Renewable and Sustainable Energy Reviews 77 (2017) 566–579

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A feasibility study of solar energy in South Korea

Omid Nematollahi, Kyung Chun Kim*

School of Mechanical Engineering, Pusan National University, Busan 609-735, Republic of Korea

ARTICLE INFO

Keywords:
Solar energy
Horizontal radiation
Clearness indices
GIS
South Korea

ABSTRACT

Through the years using renewable energies become one of the interesting issues in each country. Among the renewable energies, solar energy is more attractive. Governments planned to install more solar power plants. Feasibility study is an important step of every solar energy project. This paper investigates the feasibility of using solar energy in different regions of South Korea. For this purpose, the maximum, minimum, and average values of yearly horizontal radiation were calculated for 24 stations for a five-year period. Monthly and annual clearness indices for these stations were then calculated. The annual average horizontal radiation map and Geographic Information Systems (GIS) maps of global horizontal radiation were prepared for each month of the year. Maps were then prepared for the annual average of monthly mean clearness index for the 24 stations. Furthermore, the sunshine hours were presented for 78 stations for a three-year period. The results show that the central and southern regions of South Korea receive higher quantities of horizontal radiation, but not the northern areas.

1. Introduction

In the 1970s, there were significant petroleum shortages and higher prices. There were two big crises, one in 1973 (an oil crisis) and one in 1979 (an energy crisis). Countries have since planned many programs to use renewable energy like solar, wind, geothermal energy. Demand is also growing, and it is expected that the world electricity usage will reach 32,922 terawatt hours by the year 2035 (approximately two times the amount used in 2008) [1].

The total energy consumption in 2014 is shown in Fig. 1. Oil consumption represents about 39.9%, while other sources such as geothermal, solar, wind, and heat represent 3.3%. Therefore, there is a long way to go in changing energy consumption resources from non-renewable (oil, coal, natural gas) to renewable sources (solar, wind, geothermal, etc.) [2].

The top five countries for investment in renewable power and fuels in 2015 were China, the United States, Japan, the United Kingdom, and India (not including hydro > 50 MW) [3]. Solar energy includes solar photovoltaics (PV), concentrating solar thermal power (CSP), and solar thermal heating and cooling. At the end of 2015, a total of 227 GW of Solar PV was installed [3]. Fig. 2 shows the top 15 countries for solar PV [3].

South Korea represents 2% of global PV use (in the next 5 countries), adding 1 GW during 2015 with a total of 3.4 GW by the end of the year. Global operational capacity of CSP increased by 420 MW to nearly 4.8 GW at the end of 2015. The main application of solar thermal technology has been water heating in single-family houses during the last 50 years. Global operating capacity of water heating systems was nearly 435 GW (thermal) by the end of 2015 [3].

Using renewable energy helps eliminate pollution and environmental issues like CO_2 emissions. The technology related to these resources is growing fast. Sustainable development goals and enhanced energy security are included among the main factors that have attracted global attention to renewable energy [4]. Activities and investments by governments and private sectors related to R & D and supply of new technologies is strongly increasing in this area. As a result, the unit cost of power generation from renewable resources has significantly decreased, making it more competitive with traditional power generation systems.

With 10% efficiency, just 0.1% of the incident solar energy on the Earth's surface can produce 3000 GW of power. The annual solar radiation reaching the earth's surface is approximately 3,400,000 EJ [5]. Other benefits include:

1. Recovery of degraded areas.
2. Reducing dependence on the national power grid network.
3. Improved water quality.
4. Accelerated electrification of rural areas [6].

The amount of incident radiation on a point of the Earth's surface depends on several factors: the altitude, latitude, fraction of sunshine hours, relative humidity, precipitation, and air temperature. Several

* Corresponding author.
E-mail address: kckim@pusan.ac.kr (K.C. Kim).

http://dx.doi.org/10.1016/j.rser.2017.03.132
Received 9 October 2016; Received in revised form 9 February 2017; Accepted 29 March 2017
Available online 26 April 2017

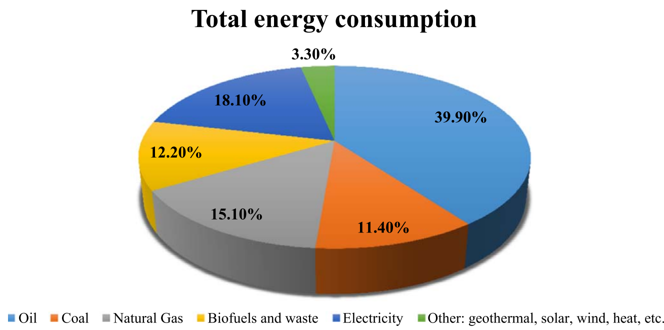

Fig. 1. Total energy consumption in 2014.

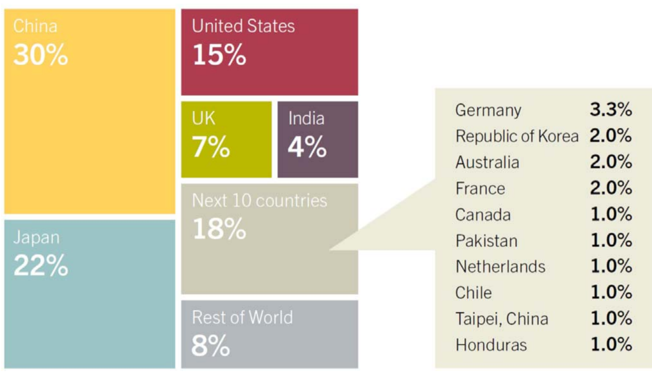

Fig. 2. Top 15 countries for solar photovoltaics.

Fig. 3. Regions of South Korea.

models have been developed to estimate the total amount of solar radiation on horizontal surfaces using various climatic parameters, such as sunshine hours, cloudiness, relative humidity, minimum and maximum temperatures, wind speed, etc. [7–9].

One of the important parts of any project or any idea before starting is feasibility studies. A feasibility study investigates the viability of a proposal, business venture, or idea. The principal function is to determine if a project will continue or not. In renewable energy projects, it is also helpful for recognizing the potential of an energy source. From the point of view of solar energy, it involves evaluating how much irradiance there is on the earth's surface in a specific region.

A number of studies have been conducted on the potential of solar energy. Osmani et al. [10] investigated renewable energy sources in the United States for electricity generation. They studied the resource potential, current usage, and the overall situation of renewable energy. The also identified the different challenges, which include economic, operational, sustainability, and technical challenges. Lastly, they discussed a sustainability evaluation outline for renewable resource deployment for electricity generation in the U.S.

Tucho et al. [11] assessed the potential of renewable energy sources for large-scale and standalone applications in Ethiopia. They presented an energy system and examined the available energy, and they mentioned that the three main sources include solar, wind, and hydroelectric sources, which could supply enough energy to fulfill the demand. In the case of solar energy, they estimated an annual geographic potential of 192 PWh from land and 0.1 PWh from rooftop areas. Since household energy use for cooking in Ethiopia is 10 times that in Western countries, they concluded that there is a strong need to satisfy this demand.

Izadyar et al. [12] reviewed previous studies on various potential parameters for renewable energy systems (theoretical, geographical, and technical parameters), as well as various methodologies for estimating these parameters in different conditions. The focus was on hybrid renewable energy systems. Okoye et al. [13] discussed the current energy situation in Nigeria and assessed the potential of solar-based technologies for electricity generation in three strategically located cities: Onitsha, Kano, and Lagos. Solar resources were modeled using synthetic hourly meteorological data for a whole year. Kano had the largest average daily global horizontal resources (6.08 kWh m^2), while the values for Onitsha and Lagos were 4.43 kWh m^2 and 4.42 kWh m^2, respectively. Furthermore, a standalone PV system on a sloping surface was sized to generate power for household usage based on an intuitive numerical simulation. They concluded that standalone PV electricity is technically and economically viable for urban residential applications in Nigeria while considering the current infrastructure and energy policies.

Alamdari et al. [14] studied many sites to evaluate solar energy in Iran using data from 63 stations. The values for the maximum, minimum, and average annual horizontal radiation were obtained for each station, and the annual average horizontal radiation was higher than 500 W/m^2 at some stations. Moreno-Tejera et al. [15] analyzed 13 years of global horizontal insolation and direct normal insolation in Seville, Spain, at different time resolutions ranging from annual to nearly instantaneous (5 s). They also proposed a new methodology for gap filling. The instantaneous values of global horizontal insolation and direct normal insolation had bimodal distributions, and they suggested that a 10-min distribution was a good time resolution for the simulation of concentrated solar power. The mean daily value for one year of insolation was 4.98 kWh/m^2 for global horizontal insolation and 5.68 kWh/m^2 for direct normal insolation.

Aliaga et al. [16] analyzed solar resources for agricultural pumping purposes and used the Geographic Information System (GIS) to investigate solar resource variability. A wide assessment was proposed in terms of energy, economics, and viability, and they compared two Mediterranean countries: Spain and Morocco. Their proposed methodology was able to solve multi-dimensional problems corresponding to agriculture division and energy requirements applied to irrigation processes based on aquifers, water resource control, and solar resource integration.

