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Photovoltaic Solar System for the Residents of Faisalabad: A Cost-Benefit Analysis

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ABSTRACT

The negative environmental impact of fossil fuels is growing, with the accumulation of the elevation financial charge of energy resources required to meet Pakistan's increasing demand for electricity uses. This study was conducted with the objective to determine the economic viability and feasibility of installing photovoltaic (PV) solar energy in Pakistan. It was discovered that Pakistan’s favorable solar radiation characteristics are crucial for improving the viability of installing solar systems. This study was conducted in an industrial city of Pakistan, Faisalabad. Using the CVM technique primary data on solar PV systems installed in the households was collected. The Cost-Benefit Analysis shows that the true financial cost of a PV module will drastically decrease when the charges of energy assets saved are used in generating conventional electricity.

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1. Introduction

A nation's ability to flourish economically and socially depends on its access to electricity. The majority of those affected by the non-availability of energy reside in rural Sub-Saharan Africa and South Asia (Srivastava & Misra, 2007). Pakistan has a sizable rural population, the majority of whom lack access to electricity. Pakistan is a developing nation and is dealing with social and environmental issues. Additionally, the country's demand for energy has increased due to the nation's constantly growing population. There is now an 8,000-megawatt (MW) imbalance between the country's demand and supply of electricity (Bhandary & Gallagher, 2022; Nawaz, Iqbal, & Anwar, 2013). Pakistan's existing energy system is reliant on fossil fuels. Most the nation's energy requirements are met by thermal energy (coal, oil, and gas) (Baloch et al., 2021). In order to lessen these environmental issues, the government is searching for alternative and clean energy sources. Pakistan has considerable potential for producing power from renewable sources. There is a potential for 346 gigawatts (GW) of wind energy, compared to 2900 GW for solar energy, 6 GW for hydropower, and 5 GW for biomass (Wang, Xu, & Solangi, 2020).

The Punjabi province administration successfully uses renewable energy (RE) to produce power. The first and largest solar energy project in Pakistan is called Quid e Azam Solar Park, and it is situated in Bahawalpur, Punjab. This project is intended to produce 1,000 MWp. 100MWp of the total capacity was produced in the first phase; the remaining 900MWp will be produced in the phases. Cholistan is where the system is situated (Khaliq et al., 2015; QASPL, 2020). A 500-acre area was covered by the 100MWp project. 392,158 modules and 100 inverters are utilized to generate 100MW of power. Conergy, a German manufacturer of solar panels, made the decision to construct a 50 MW solar project in Bahawalpur in 2012. DACC Power Generation Company and the Pakistani government jointly control this project. 30500 families were to receive energy because of the project. The project was anticipated to have a total cost of between $170 million and $190 million (Nicolas-Apruzzese, Busquets-Monge, Bordonau, Alepuz, & Calle-Prado, 2012).

Considering the characteristics, off-grid solar energy is the most practical option for generating power in the province's rural areas (Mohseni, Moosavian, & Hajinezhad, 2022; Sun et al., 2021; Xu, Shah, Zameer, & Solangi, 2019). With more than 300 bright days and 2 MWh/m2 of yearly solar irradiation, the province offers significant solar energy potential (Luqman et al., 2015). The off-grid solar photovoltaic (PV) system is the ideal energy option for rural areas, according to the Asian Development Bank, as it is affordable, simple to install, and improves the socioeconomic situation of these areas. According to Xu et al. (2019), off-grid solar PV is the greatest and most sustainable choice for rural areas because of its net energy, low life-cycle cost, and favorable environmental effects. According to Srivastava and Misra 2007, the advancement of the solar PV system has raised peoples' standards of living. The solar PV system is devoid of noise pollution, reduces carbon emissions, and harms human health. Additionally, a tone of additional studies has demonstrated that the off-grid solar PV system is the most cost-effective and environmentally friendly option for rural electrification.

