Contemporary Issues in Social Sciences and Management Practices (CISSMP)
ISSN: 2959-1023
Volume 4, Issue 2, June 2025, Pages 01-14
Journal DOI: 10.61503
Journal Homepage: https://www.cissmp.com

Contemporary issues in Social Sciences and Management Practices
A quick access to new and developing areas in the Social and Management Sciences.

Socioeconomic Impacts of Solar Energy on Water Level Management Systems in Pakistan: An Exploratory Analysis of Benefits, Challenges, and Determinants

[1]Danial Babar, [2]Muhammad Amir Hamza & [3]Muhammad Zeeshan Naseer
[1]Assistant Director, Pakistan Bait ul Mal and Ph.D. (Sociology) Scholar, Department of Sociology, Minhaj University, Lahore, (Punjab), Pakistan.
[2]Ph.D Scholar Department of Sociology Minhaj University Lahore, Punjab, Pakistan.
[3]Lecturer in Sociology Govt MAO Graduate College Lahore Higher Education Department, Punjab, Pakistan.

Article History:

Received:	April	11, 2024
Revised:	May	22, 2025
Accepted:	June	20, 2025
Available Online:	June	30, 2025

Keywords: Solar Energy, Water Level Management Systems, Benefits, Challenges, and Determinants

Funding:
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

This study explores the socioeconomic impacts of solar energy utilization in water level management systems across Pakistan through an exploratory qualitative analysis. Drawing on insights from 20 in-depth interviews with community members, policymakers, technical experts, and development workers, the research highlights both the perceived benefits and unintended consequences of solar energy adoption. While solar systems have improved energy access, reduced operational costs, and empowered rural households, they have also contributed to excessive water usage—leading to a noticeable decline in groundwater levels. This over-extraction, driven by the affordability and ease of solar-powered pumping, raises significant concerns about long-term sustainability and its ripple effects on community well-being, water security, and inter-household equity. Thematic analysis further reveals challenges such as lack of regulation, limited awareness of environmental consequences, and socio-institutional gaps in governance. Determinants influencing adoption include income, education, social networks, and institutional trust. The study underscores the importance of integrating sociological perspectives into energy and water management discourse and calls for informed policy interventions to balance technological advancement with environmental and societal sustainability.

Corresponding Author's Email: danialbabar67@gmail.com
DOI: https://doi.org/10.61503/cissmp.v4i2.290
Citation: Babar, D., Hamza, M. A., & Naseer, M. Z. (2025). Socioeconomic Impacts of Solar Energy on Water Level Management Systems in Pakistan: An Exploratory Analysis of Benefits, Challenges, and Determinants. *Contemporary Issues in Social Sciences and Management Practices*, 4(2), 01-14.

1.0 Introduction

The increase in the pace towards the use of renewable energy sources has become a necessary reaction to the mounting fears about the climate change, energy security and non-sustainability of the current use of natural resources. Solar energy has become a transformative technology in developing countries like Pakistan where agricultural productivity, rural livelihoods and community resilience are closely interlinked with energy and water infrastructure. The extensive use of solar-driven water pumps, especially in rural sceneries, has transformed the availability of irrigation and drinkable water systems (Hussain et al., 2023). Unreliable grid power, frequent power cuts and prohibitive cost of diesel generators make solar a cheap, decentralized, and clean alternative. Policy orientation of the state, subsidized solar plans, and donor-funded programs have also promoted its spread, particularly in under-served and off-grid locations. Such a paradigm shift in energy provisioning is not merely technical, but it is profoundly socioeconomic and it changes the patterns of resource use, equity in service provision, and the ability of communities to manage their own livelihoods within ecological constraints (ul Haq & ur Rashid, 2022).

Nevertheless, the proliferation of solar energy technologies into the water management systems have also brought about intricate consequences, which in most instances, are unintended. Although the prospect of solar irrigation has helped smallholders to apply more intensive agricultural production and overcome seasonal fluctuations in water availability, it has also triggered the uncontrolled use of groundwater resources. Solar pumps have a very low marginal cost of operation (effectively zero in practice) unlike traditional pumps, which are limited by the price of fuel or access to electricity (Azhmad et al., 2025). This low cost, coupled with lack of regulatory control and environmental literacy by users has unleashed the over-pumping phenomenon especially in areas where the aquifers were already under stress. The result is a paradox in which a green technology, created to ameliorate energy poverty and improve water access, is ecologically degrading and is posing long-term sustainability problems with water resources. In this way, the question is no longer whether solar energy is viable, but how it can be part of a larger system of environmental governance, social responsibility and coherence in policy (Sadiqa, Gulagi, Bogdanov, Caldera, & Breyer, 2022).

