerable amount of greenhouse gas into the environment, which is expected to enhance owing to improved human well-being and population growth [1,2]. Accordingly, and due to the many advantages of renewable energy sources including endless, no pollutant and waste production, local and regional production, etc., the renewable energy sources are of great importance to improve the quality of life [3–8] and increase sustainable development goals chiefly in developing countries such as Iran [9–14]. It is worth mentioning that the renewable energy sources including biomass, solar, and wind are the best solution in the faraway areas where cheap electricity and fuel are absent [15–25], which their current consumption rates are being addressed in the world and Iran in the next subsections.

Global renewable energy resources statue

2015 was an unprecedented year for renewable energy sources due to the greatest power production from renewable energy resources [26]. The distributed renewable energies are also progressing fast to decrease the gap between the energy-benefited population and the energy-deprived population [27].

Table 1 represents the annual increase for generation of renewable electricity by type, 2018–2020. According to Table 1, the growth of electricity generated from renewable energy in 2020 has decreased compared to 2019 and 2018. This is more evident for bioenergy because of supply chain disruptions and logistical challenges in delivering solid biofuels to power plants [28].

Table 2 represents the investment rate in developed and developing countries on different renewable energy sources [30]. The results of Table 2 show that the amount of investment in bio-power is higher than geothermal and ocean. The highest amount of investment is related to

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Table 1
Annual increase for generation of renewable electricity by type, 2018–2020 [28].

Fuel type	2018	2019	2020
Hydropower	4	2	1
Bioenergy	7	8	3
Wind	11	12	12
Solar PV	33	22	16
Others	4	7	3

Table 2
Global trends in renewable energy investment, 2020 [29].

Technology	2020 (Billion USD)
Solar power	760
Wind power	743
Bio-power	145
Hydropower	1170
Geothermal power	14.1
Ocean energy	0.5

hydro, solar and wind, respectively.

Biomass, solar, and wind energy sources in Iran

Most oil-rich Persian Gulf countries are looking to expand and develop renewable energies, especially Iran that is at the forefront of renewable energy diversification [30]. However, there is a lower incentive to invest in renewable energies in Iran considering the exorbitant investment prices for producing energy from sources of renewable energy and no return on capital, which accordingly Iran ranks 98 on novel energy sources consumption globally.

Appendix 1 represents the Solar Energy Atlas in terms of kWh/m^2-day for Iran [31]. According to that, the solar energy using in the tropical regions placed at the bottom of the national grid. In the regions, there may be power outage due to extreme heat, voltage drop, frequency drop, and power substation damages, while the potential for receiving solar energy to be converted into electricity is high enough.

The estimations indicate that the initial investment cost in the photovoltaic power plants is higher than wind energy, up to 2 or 3 times, and wind turbine efficiencies are in a range of 90–95 % and solar cell efficiency is about 17 % [32]. Therefore, in the renewable energy sector, the priority is to invest in wind power plants, but policies in the household sector tend to develop such power plants alongside wind power plants due to Iran's successful scientific experience in the field of solar power plants [33]. In addition, Iran is one of the five top countries with respect to the solar energy utilization and the capacity of solar power plants.

Wind energy offers many advantages, including being free, no need for fossil fuels, a long-term low electricity price, diversification of energy sources, an approach to sustainable energy systems, higher maneuverability to operate in different capacities and sizes, no need for water, no need for big site for installation, etc [34]. The World Wind Energy Association aims to supply global power from wind power up to 10 % by 2020.

Appendix 2 represents the wind speed atlas in Iran in terms of m/s [35]. Based on that, Iran's windy areas are mainly composed of excluded, arid, and lesser developed areas, where electricity production is low and the price of transmitting power for which is high. Thus, it is a necessity to establish wind farms in these areas. In Iran, the maximum power consumption is in summer to counter the heat, which is also the windiest time of the year.

Indiscriminate destruction of forests in Iran, especially in Zagros and the northern part of the country, to supply thermal fuels cause irreparable damage to Iranian natural resources [36]. Furthermore, most agricultural waste is used to feed livestock and poultry, in the paper industry, and also for bioethanol production with 30000–40000 Rials per liter that is not cost-effective and is several times more expensive than gasoline and diesel fuels, 10,000 and 3000 Rials, respectively [37]. There are several advantages to using biomass in Iran, including significant potential, potential amplification through cultivation of energy products, compensate costs for waste disposal and environmental protection partly, saving fossil fuels, employment and development of agriculture and associated industries and helping to promote public welfare, prevention of undocumented rural migration, and tourism industry development in faraway rural areas. Correspondingly, the necessity of using biomass in renewable electricity production in Iran is more predetermined.

Appendix 3 represents the biogas production atlas from livestock waste in Iran [38]. Based on that, Isfahan, Tehran, Mazandaran, and East Azerbaijan provinces are ranked first to fourth with respect to the maximum biogas production, and Ilam and Bushehr are ranked the last.

Literature review

In 2017, Jahangiri et al. [39] have performed an analytical study on an off-grid solar cell-based system in rural areas, including Cham-e Ali, Cham-e Zin, and Chelevan villages in Saman region, Chaharmahal va Bakhtiari Province, Iran. The results indicate that the cost per kilowatt-hour of power was 1.35, 0.81, and 0.79 $/kWh for Cham-e Ali, Cham-e Zin, and Chelevan, respectively. The solar cell usage rate sat at 97 %, 57 %, and 96 %, and diesel generators that produce 87.1, 3059, and 125 kg CO_2 emissions, respectively supply the rest of the required power. In general, Cham-e Zin was selected to use of solar energy due to some environmental considerations and its predominant production power than Chelevan.

In 2018, Jahangiri et al. [40] have examined the use of wind, solar, and biomass energy to cogeneration or combined heat and power (CHP) in Zarrin Shahr, Isfahan. The results highlight that if the distance of station from accessibility point to the national electricity grid is less than 2.58 km, buying of grid electricity is superior to the biomass using. If we assume a 15 % annual increment in the prices of gas and electricity in the case of providing the needed energy by 100 % through sources of renewable energy in 25 years, then, a profit of 20310$ will be made.

In 2018, Vahdatpour et al, [41] have evaluated an off-grid hybrid solar cell-wind turbine-biomass system in the four climate regions in Iran using HOMER software to supply residential building required electricity. The results show that the use of solar cells is the ideal and cost-effective option for the cold, hot dry, and warm humid climates and the use of biomass-based systems is ideal for the moderate and humid climates.

In 2018, Alidadi et al. [42] have performed a HOMER based study to examine the use of wind and solar renewable energies in buildings of low energy consumption in Hamedan. The sensitivity analysis was performed on the data corresponding to the maximum annual capacity shortage, fuel price, wind speed, solar radiation intensity to investigate the impacts of individual parameters on the marginal produced energy cost through 180 scenarios. The results represent that the hybrid diesel generator-battery-solar cell systems are cost-effective at any irradiation intensity and wind speed for a fuel price of greater than $ 2 per liter. Based on the findings, when the distance from the national grid is greater than 6.83 km, the renewable energy hybrid system is considered.

In 2019, Moein et al. [43] have conducted a study with respect to wind and solar data of 102 stations extracted from the NASA site using the HOMER software to determine the lowest interval from the national grid for the affordable use of solar-wind energies in Iran. The findings indicate that the average total net present cost (NPC) of the solar-wind hybrid system to supply a daily average electricity load of 5.9 kWh for a residential building with a peak load of 806 W is $ 12415, which could on average provide the building's needs through renewable energy by 95.3 %. For the affordable use of renewable energy, the average lowest interval from the national grid is 593 m.

In 2019, Rahimi et al. [44] have performed a study on the impacts of biogas applications on greenhouse gas emissions rate and the economic efficiency alongside an environmental, economic, technical analysis using the HOMER software. The results show that simple using biomass can supply the energy required for a cattle farm although solar and wind energies seemed to have the highest potential for power production in Isfahan. In addition, despite the lower cost of fossil fuels based electricity in Iran compared to many other countries, in the case of using biomass to produce electricity cattle farm, the costs will be compensated by the mid-15th year and will generate profit for 9.5 years later.

In 2019, Pahlavan et al. [45] have examined the impact of the factor of heat recovery on CHP generation in solar cell based distributed generation through three different scenarios using the HOMER software. Based on the results, fossil fuel consumption, CO_2 emissions, and price per kWh of energy reduce with increasing the heat recovery factor. Furthermore, using solar cells combined with boiler and generator increases the final costs while reduce the CO_2 emissions and fuel consumption in all three scenarios among which the second scenario "using natural gas for both generator and boiler" is the cheapest, and the third scenario "using diesel fuel for generator and natural gas for boiler" is the most expensive one. The cheapest produced electricity is priced at 0.167 $/kWh. In addition, the third scenario and hybrid photovoltaics (PV)-generator micro-grid outperform with respect to the environmental pollutant production with emitting 3604 kg/year CO_2 at their best.

In 2020, Alayi et al. [46] using HOMER software, evaluated the production of electricity from 420 tons of monthly waste in the city of Hamadan. Financial and environmental analyzes were performed. The results showed that 229,735 kWh of electricity is produced per year. Also, carbon dioxide and carbon monoxide emissions decreased by 77.2 and 7.96 kg per year, respectively. The cost per kWh of energy produced by the system was $ 0.177.

Novelty

The present work aimed to help the future perspective of the renewable energy industry by determining the exact potential, right sites, price/kWh, etc., in the corresponding sector. No comparative research has been conducted up to this time on the rate of electricity production from renewable energy sources including biomass, solar, and wind in different parts of Iran. In spite of the high potential of renewable energy sources, they have not yet been utilized fully and properly. Thus, the use of a hybrid renewable power plant was investigated using the HOMER 2.81 software at 103 stations in both on-grid and off-grid. The initial investment estimation, cost per kWh of electricity produced at each station, reduction rate of CO_2 emission, rate of usable power from any renewable component at each station, the maximum energy injected to the grid at each station, identification of the station with the maximum energy injected to the national grid, and the impact of on-grid mode at each station were investigated.

HOMER and governing equations

The HOMER software is a powerful tool improved by the National Renewable Energy Laboratory in the United States to determine the possibility of renewable energy-based system performance for concluding the minimum energy cost and the minimum NPC in 8760 h/year [47]. This tool was considered for a few reasons, including it is a free software application, it simplifies the design of renewable energy-based systems in two modes of off-grid and on-grid, and it is the most powerful software that performs the environmental, economic, technical analysis at the same time over a one-year period [48–50]. According to the HOMER software performance, the technical, climate, required load, economical, search space, and equipment specifications data are fed as input into the software, and then the minimum to the maximum NPC are ordered according to the results from simulations and optimization of the possible modes.

Theory and governing equations

Economic calculations

HOMER display a list of classified systems based on the total NPC as the main output. The NPC of a system is the present worthiness of all expenses bring forth the system during its lifetime such as costs of installation, replacement, buying electricity from the grid, emissions resulted fines, minus the present value of all earned revenue during its lifetime such as revenues from sailing electricity to the grid or scrapped equipment, which is given by [50,51]:

$$NPC = \frac{C_{ann,total}}{CRF(i, R_{proj})} \quad (1)$$

where $C_{ann,total}$ is NPC, CFR is the factor of capital recovery, I is the real interest rate, and R_{proj} is the lifetime of project. All the prices and revenues are computed at a constant interest rate annually, in which the inflation-induced real interest rate is calculated and the impact of changed interest rate on the ultimate net price is used to examine the inflation role.

The CFR that represents the capital return in N years is calculated by [50,51]:

$$CRF = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (2)$$

The software calculates the annual real interest rate by [50,51]:

$$i = \frac{i' - f}{1 + f} \quad (3)$$

The cost of energy (COE) in kWh during the project useful lifetime is also calculated as follows [50,51]:

$$COE = \frac{C_{ann,total}}{E_{Load\ Served}} \quad (4)$$

where $E_{Load\ Served}$ is the actual electrical charge by the hybrid systems in kWh/year that is priced in dollars.

Solar cells

The equation below is used to compute the outlet electricity from PV [52]:

$$P_{pv} = Y_{pv} \times f_{pv} \times \frac{\overline{H}_T}{\overline{H}_{T,STC}} \quad (5)$$

Where Y_{pv} is is a PV rated capacity in kW, f_{pv} is an effectiveness factor, $\overline{H}_T$ is the solar radiation incident on a PV surface in kW/m^2, $\overline{H}_{T,STC}$ is the solar radiation incident on the cell surface under modulus test situations that equals to 1 kW/m^2, P_{pv} is the output electricity from PV in kW.

The effectiveness factor indicates the difference between the rated performance and real performance resulted from dust, shading, wiring losses, high temperature, snow cover, etc., which accounts for about 90 % that decreases down to 70 % in a warm climate. The factor is considered about 90 % in the present work.

Wind turbines

The wind turbine power curve is a turbine significant characteristic that depicts the relationship between hub height wind speed and output power. In general, the power curve determines the wind turbine performance under standard temperature and pressure (STP). HOMER multiplies the power rate forecasted from the power curve by air density to regulate the real conditions as follows [52]:

$$P_{WTG} = \frac{\rho}{\rho_0} \times P_{WTG,STP} \quad (6)$$

where ρ is the density of air, ρ_0 is the density of air under STP conditions, P_{WTG} is the power output of wind turbine, and $P_{WTG,\ STP}$ is the power curved based power output of wind turbine.

