THE ASIAN BULLETIN OF BIG DATA MANAGMENT
Vol. 4. Issue 2 (2024)
https://doi.org/ 10.62019/abbdm.v4i02.177

ASIAN BULLETIN OF BIG DATA MANAGEMENT
ISSN (Print): 2959-0795
http://abbdm.com/
ISSN (online): 2959-0809

Harnessing Karachi's Sun: A Sustainable Solar PV System for Pakistan's Energy Future

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Chronicle

Article history

Received: June 2, 2024
Received in the revised format: June 5, 2024
Accepted: June 9, 2024
Available online: June 11, 2024

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Abstract

The article offers a captivating insight based on the case of Pakistan's solar photovoltaic (PV) systems, given the exhaustion of predictable energy sources and the escalating environmental concerns. The study presents a reasonable, environmentally acceptable, and effective photovoltaic system that is tailored to the exact geographic coordinates of the area, making use of Karachi's abundant solar potential. The recommended method delivers significant environmental advantages with an absolute temperature of 26.85°C as well as a daily solar emission of 5.184 kWh/m2. The article faithfully observes a variety of power losses with the PV-syst simulation, including soiling, module inefficiencies, inverter losses, and temperature-related declines. This yields an impressive yearly energy output of 1678 MWh and a recital ratio (PR) loss of only -0.41%. To assess the likelihood solar PV power project of 1 MW, the research delves deeper into the restraints of output ratios and different types of power loss. Over ten years, carbon dioxide emanations can be reduced by 5317.367 tonnes utilizing the PVSYST toolset to forecast the system's routine. This is equivalent to implanting up to 244,598.822 trees. The economic and commercial analysis, which estimates a maintenance cost of $2,500/ annum after taking consideration of inflation rate with 2% , highlights how cost-effective the system is. This study not only establishes a standard for upcoming solar projects, but it also shows that solar energy is feasible in Karachi. It encourages a purposeful transition to environmentally friendly growth and a sustainable future by emphasizing the vital role that performance scrutiny plays in the development and maintenance of renewable energy systems.

Keywords: Carbon Dioxide Reduction, Power Loss analysis, Solar Photovoltaic system.

INTRODUCTION

Energy consumption is rising rapidly due to several factors worldwide. The world's fossil fuel sources are almost depleting, and excessive energy use will eventually come to an end. To close this gap and address the energy issue, it is crucial to produce modern yet eco-friendly energy sources. Tanveer Ahmad et al., 2020]. The majority of nations are putting in solar-powered projects to produce inexpensive, clean electricity. Global solar grid-producing capacity was 580.1 GW after 2020, and as of 2016, 3.4 GW of capacity is expected to reach stand-alone status. This represents a significant advancement over previous years [R. Sharma et al., 2020]. A PV system's measured performance ratio (PR), the most important factor to consider, is found to be higher when compared to other systems globally, including reports from India, Thailand, Indonesia, and Spain. According to observations, photovoltaic systems work best in the southern region of Pakistan, where the annual DNI is superior to 5 kWh/m2/day (Steffen Stökler et al., 2016). While assessing the effectiveness and feasbility of grid-connected photovoltaic (PV) power-producing systems, simulation software is commonly employed. As a result, it is suggested that the province of Karachi in Pakistan install a grid-connected PV system. Located at latitude 24.86 °N and longitude 67.1 °E, an 879.1 KWp grid-connected solar power plant has been completed. The azimuth angle in the south is 180°, while in the north it is 0°. Meanwhile the tilt angle is 20° that happens to sculpted by solar panel. We witness this photovoltaic system operating from January through December. The tilt angle of the solar panels must be optimized to generate electricity asll year-round. By adjusting the tilt angle, the device can capture more sunlight in the winter less in the summer when it is higher. By keeping an eye on the system year-round, adjustments may be made to optimize energy generation and efficiency.

By comparing the performance ratio of PV system with other worldwide systems such as Indonesia, India, Thailand and span, it is revealed that the higher performance ratio is one such significant factor that can't be ignored. The ratio for the performance of the yield based on final production yield, the efficiency of the inverter Phot Voltaic, similarly the capture of thermal loss, generation of energy in total amount, normalized generation and losses of array, and system losses are other improvements that were taken into account in this study. The present research also unveils this fact that during the execution of these adjustments, a significant increase in energy output was observed that improves the overall efficiency of system. It should also be noted that the escalation of energy production is an unanticipated situation that relies on the efficiency of PV inverter, indicating that the minimum the thermal capture loss the more the performance gets better. Also, by minimizing the system losses, the overall efficiency of energy production improves with certain production level. Thus, consideration of all factors eventually improves the overall efficiency and performance of system.

The potential of clean sources has been enhanced due to greater worldwide awareness of pollution and rising energy usage. The significant of all renewable energy sources and a workable solution since solar radiation is plentiful and eagerly offered ubiquitously in the globe owed to the effect of PV (Jibran Khan et al., 2016). A photovoltaic cell is a device utilized in this study to convert solar radiation into electrical energy, and it regularly produces enough power to fulfill the load's peak demand. When a high demand pulls a large amount of power from the system, it produces more electricity on sunny days as opposed to cloudy ones (Irwan et,.2015). PV systems come in three different kinds. Grid-connected, standalone, and hybrid systems: Batteries with the ability to store energy for both AC and DC loads are used in the construction of the majority of freestanding photovoltaic (PV) systems. Such systems have independent operations. Photovoltaic systems that are linked to grid, have a potential to pull power and infuse excess energy when needed.

