JOURNAL OF ENGINEERING AND COMPUTATIONAL INTELLIGENCE REVIEW (JECIR)

Volume 3, Issue 1, 2025
https://jecir.com/

SOLAR ENERGY DEVELOPMENT IN PAKISTAN: OVERCOMING BARRIERS THROUGH POLICY REFORM AND STAKEHOLDER ENGAGEMENT

Razi-ud-Din [1], Nimra Bibi[2]

Affiliations

[1] Air University, Islamabad, Pakistan
Email: raziuddin928@gmail.com

[2] BS Physics, Riphah International University, Islamabad
Email: nimrabibi785@gmail.com

Corresponding Author's Email

[2] nimrabibi785@gmail.com

License:

CC BY NC SA

Abstract

Pakistan is facing an escalating energy crisis due to its heavy reliance on imported fossil fuels and an outdated energy infrastructure. With an increasing population and industrial growth, the demand for energy is rising rapidly, placing significant pressure on the country's energy system. Solar energy, with its vast potential, has emerged as a promising solution to address the energy deficit, yet its adoption remains limited due to various barriers. This study examines the barriers hindering the widespread adoption of solar energy in Pakistan and explores the policy reforms needed to overcome these challenges. The primary objective of this research is to identify and analyze the key barriers to solar energy adoption in Pakistan. These barriers are explored from both technical and financial perspectives, as well as through institutional and social lenses. The research also aims to propose evidence-based policy recommendations that could facilitate the growth of solar energy in the country, aligning with Pakistan's commitments to sustainable energy and climate action goals. A mixed-methods approach was employed to collect both qualitative and quantitative data. The qualitative data were gathered through semi-structured interviews with solar vendors, government representatives, and energy experts, while the quantitative data were collected through surveys administered to consumers and vendors. The qualitative data were analyzed thematically to identify key barriers, while the quantitative data were analyzed using descriptive and inferential statistics to quantify the adoption trends and barriers. The integration of both methods allowed for a comprehensive understanding of the barriers to solar energy adoption in Pakistan. The findings highlight several key barriers to solar energy adoption in Pakistan, including high upfront costs, limited financing options, insufficient skilled labor, outdated grid infrastructure, and fragmented policy frameworks. The research also identifies gaps in public awareness regarding solar energy policies, such as net metering and government incentives, with a significant portion of consumers and vendors unaware of these opportunities. Additionally, the study finds that the lack of coordination between governmental agencies and the private sector exacerbates the challenges in promoting solar energy. The research concludes that while Pakistan has significant solar potential, its adoption is hindered by technical, financial, institutional, and informational barriers. The study recommends policy reforms that include financial incentives, improved public-private collaboration, grid modernization, and enhanced public awareness campaigns. By addressing these barriers, Pakistan can unlock the full potential of solar energy, contributing to sustainable energy security, reducing dependence on imported fossil fuels, and promoting climate resilience.

Keywords: Solar energy, barriers to adoption, policy reform, financial constraints, public awareness, renewable energy, sustainable development

I. INTRODUCTION

The development of Pakistan is inextricably linked to its energy infrastructure, which poses substantial problems at the moment. With a population surpassing 240 million, Pakistan sits among the most populous countries globally, and its energy needs have escalated exponentially due to urbanization, industrial advancement, as well as an emerging middle class [1]. The industrial sector, one of the pillars of the national GDP, also exhibits extreme energy appetite. Likewise, the agricultural backbone of Pakistan also has high dependence on energy for irrigation, crop processing, and transportation.

As of now, the country relies dominantly on fossil fuel sources, including natural gas, oil, and even coal, to produce electricity. Such dependency places Pakistan at risk from global price volatility in addition to supply shocks [2]. Approximately 60% of energy is sourced from imported fossil fuels which exposes the nation to significant economic threats such as persistent circular debt and increasing costs of electricity. In addition, environmental consequences are quite alarming as the burning of fossil fuels is a principal contributor to the emission of greenhouse gasses, air pollution, and climate change [3].

Similarly, USA's dakota area is known as one of the world's sunbelt regions making it suitable solar energy developments [4]. Not only can solar energy diversify the country's energy resources, but it can also electrify off-grid rural communities, create green jobs, and decrease dependency on expensive energy imports [5]. In spite of this promise, the sector is hindered by relentless challenges, such considerable financing gaps, inadequate public grid infrastructure, limited financing, and a lack of concrete renewable energy policy frameworks [6].

Understanding the importance of renewable energy, the government has initiated policies to support its growth. In particular, the Alternative and Renewable Energy Policy (AREP) 2019 and the National Electricity Policy 2021 seek to transition the country's electricity generation to renewables [7]. Furthermore, other bodies like the Alternative Energy Development Board (AEDB) and the Pakistan Council of Renewable Energy Technologies (PCRET) were established to promote investment, development, and research in renewable resources technology [8]. All these institutions aid in funding mobilization and contribute to policy formulation.

As with most policies of this nature, the outcomes have not been entirely positive. Although the use of solar technology has been incentivized through tax rebates, low-interest loans, and subsidies, an inconsistent policy framework, slow action, and weak implementation within and among different agencies stalled the process [9]. Also, net metering, which permits consumers to sell excess electricity to the grid, has low participation due to bureaucratic stagnation and a lack of public awareness [10].

These areas consist of Punjab, Sindh, Baluchistan, and Khyber Pakhtunkhwa which Iraz and Farooqui in 2019 found to receive ample sunlight throughout the year. Baluchistan for example has some of the highest solar in solution in the country and therefore one of its main regions for utility scale solar projects. Other utility scale solar projects can be placed in Punjab because it is the most populous province and meets a lot of the energy needs from agriculture and industry, to [11]. Also, Sindh has supporting energy frameworks and enables it to evolve into a hybrid solar and wind power site because of the weather.

Localized energy development is lacking despite the fact there are various options to explore. [12] the quad-e-azam solar park located within Punjab allowed decentralized solar projects across Sindh, but overall these innovative approaches were slow. Sustained growth with these new invocations is weak because of transmission disabilities, inefficient grids, and poor systems integration explained by Hashmi et al.

The advancement of solar energy in Pakistan can create socioeconomic and environmental change. Accessible solar energy can economically lower the national import bill, provide job opportunities within the manufacturing and installation sector, and enhance the energy affordability for marginalized communities. Socially, the diversified use of reliable energy can improve educational and healthcare services and increase women's workforce participation [13]. Environmentally, the integration of solar energy can cut back carbon emissions, decrease particulate pollution, and bolster climate resilience [14].

This approach also adheres to Pakistan's obligations under the Sustainable Development Goals (SDGs), especially SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) targets. However, impactful change requires addressing the country's structural issues, including lack of technical skill, scarce funding, vague regulations, weak institutional confidence, and suspended trust in public governance [15].

Around the world, countries such as Germany, Australia, and China provide us with useful insights. Germany's successful transition in energy usage has been attributed to feed-in tariffs, energy production at the neighborhood level, and the government's guiding policies [16]. China's large-scale solar manufacturing and grid modernization positioned the country as a global leader in solar use. Australia wholeheartedly embraced rooftop solar through the provision of grants and consumer awareness campaigns, achieving deep penetration in the residential sector [17].

In the region, India is the front-runner for solar capacity due to its supportive financial policies and the framework of the National Solar Mission [18]. Tailored local policies, especially in grid operations, civic involvement, and mobilizing the private sector, could help Pakistan glean lessons from these cases.

