Prepublished copy

Nature Environment & Pollution Technology

This is a peer-reviewed prepublished version of the paper

Spatial Analyses of Reliability of Solar Power in the Western Part of Iraq

Raid Khider Salman[1†], Sabah Sultan Farhan[1], Muneer Naji Al-Falahi[2], Thaer Eyada Mohammed[1]

[1]Renewable Energy Research Center/ University of Anbar/ Iraq

[2]Upper Euphrates Basin Development Center /University of Anbar/ Iraq

Abstract – Statistical and meteorological investigations were conducted on the western part of Iraq, represented by Anbar governorate. The region of study was divided into four parts according to the four geographical directions. The study included examining the physical and meteorological data of the region in order to find out the capability of the region for the solar power exploitation. Physical and meteorological variables showed a good trending agreement except for the diffuse horizontal irradiation and air temperature which exhibited inverse trends. Regions with elevated terrains such as the western and southern parts showed greater values of solar power gain. Statistical and meteorological data revealed promises indications of solar power feasibility for the selected region.

Key Words	Iraq Solar Power feasibility, Anbar Solar Energy, Solar power feasibility, Meteorological data
DOI	https://doi.org/10.46488/NEPT.2025.v24i02.D1681 (DOI will be active only after the final publication of the paper)
Citation of the Paper	Raid Khider Salman, Sabah Sultan Farhan, Muneer Naji Al-Falahi, Thaer Eyada Mohammed, 2025. Spatial Analyses of Reliability of Solar Power in the Western Part of Iraq. *Nature Environment and Pollution Technology*, 24(2), D1681. https://doi.org/10.46488/NEPT.2025.v24i02.D1681

INTRODUCTION

It is clear fact that the demand for energy has enormously increased during the last few decades, due to the population expansion. Fossil fuel is no longer the best energy source due to its negative effect on the environment (Balat 2005). Moreover, fusel fuel is depleted source of energy, so that it may be exhausted after couple decades (Nacke, Cherp et al. 2022), leaving us in total darkness and stopping of vital systems. Therefore, the demand for clean and renewable energy resources become one of the highest priorities of the recent researchers (Sankari & Kumar 2023). Apparently, sun is the main source of the w hole biological, physical and chemical activities on earth. Thus, its power can be considered as the major renewable energy source that can be used to produce clean and non-depleted amount of anergy. According to the literatures, solar energy was used since the 7th century B.C., either in lighting fire using the solar concentrating glass ware (Glassmeier, Boehnhardt et al. 2007, Schoch 2012), or in sustainable nutrition applications such as drying seeds and fruits for consuming in other seasons (Delyannis 2003, Silvi 2008). Therefore, solar energy is considered to be the eldest renewable source used by the human being. After discovering the electricity several solar energy techniques were developed to help generating electric power. However, only two among them maintained the world energy demands for thermal and electric applications (Quaschning 2016). The first technique is the photovoltaic solar panels, in which solar radiation photons absorbed by semiconductor-based materials layers to produce electric current via the photoelectric effect (Techo J. et al. 2024, Salman R 2019). The other technique is the solar concentrators, in which the electrical energy produced by the thermal solar radiation in special power plants besides their fundamental purpose of buildings' heating (Tyagi, Agarwal et al. 2017).

Iraq is one of the longest daylight intervals countries during the whole year (Al-Kayiem & Mohammad 2019). Baghdad receives more than 3,000 hours of sun radiation each year. The intensity of sun radiation ranged between 416 W/m2 in

January to 833 W/m2 in June (Kazem & Chaichan 2012, Al-Kayiem and Mohammad 2019). The western part of Iraq represented by Anbar governorate is the largest part of the country with open desert enclosure.

