IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 30 October 2023, accepted 27 November 2023, date of publication 8 December 2023, date of current version 29 January 2024.

Digital Object Identifier 10.1109/ACCESS.2023.3341213

RESEARCH ARTICLE

Evaluation of Centralized Management and Distributed Deployment of Photovoltaic System for Domestic Households

HAMZA SAADAT[1], AFSHAN NASEEM[1], SHAHBAZ ABBAS[1], MEHRAN ULLAH[2], MAJID ALI[3], AND MASOOD RAZA[1]

[1]Department of Engineering Management, College of Electrical & Mechanical Engineering (CEME), National University of Sciences & Technology (NUST), Islamabad 44000, Pakistan
[2]School of Business and Creative Industries, University of the West of Scotland, Paisley, PA1 2BE Scotland, U.K.
[3]U.S.-Pakistan Center for Advanced Studies in Energy (USPCASE), National University of Sciences & Technology (NUST), Islamabad 44000, Pakistan

Corresponding author: Mehran Ullah (mehran.ullah@uws.ac.uk)

ABSTRACT Availability of smooth power supply for the industrial and residential consumption is a major resource that assists the economic and social development of a nation. Automation and intelligent systems are energy intensive and the adequate electricity is required in order to operate such systems. However, there are electricity generation and distribution challenges in most of the developing countries as a result of disparity in the energy supply & demand and the absence of improved infrastructure. Pakistan being the 5th most populated developing country has the substantial demand of energy, accounting for 56% of total generation whereas thermal energy accounts for 61% of all electricity generated in Pakistan. Therefore, it is required to look for the feasible alternate solutions to address these challenges by incorporating renewable energy and the net metering. In first phase of this study, a survey was conducted to collect the feedback from the photovoltaic (PV) consumers and in second phase, market assessment was performed and the electricity systems were designed & analyzed using cost benefit analysis to measure the financial performance as well as carbon credits. Analysis was performed using Meteonorm, Google Maps and Helioscope Simulation software. Following the objective of this study, a self-sustaining power distribution system for a housing society using net metering is proposed to balance the energy production and consumption, combating greenhouse gases emissions from the energy produced by fossil fuels and to upgrade the existing electricity distribution system. The results indicate a remarkable performance of the centralized power distribution system. Till date, no specific study has proposed a sustainable centralized model for addressing energy issues as a self-sustaining power distribution system in a housing society. The proposed integrated model can aid in maximizing the use of PV system.

INDEX TERMS Housing society, net metering, photovoltaic systems, self-sustaining electricity distribution system.

I. INTRODUCTION

Sustainable development practices offer pathways towards sustainable and self-sufficient societies [1]. However, most developing countries are struggling to stabilize their economies, manage resources, accelerate population growth, and mitigate climate change vulnerabilities [2]. It is quite difficult for such developing countries to implement capital-intensive sustainable development practices, and there is a need to look for affordable alternative options for sustainable transition. Pakistan being the 5th most populated country is facing an energy deficit of over 5000 MW and this gap in the energy production and consumption may escalate in the coming years as a consequent of industrial production and the establishment of new housing societies to manage the energy requirements of the residents [3]. It is

The associate editor coordinating the review of this manuscript and approving it for publication was Lorenzo Ciani.

quite challenging for the Pakistani government to optimize the energy security and ensuring the accessibility of energy to every in the prevailing economic crisis and the scarcity of natural resources [4]. One of the reasons for the economic decline is the energy crisis as adequate availability of energy is a significant factor for the industries, businesses and for the domestic households [5]. Apart from the gap in energy demand and supply, there are energy losses as a result of outdated power transmission and distribution system [6].

Owais et al. [7] states that buildings contribute 30-40% of the overall energy consumption globally, and these buildings produce one-third of the overall greenhouse gases. It has also been stated that 80 percent of the overall energy produced in this world is obtained from the burning of fossil fuels, which ultimately impacts climate. Switching to renewable sources can positively impact the environment. Renewable sources including solar, wind, biofuel, waste-to-energy, geothermal, mini hydropower plants, and maritime sources together added 157 GW to global power (electricity) in 2020, setting new records. Renewable energy has increased the proportion of capacity, investment, and power supply, reflecting the ensuing shift in worldwide energy generation. By the end of 2022, global renewable generation capacity amounted to 3372 Gigawatt (GW), growing the stock of renewable power by a record 295 GW or by 9.6 per cent. An impressive 83 per cent of all power capacity added last year was produced by renewables. Advances in renewable energy systems and targeted procedures and strategies are driving an increase in RE generation worldwide [8].

The electrical load pattern in areas varies from season to season [9]. In many developing countries, transmission and distribution (T&D) loss is considered one of the major issues. But in this scenario the capacity of strategically positioned Distributed generation (DG) systems to decrease distribution losses provides a compelling case for net metering. Moreover, transmission and distribution (T&D) infrastructure can give an opportunity for net metering to improve the situation by resolving some of the problems with the system's functionality. Because mini, distributed generators are connected to the grid at the low voltage (distribution side) level, producing electricity near to load centers. It will reduce transmission and distribution losses, which are encountered when electricity is delivered to the loads which are way too far from generating station [10].

With the growing popularity of renewable energy sources, countries are working on the strategies to lay forth a comprehensive framework for renewable energy generation as well as encourage the use of renewable technology [11]. Many countries are now preparing to tap into alternative energy sources, such as renewable, to fulfill rising electricity demands. Furthermore, trying to develop policies, strategies, and programs to ensure that the country's energy supply is clean, inexpensive, and long-term, with a higher proportion of renewable in the mix [12] which may help to meet international obligations of cutting greenhouse gas emissions and limit global warming [13]. Photovoltaic (PV) solar energy flows continuously from the sun and through the PV system. Solar energy warms the earth, causes wind and weather, and resultantly help in sustaining the plant and animal life. Solar energy, heat and light are emitted as electromagnetic radiation. Solar energy can be used by humans both directly and indirectly. It is converted into heat and electricity. It can be used for various purposes, including electricity generation, lighting, indoor comfort and water heating for residential, commercial and industrial use. The best way to use solar energy is to install solar panels on homes and businesses buildings or locations. The sun provides enough energy in one hour to meet all our energy needs for the year [14]. Table 1 depicts the presence and potential of different types of renewable energy resources in some of the Asian countries. The figure indicates that Pakistan has a high potential of renewable energy specifically of solar among all south Asian countries [15].

TABLE 1. Potential of solar, hydro and wind power in the south asia countries, source.

Countries	Solar Power kWh/m2.day	Hydro-power GW	Wind Power GW
Pakistan	5.3	59	132
India	5	150	102
Sri Lanka	5	2	24
Afghanistan	6.5	25	158
Bangladesh	5	0.3	30
Nepal	4	83	0

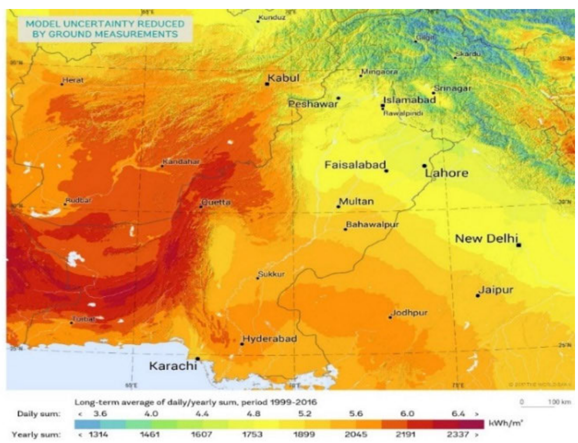


FIGURE 1. Photovoltaic electricity potential in pakistan.

Photovoltaic electricity potential in Pakistan has been depicted in Figure 1 whereas global horizontal irradiation has been depicted in Figure 2.

While highest solar insulation does not coincide with maximum demand, there is great ability for low-cost solar

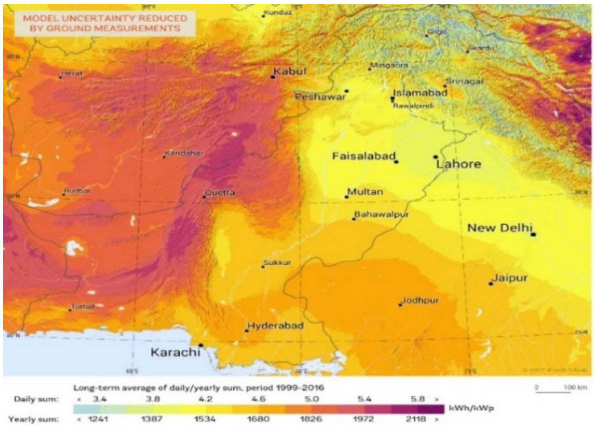


FIGURE 2. Global horizontal irradiation in pakistan.

electricity to replace expensive daytime output (between 10 a.m. and 2 p.m.). The predicted irradiance values drop steadily from south to north, and more than 90% of the land area receives more than 1500 kWh/m2 per year. The south and south-west of the nation receive the most solar irradiance, but even areas which have nominal levels of solar reserves have a superior insulation profile than Germany, which is the overall largest distributed PV market [16]. The capital prices of net metering installations in Pakistan are reasonable/viable as compared to universal costs for roof-top solar PV in all three market cases: domestic, merchandise, and industrial. Furthermore, in most regions of the country, the levelized cost of electricity (LCOE) for all unsubsidized energy users is at or below grid-parity, with rooftop PV energy charging less than unsubsidized electricity charges of the country [17]. Typical commercial and industrial systems have a payback time of 3 to 5.9 years. A 5-kW domestic PV system's unadjusted payback period is about 3.7 years, and it might be even shorter if panel costs fall or power rates rise [18]. A standalone PV system with Hybrid Energy Storage System was proposed by Karunanithi [19]. This system was consisted of two energy storage devices; one was Lithium-Ion Battery bank and Supercapacitor pack. It was preferably used for household applications. The design of this PV considered the average solar radiation of the area. There are few studies on the comparison of centralized and decentralized energy systems [20], [21], effectiveness on net metering [22]. However, there are limited studies available on a sustainable and comprehensive centralized model for addressing energy issues as a self-sustaining power distribution system in a housing society that evaluated the cost and technical parameters of the centralized PV energy system. The literature lacks any study conducted on a developing country such as Pakistan while integrating net metering based on primary data analysis.

Keeping in view the need of development of an economical, effective and efficient power distribution system, this research gives the investors, utility users and government officials, the techno-economic feasibility of deploying distributed PV Solar modules at domestic level with centralized systems for the housing society with an on-grid technology. On grid System has been selected due to its less operational cost, reduce electricity bills and less technical issues. Similarly, LCOE and capital expenses were calculated and presented using principal market information and are representative of current rooftop solar PV system prices. Moreover, it depicts that centralized management system with distributed deployment of PV system may ultimately benefit all stakeholder involved. Centralized system may decrease the upfront cost for each house whereas increase the total energy produce per annum.