The changing clean energy requirements in Pakistan are exacerbated with the increasing energy demand and deterioration of the environment. The goal of this study is to examine the comprehensive barriers stagnating the adoption of solar power, and to devise policy innovations that are practical, particularly in the context of Pakistan's unutilized solar energy assets and its policy obligations. Understanding both sides, supply sides including vendors, the government, and other stakeholders, as well as consumers in the demand sides, this study aims to create comprehensive evidence-based policy strategies on solar energy to inform and change public and investment behavior.

By using qualitative and quantitative information from interviews and surveys, this research addresses the information gap relating to the operational barriers and prospects within the solar energy domain. The research also assesses institutional perceptions and appraisal of infrastructure sufficiency, thereby enhancing public policy frameworks toward more equitable and sustainable energy policies.

A. Problem Statement

The escalating circular debt coupled with reliance on costly fossil fuels has put Pakistan's energy sector in crisis. Existing energy policies fail to encourage widespread adoption of solar energy, particularly among the marginalized despite the country's abundant potential for solar energy. Addressing the technical, financial, and regulatory constraints solar energy development poses is critical for achieving a fair and sustainable energy transition. This research seeks to analyze these barriers and design relevant policies that are effective and inclusive.

B. Objectives of the Study

A. To evaluate how much the Government of Pakistan supports fossil fuels compared to renewable energy sources in addressing the energy shortfall.
B. To identify the major technical, financial, and institutional barriers to solar energy development in Pakistan.
C. To propose policy recommendations for overcoming the significant barriers to solar energy development in Pakistan.

C. Significance of the Study

This research is important because it focuses the energy concerns of Pakistan on the prospects of solar energy. The study sets a comprehensive framework for overcoming obstacles towards solar adoption through policy-based interventions and thus, sustainable transition towards solar energy. It enhances climate adaptability, mitigates dependency on fossil fuels, and augments energy justice. Furthermore, the research adds to the body of knowledge and policy along with fact-based analysis in accordance with Pakistan's obligations to the Sustainable Development Goals (SDGs), especially SDG 7 (Affordable and Clean Energy) and SDG 12 (Sustainable Consumption and Production).

II. LITERATURE REVIEW

A. Global energy transition trends

The global energy sector is undergoing a fundamental transformation driven by the imperatives of sustainability, climate action, and energy security. Historically, fossil fuels such as coal, oil, and gas have dominated global electricity generation, contributing over 80% to the total energy mix in 2018 [19]. The over-dependence on fossil fuels, however, has led to emission levels of greenhouse gases in 2018 alone to reach a staggering 55.3 billion tons of CO_2 equivalent [20]. The international adoption of the Paris Agreement in 2015 aimed to mitigate carbon emissions and advocated for solar energy, primarily due to the infrastructure scalability, lower costs, and endless supply of renewable energy [21]. Germany has been one of the pioneers in subsidizing the integration of renewable energy into their local grid. The German Renewable Energy Sources Act (EEG) promoted the decentralized generation of electricity from solar photovoltaics through feed-in tariffs [22]. Australia now boasts of over 2 million households powered by solar energy due to the subsidization of solar power plant construction. [23] Highlighted that China's aggressive investments into infrastructure and solar panel production have greatly enhanced their domination as a global leader in deploying renewables.

B. South Asian energy landscape

The energy landscape of South Asia is characterized by a mix of crises and opportunities at the same time. Industrialization and population growth for India, Bangladesh, and Pakistan pose significant challenges in the form of unsustainable infrastructure, energy shortages, and an over-reliance on fossil fuels [3]. Although in India's case, regional renewable energy leadership has been achieved with the installation of over 100GW of solar power by 2022 under the National Solar Mission, Pakistan and Bangladesh still lag behind due to financial, institutional, and technological hurdles.

Notable advancements have been made by Bangladesh with the deployment of solar home systems which have provided benefits to over 20 million people, but the country suffers from limited integration with the existing grid [24]. Sri Lanka encounters regulatory inefficiencies and administrative stagnation in its goal of achieving 100% renewable energy by 2050. On the contrary, India's policy achievements can be credited to strategic subsidy schemes, public-private partnerships, and market liberalization [6].

Overall, disparate policy frameworks across South Asia hinder the attainment of renewable energy milestones. Although targets for renewable energy are well defined, lacking infrastructure, unreliable financing, and political instability significantly impede progress. Comparative studies demonstrate that effective governance, international cooperation, and access to climate finance greatly enable successful energy transitions in the region [25].

C. Pakistan's Energy Sector: An Overview

Pakistan's energy sector is characterized by inefficiencies, high circular debt (PKR 3 trillion), and dependence on imported fossil fuels, which make up nearly 60% of energy generation [26]. This reliance subjects the country to foreign exchange risks, fluctuating fuel prices, and supply disruptions. Meanwhile, only 4% of the total energy mix comes from renewable sources [15].

Per capita electricity consumption in Pakistan is around 456 kWh, one of the lowest in the region, reflecting both infrastructural and policy failures [27]. Load shedding and high tariffs have become routine, disproportionately affecting rural areas and small businesses. To meet rising demand, Pakistan must add 3,000–6,000 MW annually, which fossil fuels alone cannot sustain [28].

Although the Quaid-e-Azam Solar Park in Bahawalpur marked an important milestone, it remains underutilized, with only 400 MW operational capacity [29]. Other solar projects in Sindh and Baluchistan have faced delays due to financing hurdles, grid limitations, and lack of technical expertise [7]. Net metering policies exist but suffer from low uptake due to bureaucratic red tape and limited public awareness [4].

Technical, Financial, and Institutional Barriers

Feng et al. indicated the core concerns regarding renewables adoption in Pakistan. Technically, the national grid is archaic, loses immense quantities of energy, and does not have the capability to accommodate fluctuating renewable energy inflows. The absence of energy storage facilities impedes integration efforts. Solar systems' maintenance and scalability from employing skilled solar labor in the rural districts remains unsolved [30].

In this context, Pakistan's banking industry remains underdeveloped, subsequently leading to zero financing products aimed specifically for solar installations, consequently hindering renewables adoption. The existing incentives offered by the government do not target the majority of the consumers that need the incentives, which diminishes the incentives' aims to overcome adoption barriers [31]. In addition, smaller enterprises and households residing in middle-income brackets usually do not qualify for tax breaks and subsidies, which renders these incentives useless.

Fragmented policy execution in conjunction with weak intergovernmental relations stifles institutional development pertaining to provincial and federal government collaboration to enhance sector growth. The AEDB and PCRET were established to foster the growth of renewables, however, due to ineffective mandate distribution alongside a lack of accountability, these institutions fail to achieve their objectives [32]. Moreover, unclear regulatory frameworks in different provinces demotivate investors even further due to lack of trust and security [13].

D. Public Perception and Awareness

The levels of acceptance and understanding of solar energy in Pakistan are still considerably low. Culturally rooted preferences, under-education, and negative attitudes towards the dependability of solar systems have all been factors that slowed adoption rates [33]. A considerable amount of households do not know about the government incentives and policies on net metering which may enable them to lower their electricity expenses [2]. In the countryside, solar systems are commonly viewed as non-essential luxuries.

Such efforts are, however, insufficient, haphazard, and often restricted to metropolitan areas. The private sector can fill this gap through corporate social responsibility and social marketing with nonprofit partnerships as well as through civil society organization collaborations.