Ruiz-Arias et al. [17] proposed a method combining grid-modeled and ground-observed solar radiation data. The method is based on an optimal interpolation technique to adjust the gridded solar radiation.

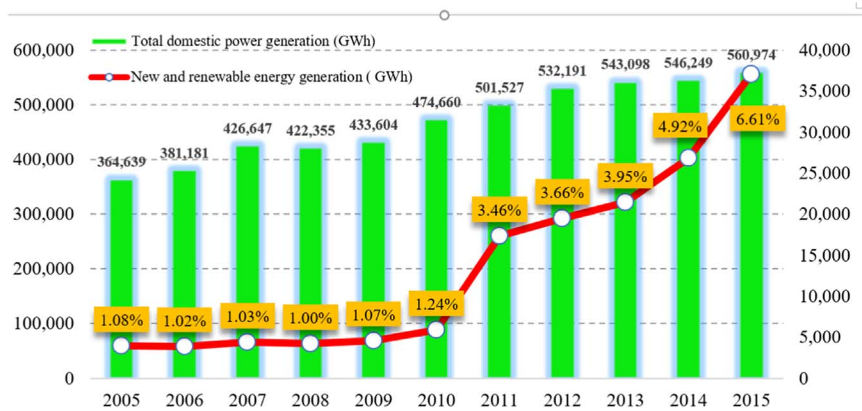

Fig. 4. Total domestic power generation [34].

Table 1
Energy production in each sector in 2014 and 2015 (Unit: MWh) [34].

Division		2014 Power generation	2014 Share (%)	2015 Power generation	2015 Share (%)
new-renewable energy		26,882,190	4.92	37,078,863	6.61
renewable energy		25,939,134	4.75	35,983,514	6.41
new energy		943,056	0.17	1,095,349	0.20
renewable energy	Solar energy	2,556,300	9.5	3,979,159	10.7
	Wind energy	1,145,557	4.3	1,342,439	3.6
	Hydropower	2,753,924	10.2	2,150,013	5.8
	Ocean	492,172	1.8	496,354	1.3
	Bio	4,656,237	17.3	5,546,583	15.0
	waste	14,334,944	53.3	22,468,966	60.6
new energy	Fuel cell	943,056	3.5	1,089,260	2.9
	Integrated Gasification Combined Cycle (IGCC)	0	0.0	6,089	0.0

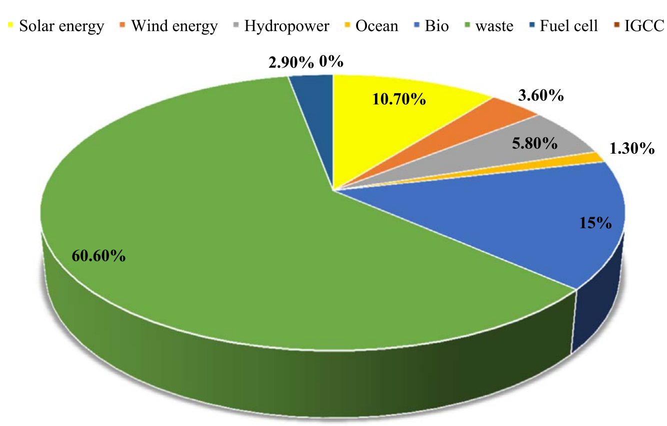

Fig. 5. Energy production of new-renewable energy sector [34].

The method produces adjusted gridded values that are (or nearly always are in the case of direct irradiation) within the expected measurement uncertainty of the ground observations. The method was tested using global and direct monthly irradiation data for a 10-year period from 2003 to 2012 over Spain and the Balearic Islands.

Anwarzai and Nagasaka [18] used the GIS method to investigate the solar and wind energy in Afghanistan. Furthermore, they used the SAM(system advisor model) for determining the CSP technologies yearly annual production. Corresponding their results the west part of the country and near hydropower plant. But they concluded that the main problem in this country is the lack of transmission lines.

Furthermore, Modi et al. [19] reviewed the solar energy based heat and power production systems in Denmark. They considered the following technologies (1) solar photovoltaic modules, (2) solar flat plate collectors, (3) a ground source heat pump, (4) a biomass burner, and (5) an organic Rankine cycle. These technologies compared through their economical and environmental situations. The main conclusion was that solar-biomass hybrid in small or large scales for Nordic climate. Also they mentioned that a hybrid plants with an organic Rankine cycle with solar thermal collectors and a biomass burner is interesting for large scales.

Sindhu et al. [20] using a combination between Analytical Hierarchical Process (AHP) and fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) investigated the possibility of solar farm site selection in India. They concluded that the best location in India is Sonepat followed by Rohtak, Chandigarh, Gurgaon and Hisar in state of Haryana, India.

Halder [21] investigated the ten case studies with 20, 30 and 42 Wp for assessing the economic feasibility of solar home systems at two villages in Bangladesh. The study showed that the Solar home systems for small business and household with small income are economically feasible.

Table 2
Locations of stations.

No.	Station	Lat. (N)	Long. (E)	Radiation Measurement	Sunshine Hours Measurement
1	Sokcho	38°15′	128°33′	☀	
2	Cheorwon	38°08′	127°18′	☀	
3	Dongducheon	37°54′	127°03′	☀	
4	Paju	37°53′	126°45′	☀	
5	Daegwallyeong	37°40′	128°43′	☀	☀
6	Chuncheon	37°54′	127°44′	☀	☀
7	Baengnyeongdo	37°57′	124°37′	☀	
8	Bukgangneung	37°48′	128°51′	☀	☀
9	Gangneung	37°45′	128°53′	☀	☀
10	Donghae	37°30′	129°07′	☀	
11	Seoul	37°34′	126°57′	☀	☀
12	Incheon	37°28′	126°37′	☀	☀
13	Wonju	37°20′	127°56′	☀	☀
14	Ulleungdo	37°28′	130°53′	☀	
15	Suwon	37°16′	126°59′	☀	☀
16	Yeongwol	37°10′	128°27′	☀	
17	Chungju	36°58′	127°57′	☀	
18	Seosan	36°46′	126°29′	☀	☀
19	Uljin	36°59′	129°24′	☀	
20	Cheongju	36°38′	127°26′	☀	☀
21	Daejeon	36°22′	127°22′	☀	☀
22	Chupungnyeong	36°13′	127°59′	☀	☀
23	Andong	36°34′	128°42′	☀	☀
24	Sangju	36°24′	128°09′	☀	
25	Pohang	36°01′	129°22′	☀	☀
26	Gunsan	36°00′	126°45′	☀	
27	Daegu	35°53′	128°37′	☀	☀
28	Jeonju	35°49′	127°09′	☀	☀
29	Ulsan	35°33′	129°19′	☀	
30	Changwon	35°10′	128°34′	☀	
31	Gwangju	35°10′	126°53′	☀	☀
32	Busan	35°06′	129°01′	☀	☀
33	Tongyeong	34°50′	128°26′	☀	
34	Mokpo	34°49′	126°22′	☀	☀

(continued on next page)

Table 2 *(continued)*

No.	Station	Lat. (N)	Long. (E)	Radiation Measurement	Sunshine Hours Measurement
35	Yeosu	34°44′	127°44′	☀	
36	Heuksando	34°41′	125°27′	☀	☀
37	Wando	34°23′	126°42′	☀	
38	Gochang	35°20′	126°35′	☀	☀
39	Suncheon	35°01′	127°22′	☀	
40	Jindo	34°28′	126°19′	☀	
41	Jeju	33°30′	126°31′	☀	☀
42	Gosan	33°17′	126°09′	☀	☀
43	Seongsan	33°23′	126°52′	☀	
44	Seogwipo	33°14′	126°33′	☀	
45	Jinju	35°09′	128°02′	☀	☀
46	Ganghwa	37°42′	126°26′	☀	
47	Yangpyeong	37°29′	127°29′	☀	
48	Icheon	37°15′	127°29′	☀	
49	Inje	38°03′	128°10′	☀	
50	Hongcheon	37°41′	127°52′	☀	
51	Taebaek	37°10′	128°59′	☀	
52	Jecheon	37°09′	128°11′	☀	
53	Boeun	36°29′	127°44′	☀	
54	Cheonan	36°46′	127°07′	☀	
55	Boryeong	36°19′	126°33′	☀	
56	Buyeo	36°16′	126°55′	☀	
57	Geumsan	36°06′	127°28′	☀	
58	Buan	35°43′	126°42′	☀	
59	Imsil	35°36′	127°17′	☀	
60	Jeongeup	35°33′	126°51′	☀	
61	Namwon	35°24′	127°19′	☀	
62	Jangsu	35°39′	127°31′	☀	
63	Jangheung	34°41′	126°55′	☀	
64	Haenam	34°33′	126°34′	☀	
65	Goheung	34°37′	127°16′	☀	
66	Bongwhoa	36°56′	128°54′	☀	
67	Yeongju	36°52′	128°31′	☀	
68	Mungyeong	36°37′	128°08′	☀	

