

DESIGN & RELIABILITY OF SOLAR PV SYSTEM AS SUSTAINABLE ENERGY SOURCE FOR THE UNIVERSITY OF LARKANO

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ABSTRACT: Pakistan is facing an acute energy crisis due to the increasing energy demand in various sectors, and the load shedding of electricity has become a prevalent concern. Therefore, this study was conducted at the University of Larkano, Sindh, Pakistan, to investigate and propose a solar photovoltaic (PV) system for supplying electricity to fulfill the energy needs during load shedding while also lowering the operating cost of installed diesel generators that are used for backup during load shedding. Likewise, this study aimed to ascertain the reliability of a solar PV system in terms of shading risk to examine losses of PV modules, saving of carbon dioxide (CO₂) emissions, actual energy production during the lifespan, payback period, levelized cost of energy (LCOE), solar PV system life cycle cost, and average unit cost. PVSyst software version 6.6.3 was employed for the design and reliability of the proposed photovoltaic (PV) system. The total energy requirement of the light appliances for replacement with solar PV system was 717.94 kWh/day. Moreover, the results showed that all the buildings of the engineering campus required a 178.8kWp PV system, with 596 modules that will produce 8573.25MWh during a 30 yrs lifespan. Similarly, when all types of energy losses were considered, the total energy supplied to the end user was obtained 201.32MWh/yr., with an average unit cost of 0.06 USD\$/kWh and a performance ratio of 55.51%, which is satisfactory. In addition, the proposed solar PV system electrification will save approximately 2,968.9 tons of carbon dioxide CO₂ throughout its lifetime, with a payback period of 8.5 yrs., LCOE of 0.032 US\$/kWh, life cycle cost (LCC) of 275,191 US\$. Likewise, electricity purchased from SEPCO is 2.5 times costly than the suggested solar PV system unit cost, while electricity generated from diesel generator sets is 3.33 times more expensive.

Keywords: *PV_{SYST}, Solar Photovoltaic (PV), Carbon dioxide (CO₂), Reliability Optimization, Renewable energy (RE), Life cycle cost (LCC), Energy Efficiency (EE).*

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INTRODUCTION

Solar energy has several benefits over fossil fuels, for instance universality, free pollution production, diversity, and long-term reliability. The photovoltaic sector has risen significantly in past years. The installations of solar PV system risen annually 29.5 GW in 2012, to 107 GW in 2017, bringing global PV power to about 520 GW in the end of 2018 [1]. The International Renewable Energy Agency released Global Energy Transformation in 2019, a Roadmap to 2050 . According to their predictions, the rated size of solar power is anticipated to reach 8500GW by 2050, accounting for over two-fifths of worldwide electricity output [2]. PV energy is an attractive source for shifting to renewable energy [3]. The top ten world countries are producing solar power by means of solar photovoltaic (PV) technologies are 35.5GW in Germany, 18.3GW in China, 17.6GW in Italy, 13.6GW in Japan, 12.0GW in the U.S., 5.6 GW in Spain, 4.6 GW in France, 3.3 GW in

Australia, 3.0GW in Belgium and 2.9GW in the U.K. [4]. Designers frequently employ simulation software for PV systems to aid in dimensioning and predicting electrical production [5]. Among other applications, PVSyst has been used for the assessment of solar potential, performance analysis of PV systems, design and simulation, and economic evaluation [6,7,8,9]. These analyses also included the use of other tools such as PVSol and SAM. The quality of the results, as with any simulation, is determined by the input parameters utilized, therefore the higher the number of parameters provided by the users , the more complex the simulations and results [10,11,12]. In PV system design, PV module alignment and tilt angle choices are important for the efficient operation of the modules. The PV system produces less electric energy if the tilt angle and orientation are not properly set, as opposed to the optimum settings, which may have an impact on the investment's economic indicators, for example extension in the payback period [13]. Knowing the local climate

and other conditions (for example, environmental conditions) is essential for maximizing the annual quantity of energy that can be produced. The best settings (e.g., string distances) may vary depending on the area of the location [14]. The size and efficiency of the PV system strongly depend on the meteorological conditions. For PV system design and optimization, specific findings associated with meteorological conditions, such as ambient temperature and solar energy must be obtained [15,16]. The Efficiency of a PV array firmly depends on the position of the sunlight [17]. In addition, cell temperature is an important factor in evaluating the efficiency of PV cells, [18]. The temperature of the cell affects the performance of the modules, depending on the manufacturing of the photovoltaic cells [19]. The most common technique of optimization followed by the researchers begins by identifying a particular field, and then data about the series of time are obtained for ambient temperature and solar energy[20,21]. Later, the ideal angle of tilt was calculated by measuring the energy of solar radiation on the tilted surface. The Estimation of

system energy sources (PV array batteries, diesel generators and wind turbines) was later carried out based on the design of the PV for grid-tied, Hybrid or Standalone systems [22,23]. Solar, hydropower, wind, and biomass are four principal renewable energy sources in Pakistan. These reserves offer solutions to the country's longstanding energy crisis. Out of these resources, Pakistan has great potential for solar power with an estimation of 2.9 million MW. The annual average global solar radiation is very high in the country of approximately 5.3 kWh/m²/day [24,25,26,27]. Pakistan is situated between 62° and 75° east longitudes and 24° and 37° north latitudes, covering a 796,096 km² land area [28].The use of solar energy benefits from this geographical location and climatic conditions. Almost every part of the country receives 8 to 10 hours of high-level solar radiation every day, with more than 300 days of sunshine every year [29,30]. The irradiation for major cities of Pakistan including Larkana and the surrounding regions is explained in Figure 1 [31].

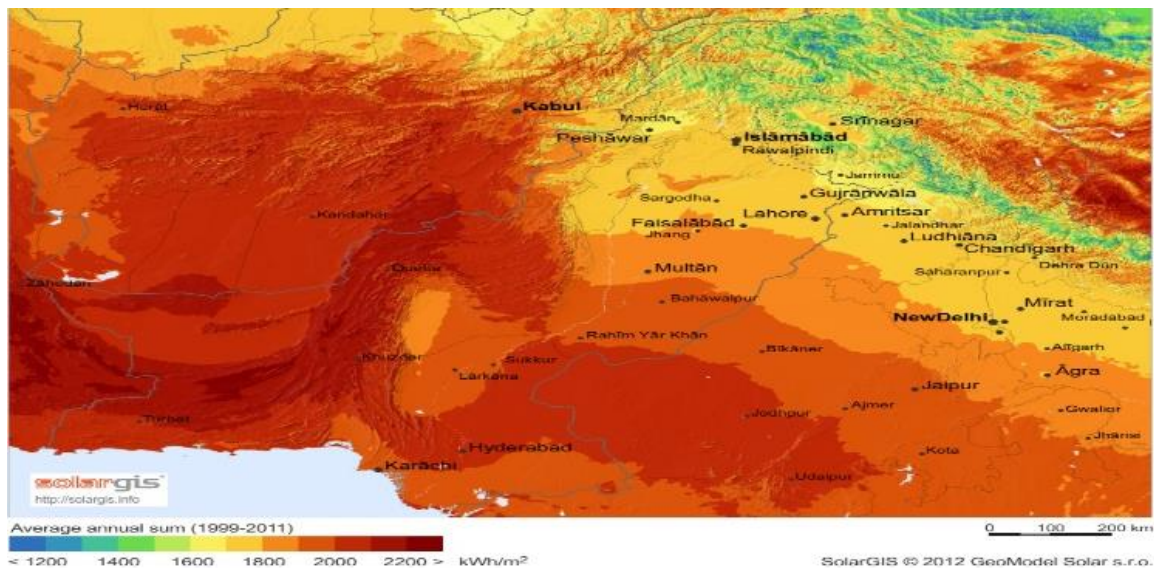


Fig. 1. Global horizontal radiation of Larkana, Pakistan [31].