With a total population of 1,780,467 people, Anbar needs a huge amount of energy that reaches a peak estimated value of 1500MW(1.5GW) (Iraqcoalition.org 2018). This amount of power comes due to the expanding in publicity during the last decades. However, due to the conflicts that the country generally and the nominated region specifically undergone, the real amount of power provided to the province is only about 400M. this enormous shortage of power needs to be substituted, which urged the engineers and researchers to search for the best solution for this issue. The geographic location of Anbar makes it exposed to a high solar radiation in comparing with the other parts of Iraq (see Figure 1), with the longest interval during the day. Therefore, solar power apparently is the key to the power shortage problem solution. The provincial capital of Anbar is Al-Ramadi, which lies 100Km north west of Baghdad. Al-Ramadi contains the highest population among the other province districts, of about 620,480 individuals.

Many relative studies have been conducted. One of the most common studies focused on the design and optimization of solar energy systems in order to improve their efficiency and reduce costs (Al-Naffakh and Al-Qassab 2021, Alturki, Al-Shamma'a et al. 2021, Aziz, Tajuddin et al. 2022). These studies focused on factors such as the selection of solar panels, the design of the electrical system, and the integration of energy storage systems. Another study related to the evaluating the economic feasibility of a hybrid power station that combines solar panels and wind turbines, and connects it to the national grid in Al-Hayy City in the center of Iraq. That study involved a detailed analysis of the technical and financial aspects of the project, including the cost of the solar panels and wind turbines, the projected revenues from the sale of electricity, and the potential savings on fuel costs. It has also considered the current state of the electricity grid in the city, and the potential benefits and challenges of connecting the hybrid power station to the national grid (Abass, Pavlyuchenko et al. 2021). Another comprehensive study looked at the potential for solar energy in Iraq, covering the topic from the early stages of development to the present day. That article covered the historical background of solar energy development in Iraq, including the current state of solar energy infrastructure and technology in the country, as well as the current policies and regulations that impact the development of solar energy in Iraq (Istepanian 2020).

Overall, the literature studies either concentrated on the solar technology or aimed other parts of Iraq in their researches.

The current study aims to investigate the reliability of Anbar, the Irai governorate for the solar power exploitation. It is looking into the specific geographical, topological and physical characteristics of different areas in the governorate that can determine its ability for hosting solar power, and what is the best technology that can be utilized within.

