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GIS-Based Wind and Solar Power Assessment in Central Mexico

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Abstract: In Mexico, the economic and industrial development is in the center and north; this represents more than 50% of the country's total consumption. Data on population and energy consumption will be obtained from the following sources: the National Institute of Geography and Statistics (INEGI), and the Energy Information System. Regarding meteorological data, two databases are used: the Automatic Weather Stations (AWS) (for solar irradiance data) and the MERRA-2 reanalysis data (for wind data). These data will be analyzed for use in a geographic information system (GIS) using kriging interpolation to create maps of solar and wind energy. The area studied includes the following states: Mexico City, Puebla, State of Mexico, Hidalgo, Morelos, Zacatecas, Queretaro, San Luis Potosi, Guanajuato, Aguascalientes and Tlaxcala. The results showed that the areas with the highest solar potential are Hidalgo, Estado de México, Morelos, northern Puebla, southern Queretaro, northwestern Guanajuato, and northern Zacatecas, with 5.89 kWh/m^2/day, and the months with the highest solar potential are March, April, May, and June. Regarding wind potential, the maximum wind power density is in Puebla, with 517 W/m^2, and the windy season in central Mexico spans June, July, August, September, October, and November.

Keywords: AWS; GIS; kriging; MERRA-2; Mexico; solar; wind; wind power density

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1. Introduction

Mexico is one of the leading economies in Latin America; the country has a large population, extensive territory and a vast diversity of natural resources. The energy consumption of the country is the second largest in Latin America, only after Brazil; the combination of these factors and the new prominent energy policies give great potential for energy investments [1].

According to information from the National Secretary of Energy (SENER), the National Energy System in Mexico (SEN) is an integrated system that provides service to more than 120 million users, with a network that unites nine regions, including a bidirectionally interconnected system with the United States of America. This system can supply the growing energy demand derived from population and production growth. In 2019, Mexico reached a gross electrical consumption of 324,927 GWh, which represents an increase of 2.1% compared with 2018 [2].

In 2020, the gross national consumption of the SEN decreased by 315,968 GWh, showing a decrease of 2.76% compared with the consumption of 2019. This phenomenon was derived from the suspension of productive activities due to the health emergency caused by COVID-19. However, the growth of gross consumption during the last ten years is reportedly an average of 2.2%; it is expected that this will be approximately up to 500,000 GWh for the year 2035 [3]. Table 1 shows the behavior of gross consumption in Mexico from 2016 to 2020 according to data from the National Electrical System Development Program of Mexico [4].

Table 1. Evolution of the gross electrical consumption in Mexico (GWh).

2016	2017	2018	2019	2020
298,791.7	309,727	318,236	324,927	315,968

The installed electrical capacity in Mexico has grown steadily in recent years; currently, the National Energy System in Mexico (SEN) has an installed capacity of approximately 89,479 MWh, including plants from the Federal Electricity Commission (CFE) and Independent Producers of Electric Power (PIE), Self-supply (AU), Cogeneration (COG), Small Production (PP), Import (IMP), Export (EXP) and Continuous Own Uses (UPC). This capacity supplies the instantaneous maximum demands that occur mainly in the summer months, oscillating around 50,000 MWh; nevertheless, this maximum demand is expected to reach an approximate value of 75,000 MWh, approaching 84% of the total value of installed capacity today. To date, in Mexico, only 29,443 MW of this installed capacity comes from renewable energy sources (REs); therefore, the outlook for these energies in Mexico is promising, and driven by the country's new legislation and energy policies which aim to achieve the energy transition by increasing production and the percentage of participation in the total installed energy capacity [5].

Climate change is no longer a long-term problem; it is currently causing extreme weather conditions worldwide, where significant droughts, new high-temperature records, and an increase in the average number of natural phenomena such as cyclones, hurricanes, and wildfires among others, are being experienced. These changes will have an alarming impact on food and water supplies shortly, as agriculture is one of the industries most affected by these new environmental conditions. The global energy model of the International Renewable Energy Agency (IRENA) presented the technical and economic parameters of an energy transition until 2050. This report suggests that by 2050, 86% of electricity generation will be renewable, and 60% will come from solar and wind. These REs would lead to expansion; forecasts for 2050 show a capacity of 14,500 GW for these two technologies alone [6].

Mexico must make a great effort to move from an energy system based on fossil fuels to a system that takes advantage of the tremendous renewable energy potential that the country possesses. According to the renewable energy roadmap for Mexico, REmap2030, Mexico has the potential to generate 280 TWh of RE by 2030, with wind and solar energy as some of its primary sources [1]. The increase in the capacity of REs has been constant. Figure 1 shows the behavior of the total capacity of REs in Mexico over the last ten years [5].

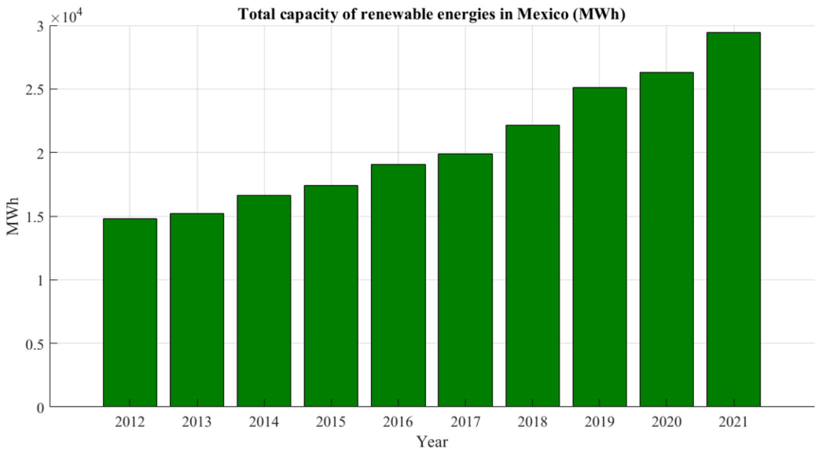


Figure 1. The total capacity of renewable energies in Mexico (2012–2021).

The proportion of RE in the total electrical capacity in Mexico is shown in Figure 2; the trend of increased participation of RE in Mexico has been positive in the last decade.

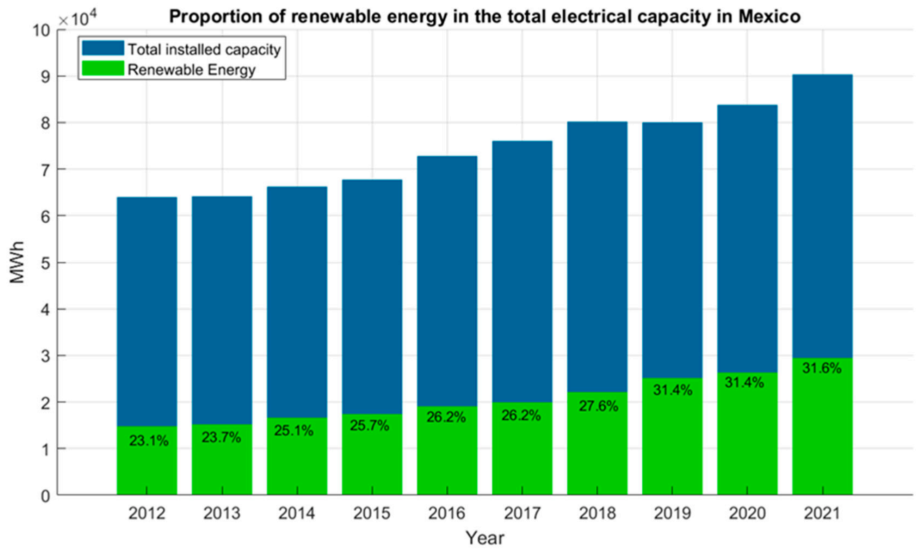


Figure 2. Renewable energy percentage in the total electrical capacity in Mexico.

Integrating different RE technologies has been critical to achieving this capacity; among them are Hydropower, Wind, Solar Photovoltaic, Bioenergy, and Geothermal. Data in Table 2 show the growth and contribution to the total installed capacity of RE in recent years in Mexico.

Table 2. Growth of RE by type of technology in Mexico.

Technology	2016	2017	2018	2019	2020
Hydropower	12,642	12,642	12,671	12,671	12,671
Wind	4199	4876	6050	6504	7692
Solar	1126	2555	4440	5163	7040
Bioenergy	1027	1109	1014	1016	1064
Geothermal	926	951	951	951	976

Data in Table 2 show the increasing trend in integrating REs. This growth has been driven mainly by wind and photovoltaic energy, as the hydroelectric capacity of large plants installed for several decades has not increased significantly in the last ten years. Figure 3 shows the percentage of installed capacity by technology as of 2021, recognizing solar photovoltaic (SPV) and wind turbines (WTB) as the most promising technologies.