(continued on next page)

Table 2 *(continued)*

No.	Station	Lat. (N)	Long. (E)	Radiation Measurement	Sunshine Hours Measurement
69	Yeongdeok	36°31′	129°24′	☀	
70	Uiseong	36°21′	128°41′	☀	
71	Gumi	36°07′	128°19′	☀	
72	Yeongcheon	35°58′	128°57′	☀	
73	Geochang	35°40′	127°54′	☀	
74	Hapcheon	35°33′	128°10′	☀	
75	Miryang	35°29′	128°44′	☀	
76	Sancheong	35°24′	127°52′	☀	
77	Geoje	34°53′	128°36′	☀	
78	Namhae	34°48′	127°55′	☀	

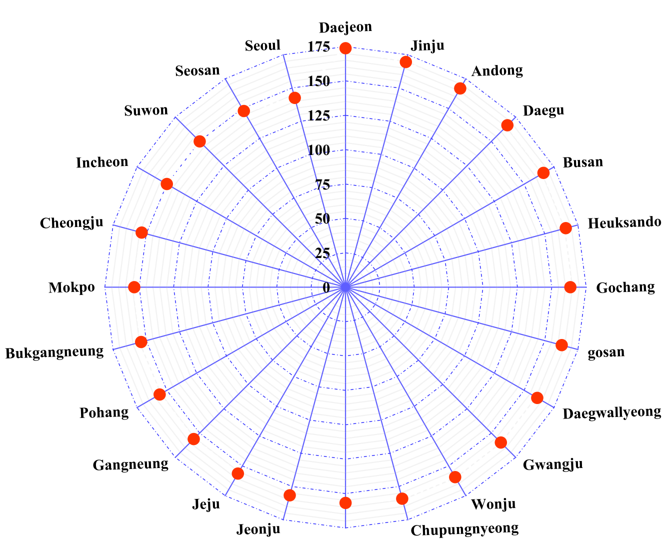

Fig. 6. Annual average global solar radiation.

Escobar et al. [22] modified an existing solar radiation estimation method for Chilean conditions. The model was validated using ground station data. They showed that there are high radiation levels in Chile and that the northern area is one of the best locations for solar energy applications. Nematollahi et al. [23] evaluated renewable energy resources across Middle Eastern countries. They used RETScreen software data to produce a solar and wind atlas for the region. According to the GIS maps of solar irradiation, Yemen, Saudi Arabia, and Egypt had the highest exposure. Iran, Turkey, Iraq, Egypt, Yemen, and Oman were also among the top countries with high wind potential.

Al-Sharafi et al. [24] investigated the potentials od power generation and hydrogen production using solar and wind energy in Saudi Arabia. They used photovoltaic (PV) array, wind turbines, converter, batteries, electrolyzer, fuel cell (FC) and hydrogen tank. Different configuration including PV/battery bank, wind/battery bank, PV/wind/battery bank, PV/FC, wind/FC and PV/wind/FC was evaluated. Their results showed that combination of 2 kW PV array, 3 wind turbines, 2 kW converter and 7 batteries storage bank is the best arrangement that results to the lowest levelized cost of energy of 0.609 $/kWh at Yanbu area.

Zell et al. [25] evaluated and mapped solar radiation in Saudi Arabia. They used one-year data with one-minute intervals from 30 stations throughout the country. The annual average daily global horizontal radiation was from 5700 to 6700 Wh/m^2. Direct normal irradiation ranged from 4400 to 7300 Wh/m^2. This study shows very good potential for using PV systems.

He and Kammen [26] used 10 years of hourly solar irradiation from 200 sites to assess China's solar resources. They found a potential stationary solar capacity of 4700 to 39,300 GW, distributed solar capacity of about 200 GW, and annual solar output that could reach 6900 to 70,100 TWh. These potentials are most concentrated in northwest provinces, especially Inner Mongolia, Xinjiang, and Gansu.

Stökler et al. [27] presented a solar resource assessment for Pakistan. They used satellite and ground measurements to create a validated atlas. Annual sums of direct normal irradiance and global horizontal irradiance exceeded 2000 kWh/m^2 in most parts of the country.

Yadav et al. [28] used a new technique for selecting inputs to predict solar radiation with artificial neural networks (ANNs). They developed ANN models with a fitting tool (Nftool) and used it to predict solar radiation for 41 locations in Gujarat and 35 locations in Rajasthan in Northwestern India. The annual average solar radiation ranged from 4.92 to 5.62 kWh/m^2/day for Gujarat and from 4.66 to 5.54 kWh/m^2/day for Rajasthan.

In the case of South Korea, Byrne et al. [29] reviewed efforts to describe and define a solar city concept and an evaluation method for estimating solar electric potential on rooftops. They used Seoul as a case study. They demonstrated a potential equivalent to almost 30% of the city's annual electricity consumption using rooftop-based distributed PV systems. Using their methodology, it is possible that about 66% of the daytime electricity demand in Seoul can be served by solar power systems on a typical day.

Park et al. [30] developed an empirical model to predict solar radiation from sunshine hours in Korea. They used a topographical factor to overcome the problem of complex terrain. They showed that spatial variation of the incidence radiation is mostly affected by topographical and atmospheric features, while the latitudinal gradient is almost irrelevant.

Koo et al. [31] expanded a framework for the analysis of the potential of a rooftop PV system to attain net-zero energy solar buildings. To validate the proposed outline, a total of 5418 elementary school facilities located in 16 administrative divisions in Korea were selected as case studies. Their framework can also be applied to any other country or sector.

The present study investigates the feasibility of using solar energy in different regions of South Korea. For this purpose, the maximum, minimum, and average values of annual horizontal radiation were calculated for 24 stations for a period of five years. Then, monthly and annual clearness indices for these stations were calculated. The annual

Table 3
Radiation values at different stations.

Site	Maximum irradiation (W/m^2)	Minimum irradiation (W/m^2)	Average irradiation (W/m^2)	Site	Maximum irradiation (W/m^2)	Minimum irradiation (W/m^2)	Average irradiation (W/m^2)
Daejeon	266.3	91.0	173.8	Chuncheon	235.9	83.1	156.9
Jinju	244.5	108.2	169.5	Jeonju	238.0	82.8	156.6
Andong	255.0	93.8	166.9	Jeju	247.2	59.1	156.5
Daegu	254.3	98.4	166.5	Gangneung	237.8	89.9	156.1
Busan	237.2	106.4	166.2	Pohang	231.0	94.4	156.0
Heuksando	255.0	73.5	165.8	Bukgangneung	227.2	91.5	153.9
Gochang	249.6	87.8	163.5	Mokpo	234.5	78.1	153.6
gosan	249.5	65.5	162.8	Cheongju	233.6	81.0	153.4
Daegwallyeong	242.4	92.8	161.0	Incheon	227.1	82.0	150.0
Gwangju	242.5	84.0	159.8	Suwon	229.2	82.9	149.9
Wonju	239.9	85.3	159.5	Seosan	229.5	76.4	147.9
Chupungnyeong	245.1	89.2	159.2	Seoul	218.2	82.2	142.5

Table 4
Monthly clearness index.

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
Daegwallyeong	0.59	0.52	0.58	0.47	0.53	0.41	0.39	0.41	0.45	0.54	0.45	0.55	0.49
Chuncheon	0.51	0.50	0.55	0.45	0.51	0.48	0.36	0.42	0.46	0.52	0.41	0.47	0.47
Bukgangneung	0.55	0.47	0.53	0.46	0.49	0.39	0.39	0.40	0.44	0.53	0.44	0.55	0.47
Gangneung	0.50	0.44	0.52	0.48	0.52	0.41	0.40	0.42	0.45	0.54	0.43	0.52	0.47
Seoul	0.49	0.45	0.51	0.44	0.47	0.40	0.28	0.35	0.44	0.51	0.40	0.46	0.43
Incheon	0.50	0.46	0.52	0.45	0.49	0.44	0.34	0.40	0.44	0.49	0.41	0.46	0.45
Wonju	0.52	0.48	0.54	0.45	0.52	0.47	0.37	0.42	0.49	0.56	0.42	0.48	0.48
Suwon	0.51	0.48	0.53	0.45	0.50	0.45	0.34	0.39	0.41	0.49	0.40	0.46	0.45
Seosan	0.48	0.45	0.52	0.45	0.50	0.43	0.34	0.38	0.44	0.47	0.37	0.41	0.44
Cheongju	0.48	0.43	0.52	0.45	0.51	0.44	0.36	0.42	0.46	0.52	0.38	0.44	0.45
Daejeon	0.55	0.50	0.59	0.50	0.58	0.48	0.41	0.46	0.52	0.61	0.45	0.49	0.51
Chupungnyeong	0.54	0.47	0.55	0.46	0.53	0.44	0.39	0.40	0.47	0.52	0.42	0.48	0.47
Andong	0.55	0.48	0.56	0.47	0.55	0.46	0.43	0.44	0.47	0.55	0.44	0.50	0.49
Pohang	0.50	0.43	0.53	0.48	0.50	0.40	0.42	0.38	0.43	0.52	0.45	0.50	0.46
Daegu	0.58	0.49	0.58	0.50	0.55	0.36	0.43	0.42	0.47	0.55	0.46	0.51	0.49
Jeonju	0.48	0.43	0.52	0.46	0.51	0.42	0.38	0.41	0.47	0.55	0.40	0.43	0.46
Gwangju	0.50	0.43	0.53	0.48	0.52	0.40	0.38	0.41	0.49	0.57	0.43	0.43	0.47
Busan	0.58	0.45	0.54	0.49	0.51	0.39	0.44	0.43	0.47	0.55	0.49	0.55	0.49
Mokpo	0.46	0.41	0.51	0.47	0.51	0.40	0.38	0.40	0.47	0.52	0.39	0.39	0.44
Heuksando	0.41	0.42	0.56	0.52	0.55	0.45	0.39	0.45	0.52	0.58	0.41	0.37	0.47
Gochang	0.49	0.44	0.54	0.47	0.54	0.45	0.41	0.43	0.49	0.57	0.41	0.45	0.47
Jeju	0.33	0.33	0.49	0.49	0.53	0.39	0.47	0.45	0.49	0.53	0.36	0.29	0.43
gosan	0.36	0.39	0.53	0.51	0.54	0.39	0.46	0.47	0.51	0.55	0.38	0.32	0.45
Jinju	0.60	0.49	0.57	0.50	0.53	0.41	0.41	0.42	0.48	0.57	0.48	0.56	0.50