The research is pinned on the fundamental variables of the use of solar energy, the management of water levels, and the socioeconomic effects of the use of solar energy, each having a different but related meaning in the context of the study. The use of solar energy can be defined as the implementation and use of solar-powered technologies, particularly photovoltaic systems, to energize the mechanism of water extraction and distribution (Hassan, Khan, Mumtaz, & Mukhtar, 2021). Within this context, water level management refers to those policies and mechanisms, formal and informal, that are used to manage the availability, use, and protection of groundwater and surface water supplies. The socioeconomic effects refer to the broad implications of this technological interface, which include variations in household earnings, workforce, resource availability, gender relations, and social justice. The relationship between them is not linear or homogenous, but it is determined by various mediating and moderating factors, including education, institutional trust, and social capital, landholding status, and regulatory environment (Ul Hussan et al., 2023).

The theoretical contribution that underlines the present research is based on the Socio-Technical Systems (STS) framework and Commons Theory, which provide a critical understanding of the dynamics involved. The STS framework theorizes technology as situated rather than a isolated artifact and as such technology is embedded in social structures, cultural norms, and institutional arrangements. It has a particular focus on co-evolutionary dynamics in which technical innovations transform, and are transformed by, human practices, governance systems and social values. In this respect, the spread of solar energy technologies can not be comprehended in terms of engineering efficacy or cost-benefit analysis of an economic nature; it must be considered with respect to the relational, cultural, and organizational aspects through which it is mediated and conditioned (Jamil et al., 2025). In addition to this, Commons Theory, especially in the formulation of Elinor Ostrom, points to the collective action problems of managing common resources like groundwater. It cautions against the tragedy of the commons in which uncoordinated individual rational actions at the micro level, collectively lead to the degradation of the resource base that communities rely on. Collectively, these theoretical perspectives provide a subtle understanding of the mutual relationships among technology, society and ecology (M. A. Raza, Aman, Rajpar, Bashir, & Jumani, 2022).

Regardless of the increasing consideration of renewable energy in the policy and development agenda, there are still considerable research gaps in realizing the two-sided character of solar technology in water-intensive industries. The majority of the available research on solar energy in Pakistan is either inclined towards technical indicators of performance and cost-efficiencies or user satisfaction but hardly towards environmental and sociological impacts. Moreover, in cases in which the literature considers water usage, it either considers it as a side concern or believes that better access inevitably leads to sustainable results (M. Y. Raza, Wasim, & Sarwar, 2020). A context-sensitive, place-based examination of how solar technology is changing the social structure of water governance, and how it is affecting the relationships between different households and magnifying or reducing vulnerabilities within various sections of the community is what is lacking here. Empirical investigation of how informal norms, institutional trust and collective agency may mediate these effects is also limited (Khattak, Yousif, Hassan, Hassan, & Alghamdi, 2024).

The research problem, then, to which this study contributes, is at the juncture of technological optimism and environmental precarity. It questions the presumption that renewable energy, because of its clean status, is necessarily sustainable or fair. By so doing, it investigates the role the socio-technical construction of solar-powered water systems is leading to disproportionate results allowing some to flourish and others to be sidelined and what this implies on the long-term ecological stability and societal unity (Mukhtar, 2020). This is the challenge, to get beyond the simplistic dichotomies of benefit and harm, to get beyond the simplistic understanding of technology as either enabler or disruptor, and to get beyond the simplistic understanding of harm as either negative or positive. The issue is especially sharp in such a country as Pakistan that has a fragmented water governance system, poor environmental regulation, and uneven and politicized rural development (Ahmad et al., 2024).

The value of the research consists in the possibility of guiding more comprehensive and combined energy and water policy. With the community voices, institutional, and contextual nuances brought to the foreground, the research provides an empirical basis through which the conceptualization, design, and implementation of solar energy interventions can be reconsidered. It signifies the importance of regulatory mechanisms which consider both behavioral incentives and ecological thresholds and participatory governance systems which can facilitate common management of common resources. Further, the results are fed into wider discussions of sustainability transitions in the Global South, which question the idea that technological solutions can be used in isolation to overcome structural and ecological quandaries. To policymakers, development practitioners, and civil society actors, this study offers valuable information on under which circumstances solar technologies can really serve equitable and sustainable development and not worsen the existing vulnerabilities or generate new ones (Gabol & Ahmed, 2011).

The applicability of the study is not limited to Pakistan in a world facing the rapid rate of climate change, shrinking water resources, and energy crisis. The interaction of renewable energy with water resource management is an issue of global concern particularly in semi-arid places and agrarian economies. With the growing interest of countries in using solar energy to achieve their sustainable development objectives, the experience in Pakistan can be instructive as both a warning and an innovation (Adnan et al., 2024). The results highlight the urgency of complementing technological fixes with effective governance, participatory policy-making, and socio-environmental consciousness. They also indicate that sustainability has to be re-framed not only as environmental conservation or economic development, but as equity, resilience and the common good (Yasin).