Battery

The HOMER software calculates the maximum power received by a battery at each time step, which varies with respect to the percentage of remaining battery charge, discharge history, etc. The HOMER software consider the maximum power equal to the minimum energy for kinetic battery model, the maximum charge rate of the battery, and maximum charging current according to the equation below [53]:

$$P_{batt.\ cmax} = \frac{Min\left(P_{batt.\ cmax.kbm}.P_{batt.\ cmax.mcr}.P_{batt.\ cmax.mcc}\right)}{\eta_{batt.c}} \quad (7)$$

where $\eta_{batt.c}$ is the battery charge efficiency.

Generator

HOMER plots the corresponding efficiency diagram based on a given fuel curve that depicts the amount of fuel consumed by the generator to produce electricity. HOMER supposes a straight line for the fuel curve. Fuel consumption of the generator is mentioned in units/hr as a function of its electrical output as follows [44]:

$$\dot{m}_{fuel} = F_0 Y_{gen} + F_1 P_{gen} \quad (8)$$

where F_0 is the intercept coefficient of the fuel diagram in units/hr.kW, F1 is the fuel diagram slope in units/hr.kW, Y_{gen} is the generator rated capacity in kW, and P_{gen} is the electrical output in kW.

The generator electrical efficiency is the output electrical energy to input fuel chemical energy that is calculated in HOMER according to the equation below [54]:

$$\eta_{gen} = \frac{3.6\, P_{gen}}{\dot{m}_{fuel} LHV_{fuel}} \quad (9)$$

where LHV_{fuel} is the fuel low heating value in MJ/kg.

Electric inverter

The electric inverter size is specified according to the size of the renewable direct current (DC) electricity producer's renewable equipment to maximize the amount of energy received by electric inverter. The constant R is defined as the renewable DC electricity producer's renewable equipment to the inverter size ratio [55]:

Since the renewable DC electricity producer's renewable equipment does not always operate with rated power, the size of the electric inverter is always less than or equal to the size of the renewable DC electricity producer's renewable equipment ($R \geq 1$). In general, a big electric inverter is not cost-effective [56].

National grid

If the monthly net generated electricity is calculated, HOMER will calculate the total annual energy cost due to the equation below [57]:

$$C_{grid.\ energy} = \sum_{i}^{rates}\sum_{j}^{12}\begin{cases} E_{net\ grid\ purchases.i.\ j} \bullet c_{power.i}\, if\, E_{net\ grid\ purchases.i.\ j} \geq 0 \\ E_{net\ grid\ purchases.i.\ j} \bullet c_{sellback.i}\, if\, E_{net\ grid\ purchases.i.\ j} < 0 \end{cases} \quad (10)$$

where $E_{net\ grid\ purchases.i.\ j}$, $c_{power.i}$, and $c_{sellback.i}$ are the net grid purchase in j^{th} month when i^{th} rate is applied, grid electricity price for i^{th} rate, and electric sale price for i^{th} rate.

Information needed for simulation

Solar and wind speed

Appendixes 4 to 6 represent the maps for annual average (20 years) radiation incident on the surface of earth, wind speed, and index of air clearness for 103 study stations in Iran yearly, which corresponding data were extracted from the NASA site [58].

Livestock biomass

According to the experts and reference [59], an average of 9 kg/day manures per one was considered for cows, buffaloes, and camels, and an average of 1 and 1.3 kg/day manures per one was considered for sheep and goats, respectively. The amount of biomass available per month was considered 1 % of the total animal waste in each province. The carbon content in animal waste and gasification ratio for all the stations were defined 5 % and 0.7, respectively. The cost per ton of animal waste was defined $18 with respect to the shipping cost of 50 % and the dollar price of 120,000 Rial. The amount of animal waste per day is given in Table 3 [60].

Consumed electricity

The average electricity consumption in kW/day was determined from a residential building electric bill in one year that is depicted in Fig. 1. Based on this figure, the highest electrical power demand is for July (806 W); the highest average monthly electrical power demand is for August (308 W). The average annual electrical power is 246.7 W and the load factor is 0.36, which is the mean yearly used electricity divided by the maximum load in a specified period.

Price and equipment type

The price per liter of gasoline was defined $0.192144 with an assumption of project useful life of 25 years. The annual increment rate of fossil fuel price was considered about 10 % over 25 years in Iran [42].

The prices, sizes, useful life, and other applicable data on the components defined in the simulation were given in Table 4. It should be mentioned that the positioning angles of solar cells, which lack a solar tracking system, are equal to the latitude of the study area.

Grid connection

Considering the national grid accessibility at the study stations, the concerned wind system was jointed to the grid with the possibility of purchasing from the national grid and also of selling the surplus electricity to the grid. Three schemes were used for buying and selling electricity in the same price, so that $0.12, $0.07, and $0.05 per kWh for off-peak hours, peak hours, and mid-peak hours, respectively. From 23:00 PM to 8:00 AM is off-peak hours, from 8:00 AM to 4:00 PM is mid-peak hours and at other times, it is peak hours [62]. Furthermore, since CO_2 is the major produced pollutant, 632 gr of CO_2 is considered per kWh of national grid electricity [63]. The considered capacity of

Table 3
Animal waste per day in ton in each province [60].

Province	Animal waste per day (ton)	Province	Animal waste per day (ton)
East Azarbaijan	8684	Fars	10,349
West Azarbaijan	8564	Qazvin	4221
Ardebil	5316	Qom	1376
Isfahan	7118	Kordestan	3898
Alborz	1686	Kerman	6867
Ilam	2701	Kermanshah	3991
Bushehr	1622	Kohgiluyeh va Boyer-Ahmad	2404
Tehran	4857	Golestan	4718
Chaharmahal va Bakhtiari	3412	Gilan	4302
South Khorasan	3039	Lorestan	5148
Razavi Khorasan	11,559	Mazandaran	7759
North Khorasan	2878	Markazi	3997
Khozestan	7878	Hormozgan	1794
Zanjan	2558	Hamedan	4822
Semnan	2634	Yazd	2451
Sistan va Baluchestan	5022		

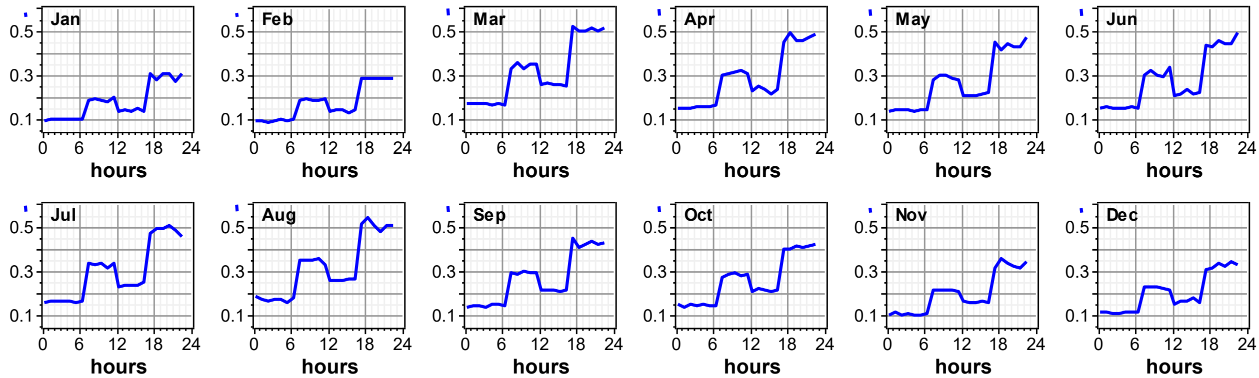


Fig. 1. Amount of electricity required per day.

Table 4
Simulated hybrid power plant data.

Component	Purchase ($/kW)	Replacement ($)	Maintenance ($)	lifetime	Size (kW)	Other information
Solar cell [61]	3200	3000	0	20 years	0–4	Lifetime: 20 years Derating factor: 90 % Azimuth: South
Battery Trojan T-105 [61]	174	174	5	845 kWh	0–20	Lifetime: 845 kWh Battery/string: 1 Initial charge: 100 %
Wind turbine BWC XL.1 [61]	5725	3650	100	20 years	0–3	Rated power: 1 kW DC Lifetime: 20 years Hub height: 25 *m*
Converter [61]	200	200	10	10 years	0–2	Lifetime: 10 years Efficiency: 90 %
Biomass generator [40]	800	700	0.001	15,000 h	0–6	Lifetime: 15,000 h Minimum load ratio: 30 % Efficiency: 24 %
Diesel generator [61]	200	200	0.5	15,000 h	0–3	Lifetime: 15,000 h Minimum load ratio: 30 % Efficiency: 34 %

electricity to buy from/sell to the national grid was 1000 kW.

Price per km cabling, annual maintenance cost per km cabling, and average price for grid electricity should be determined for comparison of the cost of using the national grid with that of purchasing the hybrid renewable system, which were considered $7600.6, $160, and 0.01392 according to the experts, respectively.

GIS software

The model used for interpolation in GIS software is the Inverse distance weighting method, which is common and widely used. This method uses the averaging of sample points that are adjacent to each unknown point. The effect of the intensity of spatial dependence on data can be applied using power in the inverse distance. The second inverse power of this model has been used repeatedly by researchers [64–66].

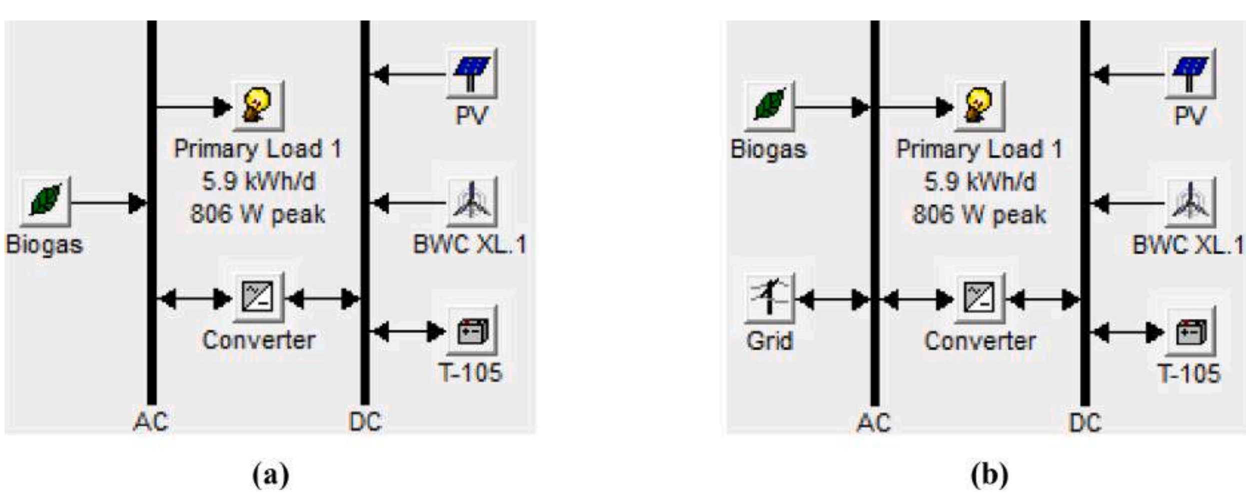


Fig. 2. A schematic of simulated power plants, a) biogas generator and off-grid, b) biogas generator and on-grid.