Further to discussion, hybrid systems are supposed to integrate distinct characteristics of "standalone" and "grid-connected" systems with the help of battery storage and grid electricity. Each of the PV system provides multiple benefits along with few drawbacks, thus, giving choice to consumer to consider those energy solutions that fulfill their requirement. In addition to this, the system is efficient due to charge controller as it stops batteries from being overcharged. It is argued that PV systems that are based on grid-connection are well-appreciated by corporations especially those that intend to replace their traditional systems with environmentally-friendly systems. Interestingly, such systems have a potential to produce more energy than requirement especially in summer season. This allows corporations either to store the excessive electricity in batteries or directly feed the electricity back into the system (Kumar Ravi et al., 2021). The third is a hybrid photovoltaic system that works with the grid and can store energy. It also has a battery backup system. The ability to use stored energy if the Grid is unavailable is a major advantage of this. (Irwan et al., 2015). Khaliq et al. (2024) scrutinized the amalgamation of solar energy and project management in the context of Pakistan's sustainable agriculture, particularly Baluchistan. Authors explained that how a 10-acre farm, equipped with solar-powered water supply, can be sufficient for 10 irrigation sets.

Thus, demonstrating profitable and environmentally-friendly agronomic mechanism. As per study's statistics, with the production of vegetables such as spinach, potatoes and onion, a profit of 1.62 million PKR can be achieved with a breakeven point of 1.76 years. This indicates the significance of solar energy that indeed has a potential to address water scarcity and establish standards for sustainable agricultural practices in the future (Khaliq et al., 2024). In most situations, the output of the photovoltaic system is influenced by the location of the solar photovoltaic panel. Having said argument, the aim of the study is to employ PV system software in order to vitalize and build solar PV system in Pakistan which fulfills the energy need of consumers.

LITERATURE REVIEW

Study of Kumar et al. (2017) assessed the Haripur's system performance of entire year and revealed that the growing energy demand of city will be fulfilled by PV system that appears to be a feasible alternative. Another comparative study captured the azimuth view of system performance with the inclusion of carbon emission count device (Yadav et al., 2015). The research is considered an important milestone as it unfolds the constant hunt for renewable energy resources. Study of Nadeem et al. (2024) also explored alternative model of energy resources by conducting a notable analysis. The study investigated "*Piezoelectric Floor Energy Harvesting Power Generation*". With a thorough assessment, it is revealed that the system is not only effective but also suitable in case of renewable resources. Similarly, Sharma et al. (2018) peeped into the inverter yield, also called the end device yield or useful energy yield and revealed that the system has normalized output of 4.6 kWh/kWp/day and an annual efficiency ratio of roughly 81.67%.

Study of Nadeem et al. (2020) highlights this shortfall diagram, which displays the discrepancy between energy produced by PV systems and actual energy supplied in to the grid. This allowed us to identify those areas which need improvement in terms of energy competence and its usage. The study further invested standalone PV systems by using simulation tool of PV system. Findings of Spea et al. (2019) covered various aspects in simulation results such as overall energy equipped by PV array, unuse energy, load energy, PV competence, output ratio etc. In the context of Karachi, there are several studies that considered output ratio, different form of power losses etc. while measuring PV performance (Kandasamy et al.s, 2013]. One such study claims that a 1 MW PV power plant can be considered sufficient for long-term energy supply regardless of high building expenses which businesses have to bear at initial stage. In order to increase energy output and reduce power losses, the study also emphasized how crucial it is to use high-quality components and effective power management systems. The findings demonstrate the overall advantages of solar PV investment. The study used simulation techniques to anticipate the year's energy output and create an accurate SAPV approach. The PV-syst tackles suite was cast off to pretend the SAPV stratagem system (S. Morshed et al., 2015). In a different study, the authors (S. Barua et al., 2017) talk about how to increase electricity generation in a solar power plant in Pakistan by optimizing solar panel propensity. Several computer programming and simulation tools are used for the largest and most efficient integration of solar energy.

METHODOLOGY AND SIMULATION

The disposition of PV system is determined by its location and solar radiation levels. Solar panel quality, alignment, and inclination are often determined by their inverters and modules. The location's sun irradiance, wind speed, and ambient temperature are measured through weather monitoring (Karachi, Pakistan). Figure 1 shows the method taken to achieve the required outcome. The programmed PVsyst simulation is the one used in this study. All of the figures for the suggested site are produced exclusively by the replication phase. Due to the ending of modeling of computer, this article (Jones et al., 2015) addressed all simulation impacts. The simulation section of this paper, which will have the following aspects, will be its most interesting feature.

Orientation

The graphic illustrates the following: tilt angle, quick optimization (summer yearly irradiance yield), annual Irradiance yield (transposition factor, loss relative to optimum, worldwide on collecting plane), and azimuth angle. April through September are included; October through March is winter and pertains to the field's alignment section requirements. The tilt angle in the region where the solar orientation is focused by the azimuth angle as an aspect to true north is noticed as the horizontal plane-wise location of the solar panel. Efficiency is impacted by alignment and transference losses, which are included in losses and included into the annual Mateo yield.

PV system

This section discusses the significant variable quantities, such as choosing an inverter, a PV module, and the number of units to link in sequence to get the collection. The relevant circumstances are Isc (STC) 1456 A and Impp (STC) 985 A. The instruction consists of 22 units and 174 strings. The total worth and recital of the solar array are dogged by these factors. The PV unit and inverter that best chance the project's exclusive needs should be cautiously elected to exploit the system's output. An additional major factor distressing the array's performance and consistency across different scenarios is the number of units in strings and series. Altogether of they must be taken into interpretation although erecting a solar system. Therefore, 800 kwp is the array's trifling power lower than standard examination settings, which also include predictable power and strings. Table 1 and Fig. 3 validate that there are around 4002 units in use. The sizing voltages are 25.5 V and 41.7 V at Vmpp (60°) and VOC (-10°), correspondingly. Si polycrystalline and Trina solar elements are the 2 assortments of solar units. The inverter harvests 400 volts as its yield voltage. The term "VMC" denotes to an inverter category that has 3 MPPT and an extreme input voltage of 1000 volts. It activates in the 200–1000-volt variety.