This study aims to achieve the following objectives:

- Highlight the effectiveness of installing centralized PV systems on rooftops in a housing society
- Identify and prioritize barriers that hinder the implementation of solar energy at the domestic and housing society levels
- Critically conclude cost-benefit economic parameters for adopting rooftop PV systems and propose the best-suited model for consumers and utilities

II. LITERATURE REVIEW

A. EXISTING STUDIES ON SOLAR ENERGY

Renewable energy sources such as solar, wind and hydro-power have a significant potential in Pakistan [23]. These natural resources have the ability to counter long-term power crisis dilemma. Hence, by continuing a uniform progress to utilize these resources is a critical step in addressing current electricity issues in an appropriate manner that will ultimately result in sustainable environment. Ashraf and Khan [24] investigated that how power can be generated from various accessible resources, as well as how to eliminate shortfalls by utilizing renewable resources. The major factors observed in this study includes electricity production and consumption, as well as installed capacity from various power sources. According to Baloch [25], the power crisis has a significant impact on the residential, industrial, health, and education sectors. A study determines the critical criteria that affect smart grid reliability from the perspective of users and investigate the role big data plays in smart grid reliability [26]. Moreover, Durrani et al. [27] analyzed that the current energy policy in Pakistan must include the complexities of electric power generation, expansion, and compliance with global accords.

Solar energy including the photovoltaic and concentrated solar cells have been considered as the potential sources of generating energy from the sun. Shaikh et al. [28] also emphasized on solar energy's significance as a natural resource and one of the best solutions to overcome the current energy crisis in Pakistan. Khalil and Zaidi [29] found that solar as a natural source of energy is abundantly available on the planet and is capable of providing significant amounts of energy without while reducing the carbon emissions. The results were generated by conducting a survey of wind speed and solar radiation intensity in various areas. Furthermore, the data was compared between a 1 kVA wind turbine, and 1 kVA solar PV system along with a 1 kVA gasoline generator (1 kVA). The comparison suggested that wind and solar energy are the better alternate energy sources in Pakistan as compared to fossil fuels based on their renewable nature, spatial availability and intensity.

Adnan et al. [30] analyzed the magnitude of solar radiation data of 58 distinct energy production stations and revealed that solar radiations of 5–7 kWh m2 days were received over 95 percent of Pakistan's entire territory. In addition, 1 kW of solar PV may provide 0.23 kW of power, which is a substantial increase Pakistan's solar power potential is projected to be at 2,900,000 MW (2900 GW) by the AEDB. Table 2 explains location climate data of Pakistan.

TABLE 2. Geographical climate data (31).

Property	Geographical Climate Data		
Location	**Karachi**	**Lahore**	**Islamabad**
Latitude	24.9 ° N	31.5°N	33.6°N
Longitude	67.1°E	74.4°E	73.1°E
Avg Air Temperatu re	26.1°C	24.4°C	21.6°C
Daily solar radiations-horizontal	5.34kWh/m 2/d	4.68kWh/m 2/d	4.02kWh/m 2/d
Heating Degree-days	0°C-d	352°C-d	659°C-d
Cooling Degree-days	5,861°C-d	5,240°C-d	4,236°C-d

B. PERCEPTIONS ABOUT CONSUMPTION OF SOLAR ENERGY

Steffen et al. [32] found that it is required for families to make financial expenditures in order to replace windows, install heat pumps, and install PV systems to meet household energy requirements. As a result, these home improvements require a significant amount of capital. Given the significant link between wealth and emissions, it is plausible to believe that the governments that produce the most emissions are also in the best position monetarily to pay the costs of these emissions. This is because economics and emissions tend to go hand in hand. Reducing the amount of carbon dioxide produced as a household energy consumption in the United States, there is a potential to open up new avenues for combating energy poverty.

It was identified that "deep" energy retrofits as one of the solutions to address the emissions challenges that may be implemented on the consumption side of the problem [33]. These retrofits aim to reduce the amount of energy that is used for heating, cooling, and lighting. In addition, Schelly and Letzelter [34] discovered that the occupants' decision to buy a PV system is more highly influenced by whether or not they own a home than by economic concerns, despite the fact that economic factors do matters.

1) PERCEPTIONS ABOUT OWNERSHIP AND SOLAR ENERGY USE

The existing studies on homeownership suggested that user homeownership has an effect on the spread of renewable technology [35], [36]. On the other hand, the effect of environmentalism was mostly ignored despite its significance. Wu [37] demonstrated that environmentalism and homeownership are new external variables in technology acceptance model (TAM). Consequently, home ownership is going to be incorporated as one of the model's additional components in this research. This is going to be done so that the relationship between these antecedents' homeowners and the desire to install solar PV may be researched.

H1: Homeownership influences perceptions about solar energy use

2) INCOME AND PERCEPTIONS ABOUT SOLAR ENERGY USE

The investigation by previous studies analyzed that either use of solar energy was favorably correlated with respondents' income levels, or not [34], [38]. Alipour et al. [39], conducted survey-based research by distributing demographics and adoption variables into sections A and B. Section A comprised of information about the respondent's gender, marital status, age, race, educational level, job, household size, monthly power bill, monthly income, and dwelling types. Section B was sorted into the five categories: environmentalism, knowledge, perceived ease of usefulness (PEU), perceived usefulness (PU), and the desire to adopt. The findings indicated that high level of education as well as a high income have a significant and favorably influence on the desire to adopt renewable energy. This trajectory suggested that countries with high income household are self-assured in their capacity to protect the natural world and are opting to install solar PV systems in their homes. Consumers who were concerned about the environment were more likely to accept solar PV. In addition, Bashiri and Alizadeh [40] also discovered that the customers with high income believed may support in reducing carbon emissions.

H2: High income favorably relates to the perceptions about solar energy use

3) EDUCATION LEVEL AND PERCEPTIONS ABOUT SOLAR ENERGY USE

Opinions of educators regarding a variety of environmental concerns have acquired a significant amount of scholarly focus in academic circles [41]. On the other hand, in the light of the global ecological concerns, knowledge and education have been the focus of new study domains involving sustainable development (SD) and, more recently, environmental sustainability through the use of solar energy. A previous study [42] discovered a connection between the creative aim to produce solar power plants and the amount of knowledge through education at various areas around the country. They conducted quantitative viabilities and argued that a community might foster an environment that was filled with pleasure by fostering qualities such as inventiveness, flexibility, knowledge, and drive in its individual members. All of these factors, including the illumination of their education, contribute to the enhancement of happiness, which in turn contributes to the enhancement of customers' intentions to make use of solar plants. As a consequence, the dissemination of such information and education might more effectively motivate customers to make efficient use of solar energy. A case study in the recent research found that education contributes in the intentions of customers towards the use of solar energy. They focused the educational field of instructors as one of the crucial factors, and those who were specialized in science education have a greater awareness about the alternate forms of energy than instructors who teach humanities. They concluded that education has a significant influence on people's intentions to use solar energy. This conclusion was reached in the light of the findings and further needed to be analyzed in this research with the following hypothesis:

H3: Education level is significant in perceptions about solar energy use

4) ROOFTOP SPACE AND PERCEPTIONS ABOUT SOLAR ENERGY USE

It is vital for the energy conservation and sustainable development to utilize buildings roofs for the installation of solar PV panels for the production of electricity. Recently, in a study performed in Saudi Arabia by Khan and Stach [43] investigated the prospect of installing solar PV modules on the roofs of university housing units to determine whether or not this would be worthwhile [44]. It was estimated that around 30 percent of the home power demands might be produced by the rooftop installation; however, the various stakeholders need to conduct essential regulatory reforms and the awareness about this solution should be promoted in order to make this a reality. A study in the region of Al-Khobar also determined the feasibility of utilizing uncontrolled building roofs for the production of power [45]. This study considered residential apartments and villas that are located in the Al-Khobar region. It is important to note that only one-fourth of the total units are appropriate for the effective production of power from solar energy systems. In order to improve the efficiency level of installing rooftop PV systems, the authors proposed a number of modifications to the regulations that are now in place, in addition to raise the intensity of public awareness. Elshurafa et al. [45] conducted pilot study on the usage of mosque rooftop space for the installation of solar photovoltaic systems. The findings based on the technological and economic analysis suggested that the installation of solar PV systems may lower overall power costs by fifty percent. It is projected that careful budgeting and planning would result in reduction in costs of up to one hundred percent.

H4: Rooftop space utilization influences perceptions about solar energy use

5) ENERGY CONSUMPTION AND PERCEPTIONS ABOUT SOLAR ENERGY USE

Owais et al. [7] stated that in Pakistan, data on residential energy usage is only accessible in the form of monthly electricity bills, making it difficult to determine appliance-specific energy consumption. It also makes it challenging to draw an associated between residential power consumptions and numerous driving forces. Amber et al. [46] collected data from 523 households using surveys and interviews in Mirpur city of Pakistan to compute average electricity consumption per house. According to the findings of this study, the typical household's power use is 2460 kWh/year with an average family size of seven people and a 78.91 m2 floor space. The homes were distributed into four groups based on their possession of various equipment, and afterwards the consumption patterns were established and compared. Residences with air conditioning (AC) systems consume 44% more power than the houses without AC. These comprehensive findings are quite beneficial for policymakers and building designers. Amber et al. [46] gathered data from 523 different Pakistani homes, which were then analyzed, and the results revealed that there are numerous key elements that influence the amount of electricity used in residential buildings. According to the findings, the average Pakistani home consumes 24 kWh/m2/year of electricity. Despite the fact that this study is beneficial, it does not provide a comprehensive analysis of the power consumption for typical residential structure. As a result, comprehensive research is necessary in order to appreciate several aspects, such as the customer impression of the amount of electricity consumed in the residential structures in Pakistan. However, data collection is challenging in a third world country, since the information can only be obtained from the monthly electricity bills. According to a study [44], the national demand of energy is predicted to be more than treble by the year 2050. Individual viewpoints were examined using a number of methodologies, and concluded that energy usage is positively connected with the respondents' perceptions of solar energy use. Ayaz et al. [47] also suggested that Pakistan's primary reliance is on conventional energy sources, and that the country is not making significant headway towards the utilization of renewable energy sources in the national power generation.

H5: Energy consumption impacts perceptions about solar energy use

C. CENTRALIZED ENERGY MANAGEMENT SYSTEM (CEMS)

Given the different control tasks and time constants involved in the operation of an energy system, a hierarchical approach has been adopted for designing microgrids' control systems. Two main approaches can be identified in the secondary control: centralized and decentralized. The decentralized approach aims to achieve economical operation of a microgrid while providing the highest possible autonomy to the different distributed energy resources (DER) and loads. Decentralized approaches have been primarily addressed in the technical literature by using the Multi-Agent Systems (MAS) framework [48]. The centralized approach features a central controller that is provided with the relevant information about the microgrid, as well as the information from forecasting systems, in order to determine the dispatch of the resources according to the selected objectives [49]. A proper CEMS can be designed to not only supervise and control the entire system, but also to gather and manage information, and to optimize and provide expert dispatch to achieve an efficient and economical manner. However, a CEMS also has disadvantages, for example, a fault in the central unit of the CEMS may cause a breakdown of the whole system [50]. In a DC residential distribution system, the function of the energy management system can be implemented in a centralized way. This residential distributed system (RDS) follows a CEMS similar to the structure for a microgrid [51]. The CEMS consists of a central controller and wireless communication that is provided with the relevant information from the meters of different actors in the DC system environment.