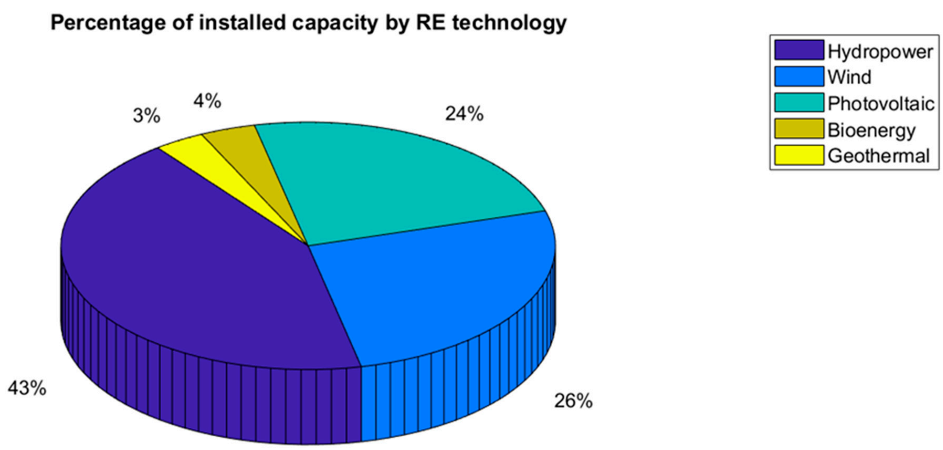


Figure 3. Renewable energy percentage in Mexico by technology (2021).

According to data presented, a promising future can be foreseen for the RE industry in Mexico; this is mainly driven by the new energy policies and regulations forming through agreements to mitigate global climate change and achieve transition energy in the medium term. However, these policies seek greater participation of the Federal Electricity Commission CFE in generating plants, which could hinder investment in RE projects [7]. In Mexico, the Program for the Development of the National Electric System (PRODESEN 2021–2035) [3], which defines the national energy policy in terms of electricity concerning the National Development Plan 2019–2024, declares three main objectives:

(1) Reactivation and development of power plants of the CFE.
(2) Guaranteeing universal access to electricity, thus contributing to the country's economic growth in quality conditions.
(3) Compliance with the environmental commitments contracted with international bodies regarding reducing emissions and climate change, for which the increase of electricity generation through clean and renewable energy is proposed.

A top priority of the Government of Mexico is to guarantee the efficiency, quality, reliability, continuity, and security of the SEN; according to the new law of the Electricity Industry of Mexico, published in 2021, this will be achieved with the modernization and rehabilitation of CFE generation plants, in addition to the construction of new plants of this same entity (Objective 1–2). These new criteria may delay the development of various projects of a renewable energy nature, as priority will be given to CFE plants. However, the commitment that integrates these new energy policies in terms of clean energy also brings areas of opportunity for the energy industries. According to analysis of energy resources, solar photovoltaic (SPV) and wind turbines (WTB) have been recognized as the most promising technologies, owing to the rapid decline in their per-kWh cost and fast-growing popularity [8]. However, the intermittent nature of solar and wind resources, which are spatially different from one location to another, always necessitates a proper integration of energy storage [9] and a comprehensive geographical analysis of their potential to ensure a cost-effective and reliable design [10]. Due to the above, the energy industries will face new challenges in investing in Mexico; this is why the new proposals for RE projects require the application of the most exhaustive analyses and models based on geospatial information of potential sites for the installation of solar and wind energy sources.

GIS technology provides unique capabilities for organizing, analyzing and editing geo-referenced data and spatial maps [11]. GIS technology has recently been applied in the determination of onshore wind dissipation maps and their potential in Turkey [12] and Iran [13,14], evaluation of the onshore wind energy potential in China [15], spatial analysis in the development of a floating offshore wind farm in northwest of Spain [16], assessment of wind/solar resources and hydrogen production within Iran [17], evaluation of the prospects of small-scale pumped hydro energy storage in Tibet [18], finding the optimal geographical location and size of large-scale SPV facilities in French Guiana [19], analysis and optimization of a pure renewable grid system with electric vehicle charging in Australia [20], and assessment of potential geothermal energy areas in China [21].

Given the complexity of decision-related matters in designing energy system infrastructures, GIS provides powerful decision-supporting tools that help judge various alternatives, considering different criteria. The most common application of GIS technology is found in regional and national suitability modeling of solar and wind energy systems, location ranking, and visualizing geospatial data [22–24]. Several studies have developed a combination of GIS and the analytic hierarchy process (AHP) method to find the best geographical sites and technical potentials of large-scale on-grid SPV, concentrated solar power plants, and off-grid SPV systems in the Economic Community of West African States countries, Mediterranean zone, and Tanzania, respectively. All of the above have topographical, legal and social constraints, and techno-economic and socio-environmental criteria [25–28]. Hosseini Dehshiri and Hosseini Dehshiri [29] have also studied this combination, identifying the most suitable places to produce hydrogen by wind energy in Yazd, Iran province. In India, Saraswat et al. [30] investigated the spatial suitability of solar and wind farm locations based on technical, economic, and socio-environmental perspectives. Likewise, Alami Merrouni et al. [31]; Colak et al. [32]; and Mensour et al. (2019) [33] applied the GIS-AHP approach to identify appropriate locations to construct SPV power plants in Southern Morocco, Eastern Morocco, and Malatya provinces of Turkey, respectively. Additionally, Asakereh et al. [34] proposed an integrated fuzzy logic with GIS-AHP to prioritize the land suitability for installing SPV farms in Khuzestan province in Iran, based on techno-economic and environmental attributes. Nagababu et al. [35] built a combination of GIS with AHP and TOPSIS to identify plausible regions in India for installing wind farms at the microscopic level, based on technological, economic, social and environmental aspects. Sindhu et al. [36] utilized a hybrid combination of AHP-fuzzy TOPSIS and GIS to investigate the spatial suitability of the SPV system in India, by analyzing social, technical, economic, environmental and political aspects. Additionally, Gil-García et al. [37] and Noorollahi et al. [38] used fuzzy GIS-based solutions for optimal offshore wind location assessment, and to locate and evaluate the potential of SPV plants.

Moreover, Messaoudi et al. [39] applied GIS-AHP for the site selection of a WTB-powered hydrogen refueling station located in the Adrar area of Algeria. Ayodele et al. [40] proposed a GIS-interval type-2-fuzzy AHP for wind farm location analysis in Nigeria, considering economic, environmental and social criteria. Konstantinos et al. [41] combined AHP-TOPSIS decision-making with GIS technology for spatial planning of suitable locations for installing wind farms in Eastern Macedonia and the Thrace region of Greece. Villacreses et al. [42] developed a GIS-based model for site suitability analysis of WTB farms in Ecuador, by assessing the various meteorological, location, and environmental parameters, where the AHP method is executed to quantify the importance of each parameter. In addition, OWA, VIKOR, TOPSIS and occupational repetitive actions (OCRA) methods are utilized and compared to evaluate the alternatives. Recently, Y. Xu et al. [43] proposed a new approach integrating GIS, interval AHP and stochastic VIKOR to obtain the preferable sites for installing wind farms in the Wafangdian region of China. The relative weights of economic, environmental, and social criteria were determined using AHP, and the ranking of various alternatives was carried out through VIKOR. Further, Ali et al. [44] assessed different economic, environmental and physiographic aspects using GIS-AHP to locate utility–scale WTB and SPV farms in Songkhla, Thailand.

Various authors have evaluated the REs in Mexico integrating GIS capabilities, such as the case of Diez-Rodríguez et al. [45], which proposed a novel method for planning onshore wind energy in Mexico using a geospatial system of collective intelligence (SIGIC); Canul-Reyes et al. [46] evaluated potential zones for offshore wind development in the Gulf of Mexico. In this way, Hernández-Fontes et al. [47] presented a particular study, based on GIS, of the offshore wind energy resources in the coast of Michoacan, Mexico, and Arenas-López [48] evaluated the offshore wind resource potential, assessing up to approximately 80 km off the coast of Mexico. The solar resource was studied by Rosas-Flores et al. [49], who performed an energy savings analysis for solar photo-voltaic technology implementation in rural and urban zones in Mexico, using GIS; Valenzuela-Domínguez et al. [50] developed a GIS analysis of the State of Nuevo León in Mexico to identify solar energy opportunities in this zone. However, despite this series of efforts, no study currently locates areas with the most significant wind and solar potential in the central zone of Mexico.

The main objective and contribution of this work is to offer maps of solar irradiation and wind speed of Central Mexico to identify the areas with the greatest energy potential in this zone; thus far, there are not enough studies that present these values. Investors, government, society and academia can use these maps to gain a preliminary idea of the area they are interested in studying.

2. Materials and Methods

In Mexico, the Federal Commission of Electricity divided the country in seven electrified regions [51], as seen in Figure 4. The area of central Mexico studied in this case includes some of these regions, and the states of Aguascalientes, Guanajuato, Queretaro, Hidalgo, Tlaxcala, Estado de Mexico, Zacatecas, Mexico City (CDMX), Puebla, Morelos, and San Luis Potosi (see Figure 4).

