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Assessing the Viability of Solar Water Pumps Economically, Socially and Environmentally in Soan Valley, Punjab

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Abstract**—**One of the key solutions to the climate change crisis is to develop renewable energy resources, such as solar and wind power and biogas. This paper explores the socioeconomic and environmental viability of solar energy, based on a case study of the Soan Valley Development Program. Under this project, local farmers were provided solar water pumps at subsidized rates. These have been functional for the last seven years and have gained popularity among the local communities. The study measures the economic viability of using solar energy in agriculture, based on data from 36 households, of which 12 households each use diesel, electric and solar water pumps. Our findings are based on the net present value of each technology type. We also carry out a qualitative assessment of the social impact of solar water pumps relative to diesel and electric pumps. Finally, we conduct an environmental impact assessment, using the lifecycle assessment approach. All three analyses indicate that solar energy is a viable alternative to diesel and electricity.

Keywords**—**Alternative energy sources, pollution control adoption and costs, solar energy pumps, sustainable development.

I. Introduction & Literature Review

ENERGY is a basic need, spanning functions from domestic lighting and cooking to irrigation, industry, transport and communications. Achieving universal access to energy remains a key development challenge and priority. Many parts of the developing world face severe energy constraints, which adversely affect the quality of life and economic progress. A significant proportion of resources are, therefore, channeled toward energy generation and provision in these countries. However, traditional sources of energy, such as fossil fuels, are associated with greenhouse gas emissions, including carbon dioxide, methane, water vapor and sulfur dioxide However, burning fossil fuels releases greenhouse gases (GHG) such as carbon dioxide (CO_2), methane, water vapour, and sulphur dioxide into the atmosphere, resulting in serious environmental threats and increased risk of diseases [4]. Given the pressure to shift to clean energy in order to control the impact of climate change, more and more countries are increasingly exploring renewable energy sources.

In 2013, 13.5% of the world total primary energy supply was produced from renewable energy sources [3], including solar, wind and hydel power. The transition to renewable resources has economic and environmental benefits for developing countries. Those countries that depend on agriculture need an adequate and consistent water supply to sustain crop yields and productivity. Farmers in Pakistan have traditionally relied on conventional technologies such as diesel or electric pumps for irrigation, which are expensive to maintain and can be hazardous to the environment.

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Pakistan's ongoing energy crisis has resulted in persistent power outages with serious consequences for economic growth and development. About 64 million people in Pakistan do not have access to electricity, while 112 million still use biomass for cooking [1]. An estimated 2% of gross domestic product (GDP) was lost during 2011-12 due to power sector outages [8]. Crop yields and productivity have declined as a result of frequent disruption to water supply for irrigation.

Despite efforts by the Government and various donor agencies, the gap between energy demand and supply continues to increase [9]. While Pakistan has a potential of 60,000 MW hydel generation while it currently generates only 6700 MW [8]. We argue that switching to solar-powered pumps for irrigation will not only ensure a reliable water supply but also lower down cost of irrigation and help meet the agriculture sector's energy needs without damaging the environment.

Reference [3] points out that the consumption of fossil fuels accounts for the bulk of greenhouse gas emissions. Despite high emissions, rising prices and finite resources, fossil fuels still provide 83–85% of the world's energy, with only 15–17% generated using renewable resources. One long-term concern is that fossil fuels are unsustainable: as limited resources, they will either run out or become too difficult to extract. In the medium term, the pollution generated by mining, refining and consuming these fuels is a global concern. This provides a rationale for exploring the viability of Solar energy for agriculture in Pakistan [6] showed in a study that the typical irrigation system consumes a large amount of conventional energy. A photovoltaic water pumping system is a suitable alternative because it would provide electricity to off-grid areas, allow farmers to diversify their crops, thus increasing crop yield, enable more efficient water use and contribute to socioeconomic development.

Reference [5] studies the use of solar pumps in rural Bangladesh, where low operating and maintenance costs, easy installation and long life has made solar technology increasingly popular. The authors use the net present value (NPV) and internal rate of return (IRR) of solar pump systems to demonstrate their feasibility.

Reference [2] analyzes the viability of solar irrigation pumps in Maharashtra, India, where farmers use solar energy to run the existing submersible and diesel pumps. He concludes that these solar pumping systems are integrated with micro irrigation, which helps conserve water, increase crop yields, and lower expenditure on fertilizer and other farming inputs. Overall, the increase in productivity leads to a rise in farmers' net incomes.