III. METHOD

In this study, a quantitative research methodology was chosen. To evaluate the current statistics regarding the influence of energy resources on Pakistani consumers, it is necessary to evaluate their responses using a quantitative methodology so that effective interpretation of statistical data can be performed. Moreover, a deductive approach was used to find specific findings.

A. INSTRUMENT

To measure the responses of citizens about the consumption of energy resources, an instrument was developed after discussions with five area experts. Based on this feedback, the instrument was initially designed and then discussed with experts to verify its content. Initially, 50 responses were gathered before starting the survey to validate the instrument. The Cronbach's alpha values were within the acceptable range, which showed the consistency of the items in the instrument. There were two sections in the questionnaire. Section A comprised respondents' profiles, which included gender, education level, age, household size, monthly income, residence type and category, availability of space, and electricity consumption. Moreover, consumers already using PV systems are requested to mention the reason for choosing the PV system.

In section B, there are eleven items which were measure on Likert scale 1-5. The following items were included:

1. We should increase the use of PV energ
2. Enough information is available on solar energy and its technologies
3. Energy produced from solar energy can replace the use of fossil fuel
4. Excess Electricity can be sold to electricity companie
5. Renewable energy is too costly for me to consider for my hom
6. I am willing to pay more for electricity coming from solar than from fossil fuels for environmental reason
7. Solar PV can help to improve the environment
8. I would be more interested in buying a home with solar PV installe
9. Solar PV can reduce your electricity bills
10. Solar PV can help to improve the economy
11. The community should have an electricity generation for the houses and common area

One additional question was asked from the participants to find the probable reason of not setting up solar energy at rooftop.

B. DATA COLLECTION

The target population for the current study was citizens who consumed energy resources and potential customers. Their consumption ratios and relative interests in solar electricity were also gathered. There was a total of 250 respondents. Each response was collected after a direct survey and interaction. A purpose-sampling technique is used. The rationale behind the selection of the purposive sampling technique is to select quality responses. This is because it was necessary for the respondents to understand the relevance of the topic more clearly and elaborate the answers in a clearer manner.

The research methodology is based on 5 phases as depicted in figure 3.

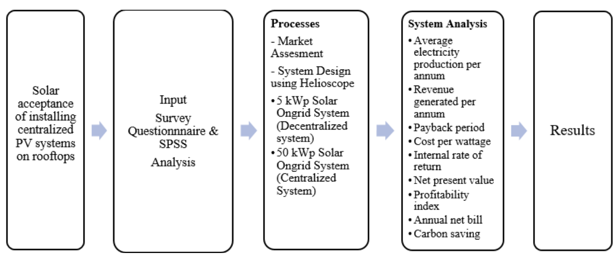


FIGURE 3. Research methodology process.

Firstly, literature review was carried out to highlight the importance of the topic and point out the research gap. In second phase, a survey was carried out to deduce the public response. There responses were later analyzed using Statistical Package for the Social Sciences (SPSS) software and results were analyzed. Based on the results obtained from the survey analysis two different models were designed on Solar energy software Helioscope and their socio-economic analysis has been carried out to mitigate barriers highlighted by the participants and conclude the best feasible option for consumer and utility.

IV. RESULTS AND ANALYSIS

The approaches to collect the quantitative data is through Likert scale questionnaires and objective questions. Following the objective of this study, a relevant questionnaire was adapted according to the scope of study to collect primary data [52]. Based on a Likert scale of 5, 20 questions were asked from the 250 residents. The sample taken for the data collection are the residents of a housing society in the capital city Islamabad. The reason for choosing this society is that this society has been recently established and the development process is continuous. Implementing and testing technological solutions particularly in energy is much easier in a planned housing society rather than an unplanned traditional way of Pakistani housing system. In addition, this housing study was approachable and convenient for the data collection.

The demographic results of the survey are depicted in the Table 3. From the Table 3, it is observed that the male residents actively participated in the survey. The range of age-group that were maximum involved in providing the data are from 25- 34 and 35-44 which are considered as experienced and responsible respondents.

Most of the respondents of the survey are well educated having a bachelor and master degree which justifies the validity and authenticity of responses. Other responses that are directly linked to achieve the objective of the study is the information about residents' household size, monthly income, type and ownership of the house which are presented in the Table 4. From Table 4, it is obvious that most of residents responded that they have a family of 4-6 persons. The monthly income of most respondents ranges in between 40000 – 80000 Pakistani rupees which indicates that middle income level as per the distribution of income in the Pakistani income system. Maximum respondents are living in the independent houses and are owners of the houses which reflects a decision-making power of testing, modifying and improving residential energy systems.

The Table 5 displays the 4 reasons of adopting solar energy systems and from the collected data, respondents consider solar energy systems as the systems that reduce their energy bills over other features of renewable energies such as clean energy, generating own power and reliability. Therefore, this information is helpful in knowing consumer's preferences in adopting solar energy system in a developing country.

Electricity consumption is another significant estimation in developing a centralized energy system. Table 6 provides the information about electricity load in kW and annual consumption. From the Table 7, around 50% of the residents informed that their electricity load is 3-5kW and 5000 kWh (4250 Off Peak, 750 On Peak) electricity consumption annually.

On asking the question regarding the rationale behind not using solar energy within their roof tops, certain barriers were identified based on the residents' responses as shown in Table 7. The defacing property or damaging others property by installing solar energy system at roof top is considered unfavorable by the 8% respondents. 21% mentioned that

TABLE 3. Demographic results.

Description	Percentage
Gender	
Male	72
Female	28
Age Group	
20-24	18
25-34	35
35-44	23
45-55	15
Above 55	9
Education Level	
High School	18
Bachelor	31
Master	39
Postgraduate	12

TABLE 4. Respondent response related to household.

Description	Respondent Percentage
Household Size	
1-3 Persons	24
4-6	42
7-10	30
Above 10	4
Household Monthly Income	
Under 25000	6
25000-39999	13
40000-59999	26
60000-80000	21
80000 and above	18
No Answer	16
Type of Residence	
Apartment / Flat	21
Independent House	52
Portion of a House	27
Ownership of House	
Rented	35
Owned	56
Provided by Employer	9

TABLE 5. Reasons to adopt solar energy.

Reason to Adopt Solar Energy Technology	
Clean Energy	13 %
Generate Own Power	22 %
Cheaper & Reliable energy	18 %
Reduce Electricity Bills	47 %

TABLE 6. Electricity load and annual consumption.

Electricity Load (in kW)	
3 Kw	26%
3-5 Kw	46%
5-12.5 Kw	19%
Above 12.5 Kw	9%
Electricity Consumption Per Annum	
5000kWh (4000 Off Peak, 1000 On Peak)	23%
5000kWh (4250 Off Peak, 750 On Peak)	41%
6000kWh (4800 Off Peak, 1200 On Peak)	13%
6000kWh (5100 Off Peak, 900 On Peak)	10%
7000kWh (5600 Off Peak, 1400 On Peak)	6%
7000kWh (5950 Off Peak, 1050 On Peak)	7%

TABLE 7. Barriers/reasons not to use solar energy on rooftops.

Barriers	Response
Deface the property	8%
Lack of Space	21%
No issue with current Electricity cost	9%
High Initial Investment	24%
Limited knowledge of its working	15%
Limited knowledge of its regulatory procedures	17%
Others	6%

there is a lack of space on rooftop. 9% said that they have no issue in paying current electric bills. 24% highlighted that installation process is too expensive to be used within homes. While 15% respondents mentioned that they do not have much knowledge about the use of solar technology principles relatively. Whereas 17% responded that they do not have any significant knowledge about the regulatory framework which needs to be adopted while installation of renewable resources and specifically the legal pattern which should be followed. 6% replied that they have other issues regarding the installation process. Overall, Table 7 shows that lack of space and high initial investment are the major barriers in adopting solar energy system on residential roof tops.

A. HYPOTHESES TESTING AND JUSTIFICATION

On the basis of results which are being gathered by analyzing the data using SPSS software is explained in this section. The overall Cronbach's Alpha of all variables is 0.828 that is greater than 0.7 which indicates that the model of the study is reliable. Table 8 shows Cronbach's Alphas values for each variable and all values are greater than 0.7. Therefore, the data of the estimated variables is reliable.

TABLE 8. Reliability test of the study.

Description	Cronbach's Alphas	N
Overall	0.828	6
Solar Acceptance-SA	0.822	4
Income-INC	0.813	3
Rooftop Space-RS	0.828	2
Home Ownership-HO	0.876	4
Energy Consumption-EC	0.802	4
Education Level-EL	0.866	4

The model summary in the Table 9 demonstrates that the value of R square is 0.631 which means that independent variable within the current study explains 63% towards the dependent variable i.e., solar acceptance relatively. In order to check the significant relationship F value from ANOVA results will be examined. Table 10 suggests that the value for F is 86.022 which is more than 2 and it shows that model is significant as F is the variation between the sample means within the variables in the ANOVA test.

TABLE 9. Model summary.

Model	R	R Square	Adjusted R Square	Std Error of The Estimate
1	0.715^{a}	0.631	0.624	0.417

Table 11 shows that income has positive and significant influence towards solar acceptance as the value of coefficient is 0.180 therefore suggests that income is impacting positively towards solar acceptance. In Table 10, the p-value is $0.002 < 0.05$ which indicates that the null hypothesis is rejected. Moreover, the t-value is 3.204 which indicates that there is a significant relationship between the variables. In the same manner roof top space influence positively towards solar acceptance as the coefficient value is positive i.e., 0.136 which indicates that roof top space is impacting positively towards the solar acceptance relatively.The

TABLE 10. ANOVA result.

Model	Sum Of Squares	Df	Mean Square	F	Sig.
Regression	74.85	5	14.97	86.02	.000[b]
Residual	43.68	251	0.174		
Total	118.53	256			
1.	Dependent				
2.	Variable : SA				
3.	Predictors : (Constant) EL,RS,EC,INC,HO				

TABLE 11. Coefficients (a. Dependent Variable: SA).