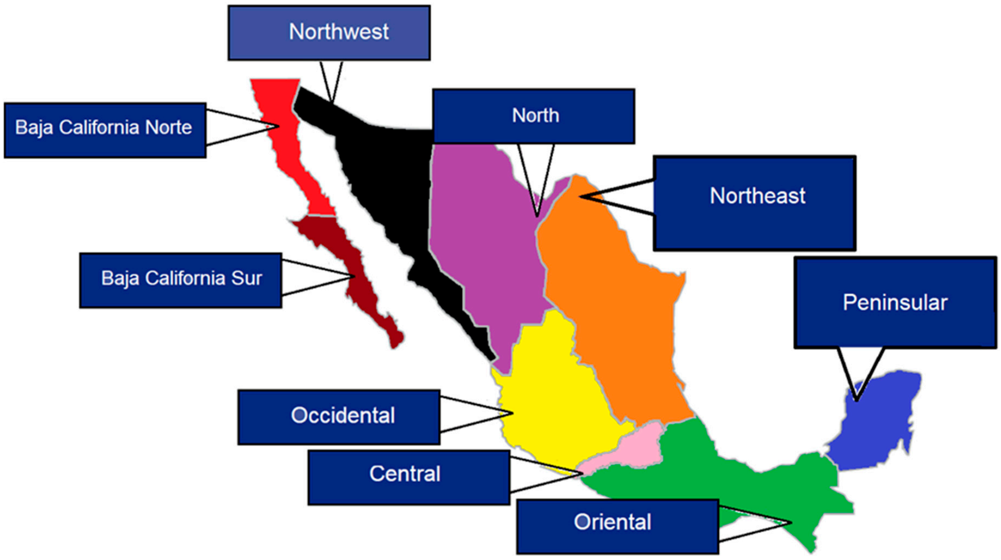


Figure 4. Electric National System of Mexico.

As shown in Figure 4, central Mexico includes Central, Occidental, and Oriental regions. In Figure 5, the location of 11 states in central Mexico, Aguascalientes, Guanajuato, Queretaro, Zacatecas, San Luis Potosi, Morelos, Hidalgo, Mexico City, Puebla, State of Mexico, and Tlaxcala, are presented.

Figure 5. Central Mexican states.

Table 3 shows the population of each state in Central Mexico, according to the National Institute of Statistics and Geography (INEGI) [52].

Table 3. Population in Central Mexico per state.

State	Population
Aguascalientes	1,425,607
Guanajuato	6,166,934
Queretaro	2,368,467
Zacatecas	1,622,138
San Luis Potosi	2,822,255
Morelos	1,971,520
Hidalgo	3,082,841
Mexico City	9,209,944
Puebla	6,583,278
State of Mexico	16,992,418
Tlaxcala	1,342,977

The sum of the population of the states studied is 53,588,379 inhabitants, which represents 42.5% of the total population, which is 126,014,024 inhabitants.

In the states shown in Figure 5, the National Water Commission [53] has installed 43 automatic weather stations (AWS), as shown in Figure 6. The data range from 1990 to 2021; the year 2022 was not considered, as only full years were analyzed.

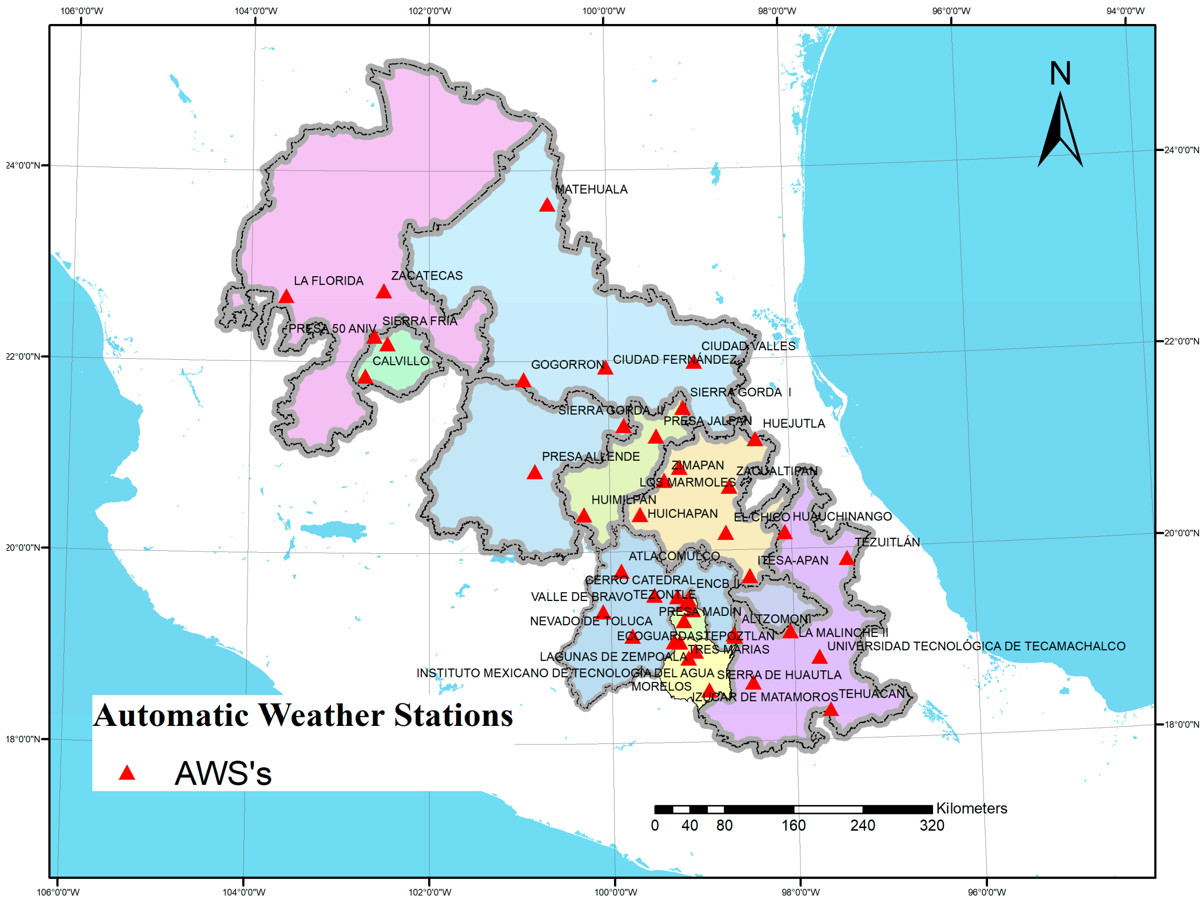


Figure 6. Automatic Weather Stations in Central Mexico.

The AWSs are autonomous and automatic systems formed by a set of measurement sensors, electrical, electronic and mechanical devices mounted on a support structure where they are distributed, oriented and connected to the data acquisition, processing and storage system of the station, in order to measure and record the meteorological variables prevailing at the site and transmit the data obtained to the central office, where they will be used and stored in a database. The sensors in an AWS measure wind speed, wind direction, temperature, atmospheric pressure, relative humidity, solar radiation and precipitation. AWSs will be used to create solar irradiance maps for the central region of Mexico.

To avoid the interpolation being cut off or not well defined, the data of 128 points from MERRA-2 will be used and placed around the entire shapefile of central Mexico. MERRA-2 is a reanalysis data set with hourly records from 1980 to 2022 of variables such as wind speed, wind direction, temperature, and atmospheric pressure. These data will be used to produce monthly and annual wind maps. MERRA-2 data were obtained from https://www.ul.com/services/windnavigator-wind-energy-site-prospecting-and-feasibility, where the data are downloaded after payment. These are .tab files, which are entered into the geographic information system and a coordinate system projected in Lambert Conformal Conic is used, then they are converted into a shapefile to perform the interpolations. For the AWS, the files used are in CSV and thus are entered into the GIS to convert them also into shapefiles.

2.1. Elevation

INEGI [52] is the office in charge of storing Mexico's geographic information, and according to its data, a characteristic element of the Mexican relief and geography is the fact that mountains cover a large part of the country's territory. Mexico's relief is that of a mostly mountainous and highland country. More than 70% of the country of Mexico is made up of mountain systems. However, there are also plains, peninsulas, valleys, plateaus, and depressions, the EPSG: 6372 of Mexico ITRF2008. Figure 7 shows the elevation of central Mexico.