Energy consumption in Pakistan is increasing owing to industrialization and population growth. Therefore, it is essential for the state to adjust the provision of electricity to the growing need in the national, educational, and business sectors, which are the key sectors of electricity users in Pakistan [32]. The country's current electricity demand is 25000 MW, which is expected rise to 40000 MW further by 2025. Pakistan can generate 160000 MW of solar energy. Nevertheless, non-conventional energy accounts for 1% , and the government intends to increase it further 5% by 2030 [33,34,35]. At present the country is already facing a serious energy crisis, which has resulted in frequent load shedding in the country over the last two decades.

Therefore, during peak hours, the supply of electricity could not be sustained, causing regular power shutdowns in rural areas at 16 to 19 hrs., and in urban areas 13 to 14 hrs. [36]. The purpose of this study is to suggest an alternative solution for supplying of electrical power to meet the energy needs of the University of Larkano, Sindh, Pakistan, which is experiencing similar issues such as electricity load shedding (a common problem) that affects teaching and research activities in various ways due to hot climate conditions, rising electric power demand due to the construction of new buildings and facilities on campus, and the high operating costs of installed diesel generators used for backup during load shedding. In this regard, the authors investigated various

possible options for electricity supply such as wind, biomass, and solar. Because of the lack of land space, capital cost and other limitations such as the average wind speed of Larkana being 1.38 m/s which is not sufficient to generate electricity, and biomass is not readily available and requires a large space for storage. Finally standalone roof mounted solar photovoltaic (PV) system was proposed to meet the objective of the study, because the annual average solar radiation of the site was 5.5 to 5.8kWh/m², it has low capital cost, is reliable, and easy to install on the roof for various buildings of University of Larkano.

Reliability optimization of solar PV system: PV systems are the most important part of solar energy systems, and their life span and reliability are related to the power production efficiency of the installed PV system, and hence to the investment for the cost of electricity production and payback time [37]. The Increased financial risk results from inaccuracies in the estimation of service lifetime and reliability. Therefore, it's critical to accurately assess the durability and lifespan of PV panels. Collecting life data (also known as failure data) is a common method for assessing the reliability of PV modules and then using statistical analysis to determine the PV module's reliability [38]. The depreciation of PV modules from installments to breakdowns covers a large amount of data on their reliability. Choose an appropriate deterioration model to present the law of degradation if we can periodically evaluate the performance metrics of PV modules. The performance degradation approach refers to the process of evaluating PV modules using this model. In the process of performance deterioration, the degradation model is one of the most important components. An incorrect degradation model can result in large variances in PV module life estimation, leading to misinformed decisions by stakeholders such as investors and PV plant owners [39]. The general path approach, graphical technique, and stochastic process method are the three types of reliability degradation modelling methodologies [40,41]. Unfavorable effects in conventional crystalline PV module cells generate variations in operation among PV cells. Losses owing to mismatch losses, regional topographical conditions, shading, and contamination by dust, dirt, or bird/insect excreta, are examples of negative consequences [42,43,44,45]. Shading is a serious risk in this technology due to the risk of damage to the PV modules. When PV cells are shaded, they act as current sources, converting electric power to heat and causing significant localized dissipation if the currents of the cells in a series are altered. This technique results in a phenomenon known as hot spots (hot cells) or hot strings, which permanently harm PV module [46,47]. Previous research has focused on developing simplified methods for simulating the I-V curve in shading scenarios [48],

while others assessed the effects of various shading patterns [49], by modifying the PV module's settings, these shading effects can be reduced [50], or the PV array [51]. The PVsyst software provides the user with three methods for estimating shading effects. Perform shading analysis, one must either create a 3D model with the provided tools or import one created with another program. According to the PV system's shading losses are proportional to the area shadowed, according to the linear shading approach. The first model considers only irradiance losses in the module plane and offers two options: calculation using shadow tables (which is faster) or simulation (slower). The second method calculates losses by string, if when the shadow passes through a string of modules, all of them become unproductive; the user can then determine the fraction of the electrical effect. This model indicates the highest loss limit, according to the software's manual. In the detailed model (third option), the modules are subdivided into submodules based on the bypass diodes. The I-V curve is created by calculating the fraction of linear shading for each submodule. The voltages of the submodule curves are added in series, while the currents of the submodule curves are added in parallel, yielding the final curve. In this study PVsyst software version 6.6.3 was used for design, and reliability optimization. Furthermore, reliability optimization was assessed by considering shading risk to determine various losses of PV module for example of Lc collection losses (PV array losses), Lu Unused energy (Full battery), Ls system losses and battery charging, and energy supplied to the user by taking these losses into consideration. Likewise, saving of carbon dioxide (CO₂) emissions, actual energy production during lifespan, payback period, levelized cost of energy (LCOE), life cycle solar PV system cost, average unit cost comparison with electricity purchased from Sukkur electric power company (SEPCO) and electricity generated from diesel generator sets in the engineering campus.

Levelized Cost of Energy (LCOE): The initial solar PV system cost was calculated using dollar per watt (\$/Watt), which excluded several factors (such as solar equipment performance, financial policies, and system life cycle) [52]. The LCOE is a more precise cost of energy measurement that is well recognized, acceptable, and commonly utilized methodology adopted by many scholars and agencies [53,54,55]. The LCOE is defined as the ratio of the PV system's LCC to the total energy generated over its lifetime, as shown in Eq (1) [56].

$$LCOE = \frac{\text{Life cycle cost (LCC)}}{\text{Life cycle energy produced}} \quad (1)$$

Life cycle cost (LCC): A life-cycle cost study determines the entire cost of a PV system, which includes all costs incurred throughout its lifetime, as shown in Eq

(2). Several costs are considered when measuring LCC, such as Replacement cost, Investment cost, and Maintenance cost. The Investment cost is considered as the cost of PV modules, charge controllers, batteries, inverters, and mechanical systems to support PV modules, circuit breakers, and special cables, as well as installation costs. The expense of replacing the batteries, charge controller, inverter, and wires when they reach the end of their useful lives is referred to as replacement cost. The cost of annual maintenance is the expenditure that is incurred every year [56].

$$LCC = C_{Investment} + C_{Replacement} + C_{Maintenance} \quad (2)$$

PV System payback period: To calculate solar PV system payback period, we need to determine the installation cost and yearly energy saving as shown in Eq (3). Furthermore, yearly energy saving is a product of the average cost of electricity and yearly energy production as shown in Eq (3) [57,58].

$$Payback\ period = \frac{Investment\ cost}{Yearly\ energy\ saving} \quad (3)$$

MATERIALS AND METHODS

This study was conducted at Larkana district, Sindh province in Pakistan, shown in Figure 2. The selected site was the engineering campus for the University of Larkano as shown in Figure 3. The faculty building consists of various department buildings such as Mechanical Engineering (ME), Civil Engineering (CE), Electrical Engineering (EL), Electronics Engineering (ES), Admin block, and Library. The shortage of electricity is a common problem across the country as well as in Larkana District. The same problem exists in the engineering campus, which is affecting teaching and research activities in various ways due to hot climate conditions. Engineering, campus site located at 27.56° North and Longitudinal angle is 68.21° East, with 5.5 to 5.8 kWh/m²/day solar radiation, which only requires utilization in a proper way.



Fig. 2. Satellite map & location of Larkana in Pakistan.



Fig. 3. Satellite map of University of Larkano.

