Journal of Computing & Biomedical Informatics
ISSN: 2710 - 1606

Volume 07 Issue 02
2024

Research Article
https://doi.org/10.56979/702/2024

Reducing Carbon Emissions and Costs of Electricity with Solar PV Systems in QUEST Nawabshah, Pakistan Administration Building

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Received: May 23, 2024 **Accepted**: August 21, 2024 **Published**: September 01, 2024

Abstract: The ongoing electricity crises in Pakistan have led to significant uncertainty and increased costs associated with fossil fuels. This circumstance substantially challenges the country in meeting its escalating electricity demands. This study focuses on the Techno-Economic Feasibility of implementing Solar Photovoltaic (PV) systems for the administrative building of Quaid-e-Awam University of Engineering, Science, and Technology (QUEST), Nawabshah in Pakistan. The primary objectives of this research include evaluating the design feasibility of solar PV systems, analysing the building's electricity consumption sourced from grid and diesel generators, and conducting a comprehensive cost-benefit analysis. The study calculates the levelized cost of electricity (LCOE) and introduces the concept of net metering to assess its potential benefits. Findings from this research indicate that the annual carbon emissions from the building due to grid electricity usage amount to 220,614 kg of CO_2. In contrast, adopting solar PV systems would result in zero carbon emissions. The LCOE for the solar PV system is determined to be 33.7 Rs/kWh, providing a fixed cost of solar-generated electricity over the lifespan of the solar plant. The analysis also highlights the effectiveness of net metering in promoting the adoption of solar PV systems by enabling surplus energy to be fed back into the grid, thereby offering financial incentives. Results of this study underscore the viability and benefits of investing in solar energy, particularly in the context of rising energy demands and environmental concerns. The findings advocate the transition to solar power as a sustainable and economically feasible solution for reducing reliance on fossil fuels and mitigating carbon emissions in university administrative buildings.

Keywords: Solar Photovoltaic (PV) Systems; Techno-Economic Feasibility; Carbon Emissions Reduction; Net Metering; Levelized Cost of Electricity (LCOE).

1. Introduction

Pakistan is facing an acute energy crisis characterised by high costs and limited availability of fossil fuels. The country's reliance on non-renewable energy sources has led to frequent power shortages, affecting security, economic growth and quality of life. With a significant portion of the population still lacking access to electricity, a sustainable and cost-effective energy solution is paramount [1]. Recent studies highlight the vast potential of renewable energy in Pakistan, particularly solar photovoltaic (PV) systems, which can be crucial in addressing the country's energy challenges. Pakistan's location offers high solar irradiance, making it an ideal candidate for solar energy exploitation [2]. Despite this potential, the adoption of solar PV systems has been slow due to various socio-economic and political barriers [3].

The Quaid-e-Awam University of Engineering, Science, and Technology (QUEST) in Nawabshah presents a valuable case study for the techno-economic feasibility of solar PV systems in educational institutions. This study aims to evaluate the potential benefits of implementing a solar PV system in the university's administration building, focusing on design feasibility, electricity consumption, levelised cost of electricity (LCOE), and the impact of net metering.

The university can significantly reduce its carbon footprint and operational costs by transitioning to solar PV. Current research indicates that solar PV systems can reduce carbon emissions to zero and stabilise electricity costs at a fixed rate over the system's lifetime [4]. Furthermore, implementing net metering can provide financial incentives by allowing surplus electricity to be fed back into the grid, thus encouraging the broader adoption of solar PV systems [5]. This research underscores the necessity of investing in renewable energy infrastructure, particularly solar PV systems, to meet Pakistan's rising energy demands. The findings advocate for policy reforms and strategic investments to effectively harness the country's renewable energy potential and ensure a sustainable and economically viable future.

2. Literature Review

Pakistan has made significant strides in adopting solar power generation over the past decade. The Alternative Energy Development Board (AEDB), operating under the Ministry of Energy, spearheads the development of the country's renewable energy sector. The Planning Commission and Pakistan Engineering Council launched Pakistan’s first on-grid solar power station with assistance from the Japan International Cooperation Agency (JICA). This initiative, titled "Introduction of Clean Energy by Solar Electricity Generation System," resulted in the installation of 178.08 kW Photovoltaic (PV) Solar Systems at the Planning Commission and Pakistan Engineering Council’s buildings, with a total generating capacity of 356 kW. This project marked a milestone as it introduced net metering, allowing the sale of surplus electricity to the grid, a first for solar projects in Pakistan [6]. Further expanding on this progress, the Government of Punjab initiated the Quaid-e-Azam Solar Park in Bahawalpur of 100 MW electrical power capacity through 392,158 solar modules of 255W each in its first phase [3].This project contributes to the national grid and sets a precedent for large-scale regional solar energy projects.

2.1. Advantages of Solar PV Systems

Solar PV systems offer numerous environmental and economic benefits. Unlike traditional energy sources, solar power generation does not emit harmful pollutants locally, thus reducing air and water pollution. This clean energy source also mitigates the depletion of natural resources and poses no risks to human or animal health [7]. Solar PV systems are versatile and can be installed on rooftops, utilising unused space and scaling according to energy needs.