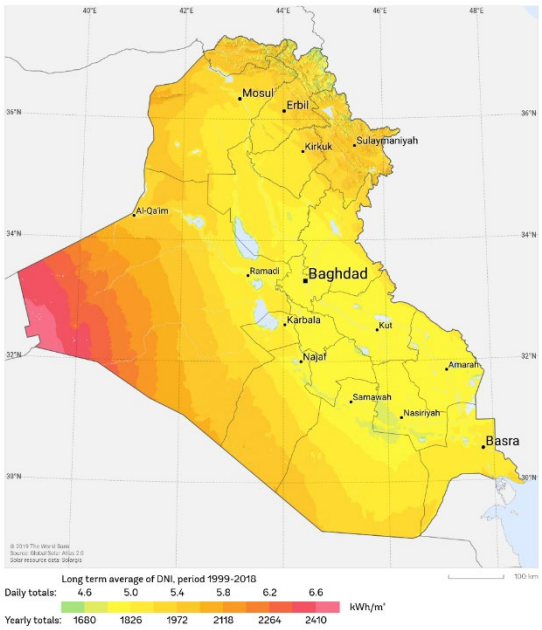

Fig. 1. Iraq normal solar irradiation means during the year

METHODOLOGY

Assessment of Solar Radiation in Iraq

It is well known that solar constant on the earth is 1353W/m^2 (Green 1981). The high value of solar radiation in Iraq indicating its high potential for solar energy development, but it is also important to take into account the other factors such as cost, the availability of financing, and the regulatory environment when evaluating the feasibility of solar energy projects in the country. However, the first task in this field is to assess the region potential itself and the solar physical parameters related to its location. It's noteworthy to mention that using the solar constant alone isn't enough to estimate the actual solar energy that can be harnessed, it's important to use other solar parametric measures to estimate the solar energy depending on the location, weather conditions, and other factors that can affect the solar energy reaching the earth surface. Therefore, statistical techniques are essential along with the meteorological data for acquiring precise determinations in this type of investigations. Global Solar Atlas (GSA) was used to collect the location solar parameters. It is an online tool that provides information on the solar resource potential of different locations around the world. It is a comprehensive, interactive map that displays data on solar radiation, temperature, and other meteorological parameters (Group 2022). Meteorological data were collected by selecting the areas under consideration by navigating the map controls and acquire their coordinates. the map then was investigated using (layers) feature in order to view the types of data such as Global Horizontal Irradiation, Direct Normal Irradiation, etc. the result data then were downloaded using CSV and Excel format. The downloaded data then were analyzed using Pearson's correlation statistical technique to finally get the required data and collecting the valuable information.

Determination Of the Study Locations

Anbar is the western part of Iraq. It is the largest governorate in the country, bordered by Syria, Jordan, and Saudi Arabia. The capital of Anbar is Al-Ramadi. The other major cities are Fallujah, Haditha, Ana, Rawa and Al-Qaim. Anbar is an important region in Iraq as it contains several key oil fields, as well as the Haditha Dam, which is one of the largest hydroelectric power stations in the country. Four distinctive locations were chosen as areas of this study, distributed according to the four geographical directions (west, North, East and South) as illustrated in Figure 2. The reason behind this procedure is to collect meteorological data from different parts of the province with variation topological and geographical environments. This information may help optimizing the province reliability statistically for solar power exploitation. The specific regions within the four areas were selected according to security, population density and social criteria. For instance, due to the conflict status in the regions, the areas were selected to be nearby the defense and security formations around the governorate. In regarding with the social factor, the study gives attention to community structure, since some of areas include conscious and well-educated individuals that can use the power sources rationally, meanwhile, other areas are less awareness about the power exploitation.

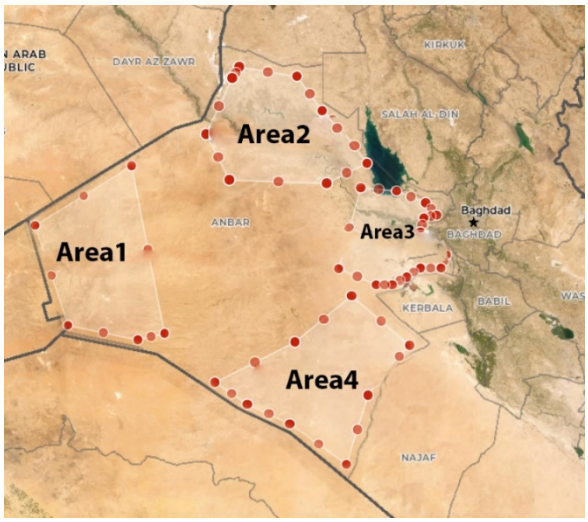

Fig. 2. Areas of study chosen in Anbar governorate

RESULTS AND DISCUSSION

Spatial Optimization

Table 1 illustrates the physical and meteorological data for each one of the nominated areas. Where PV_{OUT} is the specific photovoltaic power output, DNI is the direct normal irradiation, GHI the global horizontal irradiation, DIF the diffuse horizontal irradiation, GTI_{opta} the global tilted irradiation at optimum angle, TEMP is the air temperature, OPTA optimum tilt of PV modules and ELE is the terrain elevation.