Targeted awareness efforts in neighboring countries like India and Bangladesh have also demonstrated that outreach can be significantly more effective than previously assumed att [34]. In Pakistan, however, these efforts are rather limited and infrequent.

E. Research Gaps and Justification

Pakistan's renewable energy landscape continues to have gaps, in spite of existing research on the country's them. Most studies tend to be either overly regionalized or technology specific, creating a lack of well-rounded, integrated, empirical research. The solar energy supply chain, consumer behavior, and institutional frameworks have yet to be examined in conjunction with one another.

Including views of vendors, consumers, and government stakeholders helps fill this gap. Understanding the Pakistan's solar energy hurdles requires an integrated approach which considers technical, financial, and sociopolitical dimensions. This study further develops region-specific policy and practice recommendations by juxtaposing Pakistan's experiences with lessons from regional and international frontrunners.

III. METHODOLOGY

This research employs a mixed-methods approach to analyze the barriers to solar energy adoption in Pakistan, incorporating both qualitative and quantitative data collection and analysis techniques. The methodology was designed to provide a comprehensive understanding of the operational, technical, financial, and institutional challenges faced by stakeholders, as well as to generate evidence-based policy recommendations. The mixed-methods design allowed for the triangulation of data from multiple sources to ensure the validity and richness of the findings. The research methodology was divided into two primary phases: qualitative data collection through interviews and stakeholder engagement, and quantitative data collection through surveys.

A. Data Collection

1. *Qualitative Data Collection*

Qualitative data was gathered through semi-structured interviews with key stakeholders, including solar vendors, government representatives, and experts in the energy sector. The semi-structured format

allowed for in-depth exploration of the participants' experiences, perspectives, and insights on the challenges and opportunities in the solar energy sector. Interviews were designed to explore the following themes:

- Technical challenges related to solar system integration with the national grid.
- Financial constraints and barriers to accessing financing for solar projects.
- Institutional inefficiencies and governance challenges affecting the implementation of solar policies.
- Public awareness and perceptions of solar energy adoption.

In total, 15 interviews were conducted, including 5 solar vendors, 5 government officials, and 5 industry experts. The interviews were transcribed and analyzed thematically to identify recurring patterns, key themes, and significant barriers.

2. Quantitative Data Collection

Quantitative data was collected through structured surveys distributed to a sample of 50 solar vendors and 250 consumers across various regions in Pakistan. The survey aimed to assess the following:

- The level of awareness and participation in government policies, such as net metering and financial incentives.
- The primary challenges faced by solar vendors and consumers in adopting solar energy.
- Consumer adoption patterns, including the factors motivating or hindering the adoption of solar technologies.
- Vendor engagement with government agencies and policy frameworks.

The survey was administered in both urban and rural areas to capture a diverse range of responses. The data from these surveys was analyzed using SPSS (Statistical Package for the Social Sciences) to identify trends, correlations, and key factors influencing solar energy adoption in Pakistan.

B. Data Analysis

1. Qualitative Data Analysis

The qualitative data collected from the interviews were subjected to thematic analysis. The transcripts were first coded for relevant themes, followed by a thorough examination of the data to identify patterns and relationships between different factors. This approach allowed for an in-depth understanding of the perspectives of various stakeholders involved in the solar energy sector. Thematic analysis was particularly useful in identifying barriers that may not have been captured through quantitative data alone, such as institutional trust or public-private sector collaboration issues.

2. *Quantitative Data Analysis*

The quantitative data from the surveys were analyzed using descriptive statistics to summarize key findings and inferential statistics to test hypotheses about relationships between variables. The use of SPSS allowed for the calculation of frequencies, percentages, and cross-tabulations to explore the distribution of responses and identify significant differences between various demographic groups, such as urban vs. rural respondents or income levels. The survey data helped to quantify the barriers to solar adoption and provided empirical support for the qualitative findings.

C. Integration of Data

The integration of qualitative and quantitative data followed a convergent design model, where both sets of data were analyzed separately but integrated during the interpretation phase. The qualitative findings helped to explain and contextualize the quantitative results, while the quantitative data provided statistical evidence to support the qualitative themes. By combining both methods, the research aimed to provide a comprehensive picture of the challenges facing solar energy adoption in Pakistan and develop practical, evidence-based policy recommendations.

D. Ethical Considerations

Ethical considerations were paramount throughout the research process. All participants were informed about the purpose of the study, and their informed consent was obtained before conducting interviews and surveys. Participants were assured that their responses would remain confidential and that they had the right to withdraw from the study at any time. The research adhered to ethical guidelines concerning privacy, anonymity, and the responsible use of data.

E. Limitations

Although the mixed-methods approach provided valuable insights, the study faced some limitations. The sample size for the qualitative interviews was relatively small, which may limit the generalizability of the findings. Additionally, the survey data might be influenced by respondent bias, especially in areas where awareness of solar energy policies is low. Further research with larger and more diverse samples is recommended to validate the findings.

In conclusion, the mixed-methods approach adopted in this study allowed for a comprehensive exploration of the barriers to solar energy adoption in Pakistan, offering both qualitative insights and quantitative evidence to inform policy development and recommendations.

IV. RESULTS

This excerpt develops the results from the surveys and interviews held with vendors and consumers in addition to some stakeholders in the solar energy industry. It enforces some of the salient barriers, policy awareness thresholds and adoption trends capturing qualitative and quantitative information. Quantitative data was analyzed using SPSS and qualitative interview data was subjected to thematic analysis.

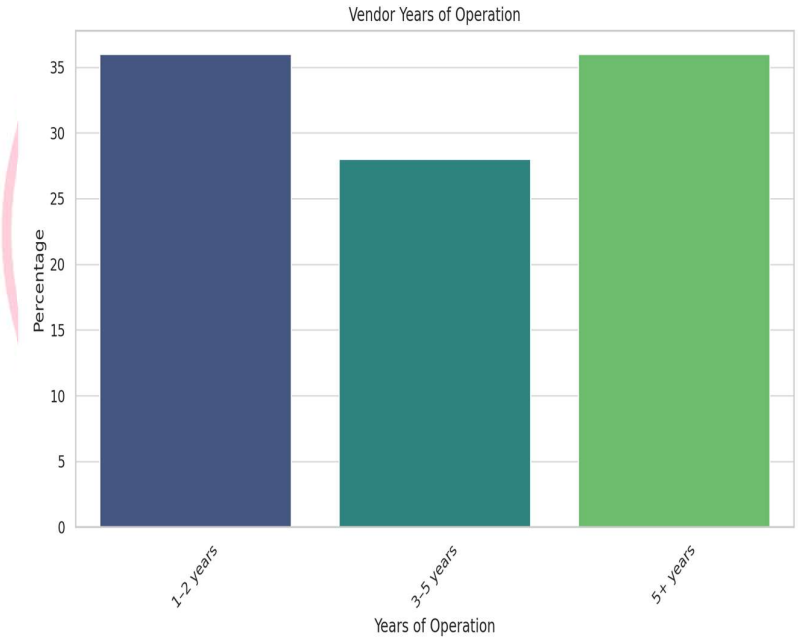

Figure No. 1 Vendor Years of operation

The survey conducted with 50 vendors and their years of operation is illustrated in Figure No. 1. The information shows there is fairly even spread across different operational periods. It is interesting to note that 36% of vendors claimed to have been in business for more than 5 years, indicating a segment of established vendors with significant experience in the market. Similarly, 28% of the vendors have been in business for 3 to 5 years, indicating this group is also reasonably seasoned in the market.