Solar energy is a locally available resource, reducing fuel transportation's environmental impact and decreasing dependence on expensive imported oil. This local availability ensures a more sustainable energy supply and, crucially, contributes to energy security [8]. Moreover, the flexibility of PV systems allows for incremental expansion, which can be particularly advantageous for homeowners and businesses as their energy needs and financial resources grow [9].

Previous Studies on Solar PV Systems

Numerous studies have evaluated the feasibility and benefits of solar PV systems in various contexts within Pakistan. For instance, a study [10] conducted at Bahria University in Islamabad proposed a grid-interactive rooftop solar PV system. The study highlighted significant carbon footprint reductions and demonstrated the economic benefits of solar PV power, showing annual carbon footprints of 296,131 $kgCO_2e$ from grid electricity and 57,640 $kgCO_2e$ from diesel generators, while solar panels exhibited zero emissions.

Another study by Shah, Valasai [11] focused on the rural areas of Balochistan, where on-grid electrification is prohibitively expensive. The study revealed that off-grid solar PV systems could provide electricity for Rs. 7.98 per kWh, significantly cheaper than conventional electricity at Rs. 20.79 per kWh, and could mitigate 126,000 metric tons of CO_2 annually if widely adopted [12]. In Cambodia, Chhim, Ketjoy and Suriwong [13] conducted a techno-economic analysis of a PV battery charging station. The study found that c-Si PV modules presented higher NPV, IRR, and a shorter payback period than diesel battery charging stations, making solar PV a viable option for rural electrification.

Manoj Kumar, Sudhakar and Samykano [14] analysed a 1 MW grid-connected solar PV plant in Malaysia, demonstrating that such plants could generate substantial electricity with significant greenhouse gas emission reductions [15]These findings are relevant to Pakistan's context, emphasizing the feasibility and environmental benefits of large-scale solar PV installations.

2.2. Solar PV in the Public Sector

Solar PV systems, often combined with battery storage and LED facilities, are widely used to provide lighting for billboards, highway signs, public facilities, parking lots, and remote communication stations. These systems reduce the dependency on generators, lowering operational costs and environmental impact [16]. In the agricultural sector, solar PV systems are used for water pumping, supplying water directly to fields or for storage. Electric vehicles can also be charged at PV-powered stations, maintaining critical battery levels using solar energy [17]. Additionally, small DC appliances such as toys, watches, calculators, and radios can operate on solar PV energy, showcasing the versatility of this technology.

2.3. Recent Research and Developments

Recent studies continue to explore the potential of solar PV systems in Pakistan. For example, a feasibility study for a PV system in Southern Pakistan concluded that solar PV could provide reliable and cost-effective energy with significant environmental benefits [18]. Similarly, a techno-economic feasibility analysis conducted by Mehmood, Waqas and Mahmood [19] in major cities of Pakistan demonstrated that stand-alone PV systems are financially viable and can save substantial amounts on conventional fuel costs [19].

Another significant contribution to the literature is the techno-economic feasibility study of a hybrid solar-biomass off-grid system for rural electrification in Pakistan. This study highlighted the potential of hybrid systems to efficiently and sustainably meet the energy needs of remote agricultural and residential communities [15]. The literature overwhelmingly supports the potential and feasibility of solar PV systems as a sustainable energy solution for Pakistan. Solar energy's advantages, such as reducing carbon emissions, ensuring energy security, and providing cost-effective electricity, make it a viable alternative to traditional fossil fuels. The studies reviewed emphasise the importance of continued investment in solar PV infrastructure, policy support, and public awareness to harness the full potential of this renewable energy source.

This extensive body of research highlights solar PV systems' critical role in addressing Pakistan's energy crisis, reducing environmental impact, and promoting sustainable economic development.

3. Methodology

The Nawabshah area exhibits significant promise for renewable energy sources like solar, wind, and biomass. Regrettably, substantial initiatives and research endeavours have been lacking in this domain. A research investigation was conducted at the Administration Block of Quaid-e-Awam University, Nawabshah, to evaluate the feasibility of solar power, as illustrated in Figure through a flowchart.