1.1. The Photovoltaic System

Becquerel made the initial discovery of the PV system in 1839. The current generation of silicon photovoltaic cells was created in 1958 and had an efficiency of 11% but a high cost of almost $1000 per watt. In space, where there was no other source of energy, the first solar cell experiment was conducted. Without the use of a heat engine, photovoltaic modules convert sunlight directly into electricity. A PV system has a long lifespan and no moving parts. It generates power without any noise or emissions that harm the environment. A photovoltaic system can be as large as a megawatt or as tiny as a few small modules. Silicon is the primary semiconductor found in the PV cell's coatings. Silicon produces electricity when exposed to sunlight. A PV panel is made up of several linked PV cells since the amount of electricity produced by a single PV cell is quite little. About 5 decades ago, the energy needed to create a PV module was greater than the amount of electricity it could produce over the course of its lifetime.

1.2. Application of PV System (PV system with direct coupling)

This technology eliminates the need for battery storage because solar panels are linked directly to loads. As it only operates during the day when solar energy is present, this technology only has a restricted range of applications. Water pumping is one of its notable applications. where a solar panel is mounted, runs only on sunlight, and may store water in place of energy.

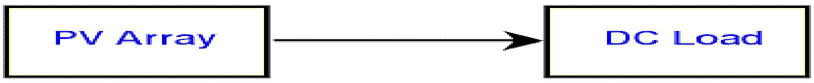

Figure 1: Structure of Direct-coupled PV system model.
Source; www.gosunsolution.com

1.3. Standalone System

An off-grid system, indeed. These systems are often used in places without access to power. This system operates independently of the power grid. The solar panels, battery, and charge controller are all part of the standalone system.

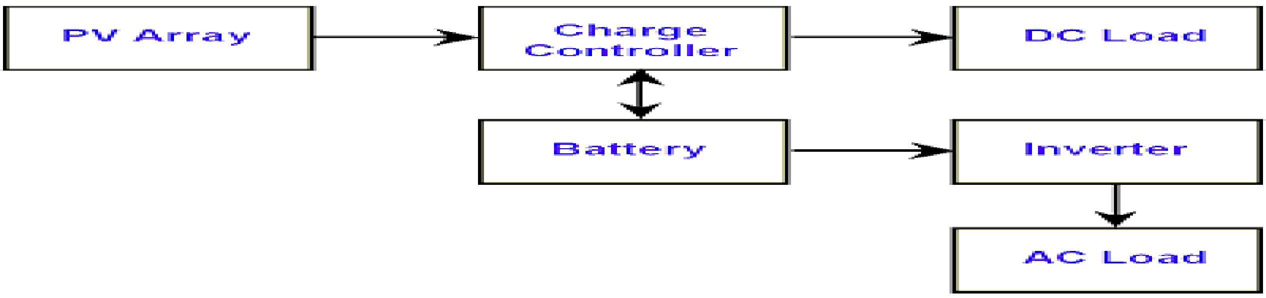

Figure 2: Structure of standalone PV system

Source; www.fsec.ucf.edu

Direct current (DC) to alternating current (AC) conversion is a common additional usage for inverters (AC). This technology is capable of producing both DC and AC.

1.4. Grid-connected system.

This system has a grid connection for the PV system. The owner of a PV system can sell the power to an electrical supply company or utilize it for personal usage throughout the day. Given that power may be purchased from the grid at night, the grid station serves as a storage facility for electricity. This technology does not require storage batteries because of this.