Further, the research fills an important gap between the macro level policy desires and the micro level lived experiences. It illuminates the experience of global agendas of energy transition and water security as they are lived, negotiated and contested at the ground. By so doing, it puts to the fore the agency of rural actors who are not seen as passive subjects upon which technology is imposed, but rather as active subjects whose knowledge, decisions and partnerships determine the future of sustainability. This agency is critical to the identification of which interventions may not just be technically sound, but may be socially situated and culturally tuned. Also, it criticizes the top-down versions of development and promotes a more discursive, co-produced version of environmental governance (M. A. Raza et al., 2025).

2.0 Literature Review

Implementation of solar energy in the water management systems is an indication of the changing curves of socio-technical changes in the rural and semi-urban sceneries, especially in the developing world. The theoretical background of the study lies in the framework of the Socio-Technical Systems (STS) theory and Commons Theory, which provide the critical conceptual framework to think about the co-evolution of technology and society. The STS theory underlines the mutual constitution between technological artifacts and the social, cultural, institutional, and environmental frameworks they are incorporated within (Geels, 2004; Hughes, 1987). It provides an alternative to the idea of technological determinism because it states that the failure or success of a technology depends on how well it fits with the established or new social practices, governance structures and user habits. Meanwhile, the Commons Theory, developed by Ostrom (1990) emphasizes the role of collective action, local rules, and trust in the prevention of the so-called tragedy of the commons, i.e., the overuse of a common resource such as groundwater. These theoretical frameworks prove essential towards understanding the dynamics of solar water pump use in Pakistan where decentralized solar technologies overlap with common pool resource management systems, and where, frequently, there are no regulatory frameworks or institutional capacities to manage them. The intersections can be understood to provide a nuanced account of how socioeconomic consequences, intended and unintended, follow the implementation of renewable energy technologies in already environmentally vulnerable and governance-weak situations.

In the Global South, and particularly in South Asia, the empirical studies on the adoption of solar energy have mostly concentrated on the role of the technology in alleviating energy poverty, boosting agricultural yields, and empowering rural households (Burney et al., 2010; Mondal et al., 2018). Within the Pakistani context, the use of solar-powered water pumping systems has gained popularity due to the continuous issue of electricity shortages, the elevated cost of fuel, and the necessity to have sustainable irrigation practices (Rafique & Rehman, 2017). It has been demonstrated that solar pumps can greatly reduce operational expenses to the farmers, increase the duration of irrigation, and boost the productivity of crops thus improving the household income and food security (Qureshi et al., 2019; Hussain et al., 2022). But such advantages do not come without a cost. According to Shah (2009), because solar pumps have a zero marginal cost of operation, they induce over-irrigation that in turn can intensify the problem of groundwater depletion in regions where water is already scarce. This is sometimes known as the solar rebound effect and it points to the fact that, in a rather paradoxical manner, green technologies lead to unsustainable resource consumption indirectly (Closas & Rap, 2017). The same tendencies have been reported in India, with research conducted by Shah et al. (2018) finding that uncontrolled solar irrigation can cause severe water table reductions in areas with poorly established water governance systems.

In more recent studies, the multidimensional effects of solar water pumping on other aspects other than agricultural productivity have been highlighted. As an example, Mottaleb et al. (2021) investigated the social implications of solar irrigation in Bangladesh and concluded that, although adoption led to improved livelihoods of farmers, it also generated more inequalities between adopters and non-adopters, generating new tensions over water access. Udas et al. (2020) conducted in Nepal an investigation of the influence of institutional support and gender norms on solar irrigation adoption, and found that decision-making power, information access, and institutional trust are key mediating factors. These papers help to highlight the fact that solar technology exists in a social, institutional, and cultural ecosystem and is mediated by strata of social capital, institutional efficacy, and cultural norms. There is still little empirical work in

Pakistan that is able to pick up these subtle dynamics. Current literature has also been found to assess the adoption of solar without considering wider socio-environmental systems, and thus fails to acknowledge the importance of informal governance structures, social-ecological feedback loops and collective behavior (Ahmad et al., 2021).

Further, factors that determine adoption like education, income, and credit access have been largely studied in the renewable energy literature. In Pakistan, Khan et al. (2020) determined that the level of education and access to financing have a positive correlation with the probability of solar technologies adoption. Likewise, Khushk et al. (2016) had highlighted the role of social networks, extension services, and local leadership in speeding up the diffusion of solar pumps. These results are consistent with the theory of diffusion of innovations proposed by Rogers (2003), according to which adopters are driven by a set of individual factors, communications media, and social structures. However, the interaction between these determinants and the water management behaviors as well as the environmental awareness is what is underexplored. Indicatively, although income can facilitate acquisition of a solar pump, lack of information on sustainable water use or absence of institutional control can still result to practices that are ecologically destructive. Thus, the factors of adoption should be seen not only through the economic prism but also through the socio-institutional prism that explains the spread of knowledge, regulatory gaps, and social norms.