II. Study Background

This study explores the socioeconomic viability of switching from electric and diesel pumps to solar pumps in the Soan Valley region of Punjab, where many farmers have recently adopted solar technology under the Soan Valley Development Program. The analysis draws on quantitative as well as qualitative data (collected through in-depth interviews with local households). There is one solar-powered pump for every three to four farmers in the area. Accordingly, the sample comprises 12 solar pumps and 24 nonsolar pumps (diesel and electric), to which roughly 120–160 households have access. The findings are based on a relative cost analysis of these technologies.

III. Methodology

Soan Valley is an interesting case study because it was one of the first areas in Punjab to be introduced to solar pumps. The indicators used in the survey include the impact on the environment, variations in income, users' occupation and level of education, and the time and money saved in using solar energy. The survey was conducted across six union councils in the district of Khushab in the Soan Valley. These include Uchhali, Anga, Siddiqabad, Naushera, Khabaki and Khura. There are nine solar pumps installed in Uchhali village, three in Siddiqabad and one in Ahmadabad village in Khabaki. The villages that operate diesel and electric pumps include Uchhali, Koradhi, Siddiqabad, Sabhral, Khura and Ahmadabad.

In order to calculate the relative economic feasibility of using these technologies, we employ the NPV as used in capital budgeting to analyze the profitability of projected investment or project. The following formula is used to calculate the NPV:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

where Ct = the net cash inflow in period t, C0 = total initial investment costs, r = the discount rate and t = number of time periods.

We use the lifecycle assessment (LCA) methodology to evaluate the environmental impact of both systems. LCA is an ISO-certified methodology (ISO 14040 and 14044) and comprises four stages (Fig. 1). It helps compare services or products, and makes decision-making more transparent [9]. We use 7.1 software for the analysis.

It has four stages as shown in Fig. 1. LCA provides a quantitative analysis of the emission to the environment during different stages of a process or product.

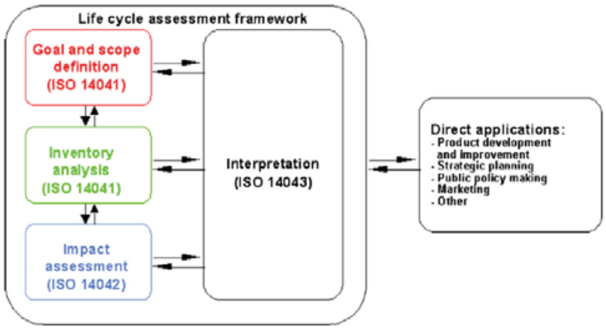

Fig. 1 Stages of Life Cycle Assessment

Life Cycle Assessment Methodology

- Goal and Scope: To identify the LCA's purpose and the expected products of the study, and to determine the boundaries (what is and is not included in the study) and assumptions based upon the goal definition
- Life-cycle inventory: To quantify the raw material and energy inputs as well as the environmental releases associated with each stage of production.
- Impact Analysis: Assessing the impacts on human health and the environment associated with energy and raw material inputs and environmental releases quantified by the inventory.
- Life Cycle Interpretation: Evaluating opportunities to reduce energy, material inputs, or environmental impacts at each stage of the product life-cycle.

LCA studies facilitate decision makers with a good comparison for a service or a product. This methodology makes the decision making process more transparent [9]. 7.1 software has been used for the analysis

IV. Findings and Discussions

The first step was to develop a socioeconomic profile of the sample households. As Table I shows, people's primary occupation is agriculture, which includes livestock and dairy farming. Some respondents were employed as teachers or in government posts. Diesel pump owners account for the largest landholdings, followed by solar pump owners. It is worth noting that the latter were better educated than other farmers, which could explain their awareness of modern technology and its economic and environmental benefits.

Table II shows that all farmers reported cost as the key constraint to adopting solar technology. Diesel and electric pump owners also cited the shortage of electricity and diesel, and price fluctuations. Solar pump users said they could channel more resources (water) and money into producing cash crops such as potatoes, which they sold to the Lays company. Other respondents appeared less likely to change their traditional cultivation patterns. About 58% of the farmers surveyed said they were 100% satisfied with solar water pumps; 40% said they were 75% satisfied and only 2% were

50% satisfied (reporting that the solar water pump did not work as well in winter, when there was less sun).