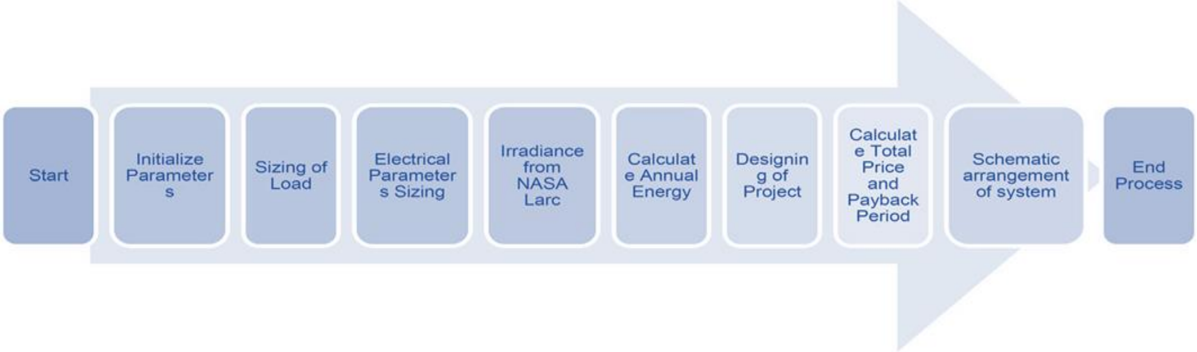

Figure 1.
Flow diagram of entire system.

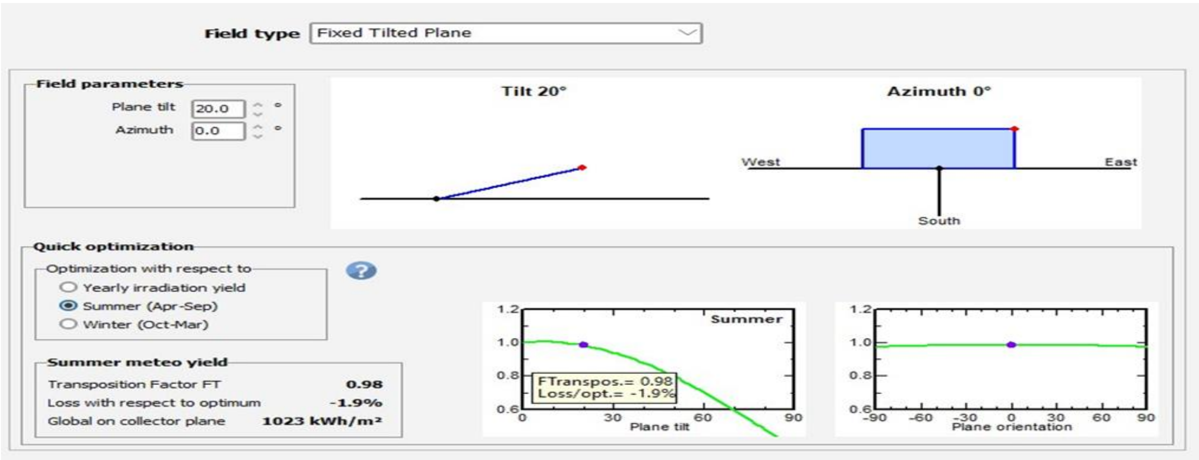

Figure 2.
Orientation of Solar Panel

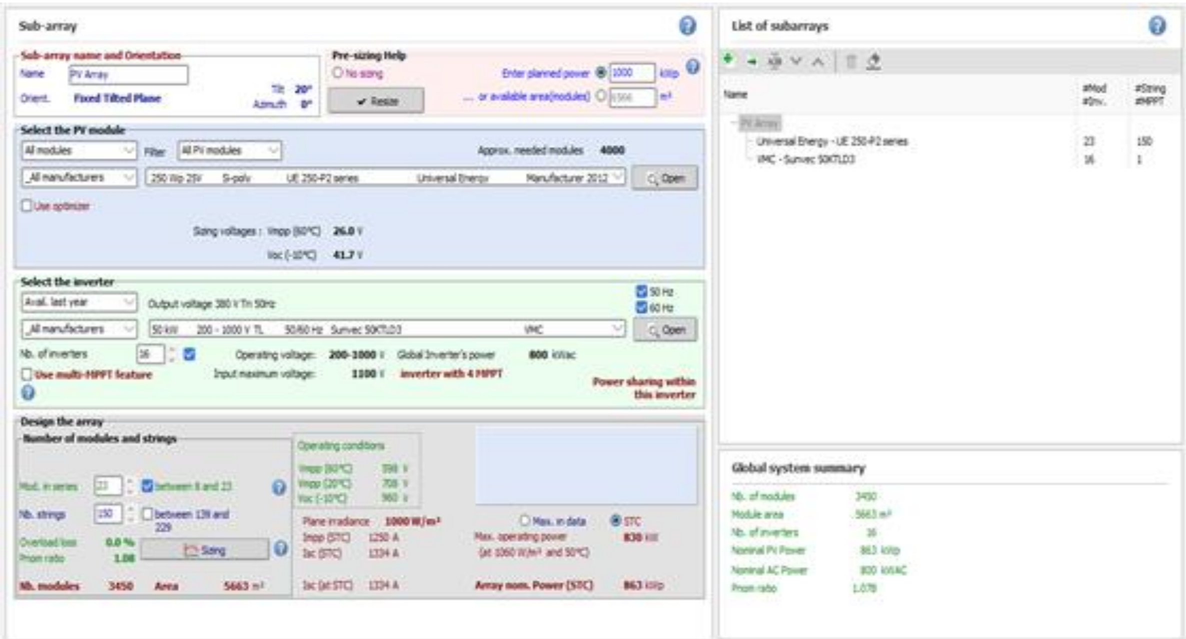

Figure 3.
Design parameters of PV systems

Table 1.
Design parameters.