average horizontal radiation map and GIS maps of global horizontal radiation (GHR) were then prepared for each month of the year. Map of the annual average monthly mean clearness index for the 24 stations were also prepared. Furthermore, the sunshine hours were presented for 78 stations for a three-year period. The results show that the central and southern regions receive higher quantities of horizontal radiation, but not the northern areas. With using the outcomes from this study everyone can estimates the value of solar radiation for desired projects. Furthermore, with using monthly mean clearness indexes, atmospheric characteristics will be accounted.

2. South Korea

South Korea, officially the Republic of Korea, is a sovereign state in East Asia. South Korea occupies the southern portion of the Korean Peninsula, which extends some 1100 km from the Asian mainland. This mountainous peninsula is flanked by the Yellow Sea to the west and the Sea of Japan (East Sea) to the east. Its southern tip lies on the Korea Strait and the East China Sea.

The country, including all its islands, lies between latitudes 33° and 39°N and between longitudes 124° and 130°E. Its total area is 100,032 square kilometers. South Korea can be divided into four general regions: an eastern region of high mountain ranges and narrow coastal plains; a western region of broad coastal plains, river basins, and rolling hills; a southwestern region of mountains and valleys; and a southeastern region dominated by the broad basin of the Nakdong River [32].

South Korea tends to have a humid continental climate and a humid subtropical climate. It is affected by East Asian monsoons with heavier precipitation in summer during a short rainy season from the end of June through the end of July. Winters can be extremely cold with minimum temperatures dropping below −20 °C in the inland region of the country. In Seoul, the average January temperature range is −7 to 1 °C, and the average August temperature range is 22–30 °C. Summer can be uncomfortably hot and humid, with temperatures exceeding 30 °C in most parts of the country. South Korea has four distinct seasons, with spring usually lasting from late March to early May, summer from mid-May to early September, autumn from mid-September to early November, and winter from mid-November to mid-March. Fig. 3 shows South Korea's regional divisions [32].

2.1. South Korea renewable energy situation

Since 2006 The Korean government has developed and applied many new policies in the energy and environment areas. Most notably, the government has committed to reducing its greenhouse gas (GHG)

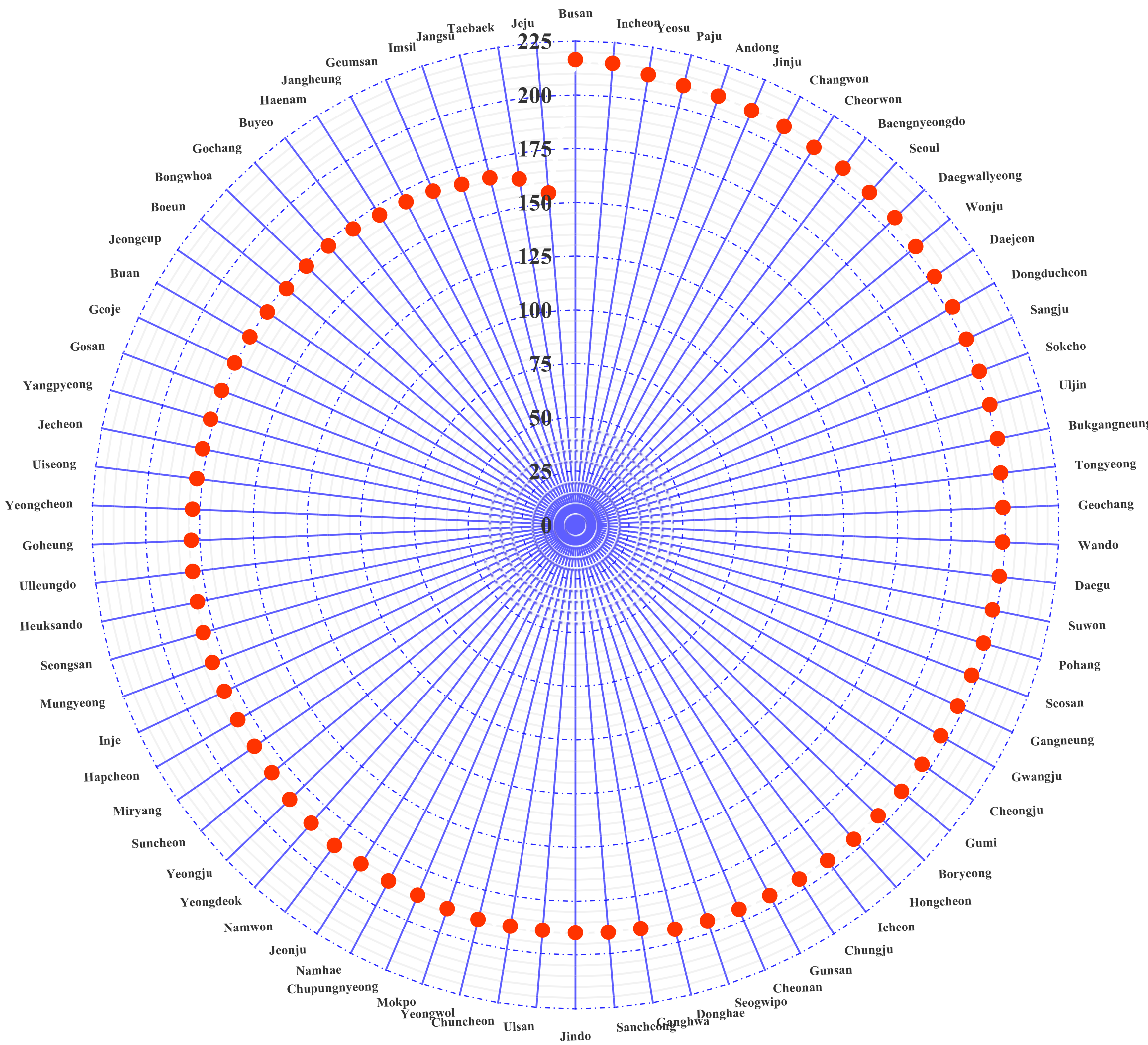

Fig. 7. Annual average monthly sunshine hours.

emissions by 30% in comparison with its business as usual (BAU) case by 2020 and has integrated this commitment into its Strategy for Green Growth. The government has established an 11% target of new and renewable energy in TPES by 2030. The government also specified several key technologies (PV, solar thermal, geothermal and bio energy) in the Third Renewable Basic Plan. In 2012, the government replaced the existing feed-in tariff mechanism with a renewable portfolio standard (RPS) applicable from 2012 for the purpose of meeting its new and renewable energy targets [33].

Fig. 4. shows the total domestic power generation (includes business operators, commercial users and new-renewable) and new-renewable energy generation. As shown in this Fig. 4 about 6.61% of total domestic power comes from new-renewable energy in 2015 that shows 1.69% increase in comparison with 2014 [34].

Table 1 shows the energy production in each sector in 2014 and 2015. Also in third column, the difference is shown [34].

Solar energy production showed a significant increase 9.5–10.7%) in power generation due to an increase in new installation capacity (1134 MW), while hydropower showed a decrease (10.2 to 5.8%) due to insufficient rainfall (72% The proportion of power generation is greatly reduced). (Increase contribution by origin) In 2015, the net increase of new and renewable power is 10,197 GWh. Fig. 5. shows a better distribution of energy production of each sector [34].

