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The Distribution of Solar Radiation and Solar Energy Intensity, and Top Locations for Constructing Solar Energy Stations in Iraq

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Abstract—**The relationship between energy consumption and environmental pollution is evident from the exacerbation of widespread negative consequences such as climate change, including global warming, humidity, floods, earthquakes, destructive storms, and uncontrollable natural phenomena. Therefore, it is necessary to shift from fossil fuel consumption to alternative or renewable sources of energy such as solar and wind. Taking advantage of solar cell energy and investing in various fields such as electricity generation and agricultural uses such as water pumping, desalination and concentrating on their applications for the development of rural areas and their use in the development of the industrial sector. As well as encourage the private sector and capital owners to invest in solar cell energy. In our study, we analyze the best solar cell power stations in Iraq. Three cities selected across the country, providing data on distributions of solar energy and the density of electricity generated. Therefore, the research included a methodology suitable for the subject. This research aims to detect the importance of solar energy and how to exploit it through mathematical equations concerning the distributions and density to reach the possibility of the minimum solar energy utilization and then reach the preferred location for the construction of solar cell stations in the study area.**

Keywords— CSP; IRENA; humidity; destructive storms; Iraq.

I. INTRODUCTION

Solar energy is a renewable energy source characterized by abundance, cleanliness, and eases of use and has been widely used in water transport, agriculture, and industry. Solar power is an obvious choice for Iraq, as the country has clear advantages for developing this key renewable energy source [1]. It is perfectly suited and situated for solar parks, with vast stretches of uninhabited land in the desert that can be used for harnessing the energy of the sun, as well as some of the world's most intense solar irradiance [2]. Several studies list concentrating solar power (CSP), solar-thermal, as well as photovoltaic (PV), and wind as the most promising renewable energy technologies in the country [3]. Moreover, renewable energy technologies like solar and wind have become increasingly cost-competitive with conventional fuels. The delivered cost of electricity from solar PVs, CSP, and wind are all declining, sometimes rapidly [4]. Renewable technologies are now the most economical solution for new capacity in an increasing number of countries and regions, according to the International Renewable Energy Agency (IRENA) [3]. Renewable energy technology is continually improving and is strongly supported by heavy investments across the world. This development is likely to continue and bring even further improvements and new breakthroughs within the field of renewable energy technology [5].

A. Climate Controls Affecting Solar Distribution

Iraq is located in the southwestern part of Asia's continent between the stations of 37022-2905 north. Since the astronomical location is the limit for the angle of the fall of solar radiation and the length of the day throughout the year, so the circle of the presentation of any area on the surface of the earth is a major officer decides the climatic conditions of any area in the world [6]. In July, the daily radiation period is approximately 14 hours, which is three hours and 48 minutes higher than the rate of solar radiation in January, which makes the summer warmer than winter. Thus, the weather stations in Iraq record large annual temperatures and increase the range by distance from the equator northern part of the country.

B. Location of Nearby Water

The location of Iraq for the seas located in the southwestern part of Asia's continent ranked second as a dominant factor in its climate. It is known that marine influences depend mainly on the distance from the water bodies and the direction of prevailing winds, and the movement of air controlled by the topography. The nearest touch is the Arabian Gulf and the Mediterranean Sea [7].

The Red Sea and the Black Sea are far away from it and prevent the effects of high mountain ranges or high plateaus.

C. Surface

The terrain is a climatic control that affects the spatial variation of the main component elements due to altitude and drop below sea level and differences in surface variation, involving solar radiation and direction. Iraq's major warring regions have played a major role in shaping its climate. The northern mountains of Iraq have contributed to increasing rain, both in terms of lifting wet winds to higher condensation levels or through the impact of the speed of the air depressions [8]. South of those mountains make a acquire heat and the desert plateau contributed to the reduction of temperature significantly because of its rise, as the temperatures recorded in the wetlands station much less than the station Baghdad. However, they fall on the same circuit [9], [10].