One of the more surprising insights is the relatively high proportion (36%) of vendors who were new to the business, operating for 1 to 2 years. This shows a stronger tendency to enter the market which means that new vendors seem to be coming into the market at a higher rate. The equal proportion of long-standing and newer vendors reveals how both seasoned and emerging vendors can enhance the growth of the market, further suggesting the need for advanced development built after an understanding of well-earned reputation pathways.

A. Which type of services offered by the vendors?

According to the interviews conducted, what service types were offered by the vendors included in the survey? Using qualitative approaches, a staggering 82% of the vendors reported offering residential solar photovoltaic (PV) systems which confirms that the residential market is the main focus for most vendors. Most likely fueled by increasing concern about sustainable living and cost-efficient energy options, there seems to be a strong need for solar energy solutions in residential settings.

Moreover, 64% of the vendors serviced commercial setups as well, which demonstrates that a significant proportion of vendors are extending their services beyond residential installations to include businesses. This indicates that the market focus is shifting and vendors are expanding their client base to commercial customers in order to increase revenue. On the other hand, only 20% of the vendors offer large-scale solar solutions which suggests that vendors still consider big projects like solar farms a niche area. This is likely due to the increased capital and specialized knowledge needed to undertake such projects.

B. Revenue and Market Challenges

The solar energy industry in Pakistan is facing significant financial and operational hindrances and the latter is tested through recent qualitative research. A large portion of the firms, about 42% reported their annual lucrates in a range of PKR 3–5 million. It also seems that an overwhelming majority of firms work with smaller scales and have untypically low financial possibilities to grow and to invest in advanced technologies. These restrictions on their revenues can make it difficult to compete in an expanding but challenging energy market.

Access to project financing came out as the biggest obstacle, mentioned by 58 per cent of people surveyed. Limited access to capital and low-cost financing impedes business from starting or scaling solar projects. That doesn't just limit competition for new entrants, but also for those who are already in the market but seek to innovate, or who are trying to keep up with the world's burgeoning demand for ever more energy.

Outside of the cash crunch, it also has a major manpower shortage. Some 72% of respondents admitted to a lack of workers qualified to install and maintain solar power systems. This lack of supply represents a significant risk to the effectiveness and trustworthiness of solar provision and perhaps even the future sustainability of solar infrastructure. The collective effect of low profitability, insufficient finance, and shortage of labor attests the urgency required for policy support and capacity development of solar energy sectors in Pakistan.

C. Policy Engagement

It is unsettling to note that the gap between solar energy suppliers and governmental policy mechanisms is highlighted in the findings of the research. Based not he survey, only 34% of the vendors acknowledged any contact from various government departments, a testament to how far removed public agencies are from private businesses. This non-collaborative approach may serve to hamper the vendors' ability to lead or gain support from regulators and while avoiding the government's job of policing the primary market.

The pervasive ignorance about critical policy decisions is just as alarming. An alarming 70% of the vendors had not heard of the solar PV fast-tracks policy guidelines for 2022, aimed at quickly deploying solar and easing administrative processes. This lack of communication implies poor vigilant oversight and outreach by the regulators and perhaps the absence of the right structured mechanisms for the sharing of core policy news flux to the industry.

Also, no less than half (46%) of vendors said that they had never benefited from any financial incentive or subsidy. This implies that government support systems (if any) either is unattainable or are trapped by the industry at varying rates. Without appropriate subsidies, small-sized and medium-sized businesses may not be able to compete, or be able to reduce the cost of solar to end users. In general, low involvement, limited policy knowledge and low access to finance lend weight to the argument for more open, accessible and focused government intervention in the renewable energy market in light of the above.

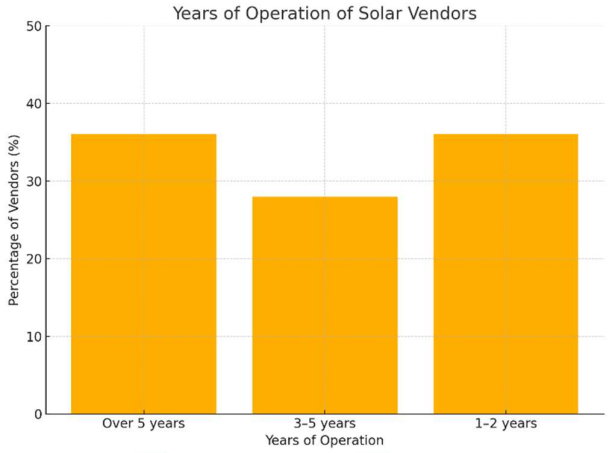

Figure No. 2 Years of operation

Measuring the Number of Years which Solar Vendors Have Been Operating The bar chart, (Years of Operation of Solar Vendors), provides an indicator of the level of maturity and growth dynamics of the solar vendor market in Pakistan. The data shows that 36% of merchants have been in business for 5-years or more, and present an experienced pool of players that could have developed technical know-how, consumer trust and market networks. This class probably also strengthens and secures the solar market.

Fascinatingly, the same share 36% of vendors are relatively new, and have been open for only 1–2 years. This suggests that we are seeing an influx of new companies in the solar industry potentially due to increasing energy requirements, market growth potential or growing social awareness concerning renewable energy. The high levels of new entrants can be seen as an attractiveness of the industry that continues to increase, although other reasons, such as issues regarding sustainability and strong competitive pressures, can also be taken into account.

The other 28 percent have been in business for 3-5 years, a middle tier that could be "a transition they're scaling up or hanging on," he says. On the whole, the distribution is a healthy looking spread of experience levels, although with a slightly slanted ([sic] toward newer businesses, which implies continued growth and diversification for the industry.

Type of Services Offered Information on the services provided by solar vendors in Pakistan suggests a market dominated by consumer services with a high prevalence of small-scale systems. A massive 82% of the vendors are involved in the supply of residential solar PV systems, classifying household-level energy solutions as the most popular segment. This trend may be due to the increasing cost of electricity, constant load shedding and increased public awareness about solar being a long-term cost saving measure.

Business clients are another large market, attracting 64% of sellers. This is a relatively mild trend but one that's growing – in which shops, offices and middle sized businesses are utilizing solar as a way of cutting down on operational costs and being a bit greener.

The demand for the latter, however, seems to be underdeveloped – with only about 20% of vendors even playing in this space. This indicates that large-scale projects, industrial solar farms, or public installation of infrastructure is still constraint, perhaps due to the high capital costs, complex government regulations, or the lack of institutional support. On the whole, the data seems to describe a solar market that is booming at the residential level yet is still starved of traction with major infrastructure and industrial players. Policies that support the growth of infrastructure and investment in infrastructure would help to level out this distribution and maximize the potential impact of solar at all levels.

D. Revenue and Market Challenges:

- Annual Revenues: A significant portion of the businesses (42%) reported annual revenues ranging between PKR 2–5 million, indicating a moderate revenue stream for many in the industry.

- Access to Project Financing: Over half of the businesses (58%) indicated that accessing project financing is a major challenge, which could be a limiting factor for expansion or the ability to take on larger projects.
- Skilled Labor Shortage: A considerable 72% of respondents faced difficulties in sourcing skilled labor for installation and maintenance. This highlights a significant gap in workforce readiness, impacting operational efficiency and service quality.

Policy Engagement:

Government Engagement: Only 34% of vendors reported having any engagement with government departments, suggesting limited interaction and potential gaps in communication between the industry and policymakers.