Design Parameter	Value
VMPP (50^0)	25.5 v
No of modules used	4002
Module Material	Si Poly Crystalline
Nominal AC Power	800 KW AC
Pnom Ratio	1.25
Nominal Power	55.0KWp
Maximum Power	880 KW DC
Module Area	$6569m^2$
Number of modules used	4002
VOC (-10^0)	41.7 v

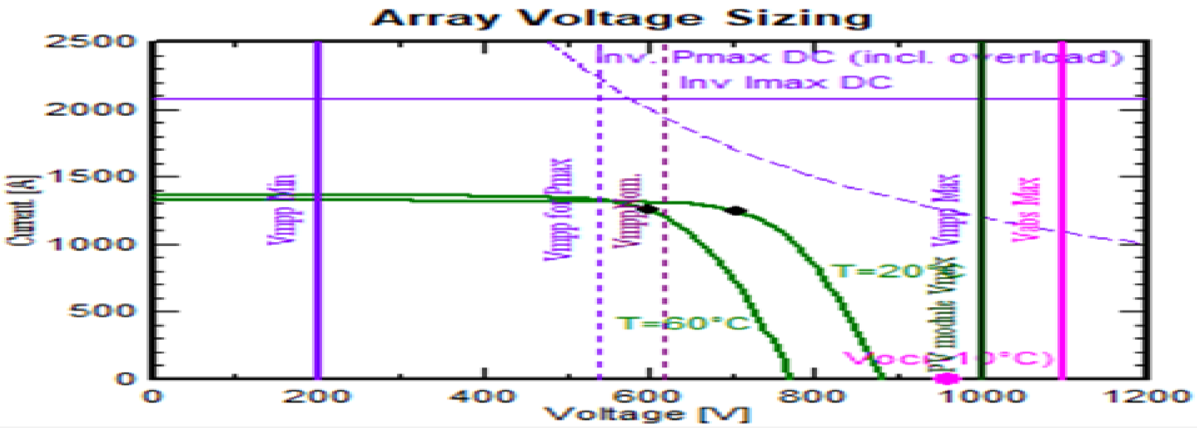

Figure 4.
Array voltage sizing.

Array voltage sizing

All of them should be taken into account while constructing a solar system. Accordingly, 800 kwp is the array's nominal power under standard test settings, which also include projected power and strings. Table 1 and Fig. 3 demonstrate that there are around 4002 modules in use. The sizing voltages are 25.5 V and 41.7 V at Vmpp (60°) and VOC (-10°), correspondingly. Polycrystalline and Trina solar units remain the two varieties of solar units. The 400 volts produced by inverter as its output voltage. The term "VMC" refers to an inverter type that has 3 MPPT and a supreme participation voltage of 1000 volts. It operates in the 200–1000 volt range.

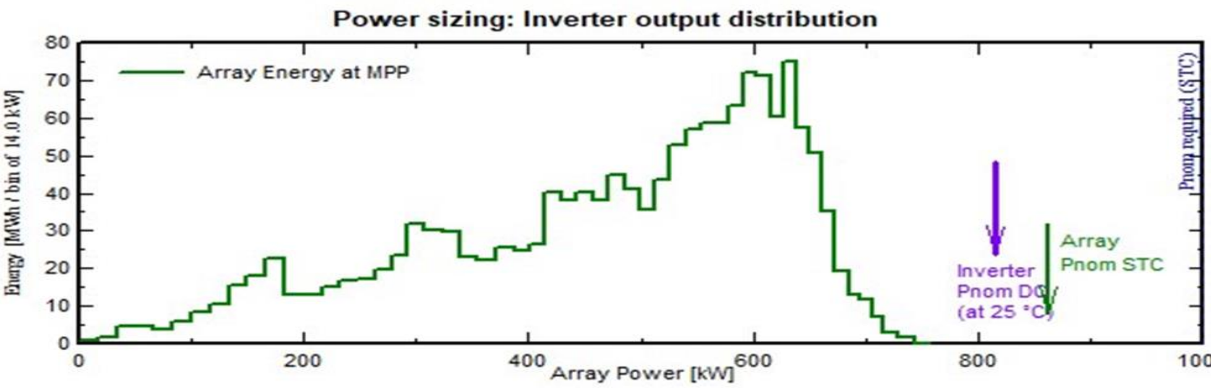

Figure 5.
Array Power.