D. Air Masses

The air masses are defined as a large part of the gas atmosphere in which the temperature and humidity conditions are homogeneous horizontally and vertically. Then, the acquire those characteristics from the region of creation, which is a large mass of land homogeneous or water surface where these blocks remain above them for a long time and move those blocks characteristics to areas that invade as soon as you leave the territory of origin. Harmonization of the air masses' thermal and moisture properties affects the rest of the climatic elements, as they are the cause of daily and seasonal weather changes that affect the distribution of solar cells and their angles [10]. Since the diameter is located between latitudes 37.22 to 29.5 north, it is under the influence of high sub-tropical pressure in the summer and under the influence of high pressure polar and weather disturbances in the winter as it is a corridor of the airdrops coming from the west to the east [11], On Iraq are:

- Continental polar air masses
- Tropical air masses
- Marine tropical air masses
- Marine polar air masses

E. Pressure Systems Affecting the Climate of Iraq

Various types of high and low-pressure systems, in varying degrees, affect Iraq. Some of them continue to influence for months, such as India's seasonal low, some of which continue for weeks, such as the Siberian, European and subtropical climates. Others are limited to hours or days, such as the Mediterranean and Sudanese depressions. This is the organization Matt is characterized by liturgical conditions, but he rarely finds that climatic conditions are similar within a single system [12] [13]. On this basis, it is possible to divide the types of the central systems affecting the rival of Iraq into two parts:

- High-pressure systems consist of high Siberian, European High, and Semi-orbital.
- Light pressure systems consist of Low Indian Seasonal, Low Sudanese, and the Mediterranean.

F. Solar Energy

Many years ago, many countries quickly used renewable energy because they clean, new energies, inexhaustible, and environmentally friendly. By varying these qualities, they reduce global combustion, air pollution and minimize non-conventional fossil fuels' depletion. At present, it ranks advanced by solar cell energy projects compared with other renewable energy resources and traditional resources [14]. This is due to lower production costs for solar cells power projects and improved technology than traditional and renewable resources, and the cultivation of solar power projects at a rapid rate. It is clear that the problem of increasing demand for electricity in Iraq, which led to the transition to the use of renewable energy as a viable alternative to the crisis. Efforts to assess solar power's potential are critical in this area to select suitable locations for the installation of a solar cell system [15]. Solar statistical models are used to analyze and assess the energy potential of specific sites. Solar data were collected from three sites across the country (the northern location of Ninawa, the central area of Al Anbar and the southern site of Al-Basrah) to analyze solar distribution data for the four seasons (summer, autumn, winter and spring) and solar energy assessment during the year [16].

Iraq has divided into 19 provinces divided by the northern, central, and southern regions. As shown in Figure 1. This study is a study of the distribution of solar and the possibility of generating energy throughout the year, and an example was taken from each region, Al Basrah (longitude: 47.816667, latitude: 30.5) from the southern region, Anbar (longitude: 41.942, latitude: 34.469) from the central region and Ninawa (longitude: 43.1189 latitude: 36.335) from the northern region [17].

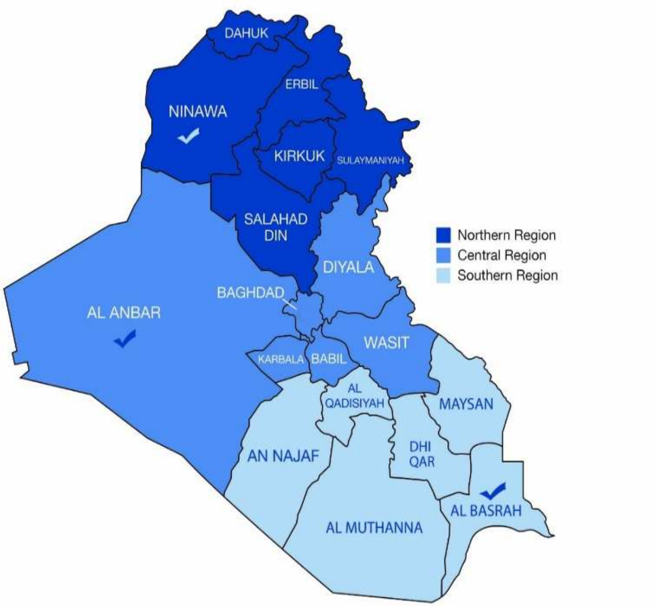

Fig. 1 Iraq Provinces

II. Materials and Method

The solar radiation data for three selected sites in Iraq collected from the NANA Prediction of Worldwide Energy Resource. The elevation, latitude, and longitude of selected stations were (47.816667 °N, 30.5°E), (41.942°N, 34.469