Model		Unauthorized Coefficient		Standardized Coefficient	T	Sig.
		B	Std. Error	Beta		
1	Constant	1.063	.134		7.921	.000
	INC	.180	.056	.212	3.204	.002
	RS	.094	.048	.105	1.980	.049
	HO	.136	.052	.160	2.633	.009
	EC	.226	.066	.265	3.413	.001
	EL	.137	.054	.163	2.544	.012

p-value is less than 0.05 which indicates that the hypothesis is rejected as the p-value for roof top space is 0.009. Moreover t-value reveals that there is a significant link between the variables. Moreover, house ownership influence positively towards solar acceptance as value for coefficient is 0.094 which indicates that house ownership impacts positively towards solar acceptance relatively. Similarly, the p-value mentioned within the table for house ownership is 0.049 which is less than 0.05 which indicates that hypothesis will be rejected. The t-value (Table 10) is less than 2 i.e., 1.980 for house ownership which indicates that it is nearby 2. Therefore, the study proposes that there is a significant relationship between house ownership and solar acceptance. The independent variable energy consumption influence positively towards solar acceptance as value for coefficient is positive i.e., 0.226 which expresses that energy consumption impacts positively towards solar acceptance. The p-value is less than 0.05 which represents that null hypothesis is rejected as the p-value for energy consumption is 0.001. The t-value mentioned within the table 6 for energy consumption is 3.413. Ultimately, recommends that there is a significant relationship between the energy consumption and solar acceptance relatively. The independent variable education level influences positively towards solar acceptance as value for coefficient is 0.137 which illustrates that education level impacts positively towards solar acceptance. The p-value is 0.012 which is less than 0.05 therefore null hypothesis will be rejected. The t-value indicates that there is a significant relationship between the education level and solar acceptance relatively. From the Table 10, t-value for the education level is 2.544.

B. DISCUSSION ON SURVEY RESULTS

1) POTENTIAL OF SOLAR ENERGY AT ROOFTOP WITHIN HOUSES/HOUSING SOCIETIES OF PAKISTAN

It is being identified that utilization of solar energy at roofs within houses of Pakistan is beneficial as its usage provides environment sustainability in a long run. According to one of the researchers the use of renewable resources within households provides sustainable growth as carbon emission can be reduced significantly in a longer run [53]. In the same manner the import consumption of fossil fuel within Pakistan is increasing due to which stabilization towards economy is not as effective. In this regard it is necessary to produce renewable resources in order to bring economic growth within the country. Therefore, the argument towards the use of potential of solar energy at roof top of houses within Pakistan is necessary in order to bring effective growth. The current climatic conditions within Pakistan are not relevant for usage of non-renewable resources due to which it is highly preferred to utilize renewable resources which may contribute in reducing the environmental pollution relatively. One of the past researchers evaluates that by using renewable resources i.e., solar energy will enable in reduction of electricity bill [54].

2) BARRIERS THAT HINDER IMPLEMENTATION OF SOLAR ENERGY AT DOMESTIC LEVEL

It is being identified that there are certain barriers which are associated with the implementation of solar energy at domestic level. One of the barriers is the cost factor, as installation of solar panels within domestic homes is expensive method relatively. Another barrier is the availability of space. As it requires large space in order to install PV system. It is identified that many local houses in Pakistan do not possess roof top area to install PV system due to which its consumption and implementation becomes a challenging task. One of the past studies evaluates that climate conditions in Pakistan (in many regions) is not favorable to install and implement PV system within houses as it requires clear and sunny weather for its proper implementation principle [55]. On the basis of presented arguments, it will be identified that the installation process of PV system is a challenging task due to relative barriers associated with it.

Some of the other barriers have been identified, including, installation of solar panel technology at roof top may damage others property or deface own property of the owner. Similarly, many citizens have less knowledge of the regulatory procedures and performance of solar panels in terms of cost benefit analysis. It was also identified that few citizens mentioned that they have no issue with electricity cost.

3) POLICY RECOMMENDATION

It is identified that the import ratio of fossil fuels needs to be reduced within Pakistan in order to lessen the usage of non-renewable resources and resultantly its consumption ratio can be minimized. Therefore, use of solar panels can be a significant initiation for renewable resources, by which environment sustainability ratio can also be increased significantly. Moreover, it is beneficial towards household consumption significantly as it one of cheaper method of electricity.

Therefore, there is a relative need of getting awareness regarding the harm associated with using nonrenewable resources i.e., fossil fuels. In this regard it is beneficial to launch environmental awareness campaigns regarding contribution towards environment by utilization of solar technology with the help of which significance of energy conservation will be understandable for the local citizens.

V. SOCIO ECONOMIC ANALYSIS OF PROPOSED MODELS

A. CASE STUDY

After getting opinions of residents, a case study has been carried out for cost benefit analysis. In this case, a real life mega residential housing society located in Pakistan was chosen. It includes 450 residential units in total which consist of 148 Apartments/Flats and 308 independent houses. Moreover, the IESCO (Islamabad Electricity Supply Company) electricity tariff and 4-hour peak time per day have been taken into account. The society has typical household design/layout thus average load for each house is consider as 5 kW. Maximum household size is 250 Sq. meter. In this study, grid line losses are not taken into consideration for the complete study.

FIGURE 4. Houses 3D layout (Sketchup).

1) COST INPUTS AND CONSTRAINTS

Selection of components has been carried out through extensive market review. While selecting the components of PV system, following parameters is taken into consideration

1. Accessibility
2. Effectiveness
3. Reliability
4. Cost

Using the quotes supplied by vendors and information gathered from the market research, estimated cost of these components was collected. Table 11 shows the estimated component wise cost of 5kWp and 50 kWp PV systems. Whereas the constraints are:

PV degradation is 0.55% per Year

PV Panels life cycle is 25 Years

Maximum degradation of PV panel over its life cycle is around 15% (depending upon maintenance)

B. BASE CASE

In order to conclude the techno economic feasibility of a Grid tied solar PV system, base study should be considered. Here the base case for residential consumer is the scenario where there may be no electricity outage and all of the electricity necessities are met with the use of the grid. In order to get the best suited and optimized solution, the base case study is essential to compare the results of proposed model. The base case provides the overall energy requirement per annum for the single household along with overall load requirement of the house. Table 12 represents the overall power requirement of a house.

The ultimate load for four-bedroom house taken into consideration comes out to be 5 kW whereas per annum average energy requirement for each house is 5110 kWh, thus it can be stated that average energy requirement for a single house is 22.73 kWh per day. Table 13 represents the Average energy requirement per annum including Off peak and On Peak Units for a household (kWh).

In developed countries, on grid or Grid tied PV system is most popular as they do not involve any kind of battery backup in its initial investment (capital cost) and ultimately payback period is less as compared to hybrid or off grid solar solutions. Here, 5kWp and 50kWp grid tied rooftop PV solar solution have been chosen, via net metering option. Consumers having grid tied system via net metering can sell excess electricity generated to the grid. These types of systems required a primary source of power to properly sync the system to grid. In case of power failure, the system will shut down automatically. The assumption, results and conclusions of this technical proposal have been refined during site visit and requirements provided in technical specifications. Analysis was performed using Meteonorm, Google Maps and Helioscope Simulation software. The decision variables for the system design are PV module selection, invertors' selection and PV array mounting.

TABLE 12. Cost accounting.

System	Equipment	Unit	Quantity	Unit Rate	Amount (RS)
5kWp On Grid System	PV Module	No	10	38,500	385,000
	Structure	No	10	3,500	35,000
	Inverter	No	1	150,000	150,000
	Cabling	Job	1	40,000	40,000
	Breaker / Fuses	No	2	1,500	3,000
	Distribution Box	No	1	5,000	5,000
	Earthing	Job	1	32,000	32,000
	Energy Meters	No	1	20,000	20,000
	Miscellaneous Items	No	1	20,000	20,000
	Installation Charges along with Transportation	Job	1	100,000	100,000
Grand Total (RS)					**785,000**
50kWp On Grid System	PV Module	No	100	38,500	3,850,000
	Structure	No	100	3,500	350,000
	Inverter	No	1	505,000	505,000
	Cabling	Job	1	500,000	500,000
	Breaker / Fuses	No	11	1,500	16,500
	Distribution Box	No	1	8,000	8,000
	Earthing	Job	10	32,000	320,000
	Energy Monitoring Meters	No	10	20,000	200,000
	Miscellaneous Items	No	1	50,000	50,000
	Installation Charges along with Transportation	Job	1	250,000	250,000
Grand Total (RS)					**6,050,000**

C. MODEL NO 1: 5KWP GRID TIED ROOFTOP PV SYSTEM (DECENTRALIZED SYSTEM)

This model is consisting of 5kWp (decentralized) Grid tied Rooftop solar PV system at one of the households located in the housing society in Pakistan. Table 15 shows the equipment details for 5kWp.

1) SYSTEM DESIGN

The decision variables for the system design are

1) PV module selection
2) Invertor selection
3) PV array mounting

The above-mentioned equipment's has been placed with shadow free spacing and at selected orientation. The installation capacity of the system is 5.4 kWp. Layout of the system is depicted in figure 5.

2) YIELD REPORT/ANALYSIS

Meteonorm (for metrological information) and Helioscope (for simulation) have been used for analysis. The results are totally based on reference irradiance and temperature information. Following figure 6 shows the schematic diagram of the system.

3) ANNUAL ENERGY REPORT

Monthly energy/units yield by the proposed PV system has been obtained from simulating software (as depicted in

TABLE 13. Average load of a house.

Description	Quantity (No)	Rating (Watt)	Total Power (Quantity x Watt) - Watt
Fans			
Bedroom	4	80	320
TV Lounge	1	80	80
Drawing/Dinning	2	80	160
Total	7	240	560
Ultimate Total (Total x Diversified Factor)			476
Lights			
Bedroom	12	18	216
TV Lounge	2	18	36
Drawing/Dinning	6	18	108
Kitchen	1	18	18
Washroom	5	12	60
Total	26	84	438
Ultimate Total (Total x Diversified Factor)			394
Exhaust Fan			
Kitchen	1	50	50
Washroom	5	50	250
Total	6	100	300
Ultimate Total (Total x Diversified Factor)			240
Heating & Cooling			
Air condition	3	1000	3000
Ultimate Total (Total x Diversified Factor)			2400
Other Loads			
Oven	1	500	500
Refrigerator	1	500	500
UPS	1	1200	1200
Power Sockets	12	15	180
Total	15	2215	2380
Ultimate Total (Total x Diversified Factor)			1785
Grand Total			5295

Figure 6), where total monthly unit production of 5kWp system is 8490.6.

a: REVENUE GENERTED PER ANNUM

For off peak units the price or revenue for the consumer who is sending the excess energy back to the primary grid via net metering will be the same as it was purchased from the electricity company. Whereas the remaining units produced by solar system will be charged at a tariff rate of 9.95RS. Therefore, the sales generated by the owner will be calculated as

Revenue Generated Per Annum (kWh) = {*Off Peak Units per Annum (kWh)* ∗ *Tariff Rate*} + {*Remaining Units Produced by Solar Per Annum* ∗ 9.95}

Off Peak Units per Annum (kWh) = 6911

TABLE 14. Details of unit consumption per annum.

