PUBLIC BUILDING SOLARIZATION INITIATIVE: A PROCESS AND COST-BENEFIT ANALYSIS

By

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CERTIFICATE

This is to certify that this thesis entitled: **"Public Building Solarization Initiative: A Process and Cost-Benefit Analysis"** submitted by **Mr. Mazhar Shahzad** is accepted in its present form by the School of Economics, Pakistan Institute of Development Economics (PIDE), Islamabad as satisfying the requirements for partial fulfillment of the degree in Master of Philosophy in Economics.

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Declaration

I declare that this research thesis is my own original work and that it fully complies with the Code of Conduct and Good Practices of the Pakistan Institute of Development Economics.

Dedicated to my family and friends

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ABSTRACT

The transition to renewable energy is essential for mitigating Pakistan's rising electricity costs, import dependence, and carbon emissions. Public building solarization has emerged as a promising strategy; however, its economic viability and policy implementation remain unexplored. Despite initiatives such as "ARE 2019" and "Fast-Track Solar Initiative 2022", institutional and financial challenges hindered progress. This study addresses this gap by evaluating both the economic feasibility and implementation process of public building solarization in Pakistan. The objectives are twofold: (i) to assess the costs and benefits of solar photovoltaic (PV) systems using cost-benefit analysis (CBA), and (ii) to examine policy implementation fidelity through a process evaluation guided by the Theory of Change (ToC). A mixed-methods research design is employed. The quantitative analysis uses CBA in the case study of a central library and then generalizes the results on an average-sized public building, while the qualitative analysis uses thematic analysis for semi-structured interviews to explore stakeholder perspectives and institutional dynamics. The findings indicate that solar PV systems are financially viable and environmentally advantageous, but weak institutional coordination, political instability, and financing constraints undermine policy outcomes. The study highlights the importance of aligning economic feasibility with governance reforms to advance sustainable energy transitions.

Keywords: Public Building Solarization, Cost-Benefit Analysis, Process Evaluation, Theory of Change, Welfare Economics, Alternative Renewable Energy, Solar Energy

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LIST OF ABBREVIATIONS

GoP	Government of Pakistan
SDGs	Sustainable Development Goals
IRENA	International Renewable Energy Agency
MW	Megawatt
PV	Photovoltaic
NEPRA	National Power Regulatory Authority
CBA	Cost-Benefit Analysis
ToC	Theory of Change
SHS	Solar Home System
UNDP	United Nations Capital Development Programme
UNCDF	United Nations Capital Development Fund
CSP	Concentrated Solar Power
RERED	Rural Electrification and Renewable Energy Development
EU	European Union

Chapter 1

INTRODUCTION

1.1 Background to the Study

Solarization refers to the integration of solar energy-generating technologies into building infrastructure (IRENA, 2023). The building sector is the major consumer of energy, accounting for 40% of the world's total primary energy consumption and responsible for 24% of the world's CO_2 emissions (Noailly, 2012). Solarization offers a strategic opportunity for public buildings. Such as reducing dependency on traditional fossil fuels and contributing to a sustainable environment (Ali et al., 2023). Furthermore, Jumbe (2004) states that energy consumption is positively correlated with economic growth, as countries with high energy consumption per capita also have high GDP per capita.

Within the building sector, public sector infrastructure, such as administrative offices, educational institutions, and hospitals, usually consumes a significant amount of electricity. Farahani et al. (2022) state that these facilities often operate during daylight, making them ideal candidates for efficient utilization of solar energy. Solarization becomes even more important in countries experiencing energy shortages and lagging in completing the commitments related to climate policies. From the use of such technologies, public sector buildings not only lead in environmental stewardship but also enhance energy security and alleviate fiscal pressures.

Since the Paris Agreement of 2015, Gielen et al. (2019) stated that worldwide government policies have shifted their focus from traditional to renewable energy sources to mitigate environmental consequences. This landmark agreement sets the objective of maintaining the Earth's temperature below 1.5°C to address the challenge of global warming. This often stems from the use of carbon-intensive fossil fuels. Key strategies for achieving Sustainable Development Goals (SDGs) involve a considerable shift from carbon-intensive fuels to clean and renewable energy (Rogelj et al., 2016).

Among all renewable energy sources, solar energy, in particular, has emerged as a favorable solution. Timilsina et al. (2012) state that solar energy is cost-competitive as compared to other sources of energy for generating electricity. Likewise, Pourasl et al. (2023) concluded in his study that solar energy has significant potential to mitigate climate change challenges. Due to this potential, the International Renewable Energy Agency (IRENA) also forecasts that the world could generate 25% of the total electricity demand from solar energy by 2050 (IRENA, 2023).

As the world is shifting, different countries take different measures regarding the adoption of renewable energy-generating technology. The Government of Pakistan (GoP) has also taken similar initiatives in the past. These initiatives include the National Energy Conservation Policy 2006, the Mid-term Renewable Energy Policy 2011, the Net Metering Policy 2015, and the Alternative Renewable Energy Policy 2019. The primary objective is to shift the electricity generation mix from fossil fuels to renewables, set the targets of 25% by 2025 and 30% by 2030, and to reduce carbon footprints by 50% by 2030.

Extending these renewables polices, the government introduced "Fast Track Solar Initiative 2022,". With a similar aim to substitute fossil fuels with solar energy on a fast track in the electricity generation mix, to encourage private investment in government projects, and to alleviate fiscal pressure. The electricity sector in Pakistan is almost 60% dependent on imported fuels (Energy Outlook Report, 2022). A small increase in global fuel prices has severe implications for Pakistan's economy, like the accumulation of more circular debt and the decrease in foreign exchange reserves. Addressing these challenges, Pakistan needs a significant transition from fossil fuels to renewable energy sources to increase its national energy security.

Given below in *Figure 1.1* shows Pakistan's two major renewable energy policies. The National Energy Conservation Policy of 2006 set a target to generate 97,000 MW from renewable energy sources by 2030; however, it only achieved generating 1,985 MW by 2024. While the Alternative Renewable Energy Policy of 2019 aims for 16,000 MW of electricity generation from renewable energy sources by 2030, only accomplished producing 2,709 MW of electricity by 2024.

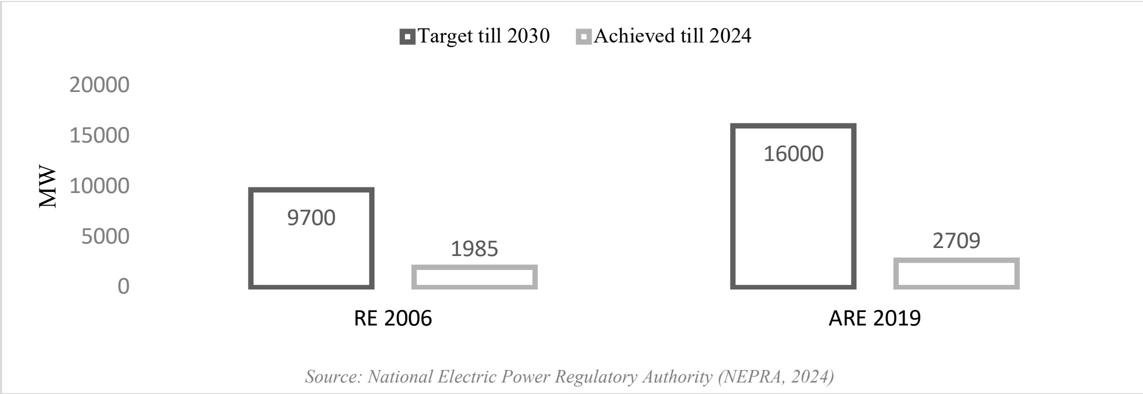

Figure 1.1: Pakistan's Policy Targets for Electricity Generation

This figure also reflects that Pakistan is facing significant challenges in its transition toward renewable energy sources. This study uses the Theory of Change (ToC) to find out these challenges and further investigate the implementation process of public building solarization. The process evaluation utilizes a logical framework model to identify areas where policy is lagging in effective execution. In parallel, the study also undertakes a cost-benefit analysis to determine the cost-effectiveness of the solar energy project in a public building. And to find whether this public building solarization is beneficial for society or a burden on taxpayers' money, which will help policymakers to assess their decisions.

The "Fast Track Solar Initiative 2022" was introduced to substitute imported fossil fuels with affordable solar energy. This intervention has multiple scopes; while this study is limited to "Public Building Solarization". Objectives behind public building solarization were to reduce the average cost of electricity generation and encourage private sector participation in public projects. Public building solarization is a common practice in developing countries to make buildings self-sufficient in electricity generation. Furthermore, Alhazmi et al. (2025) state that solarization of buildings will shift a significant load from the national electricity grid to solar energy because the building sector is a major consumer of electricity.

1.2 Statement of Problem

The GoP initiated the "Fast Track Solar Initiative 2022" for transitioning towards clean and affordable solar energy. The aim is to mitigate climate change risks, promote economic stability, and ensure energy security. However, there exist significant challenges in Pakistan, i.e., a lack of comprehensive evaluation frameworks that account for both cost-benefit analysis and the implementation process. As the literature highlights that without such a monitoring and evaluation framework, achieving the desired outcome and ensuring long-term energy and economic security is challenging.