Tools for Designing PV System: Solar and PV system design tools such as PVsyst, Ecotect, Solar pro, and Sombrero are specifically built for urban applications.

They can account for the effects of surrounding impediments in their computations due to their three-dimensional CAD environment [59,60,61]. RETscreen,

HOMER, and Hybrid2 are generic software programs designed to optimize and analyze hybrid systems. These tools can be utilized for PV production level estimations and solar energy; they support resource side calculations [61]. PVsyst software program developed by Geneva University for studying, simulating, and designing photovoltaic systems. For this study, authors selected PVsyst software because it contains library offers thorough information on the very common photovoltaic modules, inverters, and other components needed for photovoltaic system projects. It also accounts for losses caused by shadowing, gaps between linked modules, inverter and wire losses, and the ambient temperature differences impact on the calculation of electrical power output. This characteristic builds it a good tool for

estimating the quantity of electrical energy produced by the system.

Internet survey: A comprehensive search of the internet for the latest prices on the key PV device parts, such as modules mounting structures, and inverters. In terms of module cost, survey covered the most used PV modules on the market, modules with high costs due to high performance being omitted to keep our prices more practical. Based on their efficiency, authors calculated a weighted average of module pricing to arrive at a single representative price. The survey result of LCC components of a PV plant (\$/Wp) as shown in Table 1 [62,63].

Table 1. Survey results of LCC’s components of a PV plant normalized to (\$/Wp) [66].

Cost Item	21MW	5MW	3.432MW	YL. Solar	1MW	Survey	Average (\$/Wp)
Development	0.054	0.072			0.060		0.062
PV Panels	0.634	0.628	0.594	0.44	0.531	0.4505	0.556
Inverter	0.107	0.124	0.126	0.15	0.100	0.1598	0.132
Electrical Parts	0.165	0.153	0.138	0.1	0.156		0.135
Rack steel	0.110	0.102		0.05	0.1	0.0710	0.087
Rack Installation	0.070	0.060			0.069		0.066
Civil & Installation	0.214	0.143			0.143		0.145
Total Investment	1.354	1.282					1.184
O&M	0.014	0.032					0.025

Meteorological Data: Solar PV system was designed using PV_{SYST} software, version 6.6.3. It is design and simulation software. It is being used globally and considered as standard for PV system design and simulation work. The solar photovoltaic (PV) system with partial load fulfillment was sized to offer electricity to fulfill energy demands of engineering campus University of Larkano. Initially, the geographical location and meteorological data collected by the meteorological department, Larkana, Sindh, Pakistan. Sizing of proposed PV system the annual average daily solar radiation of Larkana was obtained 5.5 to 5.8 kWh/m², Latitude angle is 27.53° North, and Longitudinal angle is 68.21° East. The remaining data , such as the average monthly sunshine hours and days for Larkana, are shown in Figure 4, regular monthly Ultraviolet index (UV) solar radiation is demonstrated in Figure 5, the average monthly temperature is presented in Figure 6, and monthly average rainfall is demonstrated in Figure 7 [64].

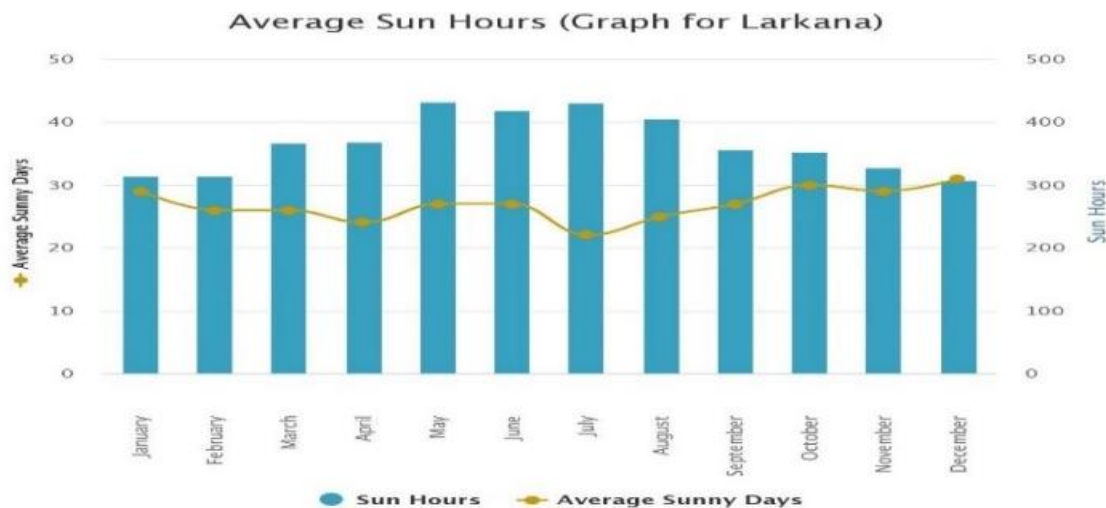


Fig. 4. Average monthly sunshine hours and days for Larkana.

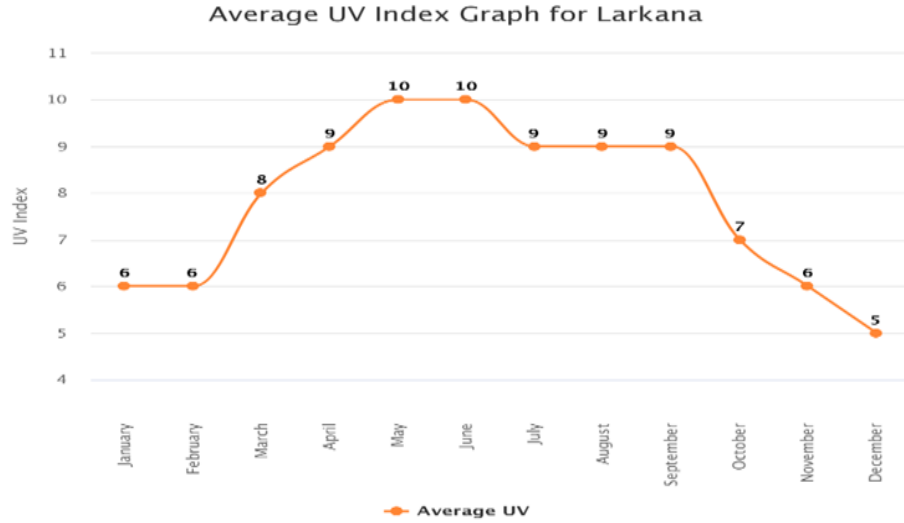


Fig.5. Average monthly Ultraviolet index solar radiation for Larkana.

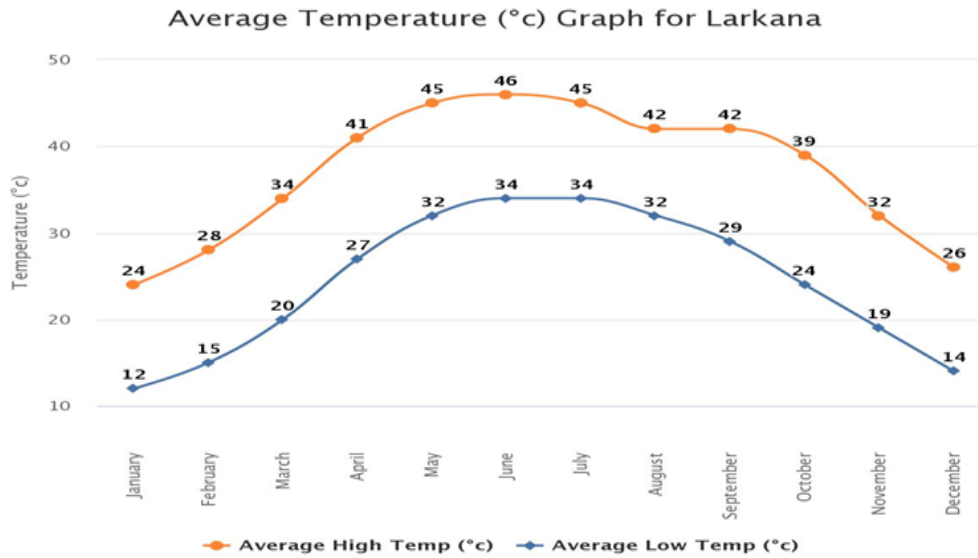


Fig. 6. Average monthly temperature for Larkana.