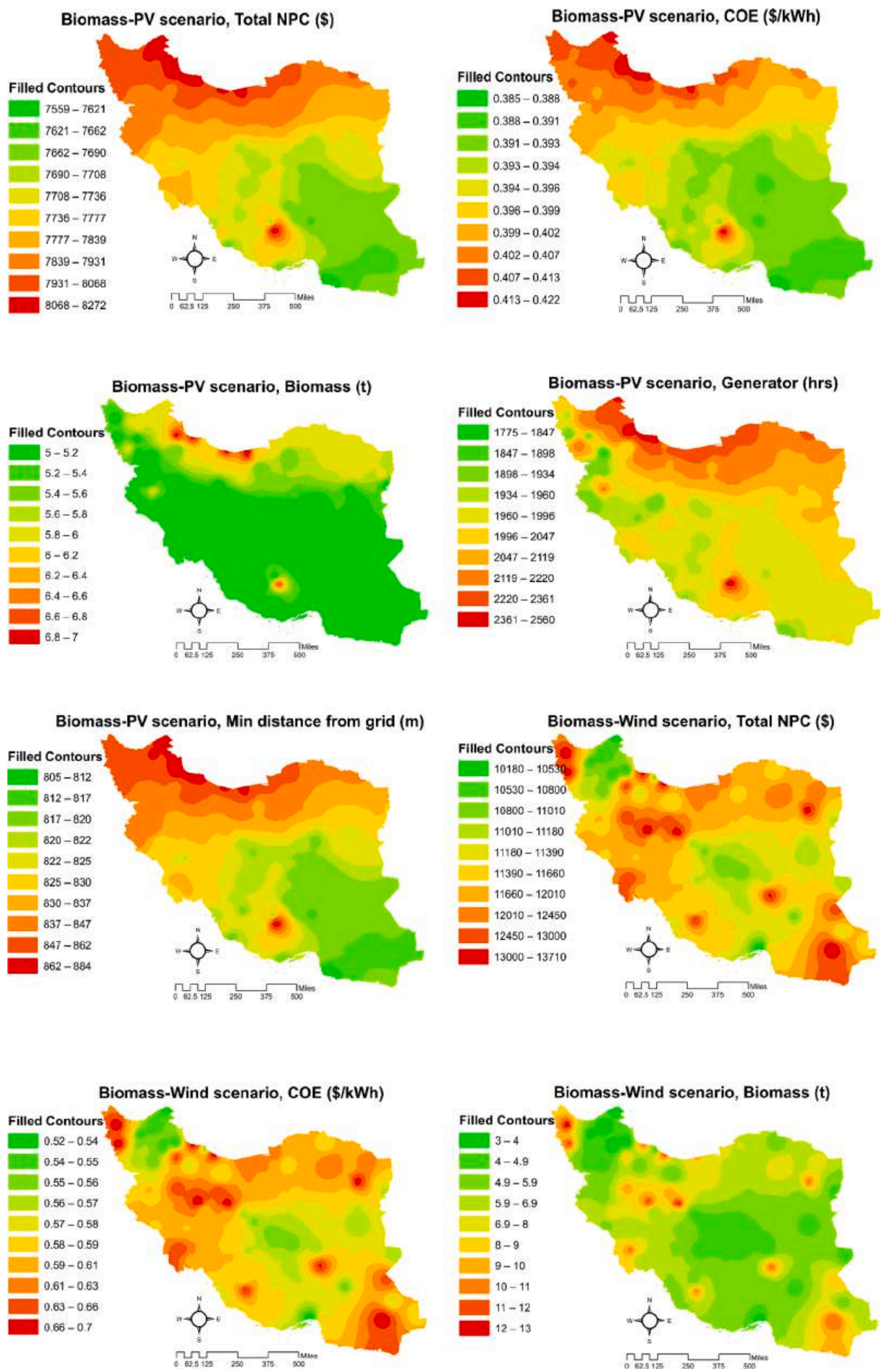


Fig. 3. Economic analysis results of different scenarios of off-grid mode.

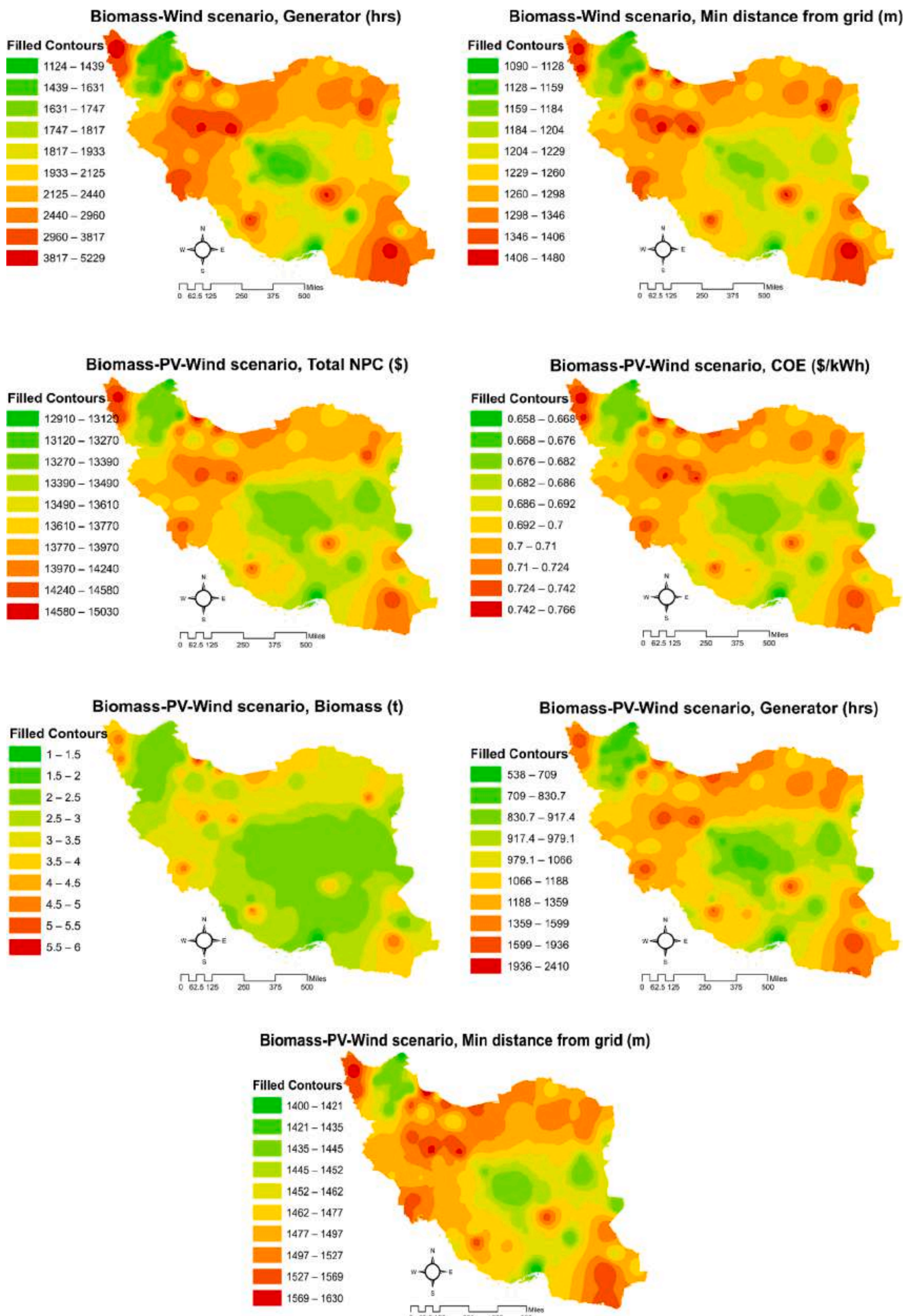


Fig. 3. (*continued*).

Results

A schematic of the renewable power plants simulated by HOMER 2.81 is represented in Fig. 2.

When the produced electricity exceeds demand, surplus electricity is saved in the battery in order to be used at peak hours. The generator is used as a support system in some cases, including when there is no solar or wind energy, their intensity is low, their application has no economic justification, and batteries are also empty.

Results for off-grid mode

Economic analysis

Fig. 3 represent the economic results from the investigation of using renewable energy-based hybrid systems at 103 stations in Iran. Fig. 3 includes information for the least distance from the grid given the cost-effectiveness of using renewable energies, generator operating, fuel consumption rate in the optimal economic case, cost per kWh of produced electricity in the optimal economic case, total NPC.

Biomass generator and wind turbine based system. The results indicate that the maximum, minimum, and average distance from the national grid to be cost-effectiveness of using wind turbines are 1.48, 1.09, and 1.26 km in the optimal economic scenario, respectively. The maximum distance is attributed to Arak, Iranshahr, Kashan, and Khoy stations and the minimum distance is attributed to Bandarabbas station. Based on the results, the cost for using the national grid is less than the cost of purchasing the biomass generator and wind turbine based system for distances smaller than the values above. In the optimal economic scenario, the average generator operating in study stations is 2326 h. The maximum and minimum generator operating times are 5229 and 1124 h for Khoy and Ahar stations, respectively. In addition, the average biomass consumed by the generator is 6.245 ton/year for study stations among which the maximum and minimum values are 13 tons and 3 tons for Khoy and Ahar stations, respectively.

The energy required by all the stations is supplied by 100 % using biomass and or wind. Thus, the consumption rate of renewable energies for all the study stations is 100 %. The maximum cost per kWh of the generated electricity $0.699 is attributed to Kashan and Khoy, the minimum cost per kWh of the generated electricity $0.519 is attributed to Bandarabbas, and the average cost per kWh of the generated electricity equals 0.596. The maximum, minimum, and average total NPCs are $13710, $10182, and $11681.9, which the maximum price is for Bandarabbas station, and the minimum one is for Kashan station.

Biomass generator and solar cell-based system. The results indicate that the maximum, minimum, and average distance from the national grid to be cost-effectiveness of using solar cells are 0.884, 0.805, and 0.832 km in the optimal economic scenario, respectively. The maximum distance is attributed to Anzali station, and the minimum distance is attributed to Jask station. Based on the results, the cost for using the national grid is less than the cost of purchasing the solar cells based system for distances smaller than the values above.

In the optimal economic scenario, the average generator operating in study stations is 2047 h. The maximum and minimum generator operating times are 2560 and 1775 h for Darab and Khomeyn stations, respectively. In addition, the average biomass consumed by the generator is 5.337 tons/year for study stations among which the maximum and minimum values are 7 tons and 5 tons for Darab and Khomeyn stations, respectively.

The energy required by all the stations is supplied by 100 % using solar energy or biomass. Thus, the consumption rate of renewable energies for all the study stations is 100 %. The maximum cost per kWh of produced electricity $0.442 is attributed to Anzali station, the minimum cost per kWh of generated electricity $0.385 is attributed to Jask station, and the average cost per kWh of generated electricity equals 0.398. The maximum, minimum, and average total NPCs are $8272, $7559, and $7807.7, which the maximum cost is for Anzali station, and the minimum one is for Jask station.

Hybrid biomass generator-solar-wind system. The results indicate that the maximum, minimum, and average distance from the national grid to be cost-effectiveness of simultaneous use of solar cells and wind turbines are 1.63, 1.4, and 1.484 km in this optimal economic scenario, respectively. The maximum distance is attributed to Anzali and Babolsar stations, and the minimum distance is attributed to Bandarabbas station. Based on the results, the cost for using the national grid is less than the cost of purchasing the hybrid renewable system for distances smaller than the values above.

In the optimal economic scenario, the average generator operating in study stations is 1156.4 h. The maximum and minimum generator operating times are 2410 and 538 h for Babolsar and Bandarabbas stations, respectively. In addition, the average biomass consumed by the generator is 2.93 ton/year for study stations among which the maximum and minimum values are 6 tons (Babolsar and Anzali stations) and 1 ton (Bandarabbas), respectively.

The energy needed by all the stations is provided by 100 % using solar and wind energies or biomass. Thus, the consumption rate of renewable energies for all the study stations is 100 %. The maximum price per kWh of generated electricity $0.766 is attributed to Anzali station, the minimum price per kWh of generated electricity $0.658 is attributed to Jask station, and the average price per kWh of generated electricity equals 0.699. The maximum, minimum, and average total NPCs are $15027, $12911, and $13705, which the maximum price is for Babolsar station, and the minimum one is for Bandarabbas station.

Environmental-technical analysis of off-grid case

Fig. 4 represent the results from the use of environmental-technical analysis of renewable energies based hybrid systems at 103 stations in Iran. This figure includes information for the surplus generated electricity, generated pollutant rate, and the percentage and the contribution of used renewable energies (wind, solar, and hybrid wind-solar) from total produced electricity.

Biomass generator and wind turbine based system. Some surplus electricity will be generated in the case of off-grid. The maximum, minimum, and average surplus electricity are 41.3 %, 14.637 %, and 0 % for 103 study stations. The maximum surplus electricity is for Bandarabbas station (see **Appendix 7**) and the minimum surplus electricity is for Arak station (see **Appendix 8**). As it is seen from the results, the percentage of electricity production from wind energy and the amount of wind-based produced electricity are 87 %, 3626 kWh/year, and 1 %, 19 kWh/year for Bandarabbas and Arak stations, respectively.

Since the generator is used for electricity production in emergencies in this scenario, some major environmental pollutants will be produced such as CO_2. The total CO_2 production for all the study stations is 111.1 kg/year. The maximum and minimum produced CO_2 emissions are 2.2 and 0.5 kg attributed to Khoy and Bandarabbas stations, respectively.

Biomass generator and solar cells based system. Some surplus electricity will be generated in the case of off-grid. The maximum, minimum, and average surplus electricity are 23.6 %, 9.69 %, and 17.9 % for 103 study stations. The maximum surplus electricity is for Jask station (see **Appendix 9**) and the minimum surplus electricity is for Darab station (see **Appendix 10**). As it is seen from the results, the percentage of electricity production from solar energy and the amount of solar-based produced electricity are 69 %, 2201 kWh/year, and 48 %, 1324 kWh/year for Jask and Darab stations, respectively.