TABLE I
SOCIOECONOMIC PROFILE OF RESPONDENTS

	Solar	Diesel	Electric
Occupation			
Agriculture	95%	100%	90%
Teaching/government job/other	5%		10%
Land ownership			
2 to 3 acres	33%	50%	67%
4 to 5 acres	50%	25%	33%
More than 5 acres	17%	25%	
Education level			
Middle	25%	34%	25%
Matric	25%	66%	75%
Intermediate	16%		
Bachelor's	34%		

TABLE II
COST AND ENVIRONMENTAL PROFILE OF SELECTED TECHNOLOGIES

	Solar	Diesel	Electric
Constraints to using technology			
Cost	100%		
Inefficiency			
Shortage of fuel/electricity		35%	75%
Rising prices of fuel/electricity		65%	25%
Associated change in choice of crop cultivation			
Shift to cash crops	100%	25%	3%
Same pattern		75%	77%
Satisfaction associated with technology			
100% satisfied	58%		
75% satisfied	40%	51%	30%
50% satisfied	2%	49%	70%
Cost components			
Initial cost	Rs 500,000	Rs 290,000	Rs 44,375
Operational cost	Rs 0	Rs 156,000	Rs 96,000
Maintenance cost	Rs 5,000	Rs 10,000	Rs 5,000
Pump ownership			
Joint	100%		25%
Individual		100%	75%
Changes in water level in the last five years			
Decline	25%	50%	58%
Constant	75%	50%	42%

Although the initial cost of a solar water pump is higher than that of a diesel or electric pump, the technology requires little maintenance and incurs no operational cost. Almost all farmers said that, given the choice, they would adopt this technology. Owners of solar pumps had bought the pump on a communal basis, with two or three farmers pooling in the money since the upfront cost was too high for one person to bear. Respondents noted that the water level had changed in the last five years. About 75% of the farmers using solar water pumps claimed they were careful when extracting and using water so as not to deplete the resource. They had also introduced drip irrigation in the area to conserve water. This may be a result of higher levels of education and environmental awareness of the impact of water scarcity.

The NPV method for calculating the economic benefit of a project is as follows. A positive NPV indicates that the projected earnings generated by a project or investment exceed the anticipated costs. Thus, a positive NPV implies that the project will be profitable and a negative NPV means it will result in a net loss.

The estimated subsidized cost of a 1,600 W single solar panel is Rs 500,000. Respondents said that the continuous energy supply produced by solar technology had increased crop productivity in the shape of profits by about 5% compared to the previous year. The maintenance cost of a solar panel is estimated to be Rs 5,000 per year. A cost saving of Rs 96,000 is expected in the case of electricity and a saving of Rs 161,000 in the case of diesel. An NPV of Rs 144,168 (at a discount rate of 8%) and Rs 241,287 (at a discount rate of 5%) indicates profitability if farmers shift from electricity to solar power, with a payback period of 7 and 6.18 years, respectively. A higher NPV is expected – Rs 3,811,509 (at a discount rate of 8%) and Rs 743,199 (at a discount rate of 5%), with a shorter payback period of 3.7 and 3.46 years, respectively – if farmers move from diesel to solar power.

The results reveal that farmers using electricity or diesel to run their turbines are better off shifting to solar power; the maximum advantage accrues to diesel users. The payback period, when compared to electricity and diesel, is not more than a year. Thus, capital budgeting favors the use of solar panels.

The operational cost breakdown for a diesel pump is as follows. Assuming an average working day of 6.5 hours and a diesel consumption rate of 2.5 l/hour, the total diesel requirement per day is 6.5 x 2.5 = 16.25 l. The daily cost of diesel is Rs 80/liter x 16.25 = Rs 1,300. Assuming 20 working days a month on average, this yields a monthly cost of 1,300 x 20 = Rs 26,000 and an annual cost of Rs 26,000 x 6 = Rs 156,000 (the irrigation period is six months long). The operational cost breakdown for an electric pump is as follows. On average, 800 units are consumed per month by a 1,500 hp motor. Given an average price per unit of Rs 20, the total monthly bill is Rs 16,000, while the total bill for six months is 16,000 x 6 = Rs 96,000. These figures are given in Table III.

TABLE III
COMPARATIVE COST OF DIESEL, ELECTRICITY AND SOLAR POWER

Cost component	Diesel	Electricity	Solar
Initial cost at $t = 0$	Rs 290,000	Rs 44,375	Rs 500,000
Operational cost/year	Rs 156,000	Rs 96,000	Rs 0
Maintenance cost/year	Rs 10,000	Rs 5,000	Rs 5,000

Assuming that the annual operational cost (Rs 156,000) and maintenance cost of a diesel pump (Rs 10,000) remains constant over years 1 to 10, the net saving associated with switching to a solar pump is 156,000 + 10,000 – 0 – 5,000 (maintenance cost of solar pump) = Rs 161,000. Table IV presents the comparative NPV of solar and diesel pumps

In calculating the NPV and payback period, we assume that crop income remains constant (with 2% profit) as do maintenance and operating costs. The interest rate is 5–8%, based on the consumer price index, which measures changes in product costs over a specific period and is used as an indicator of the cost of living and economic growth. The calculated NPV is positive, as shown in Table IV. This means that, even if the upfront cost of a solar pump is high, the user will still save on the cost of fuel. With no operational cost, the payback period is 3.46 years at a discount rate of 5% and 3.7 years at a discount rate of 8%.