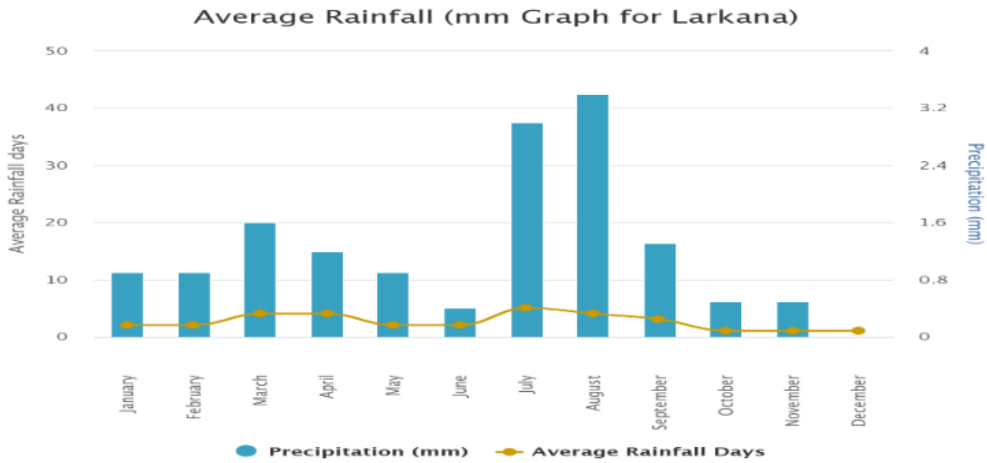


Fig. 7. Average monthly rainfall for Larkana.

After obtaining required meteorological data, it was then incorporated into the software, with energy load requirement of each building, investment cost, replacement, and maintenance cost to simulate the required results. The solar photovoltaic system was designed on Jinko solar, Model JKM 300M-60-V with 30 years life span and battery Volta 6SB100. Provision of the battery replacement lifetime is after every 4.9 years. The system was designed for one-day autonomy to provide electricity when there is no solar radiation. The electricity demand total connected load, base load, peak load, and average load were determined by conducting actual energy audit of each building of the campus. Electrical energy load was obtained by ratings of all light appliances and measuring voltage and current (V and I) within millimeters. According to the proposed system base load (to be shifted to solar PV System) and peak load (air conditioners, heavy machinery of entire labs of all departments will remain on SEPCO and Gen set). Likewise, the existing electricity demand and cost was determined from energy audit, utility bills, and fuel cost of diesel generators. Similarly, because of

unavailability of additional land space to install PV panels in the University of Larkano, it is proposed that standalone PV panels be installed on the rooftops of each building to meet the energy requirement. Likewise, reliability optimization of designed solar PV system was determined in terms of shading risk to determine various losses for example of Lu Unused energy (Full battery), Lc collection loss (PV array losses), Ls system losses and battery charging, and energy supplied to the user. Likewise, saving of carbon dioxide (CO₂) emissions, actual energy production during lifespan, performance ratio, payback period, LCOE, life cycle cost of solar PV system, average unit cost comparison with electricity purchased from Sukkur electric power company (SEPCO) and electricity generated from diesel generator sets in the campus. However, other input data needed for PVsyst software, such as the energy load requirement of each building shown in Table 2, and the PV module, battery and inverter specifications are shown in Table 3,4 and 5 respectively, and geographical site illustrated in Figure 8.

Table 2. Energy load requirement of each Department Building

Sr. No	Building/Departments	Load (kWh)/day
01	ME	73.59
02	ME (labs)	53.31
03	CE	58
04	EL	69.4
05	ES	68.6
06	BSRS	39.5
07	Admin block	72.8
08	Library	49

Table 3. Specifications of Standalone PV System module

PV module	
Model	Si-mono JKM 300M-60-V
Manufacturer	Jinko solar
PV module rated power	300 Wp
Operating conditions	50C ⁰
Voltage drops	0.7 V
Thermal loss factor	20.0 W/m ² K
Current at maximum power (Imp)	9.22A
Voltage at maximum power (Vmp)	32.6V

Table 4. Specifications of Battery

Battery	
Model	Volta 6SB100
Manufacturer	Volta
Voltage	48 V
Operating conditions	30C ⁰

Table 5. Specifications of Invertor

Invertor	
Model	MPPT
Efficiency	97%
Charging	53.6 / 50.1 V
Discharging	47.2 / 48.9 V