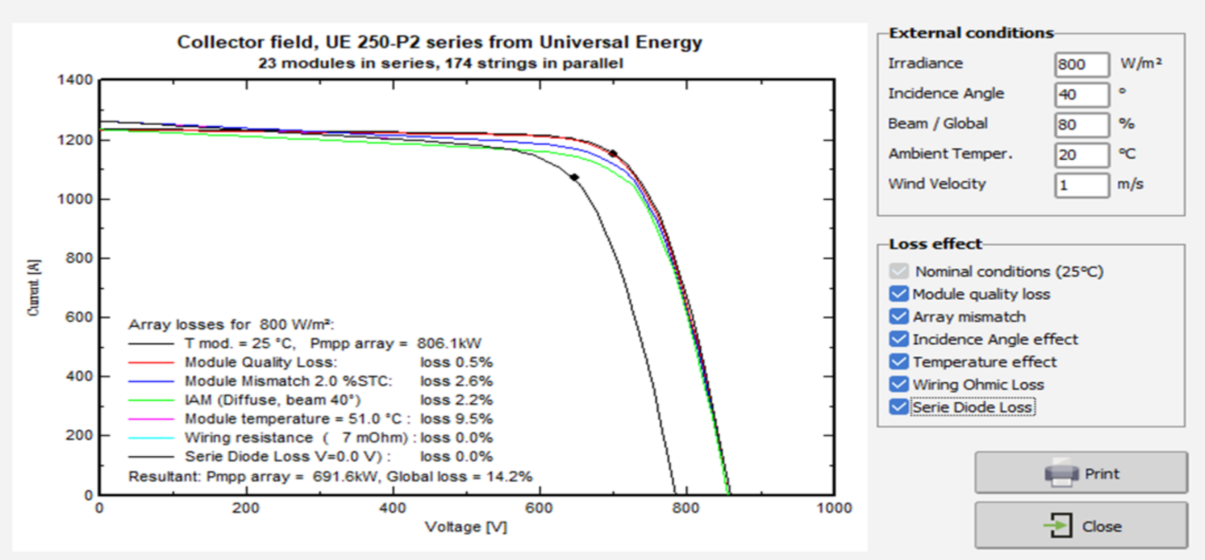

Figure 6.
VI Features of PV-syst.

Incidence angle transformer losses and Prospect line

The tilt angle must be taken into consideration during system installation as it influences the incidence angle modifier. The incidence angle modifier will adjust at that specific location by the tilt slant. Also known as the sun path or figure for the specified location (Jones K et al., 2015). In PV-syst, the horizon line defines the shade and is a necessary component.

The solar path is upward until June, when it begins to descend and remains that way until December. The cause for this singularity is that during these periods, the Earth's alliance is not inclined either in the direction of or absent from the sun. The equinoxes thereby signal the start and finish of each season. For instance, spring arrives in the northern hemisphere in March and in the southern hemisphere in October.

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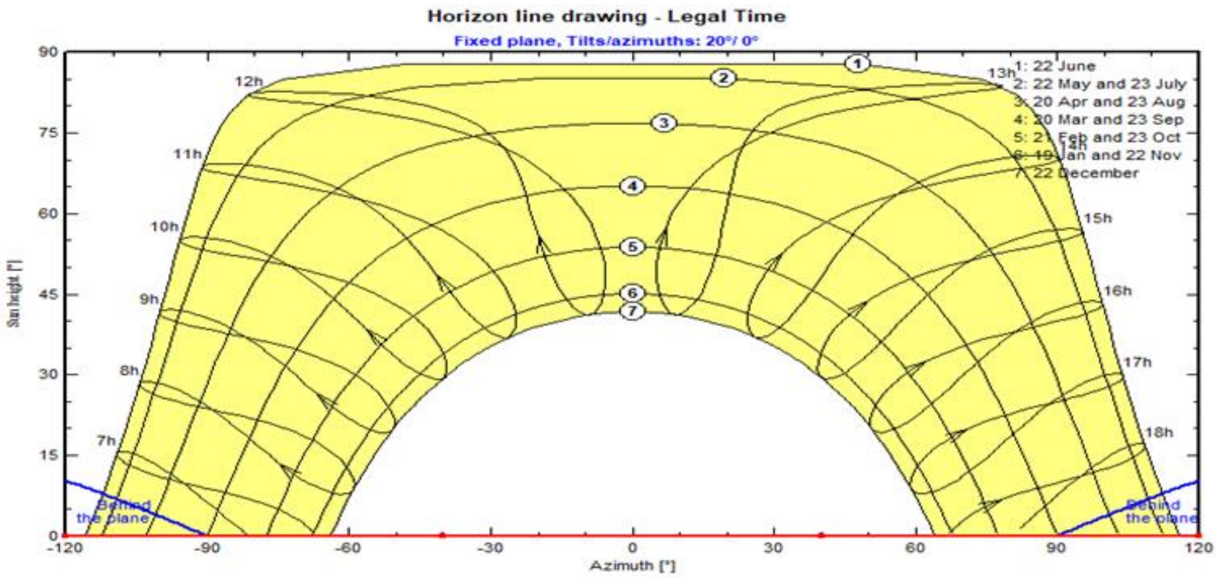

Figure 7.
Path of the Sun over a year.

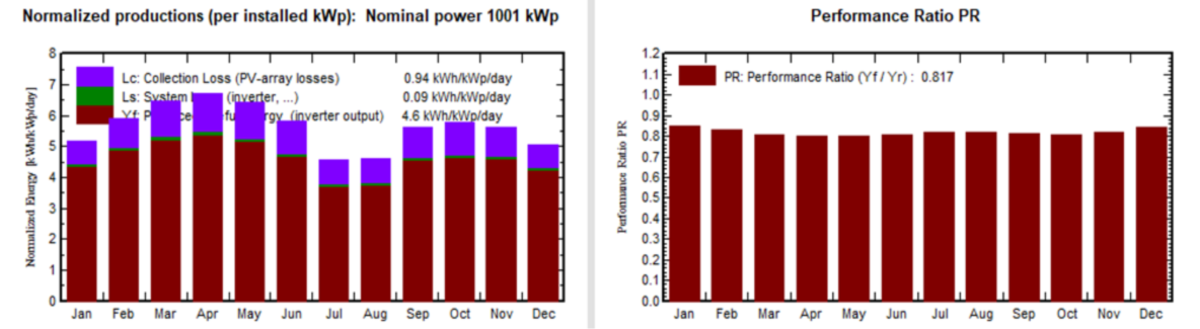

Figure 8.
Normalized productions (per installed kWh/kWp/day) and performance ratio.