Total Energy Requirement Per Annum (kWH)	5110
Total Energy Requirement Per Day (kWH)	14
Off Peak Units Per Day (kWh)	11.9
Off Peak Units Per Annum (kWh)	4344
On Peak Units Per Day (kWh)	2.1
On Peak Units Per Annum (kWh)	766

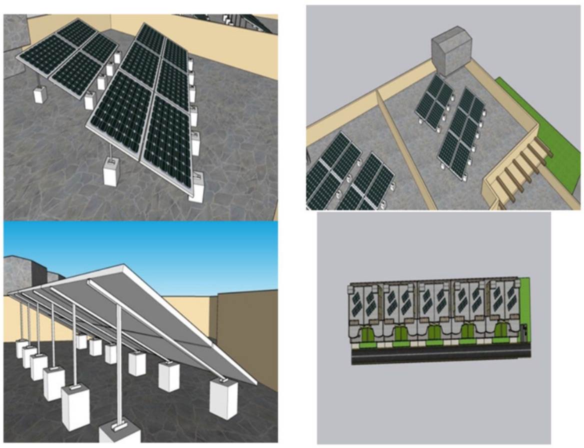


FIGURE 5. PV module orientation.

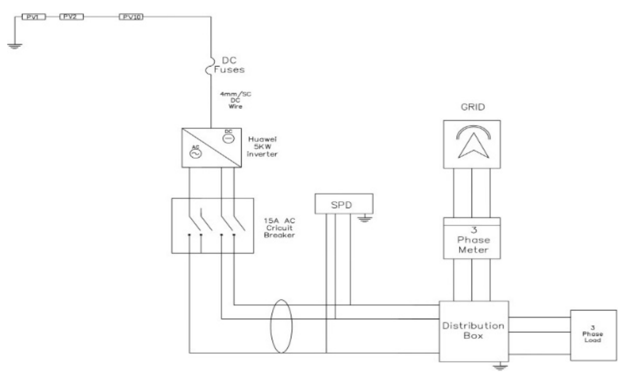


FIGURE 6. Schematic diagram of 5kWp grid tied rooftop PV system.

Tariff Rate for off peak Units (RS) = 18.01

Balance Units Produce (kWh) = Total Energy Produce per Annum (kWh) - Off Peak Units per Annum (kWh)

Total Energy Produce per Annum (kWh) = 8491

Balance Units Produce (kWh) = 8491 - 6911

Balance Units Produce (kWh) = 1580

Tariff Rate for Balance Units (RS) = 9.95

*Revenue Generated Per Annum (RS) = (6911*18.01) + (1580*9.95)*

Revenue Generated Per Annum (RS) = 140,188

TABLE 15. Equipment detail for 5kWp on-grid system.

S/No	Equipment	Description	Quantity (No's)
1	PV Modules	Tier 1, 545W Half Cut Mono- Crystalline Panels	10
2	Invertors	5kW Three Phase Grid-Tied Inverter	1
3	Structure	Elevated	----
4	Data Logger	Wi-Fi / GPRS module	1
5	Power Cabling	It includes 4C 6 mm Sq., 1C 2.5 mm Sq. and 10 mm Sq.	As per site requirement
6	Circuit Breakers	It includes DC fuses along with AC breakers	As per site requirement
7	Distribution Box	IP20 GI DB	1
8	Smart Energy Meter	PEL	1

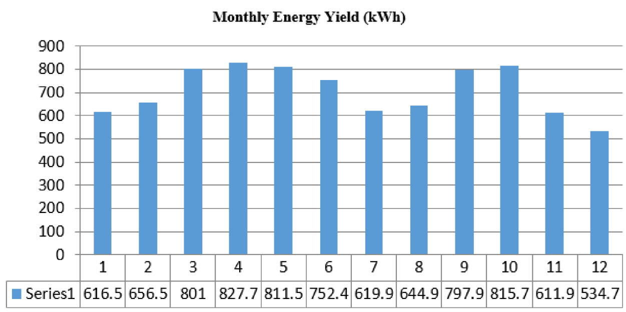


FIGURE 7. Monthly energy yield of 5kWp system.

b: RETURN ON INVESTMENT/PAYBACK PERIOD

With the help of payback period or return on investment (ROI), the feasibility of the project was estimated. If payback period is higher, then the venture may not be favorable. Payback period was calculated by following equation

Payback Period (Years) = Initial Cost of system / Revenue Generated Per Annum (RS)

Initial Cost of system (RS) = 785,000

Revenue Generated Per Annum (RS) = 140,188

Payback Period (Yrs.) = 785,000 / 140,188

Payback Period (Yrs.) = 5.59

c: COST PER WATT

Cost per watt was calculated by following formula

Cost Per Watt (RS/W) = Total Initial Cost / Total Energy Produce

Total Initial Cost (RS) = 785,000

Total Energy Produce (Watt) = 5400

Cost Per Wattage (RS/W) = 785,000 / 5400

Cost Per Wattage (RS/W) = 145.37

d: INTERNAL RATE OF RETURN

The internal rate of return (IRR) is a metric utilized in financial evaluation to estimate the profitability of potential investments. It is a discount rate in discounted cash flow analysis that makes the net present value (NPV) of all cash flows equal to zero. It was calculated as:

$Initial\ capital\ cost = \sum \{Cash\ Flow / (1+IRR)^{T}\}$

$Initial\ Investment\ (RS) = 785{,}000$

$Cash\ Flow\ per\ Annum\ (RS) = 140{,}188$

$T\ (No\ of\ Years) = 25\ Years$

$785{,}000 = \sum \{140{,}188 / (1+IRR)^{25}\}$

$Internal\ Rate\ of\ Return\ (Percentage) = 18$

e: NET PRESENT VALUE

Net present value describes the value of the system at the end of its life cycle / tenure. NPV basically provides the actual benefit that the system has provided during its life cycle. Current KIBOR value in Pakistan is 15.76% which is considered as the discount rate:

$NPV = \sum \{Cash\ Flow / (1+R)^{T}\} - Initial\ Investment$

$Cash\ Flow\ per\ Annum\ (RS) = 140{,}188$

$R\text{-}KIBOR\ Rate\ (\%) = 15.76$

$T\ (No\ of\ Years) = 25$

$Initial\ Investment\ (RS) = 785{,}000$

$NPV = \sum \{140{,}188 / (1+15.76\%)^{25}\} - 785{,}000$

$NPV\ (RS) = 81{,}599$

f: PROFITABILITY INDEX

PI is the ratio of the present value of a project's future net cash flows to the project's initial cash outflow:

$Profitability\ Index = 1 + (Net\ Present\ Value / Initial\ Investment)$

$Initial\ Investment\ (RS) = 785{,}000$

$Net\ Present\ Value\ (RS) = 81{,}599$

$Profitability\ Index = 1 + (81{,}599 / 785{,}000)$

$Profitability\ Index = 1.10$

g: ANNUAL NET BILL

Annual net bill can be calculated as

$Annual\ Net\ Bill\ (RS) = Total\ Electricity\ bill\ per\ annum\ (Base\ Case) - Revenue\ Generated\ Per\ Annum$

$Total\ Electricity\ bill\ Per\ Annum - Base\ Case\ (RS) = 158{,}115$

$Revenue\ Generated\ Per\ Annum\ (RS) = 140{,}188$

$Annual\ Net\ Bill\ (RS) = 158{,}115 - 140{,}188$

$Annual\ Net\ Bill\ (RS) = 17{,}927$

h: CARBON SAVING

Carbon dioxide traps heat and results in global warming. Because of the industrial revolution, carbon dioxide level in the universe has shown drastic increased which resulted in global warming with ramifications. The air contaminants, which are produced by fuel combustion are hazardous for human life. Since PV system is a part of renewable energy that generate electricity with the help of sun, thus it does not generate any greenhouse gases or pollutants which are considered as harmful for human health. This proposed system is expected to reduce carbon dioxide emission by 90 tons over 25-year period as shown in the Figure 8.

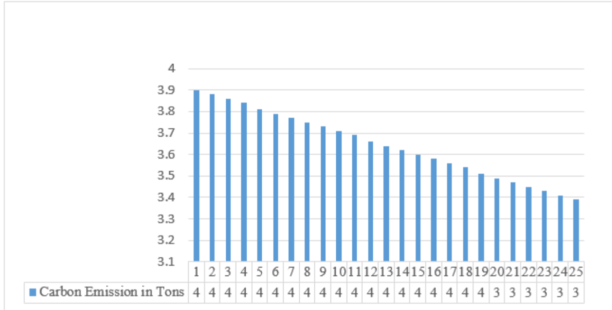


FIGURE 8. Carbon saving for 5 kWp system.

VI. MODEL NO 2: 50KWP GRID TIED ROOFTOP PV SYSTEM (CENTRALIZED MANAGEMENT SYSTEM)

This model is developed by combining the 10 houses into one single unit and each single unit is equipped with 50 kWp Grid tied Rooftop solar PV system. The location of the project is similar to model No 1. Equipment are placed together with the aim to achieve maximum efficiency. Orientation of PV module along with shadow free spacing is specially considered to achieve better results. The installed capacity of the proposed model is 50 kWp. Layouts are shown in Figure 9 whereas equipment details are depicted in table No 16.

A. SYSTEM DESIGN

The decision variables for the system design are

1) PV module selection
2) Invertor selection
3) PV array mounting

TABLE 16. Equipment detail for 50 kWp on-grid system.

Sr. No	Equipment	Description	Quantity (No's)
1	PV Modules	Tier 1, 545W Half Cut Mono-Crystalline	100
2	Invertor	50kW Three Phase Grid-Tied	1
3	Structure	Elevated	100
4	Data Logger	Wi-Fi / GPRS module	1
5	Power Cabling	It includes 4C 35 mm Sq., 1C 2.5 mm Sq. and 10 mm Sq.	As per Site Requirement
6	Circuit Breakers	It includes DC fuses along with AC Breakers	As per Site Requirement
7	Distribution Box	IP20 GI DB	1
8	Energy Meter	Three Phase Energy Meter	10

Equipment's are placed together with the aim to achieve maximum efficiency. Orientation of PV module along with shadow free spacing is specially considered to achieve better results. The installed capacity of the proposed model is 54.5 kWp. Layouts are shown in following figures:

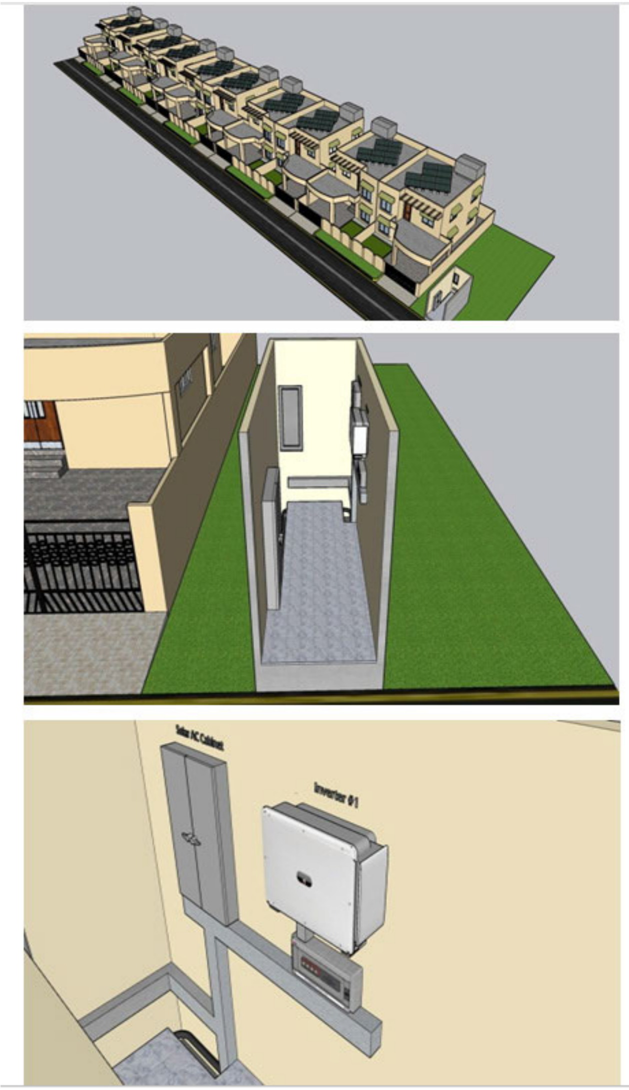


FIGURE 9. Layout of 50kWp grid tied rooftop PV PV system.