This study aims to evaluate the solarization of public buildings, one of the scopes under the "Fast Track Solar Initiative 2022". Particularly, to evaluate the effectiveness of the implementation process and identify strengths and weaknesses of this intervention. As well as conduct a cost-benefit analysis to check the economic feasibility of solarized public buildings. It proposes practical solutions that support informed decision-making in the future for sustainable development.

1.3 Research Problem

Based on the statement of the problem, this research study seeks "Public Building Solarization: A Process and Cost-Benefit Analysis".

1.4 Research Objectives

- To assess the effectiveness of the implementation process during the solarization of public buildings.
- To do a cost-benefit analysis to evaluate the economic and environmental feasibility of solarized public buildings.

1.5 Research Questions

1. How effective is the public buildings solarization initiative in terms of the implementation process?
2. What are the economic and environmental implications, both costs and benefits, associated with the implementation of solar photovoltaic (PV) systems in public buildings?

1.6 Significance of the Study

This research study provides a comprehensive evaluation framework integrating economic, environmental feasibility, and implementation process for the "Public Building Solarization Initiative". Propose valuable insights to ensure the effectiveness of the implementation process, maximize benefits, and inform future policy decisions related to solar energy adoption. The findings of this study could also be relevant to other countries pursuing similar public building solarization efforts.

Chapter 2

LITERATURE REVIEW

The world is transitioning from traditional energy sources to renewable energy sources due to rising concerns about climate change, as well as the high energy costs (Osman et al., 2023). Similarly, the Government of Pakistan (GoP) announced a "Fast Track Solar Initiative 2022" to substitute fossil fuels with solar energy in the national energy mix. This intervention has three scopes:

i. Substitution of expensive fossil fuels with solar PV energy
ii. Solar PV generation on 11 kV feeders
iii. Solarization of Public Buildings

While this study is limited to public building solarization, this chapter presents existing literature on public building solarization and is structured in two sections. The first section focuses on worldwide solar energy policies and practices, including the adoption of renewable energy policies. Also, to study the challenges encountered during implementation in peer countries, as well as in Pakistan. It helps in examining Pakistan's current policy implementation framework and identifying the challenges it faces. The second section presents literature on the key approaches used to evaluate solar PV systems, their costs and benefits, thereby determining the potential. Whereas, simultaneously, exploring the economic and environmental viability of a public building solarization initiative.

2.1 Worldwide Solar Energy Policies and Practices

2.1.1 Solar Energy Adoption

The existing literature on renewable energy adoption worldwide reveals a diverse and evolving policy landscape. Particularly, solar energy policies have been recognized for their potential to reduce socioeconomic inequality, enhance human welfare, support inclusive growth, and contribute to environmental sustainability (IRENA, 2021). These research studies offer valuable insights for policymakers to help inform policy decision-making in the transition from carbon-intensive fuels to renewables.

In solar PV systems, decentralized systems have emerged as a prominent strategy for addressing the issue of high electricity cost and inadequate grid infrastructure in developing countries. For instance, in India, the government-initiated community-based decentralized solar microgrids program in Bihar. India restored access to electricity, enhanced welfare, and enabled socioeconomic activities (Chakravarty & Roy, 2021). Similarly, in Bangladesh, a Solar Home System (SHS) program is initiated in collaboration with Rural Electrification and Renewable Energy Development (RERED), which reached millions of households (Shyu, 2023). Furthermore, Shyu (2023) concludes that SHS improved people's welfare by creating multiple employment opportunities. Based on these case studies, the decentralized interventions strategy underscores the value of small-scale, community-oriented energy solutions. Their long-term success often depends on financing mechanisms, technical capacity, and integration into broader rural development strategies.

China emerged as a global leader in solar PV technology, adopted a focused industrialization strategy. By doing so, the Chinese government attracted private sector investments in the solar PV market and created employment opportunities (Brühl, 2024). Whereas such an approach has proven effective in scaling up the production capacity, it also carries potential risks, including environmental trade-offs related to large-scale manufacturing (Noh et al., 2014). Based on these studies, China's alignment of solar industrial policy with its broader national economic strategy ensured policy coherence. While policy coherence is often missing in countries where energy sector governance is fragmented. This integrated policy framework offers important lessons for other countries; however, its transferability is limited by differences in political economy, institutional capacity, and access to capital.

Furthermore, decentralized solar PV deployment highlights the role in improving access to basic services in rural contexts. For instance, Godenho (2019) highlights that the Rwanda government, working alongside the European Union (EU), has utilized off-grid solar systems to electrify rural schools. This intervention has not only addressed energy shortages but also contributed to improving educational outcomes by providing well-lit classrooms (Godenho, 2019). Similarly, in Kenya, the government collaboration with the United Nations Capital Development Fund (UNCDF), launched a solar-powered cold storage initiative to overcome the post-harvest food losses. It played an important role in the agricultural sector by extending the shelf life of perishable produce (UNCDF, 2023). Furthermore, the same strategy is adopted to support the health care sector by ensuring reliable refrigeration of temperature-sensitive medical supplies in those areas where grid electricity access is limited (UNDP, 2024). These case studies highlight the adaptability of decentralized solar solutions. However, their success depends on sustained technical maintenance, integration into sectoral development plans, and the provision of complementary infrastructure and services.

In North Africa, large-scale solar projects have emerged as a strategic driver of national energy transition, aiming to reduce fossil fuel dependency. In Morocco's Noor Ouarzazate Solar Complex, one of the largest concentrated solar power (CSP) plants developed through public public-private partnership. Illustrating how CSP can enhance national energy security and mitigate greenhouse gas emissions (World Bank, 2020). Such a successful project underscores the potential of public-private partnerships (PPP) in mobilizing investments and expertise for solar energy infrastructure. Nonetheless, the financial and institutional demands of such large-scale projects present significant barriers for countries with limited fiscal resources. Their economic competitiveness must be weighed against falling prices of PV technology.

Collectively, all these case studies explain the diverse pathways through which solar energy adoption can be operationalized. These adoption techniques range from decentralized community-based solutions to capital-intensive mega energy projects. While each approach offers unique advantages, its outcomes depend heavily on contextual factors. Such as governance capacity, policy coherence, financing structures, and integration with international development goals. This suggests that renewable energy adoption is not a one-size-fits-all process, but rather one that requires tailored strategies informed by local realities and long-term sustainability considerations.

2.1.2 Challenges with Solar PV Adoption

This subsection of the literature review focuses on policy frameworks governing solar energy deployment and identifies the challenges and structural gaps within them, particularly those related to the integration of solar solutions. Whereas in the above subsection of solar PV adoption, the global trends highlight the transformative potential of solar PV in achieving energy transition goals. The success of such initiatives depends on coherent policy design, adequate institutional capacity, and supportive regulatory environments. In developing economies, fragmented governance structures, inconsistent policy execution, and insufficient interagency coordination undermine the scalability and sustainability of solar PV interventions. Furthermore, challenges related to financing, technology advancement, and grid integration persist, often exacerbated by sociopolitical constraints and limited technical expertise. These structural bottlenecks not only slow the pace of solar PV adoption but also diminish its capacity to deliver long-term socioeconomic and environmental benefits.

The adoption of solar PV technology is shaped by a complex interplay of institutional, technical, financial, and socio-political factors, which vary significantly across countries. In

Pakistan, Gruijters and Peters (2019) studies on solar energy development highlight that fragmented institutional arrangements and the absence of long-term planning are the primary barriers to the advancement of solar energy. Furthermore, it identifies a lack of integration between energy policies and industrial development, which has prevented the establishment of local solar panel manufacturing capacity (Gruijters & Peters, 2019).

At the governance level, Ulpiani et al. (2023) underscore the importance of robust policy frameworks and the active role of the private sector in accelerating solar energy adoption. The study findings indicate that countries with a strong governance structure and coherent policy instruments are more likely to achieve climate neutrality within the set timeframe (Ulpiani et al. 2023). It suggests that policy design must go beyond target setting, embedding enforceable mechanisms and incentives that can mobilize both public and private capital.

From a technical perspective, Payel et al. (2023) stated that inadequate infrastructure in the developing countries is the primary technical challenge to integrate solar energy into the national grid. They argue that without grid modernization, the variability of solar power limits its scalability. Complementing this view, Saraswat et al. (2024) highlight that geopolitical risk, regulatory barriers, and infrastructure gaps as further obstacles to PV deployment. They stressed the importance of international cooperation in overcoming these challenges to achieve the broader Sustainable Development Goals (SDGs).

Comparing these constraints, some countries demonstrate policy models that have successfully stimulated solar adoption. In the United States, Al-Sharafi et al. (2023) stated that net metering polices allow residential customer to offset their electricity bills by feeding surplus electricity into the grid. This played an important role in solar PV market expansion (Al-Sharafi et al., 2023). Furthermore, the Federal Investment Tax Credit (FITC) provides a tax credit for solar installations, incentivizing both residential and commercial consumers. Such policies have created a favorable environment for solar PV market development. Similarly, in Germany, Hodge et al. (2024) attribute the country's PV success to the well-timed government incentives, particularly the Feed-in-tariff (FIT) scheme, which offers guaranteed payments for electricity generated from a rooftop system. These case studies illustrate that predictable, long-term incentives can reduce investment risk, encourage private sector participation, and drive market growth.