Since the generator is used for electricity production in emergencies in this scenario, some major environmental pollutants will be produced

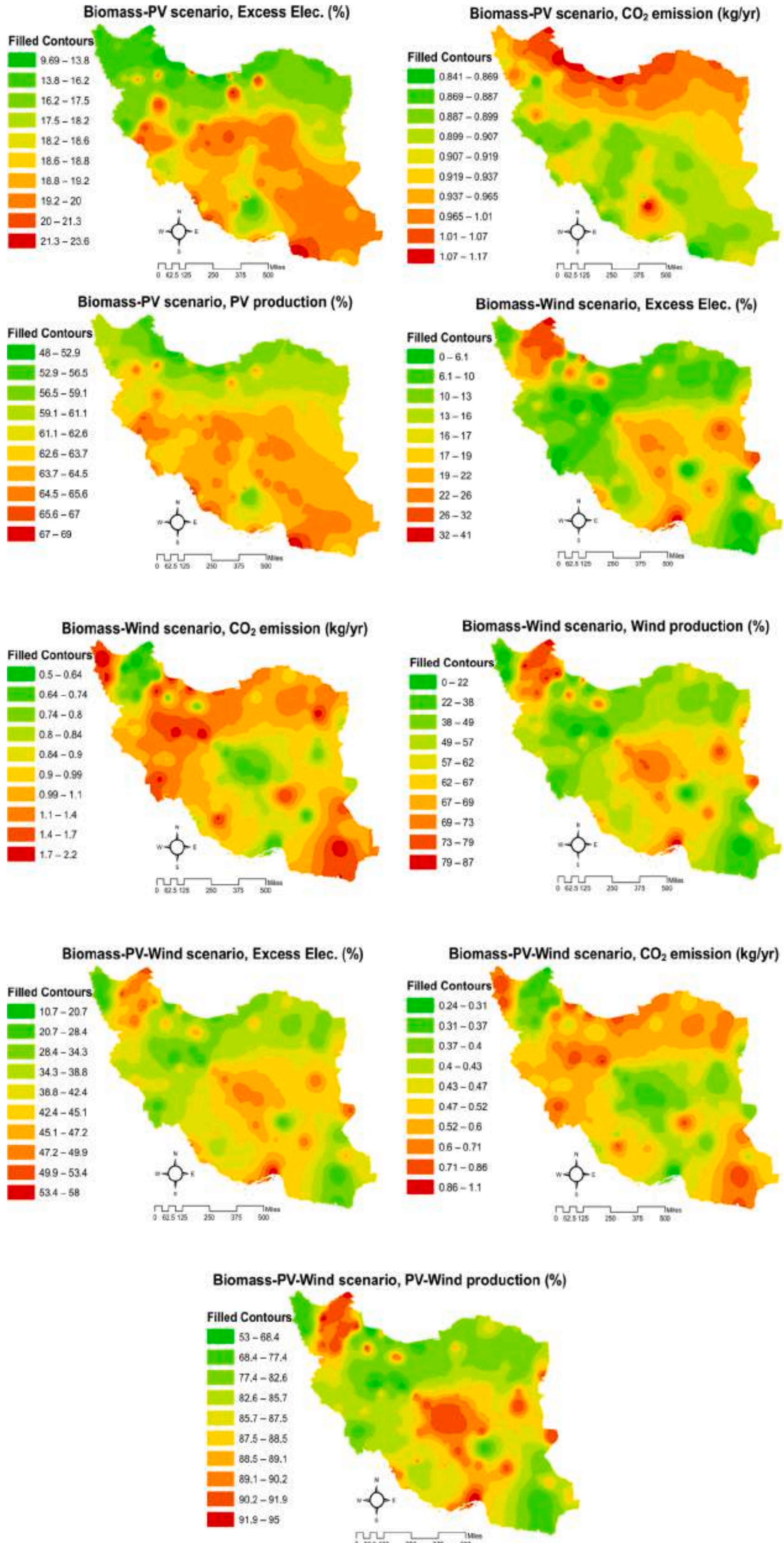


Fig. 4. Environmental-technical analysis of different scenario of off-grid mode.

such as CO_2. The total CO_2 production for all the study stations is 96.7 kg/year. The maximum and minimum produced CO_2 emissions are 1.17 and 0.841 kg, which are attributed to Darab and Khoy stations, respectively.

Biomass generator and hybrid solar-wind system. Some surplus electricity will be generated in the off-grid case. The maximum, minimum, and average surplus electricity are 58 %, 10.7 %, and 39.17 % for 103 study stations. The maximum surplus electricity is for Bandarabbas station (see **Appendix 11**) and the minimum surplus electricity is for Anzali station (see **Appendix 12**). As it is seen from the results, the percentage of electricity production from solar and wind energies and the amount of solar and wind energies based produced electricity are 33 %,62 %, 1908 kWh/year, and 3626 kWh/year, and 50 %,6%, 1396 kWh/year, and 161 kWh/year for Bandarabbas and Anzali stations, respectively.

Since the generator is used for electricity production in emergencies in this scenario, some major environmental pollutants will be produced such as CO_2. The total CO_2 production for all the study stations is 53.1 kg/year. The maximum and minimum produced CO_2 emissions are 1.1 and 0.236 kg, which are attributed to Babolsar and Bandarabbas stations, respectively.

Results for on-grid mode

Economic analysis

Fig. 5 represent the economic results from the investigation of using renewable energy-based hybrid systems at 103 stations in Iran. This figure includes information for the usage rate of renewable energies, the price per kWh of produced electricity in the optimal economic case and total NPC.

Biomass generator and wind turbine based system. In this scenario, the biomass generator operates for 2555 h using 10-ton biomass per year. The average percentage of renewable energy usage is 85.4 %, in which the maximum percentage of 94 % is for Bandarabbas, Parsabad, and Tabriz stations, and the minimum percentage of 68 % is for Khoy. **Appendix 13** represents the average electricity produced from wind turbines in 24 h per year for Bandarabbas, Parsabad, and Tabriz stations. As it is obvious from the results, the maximum produced electricity in Parsabad station is more than Tabriz station, while Tabriz station has the most hours with maximum produced electricity.

In this scenario, the average cost per kWh of electricity production at 103 study stations is $0.198, in which the maximum and minimum values are $0.278 and $0.129 for Khoy and Bandarabbas, respectively. The maximum and minimum values are $9465 and $7142 for Khoy and Bandarabbas, and total NPC is $8304.6 for all the study stations, respectively.

Biomass generator and solar cells based system. In this scenario, the biomass generator operates for 2555 h using 10-ton biomass per year. The average percentage of renewable energy usage is 90.2 %, in which the maximum percentage of 92 % is for Iranshahr, Jask, Khash, and Saravan stations, and the minimum percentage of 84 % is for Gorgan. **Appendix 14** represents the average electricity produced from solar cells in 24 h per year for Iranshahr, Jask, Khash, Saravan, and Gorgan stations. As it is obvious from the results, the amount of electricity produced in warm months is lower than the coldest months, indicating the electricity production from solar cells reduces with increasing temperature.

In this scenario, the average cost per kWh of electricity production at 103 study stations is $0.116, in which the maximum and minimum values are $0.217 and $0.106 for Jask and Bushehr stations, respectively. The maximum and minimum values are $8636 and $4719 for Gorgan and Jask stations, and total NPC is $4923.9 for all the study stations, respectively.

Biomass generator and hybrid solar-wind system. The average percentage of renewable energy usage is 95.1 %, in which the maximum percentage of 98 % is for Bandarabbas station, and the minimum percentage of 88 % is for Anzali. **Appendix 15** represents the average simultaneous electricity production from solar cells and wind turbines in 24 h per year for Bandarabbas, Anzali and Babolsar stations. As it is obvious from the results, the results indicate the absolute superiority of Bandarabbas station compared to Anzali and Babolsar stations.

In this scenario, the average cost per kWh of electricity production at 103 study stations is $0.207, in which the maximum and minimum values are $0.299 and $0.141 for Babolsar and Bandarabbas stations, respectively. The maximum and minimum values are $812015 and $9822 for Babolsar and Bandarabbas stations, and total NPC is $10823.7 for all the study stations, respectively.

Environmental analysis of on-grid case

Fig. 6 represent the results from the use of environmental analysis of renewable energies based hybrid systems at 103 stations in Iran. This figure includes information for produced pollutant rate.

Biomass generator and wind turbine based system. In this scenario, the Khoy station with −251 kg CO_2 emission per year and Bandarabbas station with −2272 kg CO_2 emission per year occupy the maximum and minimum ranks on CO_2 production rate, respectively. A total of 121835 kg CO_2 emissions per year have been prevented at the study stations.

Biomass generator and solar cells based system. In this scenario, the Darab station with −1001 kg CO_2 emission per year and Jask station with −1449 kg CO_2 emission each year occupy the maximum and minimum ranks on CO_2 production rate, respectively. A total of 134529 kg CO_2 emissions each year have been prevented at the study stations.

Biomass generator and hybrid solar/wind system. The average surplus electricity produced for the study stations is 2.9 %, which the Parsabad station with 6.32 % is at the top of the table. In this scenario, the Babolsar station with −1107 kg CO_2 emission each year and Bandarabbas station with −3395 kg CO_2 emission each year occupy the maximum and minimum ranks on CO_2 production rate, respectively. A total of 219801 kg CO_2 emissions per year have been prevented at the study stations.

Conclusion

So far, no comprehensive study has been conducted on the biomass-based renewable hybrid system in Iran. Therefore, in order to help decision-makers in the field of renewable energy in both on-grid and off-grid, using GIS software, an attempt has been made to select suitable areas for operation. Knowing the potential of different points and focusing on the suitable areas are the most important points in renewable energy projects. Accordingly, the design of the renewable hybrid power plant was performed at 103 stations with respect to wind and solar data extracted from the NASA site using the HOMER software for simulation. Four scenarios were investigated, including off-grid, on the grid, the use of diesel generator, and biomass generator. The environmental, economic, energy parameters were addressed and a comprehensive analysis was conducted on the different site's potential for using renewable energy sources by individual and hybrid systems.

- In the scenario "using a biogas generator-wind turbine system in off-grid mode," Bandarabbas station with the least distance of 1.09 km from the national grid was considered as the best option.

- In the scenario "using a biogas generator-wind turbine system in off-grid mode," the average cost per kWh of produced electricity was $0.598.

- In the scenario "using a biogas generator-solar cell system in off-grid mode," Jask station with the least distance of 0.805 km from the

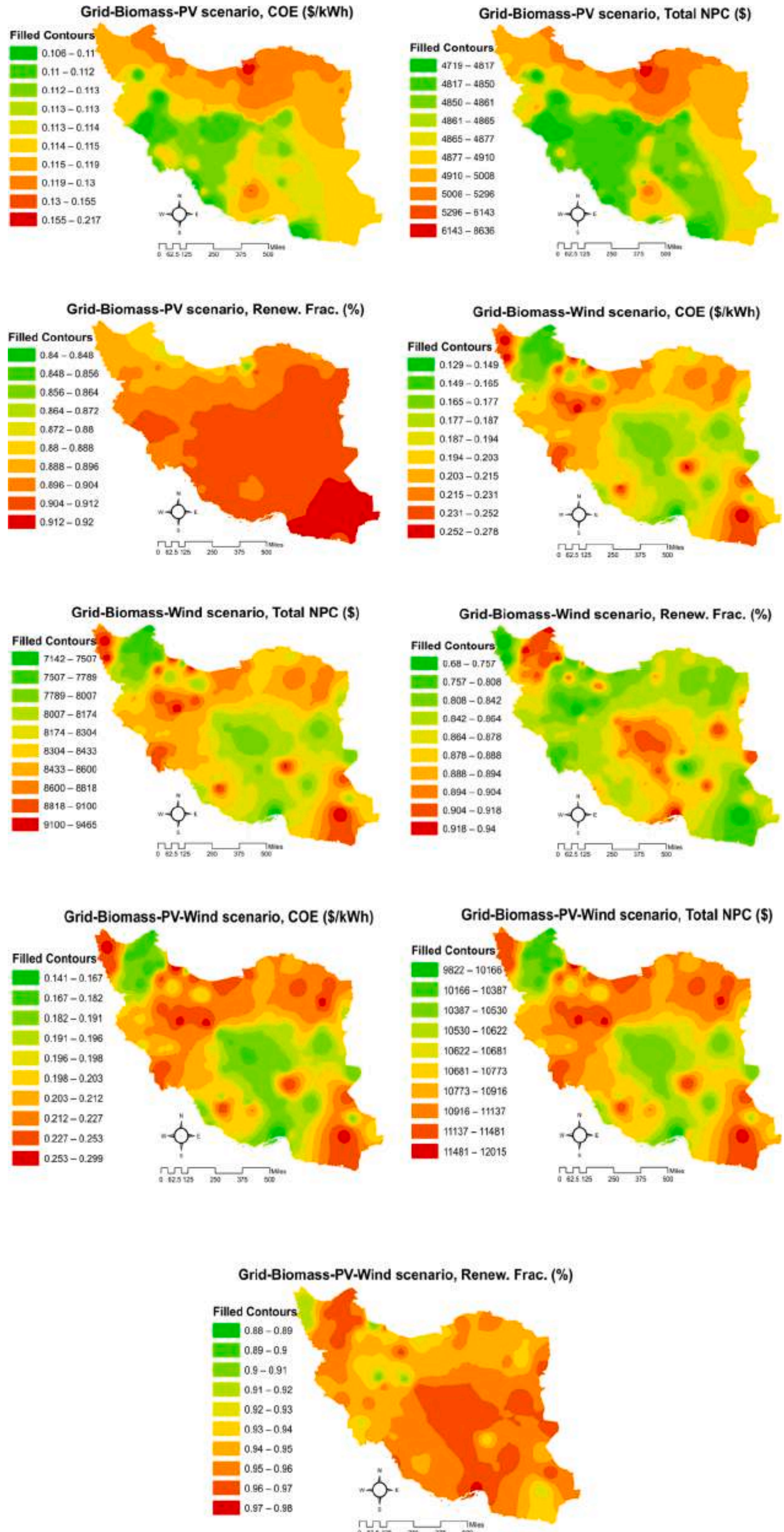


Fig. 5. Economic analysis of different scenario of on-grid mode.