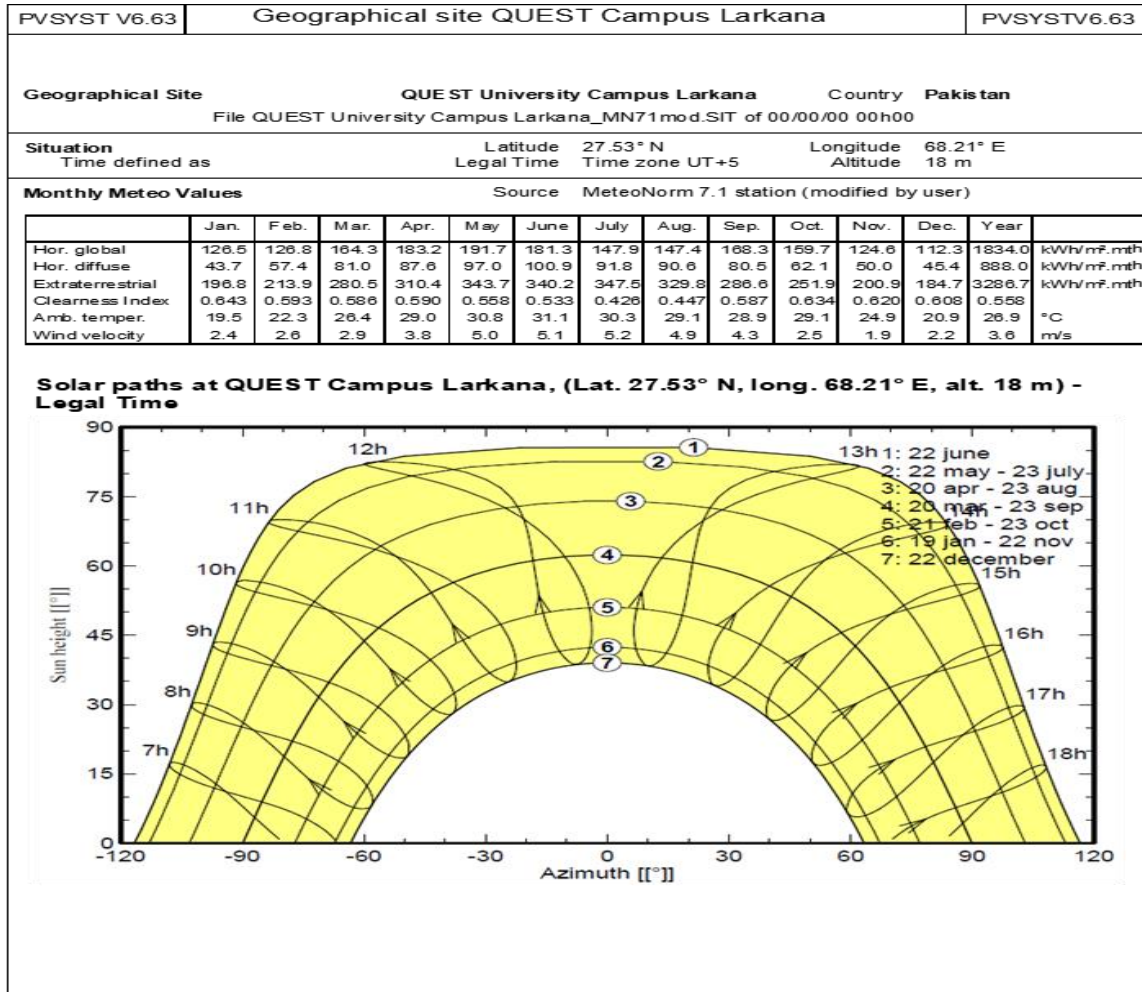


Fig. 8. Geographical site of The University of Larkano

RESULTS AND DISCUSSION

The performance and detailed overview of the results, including PV panels required, required batteries, nominal power, Lu Unused energy (Full battery), Lc collection loss (PV array losses), Ls system losses and battery charging, and energy supplied to the user, saving of CO₂ emissions, total energy available and the annual production of the PV system for each building are presented in this section. Therefore, there are twelve different buildings are present in Engineering Campus, the Mechanical Engineering Department (ME), civil engineering department (CE), electrical engineering

department (EL), electronic engineering department (ES), basic sciences and related studies (BSRS), administration block and library Simulation results of all the buildings are given as follows:

PVsystr software results: A total 66 number of photovoltaic modules with a nominal power of 19.80kWp and 72 batteries are required to be installed in the department of the ME building. In resulting Figure 9, shows the result of ME building, such as unused energy (full battery) loss 1.66kWh/kWp/day, losses in PV array 0.94 kWh/kWp/day, battery charging and losses of system 0.36kWh/kWp/day, energy delivered to the user 2.6kWh/kWp/day, performance ratio 46.72%, and solar

fraction 97.8%. Likewise, 44 solar modules with nominal power of 13.20kWp, and 56 number of batteries required to be installed in CE department building. While unused energy (full battery) loss 1.12kWh/kWp/day, losses of PV 0.94kWh/kWp/day, battery charging and system losses 0.51kWh/kWp/day, and energy provided to the user 2.99kWh/kWp/day, performance ratio of 53.83%, and solar fraction 95.3% are shown in Figure 10. In the EL department building, 64 solar modules with nominal power of 19.20kWp, and 68 batteries are required to be installed. Moreover Figure 12, explaining the results of EL building such as unused energy (full battery) loss 1.71kWh/kWp/day, PV losses 0.94kWh/kWp/day, battery charging and system losses 0.38kWh/kWp/day, energy supplied to the customer 2.53kWh/kWp/day, performance ratio of 45.5%, and solar fraction 97.9%. Likewise, the ES department requires the installation of 52 number of photovoltaic modules with a nominal power of 15.60kWp, and 68 batteries. In resulting, unused energy (full battery) loss 1.1kWh/kWp/day, PV losses 0.94kWh/kWp/day, battery charging and system losses 0.48kWh/kWp/day, and energy supplied to the user 3.04kWh/kWp/day, performance ratio of 54.7%, and solar fraction 96.7% are shown in Figure 13. In the BRSR

department building, 32 solar modules with nominal power of 9.60kWp, and 40 batteries are required to be installed. However, Figure 14 explains the results of BRSR building such as unused energy (full battery) loss 1.28kWh/kWp/day, losses of PV array 0.94kWh/kWp/day, battery charging and system losses 0.47kWh/kWp/day, and energy given to the user 2.88kWh/kWp/day, performance ratio of 51.7%, and solar fraction 97.5%. In the admin building 54 solar modules with nominal power of 16.20kWp, and 72 batteries required to be installed. While unused energy (full battery) loss 1.04kWh/kWp/day, PV losses 0.94kWh/kWp/day, battery charging and losses system of 0.47kWh/kWp/day, and energy supplied to the user 3.11kWh/kWp/day, performance ratio 55.9% and solar fraction 96.8% are shown in Figure 15. Similarly, Library building requires the installation of 38 number of photovoltaic modules with a nominal power of 11.40kWp, and 48 batteries. In resulting, unused energy (full battery) loss 1.29kWh/kWp/day, PV losses 0.94kWh/kWp/day, battery charging and losses of system 0.35kWh/kWp/day, and energy transferred to the user 2.99kWh/kWp/day, performance ratio of 53.7%, and solar fraction 97.1% are shown in Figure 16.

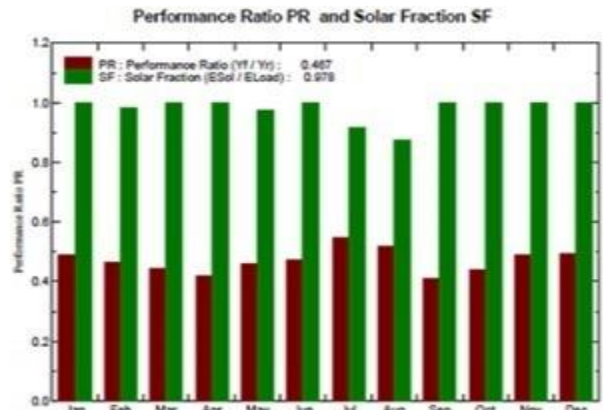
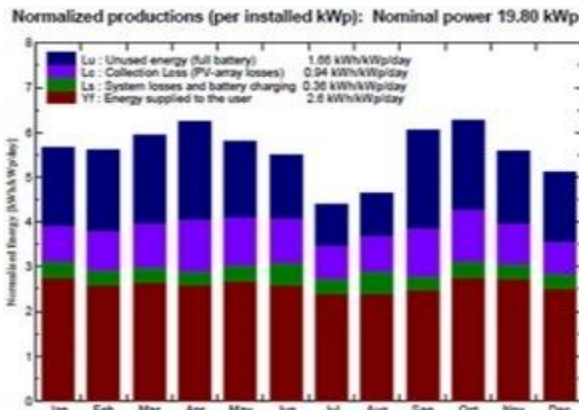