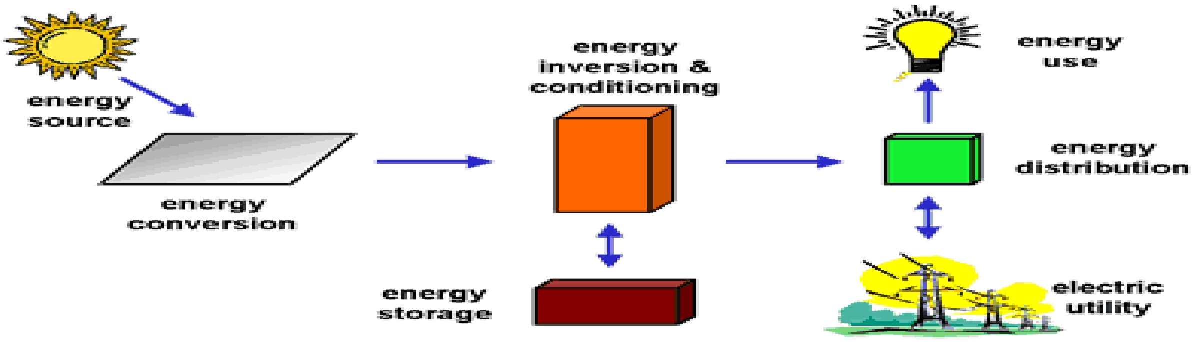

Figure 3: Structure of Grid connected system
Source; www.pasolar.ncat.org
linked hybrid system (on grid system)

This technology allows for the use of two or more different electrical sources. A renewable source, like as wind, a generator, or the utility grid, might be the second source. In order to obtain energy during load shedding hours, this technology is mostly used in residential areas. According to their needs, they have a solar system for load shedding hours and use grid power during the rest hours.

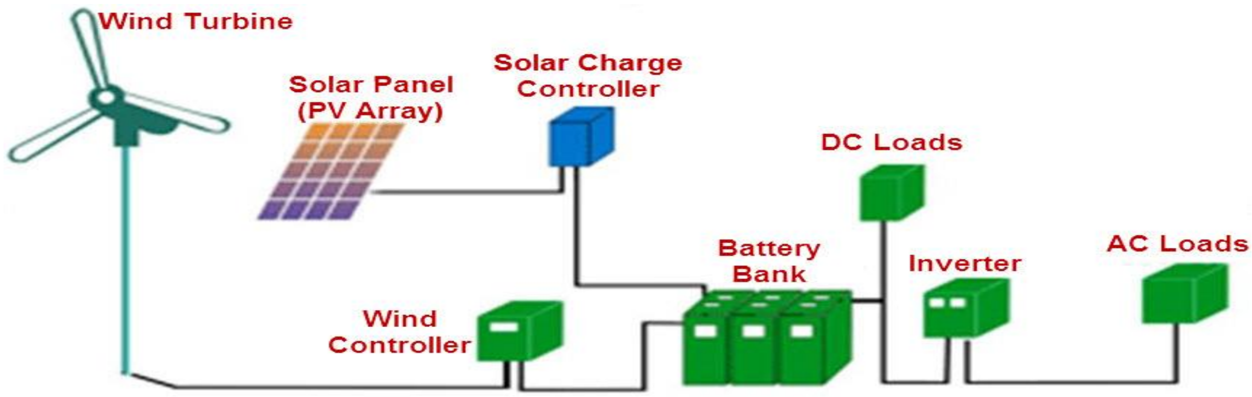

Figure 4: Structure of Hybrid-connected system
Source; www.noutilitybills.com

2. Literature review

Fossil fuels are available in limited quantity at different parts of the world. These are not evenly distributed but solar energy is available in each part of the earth with different intensity (Simpson, 2006). Numerous studies have looked at the costs associated with building solar PV systems. A Levelized cost of electricity (LCOE) for solar PV systems is presented in most articles. According to Yaqub et al 2012, the LCOE of a solar PV system in California was $0.322 per kW-hour. As a result, the cost of installing the solar PV system was not cost-effective when compared to the $0.15/kW/h home retail price of power in California in 2007 (Comello & Reichelstein, 2017).

Aqeeq, Hyder, Shehzad, and Tahir (2018) examined the LCOE of solar PV systems in Pakistan, is likewise predicted to be greater than $0.15/kWh. However, it is anticipated that by

2020, the LCOE of solar PV systems would fall to $0.11/kW/h. Retail energy prices are anticipated to increase in the future due to utility companies' desire to recoup greater fixed expenses and potential cost increases brought on by carbon laws, according to Branker et al 2011. The diverse cost structures with different technologies, such as thin-film PV modules, organic PV modules with flexible panels, etc., in the future, are predicted to cause the LCOE of solar PV to decrease even more. As a result, solar PV installations in North Carolina will be price competitive with retail power in 2020.