°E), (43.1189 °N, 36.335°E) for Al-Basrah, Anbar, and Ninawa, respectively, as shown in Table 1. In the present study, the average daily solar radiation is used as an input parameter. According to daily average solar radiation, the monthly and annual average solar radiation is estimated at a standard slope of 30^0. Extrapolation of stations elevations been used to estimate the solar radiation at 10 m high for ground level in each season

TABLE I
SOLAR RADIATION

Site	Season	Radiation (kW-hr/m^2/day)		
		Sample 1	**Sample 2**	**Sample 3**
Al-Basrah (30^0)	Winter	7.369	7.251	7.498
	spring	9.133	9.013	9.263
	summer	9.897	9.777	10.027
	Autumn	8.573	8.453	8.703
Al Anbar (30^0)	Winter	7.013	6.894	7.142
	spring	8.369	8.249	8.499
	summer	8.909	8.789	9.039
	Autumn	8.065	7.945	8.195
Ninawa (30^0)	Winter	7.063	6.945	7.193
	spring	8.467	8.347	8.597
	summer	9.239	9.119	9.369
	Autumn	8.145	8.025	8.275

III. RESULTS AND DISCUSSION

The average annual solar radiation is not a real indicator of the possibility of using it to generate electricity because the solar cell is a rapidly changing element and is associated with changing the controls affecting it. Therefore, in this study, we did our best to calculate solar cell power's nearest value to determine the best site for solar cell stations. The analysis of solar radiation and data was conducted in three selected locations in Iraq. (As shown in Table 2 Location Data and Figure 3 Map of sites).

TABLE II
LOCATION DATA

#	Location	Latitude	Longitude	Location in Iraq
1	Al Basrah	30.5 N	47.816667 E	South
2	Anbar	34.469 N	41.942 E	Central
3	Ninawa	36.335 N	43.1189 E	North

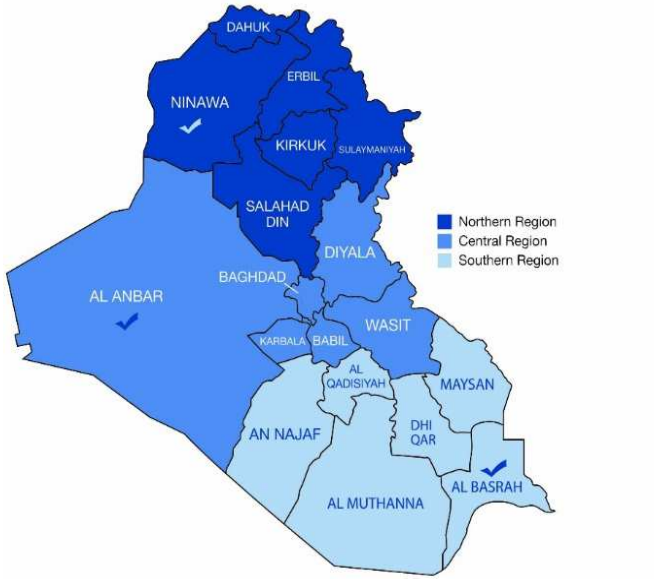

Fig. 2 Map of Sites

Mean radiation and Standard Deviation

$$V^{-} = \left(\frac{1}{N}\sum_{i=1}^{N} Vi\right) \quad (1)$$

$$\sigma = \left(\frac{1}{N}\sum_{i=1}^{N}(vi - V^{-})^2\right)^{\frac{1}{2}} \quad (2)$$