3. Weather data

Data from 24 stations in the last five years (2011–2015) were investigated for solar radiation measurements, and data from 78 stations in the last three years (2013–2015) were used for measurements of sunshine hours. These stations are uniformly distributed across the country. Numerous data from a wide range of regions were used to obtain reliable estimations of radiation and sunshine hours. Table 2 presents the locations of the stations. The data were obtained from the Korean Meteorological Administration [35].

The collected data were first rearranged and adjusted to eliminate probable errors. Data from weather stations were used to evaluate horizontal solar radiation and sunshine hours. Fig. 6 gives an overall sense of the annual averages for all of the stations. At 173.8 W/m^2, Daejeon has the highest annual average monthly solar radiation, followed by Jinju, Andong, Daegu, and Busan.

Table 3 shows the maximum, minimum, and average values of GHR at each station. With a GHR of about 266.3 W/m^2 in May, Daejeon again has the highest value. Jeju has the lowest GHR of 59.1 W/m^2 in December. The overall average GHR in South Korea is 158.7 W/m^2.

South Korea has modest solar resources compared to countries in subtropical latitudes. The GHRs received annually in Daejeon, Jinju, Andong, Daegu, and Busan are 173.8, 169.5, 166.9, 166.5, and

Table 5
Total sunshine hours.

No	Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1	Busan	231	175	246	218	280	168	198	209	217	242	193	218	216
2	Incheon	189	188	251	213	277	246	165	215	226	251	174	188	215
3	Yeosu	217	185	242	212	283	173	181	213	211	250	181	199	212
4	Paju	184	182	245	212	273	235	168	217	222	241	159	186	210
5	Andong	211	183	257	218	298	205	195	208	185	220	152	190	210
6	Jinju	217	179	247	216	275	169	181	196	209	243	179	202	209
7	Changwon	224	178	245	213	278	169	183	197	204	234	182	203	209
8	Cheorwon	170	178	250	213	277	234	174	210	225	237	151	175	208
9	Baengnyeongdo	170	176	241	234	275	235	158	240	242	235	146	136	207
10	Seoul	182	177	247	214	278	222	150	192	222	243	164	186	206
11	Daegwallyeong	190	183	254	222	294	179	179	191	181	227	169	204	206
12	Wonju	173	178	248	206	281	231	174	202	208	238	148	164	204
13	Daejeon	176	162	248	211	290	212	175	205	214	243	139	162	203
14	Dongducheon	173	176	248	208	274	227	156	195	217	232	152	175	203
15	Sangju	189	169	246	211	298	201	187	198	187	216	142	173	201
16	Sokcho	191	169	239	206	273	164	195	195	192	226	165	198	201
17	Uljin	204	166	231	211	269	174	194	193	190	219	163	198	201
18	Bukgangneung	197	170	238	210	277	156	190	199	186	222	162	199	200
19	Tongyeong	214	171	230	199	262	154	167	181	202	231	179	201	199
20	Geochang	210	178	245	213	289	173	184	182	176	209	149	181	199
21	Wando	195	167	233	208	280	169	184	196	212	233	149	163	199
22	Daegu	215	170	247	207	286	166	167	169	187	227	161	183	199
23	Suwon	173	173	242	203	266	220	135	188	211	240	155	172	198
24	Pohang	189	159	230	205	275	161	194	188	193	216	171	191	198
25	Seosan	171	164	240	213	270	220	146	202	216	243	132	150	197
26	Gangneung	188	166	236	203	264	160	187	200	180	218	162	200	197
27	Gwangju	191	164	240	208	277	179	164	188	208	237	146	153	196
28	Cheongju	166	155	243	208	273	213	166	197	204	237	131	159	196
29	Gumi	180	162	238	218	294	193	189	188	189	212	136	153	196
30	Boryeong	176	158	240	212	260	218	144	198	213	239	138	151	195
31	Hongcheon	159	171	240	202	271	225	172	193	200	211	141	159	195
32	Icheon	170	173	241	212	266	223	153	182	195	222	137	169	195
33	Chungju	165	171	247	212	284	225	155	187	196	223	124	150	195
34	Gunsan	180	159	234	208	263	206	151	198	215	238	138	148	195
35	Cheonan	153	159	245	211	277	213	153	200	208	239	138	137	194
36	Seogwipo	198	154	220	200	260	141	164	210	201	234	171	178	194
37	Donghae	186	156	230	208	274	159	186	188	181	216	162	179	194
38	Ganghwa	173	172	232	195	250	208	122	174	205	230	146	175	190
39	Sancheong	181	170	241	201	274	168	168	176	190	211	144	157	190
40	Jindo	189	156	225	208	281	157	116	178	215	246	154	152	190
41	Ulsan	215	164	236	199	231	115	145	172	197	219	176	201	189
42	Chuncheon	157	169	241	192	262	215	153	189	200	204	136	152	189
43	Yeongwol	158	164	237	203	283	211	154	177	186	210	134	152	189
44	Mokpo	176	148	221	206	261	170	154	199	212	233	138	141	188
45	Chupungnyeong	182	159	233	196	275	174	155	173	184	216	139	161	187
46	Namhae	194	164	222	201	265	145	152	181	183	212	154	173	187
47	Jeonju	165	151	226	202	272	181	155	187	200	228	130	142	187
48	Namwon	183	161	231	198	271	173	157	171	197	225	128	143	187
49	Yeongdeok	184	149	220	197	265	162	179	177	177	200	142	173	185
50	Yeongju	184	167	236	190	281	178	132	158	178	214	134	160	184
51	Suncheon	190	160	233	192	251	140	133	169	187	224	147	162	182
52	Miryang	203	158	227	190	254	140	138	162	166	210	153	175	181
53	Hapcheon	188	164	235	197	263	147	144	163	167	205	137	165	181
54	Inje	149	152	223	186	251	210	166	184	180	185	125	157	181
55	Mungyeong	177	162	238	188	273	169	134	158	175	216	127	151	181
56	Seongsan	172	135	212	192	254	115	162	203	195	223	150	150	180
57	Heuksando	149	136	231	210	237	168	124	186	215	237	138	122	179
58	Ulleungdo	105	103	204	213	289	175	202	206	191	220	133	110	179
59	Goheung	182	154	217	183	258	131	143	178	184	218	139	161	179
60	Yeongcheon	177	154	230	188	263	149	152	161	168	210	135	154	178
61	Uiseong	182	153	225	185	273	161	150	157	158	206	126	156	177
62	Jecheon	168	160	223	182	257	181	124	148	172	220	129	160	177
63	Yangpyeong	163	163	231	181	238	190	121	148	185	211	132	156	177
64	Gosan	135	122	195	188	247	143	161	209	202	248	144	118	176
65	Geoje	182	151	219	191	246	134	127	165	181	203	145	162	175
66	Buan	151	136	219	198	255	180	141	184	197	212	114	112	175
67	Jeongeup	150	132	205	185	246	182	174	201	205	200	117	95	174
68	Boeun	152	143	230	191	264	185	126	160	179	212	112	130	174
69	Bongwhoa	180	160	224	178	261	162	121	150	157	190	134	167	174
70	Gochang	156	138	224	202	260	164	130	175	186	214	111	119	173
71	Buyeo	160	147	223	190	252	175	123	163	181	210	107	133	172
72	Haenam	172	138	202	181	254	132	126	172	187	218	128	136	170
73	Jangheung	171	148	214	185	249	122	119	156	184	220	129	138	170
74	Geumsan	162	147	223	188	261	162	132	154	163	190	107	135	169

(continued on next page)

Table 5 *(continued)*

No	Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
75	Imsil	160	144	218	183	258	149	121	149	180	207	114	120	167
76	Jangsu	169	148	219	182	263	144	123	144	165	196	112	129	166
77	Taebaek	164	157	226	183	237	142	109	126	139	186	128	158	163
78	Jeju	113	94	182	184	248	130	187	184	183	187	97	69	155

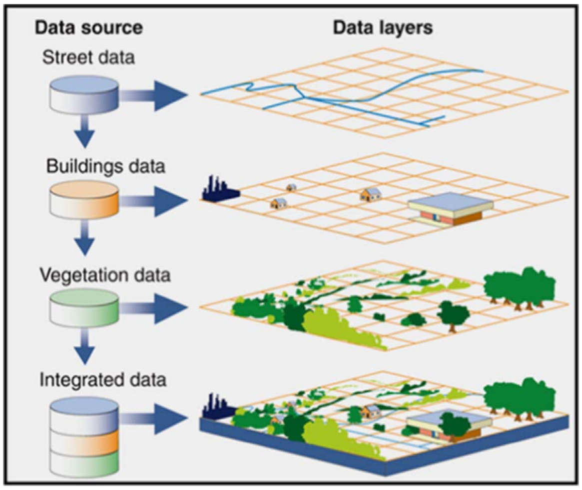

Fig. 8. Simple sample of GIS themes.

166.2 W/m^2, respectively. These average values result from the significant seasonal variability. Solar irradiance is high from about April to September. The annually average solar irradiation is slightly over half of that received in parts of Southern Europe and North Africa, yet it is adequate to meaningfully reduce the domestic demand for heat and power [36].