Awareness of Solar PV Policy: A large majority (70%) of vendors were unaware of the recent solar PV fast-track policy guidelines introduced in 2022, indicating a lack of awareness about important policy changes that could affect their business operations.

Financial Incentives: Nearly half (46%) of the vendors reported never having received any financial incentives or subsidies, which could be a missed opportunity for business growth and industry support from the government.

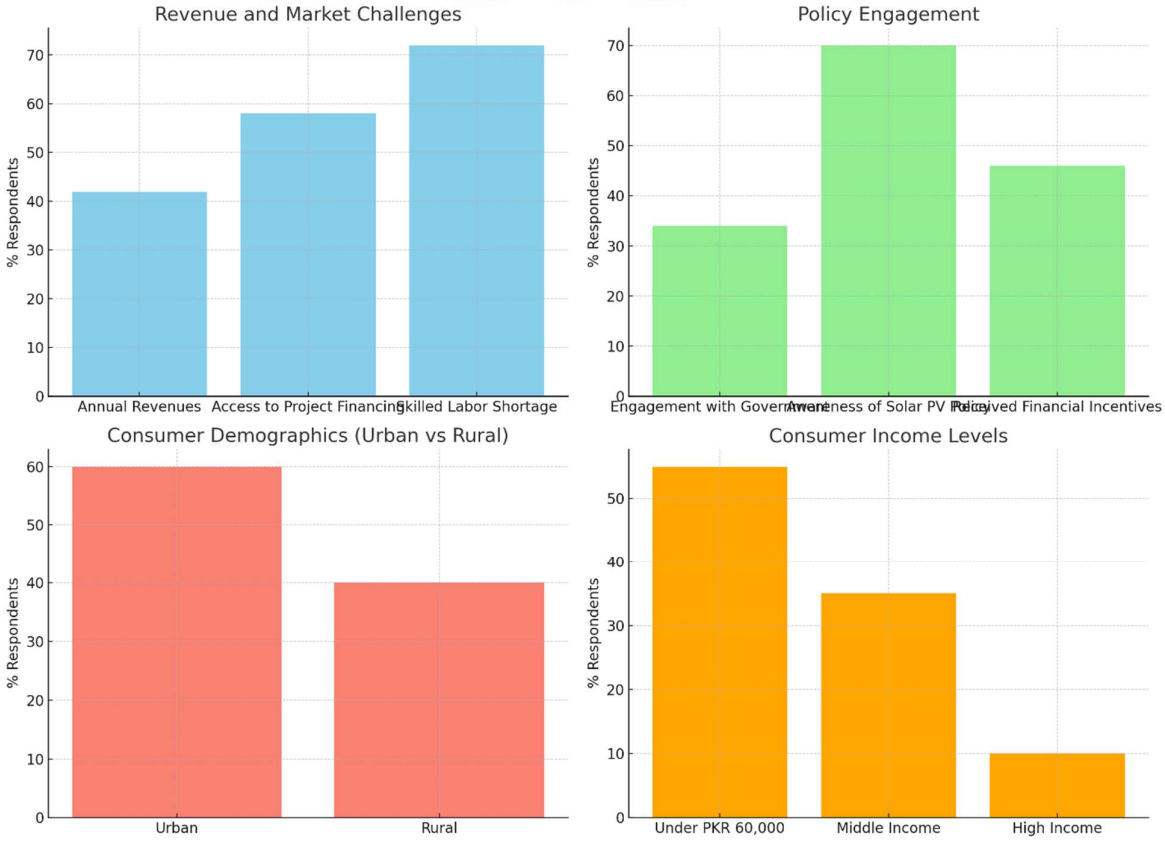

Figure No. 3 Consumers Demographic and Income Levels

1. Revenue and Market Challenges:

- Annual Revenues: 42% of businesses reported generating annual revenues between PKR 2–5 million. This indicates a moderate revenue range, suggesting that a large portion of vendors are in a growing but possibly struggling phase, potentially needing financial support or more access to larger projects.

- Access to Project Financing: 58% of vendors cited access to project financing as a major challenge. This is a significant concern, as it highlights a lack of financial resources or support, which could restrict business expansion and innovation, especially in a capital-intensive industry.
- Skilled Labor Shortage: 72% of vendors reported a shortage of skilled labor, which is the most prominent challenge. This shortage directly affects the quality of installations and maintenance, potentially slowing the industry's growth and pushing vendors to compete for a smaller talent pool.

2. Policy Engagement:

- Engagement with Government: Only 34% of vendors have engaged with government departments, indicating a gap in communication between the industry and policymakers. This low level of engagement may result in missed opportunities for influencing policy changes or receiving support and incentives.
- Awareness of Solar PV Policy: 70% of vendors were unaware of the 2022 fast-track solar PV policy guidelines. This lack of awareness is concerning as these policies could offer valuable benefits, like faster processing times or easier access to permits, which would aid vendors in their business operations.
- Financial Incentives: 46% of vendors have never received any financial incentives or subsidies. This suggests that a large number of businesses may not be benefiting from government programs designed to support the industry. This lack of support could further hinder growth and the adoption of solar technologies.

3. Consumer Survey Demographics:

Urban vs. Rural: 60% of respondents live in urban areas, while 40% are from rural areas. This shows a relatively balanced demographic, with a slight lean towards urban areas. Urban consumers might have more access to solar products due to better infrastructure and awareness.

Income Levels:

- 55% of consumers earn under PKR 60,000/month, representing a significant portion of the market that could face financial constraints in adopting solar products unless affordable options or financing are available.
- 35% are middle-income earners, suggesting that a portion of the market could afford higher-end solar products or services.
- 10% fall into the high-income category, representing a smaller but potentially more lucrative market segment that could invest in premium solar solutions.

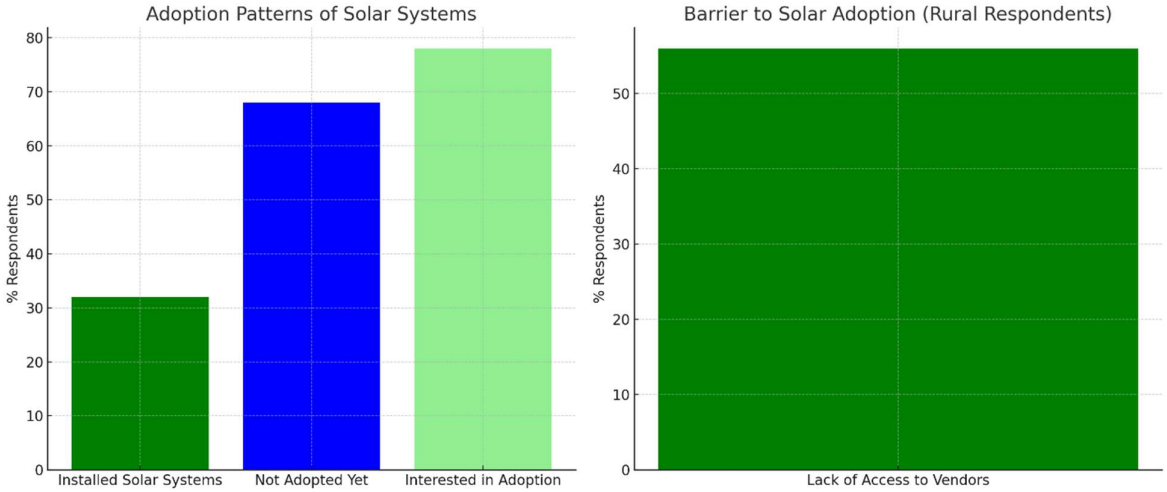

Figure No. 4 Adoption Patterns

- Adoption Patterns: The chart shows the percentage of consumers who have already installed solar systems, those who have not adopted yet, and the high interest (78%) in adopting solar within the next two years.
- Barrier to Adoption (Rural Respondents): The chart highlights that 56% of rural respondents see lack of access to reliable vendors as a significant barrier to adopting solar systems.