A. By Season

TABLE III
MEAN SOLAR RADIATION AND STANDARD DEVIATION

Site	**Season**	**Radiative (kW-hr/m^2/day)**			**Mean radiation**	**Standard Deviation**
		Sample 1	**Sample 2**	**Sample 3**	**V**	**σ**
Al-Basrah (30^0)	**Winter**	7.369	7.251	7.498	7.373	0.123644
	Spring	9.133	9.013	9.263	9.137	0.125033
	Summer	9.897	9.777	10.027	9.901	0.125033
	Autumn	8.573	8.453	8.703	8.576	0.125033
Al Anbar (30^0)	**Winter**	7.013	6.894	7.142	7.016	0.123644
	Spring	8.369	8.249	8.499	8.372	0.125033
	Summer	8.909	8.789	9.039	8.912	0.125033
	Autumn	8.065	7.945	8.195	8.069	0.125033
Ninawa (30^0)	**Winter**	7.063	6.945	7.193	7.067	0.124376
	Spring	8.467	8.347	8.597	8.471	0.125033
	Summer	9.239	9.119	9.369	9.242	0.125033
	Autumn	8.145	8.025	8.275	8.148	0.125033

The average solar radiation for selected sites is shown in Table 3 Mean solar radiation and Standard Deviation. From this table, we observed that Al-Basrah have mean solar radiation in summer is 9.901 (kW-hr/m^2/day), spring is 9.137 (kW-hr/m^2/day), autumn is 8.576 (kW-hr/m^2/day), and winter is 7.373 (kW-hr/m^2/day). So it is clear that the highest solar radiation recorded in Al-Basrah was in the summer Figure 3. Al-Anbar have mean solar radiation in summer is 8.912 (kW-hr/m^2/day), spring is 8.372 (kW-hr/m^2/day), autumn is 8.069 (kW-hr/m^2/day) and winter is 7.016 (kW-hr/m^2/day). So it is clear that the highest solar radiation recorded in Al-Anbar was in the summer Figure 4.

Ninawa have mean solar radiation in summer is 9.242 (kW-hr/m^2/day), spring is 8.471 (kW-hr/m^2/day), autumn is 8.148 (kW-hr/m^2/day) and winter is 7.067 (kW-hr/m^2/day). So it is clear that the highest solar radiation recorded in Ninawa was in the summer, as shown in Figure 5.