FINDINGS AND DISCUSSIONS

Solar data is considered one such as primary source of information that is required to measure electricity generation in a proper manner. In this study, data for humidity and temperature was considered which was extracted from meteorological records. This data is utilized to conduct a thorough assessment of selected sites (Fig. 7). Fig. 8 highlights that energy to performance ratio is normalized. Moreover, figure 81.7% indicates that performance ratio of a system is quite satisfactory and the system is in fine working order. The normalised production yielded the following three crucial metrics: system loss and collection loss. System loss which is also known as inverter loss is 0.1kwh/kwp/day, whereas, collection loss, known as PV-array loss, is1.16 kwh/kwp/day, displayed in Figure 9. The last crucial metric is useable energy generated by system that is 4.94 kwh/kwp/day (Pourdaryae et al., 2020). Based on data congregated from meteorological records and examined at the chosen places, the ambient temperature, global horizontal radioactivity, global incident, and horizontal diffuse treatment, all shown in horizontal form below. Table 2 displays the operative and IAM, the plane, the energy injected into the grid, the performance ratio, and operative energy at the collection's output.

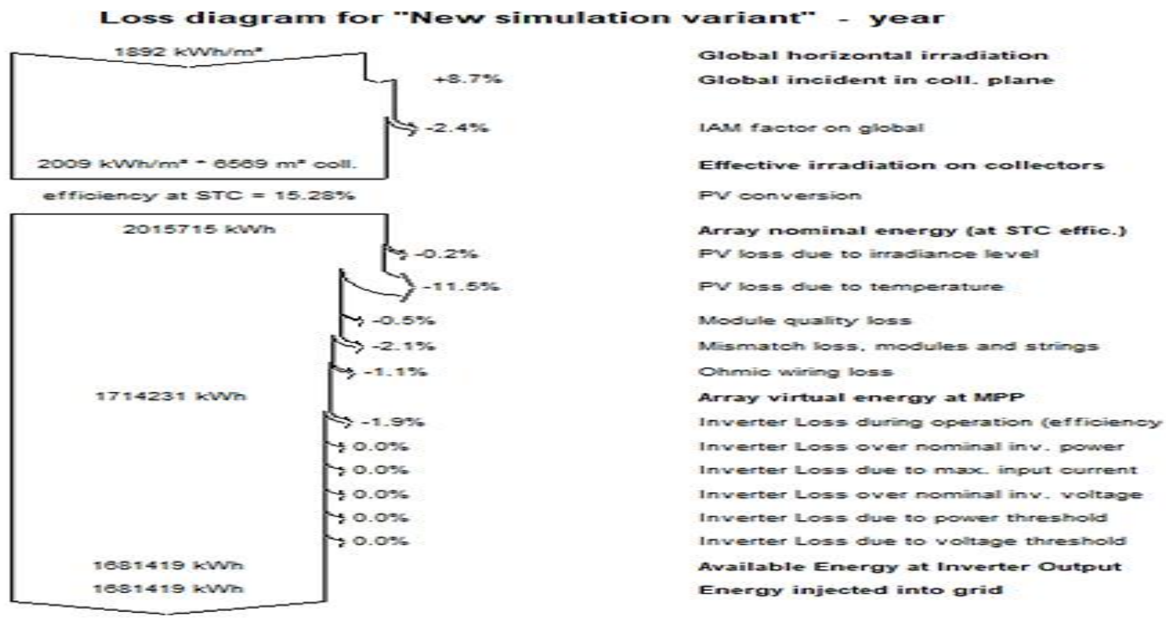

Figure 9.
Loss Diagram.

Table 2.
Solar irradiation showcase.

	GlobHor-kWh/m2	DiffHor-KWh/m2	T_Amb °C	Globinc kWh/m2	GlobEff kWh/m2	EArray kWh	E_Grid kWh	PR ratio
January	124.9	46.7	18.61	160.3	156.5	138300	135725	0.846
February	137.3	50.5	21.55	165.1	161.6	139730	137080	0.830
March	181.2	68.7	26.28	200.4	196.1	165530	162400	0.810
April	197.0	78.7	29.18	201.7	197.3	164610	161427	0.800
May	208.0	96.0	31.31	200.0	195.0	163134	160058	0.800
June	184.8	103.0	31.58	174.2	169.5	143345	140648	0.807
July	148.1	98.4	30.70	141.2	137.2	117635	115336	0.816
August	144.6	96.0	29.39	142.7	138.9	119464	117097	0.820
September	159.6	85.5	29.14	168.2	164.2	139826	137175	0.815
October	155.1	68.1	29.33	178.7	174.7	146842	144111	0.806
November	132.7	44.8	24.69	168.6	164.8	141202	138532	0.821
December	119.1	42.7	20.10	156.6	152.9	134416	131831	0.841
Years	**1892.3**	**879.1**	**26.85**	**2057.8**	**2008.6**	**1714035**	**1681419**	**0.817**