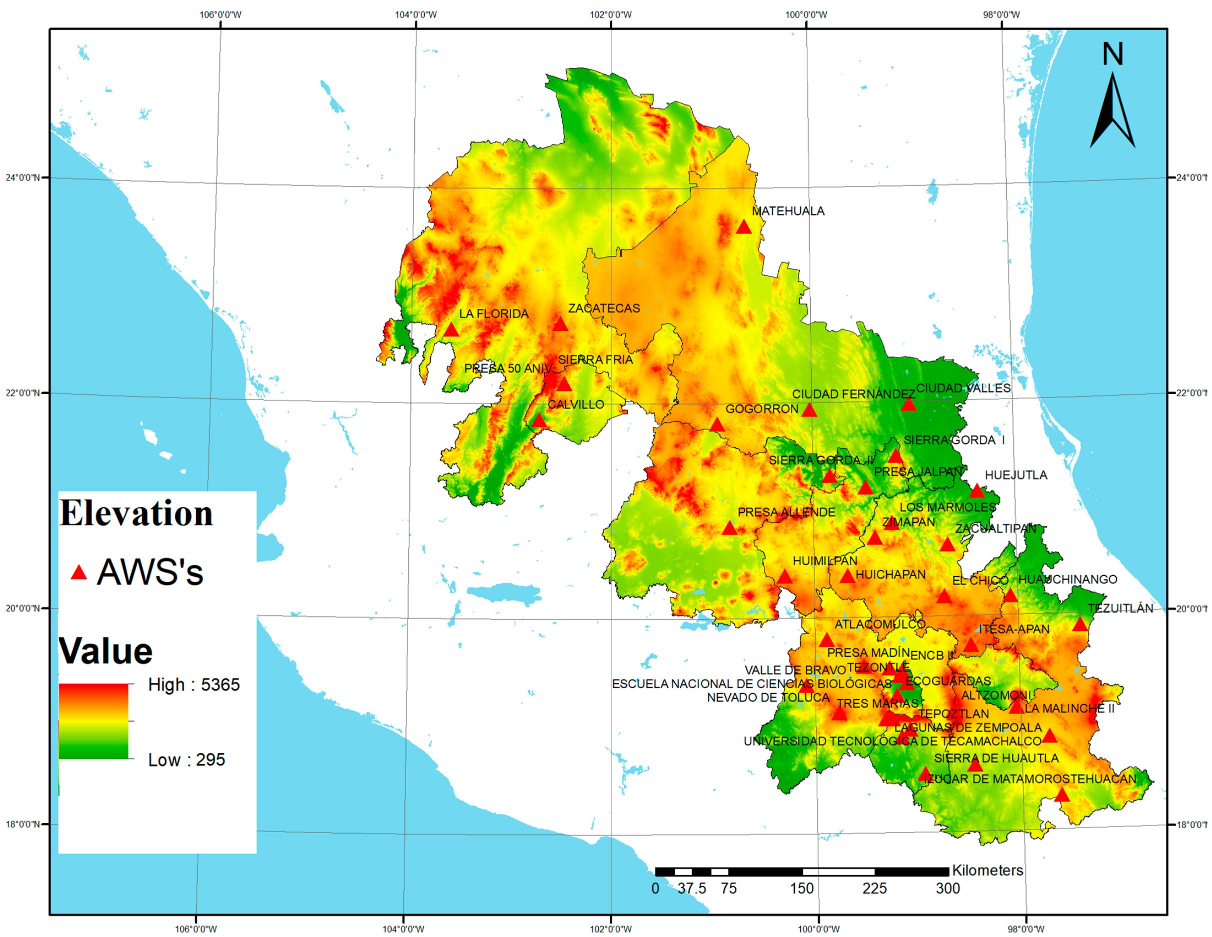


Figure 7. Central Mexico elevation map.

As shown in Figure 7, the elevation of central Mexico ranges from 295 m above sea level to 5365 m above sea level.

2.2. Kriging Interpolation

According to Oliver and Webster [54] kriging is an advanced geostatistical procedure that generates an estimated surface from a sparse set of points with z-values. A set of interpolation methods that are formed by geostatistical methods, such as kriging, are based on statistical models that include autocorrelation, i.e., statistical relationships between measured points. Thus, geostatistical techniques not only can produce a prediction surface, but also provide some measure of the certainty or accuracy of the predictions. Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain surface variation, see Figure 8. Some authors have used ordinary kriging interpolation to analyze energy resources. Canales et al. [55] used kriging interpolation to analyze wind and solar resources; Bessafi et al. [56] found that the kriging model and the variogram influenced the results of the solar radiation analysis; Alsamamra et al. [57] developed a model to compare the ordinary and residual kriging methods for mapping, finding that ordinary kriging method it is valuable for some seasons of the year. Kriging will be used so that wind and solar datasets over the entire central region of Mexico can be interpolated to show a complete wind map of this region.

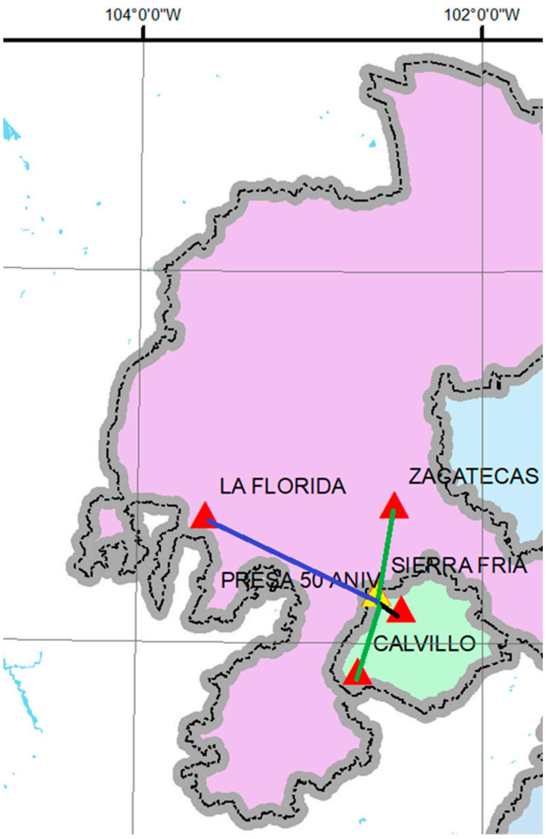


Figure 8. How kriging works.

Kriging weighs the surrounding measured values to obtain a prediction of an unmeasured location, as seen in Figure 8 and expressed in Equation (1).

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(S_i) \quad (1)$$

where $Z(S_i)$ is the measured value at the ith location, λ_i is an unknown weight for the measured value at the ith location, s_0 is the prediction location and N is the number of measured values.

The following is the process for performing interpolation in a geographic information system.

1. Raster type layers, obtained from INEGI, are products that represent the elevations of the Mexican continental territory by means of values that indicate points on the terrain surface whose geographic location is defined by coordinates (X,Y), to which values representing the elevations (Z) are integrated. The points are regularly spaced and distributed with a resolution of 15 m × 15 m.
2. The data used are divided in two. The wind data that are obtained by MERRA-2 are from reanalysis provided by NASA; these data are downloaded with *.tab format. The irradiance data are obtained with the AWS installed within the states of Central Mexico; however, AWS were used outside the Central zone to avoid erroneous interpolation. These data have the extension *.CSV.
3. Both the rasters and the *.tab and *.CSV files are loaded into a geographic information system, and the Lambert Conformal Conic projected coordinate system for Mexico is used.
4. Arctoolbox and Spatial Analyst Tools are used to interpolate with kriging.
5. The maps are trimmed and analyzed.

3. Results

The population of central Mexico amounts to 53,588,379 inhabitants [52], which causes a great demand for electricity. In this study, both the overall solar resource assessment and the wind resource assessment are assessed.

3.1. Solar Global Resources Assessment

According to data from AWSs, the average solar irradiation in Central Mexico is 6.16 kWh/m^2/day. Figure 9 shows the solar average irradiance by month.