In India, Jain et al. (2023) observe rapid solar PV sector growth, with an installed capacity surpassing 60 GW as of late 2022. The policies support solar home lighting systems, particularly in rural areas, coupled with low solar tariffs, have accelerated rooftop adoption. Furthermore, the study records that the foreign exchange market has a significant role in the development of the solar PV market. This highlights the relation between macroeconomic factors and solar PV energy expansion.

However, other contexts reveal the detrimental effects of policy incoherence. In Indonesia, Syafina and Oluleye (2024) identifying policy misalignment between policy instruments and private sector return on equity (ROE) expectation is a crucial reason for policy failures. The finding reinforces the argument that poorly structured incentives can deter investor participation, even where technical potential exists.

In Pakistan, Mustafa et al. (2024) explored the implementation challenges, focusing on the Solar Net Metering Policy 2015. Identify that the absence of an inadequate green financing mechanism is the main cause of policy ineffectiveness, highlighting governance challenges. That without clear, measurable, and achievable policy targets, and alignment between strategic objectives and administrative capacity, even well-intentioned energy policies are unlikely to yield sustained progress.

The literature shows challenges associated with the adoption of solar photovoltaic (PV) technology. Indicates that while technological solutions for solar PV deployment are increasingly accessible, their successful implementation depends on governance, strategic alignment with industrial policy, adequate infrastructure, and well-calibrated financial incentives. Countries that have effectively scaled solar PV adoption, such as China, the United States, Germany, and India, exemplify the significance of integrating policy stability with market-oriented incentives. In contrast, the experiences of Pakistan illustrate the risks associated with fragmented policy frameworks and poorly aligned incentives. Further, emphasizes that policy coherence, institutional capacity, and investor confidence are interdependent factors in the transition to renewable energy.

2.2 Economic and Environmental Perspectives on Solar Energy

The discussion earlier under the section: worldwide solar energy policies and practices illustrated the structural, financial, and institutional barriers that hinders solar PV deployment. However, despite these obstacles, the literature remains largely consistent in emphasizing the considerable economic, environmental, and energy security benefits associated with PV systems. Keeping these benefits alongside the earlier identified challenges, the literature underscores a dual reality: while barriers impede rapid transmission, the potential gains from adoption remain too substantial to ignore.

At the microeconomic level, PV has been shown to yield significant cost savings for individual buildings. Behi et al. (2020) using a load-modelling financial analysis technique, they estimate that transitioning to solar PV can reduce building-level energy expenditures by up to 24%. Similarly, Bošnjaković et al. (2021) through PVGIS-5 simulations in Croatia demonstrated that even small-scale kilowatt (kW) systems can meet the annual electricity needs of relatively large facilities if optimally oriented. These findings suggest that, for consumers, the adoption of PV translates into reduced electricity costs and greater self-sufficiency, outcomes that directly address affordability concerns noted above in the subsection, Challenges in Solar PV Adoption.

Solar PV adoption offers benefits in terms of national energy security and alleviate fiscal pressure. Bódis et al. (2019) show that rooftop PV in the European Union could meet 24.4% of current electricity demand at prices below two-thirds of residential tariffs. In Pakistan, Jamil et al. (2022), using RETScreen analysis of the Quaid-i-Azam Solar Park, estimate a payback period of 5.6 years with a benefit-cost ratio of 1.33, confirming the financial reliability of utility-scale PV even in an developing economy. Aqsa Muhammadi et al. (2024) further highlight Pakistan's geographic advantage, noting that the country could potentially generate up to 100,000 MW from solar energy. Stressed that this is the opportunity to reduce dependence on imported fossil fuels and strengthen macroeconomic resilience.

The literature also reflects methodological diversity in estimating solar PV's cost and benefits. Fakhraian et al. (2021) reviews a range of techniques, from mathematical modelling to statistical sampling, concluding that open-source microdata can improve assessment accuracy. Rohayani et al. (2024), However, critique satellite-based levelized cost of energy (LCOE) estimates, arguing that these often overstate benefits compared to analyses based on monthly benefit-cost ratios, which provide a more realistic representation of economic viability. In China, Sun et al. (2022) apply a GIS-based spatial model that incorporates rooftop availability, irradiance, and shading to refine potential estimates. Such methodological variety explains why assessments differ in their conclusions, and also reveals that the robustness of benefits depends heavily on the choice of approach (Hammersley, 2023).

From an environmental perspective, solar PV adoption is consistently linked to carbon emission reductions and broader sustainability gains. Sun et al. (2022) show that rooftop PV in Wuhan not only fulfils urban energy demand but also lowers greenhouse gas emissions. At the

European scale, Ulpiani et al. (2023) emphasize PV's role in advancing climate neutrality by 2030, provided it is complemented by grid modernization and energy storage investments. This evidence suggests that beyond economic viability, PV contributes to long-term decarbonization strategies and climate commitments.

In conclusion, while challenges surrounding financing, infrastructure, and institutional capacity remain pressing, the literature affirms that solar PV offers substantial and multi-layered benefits. Building-level analyses highlight affordability gains, while national-level studies underscore its contribution to energy security and macroeconomic stability. Environmental studies reinforce their centrality in achieving decarbonization targets. Importantly, the divergence in assessment methodologies highlights the need for standardized and context-sensitive evaluation frameworks to better inform policy choices. Thus, although PV adoption in practice is constrained by the challenges earlier identified, the weight of evidence positions it as a cornerstone of the global and national energy transition.

2.3 Research Gap

The existing body of literature highlights the substantial potential of solar photovoltaic (PV) systems across different regions of the world. Studies such as Behi et al. (2020), Sun et al. (2022), and Ulpiani et al. (2023) emphasize the environmental and financial benefits of solar PV, demonstrating its role in reducing carbon emissions and lowering electricity generation costs. Similarly, research in the European and Chinese contexts has relied heavily on advanced tools such as GIS modeling, PVGIS-5, and satellite-based estimations to assess solar PV potential and optimize system design. These works have been instrumental in establishing the technical and environmental feasibility of PV deployment. However, many of these studies have been confined to specific regions or urban contexts, leaving limited room for generalization to other developing economies with unique institutional and infrastructural constraints.

In the case of Pakistan, several studies such as Jamil et al. (2022) and Aqsa Muhammadi et al. (2024) have illustrated the country's vast solar energy potential. These works suggest that, Pakistan due to its geographical location, possesses higher solar irradiance levels compared to the global average, thereby making PV integration both feasible and desirable. Nonetheless, these studies have primarily concentrated on utility-scale solar plants or broad national-level estimations, often overlooking the more decentralized applications of PV systems, such as solarization of public buildings. Furthermore, the methodological reliance on simulation tools like RETScreen and satellite-based estimations has raised concerns about accuracy, as noted by Rohayani et al. (2024), who argue for the use of actual monthly electricity data to better reflect economic outcomes. This highlights a persistent gap between modeled estimates and ground-level realities in the Pakistani context.

Another gap lies in the limited integration of cost-benefit analysis with institutional and implementation perspectives. While international studies for instance Ulpiani et al. (2023) have pointed toward the importance of considering economic, technical, physical, and geographical sub-potentials, the literature has not adequately addressed how these interact with governance challenges and process-related constraints in developing countries. In Pakistan, despite policy initiatives promoting renewable energy adoption, there is little empirical research that systematically evaluates both the financial viability and the institutional process of implementing PV systems in public sector buildings. This is particularly significant given the challenges already identified in solar adoption, such as a lack of coordination among stakeholders, infrastructure bottlenecks, and financing constraints.

Therefore, while the global and national literature provides important insights into the technical, financial, and environmental dimensions of solar PV adoption. There remains a lack of comprehensive analysis that combines cost-benefit analysis with process evaluation in the context of Pakistan's public building solarization initiative. Addressing this gap is crucial for ensuring that policy ambitions translate into effective implementation. Also, identifying whether the theoretical benefits of solar PV are realized in practice. This study seeks to bridge this gap by adopting a mixed-methods approach that integrates economic assessment and process evaluation, thereby providing new empirical evidence to the debate on renewable energy adoption in developing countries.

The key research gaps are as follows:

- Most existing studies in Pakistan focus on utility-scale PV potential, while decentralized PV is unexplored.
- Heavy reliance on simulation and satellite-based tools (e.g., RETScreen, LCOE satellite modeling) may misrepresent actual project viability, whereas no empirical data-based approaches are carried out.
- There is an absence of research study that combines cost-benefit analysis with process evaluations, particularly in the context of public sector solarization initiatives.

- The gap between policy ambition and implementation realities in Pakistan remains largely undocumented, requiring research that links economic feasibility with governance and coordination challenges.

Taken together, these gaps demonstrate the need for a comprehensive framework that not only evaluates the economic viability of solar PV adoption but also situates it within the broader institutional and policy context. To address this need, the following section outlines the theoretical framework underpinning this study, drawing on the Theory of Change (ToC) and Cost-Benefit Analysis (CBA) to guide both the analytical approach and the interpretation of findings.