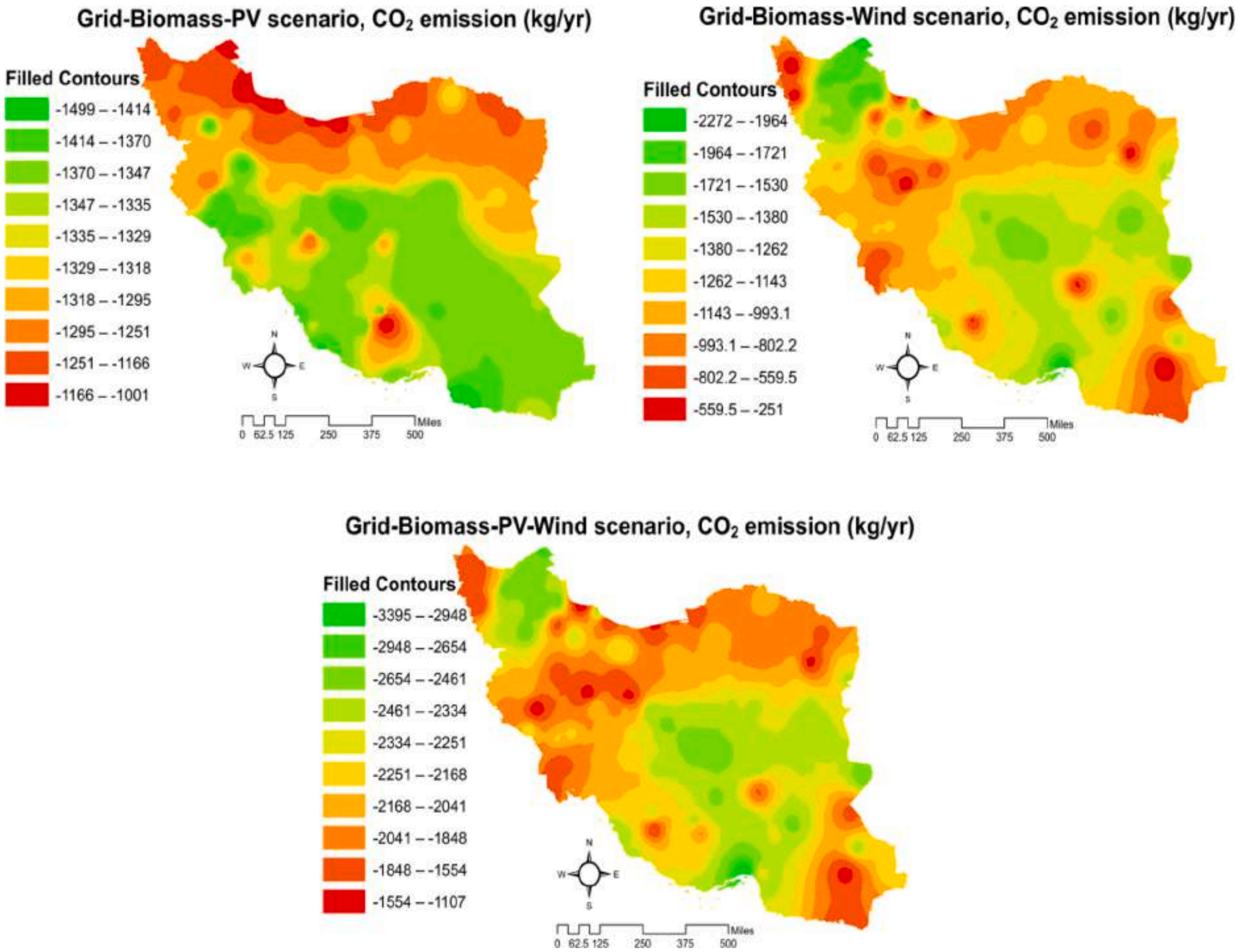


Fig. 6. Environmental analysis for different scenario of on-grid mode.

national grid was considered as the best option.

- In the scenario "using a biogas generator-solar cell system in off-grid mode," the average cost per kWh of produced electricity was $0.398.

- In the scenario "using a biogas generator- wind turbine-solar cells system in off-grid mode," Bandarabbas station with the least distance of 1.4 km from the national grid was considered as the best option.

- In the scenario "using a biogas generator-wind turbine-solar cells system in off-grid mode," the average cost per kWh of produced electricity was $0.699.

- In the scenario "using a biogas generator-wind turbine system in on-grid mode," Jask was considered as the best option.

- In the scenario "using a biogas generator-wind turbine system in on-grid mode," the average cost per kWh of produced electricity was $0.198.

- In the scenario "using a biogas generator-wind turbine system in on-grid mode," a total of 121835 kg CO_2 emissions are prevented annually.

- In the scenario "using a biogas generator-solar cell system in on-grid mode," Jask and Bushehr stations were considered as the best options.

- In the scenario" "using a biogas generator-solar cell system in on-grid mode," the average cost per kWh of produced electricity was $0.116.

- In the scenario "using a biogas generator-solar cell system in on-grid mode," a total of 134529 kg CO_2 emissions are prevented annually.

- In the scenario "using a biogas generator- wind turbine-solar cells system in on-grid mode," Bandarabbas station was considered as the best option.

- In the scenario "using a biogas generator-wind turbine-solar cells system in on-grid mode," the average cost per kWh of produced electricity was $0.207.

- In the scenario "using a biogas generator-wind turbine-solar cell system in on-grid mode," a total of 219801 kg CO_2 emissions are prevented annually.

CRediT authorship contribution statement

Mohammad Hossein Razavi Dehkordi: Formal analysis, Methodology, Software, Validation, Resources, Writing – original draft, Writing – review & editing. **Amir Homayoon Meghdadi Isfahani:** Formal analysis, Methodology, Software, Validation, Investigation, Writing – original draft. **Ehsan Rasti:** Formal analysis, Investigation, Resources, Writing – original draft. **Reza Nosouhi:** Formal analysis, Investigation, Resources, Writing – review & editing. **Mohammad Akbari:** Methodology, Software, Validation, Investigation, Writing – original draft. **Mehdi Jahangiri:** Formal analysis, Methodology, Software, Validation, Supervision, Writing – review & editing, Resources.

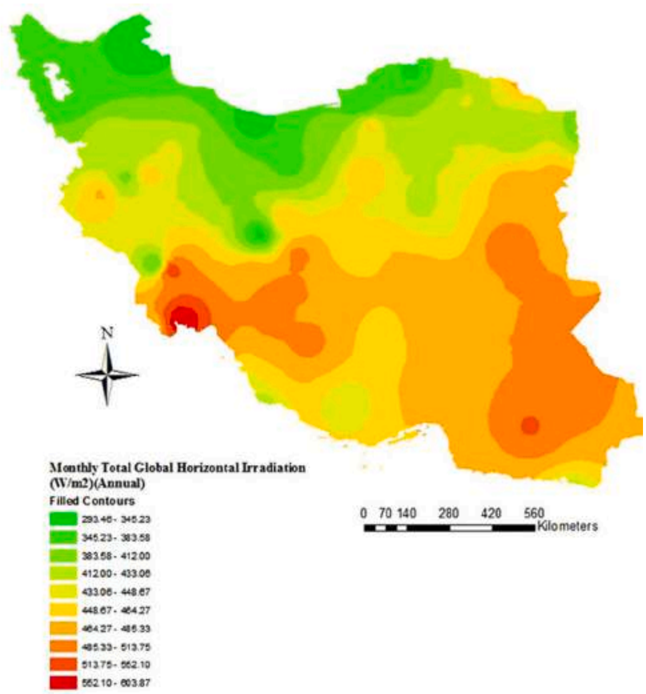
Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

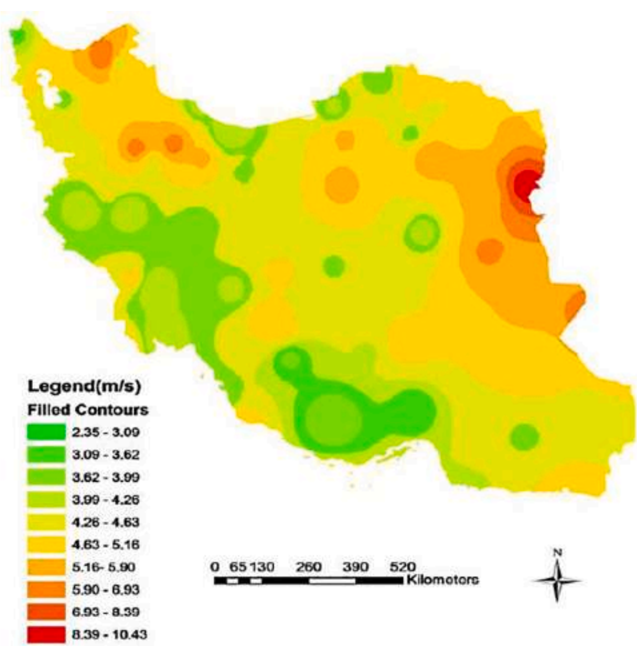
Data availability

No data was used for the research described in the article.

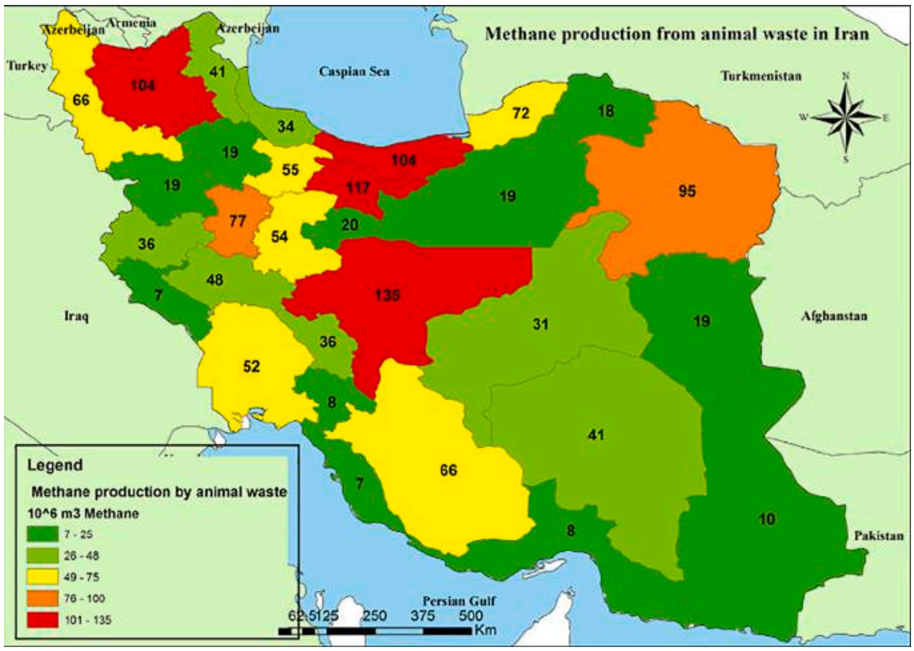
Appendix 1. Solar Energy Atlas in Iran [15].



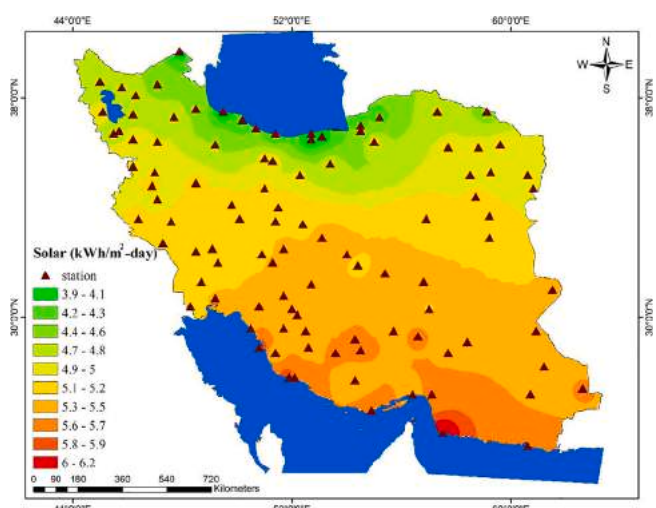
Appendix 2. Wind speed atlas in Iran [35].



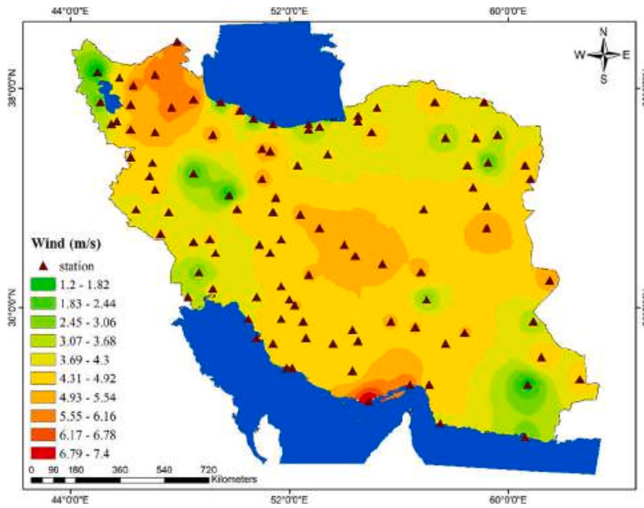
Appendix 3. Annual biogas production atlas in Iran [38].