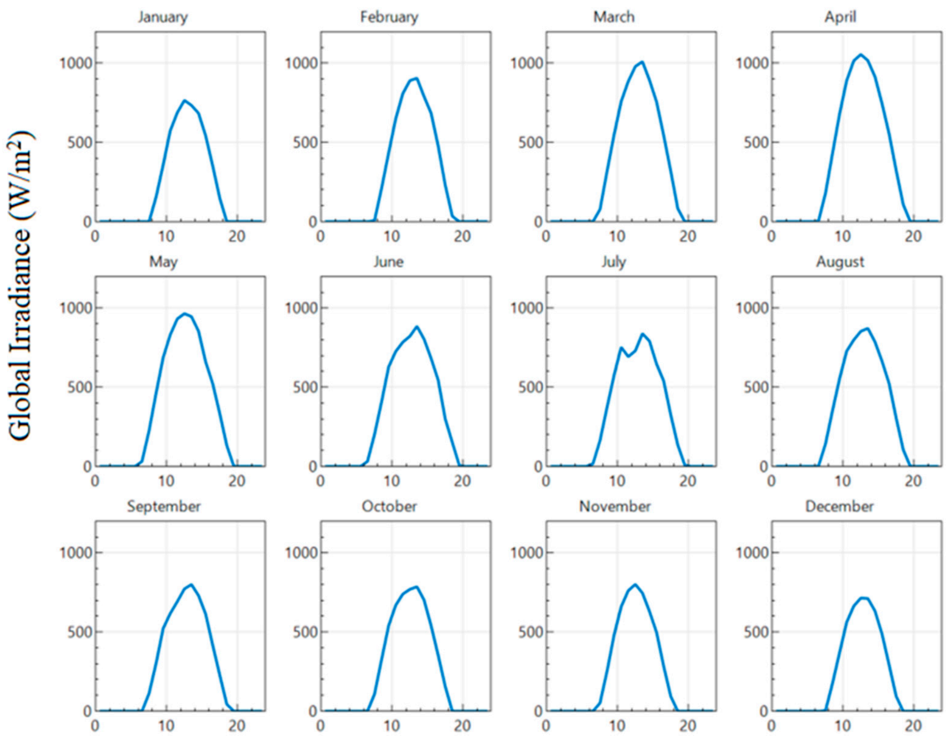
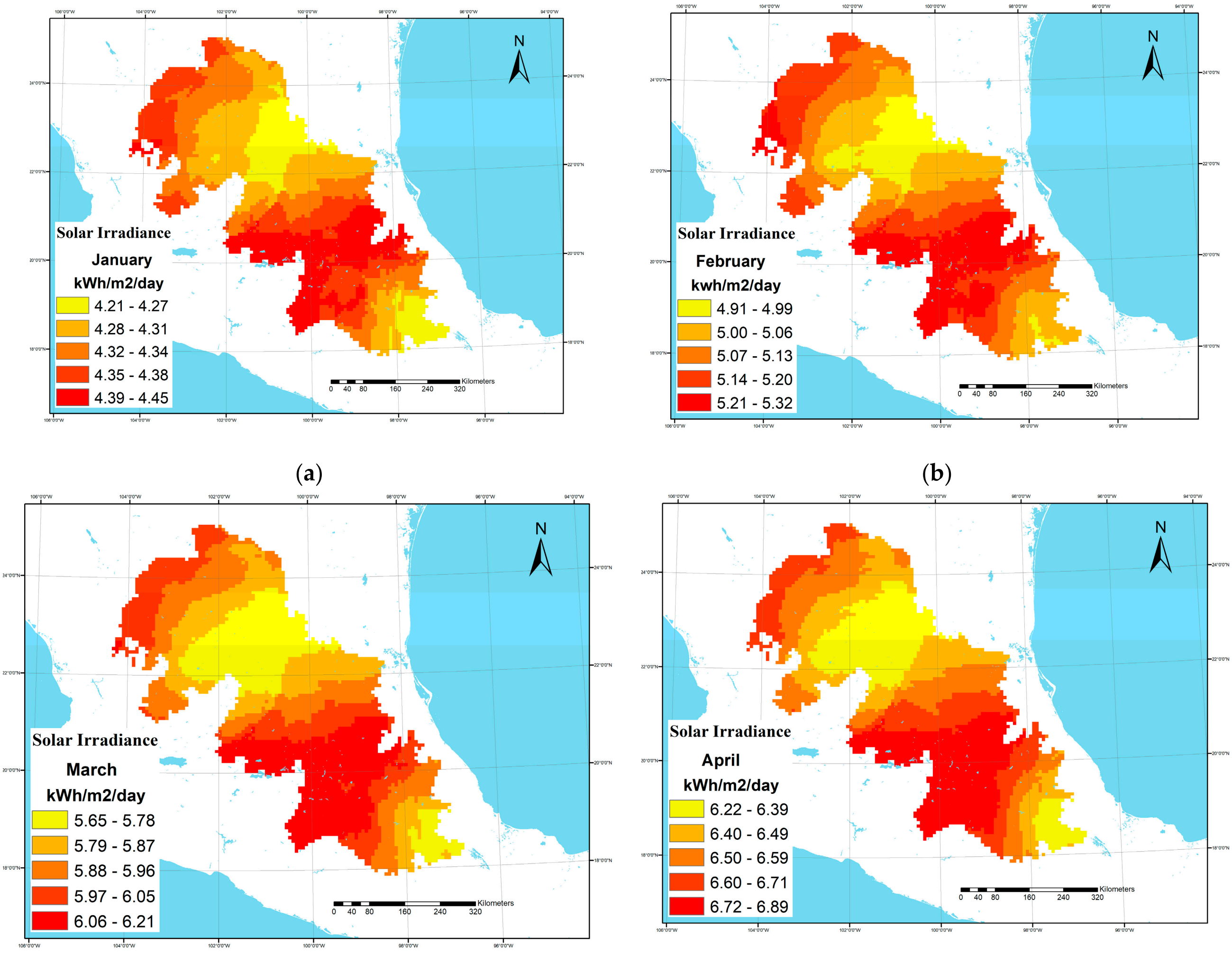


Figure 9. Average solar irradiation in Central Mexico.

Figure 9 shows the average global irradiance of Central Mexico. It can be observed in which months there is greater solar potential; these months are March, April, and May, with more than 1000 W/m^2. However, February, June, July and August also present around 900 W/m^2.

Solar irradiation has been modeled using ArcGIS with the kriging interpolation model, and will be presented annually and in blocks of four months, for the reader's convenience. Figure 10a–d shows the average solar irradiation on January, February, March, and April.



(a) (b) (c) (d)

Figure 10. Average solar global irradiation in Central Mexico in (**a**) January, (**b**) February, (**c**) March, and (**d**) April.

In these first months of the year, the most intense solar radiation or quantity of solar radiation occurs in the states of Guanajuato, Queretaro, Hidalgo, State of Mexico, Mexico City, Morelos, and in the northern part of Puebla.

The irradiation in May, June, July and August is presented in Figure 11a–d.

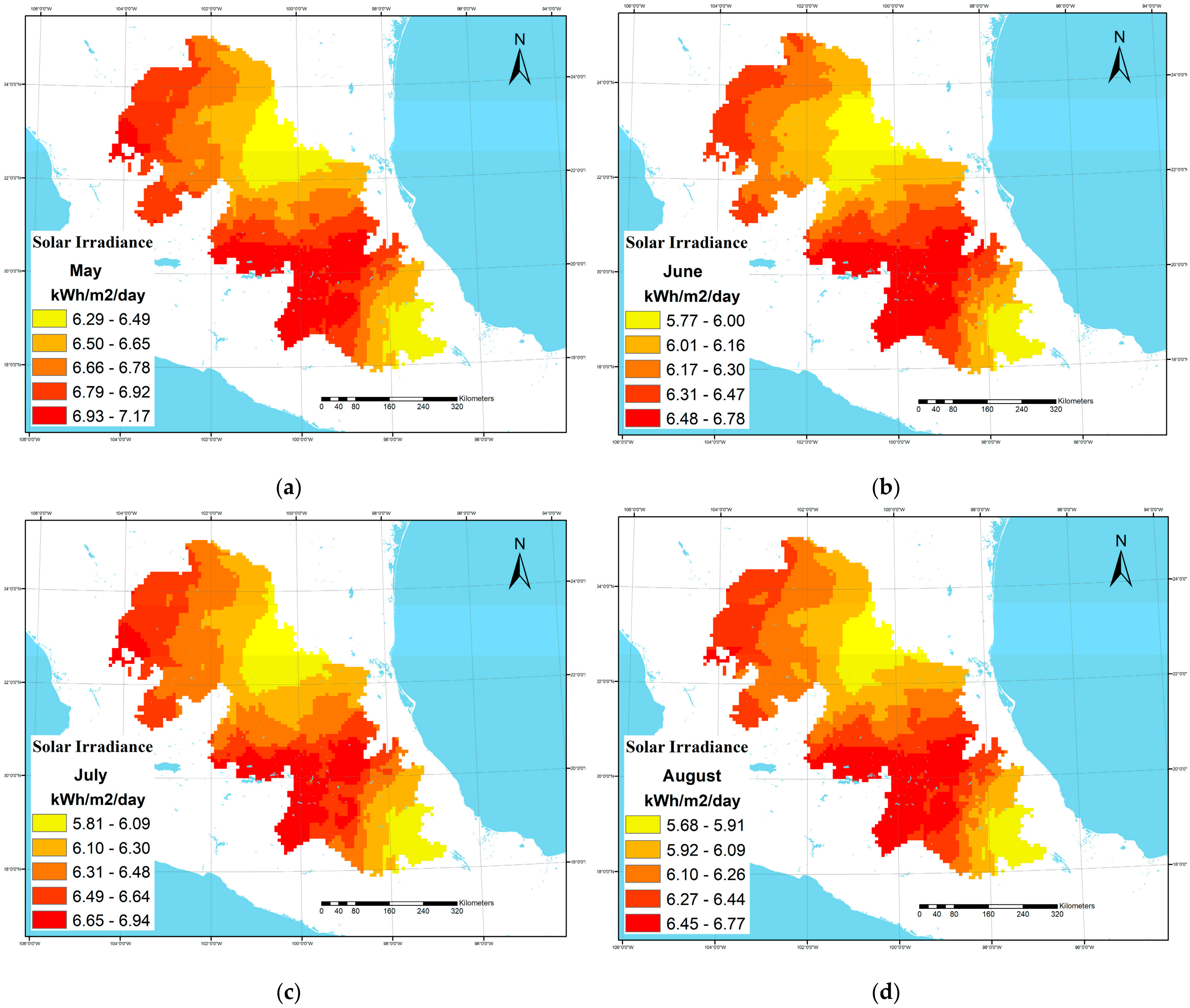


Figure 11. Average solar global irradiation in Central Mexico in (**a**) May, (**b**) June, (**c**) July, and (**d**) August.