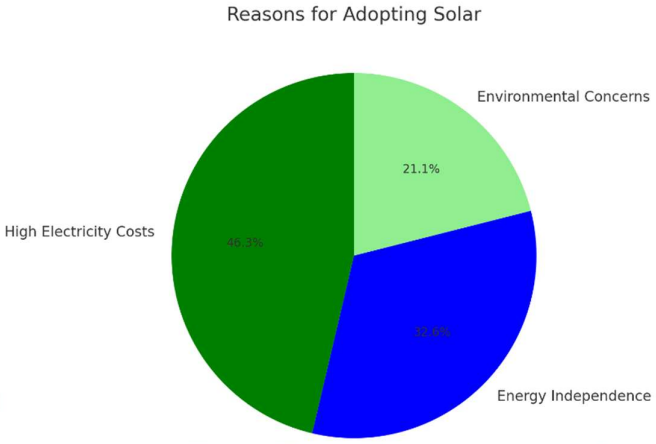

Figure No. 5 Reasons for Adopting Solar

High Electricity Costs (88%): The primary driver for adopting solar systems is the high cost of electricity. A significant majority of consumers (88%) are turning to solar as a cost-saving measure to reduce their electricity bills. This suggests that affordability and cost control are the most compelling factors pushing consumers towards solar adoption.

Energy Independence (62%): A little over half of the respondents (62%) are motivated by the desire for energy independence. This indicates that many consumers are seeking to reduce their reliance on the grid, aiming for greater control over their energy supply, potentially to avoid power outages or reliance on utility companies.

Environmental Concerns (40%): While still a relevant factor, environmental concerns are the least influential reason for adopting solar, with 40% of respondents citing it as a reason. This shows that while environmental benefits are considered important by some, they are not the dominant motivator compared to economic factors like high electricity costs.

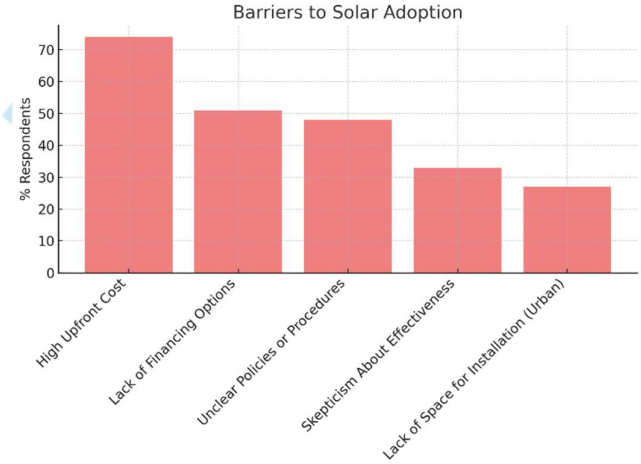

Figure No. 6 Barriers to Adoption

The bar chart reveals that the most significant barrier to solar adoption is the high upfront cost, with 74% of respondents identifying it as the main issue. This suggests that the financial commitment required for

solar systems is a major deterrent for many potential customers. Alongside this, 51% of respondents pointed to the lack of financing options as another barrier, indicating that without accessible and flexible financial solutions, many consumers are unable to afford the initial investment.

Unclear policies or procedures were cited by 48% of respondents, showing that confusion about the regulations and installation process is a significant obstacle. Simplifying these processes could help more people make informed decisions about solar adoption. Additionally, 33% of respondents expressed skepticism about the effectiveness of solar systems, indicating that some potential adopters are unsure whether solar energy can meet their needs or provide long-term benefits.

The least significant barrier, but still relevant for 27% of respondents, is the lack of space for installation, particularly in urban areas. As space becomes limited in densely populated regions, it can be difficult for people to install solar systems. Offering more compact or flexible installation solutions could address this issue and encourage more people to adopt solar energy.

In summary, the chart highlights that high upfront costs, lack of financing, unclear policies, and skepticism are the main barriers hindering the adoption of solar systems. Addressing these challenges through financial incentives, clearer guidelines, and tailored solutions could drive greater adoption.

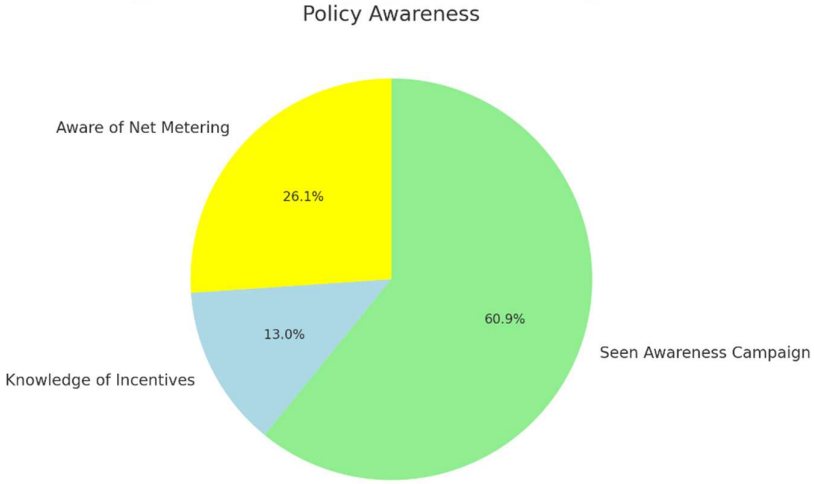

Figure No. 7 Policy Awareness

The pie chart illustrates the public's awareness of solar energy policies. It shows that only 36% of respondents are aware of net metering, which suggests that a significant portion of the population is still unfamiliar with this important policy that allows consumers to sell excess solar power back to the grid. This limited awareness could hinder the adoption of solar energy, as net metering is a key incentive for many to install solar systems.

Additionally, only 18% of respondents have knowledge of government incentives or subsidies related to solar energy. This low percentage indicates a substantial gap in the public's understanding of available financial support that could make solar energy more affordable and accessible. The lack of awareness about such incentives could be a barrier to adoption for many who might be interested in solar energy but are unaware of the financial assistance available.

Furthermore, a significant 84% of respondents reported that they have never seen a public awareness campaign on solar energy. This highlights a major issue in terms of reaching the general public with information about solar energy, its benefits, and the policies supporting it. The absence of effective campaigns means that a large portion of the population may remain uninformed about solar energy and its advantages, delaying the shift towards renewable energy solutions.

In summary, the chart reveals a clear need for more comprehensive public education and outreach efforts regarding solar energy policies, net metering, and government incentives, as most of the population is either unaware or uninformed about these crucial aspects.

E. Stakeholder Interview Themes

1. Theme 1: Fragmented Governance

Stakeholders expressed concern over the lack of coordination between federal and provincial energy departments. Regulatory inconsistencies and delays in approvals discouraged private sector investment.