B. YIELD REPORT/ANALYSIS

Helioscope software which is one of the renowned software for solar design has been used. These outputs are primarily based on reference irradiance and temperature information which can be changed based on actual input.

The schematic diagram for centralized system is shown below in Figure 10

1) ANNUAL ENERGY REPORT

Monthly Energy / Units by the proposed PV system has been obtained from simulating software and is presented in table 17, where total monthly unit production of 50kWp system is 95048.

a: REVENUE GENERATED PER ANNUM

Profit generated by the proposed system can be calculated as:

Revenue Generated Per Annum = {Off Peak Units per Annum (kWh) ∗ Tariff Rate} + {Remaining Units Produced by Solar Per Annum ∗ 9.95}

Off Peak Units per Annum (kWh) = 6,911 ∗ 10

Off Peak Units per Annum (kWh) = 69,110

Tariff Rate for Off peak Units (RS) = 18.01

Balance Units Produce (kWh) = Total Energy Produce per Annum (kWh) - Off Peak Units per Annum (kWh)

Total Energy Produce per Annum (kWh) = 95,048

Balance Units Produce (kWh) = 95,048 – 69,110

Balance Units Produce (kWh) = 25,938

Tariff Rate for Balance Units (RS) = 9.95

*Revenue Generated Per Annum (RS) = (69,110*18.01) + (25,938*9.95)*

Revenue Generated Per Annum (RS) = 1,502,754

b: RETURN ON INVESTMENT/PAYBACK PERIOD

In order to evaluate the feasibility of a project, payback period or return on investment is critical. Payback period plays an important role in deciding to take up the venture. This can be calculated as:

Payback Period = Initial Cost of system / Revenue Generated Per Annum

Initial Cost of system (RS) = 6,050,000

Revenue Generated Per Annum (RS) = 1,502,754

Payback Period =6,050,000 / 1,502,754

Payback Period (Years) = 4.02

c: COST PER WATTAGE

Cost per wattage can be calculated by following formula:

Cost Per Wattage (RS/W) = Total Initial Cost / Total Energy Produce

Total Initial Cost (RS) = 6,050,000

Total Energy Produce (Watt) =54,000

Cost Per Wattage (RS/Watt) = 6,050,000 / 54,000

Cost Per Wattage (RS/Watt) = 112.03

d: INTERNAL RATE OF RETURN

The internal rate of return (IRR) is a commutation utilized in financial evaluation to estimate the profitability of potential investments. It can be calculated as:

$Initial\ capital\ cost = \sum \{Cash\ Flow / (1+IRR)^T\}$

Initial Investment (RS) = 6,050,000

Cash Flow per Annum (RS) = 1,502,754

T (No of Years) = 25 Years

$6{,}050{,}000 = \sum \{1{,}502{,}754 / (1+IRR)^{25}\}$

Internal Rate of Return (%) = 25

e: NET PRESENT VALUE

Net present value basically provides the actual benefit that the system has provided during its life cycle. Current KIBOR value in Pakistan is 15.76%

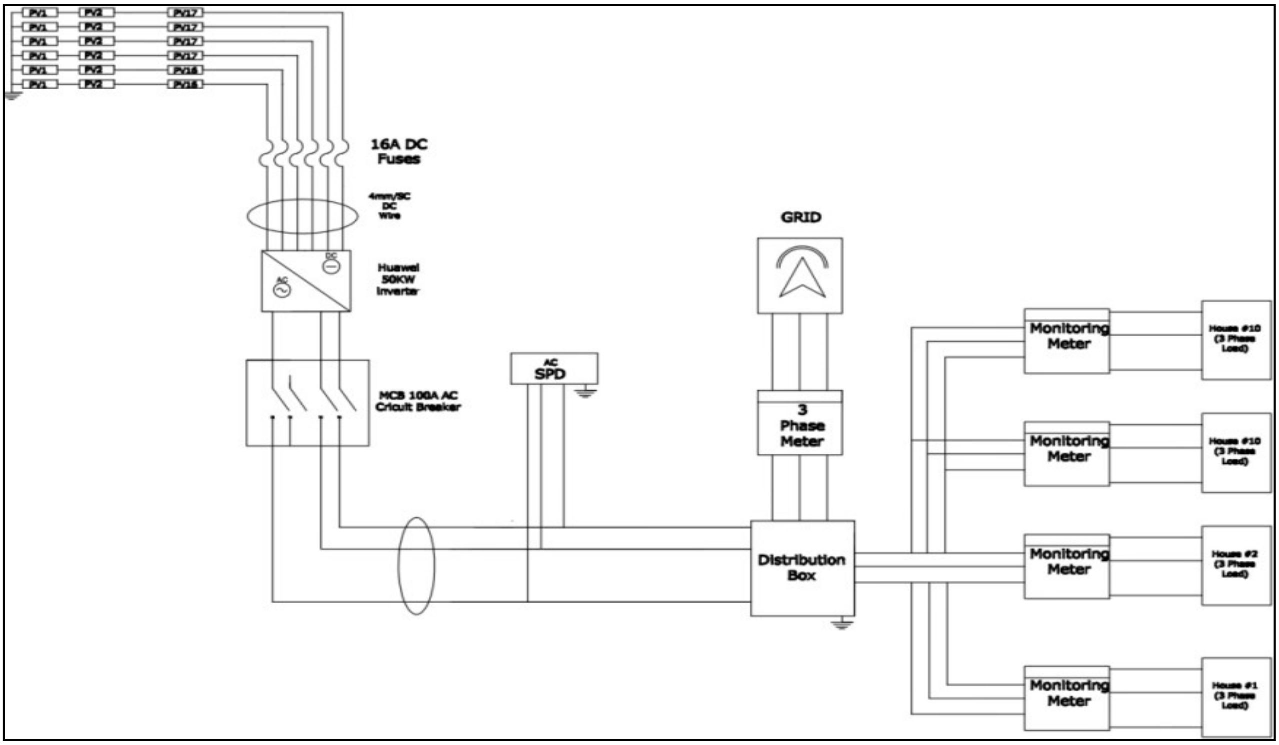


FIGURE 10. Schematic diagram for 50 kWp system.

NPV = $\sum$ *{Cash Flow / $(1+R)^T$ } – Initial Investment*
Cash Flow per Annum (RS) = 1,502,754
KIBOR Rate –R (Percentage) = 15.76 %
T (No of Years) = 25
Initial Investment (RS) = 6,050,000
NPV = $\sum$ *{1,502,754 / $(1+15.76\%)^{25}$ } – 6,050,000*
NPV (RS) = 3,239,562

f: PROFITABILITY INDEX

PI is the ratio of the present value of a project's future net cash flows to the project's initial cash outflow:

Profitability Index = 1+ (Net Present Value / Initial Investment)
Initial Investment (RS) = 6,050,000
Net Present Value (RS) = 3,239,562
Profitability Index = 1+(3,239,562/6,050,000)
Profitability Index = 1.53

g: ANNUAL NET BILL

Annual net bill can be calculated as:

*Annual Net Bill (RS) = (Total Electricity bill per annum (Base Case) * 10) - Revenue Generated Per Annum*
Total Electricity bill per Annum – Base Case (RS) = 158,115
Revenue Generated Per Annum (RS) = 1,502,754
*Annual Net Bill (RS) = (158,115 * 10) – 1,502,754*
Annual Net Bill (RS) = 78,396

h: CARBON SAVING

By utilizing the PV system to produce energy, the cultivation of greenhouse gases or pollution becomes easy. The proposed model of PV system is expected to diminish carbon dioxide emission by 1018 tons over 25-year life span is demonstrated in Figure 11.

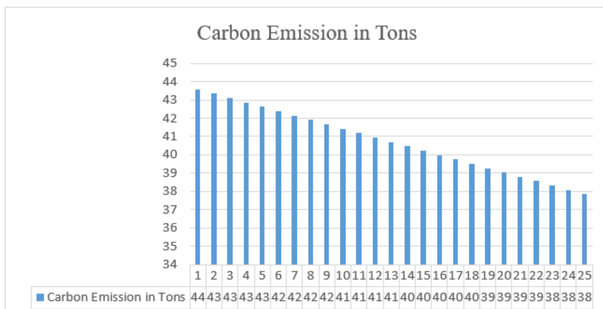


FIGURE 11. Carbon saving for 50 kWp system.

VII. TECHNICAL EVALUATION OF THE MODEL

A well-known software for PV system, Helioscope, has been used for simulations and meteonorm metrological information has been utilized to inspect the amount of energy injected into the grid. These results are totally based on reference irradiance and temperature information which might also additionally range primarily on real input. Monthly Energy / Units by the 5kW and 50kW PV system has been obtained from simulating software. Table 16 shows the values of Monthly Unit Production of 5kWp and 50kWp System.

For off peak units, the price or revenue for the consumer who is sending the excess energy back to the primary grid via net metering will be the same for as it was purchased from the electricity company. Whereas the remaining units produced by PV system will be charged at a tariff rate of 9.95 Rs. Similarly with the help of payback period or return on investment (ROI), it is possible to estimate the feasibility of the project. In case payback period is quite high then the venture may not be chosen in most of the cases. Moreover, cost per wattage can be calculated by dividing total initial cost from total energy production. The inner rate of return (IRR) is a metric utilized in financial evaluation to estimate the profitability of potential investments. It is a discount rate in discounted cash flow analysis that makes the net present value (NPV) of all cash flows equal to zero. Additionally, annual net bill can be calculated by subtracting total electricity bill per annum from revenue generated per annum. PI is the ratio of the present value of a project's future net cash flows to the project's initial cash outflow. Net present value describes the value of the system at the end of its lifecycle / tenure. NPV basically provides the actual benefit that the system has provided during its life cycle. Current KIBOR value in Pakistan is 15.76% which is considered as the discount rate. Conclusively, carbon dioxide levels have risen significantly, resulting in worldwide warming with repercussions. Carbon dioxide traps heat and come up with ozone depletion and global warming. Since the industrial revolution carbon dioxide level in the universe has shown drastic increased, which resulted in global warming with ramifications. Moreover, these air contaminants which are produced by fuel combustion are hazardous for human life. Since PV system is a part of renewable energy that generate electricity with the help of sun thus it does not generate any greenhouse gases or pollutant that is considered harmful for human health. The proposed model of PV system 5kWp and 50kWp is expected to diminish carbon dioxide emission by 90 tons and 1018 tons over 25-year life span respectively.