Fig.9. Solar production, fraction, and performance ratio for ME Dept

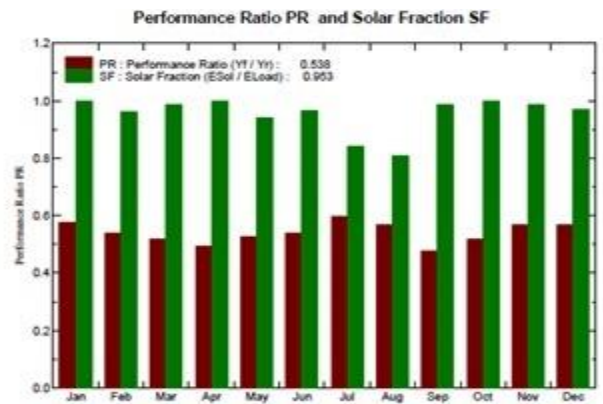
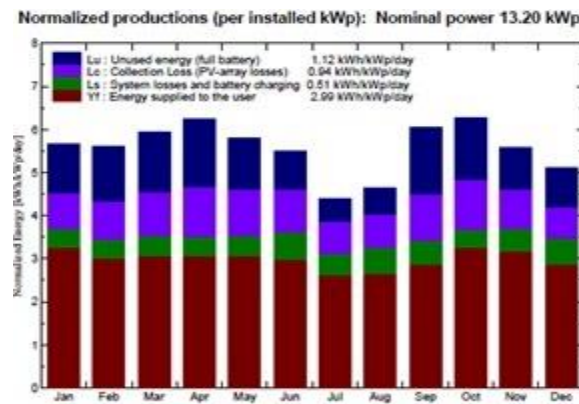
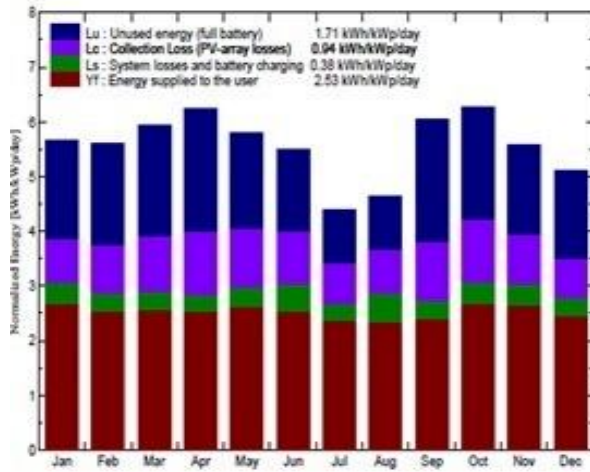


Fig.10. Solar production, fraction, and performance ratio for CE Dept

Normalized productions (per installed kWp): Nominal power 19.20 kWp



Performance Ratio PR and Solar Fraction SF

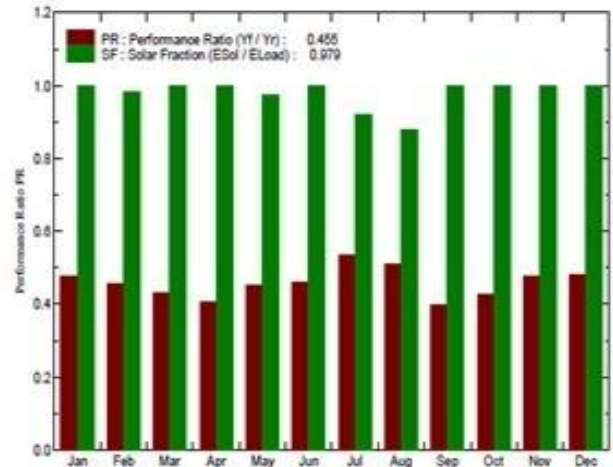
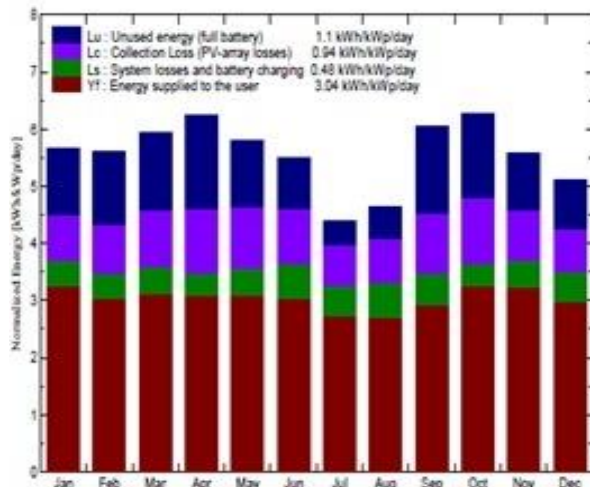


Fig. 11. Solar production, fraction, and performance ratio for EL Dept

Normalized productions (per installed kWp): Nominal power 15.60 kWp



Performance Ratio PR and Solar Fraction SF

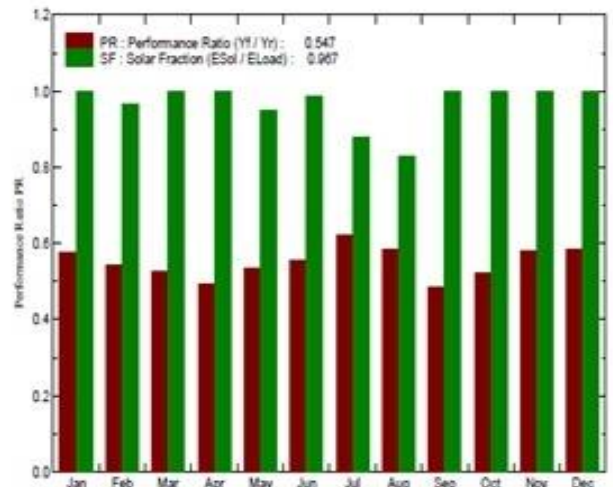
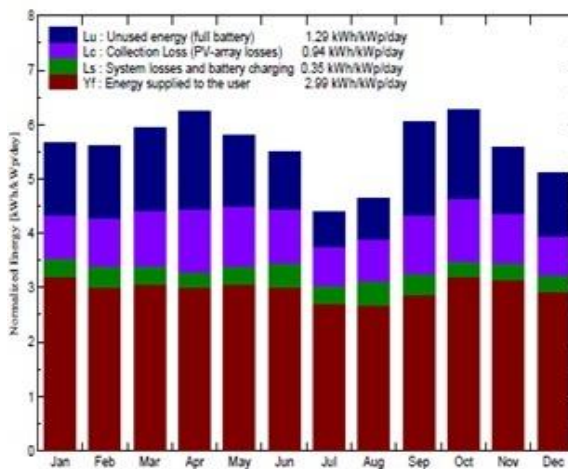