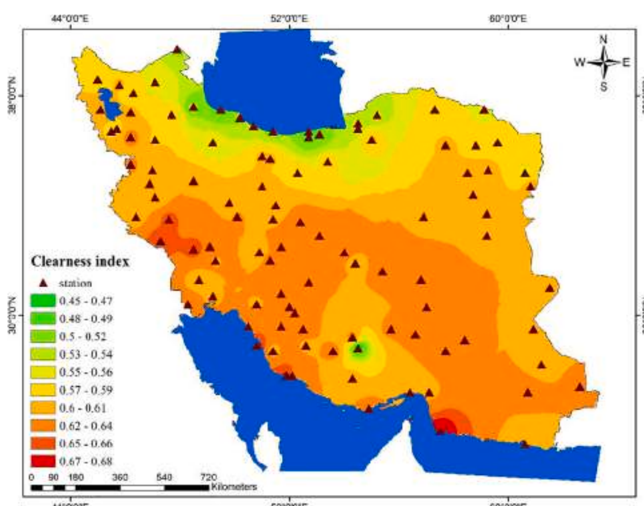
Appendix 4. Map for radiation incident on earth's surface in Iran [43].



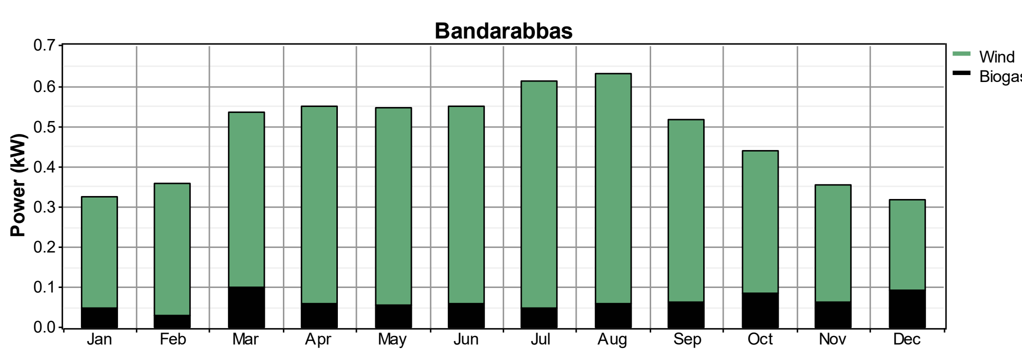
Appendix 5. Map for wind speed at 10m height in Iran [43].



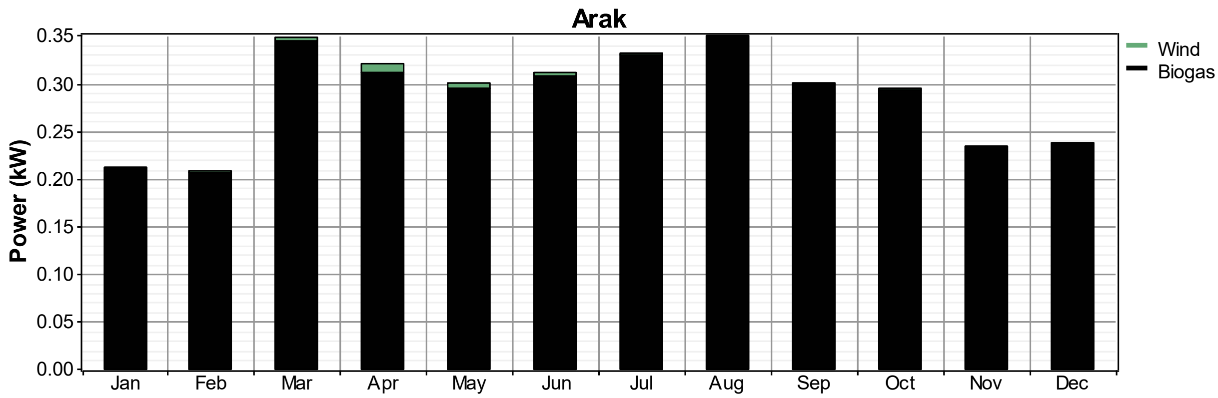
Appendix 6. Map for air clearness index in Iran [43].



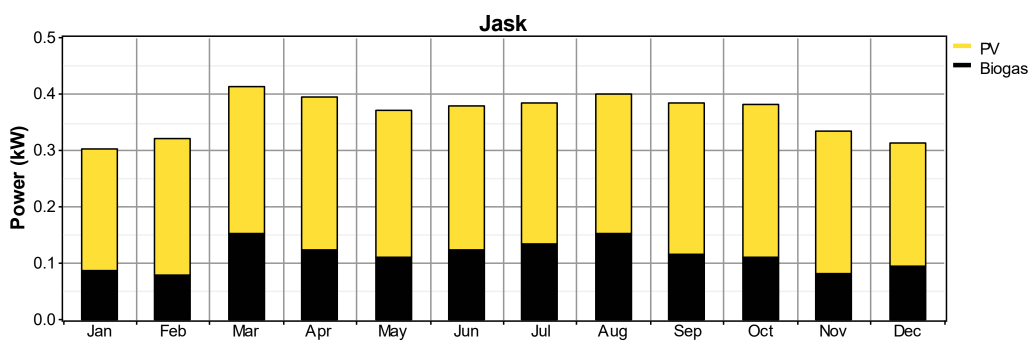
Appendix 7. Monthly average electricity production for Bandarabbas station.



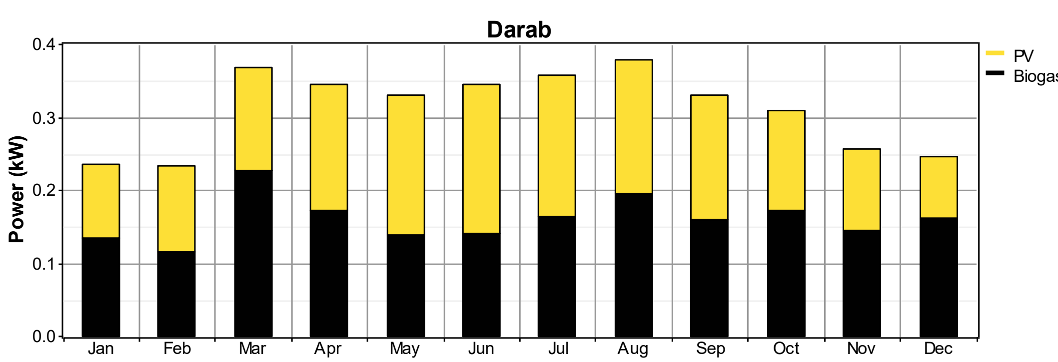
Appendix 8. **Monthly average electricity production for Arak station.**



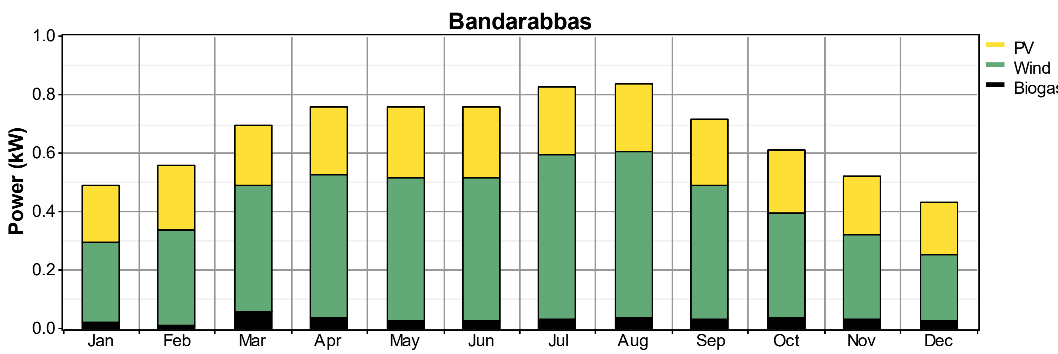
Appendix 9. **Monthly average electricity production for Jask station.**



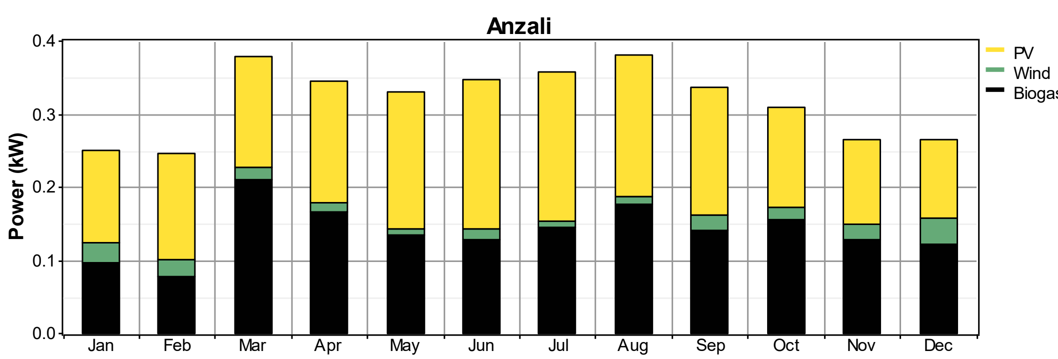
Appendix 10. **Monthly average electricity production for Darab station.**



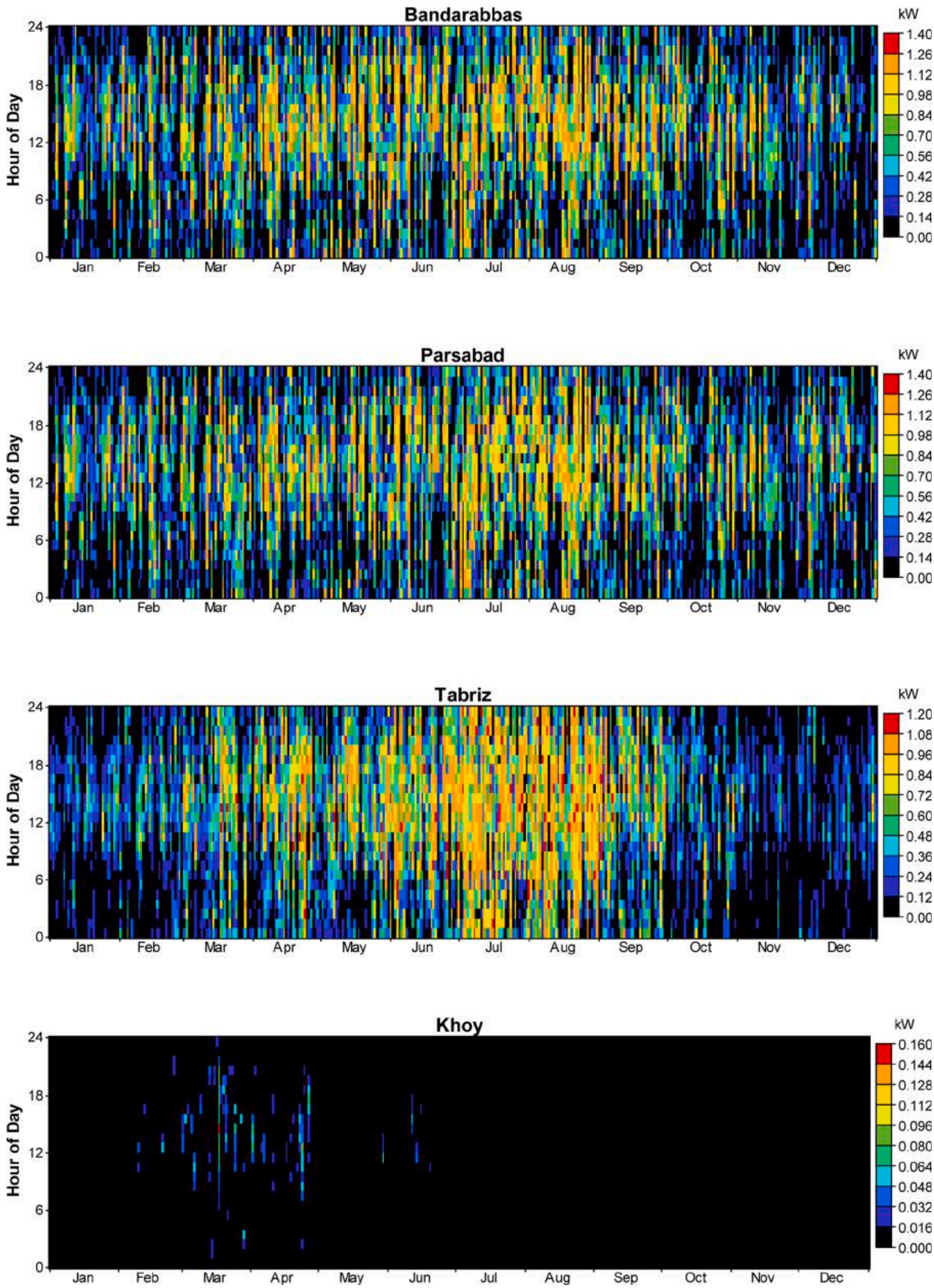
Appendix 11. Monthly average electricity production for Bandarabbas station.