VIII. DISCUSSION

From the analysis and by gathering relative responses, it was found that many of the household owners are in favor of using solar technologies, whereas some of them still face certain barriers in evaluating solar technology within their houses relatively. By reviewing certain barriers, relative policies are recommended based on the implementation of solar technology within households/at households/housing societies.

Similarly, two different models that include a 5 kWp on-grid system (decentralized) and a 50 kWp on-grid system (Centralized Management) were evaluated in order to determine the socio-economic benefits and analyze which system is best suited for a housing society. Table 18 presents the case study results. Centralized Management is cost-effective in terms of initial investment, as it would save 180,000 rupees per house which is contrary to the outcomes of He, G (20) and Zandi, M. (21). In terms of annual energy production, a centralized management system is effective, as it provides 1014 more electricity units to each house annually. In the case

TABLE 17. Monthly unit production of 5kWp and 50kWp system.

Month	Solar Generation Per Months(kWh) for5kWp	Solar Generation Per Months(kWh) for 50kWp
January	616.5	7829.61
February	656.5	7,869.61
March	801	8,014.11
April	827.7	8,040.81
May	811.5	8,024.61
June	752.4	7,965.51
July	619.9	7,833.01
August	644.9	7,858.01
September	797.9	8,011.01
October	815.7	8,028.81
November	611.9	7,825.01
December	534.7	7,747.81
Total	**8490.6**	**95,048**

TABLE 18. Case results.

Socio Economic Parameter s	Systems		
	5 kWp Decentralized System		50 kWp Centralize d System
	Single House	10 House s	10 Houses
Initial Cost (Rs)	785,00 0	7,850,000	60,50,000
Total Energy Produced Per Annum (kWh)	8,491	84,910	95,048
Revenue Generated Per Annum (RS)	119,49 9	1,194,990	1,295,854
Pay Back Period (Years)	6.56	6.56	4.66
Cost Per Watt (RS)	145	145	112
Internal Rate of Return (%)	15	15	21
Net present Value (RS)	46,294	462,940	1,960,570
Profitabilit y Index	1.05	1.05	1.32
Annual Net Bill (RS)	22,373	223,730	122,686
Carbon Saving (Tons)	90	90	900

of revenue generation, the revenue generated by the centralized system will be around 10,000 rupees per house more than that generated by a decentralized system. The payback period for a centralized system is approximately 56 months, which is 78 months for decentralized systems, which is almost one and a half years longer than that of the centralized system. The cost per watt for a centralized system is 112 rupees, which is almost 33 rupees less than that of a decentralized system. The internal rate of return for the centralized system is 21%, which is 6 percent greater than that for the decentralized system. The net present value for 10 houses in the centralized system is 1,960,570 rupees, whereas it is 462,940 rupees for the same number of houses in the decentralized system. For the decentralized system, the profitability index for the centralized system is 1.78 as compared to 1.22 which is for the decentralized system. The annual net bill in the case of a centralized system is 12268 rupees per annum for each house, whereas it is 22,373 rupees per annum in the case of a decentralized system, which is almost double that of the centralized system. For carbon savings, which is one of the most important factors for the deployment of PV systems, it is observed that the centralized system will save 1,018 tons in 25 years, whereas in the case of a decentralized system, it is reduced to 900 tons over 25 years.

IX. CONCLUSION, LIMITATIONS AND FUTURE DIRECTION

Electricity is a major and basic requirement. It plays a critical role in a country's development. Irregular voltage or improper electricity supply may not only affect citizens but also have a direct impact on a country's economic process. In Pakistan, consumers face severe electricity crises. At the same time, more than 50% of the energy produced in Pakistan is from thermal power plants, and almost 56% of the overall energy produced is utilized by domestic consumers, which ultimately results in a shortage of energy for industries. Therefore, considering the electricity shortage and impact of generation through thermal power plants, this research work and its findings will aid in the development of a system that will not only provide clean energy but may also help in overcoming the energy shortfall. This model can assist in the development of reliable and clean energy/electricity infrastructure networks for domestic units. This model will ultimately help improve Pakistan's economy.

Power demand and solar production differ from area to area. Thus, the analysis of the model faced different challenges when implanted in other parts of the world. As the impact of deploying solar energy on rooftops will vary, to enhance the scale of the investigation, the selected model can be broadened to other parts of the world as well. Moreover, the different domains of this study can be used for further study with the objective of producing clean energy and improving the electricity network. The proposed model could be investigated in various areas to evaluate the results. Additionally, studies on other types of PV systems have computed their economic outcomes and benefits. Consequently, the role of research and government regulation in the adoption and scaling up of rooftop PV systems in residential housing societies can be utilized in a better manner.

REFERENCES

[1] J. Sachs, G. Schmidt-Traub, C. Kroll, G. Lafortune, and G. Fuller, "SDG index and dashboards report 2018: Global responsibilities: Implementing the goals," Bertelsmann Stiftung, Gütersloh, Germany, Tech. Rep. 2018, 2018.

[2] A. M. Khalid, S. Sharma, and A. K. Dubey, "Concerns of developing countries and the sustainable development goals: Case for India," *Int. J. Sustain. Develop. World Ecol.*, vol. 28, no. 4, pp. 303–315, May 2021.

[3] N. H. Mirjat, M. A. Uqaili, K. Harijan, G. D. Valasai, F. Shaikh, and M. Waris, "A review of energy and power planning and policies of Pakistan," *Renew. Sustain. Energy Rev.*, vol. 79, pp. 110–127, Nov. 2017.

[4] M. A. Raza, K. L. Khatri, A. Israr, M. I. Ul Haque, M. Ahmed, K. Rafique, and A. S. Saand, "Energy demand and production forecasting in Pakistan," *Energy Strategy Rev.*, vol. 39, Jan. 2022, Art. no. 100788.

[5] J. Anwar, "Analysis of energy security, environmental emission and fuel import costs under energy import reduction targets: A case of Pakistan," *Renew. Sustain. Energy Rev.*, vol. 65, pp. 1065–1078, Nov. 2016.

[6] S. Nawaz, N. Iqbal, and S. Anwar, "Electricity demand in Pakistan: A nonlinear estimation," *Pakistan Develop. Rev.*, vol. 52, no. 4, pp. 479–492, Dec. 2013.

[7] S. Owais, W. A. Khalil, S. Gul, R. Akbar, and M. B. Sajid, "Energy consumption in residential sector of Pakistan," in *Proc. 1st Int. Conf. High Perform. Energy Efficient Buildings Homes (HPEEBH)*, 2018, pp. 1–8.

[8] A. Rahman, O. Farrok, and M. M. Haque, "Environmental impact of renewable energy source based electrical power plants: Solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic," *Renew. Sustain. Energy Rev.*, vol. 161, Jun. 2022, Art. no. 112279.

[9] F. Masroor, M. Ashfaq, M. Siddiqui, M. M. Hussain, M. H. Shahbaz, M. K. Sadeghi, and G. A. B. Saeed, "The power sector of Pakistan. A brief review," *SYSTEM, Total*, vol. 121, no. 1, pp. 2–6, 2021.

[10] J. Welstead and J. L. Felder, "Conceptual design of a single-aisle turboelectric commercial transport with fuselage boundary layer ingestion," in *Proc. 54th AIAA Aerosp. Sci. Meeting*, Jan. 2016, p. 1027.

[11] M. Yaseen, F. Abbas, M. B. Shakoor, A. A. Farooque, and M. Rizwan, "Biomass for renewable energy production in Pakistan: Current state and prospects," *Arabian J. Geosci.*, vol. 13, no. 2, pp. 1–13, Jan. 2020.

[12] I. U. H. Padda and A. Hameed, "Estimating multidimensional poverty levels in rural Pakistan: A contribution to sustainable development policies," *J. Cleaner Prod.*, vol. 197, pp. 435–442, Oct. 2018.

[13] P. A. Owusu and S. Asumadu-Sarkodie, "A review of renewable energy sources, sustainability issues and climate change mitigation," *Cogent Eng.*, vol. 3, no. 1, Dec. 2016, Art. no. 1167990.

[14] J. E. Rea, G. C. Glatzmaier, C. Oshman, P. A. Parilla, N. P. Siegel, D. S. Ginley, and E. S. Toberer, "Techno-economic analysis of a small scale solar power tower at varied locations," in *Proc. AIP Conf.*, Nov. 2018, vol. 2033, no. 1, Art. no. 040034.

[15] A. Rana and G. Gróf, "Assessment of the electricity system transition towards high share of renewable energy sources in south Asian countries," *Energies*, vol. 15, no. 3, p. 1139, Feb. 2022.

[16] S. Z. Ilyas, A. Hassan, and H. Mufti, "Review of the renewable energy status and prospects in Pakistan," *Int. J. Smart Grid*, vol. 5, no. 4, pp. 167–173, 2021.

[17] M. Irfan, N. Abas, and M. S. Saleem, "Net zero energy buildings (NZEB): A case study of net zero energy home in Pakistan," in *Proc. Int. Conf. Power Gener. Syst. Renew. Energy Technol. (PGSRET)*, Sep. 2018, pp. 1–6.

[18] S. Acha, N. Le Brun, M. Damaskou, T. C. Fubara, V. Mulgundmath, C. N. Markides, and N. Shah, "Fuel cells as combined heat and power systems in commercial buildings: A case study in the food-retail sector," *Energy*, vol. 206, Sep. 2020, Art. no. 118046.

[19] K. Karunanithi, S. Ramesh, S. P. Raja, R. Sreedhar, S. Kannan, and V. Ramudu, "Investigations of standalone PV system with battery-supercapacitor hybrid energy storage system for household applications," *Int. J. Inf. Technol.*, vol. 15, no. 1, pp. 279–287, Jan. 2023.

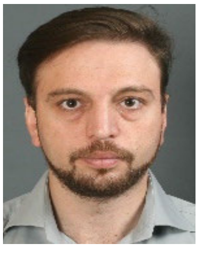
[20] G. He, B. Bluemling, A. P. J. Mol, L. Zhang, and Y. Lu, "Comparing centralized and decentralized bio-energy systems in rural China," *Energy Policy*, vol. 63, pp. 34–43, Dec. 2013.