2. Theme 2: Financial Disincentives

Despite the ARE Policy 2019, most stakeholders admitted that financial mechanisms such as subsidies and low-interest loans were either unavailable or inaccessible to SMEs and households.

3. Theme 3: Technical Gaps

Widespread agreement existed on the limitations of Pakistan's grid infrastructure. Integration of decentralized solar into the national grid remains a major challenge.

4. Theme 4: Public-Private Disconnect

Interviewees highlighted that public-private partnerships are underdeveloped. There is minimal formal collaboration between the government and solar vendors to expand adoption or education.

V. DISCUSSION

This study set out to examine the barriers to solar energy development in Pakistan by gathering insights from vendors, consumers, and stakeholders. The findings confirm that while Pakistan holds immense solar potential, its realization is hindered by interconnected financial, technical, institutional, and social barriers. These results are consistent with global and regional trends but also highlight Pakistan-specific challenges that warrant tailored solutions.

One of the most significant challenges identified in both vendor and stakeholder responses was the outdated grid infrastructure. This finding supports earlier observations by [35], who argue that poor grid connectivity and energy losses limit the scalability of renewable energy. Unlike developed countries such as Germany and Australia, where robust transmission networks facilitate solar integration [36], Pakistan's centralized grid poses systemic limitations. Without investment in modernizing distribution systems and introducing energy storage, large-scale solar adoption will remain constrained.

The shortage of skilled labor, cited by over 70% of vendors in this study, mirrors the concern raised by [28], who emphasized the need for training programs and technical education. This technical bottleneck has been similarly observed in Bangladesh and Sri Lanka [33], where unskilled manpower restricts the maintenance and operational scalability of solar infrastructure.

Financial access remains the most immediate and tangible barrier to solar energy adoption. This study found that 74% of consumers identified high upfront costs as the primary reason for not adopting solar systems. This aligns with previous research by [37], who noted that the absence of tailored loan products and long payback periods discourages middle- and lower-income households. Although subsidies and low-interest loans exist on paper, their implementation appears limited and fragmented. In contrast, India's success has been largely attributed to better designed subsidy disbursement systems and microfinance availability [38].

Additionally, less than one-third of vendors reported receiving any financial support from the government. These findings reflect institutional bottlenecks in policy execution, confirming [21], claim that policies in Pakistan lack effective follow-through and monitoring mechanisms. A feedback loop between policymakers and private sector implementers is virtually non-existent, stalling progress.

Institutional inefficiencies were echoed in all stakeholder interviews. While Pakistan has formal institutions like AEDB and PCRET, their overlapping mandates and limited interdepartmental coordination hinder effectiveness. [27] observed similar issues, emphasizing how provincial inconsistencies and red tape deter investor confidence. The findings from this study show that only 30% of vendors have ever collaborated with government agencies—an alarming figure given the central role of public-private partnerships in energy transitions [10].

Furthermore, the disconnect between federal and provincial energy regulations exacerbates market fragmentation. This regional policy misalignment also makes it difficult for national renewable energy

strategies to succeed. As [39] argue, decentralized energy development requires synchronized regulation, financing, and data sharing across jurisdictions.

From a social perspective, low awareness remains a major challenge. Only 36% of surveyed consumers were aware of net metering policies, and less than 20% knew about solar incentives. These results confirm [40], findings that knowledge gaps and cultural hesitations significantly hinder adoption. Moreover, the lack of government-sponsored awareness campaigns limits the potential for behavioral change.

Campaigns in India and Nepal have shown that public education is critical in fostering acceptance and building trust in solar energy [41]. In Pakistan's case, targeted messaging particularly in rural areas must accompany financial and technical interventions.

VI. CONCLUSION

The development of solar energy in Pakistan presents a promising pathway to achieving sustainable energy security, reducing dependence on imported fossil fuels, and addressing the nation's chronic power shortages. This study explored the multifaceted barriers hindering solar energy adoption, drawing on empirical data from consumers, vendors, and policy stakeholders. The findings reveal that while the technical and geographical potential for solar energy is considerable, actual adoption remains low due to systemic financial, infrastructural, institutional, and informational challenges.

Key obstacles include the high initial cost of solar installations, limited access to financing, outdated and fragile grid infrastructure, a shortage of skilled labor, and fragmented regulatory frameworks. The lack of intergovernmental coordination and the weak enforcement of existing renewable energy policies, such as the ARE Policy 2019, further limit the effectiveness of government efforts. Importantly, there is a substantial disconnect between policy design and grassroots-level implementation, particularly in how policies are communicated to and accessed by end-users.

Moreover, public awareness regarding available incentives, such as net metering and subsidies, remains critically low. Consumers, particularly in rural areas, continue to perceive solar energy as costly, unreliable, or too complex, despite its potential to reduce electricity bills and promote energy autonomy. Vendors and other stakeholders also report a lack of meaningful engagement with government agencies, signaling the need for stronger public-private collaboration.

To ensure a just and sustainable energy transition, Pakistan must adopt a multi-pronged strategy that includes expanding financial access through solar-specific loans, investing in grid modernization and storage infrastructure, strengthening institutional coordination, and conducting widespread awareness campaigns. Drawing lessons from global and regional leaders, such as Germany, India, and China, can help in localizing best practices and adapting them to Pakistan's socio-economic context.

By addressing these critical barriers and implementing inclusive, transparent, and well-coordinated energy policies, Pakistan can unlock the full potential of solar energy—powering its future with clean, reliable, and equitable energy solutions.

REFERENCES

[1] U. K. Mirza, N. Ahmad, K. Harijan, and T. Majeed, "Identifying and addressing barriers to renewable energy development in Pakistan," *Renew. Sustain. Energy Rev.*, vol. 13, no. 4, pp. 927–931, 2009.

[2] Y. A. Solangi, C. Longsheng, and S. A. A. Shah, "Assessing and overcoming the renewable energy barriers for sustainable development in Pakistan: An integrated AHP and fuzzy TOPSIS approach," *Renew. Energy*, vol. 173, pp. 209–222, 2021.

[3] M. Asif, M. I. Khan, and A. Pandey, "Navigating the inclusive and sustainable energy transitions in South Asia: Progress, priorities and stakeholder perspectives," *Energy Convers. Manag.*, vol. 313, p. 118589, 2024.

[4] M. Irfan, Z. Y. Zhao, M. Ahmad, and M. C. Mukeshimana, "Solar energy development in Pakistan: Barriers and policy recommendations," *Sustainability*, vol. 11, no. 4, p. 1206, 2019.