During the months of Figure 11, the solar irradiation with the highest magnitude occurs in the states of Hidalgo, southern Guanajuato, southern Queretaro, State of Mexico, Mexico City and Morelos.

The irradiation in September, October, November and December is presented in Figure 12a–d.

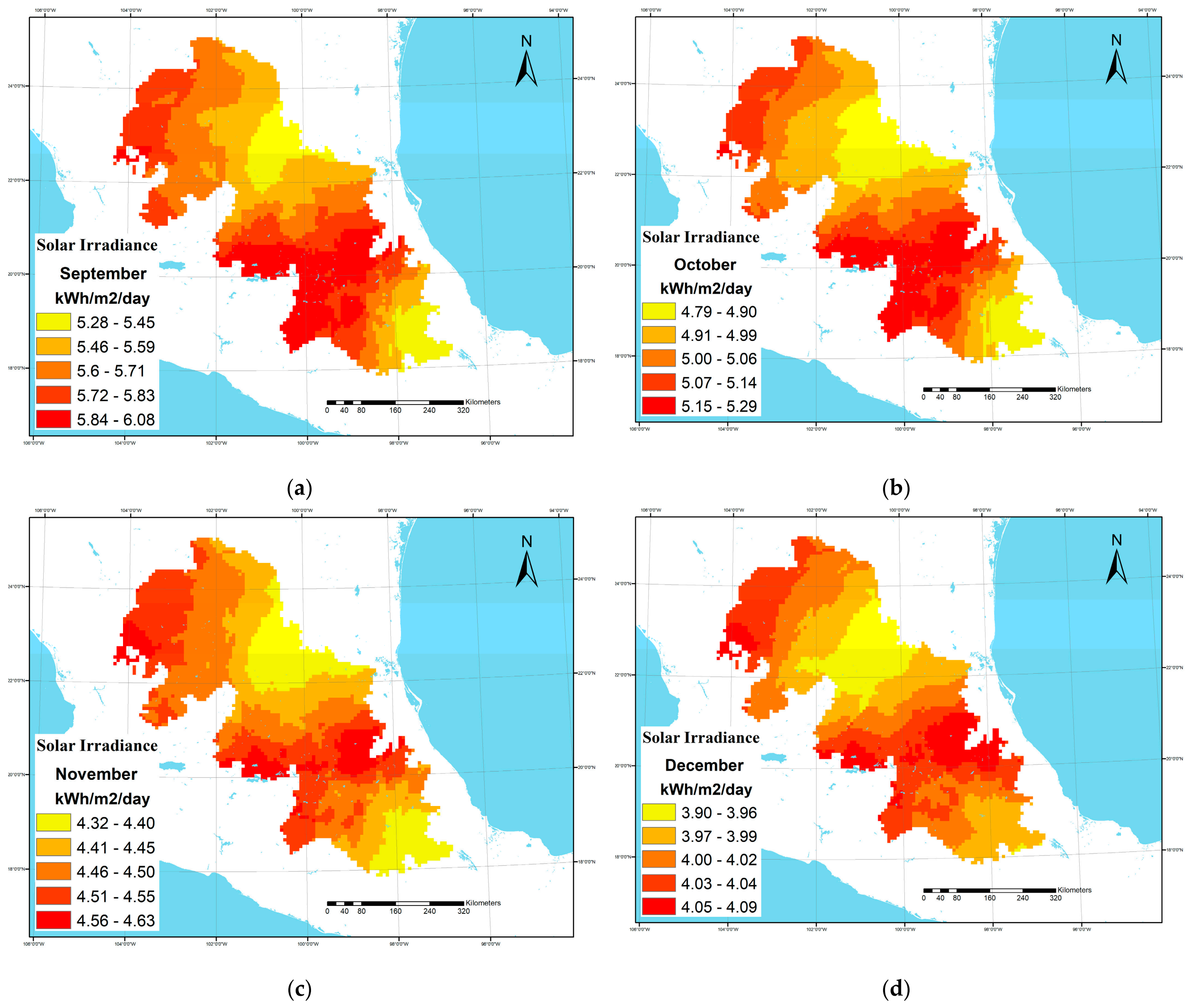


Figure 12. Average solar global irradiation in Central Mexico in (**a**) September, (**b**) October, (**c**) November, and (**d**) December.

In the last months, shown in Figure 12, the solar irradiation with the highest magnitude is only present in the states of Hidalgo, southern Guanajuato, southern Queretaro and northern Mexico State.

Figure 13 shows the annual average solar irradiation in Central Mexico.

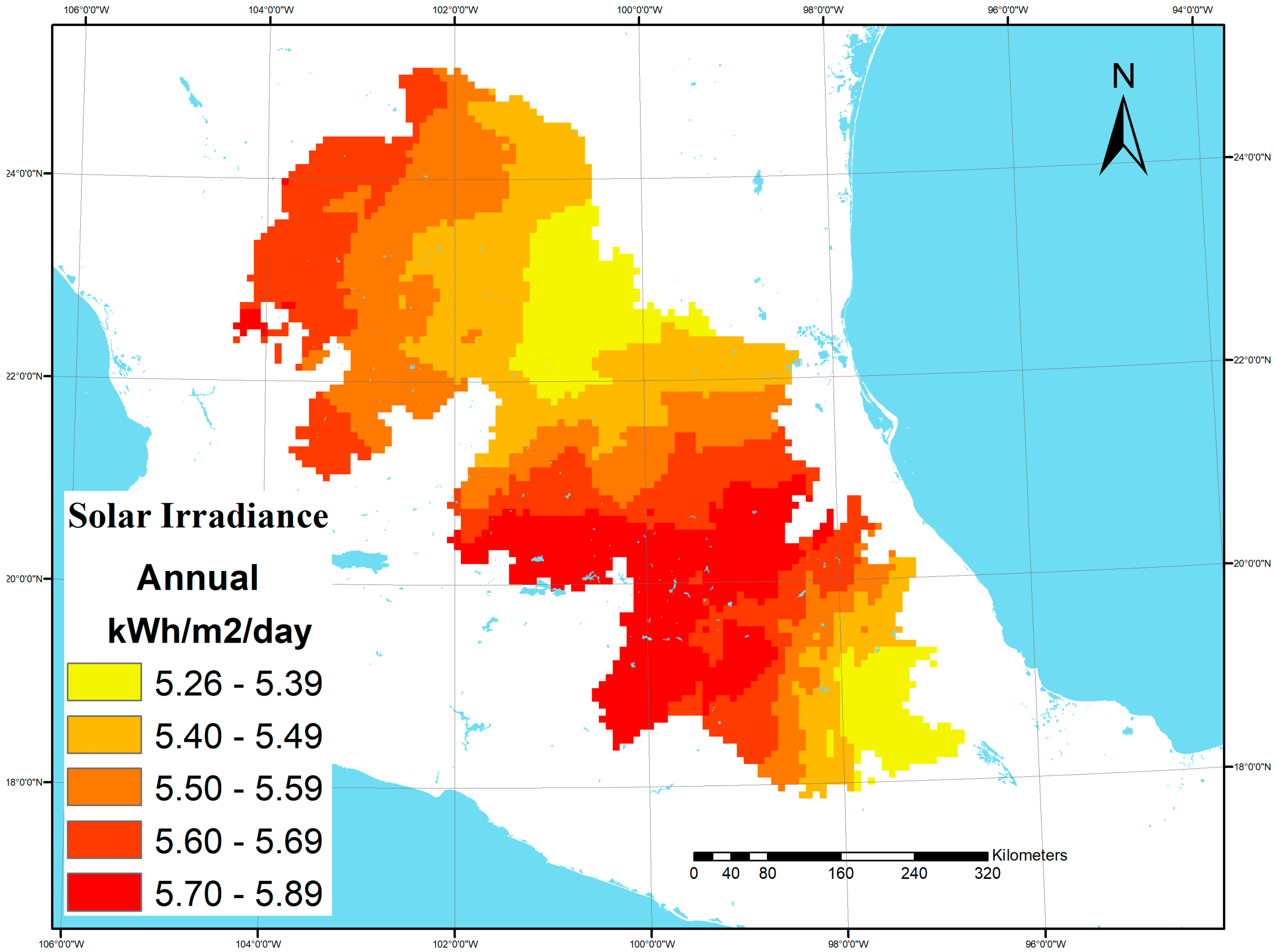


Figure 13. Annual average solar irradiation.