4. Monthly mean clearness index

When solar radiation moves through the atmosphere, a part of it will be lost to absorption, reflection, and transmitting radiation diffusion. This reduction is created by moisture, dust, clouds, or temperature variation through the layers of the atmosphere. Clouds are the most important part on this attenuation with their seasonal changes. The attenuation can be expressed by the clearness index $\overline{K_T}$, which is defined as the global solar radiation on the surface of the earth divided by the extraterrestrial radiation. In other words, it is the proportion of the extraterrestrial solar radiation that makes it through to the surface [37]:

$$\overline{K_T} = \frac{\overline{H}}{\overline{H_0}} \tag{1}$$

where $\overline{K_T}$ is the monthly average of the daily clearness index, $\overline{H}$ is the monthly average of daily total radiation received by the horizontal plane on the Earth, and $\overline{H_0}$ is the radiation received by the same plane at same coordinates outside the Earth's atmosphere. The solar radiation on a horizontal plane outside the Earth's atmosphere is obtained from the following equation [37]:

$$G_{on} = G_{sc}\left[1 + 0.033\cos\left(\frac{360*n}{365}\right)\right]\cos\theta_z \tag{2}$$

where G_{sc} is solar constant ($G_{sc} = 1367$ W/m^2), n is the day of the year (e.g., for January 1st, n = 1), and θ_z is the zenith angle (the angle between a vertical line and the sun's beam) obtained from the following equation:

$$\cos\theta_z = \cos\delta\cos\phi\ \cos\omega + \sin\delta\ \sin\phi \tag{3}$$

where ϕ is the location's latitude, and δ is the tilt angle defined by:

$$\delta = 23.45\sin\left(360\frac{(284+n)}{365}\right) \tag{4}$$

where ω is the hour angle (equivalent to 15 degrees per hour from solar noon). Sunrise and sunset hour angles can be obtained from Eq. (3) with $\theta_z = 90^{\circ}$:

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \tag{5}$$

The day length is defined as twice the time interval from noon to sunset:

$$t = \frac{2}{15}\omega_s \tag{6}$$

To determine the amount of daily radiation, Eq. (2) can be integrated from sunrise to sunset:

$$H_0 = \frac{24}{\pi}G_{sc}\left[1 + 0.033\cos\left(\frac{360*n}{365}\right)\right] \times \left[\cos\phi\cos\delta\sin\omega_s + \frac{2\pi\omega_s}{360}\sin\phi\sin\delta\right] \tag{7}$$

where H_0 is in $J/m^2 day$.

The monthly mean of daily extraterrestrial radiation $\overline{H_0}$ can be calculated using Eq. (7) for the mean day of the month. Table 4 shows the monthly clearness indices for stations throughout the country. The annual average is presented in the last column.

According to Table 4, Daejeon station has the highest clearness index of about 0.61 in October. Seoul station has the lowest index of about 0.28 in July. Based on the annual average clearness index, the maximum and minimum annual values are 0.51 in Daejeon and 0.43 in Jeju and Seoul stations. The overall average clearness index for all stations in South Korea is about 0.47.

5. Sunshine hours

Field investigations are required to gain detailed information about solar radiation in a given region. The sunshine hours are defined as the time during which the sun is visible, and this parameter is crucial for identifying regions with the potential for installing solar equipment and power generators [37]. The amount of daily sunshine hours at the study stations is reported as the annual average of monthly sunshine hours in Fig. 7.

Clearly, Busan station has the highest annual average of total sunshine hours per month (about 216 h), while Jeju station has the lowest (only about 155 h). The annual average of total monthly sunshine hours in South Korea is about 189 h. The total sunshine hours per month in all 78 stations are shown in Table 5.

The highest sunshine hours is 298 in May for Andong station, and the lowest one is 69 in December for Jeju station. Among the different months, May and November have the highest and lowest total sunshine hours, respectively.

6. Solar radiation GIS maps

Maps have been used for geographical issues in the last few decades, and with improving computer efficiency, the different maps have been combined with computer graphics and databases to create the Geographic Information System (GIS). The system uses layers

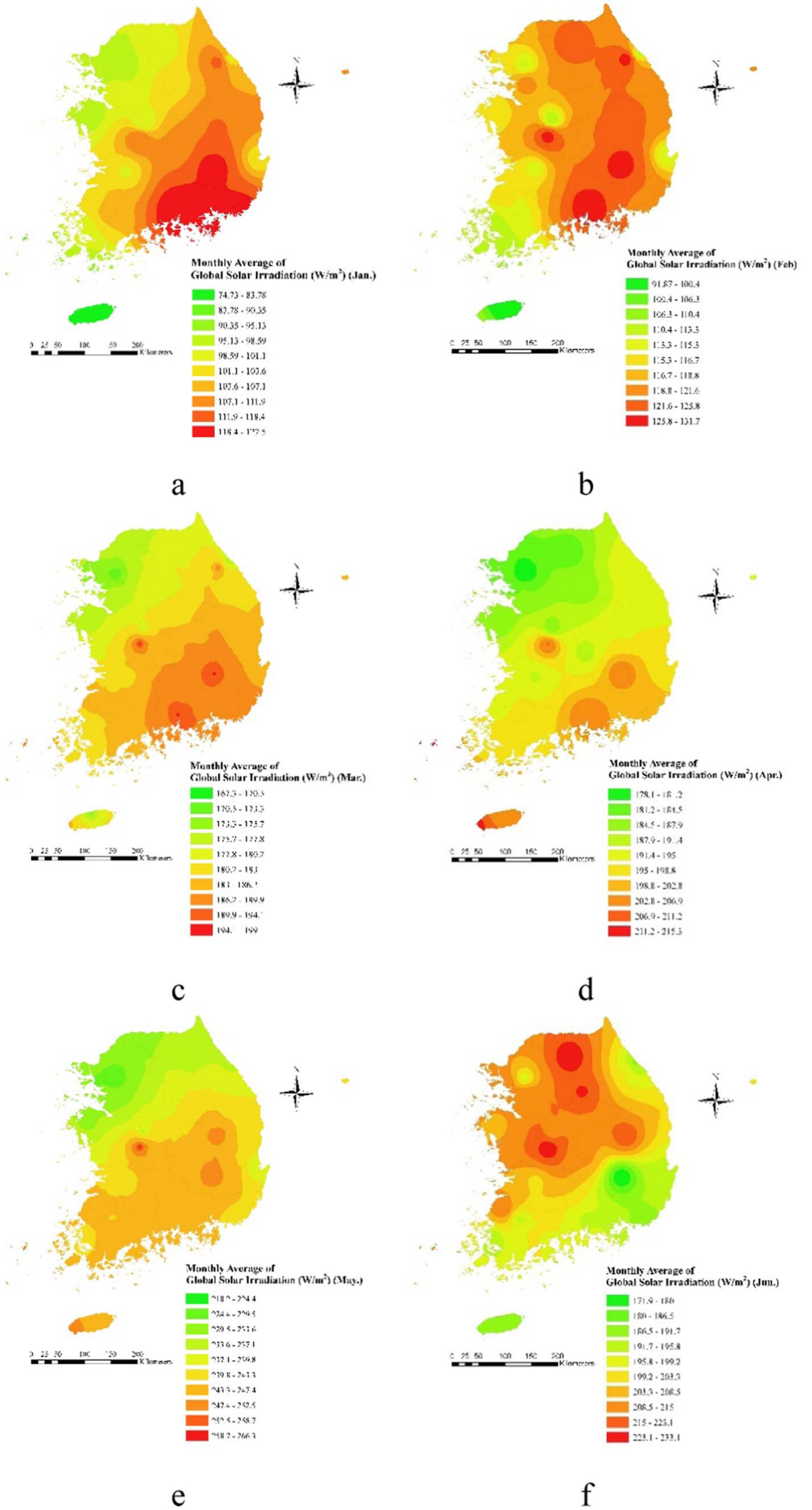

Fig. 9. Monthly average radiation on horizontal surface in (a) January, (b) February, (c) March, (d) April, (e) May, and (f) June. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