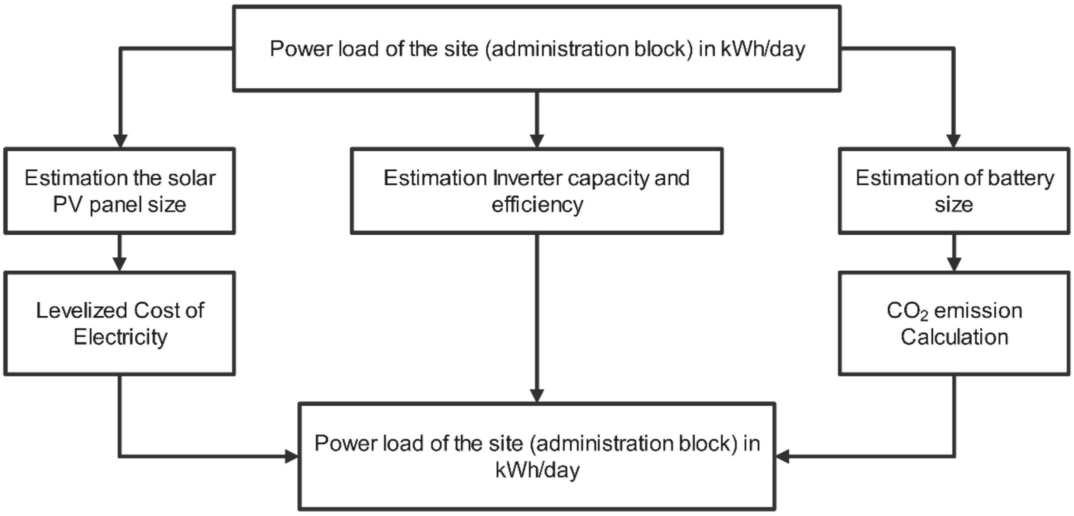

Figure 1. Methodology Flow Chart

3.1. Study area

The research study site is at Quaid-e-Awam University Nawabshah, at latitude 26.2395 and longitude 68.4034. Figure depicts this location, with the red box indicating the site's position at the Administration Block.

3.2. Sizing of Solar PV and Battery Storage

A typical off-grid photovoltaic (PV) system comprises essential components such as a PV module, system controller, battery storage, DC to AC inverter, and load. The PV panels capture solar energy, convert it to DC, and transmit it to the system controller. Subsequently, the DC power is utilised to supply the load through a DC-AC inverter. The local solar radiance significantly influences the electricity generation of a PV system. One of the critical aspects of designing a PV system is accurately estimating the load the system must support. This can be determined by compiling a list of required appliances, their power ratings (W), the duration of operation, and summing up the kilowatt-hours per day, which in this case is 809.1 kWh/day. Solar energy is only accessible during daylight hours when the sun is shining. Therefore, electricity storage solutions like battery units are indispensable to ensure a consistent power supply, especially during night time and cloudy weather.

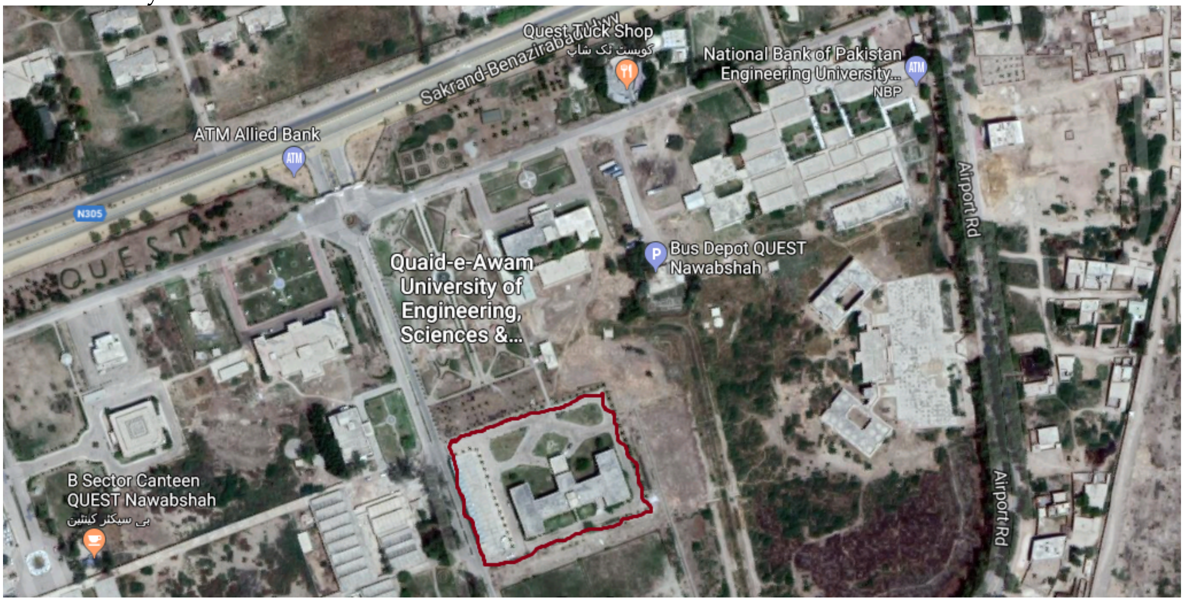

Figure 2. Administration block QUEST Nawabshah

3.3. Data Sources

The electrical devices utilised within the QUEST Administration Block exhibit varying power consumption levels. Some devices, such as air conditioners and photocopy machines, fall into the category of high-power consumption equipment. In contrast, fans, computers, printers, heaters, water dispensers, microwave ovens, scanners, water coolers, and sound systems, operate within the low to intermediate power consumption range as depicted in Figure 3.

The data collection site is situated in the administration block. The lighting arrangements in the rooms are tailored according to each room's specific area. Upon visual inspection, it is evident that the rooms are equipped with a combination of tube lights and energy-efficient bulbs. The room inventory comprises 82 tube lights, 31 high-energy-saving bulbs, and 139 small energy-saving bulbs, as illustrated in Figure 4.

3.4. Data Collection Related Issues

In the data collection process, challenges were encountered, which are outlined as follows:

- Appliance data was gathered through a visual inspection of all rooms within site, specifically the administration block.
- Detecting the tonnage of air conditioning units visually proved to be impossible. The tonnage typically ranges from 1 to 2 tons, and an electrical technician's assistance is required to determine each air conditioning unit's tonnage accurately.
- Different computer components, such as the CPU, keyboard, monitor, and mouse, possess varying power requirements, necessitating calculating their average power consumption.