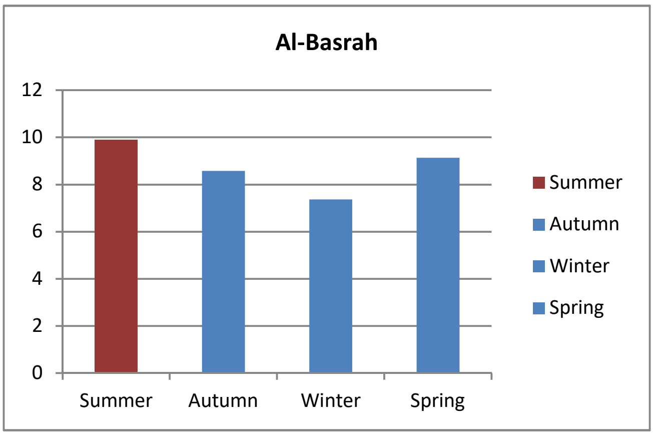

Fig. 3 Al-Basrah Mean solar radiation

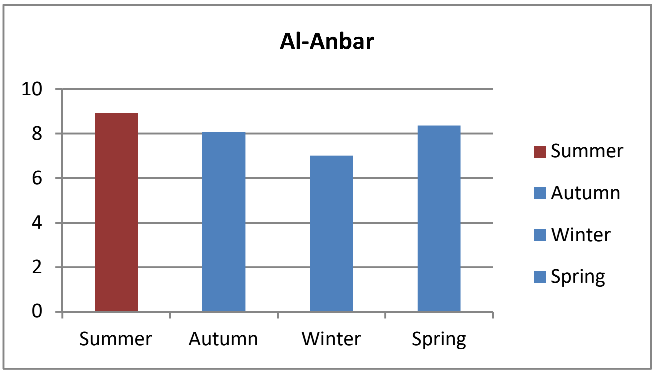

Fig. 4 Al-Anbar Mean solar radiation

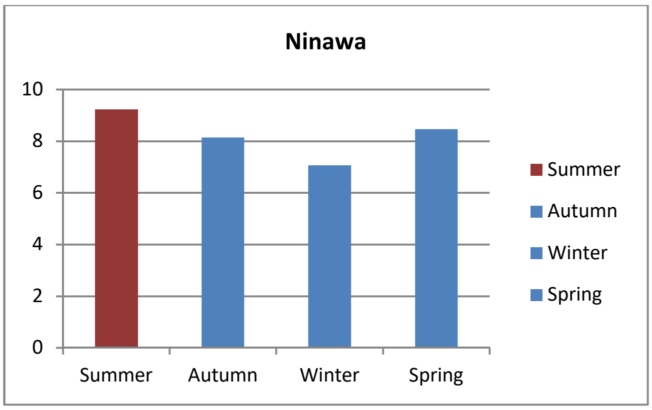

Fig. 5 Ninawa Mean solar radiation

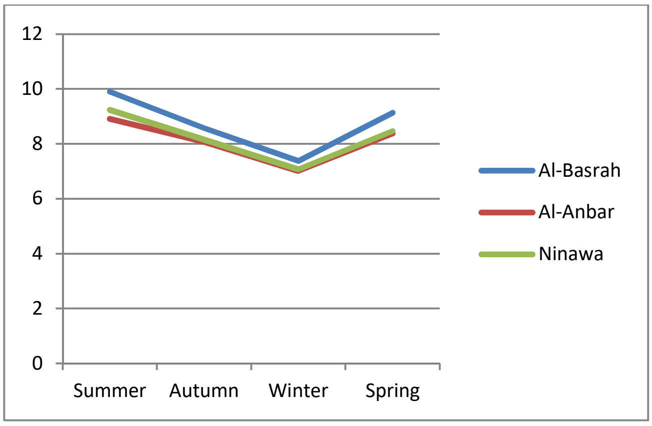

Fig. 6 Mean solar radiation

As shown in Figure 6, it is clear that the highest rate of solar radiation was in Al-Basrah followed by Ninawa and then Al-Anbar.

B. By Annual

Figure 7 and Table 4, shown that, by analyzing the annual radiation, it is clear that the highest average radiation was in Al-Basrah with 8.747 (kW-hr/m^2/day), Ninawa with 8.232 (kW-hr/m^2/day) then Al-Anbar with 8.092 (kW-hr/m^2/day).

TABLE IV
SOLAR RADITION

Site	Season	Radiation			Mean Radiation	Mean Radiation By Annual
		Sample 1	Sample 2	Sample 3	V	
Al-Basrah (30^0)	**Winter**	7.369	7.251	7.498	7.373	8.747
	Spring	9.133	9.013	9.263	9.137	
	Summer	9.897	9.777	10.027	9.901	
	Autumn	8.573	8.453	8.703	8.576	
Al Anbar (30^0)	**Winter**	7.013	6.894	7.142	7.016	8.092
	Spring	8.369	8.249	8.499	8.372	
	Summer	8.909	8.789	9.039	8.912	
	Autumn	8.065	7.945	8.195	8.069	
Ninawa (30^0)	**Winter**	7.063	6.945	7.193	7.067	8.232
	Spring	8.467	8.347	8.597	8.471	
	Summer	9.239	9.119	9.369	9.242	
	Autumn	8.145	8.025	8.275	8.148	