Chapter 3

THEORETICAL FRAMEWORK

A theoretical framework provides the foundation upon which a study is developed. It helps in guiding the choice of methodology, the interpretation of results, and the integration of findings within the broader academic discourse. For a study on the solarization of public buildings, it is essential to adopt a framework that not only captures the economic viability of solar PV but also addresses the institutional and process-related dimensions of policy implementation. This study, therefore, draws on two complementary theoretical lenses: The Theory of Change (ToC), which provides a process-oriented perspective on how policies are expected to generate outcomes, and Cost-Benefit Analysis (CBA), which offers an economic evaluation of the feasibility and efficiency of solar PV adoption. Together, these theoretical frameworks allow for a holistic evaluation that accounts for both the procedural fidelity of implementation and the quantifiable benefits of solarization.

3.1 Theory of Change (ToC)

The Theory of Change emerged as a planning, monitoring, and evaluation tool in the 1990s, widely applied in development policy and program implementation. Its central premise is to make explicit the causal pathways through which interventions are expected to achieve desired outcomes. Rather than focusing solely on outputs, ToC emphasizes the underlying assumptions, contextual factors, and institutional dynamics that shape policy outcomes. In the context of solar energy initiatives, ToC is particularly valuable because transitions to cleaner energy systems involve multiple stakeholders, institutional layers, and infrastructural constraints that cannot be captured through economic indicators alone.

In the context of public buildings solarization, ToC helps trace how the government-led Fast Track Solar Initiative 2022 is expected to lead to specific outcomes. Such as reduced electricity generation costs, improved energy security, decreased carbon footprints, and enhanced institutional credibility in solar energy transitions. The framework highlights key assumptions, such as the availability of financing, coordination among government agencies, and the readiness of grid infrastructure, that must hold for the initiative to succeed. By doing so, it becomes possible to identify "implementation gaps" where the actual process diverges from the intended pathway, thus providing insights into challenges of policy design, execution, and fidelity.

Furthermore, ToC is particularly suited for evaluating process-related challenges identified in the literature, such as weak coordination among stakeholders, financing barriers, and infrastructural bottlenecks. It allows for mapping how these barriers disrupt the causal chain linking inputs to outcomes. For example, inadequate grid capacity may prevent solar energy generated in public buildings from being integrated effectively, thereby undermining the intended cost savings and emissions reductions. Thus, ToC provides a structured framework for assessing not just whether policy targets were achieved, but whether the implementation processes aligned with the original logical framework of intervention.

3.2 Cost-Benefit Analysis (CBA)

Although ToC provides a process-oriented lens, Cost-Benefit Analysis offers an economic rationale for evaluating the desirability of solar PV systems. CBA is grounded in welfare economics, where the efficiency of an intervention is judged by comparing its expected benefits with its associated costs, expressed in monetary terms. A project is deemed viable if the present value of benefits outweighs the present value of costs, typically captured through indicators such as the Benefit-Cost Ratio (BCR), Net Present Value (NPV), and Internal Rate of Return (IRR).

In the context of solar PV adoption, CBA plays a crucial role in quantifying both the tangible and intangible benefits of the project. Tangible benefits include reduced electricity costs, saving foreign exchange reserves, and generate revenues through carbon credits. Intangible benefits include environmental gains from reduction in greenhouse gas emissions, improved electricity access, generate employment opportunities and generate positive other social externalities. Such as enhanced trust in public institutions leading the clean energy transition. In contrast, costs encompass not only the upfront capital expenditures on solar PV systems but also operation and maintenance expenditures, disposal costs, potential battery replacement costs for off-grid systems, and the opportunity cost of public resources allocated to the project.

Applying CBA to public building solarization enables policymakers to assess the financial viability of scaling up solar PV adoption. Also compares solar PV project investments with alternative energy sources. For example, fossil-fuel-based generation may appear cheaper in the short run, a CBA that incorporates environmental externalities often demonstrates the superior long-term efficiency of solar PV projects. Moreover, CBA provides decision-makers with a rigorous economic justification to allocate scarce resources toward solar energy in a fiscally constrained environment such as in Pakistan.

3.3 Integrating ToC and CBA

ToC and CBA address different but complementary aspects of solar PV adoption. ToC emphasizes the pathways, assumptions, and institutional processes underlying implementation, while CBA focuses on the economic efficiency and viability of the intervention. For a comprehensive evaluation of public building solarization, it is therefore necessary to integrate both frameworks.

The integration of ToC and CBA allows for an assessment of both implementation process and intervention outcome in terms of economics and environment. For instance, if a CBA indicates that solar PV adoption in public buildings yields high economic returns, but ToC analysis reveals gaps in institutional coordination or infrastructural readiness. Then the policy's failure cannot be attributed to economic inefficiency but rather to implementation fidelity errors. Conversely, if ToC analysis shows strong alignment with policy pathways but CBA demonstrates poor economic returns, then the initiative may require revisiting its financial assumptions or exploring complementary mechanisms such as subsidies, financing schemes, or carbon pricing.

By using ToC alongside CBA, this study ensures that the evaluation is not narrowly confined to economic metrics or overly focused on process dynamics in isolation. Instead, the combined approach captures the full spectrum of issues influencing the success or failure of solarization initiatives. This two-fold framework is particularly appropriate for Pakistan, where renewable energy policies often struggle not only with economic justification but also with executional challenges linked to institutional capacity and political instability.

3.4 Relevance to the Present Study

The dual use of ToC and CBA directly informs both components of this research: the process evaluation of public building solarization initiatives and the cost-benefit analysis of solar PV systems for a specific case study. ToC provides the conceptual basis for exploring implementation gaps through qualitative methods, while CBA provides the economic foundation for evaluating financial and environmental outcomes through quantitative assessment. Together, they allow for a multi-dimensional analysis that speaks to both policy design and feasibility.

Furthermore, the theoretical framework ensures that this study does not treat solarization merely as a technical or economic intervention, but as a complex socio-economic and institutional process. By adopting ToC and CBA, the study can address the intertwined challenges of policy implementation and financial viability. This framework, therefore provides a robust foundation for the subsequent methodological approach, ensuring that both qualitative and quantitative dimensions of the research are coherently aligned.

Chapter 4

RESEARCH METHODOLOGY

This chapter presents the research methodology adopted for this study on the solarization of public buildings in Pakistan. The primary objective of this study is twofold: first, to evaluate the economic and environmental viability of solar PV system installations in public buildings through CBA; and second, to assess the fidelity of policy implementation through a process evaluation guided by the Theory of Change (ToC). The research employs a mixed-methods design, integrating both qualitative and quantitative approaches to provide a comprehensive understanding of the costs, benefits, and institutional dynamics that shape the initiative.

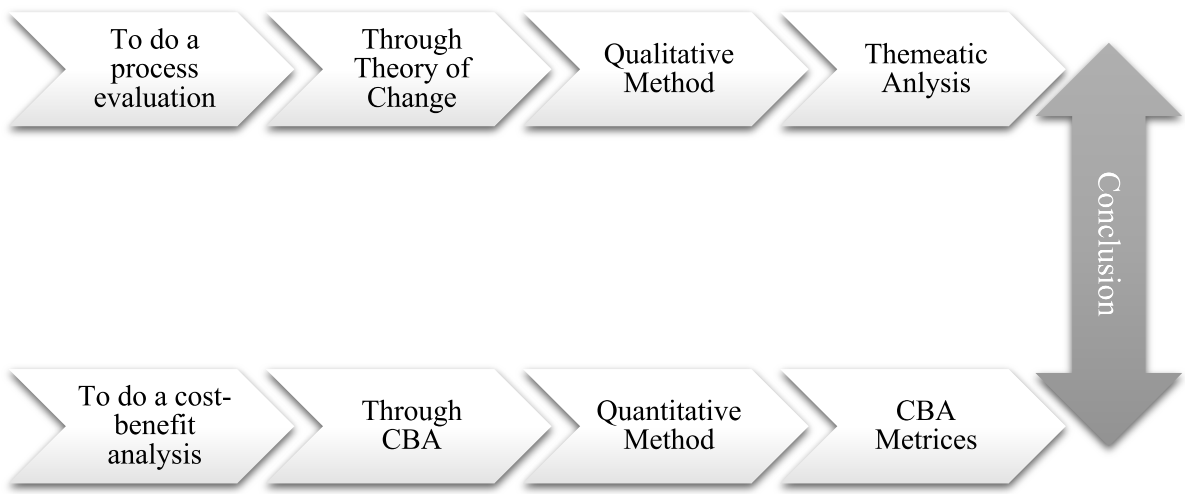

Figure 4.1: Conceptual Framework of this Research Study

4.1 Research Approach

The study aims to evaluate both the implementation process and the costs benefits associated with "Public Building Solarization Initiative 2022". Process evaluation identifies the assumptions, preconditions, and external factors necessary for successful implementation, such as regulatory support, financing, and institutional readiness. This approach explains how and why the public building solarization initiative expects to achieve the desired outcomes. Whereas the cost-benefit analysis identifies the operational costs and benefits associated with solarized public building infrastructure.