Globally, a number of variables are improving solar energy's economic viability, particularly PV systems (Ramadhan & Naseeb, 2011; Yang, Zhu, & Guo, 2018). The true economic cost of LCOE of a PV system will dramatically decrease when the value of energy resources saved from producing conventional electricity and the cost of reducing CO_2 emissions are taken into account, according to the Cost Benefit Analysis (Ramadhan & Naseeb, 2011). Asad, Mahmood, Baffo, Mauro, and Petrillo (2022) did the cost benefit analysis of Quaid-e-Azam Solar Park. The model makes advantage of RETScreen. The study's findings were encouraging, with the simple payback period coming in at 5.6 years.

An examination of the financial viability of an integrated electrification solution based on one or more solar generators and an appropriate energy storage system is made by Kaldellis et al 2008 in remote islands. The major goal of a similar system is to optimise the PV generator's contribution and reduce the remote island networks' life-cycle electricity generation costs. Also, a focus was placed on choosing the most affordable energy storage option that is accessible. The results showed that the proposed configuration is more cost-effective than the current thermal power plants in places with high and medium-high solar potential.

The economics of the developed nations, where most of the country's power is produced by solar energy, has been the subject of several studies, while countries like Pakistan have received very less attention. Punjab province of Pakistan is also increasing the amount of electricity it produces from renewable resources, such as solar energy. Therefore, it is vital to examine its economics in the industrial city of Punjab, Faisalabad, to determine if it is effective for residents to adopt solar PV systems and to teach people about the economics of solar PV systems.

3. Research Methodology

3.1. Data Collection

Purposive sampling was used to choose a sample of 120 respondents. This sort of sampling is not based on probability. Judgmental sampling is another name for purposeful sampling. This kind of sampling involves selecting the participants who will make up the sample with a specific goal in mind. With judgmental sampling, the researcher selects participants based on whether they are more appropriate for the study than other people. They are purposefully picked as subjects because of this. It was not feasible to survey the entire district because of the limited time financial conditions. To choose respondents, a multistage purposive selection approach was applied. According to a survey of the literature and my own common observation, most families having solar panels are high- and middle-income households. So, it was determined which locations had high and moderate-income groups. In Faisalabad, there were roughly 20 colonies with these income groups, including Muslim Town, Madina Town, Peoples Colony, Eden Garden, and Peoples Colony. Muslim Town, Madina Town, Sitara Sapna City, and Jinnah Colony were the four locations chosen for this study.

3.2. Questionnaire

One of the crucial responsibilities in the empirical investigation was creating the questionnaire. To get accurate information, a thorough and comprehensive research investigation is needed. In the first part of this study questionnaire, respondents were provided with the necessary information of renewable energy sources especially solar energy. In the second part the questons about their demographic information were included. The 3rd part consists on the question about their financial condition. In the 4th part they were asked about their electricity source and its specification. The questions about electricity appliances were asked. The respondents who had solar photovoltaic system were Asked about its capacity, cost, installation, usage etc.

3.4. Cost-Benefit Analysis

The benefit-cost analysis estimates and totals up the equivalent money value of the benefits and costs to the community of projects to establish whether they are worthwhile. This study incorporated this analysis to evaluate whether the solar panel system is beneficial for households or not.