Table 1
SPATIAL CHOSEN AREAS AND THEIR METEOROLOGICAL DATA

Region	Centre (deg)		PVout	DNI	GHI
	Lat	Long	kWh/kW_p	kWh/m^2	kWh/m^2
Areal (West)	32.861449	40.166016	5.03 - 5.22	5.86 - 6.51	5.62 - 5.84
Area2 (North)	31.448154°	42.539063	4.71 - 4.94	5.05 - 5.55	5.28 - 5.51
Area3 (East)	33.431718	43.483887	4.62 - 4.87	4.72 - 5.20	5.29 - 5.51
Area4 (South)	31.298118	42.539063	4.96 - 5.07	5.40 - 5.71	5.65 - 5.75

Region	DIF	GTl_opta	TEMP	OPTA	ELE
	kWh/m^2	kWh/m^2	°C	°	m
Areal (West)	1.71 - 1.93	6.41- 6.65	19.0 - 20.7	32 - 33	513 - 812
Area2 (North)	1.99 - 2.15	6.03 - 6. 29	21.2 - 23.1	31- 34	125 - 387
Area3 (East)	2.15 - 2.26	5.92 - 6. 26	23.2 - 24.6	29 - 33	41 - 185
Area4 (South)	2.08 - 2.17	6.39 - 6.51	22.4 - 23.6	32 - 33	266 - 412

Apparently, all the physical properties illustrated in Table 1 meet the meteorological trends except for the air temperature and the diffuse horizontal irradiation, who showed distinctive behavior as Figure 3 shows. This behavior required statistical correlation between the anomaly parameters and the other regular trended parameters, which will be shown in the next section including the statistical tests and their potential in this study. The variation of the specific photovoltaic power output within the different parts of the governorate may be attributed to the topological characteristics. This is evidently confirmed by the elevation graph, which shows that the north region with the greatest height has the highest photovoltaic output capacity PVout, meanwhile the least high area (the west region) has also opposite low PVout. The north and east areas exhibit very similar behavior. Very low variation was shown in direct normal irradiation though the north surface area stills slightly dominant.

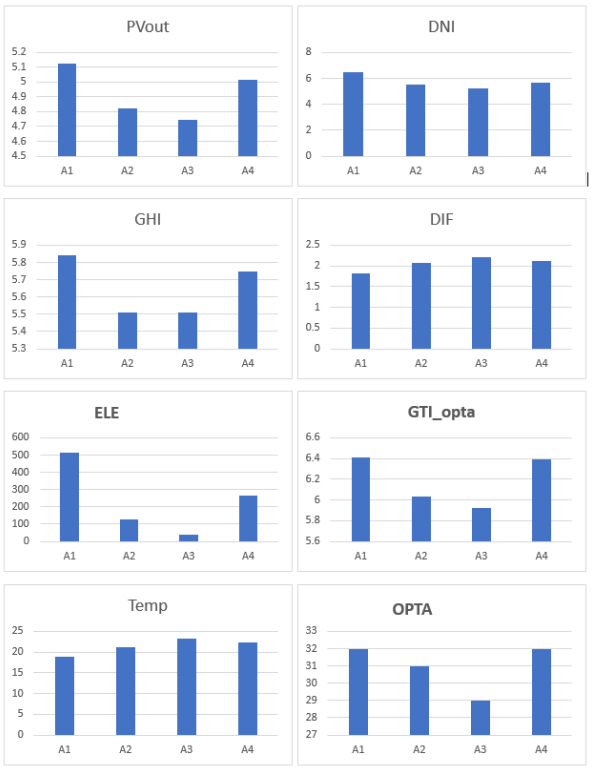

Fig. 3. Physical and meteorological characteristics comparison

Statistical analyses

Correlation analysis

As shown before most parameters shows a good agreement with each other, but the Diffuse horizontal irradiation and temperature data showed different trends which needs to be investigated statistically. The best technique for this issue is the Pearson's correlation test for one of the common parameters and one of the anomaly variables, which can be given by the following equation (Emerson, & Blindness 2015):

$$r = \frac{\Sigma_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\Sigma_{i=1}^{n}(X_i - \bar{X})^2 \Sigma_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

Where: n is the number of data points (sample size)

X_i and Y_i are the individual data points of the two variables being correlated.