This research study uses a mixed-methods research design incorporating both quantitative and qualitative data. The qualitative data is based on semi-structured interviews with experts from the stakeholders of the “Public Building Solarization Initiative”. The following are the details of the quantitative data used are as follows:

- The electricity consumption data is collected from the Islamabad Electricity Supply Company (IESCO).
- The solar PV installed capacity data is collected from the license document issued by the National Electric Power Regulatory Authority (NEPRA).
- The initial investment cost has been collected from the case study building selected.
- Information is also collected from the tender document issued by PPIB (Former AEDB).

4.1.1 Process Evaluation

A process evaluation focuses on the activities involved in the implementation process of the “Public Building Solarization Initiative 2022.” It shows the pathways for the conversion of inputs into outcomes. Providing a framework that will visualize these activities is the logical framework model.

There are three approaches in the logical framework model (Renger & Titcomb, 2002).

- A Theory approach, which is used for carrying out document analysis, assessing planning, and designing of the initiative.
- An activities-based approach is used to assess the operational/implementation phase.
- Outcome-based approach, which is used to assess whether the desired outcome was achieved or not.

The theory behind the logical framework model is the theory of change, which illustrates the links between inputs, activities, and outputs. As this study is limited only to the activity-based approach. So, the logic model was used as a tool to portray the assumptions pathway effectively, including how the program works and how it intends to achieve expected outcomes. Also visualizes the components, including the inputs, activities, outputs, and their interconnections. Such an illustration of these components makes it easy to understand the connections between these elements (inputs to outcomes). These kinds of connections also illustrate the pathways from inputs into specific actions. The following is the underlying logical framework model conceptual framework of the “Public Building Solarization Initiative.”

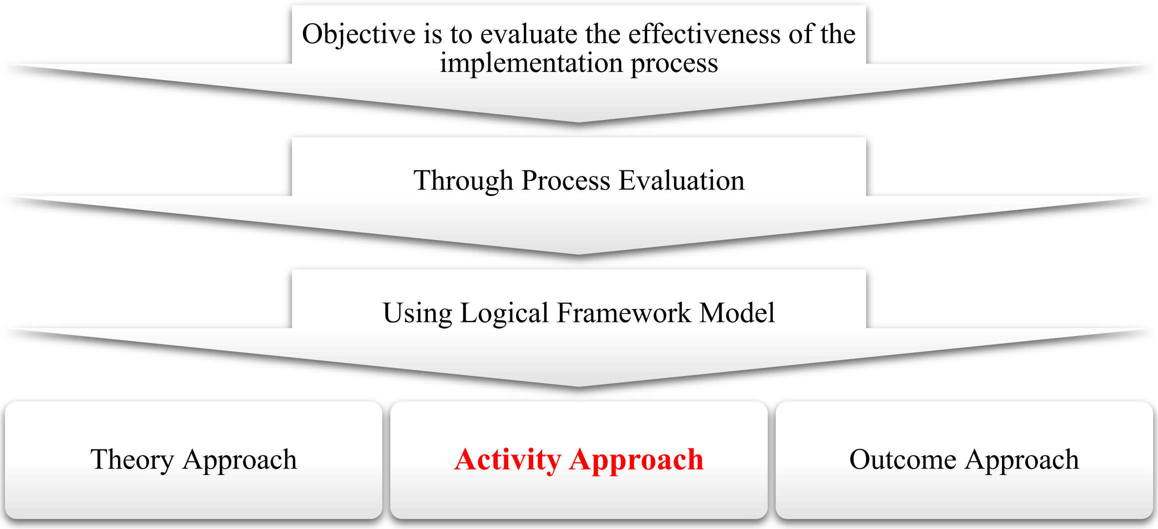

Figure 4.2: Process Evaluation Methodology Framework

The activity approach is given above in Figure 4.1, evaluating policy implementation to address objective 1, since this approach offers an analytical framework for policy implementation. It focuses on assessing the specific actions and processes undertaken during the execution of a policy. It provides valuable insights into the operational aspects of policy execution. Examining the activities carried out, the study identifies the potential bottlenecks, inefficiencies and provides insights into successful strategies in real-time. It allows for timely adjustments and improvements to the implementation process.

In contrast to the theory approach, which is more suited for analyzing policy formulation and design, and the outcome-based approach, evaluates post-intervention impacts. The activity approach bridges the gap between policy design and results. Enables policymakers and researchers to monitor and assess the effectiveness of implementation strategies as they unfold, offering a dynamic perspective on policy execution. This approach is particularly valuable for complex policies that involve multiple stakeholders, diverse activities, and extended timelines. As it provides a structured method for tracking progress and identifying areas for refinement throughout the implementation phase.

Table 4.1: Conceptual Framework Using Logical Framework Model

Inputs	Activities	Outputs	Outcomes			External Factors
			Short Term	Intermediate	Long Term	
Government space for installations	Install solar PV systems	Solarized Public Building	Clean energy	Relief for utilities from late or no recoveries and less dependency on expensive fossil fuels	Cleaner environment, CO_2 emission reduction	Policies and regulations
Financial resources	Budget Allocation and Bidding for Selection of Vendor	Selection of Successful Bidder for Installation of solar system on Building	Reduced public office electricity bills	Increased solar adoption in buildings	Reduced reliance on Imported Fossil fuels	Skilled labor availability
Technical expertise for maintenance	Third-party validation	-	-	-	Government cost savings	Public awareness
	System maintenance	-	-	-	-	Energy price fluctuations
	-	-	-	-	-	Financing options

The above Table 4.1 shows the identified inputs, activities, outputs, and outcomes. External factors may have some ability to influence any part of the logical framework model, both positively and negatively. These influences were critically illustrated during process evaluation.

Table 4.2 is given for the description of the data, and the activity done for data collection based on their nature.

Table 4.2: Description of Data Collection of Each Element of the Logic Model

	Description	Data Sources	Key Activities
Inputs	Human, financial, technical, and other resources required for solarization.	Government officials, IESCO, Contractors, Solar panels suppliers, Policy documents (e.g., Fast Track Solar Initiative 2022).	Key informant interview with government officials.
			Review Policy Documents
Activities	The solarization process, including pre-solarization planning, implementation, and post-implementation monitoring.	Government and IESCO data, key informant interviews, site reports.	Policy review and stakeholder identification.
			Site selection and solar panel installation.
			Grid integration
			Monitoring and evaluation.
Outputs	Immediate results from the activities conducted, including solar energy capacity, stakeholder participation, and training.	Installation data, IESCO reports, training attendance.	Installed solar capacity (e.g., MW).
			Number of trained personnel.
			Stakeholder engagement records.
Conclusion and Recommendations	Final assessment and recommendations based on evaluation outputs.	Evaluation results, interview insights.	Evaluate solarization effectiveness.
			Provide policy recommendations for improving the process.
			Suggest scalability improvements for other regions.

4.1.2 The Cost-Benefit Analysis

The second part of the research is designed to assess the costs and benefits associated with moving public buildings from the national grid to solar energy. CBA is an important tool for evaluating a project. It is based on welfare economics, in which the welfare of society is increased with the efficient utilization of resources. Basic economic theory used for evaluating the economic and environmental feasibility of projects. Furthermore, Mishan and Quah, (2020) stated that CBA is one of the appropriate methods for assessing socioeconomic footprints.

The comprehensive methodology consists steps given below in Figure 4.3. The objective is to assess the benefits against the costs of solarizing government buildings in both financial and environmental terms.

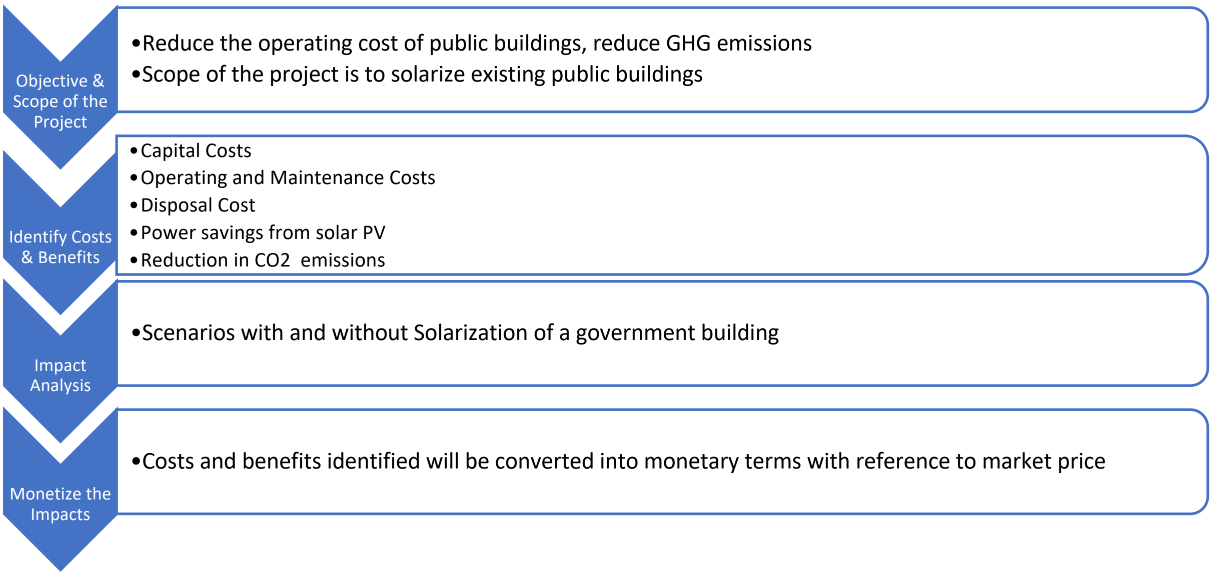

Figure 4.3: Cost-Benefit Analysis Methodological Framework

4.1.2.1 Variables for Calculating the Evaluation Metrics

1. **Capital and Depreciation Costs:**

- **Initial Installation Cost:** The upfront cost of the installation of solar panels on public buildings.