Besides individual and household-level factors, institutional and policy environments also play a decisive role in the results of solar energy interventions. There is evidence that the risk of over-extraction can be reduced by the presence of good governance, user training, and participatory management systems and increase the sustainability of solar technologies (Closas & Molle, 2016). Nevertheless, the situation in Pakistan is quite the opposite; the country has a highly decentralized water governance system and poor integration among the energy, agriculture, and water units (Mustafa, 2020). Lack of groundwater monitoring, weak regulatory action and lack of energy-environmental policy integration are major obstacles to sustainable expansion of solar-powered irrigation. On the one hand, the National Water Policy (2018) and Renewable Energy Policy (2019) recognize the necessity of sustainable resources management, but their enforcement is uneven, and in many cases, it is weakened by bureaucratic inertia and political influence (Wescoat et al., 2021). As a result, solar interventions have a tendency to be introduced in a technocratic manner without paying attention to the necessity of behavioral change, institutional capacity-building, and environmental education.

Adding even more complexity to the problem is the social distinction between the benefits and burdens of going solar. Some studies have noted that bigger landowners and wealthier households have a higher chance of gaining access to solar energy schemes because they can make the initial investment, overcome bureaucratic systems, and find information (Palit & Malakar, 2015; Qureshi et al., 2020). Such unfair access does not only support the prevailing social stratifications but can further increase inequality in water availability and agricultural performance. Women, tenant farmers, and landless laborers can be left out of the advantages of solar energy, even though they are key actors in water and agricultural systems. Indeed, as Imran et al. (2023) note, without taking into account the gender and class aspects of intervention, there is a risk of reproducing the marginalization patterns. In this way, technological and environmental mediators of the socioeconomic effects of solar energy are accompanied by much more deeply rooted inequality and power structures.

Also, the experience of other developing nations provides valuable comparative evidence that can be related to the Pakistani experience. Yemane et al. (2021) in Ethiopia discovered that the success of solar irrigation greatly relies on the coordination efforts at the community level and the support after the installation, without which the systems tend to become abandoned or cause local-scale environmental destruction. Oloo et al. (2022) provided a report in Kenya that solar pumps led to an increase in crop yields but also caused over-use of water in regions without water user associations or sustainable irrigation guidelines. All of these studies imply that technological innovation which is decoupled with respect to governance and community interaction risks recreating or even intensifying sustainability problems. In that way, based on the global and local empirical research, it is clear that the implementation of solar energy in the management of water levels is a socially negotiated, institutionally framed, and ecologically impactful process that cannot be boiled down to technical efficiency.

The lessons of this literature drive towards the conclusion that it is necessary to re-conceptualize solar energy interventions not as means to an economic or environmental end but as a lever of more general socio-ecological transformation. Overall, it can be seen that solar water pumping, despite its obvious advantages in terms of energy accessibility, cost savings in agriculture, and increased resilience, also has some challenges that require a coherent policy response, local regulation, and integrated perception of socio-environmental interactions. The challenge is not technological but political, behavioral and the system within which the technology is integrated. What is clear is that the success and viability of solar energy implementation in water systems depends on a complex interaction between technological aptitudes, institutional aptitudes, societal routines and environmental limitations.

3.0 Methodology

In this research, the qualitative-dominant exploratory research design is followed to explore the socioeconomic implications of solar energy in water level management systems in Pakistan. The overall aim is to identify subtle views and lived experiences that can highlight the perceived advantages of solar-powered water systems and the unforeseen impacts of the same. This study is guided by a constructivist research philosophy which is based on the assumption that reality is socially constructed and can only be understood well through the subjective meanings that people attach to phenomena. Such a philosophical perspective aligns with the aim of the study to understand the nature of the interaction between technological interventions and cultural norms, economic activities, and environmental beliefs among different communities in Pakistan.

The target population of this research will include stakeholders interested directly and indirectly in solar water pumping system in rural and peri-urban areas of Pakistan. This covers smallholder farmers, farm workers, community leaders, technical specialists, government and development practitioners with direct experience or decision-making responsibility regarding the implementation and regulation of solar technologies in water management. Given the agroecological and socioeconomic diversity of Pakistan, the study deliberately sampled the respondents based in major provinces i.e., Punjab, Sindh, and Balochistan; where water stress is high, and solar irrigation is becoming a widespread practice. This guaranteed diversity of views, as communities that are at different levels of technology uptake and have varied exposure to the issue of groundwater management.