- Within the administration block, the computers utilised consist of various CPU Pentium models with distinct power consumption levels. Therefore, the average power consumption of each CPU Pentium model was determined.

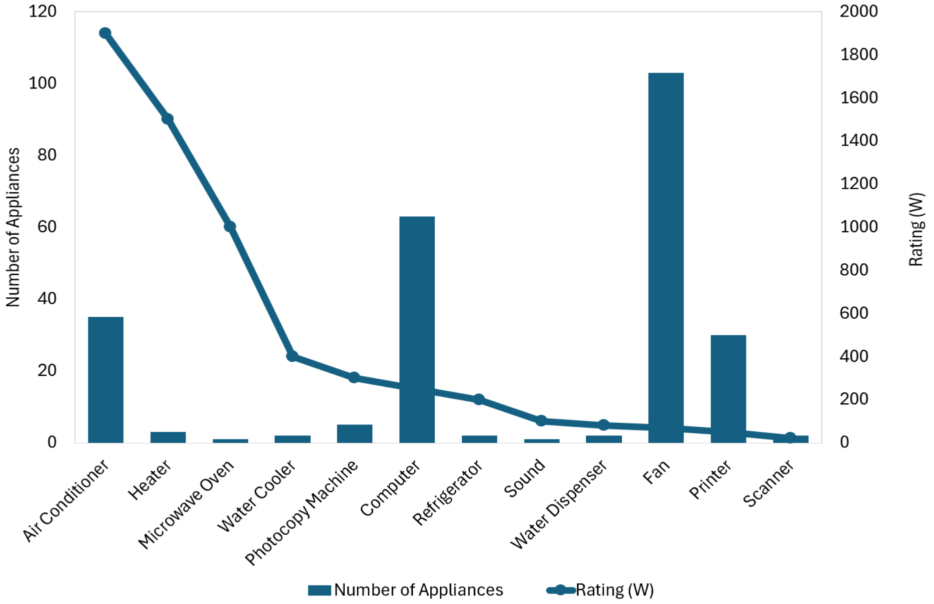

Figure 3. Administration Building Appliances Load

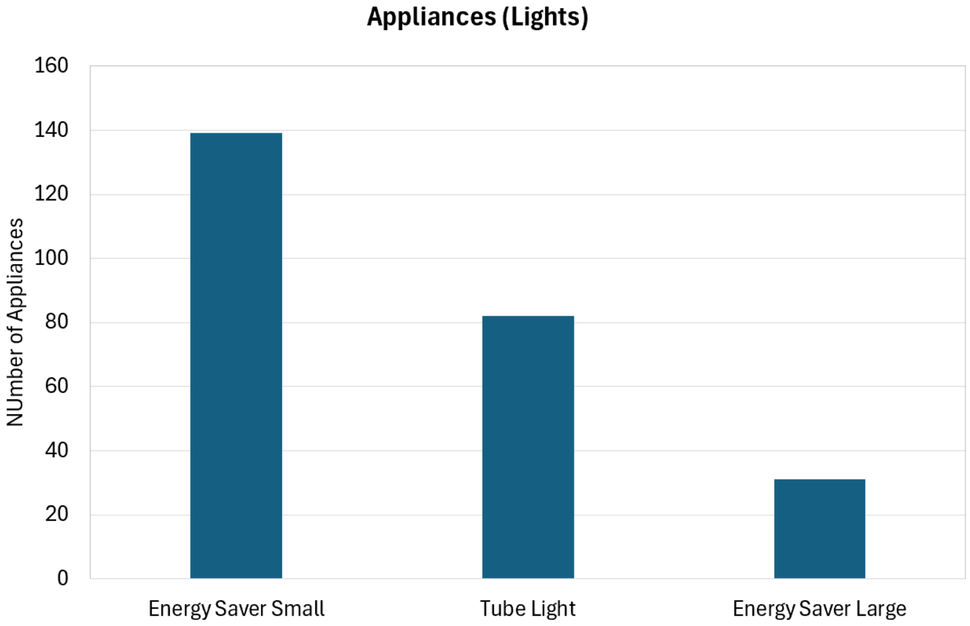

Figure 4. Administration Building Appliances (Lights)

- All collected data will be converted into kilowatt-hours (kW-hr) for standardisation. Subsequently, the electrical bills will be cross-referenced, with noticeable variations observed in certain months due to load shedding by the electricity provider, WAPDA.

3.5. Potential of Solar Energy

The solar energy potential encompasses three distinct aspects related to solar photovoltaic (PV) systems: solar PV potential, technical potential, and economic potential. The solar PV potential pertains to the solar radiation reaching the Earth. The technical potential quantifies the energy that could be produced by deploying PV systems on all suitable roof surfaces. The economic potential reflects the reduced costs of silicon cells, which convert sunlight into electricity.