$$\text{Total Cost} = C_{\text{installation/m}^2} \times A_{\text{system}}$$

Where

☞ $C_{\text{installation/m}^2}$ = installation cost per square meter (PKR/m²)

☞ A_{system} = total area of the system (m²)

- **Depreciation:** Ongoing operating and Maintenance (O&M) costs of solar panels.

$$\text{Total Depreciation Cost} = \sum \left((O\&M)_{\text{m}^2\text{/Year}} \times A_{\text{system}}\right)$$

Where

☞ $O\&M_{\text{m}^2\text{/Year}}$ = Annual operating and maintenance cost (PKR/year)

- **Disposal Cost:** This cost is associated with the decommissioning of a solar PV plant at the end of its life cycle.

$$\text{Total Disposal Cost} = C_{\text{Disposal/m}^2} \times A_{\text{system}}$$

Where

☞ $C_{Disposal/m^2}$ = Disposal cost per square meter

2. **Benefits:**

- **Energy Savings:** Savings on electricity costs due to reduced consumption from the national grid.

S_{Energy} = (Energy consumption reduction per building

×

Cost of grid electricity per Unit (kWh) × number of buildings

- **Emission Reduction:** Savings in carbon emissions due to reduced reliance on grid power.

$S_{Emissions}$ = Reduction in energy consumption

×

Carbon intensity of grid electricity ($kgCO_2$ per kWh)

3. **Net Present Value (NPV):** A key formula to account for the time value of money in evaluating long-term projects like solarization.

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^{t}} \qquad (4.2)$$

Where:

- B_t = benefits in year t
- C_t = costs in year t
- r = Discount rate (could be determined based on the cost of capital or inflation rate)
- n = project lifespan (in years)

4. **Benefit-Cost Ratio (BCR):** The ratio of total benefits to total costs, helping to assess the feasibility and effectiveness of the project.

$$\mathbf{BCR} = \frac{\sum_{t=0}^{n} B_t}{\sum_{t=0}^{n} C_t} \qquad (4.3)$$

4.1.2.2 Steps for Conducting Cost-Benefit Analysis

1. **Identify all costs and benefits:** Collect data on installation, maintenance, and disposal costs, as well as the savings from not buying grid electricity and emission reductions. Data collected from IESCO and other stakeholders (PPIB, NEECA etc.,) involved in public building solarization process.
2. **Estimate energy savings and emission reductions:** The data on energy consumption is collected from Quid-i-Azam university central library monthly electricity bill. Calculating the expected savings annually and multiplying by the current electricity tariff. Similarly, estimate the emission reduction by using the alternate source for generating electricity.
3. **Apply discounting:** The costs and benefits over the life span of solar PV plant, discounting future costs and benefits to their present value, which is crucial for accurate analysis. As the State Bank of Pakistan pay 10% on a 15-year security bond.
4. **Perform Sensitivity Analysis:** Given the uncertainties around future energy prices, changing in tariff rate, and emission factors. It is important to test how sensitive the results are when keeping the tariff rate constant.
5. **Interpret the results:** After calculating the NPV and BCR, analyze the results to determine if the solarization project is financially viable. A positive NPV and a BCR greater than 1 suggest the project is worth pursuing.

4.2 Unit of Data Collection

The study is based in Islamabad because the initiative "Fast Track Solar Initiative 2022" was first initiated in the federal territory to shift government buildings to solar energy. The data are collected from both primary and secondary sources. The primary data collected through key informant interviews (KPI) with the Ministry of Energy (MoE), PPIB, NEECA, IESCO, QAU, and the CPPA-G officials who are involved in the execution of public building solarization imitative. The secondary data was collected from policy documents and IESCO.

4.3 Locale

The study is based in Islamabad because it is the federal capital where the initiative "Fast Track Solar Energy" taken first to shift public buildings to solar energy. The data collected from both primary and secondary sources. The primary data for assessing the implementation process collected through KPI with stakeholders of the energy sector who are involved in the implementing public building solarization initiative. The secondary data gathered from policy documents, and the energy consumption data collected from IESCO.

Chapter 5

THEMATIC ANALYSIS

Exploring the implementation process of the "Public Building Solarization Initiative 2022," a qualitative analysis is carried out. Based on the six-phase approach of thematic analysis, introduced by the study (Braun and Clarke, 2006). This analytical framework is selected for its flexibility and clarity in identifying patterns across qualitative data. The data collected from 10 KPI conducted with various stakeholders, following the interview protocol and maintaining confidentiality and anonymity, as shown in Table 5.1.

Table 5.1: Data Collection from Different Stakeholders and the Number of Respondents

Stakeholders	Number of Respondent
Ministry of Energy (MoE)	2
Public Private Infrastructure Board (PPIB)	3
Islamabad Electric Supply Company (IESCO)	3
National Energy Efficiency and Conservation Authority (NEECA)	1
Quid-e-Azam University (QAU)	1

The primary objective of this chapter is to systematically explore and interpret the data. Then mapped against the anticipated pathways outlined by ToC in Table 5.4. An explanation for the six phases of thematic analysis are provided hereunder.

5.1 Familiarization with the Data

The first phase of thematic analysis involved transcriptions of KPI (Braun and Clarke, 2006). This phase of the data analysis allows familiarity with the depth of the data. Preliminary notes and memos taken to record initial observations, emergent ideas, and recurrent expressions. By doing this step, early indications of thematic patterns like policy ambiguity, financial model inadequacies, and infrastructural limitations began to surface. This foundational phase ensures that subsequent steps are informed by a comprehensive understanding of the data.

5.2 Initial Codes

The second phase of thematic analysis involves generating initial codes (Braun and Clarke, 2006). The dataset, coded systematically, with revisions of the transcription, and then each segment was tagged with codes. The codes derive directly from transcribed data because it is an inductive process. The aim was to capture both semantic and latent content that is relevant to the research objective. The initial codes include: “unclear mandates,” “procurement delays,” “lease model issues,” “grid compatibility concerns,” and “political instability.” These codes serve as the foundation for the theme’s development in the following phase.

5.3 Themes

In this step, the codes are organized into broader themes (Braun and Clarke, 2006). The transition takes place from the descriptive to interpretative level, shown in Figure 5.1. All sub-themes that share a similar concept to a common narrative are collected together under a single theme for more clarity. Such as “ambiguous direction,” “frequent changing in the head of the department,” and “changing priorities,” grouped under the theme “Policy Barriers.” Another category of sub-themes, such as “least model inefficiency” and “budget constraint,” is grouped under the theme “Financial constraints”. The last but not least sub-theme category includes “Infrastructure Limitations” and “Bi-directional meter inefficiencies”, and “Transmission and Distribution”, which are grouped under “Technological challenges”. The process of theme construction is iterative and involves the use of thematic maps to visualize interconnections.

Table 5.2: Initial Themes and Sub-Themes

Theme	Sub Themes
Policy Barriers	• Ambiguous Direction • Political Instability • Changing Priorities • High turnover in departmental leadership
Financial Constraints	• Lease Model Failure • Budget Constraint
Technological Challenges	• Infrastructure Limitations • Bi-directional Meters • Transmission and Distribution

5.4 Reviewing Themes

This phase of analysis involves a rigorous review of the themes (Braun and Clarke, 2006). This phase is conducted at two levels: the first is to assess the internal homogeneity within each theme, and the second is to assess the external heterogeneity across themes. To ensure that each theme is rational and distinct. All the details extracted are revisited to verify that they accurately reflect the thematic category under which they are assigned. In this step, some codes were re-categorized or excluded due to a lack of relevance or thematic coherence. Below is the refined thematic map, which is produced to demonstrate the structure and scope of the data.

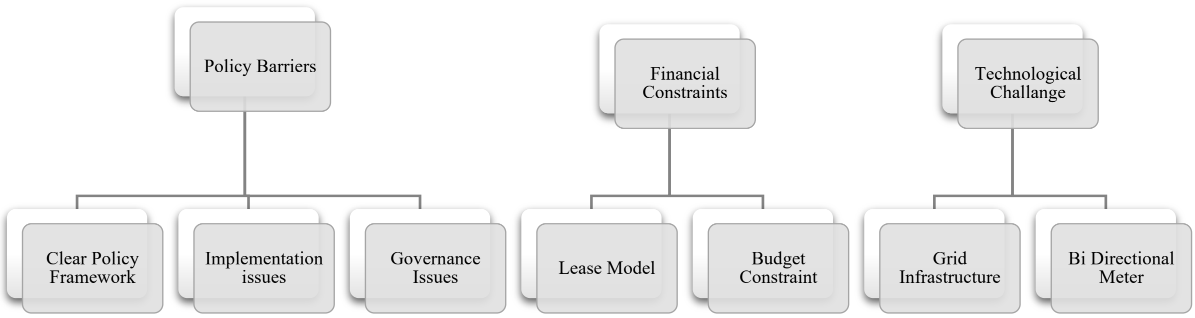

Figure 0.1: Thematic Mapping of Implementation Barriers

5.5 Themes Discussion

The last phase of thematic analysis includes defining each theme clearly to incorporate the data's core meaning (Braun and Clarke, 2006). These themes are refined to ensure they don't overlap and that each contributes specifically to understanding the implementation process. The following is a detailed discussion on each finalized theme and its respective sub-themes.