Three measures are often used in finding the present worth of the future values of a project: BCR, NPV, and IRR. These were used by Uzunöz and Akcay (2006) and also by Satyasai (2009) and are employed in this analysis. Diakoulaki, Zervos, Sarafidis, and Mirasgedis (2001) start that to characterize the venture or resource beneficial, 3 proportions require computation. first ascertain the net present worth, which ought to be bigger than nothing. After that, the benefit-cost proportion ought to be positive and thirdly the interior pace of return should be positive or more prominent than the markdown rate. In the BCR and NPV strategies, all consumptions and advantages at different seasons of the significant existence of the resource are decreased utilizing adjusted markdown components. Using the formulae below and the depiction in the recipes, BCR, NPV, and IRR have been valued:

Bt ➔ benefit (each year)
Ct ➔ cost (each year)
r ➔ discount rate
t ➔ number of years (1, 2, 3 …n)

The BCR, which is defined as the relationship between the current value of expenses and earnings, is as follows:

BCR=Σ Bt (1+r) t/ Σ Ct (1+r) t

Once the BCR is multiplied by 1, a proposal is reflected as being viable. The difference between the current value of profits and the current value of costs, known as the net present value (NPV), illustrates the net value of a development. A discounted currency flow approach and an active investment appraisal are described as follows:

NPV =Σ Bt / (1+r) t –Σ Ct /(1+r)t

In the case of capital controls, the guiding idea is to choose assignments with a positive net present value and order the collection of schemes according to scales of net present values.

IRR = r* such that NPV= 0

The IRR is the best instrument for evaluating the economic viability of drip and perforated projects. The first two steps are calculated with a specific level of discount. Here, the indirect discount rate is set so that the NPV equals zero and the PV of earnings equals the PV of expenses. The interest rate "r*" at which NPV is 0 is hence the IRR.

The next rule would be to select the project with the highest IRR compared to the cost of capital and rank schemes in accordance with this assessment.

4. Results And Discussion

The features of a PV system comprised of several components, including batteries, panels, etc., are listed below.

Table1: Users of solar panels are distributed based on their usage of power units.

Ranges for Unit Consumption	(Summer) Frequency	Percent	Ranges for Unit Consumption	(Winter) Frequency	Percent
0	4	6.7	0	4	6.7
100-300	19	31.7	50-100	16	24.7
301-500	26	43.3	101-200	25	41.7
401-700	9	15.0	201-300	14	23.3
750	2	3.3	350	1	1.7
Total	**60**	**100**	**Total**	**60**	**100**

The electrical unit usage of people who had solar panels in both the summer and the winter is shown in Table 4.14. Four of the homes were off the grid, so they used no energy throughout the summer or winter. In the group of houses with solar panels, the greatest unit usage was 750 in the summer and 350 in the winter. Between 100 and 300 and 301 and 500 units households, respectively, were represented by 19 and 26 households. Except for air conditioners, freezers, and water pumps, all of the appliances in these homes were powered by solar energy. There were just 9 families with unit consumption ranging from 401 to 700. (15 percent). Only the fans and lights in these homes were powered by solar energy.

Table: 2 Distribution of Solar Panel Non-Users Based on their Power Usage

Unit consumption ranges	In summer Frequency	Percent	Unit consumption ranges	In winter Frequency	Percent
250-400	7.9	12.9	100-200	11.9	219.9
401-800	10.8	17.9	201-300	16.9	27.8
801-1200	18.9	30.9	301-400	11.9	21.3
1201-1600	9.9	15.9	401-500	10.2	15.9
1601-2000	8.9	14.8	501-600	4.0	7.7
2200-3000	3.4	4.9	800-1200	5.3	7.3
Total	**60**	**100.0**	**Total**	**60**	**100.0**

Table 4.15's data shows that households without solar panels use a lot of electricity—up to 3000kwh. Throughout the summer, the majority of households—roughly one-third (31.7%)—fall in the 801–1200 unit range. While the greatest electrical unit usage in the case of solar dwellings was 750. There are eight households with an average power usage of 250 to 400 watts, and many of these low-income households were in leased homes. 16.7 percent of households consume between 1201 and 1600 watts of power. However, there were only 3 houses with 2200–3000-unit ranges in power usage.