[21] M. Zandi, M. Bahrami, S. Eslami, R. Gavagsaz-Ghoachani, A. Payman, M. Phattanasak, B. Nahid-Mobarakeh, and S. Pierfederici, "Evaluation and comparison of economic policies to increase distributed generation capacity in the Iranian household consumption sector using photovoltaic systems and RETScreen software," *Renew. Energy*, vol. 107, pp. 215–222, Jul. 2017.
[22] X. Jia, H. Du, H. Zou, and G. He, "Assessing the effectiveness of China's net-metering subsidies for household distributed photovoltaic systems," *J. Cleaner Prod.*, vol. 262, Jul. 2020, Art. no. 121161.
[23] A. Raheem, S. A. Abbasi, A. Memon, S. R. Samo, Y. H. Taufiq-Yap, M. K. Danquah, and R. Harun, "Renewable energy deployment to combat energy crisis in Pakistan," *Energy, Sustainability Soc.*, vol. 6, no. 1, pp. 1–13, Dec. 2016.
[24] H. F. Ashraf and S. Khan, "Analysis of Pakistan's electric power sector," M.S. thesis, Dept. Elect. Eng., Blekinge Inst. Technol., Mar. 2015.
[25] M. H. Baloch, S. T. Chauhdary, D. Ishak, G. S. Kaloi, M. H. Nadeem, W. A. Wattoo, T. Younas, and H. T. Hamid, "Hybrid energy sources status of Pakistan: An optimal technical proposal to solve the power crises issues," *Energy Strategy Rev.*, vol. 24, pp. 132–153, Apr. 2019.
[26] I. Mashal, "Smart grid reliability evaluation and assessment," *Kybernetes*, vol. 52, no. 9, pp. 3261–3291, Sep. 2023.
[27] A. A. Durrani, I. A. Khan, and M. I. Ahmad, "Analysis of electric power generation growth in Pakistan: Falling into the vicious cycle of coal," *Eng*, vol. 2, no. 3, pp. 296–311, Jul. 2021.
[28] P. H. Shaikh, F. Shaikh, and M. Mirani, "Solar energy: Topographical asset for Pakistan," *Appl. Sol. Energy*, vol. 49, no. 1, pp. 49–53, Jan. 2013.
[29] H. B. Khalil and S. J. H. Zaidi, "Energy crisis and potential of solar energy in Pakistan," *Renew. Sustain. Energy Rev.*, vol. 31, pp. 194–201, Mar. 2014.
[30] S. Adnan, A. H. Khan, S. Haider, and R. Mahmood, "Solar energy potential in Pakistan," *J. Renew. Sustain. Energy*, vol. 4, no. 3, May 2012, Art. no. 032701.
[31] A. Mehmood, A. Waqas, and H. T. Mahmood, "Stand-alone PV system assessment for major cities of Pakistan based on simulated results: A comparative study," *NUST J. Eng. Sci.*, vol. 6, no. 1, pp. 33–37, 2013.
[32] W. Steffen, J. Rockström, K. Richardson, T. M. Lenton, C. Folke, D. Liverman, C. P. Summerhayes, A. D. Barnosky, S. E. Cornell, M. Crucifix, J. F. Donges, I. Fetzer, S. J. Lade, M. Scheffe, R. Winkelmann, and H. J. Schellnhuber, "Trajectories of the Earth system in the anthropocene," *Proc. Nat. Acad. Sci. USA*, vol. 115, no. 33, pp. 8252–8259, Jun. 2018.
[33] I. Razzaq, M. Amjad, A. Qamar, M. Asim, K. Ishfaq, A. Razzaq, and K. Mawra, "Reduction in energy consumption and CO_2 emissions by retrofitting an existing building to a net zero energy building for the implementation of SDGs 7 and 13," *Frontiers Environ. Sci.*, vol. 10, Jan. 2023, Art. no. 1028793.
[34] C. Schelly and J. C. Letzelter, "Examining the key drivers of residential solar adoption in upstate new York," *Sustainability*, vol. 12, no. 6, p. 2552, Mar. 2020.
[35] Y. D. A. Adjakloe, S. A. Osei, E. N. K. Boateng, F. Agyapong, C. Koranteng, and A. N. A. Baidoo, "Household's awareness and willingness to use renewable energy: A study of cape coast metropolis, Ghana," *Int. J. Sustain. Energy*, vol. 40, no. 5, pp. 430–447, May 2021.
[36] S. A. Malik and A. R. Ayop, "Solar energy technology: Knowledge, awareness, and acceptance of B40 households in one district of Malaysia towards government initiatives," *Technol. Soc.*, vol. 63, Nov. 2020, Art. no. 101416.
[37] J. Wu, H. Liao, J.-W. Wang, and T. Chen, "The role of environmental concern in the public acceptance of autonomous electric vehicles: A survey from China," *Transp. Res. F, Traffic Psychol. Behaviour*, vol. 60, pp. 37–46, Jan. 2019.
[38] Y. A. Sulub, Z. Hamid, and M. N. M. Nazri, "Renewable energy supply and economic growth in Malaysia: An application of bounds testing and causality analysis," *Int. J. Energy Econ. Policy*, vol. 10, no. 3, pp. 255–264, Mar. 2020.
[39] M. Alipour, H. Salim, R. A. Stewart, and O. Sahin, "Predictors, taxonomy of predictors, and correlations of predictors with the decision behaviour of residential solar photovoltaics adoption: A review," *Renew. Sustain. Energy Rev.*, vol. 123, May 2020, Art. no. 109749.
[40] A. Bashiri and S. H. Alizadeh, "The analysis of demographics, environmental and knowledge factors affecting prospective residential PV system adoption: A study in Tehran," *Renew. Sustain. Energy Rev.*, vol. 81, pp. 3131–3139, Jan. 2018.
[41] C. Borg, N. Gericke, H.-O. Höglund, and E. Bergman, "The barriers encountered by teachers implementing education for sustainable development: Discipline bound differences and teaching traditions," *Res. Sci. Technolog. Educ.*, vol. 30, no. 2, pp. 185–207, Jul. 2012.
[42] N. Soleimani and E. Tebyanian, "A study of the relationship between principals' creativity and degree of environmental happiness in Semnan high schools," *Procedia—Social Behav. Sci.*, vol. 29, no. 1, pp. 1869–1876, 2011.
[43] M. Khan, M. Asif, and E. Stach, "Rooftop PV potential in the residential sector of the kingdom of Saudi Arabia," *Buildings*, vol. 7, no. 4, p. 46, Jun. 2017.
[44] A. H. A. Dehwah, M. Asif, and M. T. Rahman, "Prospects of PV application in unregulated building rooftops in developing countries: A perspective from Saudi Arabia," *Energy Buildings*, vol. 171, pp. 76–87, Jul. 2018.
[45] A. M. Elshurafa, A. M. Alsubaie, A. A. Alabduljabbar, and S. A. Al-Hsaien, "Solar PV on mosque rooftops: Results from a pilot study in Saudi Arabia," *J. Building Eng.*, vol. 25, Sep. 2019, Art. no. 100809.
[46] K. Amber, R. Ahmad, M. Farmanbar, M. Bashir, S. Mehmood, M. Khan, and M. Saeed, "Unlocking household electricity consumption in Pakistan," *Buildings*, vol. 11, no. 11, p. 566, Nov. 2021.
[47] A. Ayaz, F. Ahmad, S. Saher, and M. Noman, "Solar thermal opportunities and challenges in Pakistan," in *IOP Conf. Ser., Mater. Sci. Eng.*, vol. 899, no. 1, Jul. 2020, Art. no. 012008.
[48] A. L. Dimeas and N. D. Hatziargyriou, "Operation of a multiagent system for microgrid control," *IEEE Trans. Power Syst.*, vol. 20, no. 3, pp. 1447–1455, Aug. 2005.
[49] E. Barklund, N. Pogaku, M. Prodanovic, C. Hernandez-Aramburo, and T. C. Green, "Energy management in autonomous microgrid using stability-constrained droop control of inverters," *IEEE Trans. Power Electron.*, vol. 23, no. 5, pp. 2346–2352, Sep. 2008.
[50] J. Yue, Z. Hu, C. Li, J. C. Vasquez, and J. M. Guerrero, "Economic power schedule and transactive energy through an intelligent centralized energy management system for a DC residential distribution system," *Energies*, vol. 10, no. 7, p. 916, Jul. 2017.
[51] D. E. Olivares, J. D. Lara, C. A. Cañizares, and M. Kazerani, "Stochastic-predictive energy management system for isolated microgrids," *IEEE Trans. Smart Grid*, vol. 6, no. 6, pp. 2681–2693, Nov. 2015.
[52] A. Zahir, S. A. Khan, and A. Naseem, "Feasibility analysis of grid tied PV system based on net-metering incentive for a developing country: A case study of Pakistan," in *Proc. IEEE Int. Conf. Ind. Eng. Eng. Manage. (IEEM)*, Dec. 2017, pp. 2014–2018.
[53] M. W. Zafar, M. M. Saleem, M. A. Destek, and A. E. Caglar, "The dynamic linkage between remittances, export diversification, education, renewable energy consumption, economic growth, and CO_2 emissions in top remittance-receiving countries," *Sustain. Develop.*, vol. 30, no. 1, pp. 165–175, Feb. 2022.
[54] K. P. Amber, M. U. Saeed, M. W. Aslam, I. Hussain, and M. S. Khan, "Effect of different factors on the electricity consumption and electricity usage intensity (EUI) of residential buildings in Pakistan," *Revista Construcción*, vol. 17, no. 3, pp. 473–483, Jan. 2019.
[55] S. Ali, Q. Yan, M. S. Hussain, M. Irfan, M. Ahmad, A. Razzaq, V. Dagar, and C. Işık, "Evaluating green technology strategies for the sustainable development of solar power projects: Evidence from Pakistan," *Sustainability*, vol. 13, no. 23, p. 12997, Nov. 2021.

HAMZA SAADAT received the bachelor's degree in engineering. He is currently a M.S. Scholar with the Department of Engineering Management, College of Electrical & Mechanical Engineering, NUST, Rawalpindi, Pakistan. His research interests include sustainability, energy, and performance management.

AFSHAN NASEEM received the Ph.D. degree in engineering management. She is currently a Faculty Member of the Department of Engineering Management, College of Electrical & Mechanical Engineering, National University of Sciences & Technology, Islamabad, Pakistan. Her research interests include operations research, supply chain management, innovation, sustainability, and quality management.

SHAHBAZ ABBAS received the Ph.D. degree in sustainable energy management from the Prince of Songkla University. He is currently an Assistant Professor with the Department of Engineering Management, College of Electrical & Mechanical Engineering, National University of Sciences & Technology, Islamabad, Pakistan. He is also an Interdisciplinary, Problem Oriented, Sustainability Scientist, trained in managing technological innovations and sustainable energy systems.



MEHRAN ULLAH received the Ph.D. degree in industrial management engineering. He is currently a Lecturer with the School of Business and Creative Industries, University of the West of Scotland, U.K. His research interests include operations research, supply chain management, inventory management, logistics, and sustainable supply chain.

MAJID ALI received the Ph.D. degree in thermal hydraulics from Harbin Engineering University. He is currently an Associate Professor with the U.S.-Pakistan Center for Advanced Studies in Energy (USPCASE), National University of Sciences and Technology (NUST), Islamabad, Pakistan. His research interests include heat transfer, thermal hydraulics, and thermal energy.

MASOOD RAZA was a Faculty Member of the Department of Engineering Management, College of Electrical & Mechanical Engineering, National University of Sciences & Technology, Islamabad, Pakistan. His research interests include the IIoT and technology management.