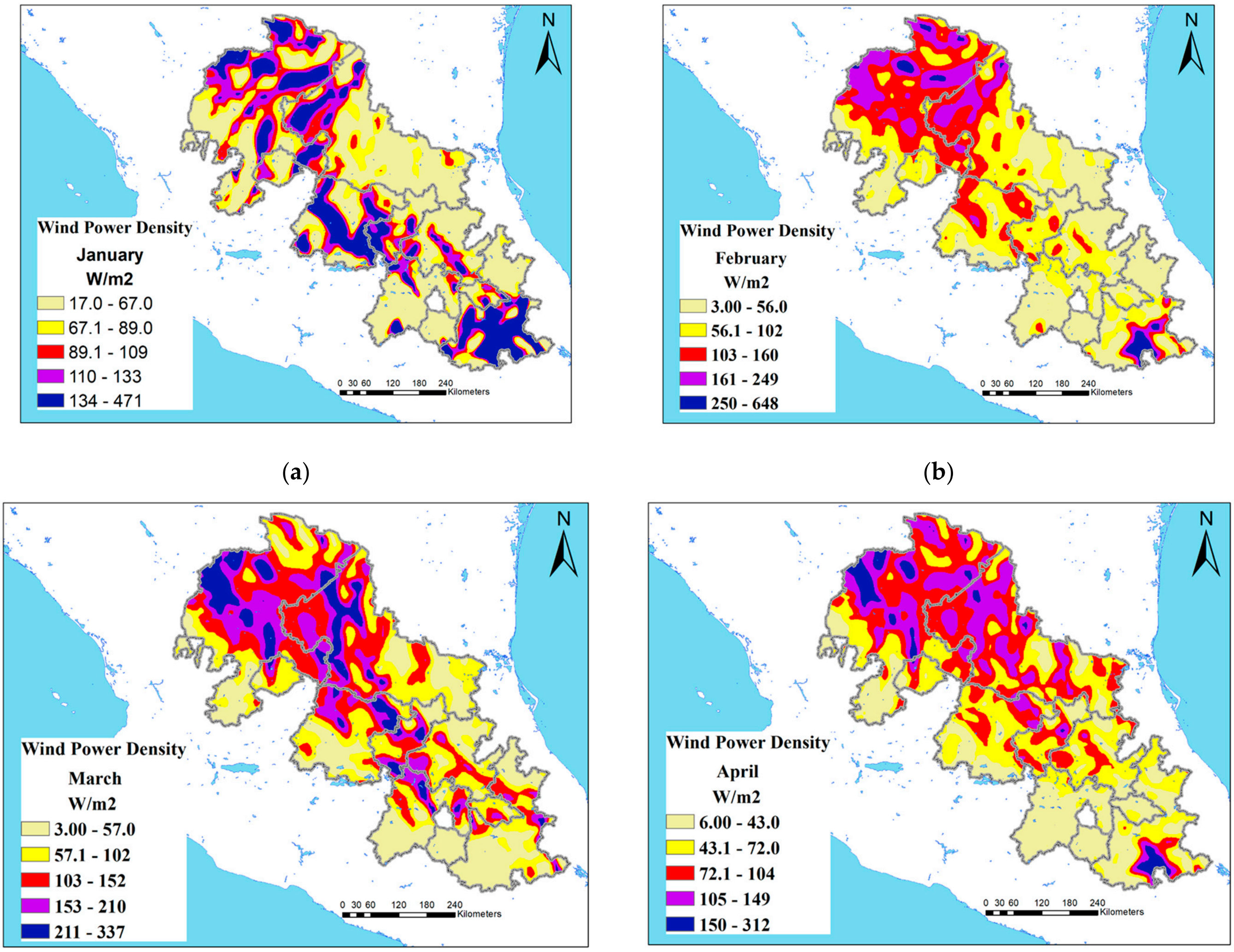
According to the map in Figure 13, the average global solar irradiation levels are between 5.60–5.89 kWh/m^2/day; the highest magnitudes are present in the states of Queretaro, southern Guanajuato, Mexico City, Hidalgo, Estado de México, and Morelos.

The figures on solar irradiation show the areas with the highest solar potential for each month of the year, and can be used for the installation of photovoltaic panels in these areas.

If 1000 photovoltaic panels with a capacity of 300 W each were installed, we would have a capacity of 300 kW; therefore, with a solar irradiation of 7.17 kWh/m^2/day in May, we would be producing 2151 kWh.

3.2. Wind Resources Assessment

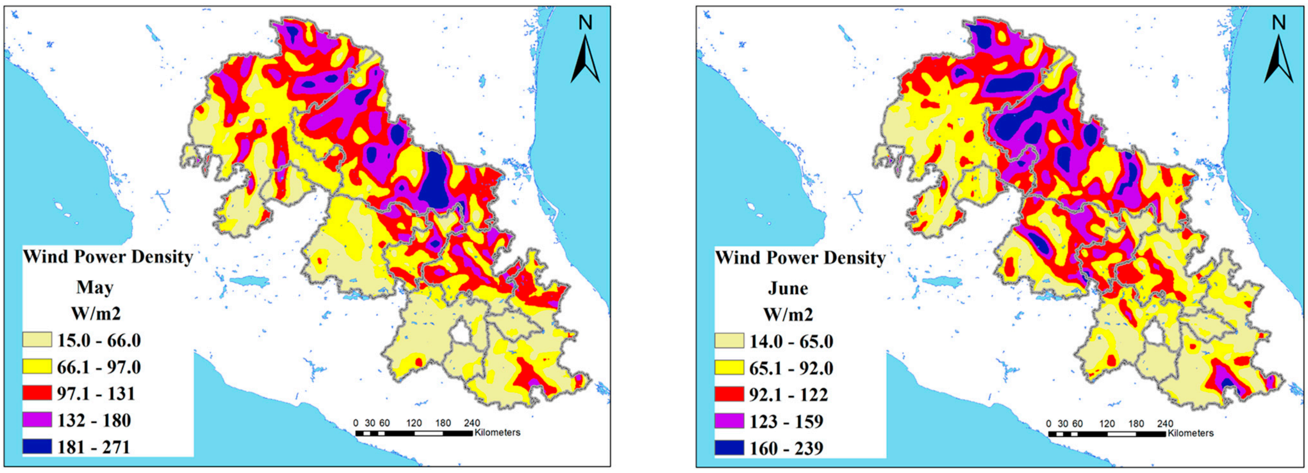
The following are maps of wind power density (WPD) measured in W/m^2 throughout central Mexico; these maps were made with kriging interpolation with AWSs data. Figures 14–16 present WPD for each month and Figure 17 presents the annual WPD. As was done for the solar resource, the WPD maps will be divided into four blocks, for the reader's convenience.



(**a**) (**b**)

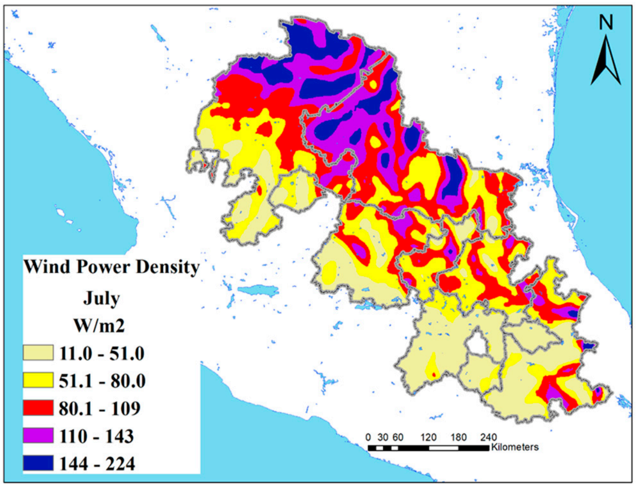
(**c**) (**d**)

Figure 14. WPD in Central Mexico in (**a**) January, (**b**) February, (**c**) March, and (**d**) April.

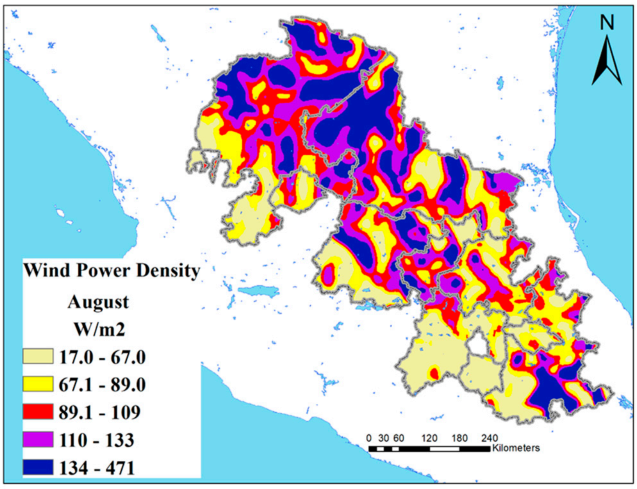


(**a**) (**b**)