Cost Range in Rupees (000)	**Percent**	**Capacity Range (watts)**	**Percent**
20-100	26.7	150	6.7
110-200	18.3	200	28.3
220-300	16.7	215	10
350-500	15	250	38.3
600-800	11.7	255	1.7
850-1000	5	260	3.3
1200-1500	5	275	10
4300	1.7	285	1.7
Total	**100**	**Total**	**100**

The data indicates that there were 4 solar panels, each having a 150-watt capacity. However, a sizable portion of solar systems (28.3%) used 200-watt plates. Since 18 (38.3% of systems) employed 250-watt solar plates, their frequency was greater. Although they were used more seldom, 255 to 285-watt solar plates were mostly employed in freshly constructed systems.

According to Table 4.20, 16 homes, or nearly one-third, spend between $20,000 and $15,000 installing solar panels. These were the homes that featured a modest solar panel that was used just for fans, lights, and televisions. The average number of solar panels between 0000 and 2 lakh was 11. (18.3 percent). The cost of installing solar systems for every device in a household, except the air conditioner, water pump, and freezer, was Rs. 3 lakhs. They appeared 9 times with a 15% frequency. Large solar panels are more expensive since they require installation charges of at least Rs. 5 lacks. Most people believe that solar energy is more expensive than any other renewable energy source. However, its benefits outweigh its drawbacks and favor the buyer. Most of the responders who have solar panels expressed great satisfaction with this source. Most homes were drawn to it because of its environmentally beneficial nature. These customers claimed that having this system keeps them comfortable since it shields them from load-shedding periods and generator noise.

4.1. Cost Benefit Analysis of Solar Photovoltaic system

The use of alternative energy sources, particularly solar energy, to generate electricity has significantly increased in modern civilization. The cost and advantages of solar panels were examined in this study. This study employed a variety of discount rates, including 6 percent, 7 percent, 8 percent, and 10 percent, to overcome the ambiguity around the discount rate. The complete cost of the investment in these projects is made in the first year, and it is also assumed that solar systems have no salvage value when their useful lives are up. This study's statistics indicate that the average cost to acquire a solar PV system is Rs. 475917. The only variable expense associated with a solar system is the requirement to replace the batteries every one to two years. The projected average maintenance cost is Rs. 64363. This price covers the cost of the typical electrical units that homes use from the grid, solar panels, and battery maintenance costs.

Solar panels are designed to last for 18 years. The savings in electricity units from installing solar systems are considered an advantage.

Table: 3 BCR, NPV, and IRR for Solar PV system (18-year useful life) at Different Discount Rates at

6%		7%		8%		10%		IRR
NPV	BCR	NPV	BCR	NPV	BCR	NPV	BCR	
1149615	2.06	1044089.343	2.01	950045.9118	1.97	739532.4172	1.84	53%

The Table shows that NPV, BCR, and IRR are positive at all discount rates. Solar energy is advantageous from an economic perspective since BCR is larger than one at 6, 7, 8, and 10%. There is a 53% IRR. The general guideline is that when starting a business or investing money, the IRR should be greater than the discount rate. The outcomes show that installing a solar PV system in the district of Faisalabad is a financially sound undertaking. Solar energy can save money over the long run, despite its high initial expenses. The practical use of solar energy was made possible by the falling costs and rising efficiency of solar PV systems.

5. Conclusion

There is a need for renewable energy to meet this growing need. Since renewable energy is a form of energy that is beneficial to the environment, at least 95 nations have laws in place to encourage investment in renewable energy (IEA, 2015). Solar energy is one of the renewable energy sources that is attracting attention globally due to its accessibility. Pakistan's geographic position makes it possible to utilize solar energy effectively. The contribution of this study is twofold. It helps the residents of Faisalabad to make decision about electricity source based on economic comparison. It also helps the government to make decision about planing any solar project in this area. The Benefit-cost analysis of this study recommended that it is economically beneficial to residents of Faisalabad. The study's results offer crucial policy recommendations that might direct the government in taking society's adoption of solar energy into consideration. Higher PV panel costs are a major barrier to the home adoption of solar energy. People will accept solar energy if prices drop. Many governments offer to finance citizens who want to put solar panels on their homes. Pakistan should implement this system.

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