Fig. 12. Solar production, fraction, and performance ratio for ES Dept

Normalized productions (per installed kWp): Nominal power 11.40 kWp



Performance Ratio PR and Solar Fraction SF

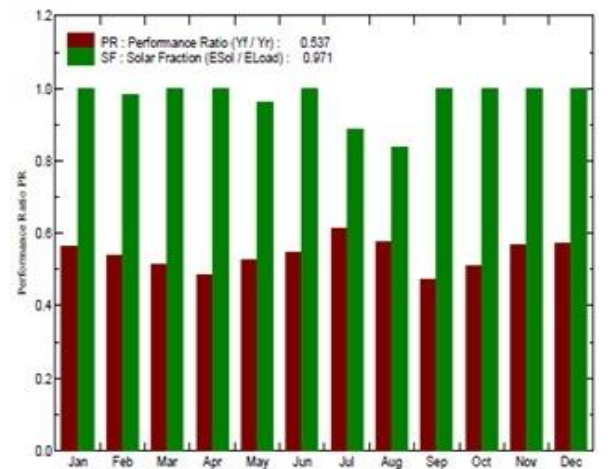


Fig. 13. Solar production, fraction, performance ratio for BSRs Dept

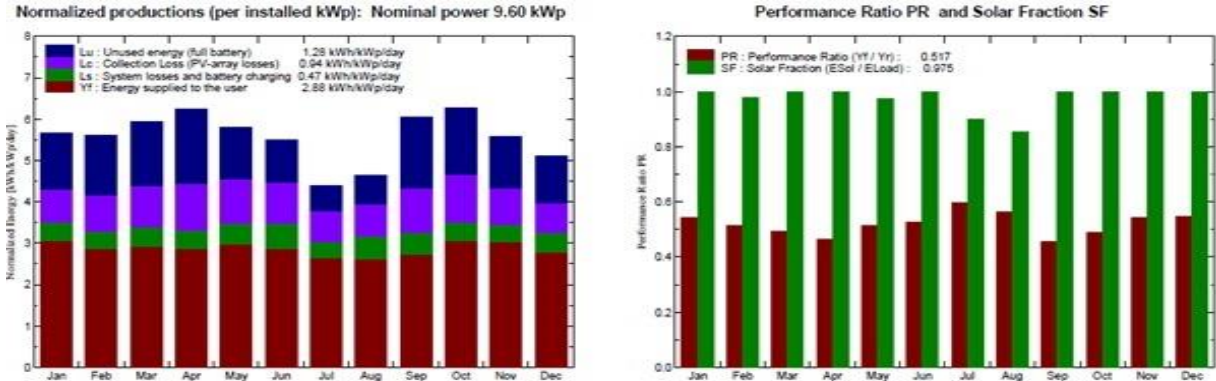


Fig. 14. Solar production, fraction, and performance ratio for Library

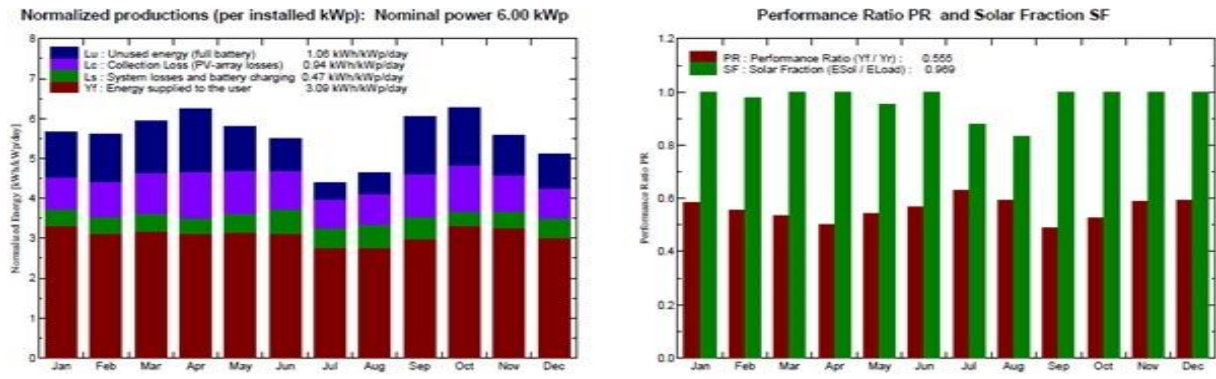


Fig. 15. Solar production, fraction & performance ratio for Admin Block

PVsyst software results of CO₂ Balance: The solar electrification of the proposed PV system during its 30yrs lifespan would approximately save 199 tons of CO₂ for ME department building, 200.3 tons of CO₂ for CE building, 323.8 tons of CO₂ for EL department building,

260.3 tons of CO₂ for ES department as demonstrated in Figure 16, and Figure 17 respectively. Similarly, the solar electrification of the Administration block would save 270 tons of CO₂, Library building would save approximately 190.9 tons of CO₂, as shown in Figure 18.

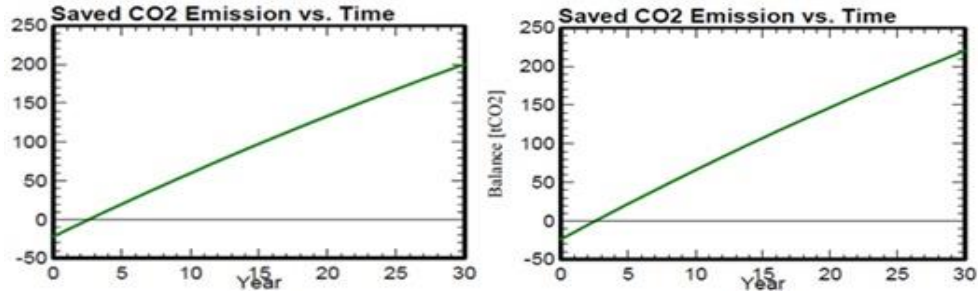


Fig. 16. CO₂ balance for ME & CE Departments

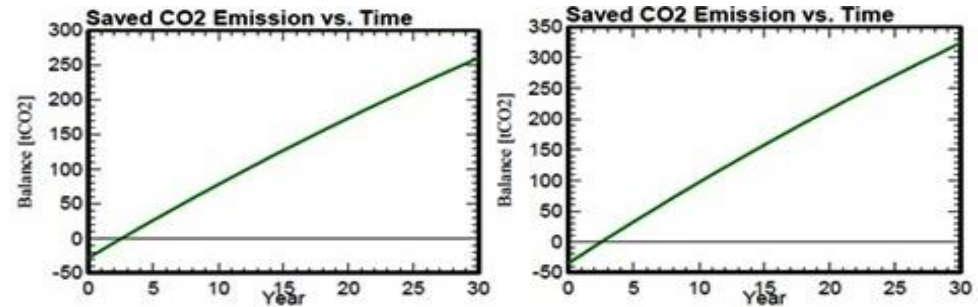


Fig. 16. CO₂ balance for EL & ES Departments

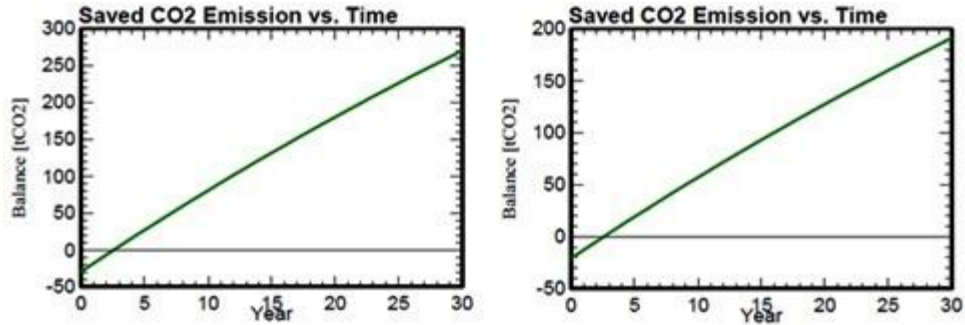


Fig. 17. CO₂ balance for Admin & Library Buildings

Reliability of PV System: The Solar PV system reliability was determined in terms of shading risk to determine various losses of PV module for example of Lu Unused energy (Full battery), Lc collection loss (PV array losses), Ls system losses and battery charging, and energy supplied to the user after accounting for these losses, saving of CO₂ emissions, payback period, levelized cost of energy (LCOE), life cycle cost of solar PV system, actual energy production during lifespan, average unit cost, and performance ratio. Furthermore, the present electricity situation was analyzed and compared with the proposed PV system unit cost. Finally, it was discovered from the results that the proposed PV system is reliable, efficient, and acceptable. Results showed that all the buildings of the Engineering Campus required 178.8kWp PV system, with 596 modules that

will produce 8573.25MWh during a 30 yrs. lifespan. Similarly, when all sorts of energy losses are considered, the total energy supplied to the end user was obtained 201.32MWh/yr, with an average unit cost 0.06 USD\$/kWh, and performance ratio acquired 55.51% which is satisfactory. In addition, the proposed solar PV system electrification will approximately save 2,968.9 tons of carbon dioxide CO₂ throughout its lifetime, with a payback period of 8.5 years, LCOE of 0.032 US\$/kWh, LCC of 275,191 US\$. Reliability optimization of designed photovoltaic (PV) system for each building of the campus is shown in Table 6. Likewise, electricity purchased from SEPCO is 2.5 times and electricity generated from diesel generators sets 3.33 times more expensive than proposed solar photovoltaic unit energy cost are demonstrated in Table: 7,8 and Table:9.