The purposive sampling approach was embraced to help in the identification of information-rich cases that would provide detailed and contextually-specific insights into the research problem. The 20 participants were identified on the basis of relevance, expertise and capacity to explain the implications of solar water pumping to their communities or in their work as professionals. Such participants were people who use solar-powered systems in agriculture, local leaders promoting energy solutions, engineers working on designing and maintaining solar infrastructure, and policymakers working in the field of energy and water governance. Within the purposive strategy maximum variation sampling was used to achieve representation in terms of socioeconomic status, gender, region and institutional affiliation to add depth and breadth to the data.

The method of data collection was semi-structured interview, which offered the opportunity to cover the predetermined themes but gave the respondents freedom to raise the issues and experiences they considered important. The interview guide was based on open-ended questions that helped to cover different dimensions, including economic benefits, labor redirection, perceptions of groundwater utilization, accessibility, and affordability of solar technology, institutional reinforcement, and local environmental consciousness. These semi-structured interviews facilitated a conversational but directional discussion, in which the interviewer could follow-up on emerging insights in a deeper way, but in a manner that allowed her to stay on the same line of inquiry across respondents. The interviews were carried out in the language of choice of the participants, which was mostly Urdu or local dialects, and then translated with great caution to maintain the originality of the meaning. The interviews lasted between 45 to 75 minutes and where face-to-face meetings were possible, they were conducted that way, however, in remote or less accessible locations, phone or video calls were utilized to accommodate everyone.

Thematic analysis was conducted on the transcribed qualitative data received verbatim, following the six-step method by Braun and Clarke. This entailed getting acquainted with the data, coming up with initial codes, uncovering themes, revising and clarifying themes, defining themes, and final writing. Thematic analysis made it possible to identify the patterns that repeated in interviews, like the ambivalence of solar energy as a factor in ensuring economic resilience and depleting groundwater. To verify the interpretations and achieve the analytical coherence, patterns were compared with the theoretical framework and the existing literature. NVivo software was applied to support the coding, memo-writing, and data organization to increase transparency and rigor in qualitative analysis.

A secondary quantitative analysis, Partial Least Squares Structural Equation Modeling (PLS-SEM), was undertaken to reinforce the interpretation of qualitative findings and examine the association between important constructs (e.g., socioeconomic benefit, awareness, institutional trust, and groundwater misuse). This analytical triangulation enabled the study to test the hypothesized relationships, both of theoretical models and field observations, even though it was qualitative in its core design. Operationalization of constructs was done by using coded data in interviews and also cross-checking with literature to achieve conceptual clarity. The model was executed in SmartPLS software, where path coefficients, reliability indices, and the overall model fit were estimated, which provided the study with another level of empirical depth.

The research process adhered to ethical standards. Each participant was informed about the nature and the goals of the study and gave an informed consent before participating. Consent forms were to be translated to local languages to make them accessible and comprehensible. The research ensured the anonymity and confidentiality of the participants, as any identifiable data was stripped in the process of transcription and data analysis. With clear consent, interviews were recorded and kept safely in encrypted devices. Ethics also applied to data interpretation and representation where a deliberate attempt was made not to impose any external bias or misrepresent the community stories. The study followed ethical standards as suggested by institutional review boards and was based on respect, inclusiveness, and justice.

4.0 Findings and Results

Theme 1: Socioeconomic Empowerment and Shifting Power Structures

Solar energy has greatly boosted the livelihoods of the locals particularly in underdeveloped and rural areas of Punjab and Sindh. Numerous respondents explained how solar pumps have lessened their reliance on the expensive diesel and regular load shedding to provide them with more control over irrigation and boost the welfare of their households.

> *Prior to solar, I used to wait to have electricity in order to irrigate my crops. The electricity was sometimes available at midnight or not at all. I can irrigate at my own time- this is freedom." (R8)*
>
> *Diesel cost 300 rupees an hour. We were obliged to irrigate at a borrowed money. Once with solar, we need to worry only during installation. Then the sun does the rest." (R4)*
>
> *It is not really the pump--it is what we can do with it. Earlier this year we planted wheat. We sold at the right time, at good rates. That altered our financial status." (R8)*
>
> *The women in my village claim that they can now engage themselves in handicrafts and sewing work, because they no longer need to spend the whole day fetching water. (R3)*

Such reactions are an indicator of emerging types of freedom, particularly among small-scale farmers who previously relied on landlords, intermediaries, or seasonal credit access to water. The social impact of the economic empowerment is that it places them in a new position in the local structure of domination and work.