5.5.1 Policy Barriers

During the interviews, the respondents highlighted the reason behind delays in policy implementation, and consistently pointed to barriers rooted in the absence of a coherent, well-structured policy framework. This theme captures three sub-themes: lack of clear policy, implementation delays, and policy uncertainty.

5.5.1.1 Lack of Clear Policy

Centralized policy planning without involving all the stakeholders, both those directly and indirectly affected by an intervention, leads to an unclear mandate (Kaddu et al., 2023). Many participants show concern about the insufficient policy framework that should direct solarization efforts towards government buildings. Some interviewees pointed out the issues already present in the policy landscape of Pakistan; renewable energy policies are present without appropriate directives for developing public sector infrastructure. Due to the absence of clear and specific guidelines, each stakeholder holds different understandings of their role in initiating solar projects. This created inconsistency in management practices at both ends (the grid and end-consumer levels). This further led to create uncertain operational procedures and additional problems in a chain reaction. And mainly affecting planning and procurement, resulting in misalignment between policy objectives and ground realities.

One of the respondents said,

"*…. In Pakistan, policies are made for some families' benefit rather than for the welfare of the people*".

The interviewee, by lowering his voice, said that the objective behind this initiative is,

"…. With the same purpose to support his family business, this intervention took place."

5.5.1.2 Implementation Delays

Implementation delays significantly reduce the effectiveness of a policy (Selepe, 2023). Respondents who participated in the study indicated that complex administrative pathways alongside confused stakeholder roles created major obstacles to progress. The respondents revealed that the delays come because of bureaucratic barriers, which drag out project timelines. One of the respondents states that,

"*… Due to political instability in the country, the implementation is delayed.*"

The rationale provided for his statement is,

"*…whenever the government changes, the director general changes, and when the new director comes, he starts something new in his own interest.*"

Because of these changes, government-driven projects dragged out project timelines or were even left in the middle. These delays or leaving the project halfway cost taxpayers money and diminish institutional progress. It also affects national and international investors from investing in government projects.

5.5.1.3 Governance Issue

The implementation of the public building solarization project faced a major governance obstacle because policy uncertainty appeared as a critical barrier. Respondents felt unsure about how public sector direction keeps changing with shifting governmental priorities, as well as changing regulations, and a lack of stability throughout political terms. This uncertain policy environment caused stakeholders to avoid risks, as it limited long-term project planning and private sector participation. Ongoing projects suffered from policy changes, which sometimes brought about their suspension or necessitated project modifications, thus substantially weakening program performance.

The "Policy Barrier" demonstrates that weaknesses within institutional policy design and implementation prevented the effective implementation of solarization programs. Improving future renewable energy interventions within the public sector requires addressing existing systemic issues, such as policy consistency, clear direction for stakeholders, and upgrading grid infrastructure.

5.5.2 Financial Constraints

The financial limitations present an obstacle to implementing solarization projects effectively in government buildings. Every participant stressed that financial resources play an essential part in executing policy. The answers to the questions about the financial models are provided in this initiative.

5.5.2.1 Financial Models

The respondents answered the questions on the finances of this initiative. They respond that there are flaws in the financing models. One of the respondents stated that,

"*…. The lease model has failed due to the economic situation of the country.*"

Furthermore, the respondent added that in the lease model, the bidder pays the full amount and then builds return on equity. The contract duration is 10 years. The lease model's sole purpose is to attract private investors, but unfortunately, it is not attracting due to no trust in the government. Also, private investors want the old Independent Power Producer (IPPs) agreement, which was in dollars, while in this initiative, the government changed the agreement from dollars to Pakistani rupees. For the private sector, this option is not viable due to the State Bank of Pakistan (SBP) and commercial bank limitations and interest rates.

On the other hand, there is the “Own Cost Model” for shifting government buildings to solar energy. In which the department bears their own cost for installing a solar PV system. The respondent talked about the selection criteria for a building to be solarized. Every building that has funds and space for a solar PV plant is eligible. Furthermore, he added that the Private Power and Infrastructure Board (PPIB) is responsible for the procurement. The respondent said that,

“…a lot of departments are solarizing their building independently. There is a high number of buildings that have undergone solarization independently.”

In summary, the initiative financing models are full of flaws according to the interviews with different stakeholders, and that is why there has been very little implementation done so far.

5.5.3 Technological Challenges

Some interviewees pointed to technological issues as major obstacles that hindered the successful execution of similar initiatives. Indicating that technical problems triggered both the construction plan expansion and degraded the lasting quality of implemented systems. The theme covered the primary subcategory, which included maintenance problems alongside technical capabilities, combined with equipment dependability tasks.

5.5.3.1 Grid Infrastructure

The questions about grid infrastructure were also included in the questionnaire, and nearly every respondent showed concern about its capabilities. They said that Pakistan does not have a well-developed grid infrastructure capable of integrating such a high share of renewable energy sources. Furthermore, one respondent observed that in other countries, utilities are permitted to have a 20% renewable energy share, whereas in Pakistan, the allowed 80%, which further increases inefficiency in the national grid. By increasing the damage rate of transformers and feeders. Additionally, one respondent said that.

“…the location for installing solar PV plant should be selected by the utility, not by the producer while in Pakistan there is no such rules.”

Because this is where the inefficiency takes place, and the cost of these inefficiencies is borne by the utilities (DESCOs) and the middle-class Pakistani who cannot afford solar energy. One of the respondents discussed that people think that this is a good initiative, and it will drag down the average electricity generation cost. But it is not happening, and the reason is that our plants are running on merit order, in which the fossil fuel-based plants are at the top of the merit order because one cannot just shut them down. So, if these expensive producers are already generating expensive electricity, there is no chance of getting to a lower average generation cost.

Furthermore, the question on transmission and distribution loss was also included. One of the respondents said that,

"*…. it is increasing the T&D loss because if someone is generating their electricity, they are cut from the grid under net metering, and all the T&D loss, which was divided by the consumers, is now divided by fewer consumers, which is increasing the cost for non-solar users.*"

All this cost will be bear by a common man who cannot afford solar energy infrastructure. Another respondent from IESCO said,

"*…. We have 53% of exports from solarized domestic and commercial buildings.*"

Further, he said that this transition is shifting the peak hours. Also, it affects system stability and system harmonics. He further added that,

"*…. by this rapid transition, IESCO bears a cost of 3408 million rupees, which shifts on non-solar households*".

5.6 Producing the Report

This step of thematic analysis synthesized the theme into a coherent narrative that addressed the central research questions (Braun and Clarke, 2006). The analysis shows that the implementation of the "Fast Track Solar Initiative 2022" deviated significantly from the ToC assumptions. The fidelity of implementation, defined as the extent to which actual execution aligns with the intended plan, was demonstrably compromised.

Table 5.3: Alignment with Theory of Change (ToC)

Theme	Sub Themes	Violated ToC Assumption
Policy Barriers	• Regulatory ambiguity • Political volatility	• Clear governance • Institutional coordination
Financial Constraints	• Inadequate financing models	• Reliable funding mechanisms
Technological Challenges	• Infrastructure inadequacies • System integration failure	• Sufficient technical and grid preparedness

The analysis identifies the challenges faced during the implementation of "Fast Track Solar Initiative 2022" by following the six-phase approach to thematic analysis. The finding confirms that there is a fidelity of implementation errors. Means that there is a gap between the plans and executed activities. Addressing these barriers is crucial for the success of future renewable energy interventions.

5.7 Discussion

The thematic analysis revealed discrepancies between the planned and executed public building solarization intervention. The realities of ground-level implementation reveal that it is not carried out as intended. Following the six-phase approach of thematic analysis suggested by Braun and Clarke (2006), underscores critical systemic and institutional barriers that are hindering the effectiveness of this intervention. Policy barriers, financial constraints, and stakeholders' engagement emerge as primary themes.

The first main theme that emerges is ***policy barriers***, which identify the absence of coherent institutional coordination and regulatory clarity. The findings revealed that there is a lack of a steady plan, an inconsistent role of stakeholders, and interruptions caused by bureaucratic procedures. These challenges in implementation have already been highlighted in the existing literature, which is causing hurdles in the effective policy execution. Effective policy execution not only depends on the quality of policy design but also on the bureaucratic actors responsible for its realization (Fernández-I-Marín et al., 2024). As the high-level official often changes with changes in the government, it leads to discontinuity in planning, reflecting the fragility of institutional memory. Samadi et al. (2024) describes these governance issues as "institutional inertia". These are hindered by misaligned administrative protocols and politicized decision-making.