TABLE IV
NPV OF SOLAR VERSUS DIESEL PUMPS AT DIFFERENT RATES

NPV 10 years @5%	Rs 743,199
PBP @ 5%	3.46 years
NPV 10 years @ 8%	Rs 580,323
PBP @ 8%	3.7 years
NPV 10 years @ 12%	Rs 409,686
PBP @ 12%	4.12 years
NPV 10 years @ 15%	Rs 308,022
PBP @ 15%	4.5 years
IRR (discount rate at which NPV = 0)	29.8%

Assuming that the annual operational cost (Rs 96,000) and maintenance cost of an electric pump (Rs 5,000) remains constant over years 1 to 10, the net saving associated with switching to a solar pump is 96,000 + 5,000 – 0 – 5,000 (maintenance cost of solar pump) = Rs 96,000. Table V presents the comparative NPV of solar and electric pumps.

TABLE V
NPV OF SOLAR VERSUS ELECTRIC PUMPS AT DIFFERENT RATES

NPV 10 years @5%	Rs 241,287
PBP @ 5%	6.18 years
NPV 10 years @ 8%	Rs 144,168
PBP @ 8%	7 years
NPV 10 years @ 12%	Rs 42,421
PBP @ 12%	8.66 years
NPV 10 years @ 15%	Rs –18,198
PBP @ 15%	Cannot be calculated
IRR (discount rate at which NPV = 0)	14%

The survey results and calculations indicate that the NPV and payback period for solar versus diesel pumps is greater than that for solar versus electric pumps. Solar pump users earn 2% of their annual income in average profits. The money they save on electricity and fuel is reinvested in crop inputs (seed and fertilizer).

In calculating the NPV and payback period, we assume that crop income remains constant (with 2% profit) as do maintenance and operating costs. The interest rate is 5–8%, based on the consumer price index. The calculated NPV is positive, as shown in Table V. This means that, even if the upfront cost of a solar pump is high, the user will still save on the cost of electricity.

Although solar pumps require considerable investment upfront, they also guarantee a fixed energy cost for the next 20 years (the life of a solar generator). Diesel pumps, on the other hand, incur a substantial maintenance cost, given the fluctuations in diesel prices and the rising demand for (and price of) oil.

The Society for Environmental Toxicology and Chemistry [10] defines LCA as the process used to “evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment.” This also entails assessing the impact of the energy and materials used, and opportunities to bring about environmental improvements. The assessment “includes the entire lifecycle of the product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal.”

In the first stage of LCA, we describe the process under consideration, identify system boundaries and review impact categories. The goal is to evaluate the solar and diesel water pump system in Soan Valley. The functional unit is 1 KWh of electricity generated. A solar pump system comprises solar modules, a pump and foundation, an electrical system for interconnection, and pipes and fittings. A diesel pump system comprises a diesel generator and a diesel and electrical system for interconnection. We do not include transport due to the limited data available.

In the second stage, we quantify the materials and energy used as well as related emissions into the air, water and soil over the lifetime of both systems (see Table VI).

TABLE VI
INPUTS FOR LCA OF SOLAR AND DIESEL WATER PUMPS

Solar water pumps	Value
Number of modules	40
Type of modules	
Pump size	20 hp
kWp	8 whp
Material (kg/module)	
Silicon	3
Aluminum	1.3
Copper	0.35
Glass	8.6
Polythene	0.00012
Hydrochloride acid	0.27
Insulating material	1.7
Diesel water pumps	
Diesel consumption	2.25 l/hour
Weight of generator	300 kg
Material	
Aluminum	120 kg
Copper	20 kg
Plastic	30 kg
Steel	250 kg

In the third stage, we calculate the impact of emissions on human beings and the environment (air, water and soil), using the Environmental Design of Industrial Products (EDIP) method, where EDIP 2003 [7] replaces the earlier EDIP 97 methodology. This stage has four steps, the first of which is to identify the impact categories. These include global warming, human toxicity (air, water and soil), acidification, eutrophication, bulk waste and ozone depletion. Table VII lists the impact categories and their units.