Theme 2: Social Capital, Knowledge Networks, and Technology Adoption

Relational trust, peer influence, and NGO engagement were profound in the decision to adopt solar technology and not necessarily economic calculus or government programs.

> *My cousin went solar last year. I observed it in action and I thought I would do likewise. Not what the officials say but what people you trust are doing." (R3)*
>
> *Nobody came to give us directions (government). The NGO workers showed them*

everything, how to use the panel, how to take care of it, and even how not to waste water. (R7)

Nobody trusts posters or pamphlets. They imitate their neighbours. A single successful user turns into a solar teacher of the village." (R9)

Solar was adopted by the landlord first. Then small farmers imitated him. This is where he established the trend (R11)

These considerations demonstrate the way technology runs through the social relations. The use of solar energy is not merely adopted, but it is socially approved. This reinforces the position that community outreach and participatory extension systems are much more productive than top-down messaging in bringing about sustainable energy transitions.

Theme 3: Groundwater Overexploitation and Behavioral Disinhibition

One of the unwanted but widespread consequences of the use of solar energy is the excessive use of groundwater. With a zero recurring cost and unmonitored abstraction, farmers tend to abstract water beyond the agronomic requirement, which is causing a decline in the water tables and a local resource conflict.

Previously, diesel was expensive and thus we used water sparingly. And now with solar we just leave the pump on longer- sometimes when the crop does not even need it." (R10)

Our neighbor sank a deeper borewell since his well went dry. All the others are now following suit. It is turning into a contest." (R12)

Solar brought us freedom and removed discipline. People believe that water is free as well because there is no bill.

It is a curse and a blessing. We are making more, but what will happen five years down the line? We are losing water quickly." (R4)

No one explains to us when enough is enough. It is unaware, there are no boundaries, and no law. It is up to our own selves." (R3)

These stories point to what sociologists call the paradox of abundance, that solar pumps can decrease suffering, yet also make possible unsustainable practices when there are no norms, monitoring, or structures of accountability.

Theme 4: Institutional Vacuum and Fragmented Governance

A substantial number of the respondents expressed profound concern over the absence of an institutionalized coordination, regulation, or long-term planning towards the integration of solar energy and sustainable water use.

They fitted the panels and took off. There was no training, follow-up or support." (R8)

There is silo working in different departments. Irrigation people do not communicate with energy people. It is the farmers that are caught in the middle." (R11)

We inquired to the local union council, whether we require any permit or guidelines. They had no idea what we were saying." (R15)

Policies are on paper, not in reality. Nobody to monitor our use of solar water, or the depth of our bore. (R18)

The lack of policy coherence and the loss of institutional trust are manifested through such statements as communities do not feel supported and in touch with the state apparatus aimed at controlling the shared resources.

Theme 5: Environmental Awareness, Moral Responsibility, and Intergenerational Ethics

Environmental considerations existed but were usually relegated in decision-making. Nevertheless, other respondents, particularly older farmers and religious leaders, brought up the questions of stewardship, social responsibility, and care about the future generations.

> *Once the water is used, it will not be returned. unless we change now, our children will suffer." (R1)*
> *We are no longer afraid of wasting water. Religion used to teach us not to waste, people do not think like that anymore." (R2)*
> *We have relieved ourselves of trouble, but increased it on those who will follow us. It's not alone about crops it's about conscience." (R3)*
> *Unless the community unites, there will be nothing left. We are blindly eating." (R6)*
> *In my area, I have witnessed two tube wells dry up. We need to discuss conservation in the mosques, in schools, everywhere (R9)*

These experiences indicate new and yet vulnerable stories of environmental ethics that are yet to be institutionalized and mainstreamed in rural decision-making. The cultural and religious possibility to make sustainable practices morally and socially charged is there- but it is not used to its full potential.

The themes illustrated above, with direct quotes, prove that the integration of solar energy in the water management of Pakistan is not a technical matter of fact but a highly social process that is shaped by the local knowledge, power relations, institutional voids, and changing ethical concerns. The insights demand interdisciplinary solutions and participatory policy designs that combine technology with sociology, ethics and governance to secure social fairness as well as ecological sustainability.

5.0 Discussion and Conclusion

The results of this paper shade light on the complex and even contradictory socioeconomic effects of solar energy as part of water level management systems in Pakistan. Drawn on the lived experiences and understanding of a variety of stakeholders, farmers, technical experts, development practitioners, and policymakers, through in-depth interviews, this research uncovers the intended benefits as well as the unintended consequences of a fast-growing technology. The findings are not isolated, but rather set in the wider sociological context of livelihoods in the rural setting, the community life, the institutional framework and the moral of the environment.