3.5.1. Solar Photovoltaic potential

Solar radiation reaches the Earth, amounting to 174 petawatts (PW) of energy, with nearly one-third reflected in space. The remaining energy, totalling 3,850,000 exajoules (EJ) annually, is absorbed by various elements like the atmosphere, clouds, oceans, and land. This absorption is equivalent to the world's energy consumption for an entire year in just one hour [20]. The data from NASA at the Nawabshah district shows the annual clearness index is 0.58 and the yearly average (kWh/m²/ day) is 4.71 as shown in Figure [21].

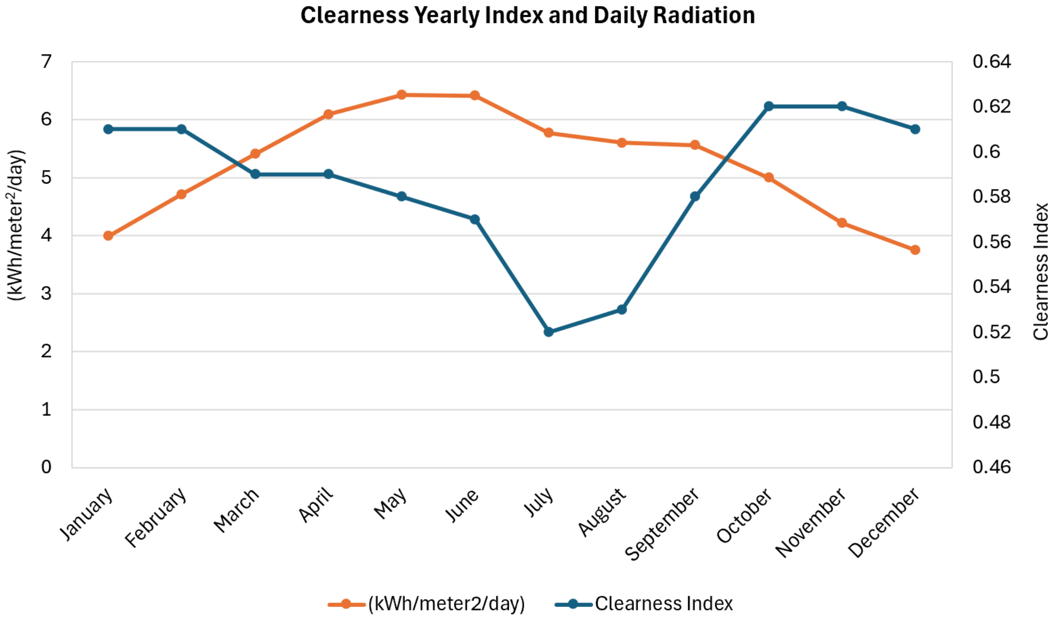

Figure 5. Clearness yearly index and daily radiation at Nawabshah [21]

3.5.2. Solar Photovoltaic Technical Potential

The technical potential of rooftop photovoltaic (PV) systems involves estimating the energy generation capacity achievable by installing PV systems on all suitable roof areas. The methodology entails utilising light detection and ranging (lidar) data, geographic information system (GIS) techniques, and PV generation modelling to assess the suitability of rooftops for PV installation. This analysis is then expanded from lidar-covered regions to encompass the entire continental United States. Statistical models are developed for small, medium, and large buildings, incorporating geographic variables correlating with rooftop PV suitability.

The accuracy of these models is evaluated by comparing their estimates with the results obtained from lidar-covered areas. Subsequently, the rooftop suitability is translated into PV generation potential, aggregating the estimates for small, medium, and large buildings to present a nationwide overview of the technical potential for rooftop PV systems. The analysis relies on lidar and building footprint datasets processed to determine shading, tilt, and azimuth for each rooftop at a horizontal resolution of one square meter [22].

3.5.3. Solar Photovoltaic Economical Potential

Solar photovoltaic (PV) power has become a prominent trend in renewable energy generation due to the significant reduction in the costs of silicon cells that convert sunlight into electricity. This economic advancement has sparked debates on the optimal deployment strategies for this technology. Previously, solar energy systems were predominantly accessible to affluent or dedicated individuals. However, with the substantial decrease in costs, solar panel systems are now increasingly accessible to a broader population [23]. The cost of electricity per watt decreases annually, leading to a surge in the installation of PV systems globally across residential and commercial sectors. Over the past decade, there has been an estimated annual 40% increase in global PV output [24].

The configuration of a PV system for a specific load becomes more intricate when determining the energy flow distribution among the system components. The energy flow pathway of this configuration is illustrated in Figure.

Energy is transferred from the solar PV panel to the battery during daylight hours through electronic circuitry. Subsequently, when the load is operational, the energy flows from the battery to the load via electronic circuitry, primarily involving the charge controller and, for AC loads, an inverter. A power inverter and battery are essential components in this system to facilitate energy supply from the solar PV panels to the load. The system's configuration is designed in opposition to the energy flow. The load and its specifications (power, operational hours, energy requirements, etc.) are initially identified. Subsequently, the sizing of the battery, power inverter, charge controller, inverter, and PV array is determined.