Table 6. Reliability of designed photovoltaic (PV) system

Buildings	PV modules Required	Investment cost (US\$)	E production (kWh/yr)	E Used (kWh/yr) After accounting losses	E Unit cost US\$/kWh	CO ₂ saving/30yrs Lifespan (tons)	Performance (ratio%)
ME	66	15259	31900	18750	0.07	332.5	46.7
ME (Labs)	40	9123	19168	13474	0.05	200.3	55.3
CE	44	9911	21090	14428	0.06	220.4	53.8
EL	64	20290	30960	17751	0.09	323.8	45.5
ES	52	11471	24910	17330	0.05	260.3	54.7
BSRS	32	10446	15383	10078	0.08	160.8	51.7
Admin block	54	11908	25847	18394	0.05	270	55.9
Library	38	8693	18266	12440	0.06	190.9	53.7
Cafeteria	20	5438	9589	6766	0.06	100.2	55.5
Camp house	42	12281	19850	17980	0.05	190.8	70.3
Faculty hostel	72	17489	34445	24931	0.06	359.90	56.8
Student hostel	72	14385	34367	29003	0.04	359.0	66.1
Total	596	1,46,694	2,85,775	201,325	Avg: 0.06	2,968.9	Avg: 55.5

PV System payback period

$$\begin{aligned} \text{Payback period} &= \frac{\text{Investment cost}}{\text{Yearly energy saving cost}} \\ &= \frac{146,694}{17,146.5} = 8.5 \text{ yrs} \\ &= \frac{\text{Yearly Energy Saving cost}}{\text{Avg. cost of electricity}} \\ &\quad \times \text{yearly energy production} \\ &= 0.06 \times 285775 = 17,146.5 \text{ US\$} \end{aligned}$$

Levelized Cost of Energy (LCOE)

$$\begin{aligned} \text{LCOE} &= \frac{\text{Life cycle cost (LCC)}}{\text{Life cycle energy produced}} = \frac{275,191}{8,573,250} \\ &= 0.032 \text{ US\$/kWh} \\ \text{Life cycle energy produced} &= 285775 \times 30 \text{ yrs lifespan} = \\ &= 8573250 \text{ kWh} = 8573.25 \text{ MWh} \end{aligned}$$

Life cycle cost (LCC)

$$\begin{aligned} \text{LCC} &= \text{CInvestment} + \text{CReplacement} \\ &\quad + \text{CMaintenance} \\ &= 146,694 + 48,485 + 80,017 = 275,191 \text{ US\$} \end{aligned}$$

Analysis of present electricity: The present electricity demand and expenses of the engineering campus, university of larkano were determined by the energy bills, fuel costs of diesel generators and production. The main electricity provider in the campus is Sukkur electric power company (SEPCO) with a total unit consumption of 130,960kWh/year with incurred cost 20,469.33US\$/year and unit energy cost 0.15US\$/kWh as shown in Table 7. Similarly , two diesel generator sets are providing supplementary electricity at the time of load shedding hours with a total energy unit production 130,369.50kWh/yr with the total cost of 26073.9US\$/year, and unit energy cost 0.20US\$/kWh as shown in Table 8. It is obvious from the results that the energy generated from the diesel generator set is more expensive than SEPCO.

Table 7. Energy unit (kWh) cost of SEPCO

Energy consumption by SEPCO (kWh/Yr)	Energy cost in (US\$/Yr)	Energy unit cost (US\$/kWh)
130,960 kWh/yr	20469.33	0.15

Table 8. Energy Unit running (kWh) cost of diesel generators

Energy production cost of Genset (kWh/Yr)	Energy cost in (US\$/Yr)	Energy unit cost (US\$/kWh)
130,369.50 kWh/yr	26073.9	0.20

Comparison of present electricity and PV system

cost: The proposed solar photovoltaic system (PV) cost is compared with the existing electricity cost purchased from SEPCO and diesel generator sets illustrated in Table 9. It was determined from the assessment that the electricity purchased from SEPCO is 2.5 times and electricity generated from diesel generator sets 3.33 times more expensive than proposed solar photovoltaic unit energy cost.

Table 9. Proposed Solar PV system unit cost difference comparison to SEPCO & Diesel Gen set

Energy source	Unit cost	Difference
	(US\$/kWh)	%
Solar PV system	0.06	1
SEPCO	0.15	2.5
Diesel Generator set	0.20	3.33

Conclusion and Future Recommendations: The present study aimed to investigate and propose a solar photovoltaic (PV) system for supplying electricity to meet energy demand at the time of load shedding while also lowering the operating cost of installed diesel generators that are used for backup during load shedding at the University of Larkano Sindh, Pakistan. In order to achieve the objective various possible options of electricity supply were investigated like wind, biomass, and solar. It was concluded that due to lack of land space, high capital cost and other limitations like average wind speed of Larkana was 1.38 m/s which is not sufficient to generate electricity, biomass which is not readily available and required large space for storage. Finally standalone roof mounted solar photovoltaic (PV) system was proposed to meet the objective of the study, because annual average solar radiation of site was 5.5 to 5.8kWh/m², it has low capital cost, is reliable, and easy to install on the roof for various buildings of University of Larkano. According to primary findings of the research, the proposed solar PV system is reliable, efficient, and best alternative solution to offer electrical power to address the load shedding problem, meet the required energy demand and cut the running expense of existing diesel generators. The total energy requirement of light appliances for replacement with solar PV was determined to be 717.94 kWh/day. In this regard, PVsyst software version 6.6.3 was used for the design of photovoltaic (PV) system to determine the number of required photovoltaic modules, and number of batteries required for storage as to supply electrical power with an adequate level of safety. Likewise, reliability optimization of designed solar PV system was assessed in terms of shading risk to determine various losses of PV module for example of Lu Unused energy (Full battery), Lc collection loss (PV array losses), Ls system losses and battery charging, and energy supplied to the user after accounting for these losses, saving of CO₂ emissions, payback period, LCOE, LCC of solar PV system, actual energy production

during lifespan, average unit cost, and performance ratio. Likewise, present electricity cost was analyzed in terms of electricity purchased from Sukkur electric power company (SEPCO) and electricity generated from diesel generator sets in the engineering campus and compared with proposed PV system unit cost. The major findings of the study revealed that all buildings of the campus require 178.8kWp PV system, with 596 modules that will produce 8573.25MWh during a 30 yrs. lifespan. Similarly, when all sorts of energy losses are considered, the total energy supplied to the end user was obtained 201.32MWh/yr, with average unit cost 0.06USD\$/kWh, and performance ratio acquired 55.51% which is satisfactory. In addition, the proposed solar PV system electrification will approximately save 2,968.9 tons of carbon dioxide CO₂ throughout its lifetime, with a payback period of 8.5 years, levelized cost of energy of 0.032 US\$/kWh, LCC of 275,191 US\$. Likewise, electricity purchased from SEPCO is 2.5 times more expensive than suggested solar PV system unit cost, while electricity generated from diesel generator sets is 3.33 times more expensive. For future recommendations studies on other software's may be carried for designing and sizing solar photovoltaic systems along with energy storage options for comparison and selection of alternatives, and automatic control system of connection shifting may be available and arranged for smooth working. The feasibility study for the possible replacement of diesel generators with natural gas generators may be conducted on the engineering campus, and classical electrical appliances may be replaced with latest energy saving appliances to save energy and cost. When it comes to the scope and justification of this study in terms of Pakistan & global context, Solar photovoltaic (PV) systems are feasible solutions to supply electricity to the educational institutions. This is the cleanest energy source, and available in daytime when demand is high. The institutions are working in daytime when the sun is at zenith and give plenty of solar energy. Solar photovoltaic is a source of green energy and provides utilizable energy with less or negligible environmental damage.

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