TABLE VII
IMPACT CATEGORIES AND UNITS

Impact category	Unit
Resources (all)	kg
Bulk waste	kg
Human toxicity soil	m3
Human toxicity water	m3
Human toxicity air	m3
Terrestrial eutrophication	m2
Acidification	m^2
Ozone depletion	kg CFC11 equivalent
Global warming 100a	kg CO_2 equivalent

In the last stage, we evaluate the results. The study area receives approximately 5 kW/m^2 of solar energy a day. A 20 hp diesel water pump works approximately three hours a day over 18 days a month, pumping water at the rate of 7.6 m^3 per hour. A 15 kWh diesel generator produces 15 kW * 3 hours * 18 days * 12 months = 9,720 kWh of electricity annually. Assuming 0.3 l of diesel are needed per kWh, the total consumption of Solar pumps replacing diesel pumps with these specifications will produce electricity as follows. A solar water pump with a capacity of 15 kWh, working six hours a day, will generate 15 * 6 * 18 * 12 = 19,440 kWh of electricity annually. This not only saves the use of approximately 5,832 l of diesel oil, but also the fuel involved in manufacturing, transportation and combustion, with clear environmental benefits. Fig. 2 compares the environmental impact of solar and diesel water pumps.

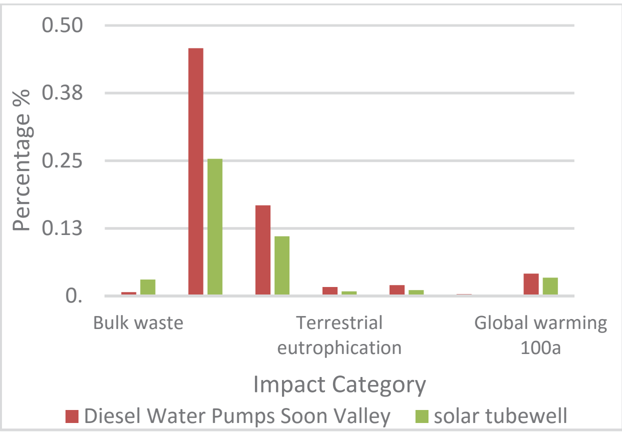

Fig. 2 Environmental comparison between diesel and solar pumps

Finally, we look at specific environmental effects. In terms of global warming, we have already discussed how greenhouse gas emissions increase the atmospheric temperature, with adverse consequences for components of the climate system (biosphere, hydrosphere, cryosphere and lithosphere).

The study shows that diesel water pumps contribute more to this category than solar pumps. Approximately 97% of global warming potential is associated with the fuel lifecycle: diesel consumption alone contributes 65% to global warming, fuel manufacture accounts for 25%, transportation for 5% and generator manufacture for 5%. Solar pumps contribute comparatively little. The emissions produced are mainly from the manufacture of the PV panel and foundation. No emissions are associated with the operation of the solar water pump itself.

TABLE VIII
COMPARISON OF 0.3 KG DIESEL PUMP WITH 1 KWH SOLAR PUMP

Method	EDIP 2003 V1.01/Default	
Indicator	Characterization	
Skip categories	With result = 0	
Impact category	Diesel water pump	Solar tubewells
Resources (all)	7.41E-05	7.31E-05
Bulk waste	1.59E-02	1.06E-02
Human toxicity soil	2.42E-01	2.03E-02
Human toxicity water	4.05E+00	1.56E+00
Human toxicity air	4.86E+04	4.86E+03
Terrestrial eutrophication	5.88E-02	4.63E-03
Acidification	7.48E-02	6.13E-03
Ozone depletion	5.73E-07	1.53E-08
Global warming 100a	6.11E-01	7.63E-02

Acidification is caused by pollutants such as SOx, NOx and NH. After mixing with water in the atmosphere, these produce acid rain, which is harmful to living beings as well as nonliving objects. Solar water pumps contribute very little to this impact category compared to diesel pumps, which are associated with the emissions produced by diesel combustion and transportation. Solar pumps eliminate this risk because they rely on solar power.

Human toxicity relates to the production of arsenic and HF. While the use of both diesel and solar pumps produces these substances, the latter does so in the manufacturing phase, not the operation phase. Diesel, however, contributes to this category throughout its lifecycle, mostly during diesel extraction (which affects the soil and water) and combustion (which affects the air).

V. CONCLUSION

The key advantage of solar energy is that it produces negligible emissions, with clear environmental benefits in terms of reducing the production of greenhouse gases. At a household level, switching to solar energy reduces energy costs. This study shows that subsidizing the switch to solar energy makes people more willing to adopt the technology, given that their monthly bills for electricity or diesel are reduced to 0. The NPV and LCA analysis indicate that there is potential for substantial personal and environmental cost saving.

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