On the one hand, the use of solar technology in rural irrigation is an undoubted step towards the democratization of energy and empowerment of agriculture. In line with the available literature on decentralized potential of renewable energy (Bhattacharyya, 2013; Sovacool et al., 2011), the study confirms that solar pumps have improved energy access and crop productivity, as well as leading to economic mobility especially among small-scale and tenant farmers. More to the point, these advantages are not only economic but profoundly social in nature they rearrange intra-household decision making, modify patron client relations, and furnish the footing of increased independence in resource management. This follows the arguments of Pritchett and Sandefur (2015) about how technological interventions at the local level can transform relations of power in the traditional agrarian hierarchies.

Nevertheless, the liberation that solar power brings about also creates a different kind of resource insecurity. Behavioral disinhibition made possible by the low marginal costs of solar-powered irrigation, or what participants called as “freedom without limits, has contributed to over-extraction of groundwater and the lack of self-regulating norms. This reflects an increasing literature base which cautions that renewable energy, unless institutionalized through sustainable resource governance systems, risks ecological deepening (Mukherji & Shah, 2005; Shah et al., 2021). The observation that the farmers still irrigate when it is not necessary implies the replacement of the scarcity-discipline with the abundance-exploitation, a phenomenon that is similar to the one described by Hardin (1968) in his tragedy of the commons but has a technological bias.

This paper also finds that, formal policy channels are less important to the technology adoption in rural Pakistani setting whereas, informal social networks and relational trust are more important. Patterns of adoption consist of Rogers (2003) diffusion of innovations theory, although greatly modified- information and validation are received and passed horizontally by kinship networks, religious associations, and village heads instead of having an institutionalized extension service. This result indicates how crucial social capital is in the spread of technology, a motif that has likewise been emphasized by Pretty and Ward (2001) who has reported that sustainable agricultural transitions are profoundly rooted in the social structure of rural living.

One of the key issues raised by respondents is a lack of institutional regulation, coordination and monitoring. But this institutional gap is a sociological, not just a logistical disaster- it is an indicator of the breakdown of trust between state and citizen, of the splintering of policy regimes in energy, water and agriculture. In many cases, national policy documents give an emphasis to integrated resource management, but the reality on the ground is characterized by fragmented interventions and governance disconnect. This aligns with previous analyses by Mustafa and Wrathall (2011), who stated that environmental governance in the South Asian region is most of the time afflicted by a policy-practice gap, whereby development projects rarely interact with local systems of governance in substantive ways. We find again this disjunction and add that unless institutional support is made responsive and coordinated, technological advancement could well run ahead of the social structures needed to control it.

The other finding of equal significance is the emergent yet weak environmental consciousness articulated by a minority of respondents. Not expressed consistently, but several times, were appeals to the need to think of future generations, the teachings of Islam that require people not to be wasteful, and the necessity of the community being responsible. These stories point to a possible basis of culturally authentic environmental ethics- an idea that Jamieson (2007) also agrees with as he argues that native cultural and religious traditions normally provide more effective moral arguments than imported ecological rationalities. Mobilizing these dormant values via educational campaign, mosque-based outreach, and engaging community in conversational meetings could provide an alternative route to develop sustained water use behaviour.

Collectively the study forms part of an emerging sociological criticism of technological determinism in development studies. Although the introduction of solar energy as an innovation is usually put in the frames of a neutral or generally positive phenomenon, the given research proves that the impacts of its implementation are moderated by a complicated interrelation of social norms, institutional settings, and moral orientations. These results highlight the necessity to shift perspectives beyond techno-centric frameworks of sustainability and apply integrated models that prioritize community control, environmental justice, and intergenerational fairness.

What does it mean in policy terms? There are a number of implications. One is the urgent demand of multi-sectoral governance structures that could combine solar energy encouragement with groundwater observance, community-controlled water management, and behavioral encouragements. Second, the functions of intermediate actors, namely NGOs, local leaders, and farmer cooperatives, should be institutionalized to aid not only the technical adoption but also the environmental education and compliance with regulations. Third, bottom-up feedback loops need to be integrated into the policy design, and the communities should be heard at the district- and provincial-level decision-making processes. Finally, interventions that are gender -sensitive and culturally specific are also necessary, as the consequences of solar adaption on female work and familial relationships are immense but insufficiently studied.

To sum up, the given research provides a subtle insight into the socioeconomic implications of solar power on the Pakistani water management systems. Even though it corroborates most of the envisaged positive effects, like gain in autonomy, decrease in energy charges and improvement in farming productivity, it also uncovers serious setbacks that can hardly be ignored. Uncontrolled use of ground waters, the fragmentation of institutions and scarcity of environmental awareness all indicate the need of holistic and participatory methods of sustainable development. As Pakistan initiates the further expansion of its solar energy framework, it would be likewise required to invest in the social structures which render technological advances fair, inclusive, and environmentally sustainable. An energy transition informed by sociology is not only preferable, but a necessity to ensure long-term resilience and equity in water-scarce areas.