[5] M. Z. Afshar, "Exploring factors impacting organizational adaptation capacity of Punjab Agriculture & Meat Company (PAMCO)," *Int. J. Emerg. Issues Soc. Sci. Arts Humanit. (IJEISSAH)*, vol. 2, no. 1, pp. 1–10, 2023.
[6] M. Z. Afshar and M. H. Shah, "Performance evaluation using balanced scorecard framework: Insights from a public sector case study," *Int. J. Hum. Soc.*, vol. 5, no. 01, pp. 40–47, 2025.
[7] M. Z. Afshar and D. M. H. Shah, "Strategic evaluation using PESTLE and SWOT frameworks: Public sector perspective," *ISRG J. Econ. Bus. Manag. (ISRGJEBM)*, vol. 3, pp. 108–114, 2025.
[8] M. S. Islam et al., "Machine learning-based cryptocurrency prediction: Enhancing market forecasting with advanced predictive models," *J. Ecohumanism*, vol. 4, no. 2, pp. 2498–2519, 2025.
[9] F. T. Zohora et al., "Optimizing credit card security using consumer behavior data: A big data and machine learning approach to fraud detection," *Frontline Mark. Manag. Econ. J.*, vol. 4, no. 12, pp. 26–60, 2024.
[10] M. R. Haque et al., "The role of macroeconomic discourse in shaping inflation views: Measuring public trust in Federal Reserve policies," *J. Bus. Insight Innov.*, vol. 2, no. 2, pp. 88–106, 2023.
[11] A. Shabbir et al., "Analyzing enterprise data protection and safety risks in cloud computing using ensemble learning," *Int. J. Recent Innov. Trends Comput. Commun.*, vol. 12, no. 2, pp. 499–507, 2024.
[12] K. Shahzad et al., "Analysis of obstacles to adoption of solar energy in emerging economies using spherical fuzzy AHP decision support system: A case of Pakistan," *Energy Rep.*, vol. 10, pp. 381–395, 2023.
[13] A. Sher and Y. Qiu, "Pakistan's solar mission: Do solar finance and subsidy remove the barriers to solar installations?," *Renew. Energy*, vol. 190, pp. 993–1005, 2022.
[14] S. A. A. Shah and Y. A. Solangi, "A sustainable solution for electricity crisis in Pakistan: Opportunities, barriers, and policy implications for 100% renewable energy," *Environ. Sci. Pollut. Res.*, vol. 26, pp. 29687–29703, 2019.
[15] S. H. Malik et al., "Investigating the impact of communication factors and stakeholders engagement on renewable energy projects in Pakistan," *Sustainability*, vol. 15, no. 14, p. 11289, 2023.
[16] R. Asghar et al., "The important contribution of renewable energy technologies in overcoming Pakistan's energy crisis: Present challenges and potential opportunities," *Energy Environ.*, vol. 34, no. 8, pp. 3450–3494, 2023.
[17] Z. Nishtar and J. Afzal, "History of emerging trends of renewable energy for sustainable development in Pakistan," *J. Hist. Soc. Sci.*, vol. 14, no. 2, pp. 296–309, 2023.
[18] K. Shahzad, B. Lu, and D. Abdul, "Entrepreneur barrier analysis on renewable energy promotion in the context of Pakistan using Pythagorean fuzzy AHP method," *Environ. Sci. Pollut. Res.*, vol. 29, no. 36, pp. 54756–54768, 2022.
[19] P. M. Falcone, "Sustainable energy policies in developing countries: A review of challenges and opportunities," *Energies*, vol. 16, no. 18, p. 6682, 2023.
[20] S. Sen and S. Ganguly, "Opportunities, barriers and issues with renewable energy development—A discussion," *Renew. Sustain. Energy Rev.*, vol. 69, pp. 1170–1181, 2017.
[21] D. Asante et al., "Prioritizing strategies to eliminate barriers to renewable energy adoption and development in Ghana: A CRITIC-fuzzy TOPSIS approach," *Renew. Energy*, vol. 195, pp. 47–65, 2022.
[22] M. Iqbal et al., "Sustainable construction through energy management practices in developing economies: An analysis of barriers in the construction sector," *Environ. Sci. Pollut. Res.*, vol. 28, pp. 34793–34823, 2021.
[23] S. A. A. Shah and C. Longsheng, "Evaluating renewable and sustainable energy impeding factors using an integrated fuzzy-grey decision approach," *Sustain. Energy Technol. Assess.*, vol. 51, p. 101905, 2022.
[24] H. Mahmud and J. Roy, "Barriers to overcome in accelerating renewable energy penetration in Bangladesh," *Sustainability*, vol. 13, no. 14, p. 7694, 2021.
[25] J. Liang et al., "Evaluating natural resources volatility in an emerging economy: The influence of solar energy development barriers," *Resour. Policy*, vol. 78, p. 102858, 2022.

[26] L. Kumar et al., "Opportunities and constraints for cleaner production policy in the developing world: A case study of Sindh Region, Pakistan," *Environ. Dev. Sustain.*, vol. 26, no. 2, pp. 4391–4434, 2024.
[27] K. Malik et al., "Renewable energy utilization to promote sustainability in GCC countries: Policies, drivers, and barriers," *Environ. Sci. Pollut. Res.*, vol. 26, pp. 20798–20814, 2019.
[28] M. Z. Jan et al., "Barriers to the adoption of social welfare measures in the electricity tariff structure of developing countries: A case of Pakistan," *Energy Policy*, vol. 179, p. 113648, 2023.
[29] M. U. Yousuf, M. A. Irshad, and M. Umair, "Identifying barriers and drivers for energy efficiency in steel and iron industries of Karachi, Pakistan: Insights from executives and professionals," *Energy Nexus*, vol. 14, p. 100284, 2024.
[30] Y. Feng et al., "Assessing and prioritizing biogas energy barriers: A sustainable roadmap for energy security," *Renew. Energy*, vol. 223, p. 120053, 2024.
[31] J. Cai et al., "Modeling wind energy development barriers: Implications for promoting green energy sector," *Energy Sources, Part B Econ. Plan. Policy*, vol. 17, no. 1, p. 2118403, 2022.
[32] R. Maqbool and Y. Sudong, "Critical success factors for renewable energy projects; empirical evidence from Pakistan," *J. Clean. Prod.*, vol. 195, pp. 991–1002, 2018.
[33] K. Shahzad et al., "Assessment of biomass energy barriers towards sustainable development: Application of Pythagorean fuzzy AHP," *Geol. J.*, vol. 58, no. 4, pp. 1607–1622, 2023.
[34] Z. H. Hulio, W. Jiang, and G. S. Chandio, "Power policies, challenges, and recommendations of renewable resource assessment in Pakistan," *Energy Explor. Exploit.*, vol. 40, no. 3, pp. 947–976, 2022.
[35] M. Y. Raza, M. Wasim, and M. S. Sarwar, "Development of renewable energy technologies in rural areas of Pakistan," *Energy Sources, Part A Recovery Util. Environ. Eff.*, vol. 42, no. 6, pp. 740–760, 2020.
[36] M. I. Khan, I. A. Khan, and Y. C. Chang, "An overview of global renewable energy trends and current practices in Pakistan—A perspective of policy implications," *J. Renew. Sustain. Energy*, vol. 12, no. 5, 2020.
[37] M. Dehghani Madvar et al., "Analysis of stakeholder roles and the challenges of solar energy utilization in Iran," *Int. J. Low-Carbon Technol.*, vol. 13, no. 4, pp. 438–451, 2018.
[38] A. Wahid et al., "Barriers to empowerment: Assessment of community-led local development organizations in Pakistan," *Renew. Sustain. Energy Rev.*, vol. 74, pp. 1361–1370, 2017.
[39] R. Uddin et al., "Renewable energy perspectives of Pakistan and Turkey: Current analysis and policy recommendations," *Sustainability*, vol. 13, no. 6, p. 3349, 2021.
[40] S. Azeem et al., "Examining barriers and measures to promote the adoption of green building practices in Pakistan," *Smart Sustain. Built Environ.*, vol. 6, no. 3, pp. 86–100, 2017.
[41] K. Batool, Z. Y. Zhao, N. Nureen, and M. Irfan, "Assessing and prioritizing biogas barriers to alleviate energy poverty in Pakistan: An integrated AHP and G-TOPSIS model," *Environ. Sci. Pollut. Res.*, vol. 30, no. 41, pp. 94669–94693, 2023.