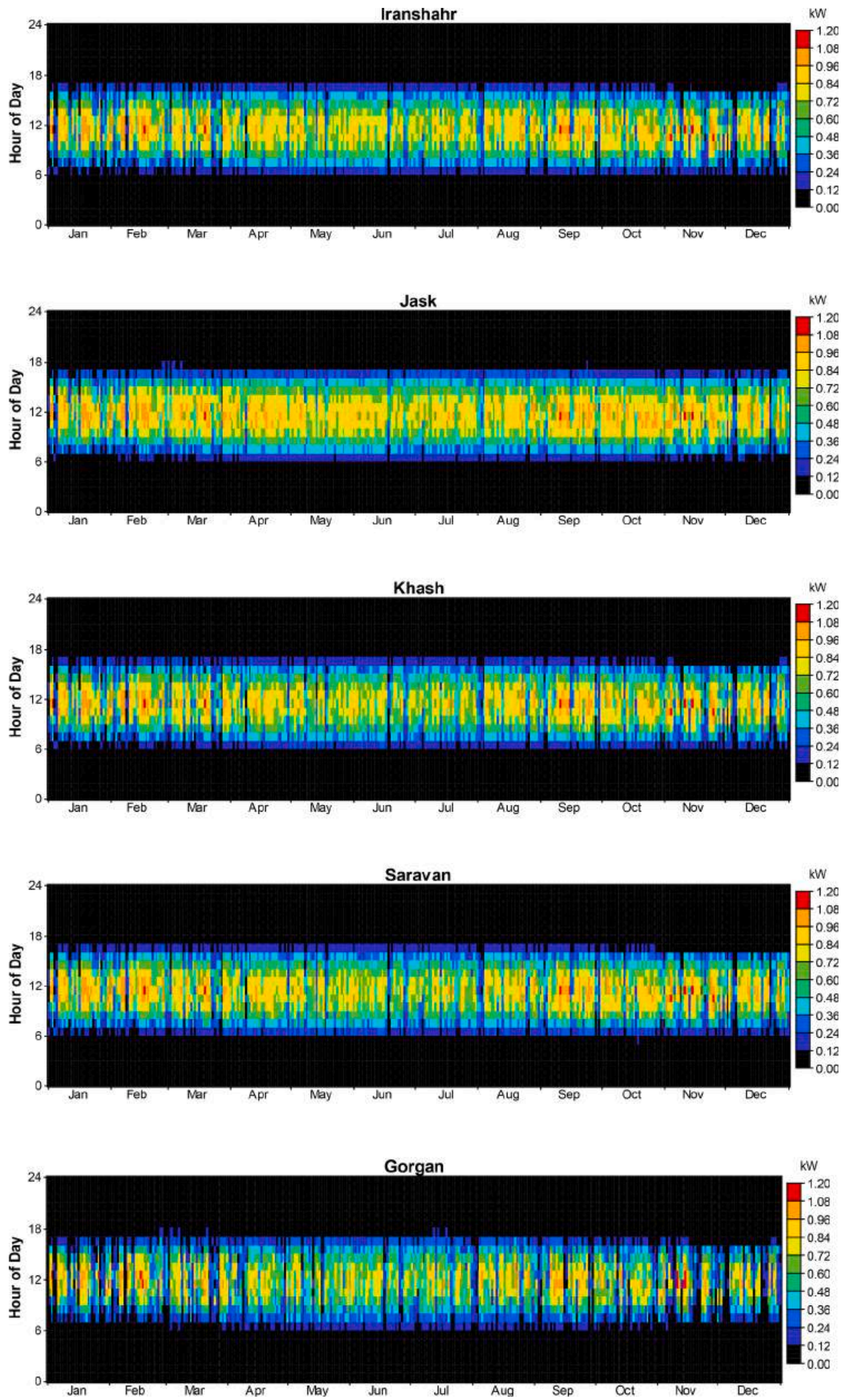
Appendix 12. Monthly average electricity production for Anzali station.



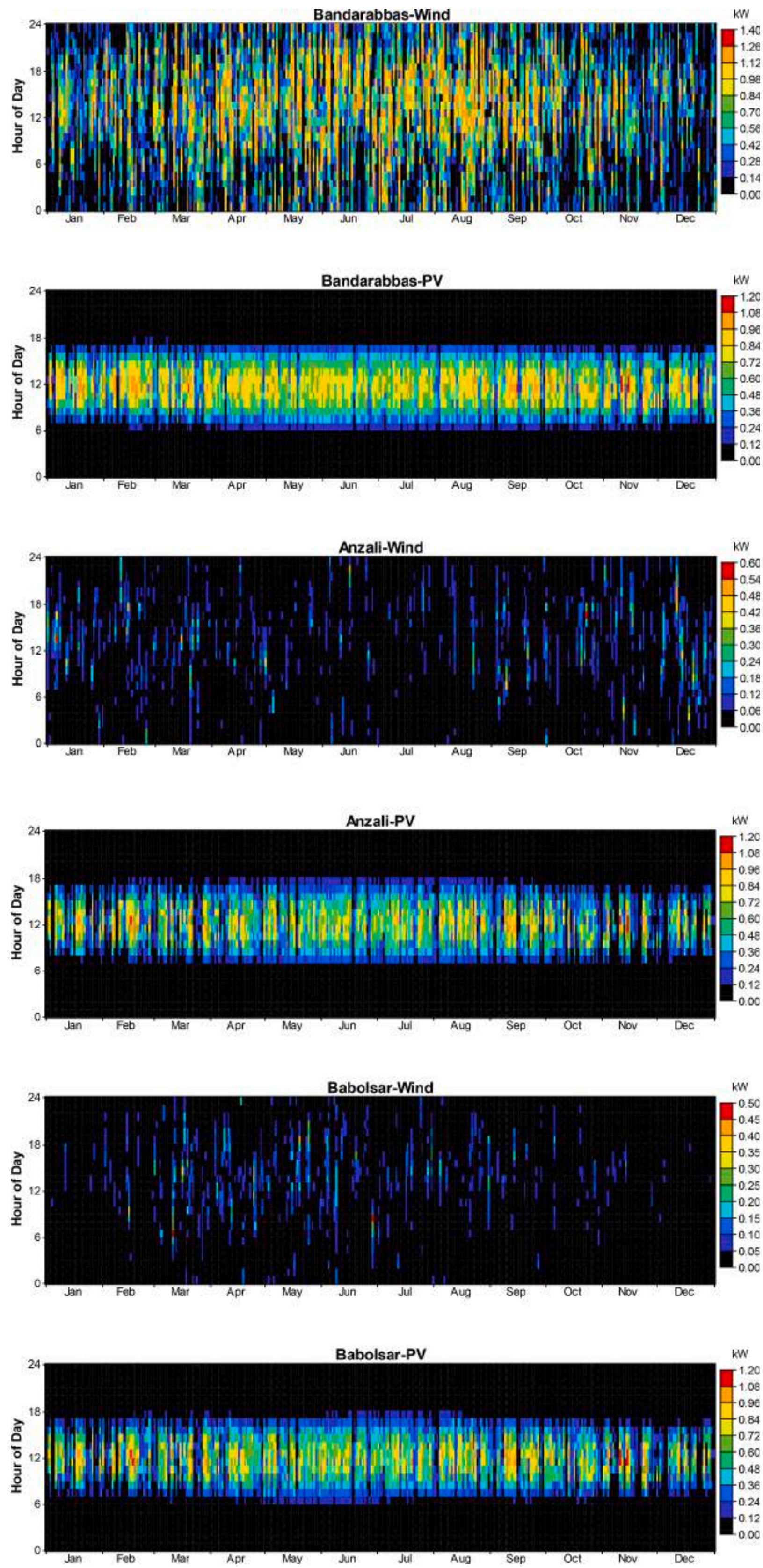
Appendix 13. Average electricity production from wind in 24 hours per year for Bandarabbas, Parsabad, Tabriz and Khoy stations.



Appendix 14. Average electricity production from PV in 24 hours per year Iranshahr, Jask, Khash, Saravan, and Gorgan stations.



Appendix 15. Average electricity production from wind and PV in 24 hours per year Bandarabbas, Anzali and Babolsar stations.



References

[1] BEE, Bureau of Energy Efficiency, 2010. http://www.bee india.nic.in/ecbc.php [Available: 21 July 2019].

[2] Singh MK, Mahapatra S, Atreya SK. Thermal performance study and evaluation of comfort temperatures in vernacular buildings of North-East India. Build Environ 2009;45(2):320–9. https://doi.org/10.1016/j.buildenv.2009.06.009.

[3] Peng Y, Xu Z, Wang M, Li Z, Peng J, Luo J, et al. Investigation of frequency-up conversion effect on the performance improvement of stack-based piezoelectric generators. Renewable Energy 2021;172:551–63. https://doi.org/10.1016/j.renene.2021.03.064.

[4] Yan SR, Fazilati MA, Samani N, Ghasemi HR, Toghraie D, Nguyen Q, et al. Energy efficiency optimization of the waste heat recovery system with embedded phase change materials in greenhouses: a thermo-economic-environmental study. J Storage Mater 2020;30:101445. https://doi.org/10.1016/j.est.2020.101445.

[5] Ershadi H, Karimipour A. Present a multi-criteria modeling and optimization (energy, economic and environmental) approach of industrial combined cooling heating and power (CCHP) generation systems using the genetic algorithm, case study: a tile factory. Energy 2018;149:286–95. https://doi.org/10.1016/j.energy.2018.02.034.

[6] Peng Y, Zahedidastjerdi A, Abdollahi A, Amindoust A, Bahrami M, Karimipour A, et al. Investigation of energy performance in a U-shaped evacuated solar tube collector using oxide added nanoparticles through the emitter, absorber and transmittal environments via discrete ordinates radiation method. J Therm Anal Calorim 2020;139(4):2623–31. https://doi.org/10.1007/s10973-019-08684-w.

[7] Zhu B, Zhong Q, Chen Y, Liao S, Li Z, Shi K, Sotelo MA. A Novel Reconstruction Method for Temperature Distribution Measurement Based on Ultrasonic Tomography. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control* 2022. https://doi: 10.1109/TUFFC.2022.3177469.

[8] Zhang K, Ali A, Antonarakis A, Moghaddam M, Saatchi S, Tabatabaeenejad A, et al. The sensitivity of North American terrestrial carbon fluxes to spatial and temporal variation in soil moisture: An analysis using radar-derived estimates of root-zone soil moisture. J Geophys Res Biogeosci 2019;124(11):3208–31. https://doi.org/10.1029/2018JG004589.

[9] Almutairi K, Mostafaeipour A, Jahanshahi E, Jooyandeh E, Himri Y, Jahangiri M, et al. Ranking locations for hydrogen production using hybrid wind-solar: a case study. Sustainability 2021;13(8):4524. https://doi.org/10.3390/su13084524.

[10] Mostafaeipour A, Goudarzi H, Sedaghat A, Jahangiri M, Hadian H, Rezaei M, et al. Energy efficiency for cooling buildings in hot and dry regions using sol-air temperature and ground temperature effects. Journal of Engineering, Design and Technology 2019;17(3):613–28. https://doi.org/10.1108/JEDT-12-2018-0216.

[11] Almutairi K, Dehshiri SS, Dehshiri SJ, Mostafaeipour A, Jahangiri M, Techato K. Technical, economic, carbon footprint assessment, and prioritizing stations for hydrogen production using wind energy: a case study. Energy Strategy Rev 2021;36:100684. https://doi.org/10.1016/j.esr.2021.100684.

[12] Qiao W, Liu W, Liu E. A combination model based on wavelet transform for predicting the difference between monthly natural gas production and consumption of US. Energy 2021;235:121216. https://doi.org/10.1016/j.energy.2021.121216.

[13] Said Z, Ghodbane M, Boumeddane B, Tiwari AK, Sundar LS, Li C, et al. Energy, exergy, economic and environmental (4E) analysis of a parabolic trough solar collector using MXene based silicone oil nanofluids. Sol Energy Mater Sol Cells 2022;239:111633. https://doi.org/10.1016/j.solmat.2022.111633.

[14] Ejaz A, Babar H, Ali HM, Jamil F, Janjua MM, Fattah IR, et al. Concentrated photovoltaics as light harvesters: Outlook, recent progress, and challenges. Sustainable Energy Technol Assess 2021;46:101199. https://doi.org/10.1016/j.seta.2021.101199.

[15] Mostafaeipour A, Hosseini Dehshiri SJ, Hosseini Dehshiri SS, Jahangiri M, Techato K. A thorough analysis of potential geothermal project locations in Afghanistan. Sustainability 2020;12(20):8397. https://doi.org/10.3390/su12208397.

[16] Zaniani JR, Ghahfarokhi ST, Jahangiri M, Shamsabadi AA. Design and optimization of heating, cooling and lightening systems for a residential villa at Saman city, Iran. *J Eng, Des Technol* 2018;17(1):41–52. https://doi.org/10.1108/JEDT-01-2018-0003.