$\bar{X}$ and $\bar{Y}$ mean (average) of the data points for X and Y respectively.

The result of r suggests three probabilities

r=+1 indicating perfect positive correlation (if X increases Y linearly increases)

r=-1 indicating perfect negative correlation (if X increases Y linearly decreases)

r=0 indicating no correlation between the tested variables

SPSS was used to run the correlation test. Table 2 shows Pearson's correlation test between the two distinctive variables the specific photovoltaic power output and the diffuse horizontal irradiation. The Pearson correlation coefficient is -0.799, indicating a strong negative correlation between the two variables. However, the negative correlation suggests an inverse relation between diffuse horizontal irradiation (DIF) and the specific photovoltaic output (SPVout). These statistical indications rendering to an atmospheric factor that can negatively affect the solar power output. This is may be attributed to the cloudy and/or overcast days that can disperse and hence reduce the light reaching the photovoltaic panels. Which in turn lead to a reduction in the photovoltaic power output

Table 2 Statistical Correlation data

		SPVout	DIF
PVout	**Pearson Correlation**	1	-0.799
	Sig. (2-tailed)		0.201
	N	4	4
DIF	**Pearson Correlation**	-0.799	1
	Sig. (2-tailed)	0.201	
	N	4	4

Cumulative distribution graphs

Cumulative distribution graph is of high importance graph that can help predicting the behavior of the variable under consideration. Figure 4 shows the cumulative distribution graph for the different areas. In general, all the areas follow the same pattern with slight variation in the west and south areas. The photovoltaic output probabilities from east and north areas show steadiness at lower profiles (from 4.4.- 4.7 KW/KWp), after which they increased dramatically. No such steadiness can be observed in the west and south regions. Indicating that the optimized areas in relating with the photovoltaic technology exploitation are the west and south areas. The output also greater within these regions than the remaining areas. The cumulative data for the four areas propose the following indications:

1. Area1: this area exhibits gradual increase the output of SPV, which implies solar radiation consistency. In other words, it suggests minimal cloudy times and more clear skies.
2. Area2: Area2 curve shows stepping behavior, in which the SPV values are higher at lower percentages. This implies an intensive sunlight receiving throughout specific intervals. In other words, this area might occasionally undergo cloudy days.
3. Area 3: this area shows a balanced weather and moderate solar irradiation, which is clearly revealed by the flat curve and the consistency in curve developing with the percentage.
4. Area4: lastly, Area 4 shows similar behavior to Area1, but might be with additional factors such as topological factors that affect the solar irradiation.

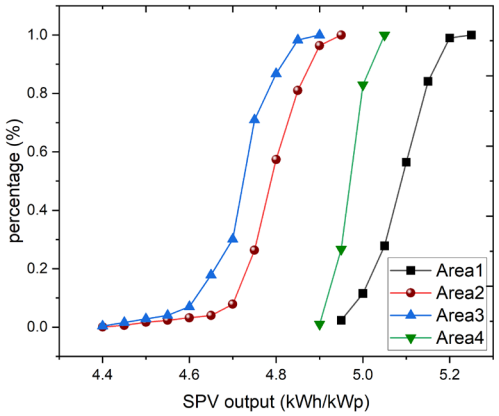

Fig. 4. Cumulative distribution graph for SPVout for the four areas

CONCLUSION

The west region of Iraq represented by Anbar governorate showed promising indications in regarding with possibility of using the solar photovoltaic panels. The west and south areas of the governorate exhibited greater potentials in regarding with the nominated technology. The elevation of terrains plays a major role in photovoltaic gain. Air temperature and diffuse horizontal irradiation have a negative potential on the solar power gain within these areas.

The four selected areas in the governorate show inconsistency in regarding with their meteorological parameters. The west and south western areas have more stable sunny days in comparing with the other two areas. Eastern area has modest weather, so the solar power output from it would be more stable but less than the output of the west and south western areas. The north part of the governorate exhibits fluctuated intervals of sunny days, so in some days high solar power output may be yielded, meanwhile in other days the weather is more cloudy and only minimum output may be produced.