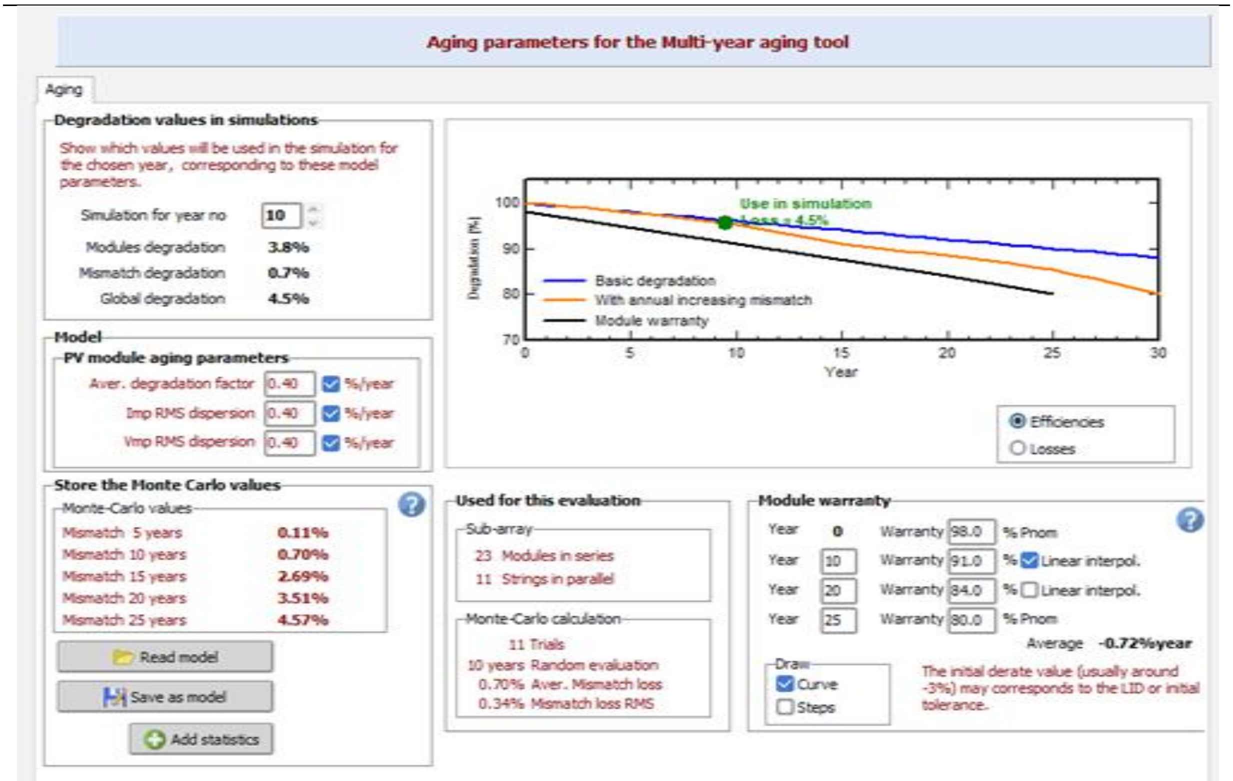

Figure 10.
Aging Parameter.

The aging factor of the PV system is shown in Figs. 10, 11, and Table 3. These numbers show that the global deterioration is 4.5%, the mismatch degradation is 0.7%, and the module degradation is 3.8% Along with the 25 years of usable out organization energy and recital ratio, the graph also displays the 25 years of 1446.37 MW, 2009 KWH/m2, PR proportion of 70.25%, and PR Loss of -0.14%.

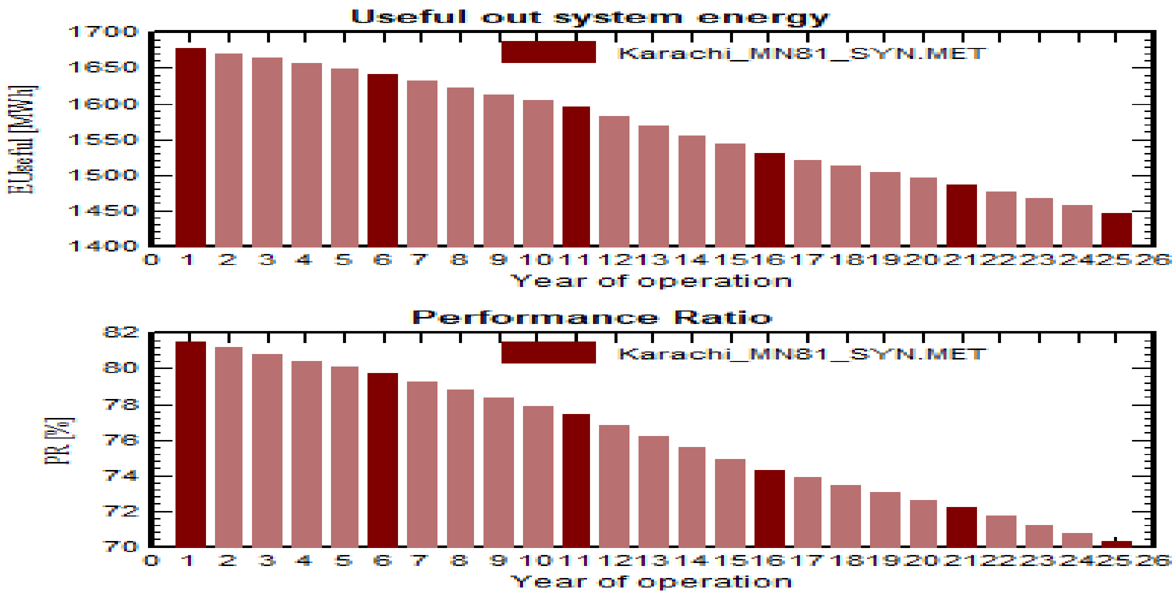

Figure 11.
Aging table and Graph.