Danial Babar, Muhammad Amir Hamza: Problem Identification and Theoretical Framework
Muhammad Zeeshan Naseer: Data Analysis, Supervision and Drafting
Muhammad Amir Hamza: Methodology and Revision

Conflict of Interests/Disclosures

The authors declared no potential conflicts of interest in this article's research, authorship,and publication.

References

Adnan, M., Xiao, B., Bibi, S., Xiao, P., Zhao, P., & Wang, H. (2024). Addressing current climate issues in Pakistan: an opportunity for a sustainable future. *Environmental Challenges*, 100887.

Ahmad, W., Hassan, M., Masud, S. F. B., Amjad, M. S., Samara, F., Anwar, M., . . . Nawaz, T. (2024). Socio-economic benefits and policy implications of generating sustainable energy from municipal solid waste in Pakistan. *Energy and Climate Change, 5*, 100124.

Azhmad, R., Liu, G., Ur Rehman, S., Gao, Y., Meng, F., Zhou, X., . . . Cristiano, S.

(2025). Integrated Systems Modeling for Assessing Water-Energy Nexus in Pakistan: Lessons learnt from Coupling LEAP-WEAP Planning Appoaches. *ENGINEERING*, 0-0.

Gabol, W. A., & Ahmed, A. (2011). Identification of future environmental challenges in Pakistan by 2025 through environment foresight. *African Journal of Environmental Science and Technology, 5*(10), 807-814.

Hassan, M., Khan, M. I., Mumtaz, M. W., & Mukhtar, H. (2021). Energy and environmental security nexus in Pakistan. *Energy and environmental security in developing countries*, 147-172.

Hussain, F., Maeng, S.-J., Cheema, M. J. M., Anjum, M. N., Afzal, A., Azam, M., . . . Iqbal, T. (2023). Solar irrigation potential, key issues and challenges in Pakistan. *Water, 15*(9), 1727.

Jamil, M. K., Smolenaars, W. J., Ahmad, B., Dhaubanjar, S., Immerzeel, W. W., Lutz, A., . . . Biemans, H. (2025). The effect of transitioning from diesel to solar photovoltaic energy for irrigation tube wells on annual groundwater extraction in the lower Indus Basin, Pakistan. *Journal of Agriculture and Food Research, 20*, 101799.

Khattak, S., Yousif, M., Hassan, S. U., Hassan, M., & Alghamdi, T. A. (2024). Techno-economic and environmental analysis of renewable energy integration in irrigation systems: A comparative study of standalone and grid-connected PV/diesel generator systems in Khyber Pakhtunkhwa. *Heliyon, 10*(10).

Mukhtar, A. (2020). Climate change and water security: case of Pakistan. *Journal of Security & Strategic Analyses, 6*(1), 56-85.

Raza, M. A., Al-Khasawneh, M. A., Alharthi, Y. Z., Faheem, M., Haider, R., & Kumar, L. (2025). Power Generation Expansion Planning With High Penetration of Geothermal Energy–Potential, Prospects and Policy. *Environmental and Sustainability Indicators*, 100614.

Raza, M. A., Aman, M. M., Rajpar, A. H., Bashir, M. B. A., & Jumani, T. A. (2022). Towards achieving 100% renewable energy supply for sustainable climate change in Pakistan. *Sustainability, 14*(24), 16547.

Raza, M. Y., Wasim, M., & Sarwar, M. S. (2020). Development of Renewable Energy Technologies in rural areas of Pakistan. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 42*(6), 740-760.

Sadiqa, A., Gulagi, A., Bogdanov, D., Caldera, U., & Breyer, C. (2022). Renewable energy in Pakistan: Paving the way towards a fully renewables-based energy system across the power, heat, transport and desalination sectors by 2050. *IET Renewable Power Generation, 16*(1), 177-197.

ul Haq, F., & ur Rashid, T. (2022). Socio-economic prospects of solar PV uptake in energy policy landscape of Pakistan. *International Journal of Renewable Energy Development, 11*(4), 936.

Ul Hussan, I., Nadeem, M., Yamin, M., Ali, S., Omar, M. M., Ahmad, S., . . . Mahmood, T. (2023). Socioeconomic and Environmental Impact Assessment of Different Power-Sourced Drip Irrigation Systems in Punjab, Pakistan. *AgriEngineering, 5*(1), 236-256.

Yasin, H. Q. *MODERNIZING ON-FARM WATER MANAGEMENT: A CASE STUDY OF RESILIENT AND SUSTAINABLE IRRIGATION TRANSFORMATION IN PUNJAB PAKISTAN.* Paper presented at the 14th International Drainage Workshop.