Figure 15. *Cont.*

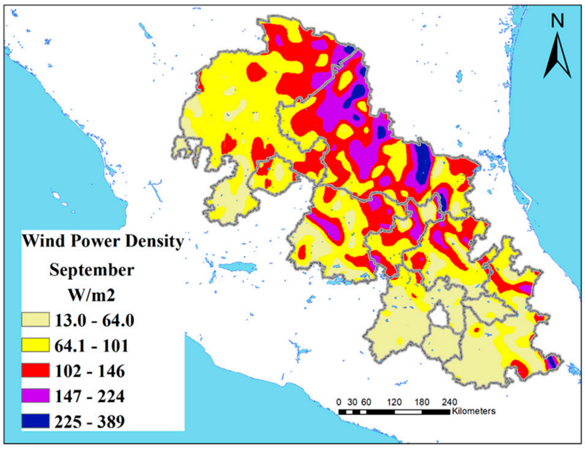


(**c**)

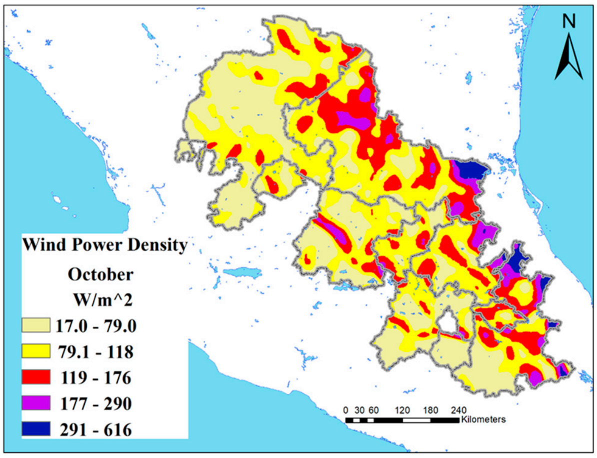


(**d**)

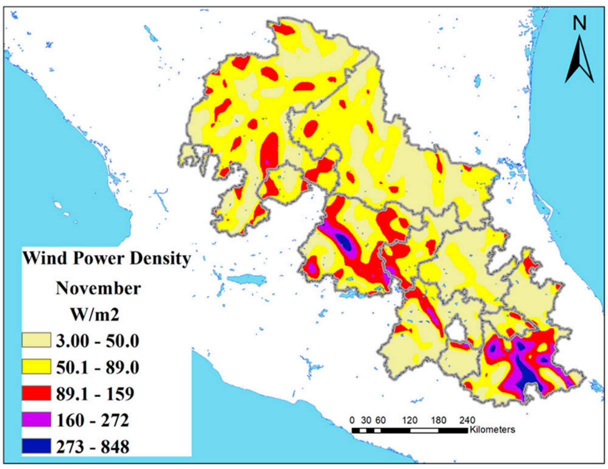
Figure 15. WPD in Central Mexico in (**a**) May, (**b**) June, (**c**) July and (**d**) August.



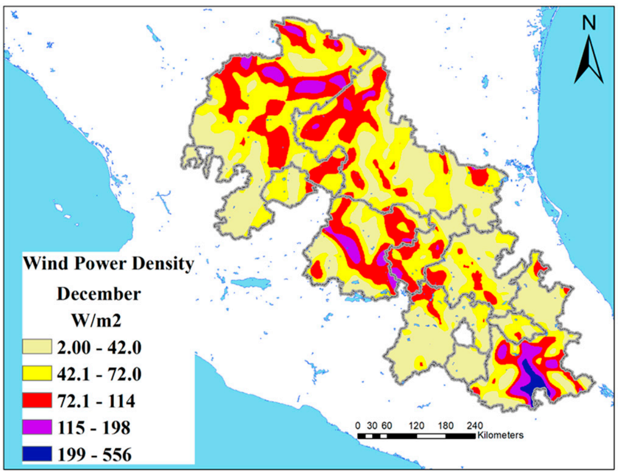
(**a**)



(**b**)



(**c**)



(**d**)

Figure 16. WPD in Central Mexico in (**a**) September, (**b**) October, (**c**) November and (**d**) December.

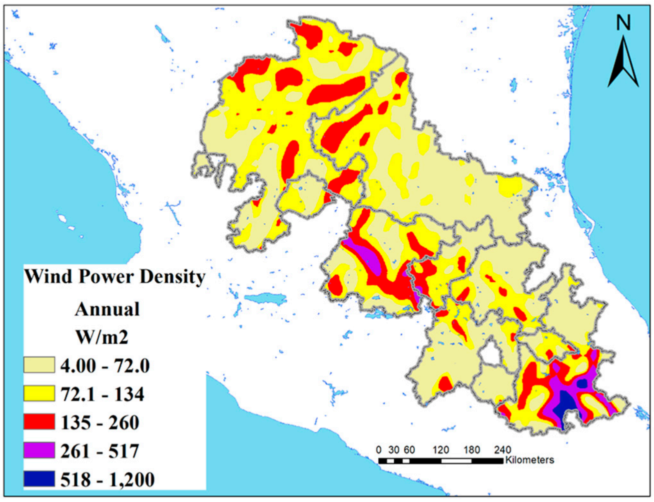


Figure 17. Annual WPD in Central Mexico.

In these first months of an average year in Central Mexico, the highest WPD occurs in the northern states of the region; these states are Zacatecas and San Luis Potosi.

The maps obtained in the months shown in Figure 15 show a windy season from June to August in the states of Zacatecas and San Luis Potosí.

The WPD in September, October, November, and December are presented in the maps in Figure 16.

Figure 17 shows the annual WPD map for the central region of Mexico.

Observing the wind resource maps, it can be deduced that the most intense winds occur in the north of the central region of Mexico. These winds could reach a WPD of up to 471 W/m^2; these highly windy areas occur in meadows north of the state of Zacatecas and north of the state of San Luis Potosi. It is also evident that in the south of the central region of Mexico, there are small areas with intense winds, however, it is important to mention that this area is highly populated and special wind turbines would have to be designed for populated regions.

With these results, we present the seasons of the year where the greatest amount of solar and wind energy can be extracted. The areas with the greatest solar potential are presented in the state of Hidalgo, State of Mexico, Mexico City, Morelos, northern Puebla, southern Querétaro, northwestern Guanajuato, and northern Zacatecas; these areas have an irradiance between 5. 60 kWh/m^2/day and 5.89 kWh/m^2/day, which is equivalent to about 6 h of power per day per square meter. With respect to wind power, the wind seasons were determined, with the months of June, July, August, September and October being the months with the greatest wind potential.

In Table 4 the results are summarized.

Table 4. Solar and wind results.

Resource	State								
	Mexico City	Morelos	Hidalgo	Puebla	Queretaro	Guanajuato	Aguascalientes	San Luis Potosi	Zacatecas
Solar (kWh/m^2/day)	5.89	5.89	5.89	5.39	5.60	5.59	5.40	5.39	5.40
Wind (W/m^2)	4.00	4.00	134	517	135	261	72	135	135

4. Conclusions

According to the data presented in this work, wind and photovoltaic energy are emerging to be the REs that will have the most dominant role in the coming decades in generating energy from renewable sources. In Mexico, the SEN needs to increase its capacity in the coming years due to the increase in demand from the country. However, according to the new energy policies and regulations in Mexico, the country will meet global commitments to reduce emissions and ensuring universal access to electricity for its population.

It has been demonstrated that Central Mexico has great wind and solar potential, and by 2030, up to 46% of its installed capacity could come from renewable sources. However, due to the intermittent nature of wind and sun, it is essential to study the most suitable location for these systems and explore a range of possible alternatives to find the best solution for all the related criteria.

The interpolations used with the ordinary kriging model to determine the areas with the greatest potential for global solar irradiation and wind had very interesting results; it was determined that the states with the greatest potential for solar irradiation are Guanajuato, Queretaro, Hidalgo, Mexico City, Morelos, Aguascalientes, Zacatecas. In these states, enough electrical energy could be produced to satisfy the population, as they have energy of up to 5.89 kWh/m^2/day. The month with the highest irradiance is May, with 7.17 kWh/m^2/day.

It is essential to evaluate the wind resource in layers, starting with the orography and roughness, and ending with the atmosphere; this analysis is known as climate generalization. With a GIS, the layers are represented on a map, and from these layers 12 maps were produced, one per month and an annual one. For the development of wind farms or for the design of wind turbines, knowing the type of wind and its power density is essential. On these maps, annually, in some areas we can observe up to 1200 W/m^2, which means that if a wind turbine of 70 m diameter is installed, about 2 MW of power would be extracted. The states with the highest wind power density are Mexico State and Guanajuato.

It was observed that with only the stations within the states, it was not possible to interpolate correctly; 128 more AWSs were used to avoid the effect of cutting the interpolation. They were interpolated with AWSs of the states adjacent to those of central Mexico.

Obtaining these maps benefits several factors in the country of Mexico, such as investors; they can observe the areas with the greatest solar and wind potential and thus identify the necessary resources to develop plans for the installation of solar farms and wind farms. The government, which is the promoter of the use of renewable energies in Mexico—since the Energy Transition Law establishes goals such as that by 2024, 35% of the total electricity generation in the country will be supplied by renewable energies—and academia—which is the pillar of education and will be able to have maps of the solar and wind resources with which they can develop research and development (R&D) projects—will also benefit.

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