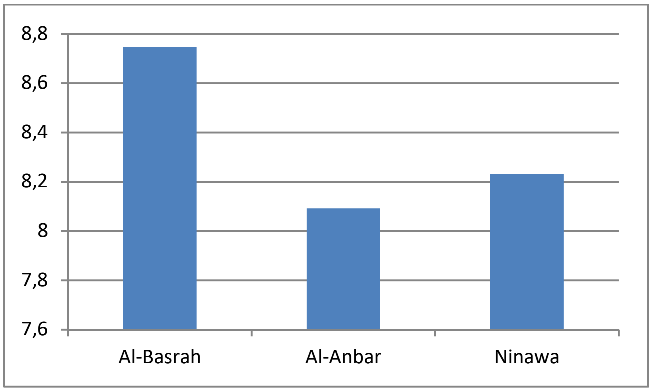

Fig. 7 Annual Solar Radition

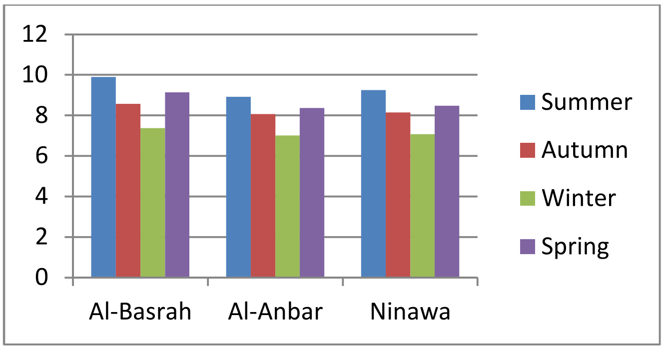

Fig. 8 Mean Solar Radition

C. *Power Density and Energy Density*

TABLE V
POWER AND ENERGY DENSITY

Site	Season	Solar Radiation			Mean Radiation	Power Density	Energy Density
		Sample 1	**Sample 2**	**Sample 3**	**V**	**PD**	**ED**
Al-Basrah	**summer**	9.897	9.777	10.027	9.901	639.039	475.393
	Autumn	8.573	8.453	8.703	8.576	391.154	290.987
	Winter	7.369	7.251	7.498	7.373	378.561	281.618
	spring	9.133	9.013	9.263	9.137	514.715	382.906
Al Anbar	**summer**	8.909	8.789	9.039	8.912	193.809	144.18
	Autumn	8.065	7.945	8.195	8.069	157.043	116.827
	Winter	7.013	6.894	7.142	7.016	123.071	91.555
	spring	8.369	8.249	8.499	8.372	190.681	141.851
Ninawa	**summer**	9.239	9.119	9.369	9.242	356.666	265.329
	Autumn	8.145	8.025	8.275	8.148	250.923	186.666
	Winter	7.063	6.945	7.193	7.067	215.204	160.093
	spring	8.467	8.347	8.597	8.471	313.443	233.176

$$PD=\frac{1}{2}\,\rho\,(V^{-})^{3} \quad (3)$$

$$ED=\frac{1}{2}\,\rho\,(V^{-})^{3}T \quad (4)$$

Based on equations 3 and 4, the power density and energy are calculated, which is shown in Table 5 above. The power density and energy density of the solar cell for selected sites are shown (Table 5). From this table, we observed that Al-Basrah have power density in summer is 639.039 (W/m2), autumn is 391.154 (W/m2), winter is 378.561 (W/m2), and spring is 514.715 (W/m2). Therefore, it is clear that the highest power density recorded in Al-Basrah was in the summer, as shown in Figure 9.

For energy density of solar, Al-Basrah has an energy density in summer is 475.393 (KWh/m2), autumn is 290.987 (KWh/m2), winter is 281.618 (KWh/m2), and spring is 382.906 (KWh/m2). Therefore, it is clear that the highest energy density recorded in Al-Basrah was in the summer, as shown in Figure 10.

Al-Anbar has power density in summer is 190.809 (W/m2), autumn is 157.043 (W/m2), winter is 123.071 (W/m2), and spring is 190 .681 (W/m2). Therefore, it is clear that the highest power density recorded in Al-Anbar was in the summer, as shown in Figure 11.