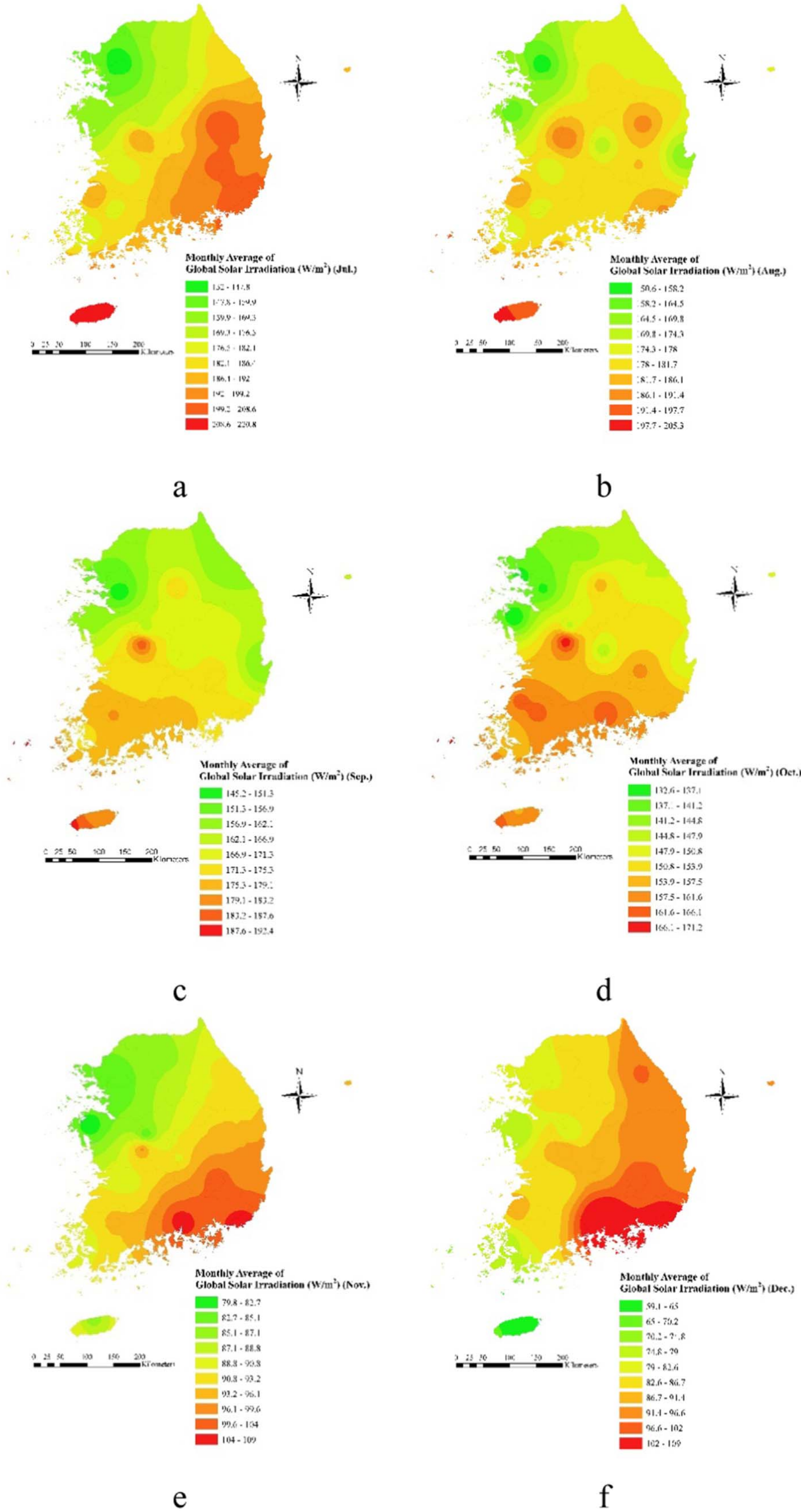

Fig. 10. Monthly average radiation on horizontal surface in (a) July, (b) August, (c) September, (d) October, e) November, and (f) December. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

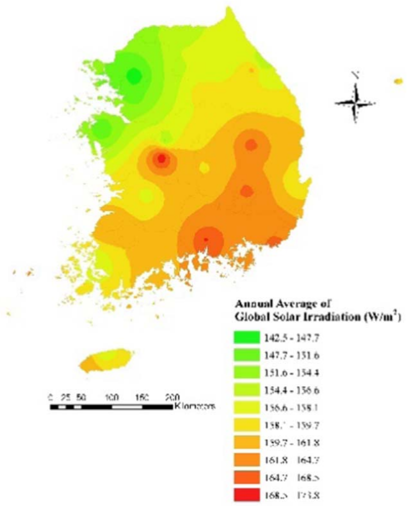

Fig. 11. Annual average of total radiation on a horizontal surface. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

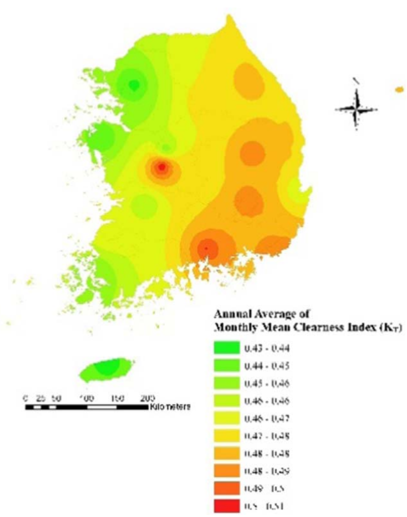

Fig. 12. Annual average of monthly mean clearness index.

called themes to combine different types of information in one independent map. Each theme represents a set of information, such as roads, altitude, rivers, forest cover, etc. These are only a small example of the wide array of information that can be viewed or analyzed with GIS, such as finding the best location for installing or constructing a new power plant, school, or any building. A very simple sample of GIS themes is shown in Fig. 8 [38].

Generally, GIS is a tool for managing, compiling, and analyzing spatial data. Elevation, temperature, contamination concentrations, or any type of data that have coordinates and a quantity can be shown in GIS maps. Each raster cell represents a measurement, such as the cell's relationship to a fixed point or a specific concentration level. In most cases, especially for weather parameters, there is information for distinct locations (for example, we used information from 24 and 78 stations in this study). Thus, we can use GIS methods to visualize the continuity and variability of observed data across a surface through the use of interpolation tools. These changes can be extrapolated or interpolated throughout a geographic space. The ability to produce surfaces from separate sample data makes interpolation methods both powerful and useful.

6.1. Interpolation methods

There are several interpolation methods for making a surface grid. The methods are based on the principle of spatial autocorrelation or spatial dependence, which measure the degree of relationship or dependence between near and distant objects. Spatial autocorrelation is specified if values are interrelated and can determine if there is a spatial pattern. This correlation is used to measure:

Similarity of objects within an area.

The degree to which a spatial phenomenon is correlated to itself in space.

The level of interdependence between the variables.

The nature and strength of the interdependence [39–43].

There are two groups of interpolation methods: deterministic and geostatistical. Deterministic interpolation methods make surfaces based on measured points or mathematical formulas. Methods such as the inverse distance weight (IDW) method are based on the extent of similarity of cells, while methods such as the trend method fit a smooth surface defined by a mathematical function. Geostatistical interpolation methods like the Kriging method are based on statistics and used for more advanced prediction through surface modeling, which also includes some measure of the certainty or accuracy of the predictions [44].

The IDW method is used when the group of points is dense enough to capture the extent of local surface variation needed for analysis, and it was used in this study. IDW defines a cell quantity using a linear-weighted mixture set of sample points. The weight allocated depends on the distance: the greater the distance, the less influence the cell has on the output value [40].

6.2. GIS maps of South Korea

6.2.1. Solar radiation

GIS maps make it easier to study and assess radiation in various locations and different months in places where there is no measurement equipment. Solar data were not available for all the potential sites, so interpolation was used to estimate the potential solar radiation or other parameters in these places.

In this work, 13 GIS maps for monthly and annual total GHR were prepared for South Korea, as shown in Figs. 9–11. The contours have a scale of 1:4,000,000.

The GIS maps are marked by different colors that show the different levels of solar radiation. Locations with higher levels are indicated by redder colors. The color transitions to green as the radiation levels decrease.

According to the maps shown in Figs. 9–10 and 11 there is a general increasing trend in the quantity of radiation from north to south in most months as the locations approach the earth's equator. The central, south, and southeast regions have higher radiation levels. As a result, using solar systems will be more economical in these regions. The north and northwest of the country have low irradiation due to the higher latitude and greater cloudiness in most months of the year. Heuksando island has good potential during March, April, September, and October. Jeju island has good potential during April, July, and August. Based on the GIS maps, the maximum solar radiation in these regions occurs in May, and the lowest one happens in December.

The total solar irradiation is highest in Daejeon, Jinju, Andong, Daegu, and Busan in most months. Seoul, Suwon, Seosan, Incheon, and Cheongju in Western and Northwestern South Korea have the lowest radiation throughout the year.

GIS software can be applied to identify proper sites that receive good amounts of solar radiation and whether they are economical based on the effects of other parameters, such as distance from cities, electrical networks, roads, elevation, etc. Therefore, this information can be used as a first step to choosing locations for solar application plants.

6.2.2. Clearness index

According to Fig. 10, Daejeon and Jinju have the highest clearness indexes, followed by Andong, Daegu, Daegwallyeong, and Busan. Fig. 12 shows that the central, south, and southeast regions have higher monthly mean clearness indexes. The maximum Annual mean clearness index among the 24 stations is 0.51 for Daejeon station. The lowest one is 0.43 for Jeju and Seoul in July. The annual average monthly mean clearness index for all stations is 0.47.