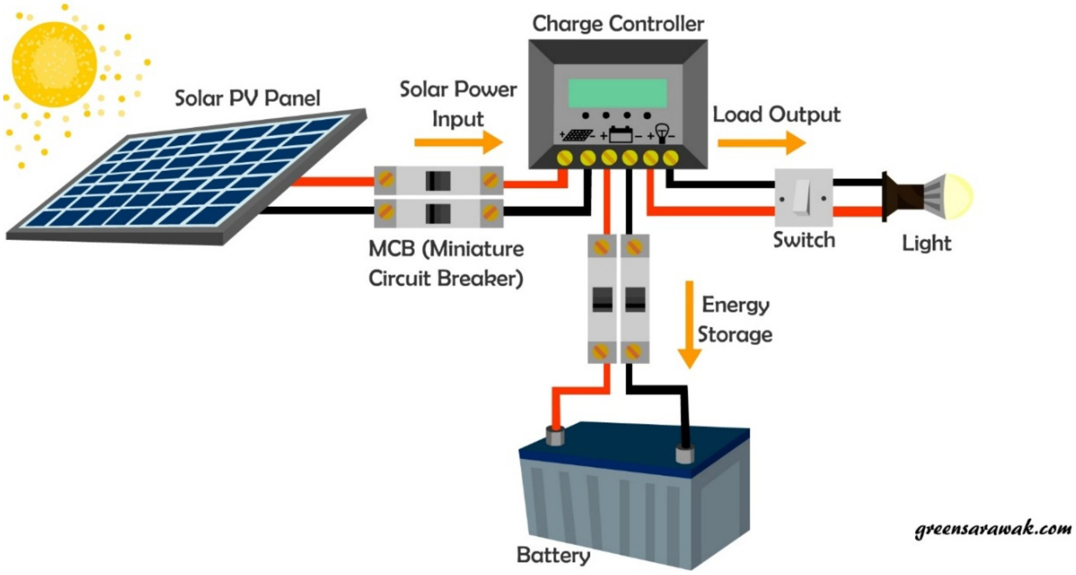

Figure 6. Energy flow diagram of Solar PV system (Source: greensarawak.com)

The overall layout of this setup can be segmented into three key steps:

1. Calculate the load in watt-hours (Wh) and size the power inverter.
2. Estimation of the battery capacity.
3. Determination of the solar PV panel size.

3.5.4. Load calculation and Power inverter sizing.

Load calculation determines the power consumption of any appliance operating on a Solar PV system. The location of the load can be identified using two tables that list all the equipment powered by the system, including various types of lights (such as tube lights, small energy savers, and large energy savers), fans, computers, air conditioners (typically ranging from 1 to 2 tons), heaters, photocopy machines, printers, water dispensers, microwave ovens, scanners, refrigerators, sound systems, water coolers, and wing lights (for occupied site sides and wings).

These tables also specify the appliances to be powered, their power ratings (W), the number of appliances used on-site, the total power consumption (kW), the duration of appliance operation in hours, and the daily electrical energy consumption (in kWh).

Table 1. Power load of the site (administration block) during the summer season

Appliances	Rating (W)	Appliances	Total Power (kW)	Duration (hr/day)	Electricity (kWh/day)
Wings Lights	40	16	0.64	18	11.5
Tube Light	40	82	3.28	7	22.9
Large Energy Saver	85	31	2.64	7	18.4
Small Energy Saver	25	139	3.48	7	24.3
Fan	70	103	7.21	7	50.4
Computer	250	63	15.7	7	110.2
Air Condition (1 ton)	1300	4	5.2	7	36.4
Air Condition (1.5ton)	1900	10	19	7	133
Air Condition (2 ton)	2400	21	50.4	7	352.8
Heater	1500	3	4.5	0	0
Photocopy machine	300	5	1.5	7	10.5
Printer	50	29	1.4	7	10.1
Water Dispenser	80	2	0.1	7	1.1
Microwave Oven	1000	1	1	0.5	0.5

Scanner	21	2	0.4	7	0.2
Refrigerator	200	2	0.4	18	7.2
Sound	100	1	0.1	0.05	0.01
Water Cooler	400	2	0.8	24	19.2
Total			117.5		809.1

Table shows electrical power utilised in appliances per day in summer is 809.1 kWh. In the summer season, all appliances are powered except the heater.

Table illustrates that during winter, the total daily electricity consumption by appliances amounts to 224 kWh. Throughout the winter season, all appliances are operational except for the fan, air conditioner (typically 1, 1.5, and 2 tons), and water cooler.

3.5.5. Inverter and converter rating

The inverter plays a crucial role in solar PV systems, especially when dealing with AC loads, as it converts DC to AC when supplying energy from the battery to the load. Conversely, a converter converts DC to DC for DC loads where the battery voltage varies. It is essential to select the appropriate capacity for both the converter and inverter for DC loads to ensure they can manage the required current at the output end. Additionally, these components must handle the current from the battery at the input end. Specifications for voltage and current ratings are necessary for both input and output in both cases. The inverter should have a higher capacity than the total power demand. An inverter with a capacity of 820 kW and the company code R8815TL is utilised for the above load. This inverter provides an output of 220V AC at 50-60Hz with an efficiency of 98.5% [25].