[17] Jahangiri M, Haghani A, Heidarian S, Mostafaeipour A, Raiesi HA, Shamsabadi AA. Sensitivity analysis of using solar cells in regional electricity power supply of off-grid power systems in Iran. J Eng Des Technol 2020;18(6):1849–66. https://doi.org/10.1108/JEDT-10-2019-0268.

[18] Qiao W, Wang Y, Zhang J, Tian W, Tian Y, Yang Q. An innovative coupled model in view of wavelet transform for predicting short-term PM10 concentration. J Environ Manage 2021;289:112438. https://doi.org/10.1016/j.jenvman.2021.112438.

[19] Said Z, Arora S, Farooq S, Sundar LS, Li C, Allouhi A. Recent advances on improved optical, thermal, and radiative characteristics of plasmonic nanofluids: academic insights and perspectives. Sol Energy Mater Sol Cells 2022;236:111504. https://doi.org/10.1016/j.solmat.2021.111504.

[20] Tian H, Qin Y, Niu Z, Wang L, Ge S. Summer maize mapping by compositing time series Sentinel-1A imagery based on crop growth cycles. *J Indian Soc Remote Sens* 2021;49(11):2863–74. https://doi.org/10.1007/s12524-021-01428-0.

[21] Chao L, Zhang K, Wang J, Feng J, Zhang M. A comprehensive evaluation of five evapotranspiration datasets based on ground and grace satellite observations: implications for improvement of evapotranspiration retrieval algorithm. *Remote Sens* 2021;13(12):2414. https://doi.org/10.3390/rs13122414.

[22] Liu L, Meng X, Miao Z, Zhou S. Design of a novel thermoelectric module based on application stability and power generation. *Case Stud Therm Eng* 2022;31:101836. https://doi.org/10.1016/j.csite.2022.101836.

[23] Chen G, Gu C, Hajaiej H, Morris PJ, Paterson EG, Sergeev A. OpenFOAM computation of interacting wind turbine flows and control (I): free rotating case. Int J Hydromechatron 2021;4(1):1–26. https://doi.org/10.1504/IJHM.2021.114169.

[24] Zahoor R, Bajt S, Šarler B. A numerical investigation of micro-jet characteristics in different pressure environments. Int J Hydromechatron 2021;4(4):368–83. https://doi.org/10.1504/IJHM.2021.120618.

[25] Singh VK, Nath T. Energy generation by small hydro power plant under different operating condition. Int J Hydromechatron 2021;4(4):331–49. https://doi.org/10.1504/IJHM.2021.120611.

[26] Renewable Energy Policy Network for the 21st Century, Renewables 2016 Global Status Report. 2016. https://www.ren21.net/gsr-2016 [Available: 24 May 2022].

[27] Sedaghat A, Mostafaeipour A, Rezaei M, Jahangiri M, Mehrabi A. A new semi-empirical wind turbine capacity factor for maximizing annual electricity and hydrogen production. Int J Hydrogen Energy 2020;45(32):15888–903. https://doi.org/10.1016/j.ijhydene.2020.04.028.

[28] Global Energy Review 2020, IEA, 2021. https://www.iea.org/reports/global-energy-review-2020/renewables [Available: 20 May 2022].

[29] Renewable Energy Indicators, Center for climate and energy solutions, 2022. https://www.c2es.org/content/renewable-energy [Available: 20 May 2022].

[30] Jahangiri M, Shamsabadi AA, Mostafaeipour A, Rezaei M, Yousefi Y, Pomares LM. Using fuzzy MCDM technique to find the best location in Qatar for exploiting wind and solar energy to generate hydrogen and electricity. Int J Hydrogen Energy 2020;45(27):13862–75. https://doi.org/10.1016/j.ijhydene.2020.03.101.

[31] Alamdari P, Nematollahi O, Alemrajabi AA. Solar energy potentials in Iran: a review. Renew Sustain Energy Rev 2013;21:778–88. https://doi.org/10.1016/j.rser.2012.12.052.

[32] Jahangiri M, Nematollahi O, Haghani A, Raiesi HA, Alidadi SA. An optimization of energy cost of clean hybrid solar-wind power plants in Iran. Int J Green Energy 2019;16(15):1422–35. https://doi.org/10.1080/15435075.2019.1671415.

[33] Pahlavan S, Jahangiri M, Shamsabadi AA, Baharizadeh A. Assessing the current status of renewable energies and their limitations in Iran. Int J Renew Energy Dev 2020;9(1):97–105. https://doi.org/10.14710/ijred.9.1.97-105.

[34] Jahangiri M, Shamsabadi AA. Designing a horizontal-axis wind turbine for South Khorasan province: a case study. Int J Precis Eng Manuf 2017;18(10):1463–73. https://doi.org/10.1007/s12541-017-0174-5.

[35] Alamdari P, Nematollahi O, Mirhosseini M. Assessment of wind energy in Iran: a review. Renew Sustain Energy Rev 2012;16:836–60. https://doi.org/10.1016/j.rser.2011.09.007.

[36] Mostafaeipour A, Qolipour M, Rezaei M, Jahangiri M, Goli A, Sedaghat A. A novel integrated approach for ranking solar energy location planning: a case study. J Eng Des Technol 2020;19(3):698–720. https://doi.org/10.1108/JEDT-04-2020-0123.

[37] Nikpour M, Pazouki M, Bio-Diesel Industrial Production from Biomass as a Renewable Source, Available at http://www.farayandno.ir/article_21404.html, [Available: 21 July 2019].

[38] Noorollahi Y, Kheirrouz M, Asl HF, Yousefi H, Hajinezhad A. Biogas production potential from livestock manure in Iran. R*enew Sustain Energy Rev* 2015;50:748–54. https://doi.org/10.1016/j.rser.2015.04.190.

[39] Jahangiri M, Khosravi A, Raiesi HA, Mostafaeipour A, 2017. Analysis of standalone PV-Based Hybrid systems for power generation in rural area. *In Proceedings of the International Conference on Fundamental Research in Electrical Engineering (ICEEC-2017)*, Tehran, Iran: 1-10. https://civilica.com/doc/672922.

[40] Jahangiri M, Rizi RA, Shamsabadi AA. Feasibility study on simultaneous generation of electricity and heat using renewable energies in Zarrin Shahr, Iran. *Sustain Cities Soc* 2018;38:647–61. https://doi.org/10.1016/j.scs.2018.01.043.

[41] Vahdatpour S, Behzadfar S, Siampour L, Veisi E, Jahangiri M. Evaluation of off-grid hybrid renewable systems in the four climate regions of Iran. J Renew Energy Environ 2018;4(1):61–70. https://dx.doi.org/10.30501/jree.2017.70107.

[42] Alidadi Shamsabadi A, Jahangiri M, Karimzadeh Bardei F, Raiesi HA. Investigation of Sensitivity Analysis in the Generation of Renewable Electricity for a Hybrid System in Iran, The 12th international Energy Conference (IEC 2018), Tehran, Iran: 1-15. . 2018.

[43] Moein M, Pahlavan S, Jahangiri M, Alidadi Shamsabadi A. Finding the minimum distance from the national electricity grid for the cost-effective use of diesel generator-based hybrid renewable systems in Iran. J Renew Energy Environ 2018;5(1):8–22. https://dx.doi.org/10.30501/jree.2018.88377.

[44] Ariae AR, Jahangiri M, Fakhr MH, Shamsabadi AA. Simulation of biogas utilization effect on the economic efficiency and greenhouse gas emission: a case study in Isfahan, Iran. *Int J Renew Energy Dev* 2019;8(2):149–60. https://doi.org/10.14710/ijred.8.2.149-160.

[45] Pahlavan S, Jahangiri M, Alidadi Shamsabadi A, Rahimi Ariae A. Assessment of PV-Based CHP system: the effect of heat recovery factor and fuel type. J Energy Manage Technol 2019;3(1):40–7. https://dx.doi.org/10.22109/jemt.2018.137207.1106.

[46] Alayi R, Jahangeri M, Monfared H. Optimal location of electrical generation from urban solid waste for biomass power plants. Anthropogenic Pollut 2020;4(2):44–51. http://ap.iauardabil.ac.ir/article_675674.html.

[47] Jahangiri M, Rezaei M, Mostafaeipour A, Goojani AR, Saghaei H, Dehshiri SJ, et al. Prioritization of solar electricity and hydrogen co-production stations considering PV losses and different types of solar trackers: a TOPSIS approach. Renewable Energy 2022;186:889–903. https://doi.org/10.1016/j.renene.2022.01.045.

[48] Aagreh Y, Al-Ghzawi A. Feasibility of utilizing renewable energy systems for a small hotel in Ajloun city, Jordan. *Appl Energy* 2013;113:25–31. https://doi.org/10.1016/j.apenergy.2012.10.008.

[49] Lund H, Duic N, Krajac G, da Graça CM. Two energy system analysis models: a comparison of methodologies and results. Energy 2007;32(6):948–54. https://doi.org/10.1016/j.energy.2006.10.014.
[50] Help of HOMER software, http://www.homerenergy.com/software.html, [Available: 20 May 2022].
[51] Lambert T, Gilman P, Lilienthal P. Micropower system modeling with HOMER, Integr. Altern. *Sources Energy* 2006; 1(1): 379-385. https://www.homerenergy.com/documents/MicropowerSystemModelingWithHOMER.pdf.
[52] HOMER ®Version 2.68 beta User Manual, 2009. www.homerenergy.com, [Available: 20 May 2022].
[53] Jahangiri M, Mostafaeipour A, Rahman Habib HU, Saghaei H, Waqar A. Effect of emission penalty and annual interest rate on cogeneration of electricity, heat, and hydrogen in Karachi: 3E assessment and sensitivity analysis. J Eng 2021;2021: 6679358. https://doi.org/10.1155/2021/6679358.
[54] Jahangiri M, Haghani A, Heidarian S, Alidadi Shamsabadi A, Pomares LM. Electrification of a tourist village using hybrid renewable energy systems, Sarakhiyeh in Iran. J Solar Energy Res 2018;3(3):201–11. https://journals.ut.ac.ir/article_68643.html.
[55] Ramli MA, Hiendro A, Twaha S. Economic analysis of PV/diesel hybrid system with flywheel energy storage. Renewable Energy 2015;78:398–405. https://doi.org/10.1016/j.renene.2015.01.026.
[56] Brecl K. Energy and economic yield of photovoltaic systems: reactive-power impact. Elektrotehniski Vestnik 2014;81(1–2):9–14. https://www.proquest.com/docview/1524722899.
[57] Mostafaeipour A, Jahangiri M, Haghani A, Dehshiri SJH, Dehshiri SSH, Issakhov A, et al. Statistical evaluation of using the new generation of wind turbines in South Africa. Energy Rep 2020;6:2816–27. https://doi.org/10.1016/j.egyr.2020.09.035.
[58] Ganoe RE, Stackhouse PW, DeYoung RJ. RETScreen® Plus Software Tutorial. In: National Aeronautics and Space Administration (NASA); 2017. p. 3–27.
[59] Study and classification of biomass resources in Iran and the world and their diversity in rural areas of the country with emphasis on ordinary solid waste and animal waste, *Fifth National Conference on Waste Management*, 2010. (In Persian) https://www.civilica.com/Paper-NCWM05-NCWM05_031.html [Available: 20 May 2022].
[60] Detailed results, statistics of the country's livestock – 2017, Plan and Budget Organization of Iran, *Statistics Center of Iran*, 2022. (In Persian) https://www.amar.org.ir/Portals/0/News/1396/a-dams96.pdf [Available: 20 May 2022].
[61] Olatomiwa L. Optimal configuration assessments of hybrid renewable power supply for rural healthcare facilities. Energy Rep 2016;2:141–6. https://doi.org/10.1016/j.egyr.2016.06.001.
[62] Rahmati Dehkordi S, Jahangiri M. Sensitivity analysis for 3E assessment of BIPV system performance in Abadan in Southwestern Iran. J Renew Energy Environ 2022;9(1):1–12. https://dx.doi.org/10.30501/jree.2021.262420.1173.
[63] Jahangiri M, Haghani A, Shamsabadi AA, Mostafaeipour A, Pomares LM. Feasibility study on the provision of electricity and hydrogen for domestic purposes in the south of Iran using grid-connected renewable energy plants. Energy Strategy Rev 2019;23:23–32. https://doi.org/10.1016/j.esr.2018.12.003.
[64] Kalbasi R, Jahangiri M, Tahmasebi A. Comprehensive investigation of solar-based hydrogen and electricity production in Iran. Int J Photoenergy 2021;2021: 6627491. https://doi.org/10.1155/2021/6627491.
[65] Nematollahi O, Alamdari P, Jahangiri M, Sedaghat A, Alemrajabi AA. A techno-economical assessment of solar/wind resources and hydrogen production: a case study with GIS maps. Energy 2019;175:914–30. https://doi.org/10.1016/j.energy.2019.03.125.
[66] Jahangiri M, Ghaderi R, Haghani A, Nematollahi O. Finding the best locations for establishment of solar-wind power stations in Middle-East using GIS: a review. Renew Sustain Energy Rev 2016;66:38–52. https://doi.org/10.1016/j.rser.2016.07.069.