7. Conclusion

The present study examined the feasibility of exploiting solar energy using data from 24 stations for radiation (five-year average) and 78 stations for sunshine hours (three-year average) throughout South Korea. The maximum, minimum, and yearly average of GHR were obtained for each station. For every station, the monthly and yearly average clearness index was calculated. After that, the total sunshine hours and annual average of the total sunshine hours were obtained for all of the other stations. The data were applied to create GIS maps for the yearly average and monthly average of GHR over the 12 months of the year. According to the maps, there is a general increasing trend in the quantity of radiation from north to south in most months. Among the stations, Daejeon, Jinju, Andong, Daegu, and Busan are the top five most promising cities in most months for installing solar equipment. May had the highest amount of solar radiation, regardless of site location. The results of this study are needed for the first step of every projects for finding available solar radiation value. Furthermore, for accounting atmospheric effects on available solar energy monthly mean clearness can be used. This work could be a guideline for other works on installing solar equipment throughout South Korea.

Acknowledgment

This study was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIP) through GCRC-SOP (No. 2011-0030013).

References

[1] Moghaddam NB, Mousavi SM, Nasiri M, Moallemi EA, Yousefdehi H. Wind energy status of Iran: evaluating Iran's technological capability in manufacturing wind turbines. Renew Sustain Energy Rev 2011;15:4200–11.
[2] Agency IE. Key world energy statistics: International Energy Agency; 2016.
[3] REN21. Renewables 2016: Global status report. In: Zervos A, editor. REN21 Renewable energy policy network/Worldwatch Institute; 2016.
[4] Mazandarani A, Mahlia T, Chong W, Moghavvemi M. A review on the pattern of electricity generation and emission in Iran from 1967 to 2008. Renew Sustain Energy Rev 2010;14, [1814-29].
[5] Thirugnanasambandam M, Iniyan S, Goic R. A review of solar thermal technologies. Renew Sustain Energy Rev 2010;14:312–22.
[6] Tsoutsos T, Frantzeskaki N, Gekas V. Environmental impacts from the solar energy technologies. Energy Policy 2005;33:289–96.
[7] Jacovides C, Tymvios F, Assimakopoulos V, Kaltsounides N. Comparative study of various correlations in estimating hourly diffuse fraction of global solar radiation. Renew Energy 2006;31:2492–504.
[8] Sabziparvar AA, Shetaee H. Estimation of global solar radiation in arid and semi-arid climates of East and West Iran. Energy 2007;32:649–55.
[9] Chegaar M, Chibani A. Global solar radiation estimation in Algeria. Energy Convers Manag 2001;42:967–73.
[10] Osmani A, Zhang J, Gonela V, Awudu I. Electricity generation from renewables in the United States: resource potential, current usage, technical status, challenges, strategies, policies, and future directions. Renew Sustain Energy Rev 2013;24:454–72.
[11] Tucho GT, Weesie PDM, Nonhebel S. Assessment of renewable energy resources potential for large scale and standalone applications in Ethiopia. Renew Sustain Energy Rev 2014;40:422–31.
[12] Izadyar N, Ong HC, Chong WT, Leong KY. Resource assessment of the renewable energy potential for a remote area: a review. Renew Sustain Energy Rev 2016;62:908–23.
[13] Okoye CO, Taylan O, Baker DK. Solar energy potentials in strategically located cities in Nigeria: review, resource assessment and PV system design. Renew Sustain Energy Rev 2016;55:550–66.
[14] Alamdari P, Nematollahi O, Alemrajabi AA. Solar energy potentials in Iran: a review. Renew Sustain Energy Rev 2013;21:778–88.
[15] Moreno-Tejera S, Silva-Pérez MA, Lillo-Bravo I, Ramírez-Santigosa L. Solar resource assessment in Seville, Spain. Statistical characterisation of solar radiation at different time resolutions. Sol Energy 2016;132:430–41.
[16] Rubio-Aliaga Á, Sánchez-Lozano JM, García-Cascales MS, Benhamou M, Molina-García A. GIS based solar resource analysis for irrigation purposes: rural areas comparison under groundwater scarcity conditions. Sol Energy Mater Sol Cells 2016;156:128–39.
[17] Ruiz-Arias JA, Quesada-Ruiz S, Fernández EF, Gueymard CA. Optimal combination of gridded and ground-observed solar radiation data for regional solar resource assessment. Sol Energy 2015;112:411–24.
[18] Anwarzai MA, Nagasaka K Utility-scale implementable potential of wind and solar energies for Afghanistan using GIS multi-criteria decision analysis. Renewable and Sustainable Energy Reviews.
[19] Modi A, Bühler F, Andreasen JG, Haglind F. A review of solar energy based heat and power generation systems. Renew Sustain Energy Rev 2017;67:1047–64.
[20] Sindhu S, Nehra V, Luthra S. Investigation of feasibility study of solar farms deployment using hybrid AHP-TOPSIS analysis: case study of India. Renew Sustain Energy Rev 2017;73:496–511.
[21] Halder PK. Potential and economic feasibility of solar home systems implementation in Bangladesh. Renew Sustain Energy Rev 2016;65:568–76.
[22] Escobar RA, Cortés C, Pino A, Pereira EB, Martins FR, Cardemil JM. Solar energy resource assessment in Chile: satellite estimation and ground station measurements. Renew Energy 2014;71:324–32.
[23] Nematollahi O, Hoghooghi H, Rasti M, Sedaghat A. Energy demands and renewable energy resources in the Middle East. Renew Sustain Energy Rev 2016;54:1172–81.
[24] Al-Sharafi A, Sahin AZ, Ayar T, Yilbas BS. Techno-economic analysis and optimization of solar and wind energy systems for power generation and hydrogen production in Saudi Arabia. Renew Sustain Energy Rev 2017;69:33–49.
[25] Zell E, Gasim S, Wilcox S, Katamoura S, Stoffel T, Shibli H, et al. Assessment of solar radiation resources in Saudi Arabia. Sol Energy 2015;119:422–38.
[26] He G, Kammen DM. Where, when and how much solar is available? A provincial-scale solar resource assessment for China. Renew Energy 2016;85:74–82.
[27] Stökler S, Schillings C, Kraas B. Solar resource assessment study for Pakistan. Renew Sustain Energy Rev 2016;58:1184–8.
[28] Yadav AK, Malik H, Chandel SS. Application of rapid miner in ANN based prediction of solar radiation for assessment of solar energy resource potential of 76 sites in Northwestern India. Renew Sustain Energy Rev 2015;52:1093–106.
[29] Byrne J, Taminiau J, Kurdgelashvili L, Kim KN. A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the city of Seoul. Renew Sustain Energy Rev 2015;41:830–44.
[30] Park J-K, Das A, Park J-H. A new approach to estimate the spatial distribution of solar radiation using topographic factor and sunshine duration in South Korea. Energy Convers Manag 2015;101:30–9.
[31] Koo C, Hong T, Park HS, Yun G. Framework for the analysis of the potential of the rooftop photovoltaic system to achieve the net-zero energy solar buildings. Progress Photovolt: Res Appl 2014;22:462–78.
[32] Wikipedia. Wikipedia: ⟨http://dx.doi.org/en.wikipedia.org/wiki/South_Korea⟩; 2016.
[33] Chanal M, Meisen P. How is 100% renewable energy possible in South Korea by 2020. San Diego, USA: Global Energy Network Institute; 2012.
[34] Kang N-H. New & renewable energy statistics 2015 (2016 Edition). ⟨http://www.knrec.or.kr⟩; 2016.
[35] Korean Meteorological Administration: ⟨http://dx.doi.org/data.kma.go.kr/data/grnd/selectAsosList.do?PgmNo=34⟩; 2016.
[36] Freeman J, Hellgardt K, Markides CN. An assessment of solar-powered organic Rankine cycle systems for combined heating and power in UK domestic applications. Appl Energy 2015;138:605–20.
[37] Duffie JA, Beckman WA. Solar engineering of thermal processes. New York: Wiley; 2013.
[38] Th IA, DA M, N HS , Coupling . GIS and photogrammetry for the development of large-scale land information system (LIS). J Geosci Geomat 2014;2:1–10.
[39] GIS Center. ⟨http://dx.doi.org/gis.tulaliptribes-nsn.gov/Home/About/GISCenter.aspx⟩.
[40] ESRI. ⟨http://www.esri.com/news/arcuser/0704/files/interpolating.pdf⟩.
[41] Jangid J, Bera AK, Joseph M, Singh V, Singh TP, Pradhan BK, et al. Potential zones identification for harvesting wind energy resources in desert region of India – a multi criteria evaluation approach using remote sensing and GIS. Renew Sustain Energy Rev 2016;65:1–10.
[42] 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.
[43] González-Longatt F, Medina H, Serrano González J. Spatial interpolation and orographic correction to estimate wind energy resource in Venezuela. Renew Sustain Energy Rev 2015;48:1–16.
[44] Alamdari P, Nematollahi O, Mirhosseini M. Assessment of wind energy in Iran: a review. Renew Sustain Energy Rev 2012;16:836–60.