Overall, the analyzed data revealed promising indications and a significant feasibility for the governorate to exploit solar power technology.

REFERENCES

Abass, A.Z., et al. Economic Feasibility Study of a Hybrid Power Station Between Solar Panels and Wind Turbine with The National Grid in Al-Hayy City in the Central of Iraq. in IOP Conference Series: Materials Science and Engineering. 2021. IOP Publishing.

Al-Kayiem, H.H. and S.T. Mohammad, Potential of Renewable Energy Resources with an Emphasis on Solar Power in Iraq: An Outlook. 2019. 8(1): p. 42.

Al-Naffakh, J. and M.R.J.I.R.J.o.A.S. Al-Qassab, Comparing the growth of renewable energy sources in Turkey, Iran and Iraq. 2021. 2(2): p. 21-26.

Alturki, F.A., et al., Optimal sizing of autonomous hybrid energy system using supply-demand-based optimization algorithm. 2021. 45(1): p. 605-625.

Aziz, A.S., et al., Design and Optimization of a Grid-Connected Solar Energy System: Study in Iraq. 2022. 14(13): p. 8121.

Balat, M.J.E.e. and exploitation, Usage of energy sources and environmental problems. 2005. 23(2): p. 141-167.

Delyannis, E.J.S.e., Historic background of desalination and renewable energies. 2003. 75(5): p. 357-366.

Emerson, R.W.J.J.o.v.i. and blindness, Causation and Pearson's correlation coefficient. 2015. 109(3): p. 242-244.

Glassmeier, K.-H., et al., The Rosetta Mission: Flying Towards the Origin of the Solar System. Space Science Reviews, 2007. 128(1): p. 1-21.

Green, M.A. Solar Cells: Operating Principles, Technology and System Applications. 1981.

Group, W.B. 2022; Available from: https://globalsolaratlas.info/map?c=11.523088,8.173828,3.

Iraqcoalition.org, Anbar Province publicity. 2018.

Istepanian, H.H., Iraq solar energy: from dawn to dusk. 2020: Friedrich-Ebert-Stiftung Jordan et Iraq.

Kazem, H.A. and M.T. Chaichan, Status and future prospects of renewable energy in Iraq. Renewable and Sustainable Energy Reviews, 2012. 16(8): p. 6007-6012.

Nacke, L., A. Cherp, and J. Jewell, Phases of fossil fuel decline: Diagnostic framework for policy sequencing and feasible transition pathways in resource dependent regions. Oxford Open Energy, 2022. 1.

Quaschning, V., Understanding renewable energy systems. 2016: Routledge.

Rabehi, A., et al., Direct and diffuse solar radiation components estimation based on RBF model: Case study. 2017. 31: p. 93-110.

Salman R. Research note: Light emitting diodes as solar power resources. Lighting Research & Technology. 2019;51(3):476-483. doi:10.1177/1477153518764211.

Sankari, S.S. and Kumar, P.S., 2023. A Review of Deep Transfer Learning Strategy for Energy Forecasting. Nature Environment and Pollution Technology, 22(4), pp.1781-1793. (10.46488/NEPT. 2023.v22i04.007).

Schoch, R.M., Forgotten civilization: The role of solar outbursts in our past and future. 2012: Simon and Schuster.

Silvi, C.J.D., History and future of renewable solar energy. 2008. 51(3): p. 409-414.

Techo, J., Techo, S., Palamanit, A., Saniso, E., Chand, A.A. and Prasannaa, P., 2024. Enhanced solar photovoltaic power production approach for electric vehicle charging station: economic and environmental aspects. Nature Environment and Pollution Technology, 23(1), pp.215-223. (10.46488/NEPT.2024.v23i01.017).

Tyagi, H., et al., Applications of Solar Energy. 2017: Springer Singapore.