Table 2. Power load of the site (administration block) during the winter season

Appliances	Rating (W)	Appliances	Total Power (kW)	Duration (hr/day)	Electricity (kWh/day)
Wings Lights	40	16	0.6	18	11.5
Tube Light	40	82	3.2	7	22.9
Energy Saver Large	85	31	2.6	7	18.4
Energy Saver Small	25	139	3.4	7	24.3
Fan	70	103	7.2	0	0
Computer	250	63	15.7	7	110.2
Air Condition (1 ton)	1300	4	5.2	0	0
Air Condition (1.5ton)	1900	10	19	0	0
Air Condition (2 ton)	2400	21	50.4	0	0
Heater	1500	3	4.5	7	3.1
Photocopy machine	300	5	1.5	7	10.5
Printer	50	29	1.4	7	10.1
Water Dispenser	500	2	1	3	3
Microwave Oven	1000	1	1	2	2
Scanner	21	2	0.04	7	0.2
Refrigerator	200	2	0.4	18	7.2
Sound	100	1	0.1	0.05	0.005
Water Cooler	400	2	0.8	0	0
Total			118.8		223.7

3.5.6. Estimation of battery size

In the design of a PV system, the depth of discharge (DOD) for batteries typically ranges from 60% to 80%. To determine the required charge capacity in ampere-hours (Ah), the energy to be supplied is divided by the system voltage. For a 48V battery, the ampere-hour calculation is then performed.

$$\text{Ah load} = \frac{\text{Total load (Wh)}}{\text{Battery Voltage (V)}} \tag{1}$$

$$\text{Ah load} = \frac{809139}{48}\ \text{Ah} \tag{2}$$

$$\text{Ah load} = 16857\ \text{Ah} \tag{3}$$

$$\text{Total Ah including depth of discharge (DOD)} = \frac{\text{Ah load}}{\text{DOD}} \tag{4}$$

$$\text{Total Ah including depth of discharge (DOD)} = \frac{16857}{0.7}\text{Ah} \tag{5}$$

$$\text{Total Ah including depth of discharge (DOD)} = 24081.57\ \text{Ah} \tag{6}$$

Based on this analysis, we opt for the Smart Battery lithium-ion technology battery with a capacity of 500 Ah and 48V [26]. To achieve a terminal voltage of 1500V, we arrange 32 batteries in series. Connecting the system in three parallel configurations ensures the necessary Ah capacity for the desired voltage. Consequently, the total number of batteries utilised in this setup amounts to 96.

3.5.7. Estimation of the Solar PV panel size

The solar PV system is designed to ensure that PV modules supply the necessary energy to the battery for daily load requirements without additional capacity for cloudy days. However, if the PV system incorporates battery storage, it must have the capability to store more energy than the daily load requirement. This surplus energy stored in the batteries enables the system to continue supplying power to the load during periods of reduced sunlight, such as on cloudy days. The average peak sun hours are estimated at 8.2 hours. The first step involves calculating the energy generation capacity of the PV modules.

By using equation

$$\text{Epv, output} = \text{Total watt (Wh/day)} \times \text{Total loss factor} \tag{7}$$

$$\text{Total loss factor} = \frac{1}{(\text{battery efficiency}) \times (1-\text{temp: losses}) \times (\text{charge controller efficiency})} \tag{8}$$

$$\text{Total loss factor} = \frac{1}{(0.85\times0.9\times0.90)} = 1.45 \tag{9}$$

$$\text{Epv, output} = 809139 \times 1.45 = 1173251.6 \ {}^{\text{Wh}}/_{\text{day}} \tag{10}$$

We must find the peak power (Wp) of how much PV modules should generate.

By using the formula:

$$\text{Peak power (Wp)} = \frac{\text{PV output} \times \text{Safety factor}}{\text{Peak sun hours}} \tag{11}$$

Due to rising temperatures and various environmental influences, the power output from the PV cell diminishes, prompting the application of a safety factor for compensation. Typically, a safety factor of 1.15 is employed [27]. This signifies that the PV module must generate 15% more power than the requirement. This evaluation usually consists of visual inspections, I-V curve field measurements (the whole plant or selected areas), and thermal evaluations by IR imaging, and, in some cases, measurements of the I-V characteristics and thermal behaviours of selected modules in the plant chosen by the laboratory.

By substituting value, we get,

$$\text{Peak power (Wp)} = \frac{1173251.6 \times 1.15}{8.2} \text{ W} \tag{12}$$

$$\text{Peak power (Wp)} = 164541.4 \text{ W}$$

This means the peak power (Wp) that the PV module will generate is 164,541 W. To generate the Wp, we select the high-efficiency 48 V, 320W.

3.5.8. Number of modules

Now, we find the number of modules.

$$\text{No: of modules} = \frac{\text{Peak power (Wp)}}{\text{Power of one module}} \tag{13}$$

$$\text{No: of modules} = \frac{164541.4 \text{ W}}{320 \text{ W}} \tag{14}$$

$$\text{No: of modules} = 514.19 \approx 516 \tag{15}$$

It means for generating 164,541 W/day, 516 modules of 320 W are required.