For energy density of solar, Al-Anbar have an energy density in summer is 144.18 (KWh/m2), autumn is 166.827 (KWh/m2), winter is 91.555 (KWh/m2), and spring is 141.851(KWh/m2). Therefore, it is clear that the highest energy density recorded in Al-Anbar was in the summer, as shown in Figure 12.

Ninawa has a power density in summer is 356.666 (W/m2), autumn is 250.923 (W/m2), winter is 215.204 (W/m2), and spring is 313.443 (W/m2). So, it is clear that the highest power density recorded in Ninawa was in the summer, as shown in Figure 13.

For energy density of solar, Ninawa have energy density in summer is 265.329 (KWh/m2), autumn is 186.666 (KWh/m2), winter is 160.093 (KWh/m2), and spring is 233.176 (KWh/m2). Therefore, it is clear that the highest energy density recorded in Al-Anbar was in the summer as shown in Figure 14.

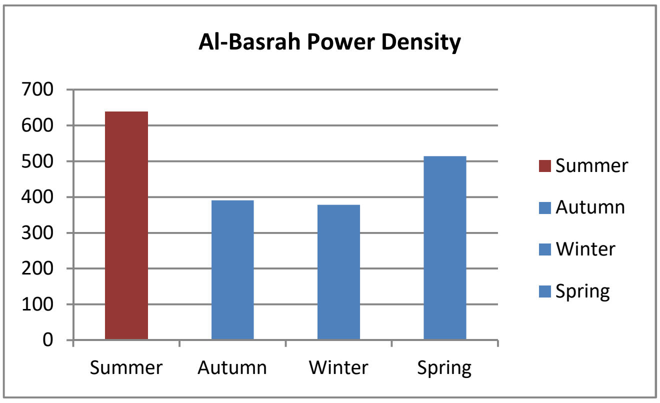

Fig. 9 Al-Basrah Power Density

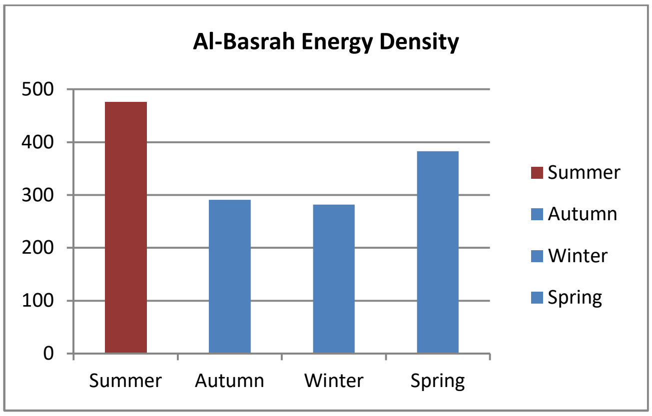

Fig. 10 Al-Basrah Energy Density

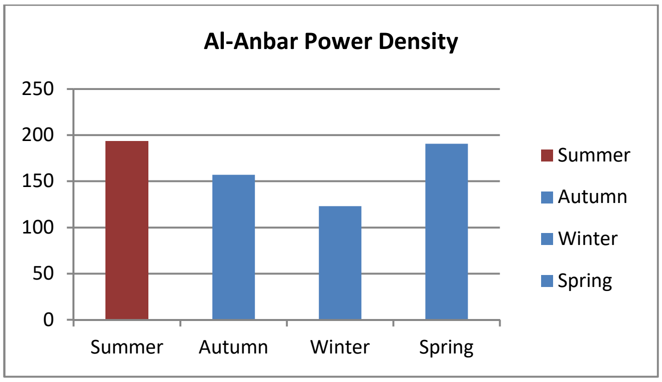

Fig. 11 Al-Anbar Power Density

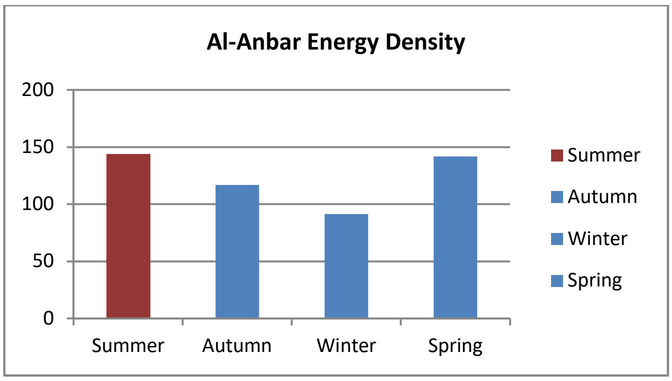

Fig. 12 Al-Anbar Energy Density

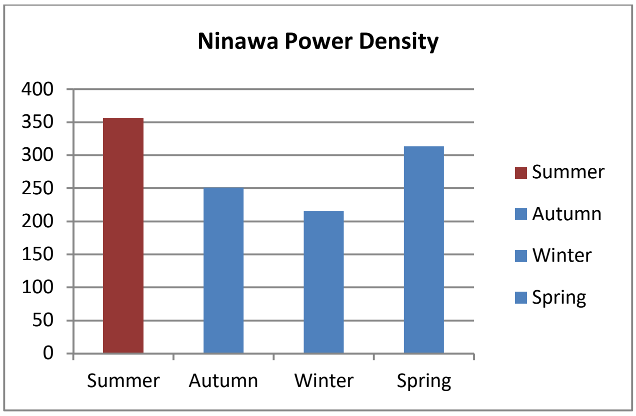

Fig. 13 Ninawa Power Density

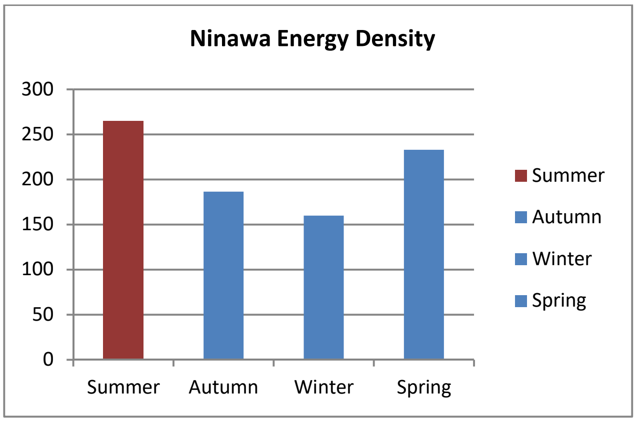

Fig. 14 Ninawa Energy Density

Based on the review of the results of the solar cell power tables, it was found that summer and spring were characterized by the highest intensity of radiation and power energy in the country compared to the winter and autumn, where the location of Al-Basrah with high density in the production of electricity. In contrast, the stations of Al-Anbar was characterized as which are very low in density and do not qualify for the use of solar cell energy to generate electricity. The reason for the increase in the values of electrification in the summer and spring is the predominance of convection, which is becoming more active during these two seasons due to the heating of the land—the increase of the pressure slope due to the deepening of the seasonal low temperature. The decrease in solar radiation in autumn and winter is due to lack of activity thermal and seasonal low dip and increased Siberian impact. The calculation of the annual energy density contributes to the identification of areas where appropriate quantities of electricity are available and in light of the results reached can be divided into sectors:

TABLE VI
COUNTRY SECTOR

#	Sector	Location	Electricity	Optimal Angle
1-	South of country	Al-Basrah and nearby places	High production	28 degree
2-	North of country	Ninawa and nearby places	Medium production	33 degree
3-	Central of country	Al-Anbar and nearby places	Low production	33 degree

IV. Conclusion

The State should be interested in preparing practical national cadres in solar energy and transfer their experiences to future generations. The State will find ways of scientific cooperation with the world's countries to learn about their experiences and educate the growing generation on the importance of renewable energy. Taking advantage of solar cell energy and investing in various fields such as electricity generation and agricultural uses such as water pumping, desalination and concentrating on their applications for the development of rural areas and their use in the development of the industrial sector. Encourage the private sector and capital owners to invest in solar cell energy.

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