Table 3.

Years	EUseful- MWh	kWh/m2	EUseful- MWh	PR%	PR loss%
1	1678.26	2009	1678.26	81.51	-0.22
2	1670.94	2009	1670.94	81.16	-0.65
3	1663.61	2009	1663.61	80.80	-1.09
4	1656.29	2009	1656.29	80.45	-1.52
5	1648.97	2009	1648.97	80.09	-1.96
6	1641.64	2009	1641.64	79.74	-2.39
7	1632.23	2009	1632.23	79.28	-2.95
8	1622.82	2009	1622.82	78.82	-3.51
9	1613.42	2009	1613.42	78.36	-4.07
10	1604.01	2009	1604.01	77.91	-4.63
11	1594.60	2009	1594.60	77.45	-5.19
12	1581.58	2009	1581.58	76.82	-5.97
13	1568.56	2009	1568.56	76.19	-6.74
14	1555.55	2009	1555.55	75.55	-7.51
15	1542.53	2009	1542.53	74.92	-8.29
16	1529.52	2009	1529.52	74.29	-9.06
17	1520.93	2009	1520.93	73.87	-9.57
18	1512.34	2009	1512.34	73.46	-10.08
19	1503.76	2009	1503.76	73.04	-10.59
20	1495.17	2009	1495.17	72.62	-11.10
21	1486.58	2009	1486.58	72.20	-11.61
22	1476.53	2009	1476.53	71.72	-12.21
23	1466.48	2009	1466.48	71.23	-12.81
24	1456.42	2009	1456.42	70.74	-13.41
25	1446.37	2009	1446.37	70.25	-14.00

The loss diagram, which can be shown in Fig. 9, shows each loss that occurs in the system step by step and indicates that the 1992 kWh/m2 drop in this area is the result of the PV system. It's a positive feature. Because of soiling and IAM losses, the system produces 1487 Mwh of total energy; the efficiency of 15.28% is shown in the loss diagram in Figure 9. Figure 12 shows the emissions of CO_2. One way to estimate the expected reduction in CO_2 emissions from solar systems is to use the Carbon Balance tool. The Life Cycle Emissions (LCE) as they are known, provide the basis for this computation and display the Carbon Dioxide emissions associated with a particular component. These numbers cover the whole process of the flow of an item or quantity, counting its production, consumption, maintenance, disposal, etc.

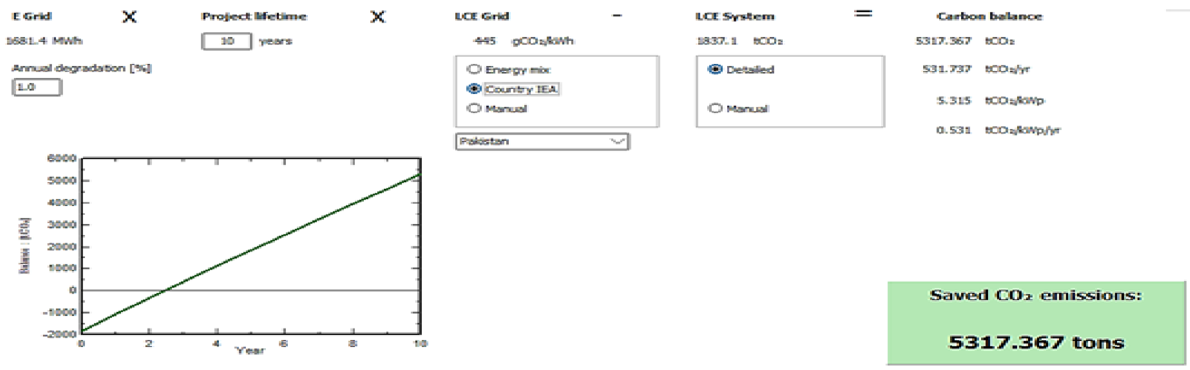

Figure 12.
co2 Emission.

As per the explanation of Carbon Tool Balance, amount of powered produced by PV installation is equal to electricity amount that already exists in the system. Also, if carbon foot print of PV installation is lesser than the carbon foot print of electricity production of grid, then the system observes a decrease in carbon emissions. Thus, sthe difference between the CO2 emissions that are created and avoided is the entire carbon balance for a solar installation. A compelling study shows that using renewable energy sources, like solar energy, may reduce carbon dioxide emissions by 5317.367 tons, which is good for the environment.

CONCLUSION

The paper deliberates the strategy and recital analysis of an 800KWp grid-associated solar structure in the Karachi region of Pakistan. Which has an annual production of 1678 Mwh, an annual specific output of 1678 Kwh, an 81.51% performance ratio, and a daily loss of 0.10 Kwh/Kwp. The device's replication disappointment is strongminded by the unit's comportment. The PVsyst program analyses several types of losses. PV-syst makes an effort to use the right templates for every potential reason why a PV system can fail. The risky areas of PV production are the PV module model, the validity of industrial data, and the Metro pieces of evidence Fitting solar gable by domiciliary load claim will qualify the system to convert autonomous.

DECLARATIONS

Acknowledgment: We appreciate the generous support from all the supervisors and their different affiliations.
Funding: No funding body in the public, private, or nonprofit sectors provided a particular grant for this research.
Availability of data and material: In the approach, the data sources for the variables are stated.
Authors' contributions: Each author participated equally to the creation of this work.
Conflicts of Interests: The authors declare no conflict of interest.
Consent to Participate: Yes
Consent for publication and Ethical approval: Because this study does not include human or animal data, ethical approval is not required for publication. All authors have given their consent.

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