3.5.9. Area of PV system

To install the system, the following process determines the required area. We have already selected the modules of 320 W solar PV modules. The area of one module is:

$$\text{Area of one module} = (\text{Length} \times \text{Width}) \tag{16}$$

$$\text{Area of one module} = (1960 \times 992) \text{ mm}^2 \tag{17}$$

$$\text{Area of one module} = 1944320 \text{ mm}^2 \tag{18}$$

$$\text{Area of one module} = 1.94\text{m}^2 = 2\text{m}^2 \tag{19}$$

The total minimum area of the PV system,

$$\text{Total minimum area of PV system} = \text{No: of modules} \times \text{Area of one module} \tag{20}$$

$$\text{Total minimum area of PV system} = 515 \times 2 \text{ m}^2 \tag{21}$$

$$\text{Total minimum area of PV system} = 1030 \text{ m}^2 \tag{22}$$

The total minimum area of this PV system is required to be about 1,030 m^2.

3.5.10. Charge Controller

We selected the charge controller, a built-in solar hybrid inverter with a capacity of 820 kW MPPT.

3.6. Levelized Cost of Electricity

To level the cost of electricity, first, we find the total initial system cost and parameters to estimate system costs and benefits, shown in Table .

Table 3. Total Initial System Cost

Equipment	Quantity	Price (Rs)
Solar panel	516	10,320,000
Solar inverter	1	8,448,000
Mounting structure	164,541	1,342,546
Cables	1	570,148
Site service	1	2,902,706
Site management	1	258,128
	Total cost	**23,841,528**

Table shows the total cost of solar panels, solar inverters, mounting structures (the structure where solar panels were mounted), cables, and site service and site management. To sum up this cost, we give the total initial system cost.

Table 4. Parameters to Estimate System Costs and Benefits

Parameters	Unit	
System Size	164,541	W
Cost of Installation	23,841,528	Rs.
System Life & Maintenance		
System Life Expectancy	25	Years
Yearly depreciation of the system efficiency	0.99	%
Yearly Maintenance and Operation Cost	204,000	Rs.

Table 5.4 will define the parameters of estimated system costs and benefits, which include system wattage, initial installation cost, system life approximation, yearly system efficiency deprecation, and yearly maintenance and operation cost.

The lifetime plant output and the initial plant cost are pivotal factors in determining the levelized cost of energy. A degradation factor of 0.99% signifies the annual changes in plant output as the plant's efficiency diminishes yearly. Equation outlines the computations for the levelized cost of energy.

$$LCOE = \Sigma[(It + Mt + Ft) / (1 + r)t] / \Sigma[(Et/(1 + r)t]$$

$$LCOE = 316{,}998{,}188.2/9{,}397{,}630 = 33.73\ Rs/KWh$$

This metric from the solar PV system indicates the cost per unit that remains constant over 25 years compared to other utility electricity. The calculated LCOE is 33.73 Rs/kWh, representing a fixed solar electrical cost consistent throughout the operating lifespan. In contrast, the cost of other utility electricity, which would be procured, is expected to rise over time.

3.6. CO2 Emission Calculation

Using the emission CO_2 equation, Table shows daily emission from the grid station to generate electricity is 613 kgCO_2, while the monthly emission is 18385 kgCO_2.

Table 5. Daily basis grid electricity table

Units (kWh)	Emission Factor	Carbon emission per day (kg-CO_2)
809.1	0.75	612.83

The administration block consumes 809.1 kWh per day. To meet this energy demand using solar photovoltaic (PV) technology, a system comprising 516 modules of 320 W each is installed. The battery storage capacity is 500Ah at 48V, and the solar PV system is designed to cover an area of 1030 m^2. This setup's LCOE is calculated at Rs 33.7 per kWh over its lifetime. The CO_2 emissions associated with grid electricity usage also amount to 613 kg daily.

4. Conclusion

The study comprehensively analysed solar PV systems' techno-economic and environmental aspects to assess their suitability for powering the site compared to diesel generators utilised during load-shedding hours. The sizing of all components of the solar PV system has been meticulously carried out to meet the specific application requirements.

Technical evaluations were performed to ascertain the site's capacity, the specifications of the solar PV system, and its operational output in the working environment to effectively meet the energy demands. An economic analysis was also conducted, encompassing the total initial cost and the levelised cost of electricity (LCOE). The calculated LCOE is Rs 33.7 per kWh, representing a consistent solar electrical cost throughout the solar plant's operational lifespan.

The environmental analysis revealed that the grid fossil fuel power system is associated with total greenhouse gas emissions of 18385 kgCO2 per month. By transitioning from grid fossil fuel energy to solar PV, the CO2 emissions are projected to decrease significantly to 220,614 kgCO2 per year. Furthermore, installing a Solar PV system is anticipated almost to eliminate emissions such as carbon monoxide, unburned hydrocarbons, particulate matter, sulfur dioxide, and nitrogen oxide.

Apart from the environmental benefits, the study highlights the escalating costs of electricity and diesel, contrasting with the decreasing costs of solar PV panels due to market penetration and economies of scale. This trend is expected to enhance the attractiveness of standalone solar PV systems.

Given the rapid depletion of fossil fuels and the increasing cost of electricity, transitioning the Administration building of Quaid-e-Awam University Nawabshah to solar PV electricity is recommended for immediate economic and environmental advantages. This shift aligns with the global trend toward sustainable energy solutions and underscores the potential for long-term cost savings and environmental preservation.

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