The second theme derived from the analysis is ***financial constraint***. Identifies that there are misalignments in funding mechanisms that hinder project uptake. The lease model was introduced to attract private sector investments in the public sector. But due to the low confidence in the private sector, the lease model failed. Similarly, the SBP initiated low-interest rate loans at 6% but for the same reason, it also didn't attract the private sector. Since the private sector invests in a favorable environment for business. While at the time of this initiative, there were frequent changes in the government of Pakistan, which signaled private sector not to invest in such volatile conditions.

More reason for not attracting the private sector lies in the tariff structure of this intervention. The tariff for solarization projects is imposed in Pakistani rupees, while the private sector wants similar tariff rates in dollars, as committed with IPPs in the past. Similarly, there is an own cost model, in which the government department/office lacks funds, due to which they never shifted to solar energy. As a result, a lot of departments didn't shift to solar energy under this initiative, while under the net metering policy, there were 280 public offices within Islamabad which are already shifted to solar energy. Issues in the financial model are limiting the scalability of the project. Understanding the organizational context is crucial in developing realistic program assumptions and resource frameworks.

The third theme that emerged is ***technological challenges***. The policymakers should consider whether they can implement this initiative with this outdated infrastructure. They never assessed the consequences of this transition from fossil fuels to solar energy. During the interviews, most of the respondents showed concerns that our grid is not mature enough to integrate such a transformation. The respondent further added that due to this transition, all the burden will be shifted onto non-solar users on the grid, bear the cost. While the assumption of ToC holds that there will be a technically prepared environment. On the ground, implementation highlights the absence of grid stability mechanisms and strategic integration planning. Therefore, the barrier to successful implementation was the structural limitations that must be accounted for. In addition, Kranenburg and Groenleer (2025) argued that technological advancement in the energy sector must be aligned with institutional readiness and regulatory coherence.

Overall, these deviations from the planned activities affirm the presence of a fidelity of implementation error, which compromised effective intervention. The thematic analysis approach adopted from the paper Braun and Clarke (2006) enabled an iterative and reflective process. The process well-lit the nuances of the implementation failures. This thematic development, through an interpretative process, is particularly effective in capturing the barriers across institutional, financial, and technical dimensions.

According to the study's findings, the implications extend beyond this specific initiative. It highlights the need for adaptive policy instruments and real-time monitoring mechanisms capable of responding to evolving implementation issues. Moreover, it suggests that ground-level actors often reshape policy outcomes in ways not foreseen by designers. This necessitates stronger institutional safeguards and clearer accountability structures. Also, the participatory governance models are used to bridge the gap between policy intent and execution.

The ToC provided a robust pathway for the intervention. The success, on the other hand, was impeded by implementation inconsistencies. Includes policy ambiguity, financial constraints, and technical unpreparedness. These insights from the analysis contribute to the broader discourse on renewable energy policy adoption. Underscores the value of rigorous qualitative analysis, answering the "How" and "Why" behind program performance. Future initiatives must account for contextual realities, anticipate systemic constraints, and prioritize fidelity to ensure that theoretically sound interventions can achieve meaningful impact.

Table 5.4: Mapping Against the Anticipated Pathways of ToC

Anticipated ToC Pathway	Underlying Assumption	Emergent Theme from Data	Nature of Alignment
Coordinated multi-agency implementation	Institutional roles are clearly defined and collaboration is effective	Lack of inter-agency coordination	Misalignment
Timely availability of financial resources	Budgetary allocations and disbursements are sufficient and punctual	Delays in funding and financial uncertainty	Misalignment
Private sector trust and participation	Policy clarity and political stability attract private investment	Loss of private sector trust due to political uncertainty	Misalignment
Robust grid infrastructure to support solar integration	Existing grid is capable of absorbing solar generation	Inadequate grid infrastructure	Misalignment
Reliable and cost-effective energy through solar adoption	Solar energy reduces electricity costs and enhances reliability	High potential for cost savings identified	Alignment
Environmental sustainability and reduced emissions	Solarization contributes to carbon emission reduction	Acknowledged environmental co-benefits	Alignment
Monitoring and evaluation mechanisms ensure course correction	Feedback loops allow timely adjustments in implementation	Weak monitoring and lack of adaptive management	Misalignment

Chapter 6

COST-BENEFIT ANALYSIS

This chapter provides a detailed CBA of a solar PV plant for on-grid and off-grid systems for government-owned buildings in Pakistan. The objective is to assess the social and financial viability. The analysis is composed of a case study of a central library located in Quaid-i-Azam University. And then the results are generalized for the assessment of an average-sized government building. The analysis is carried out for both on-grid and off-grid PV systems. This enables an understanding of financial and policy implications.

6.1 Central Library

The central library is located in a public sector university and operates under the jurisdiction of the federal government. Public sector entities are often characterized by ideal operational hours from 9 AM to 5 PM. There is substantial electricity demand for lighting and air conditioners during operational hours. The average electricity consumption for the central library is estimated at 196992 kWh annually based on the previous year's electricity consumption data. Due to the nature of the annual data, the seasonal variations are well adjusted.

6.1.1 On-Grid Solar PV

The solar PV installed on-grid system with a capacity of 135kW. It works with the configuration of the national grid under the net metering scheme. It is a bi-directional system; the extra units generated by solar PV are exported to the national grid, so that the national grid doesn't procure expensive generated electricity.

Table 6.1: Details of Quaid-i-Azam University Central Library On-grid Solar PV

Parameter	Specification/Detail
System Type	On-Grid Solar PV System
Installed Capacity	135 kW
Installation Site	Quaid-i-Azam University
System Configuration	Grid-tied, bi-directional system with Net Metering
Photovoltaic Module Type	Bifacial Monocrystalline (N-Type)
Number of PV Panels	450
Inverter Type	Grid-tied string inverter / Central inverter
Grid Interaction	Exports excess energy to national grid via net metering
Net Metering Policy	Allowed under NEPRA Regulation (2015)
System Lifespan	25 years
Operation & Maintenance (PKR)	168750
Initial Capital Cost (PKR)	16875000
Payback Period	2.04 Years
Environmental Benefits	2657.39 (PKR Million)
Funding Source	World Bank (HEC Project)
Commissioned	March, 2025

6.1.1.1 Cost and Benefit Estimation

The solar PV plant's economic and environmental viability is assessed through the annual savings from grid electricity, which is generated from fossil fuels. The 135kW bifacial monocrystalline solar PV system produces an estimated average of 4.51 MW monthly. The production capacity is found from the previous three months' data from the software installed in a net-metering system. The average annual consumption of the central library is 196992 kWh based on the previous year's consumption data. In Pakistan, the electricity generation mix depends 59.4% on fossil fuels as of 2024. Taking this share from the central library's electricity consumption, the actual consumption from fossil fuels becomes 117013 kWh. Applying the current tariff for electricity, which is PKR 46.23 per kWh, the annual financial benefit is PKR 5.42 million. It is considered savings because without solar PV, the central library would incur electricity from the national grid, which is expensive and carbon-intensive.

The total capital cost for the procurement and installation of a 135-kW solar PV plant is PKR 15.43 million; there are no operating and maintenance costs in the first year. While the upfront cost is high, the life of a solar PV plant is 25 years, which ensures that the system can generate cumulative cash flows over time. The solar panel used in this solar PV plant is a bifacial module, which is capable of converting sunlight from both front and back surfaces. This dual-sided generation further enhances the system yields and contributes to a higher effective output. Overall, it improves the system cost-effectiveness metric by reducing the payback period.

Furthermore, the solar PV system is not limited to the direct benefit of electricity savings. There are indirect benefits, including reduced carbon emissions in the air, enhanced energy security, and reduced dependency on imported fuels. Therefore, from a cost-benefit perspective, the solarization of public buildings demonstrates a high return on investment both in financial and environmental terms.

Table 6.2: Estimated Carbon Emissions Reduction (Tons) by the Central Library

Year	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
kWh	108820	116233	128310	146387	172605	210337	264905	344805	463840	644871	926591	1375985	2111787
tCO_2/kWh	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
tCO_2	54.41	54.63	60.31	68.80	81.12	98.86	124.51	162.06	218.00	303.09	435.50	646.71	992.54

Year	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
kWh	3349630	5491033	9302972	16289205	29477357	55129961	106560758	212871442	439488973	937754258	2067952638	4713056131	11101332668
tCO_2/kWh	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
tCO_2	1574.33	2580.79	4372.40	7655.93	13854.36	25911.08	50083.56	100049.58	206559.82	440744.50	971937.74	2215136.38	5217626.35

The annual savings are derived by offsetting the national grid electricity with solar PV electricity generation. These savings are calculated by multiplying the annual kWh consumption and the tariff rate (PKR/kWh). There are assumptions that the tariff rate is increasing at a rate of 7% while the annual electricity consumption increases at a rate of 4%. These assumptions are made on the basis of the growth rates calculated based on the previous 25 years of data for both electricity consumption and the tariff rate. The table below shows the estimated cost savings over the year for a 25-year life of the project.

Table 6.3: Estimated Electricity Payable by the Central Library Building

Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Annual Consumption (kWh)	108820	116233	128310	146387	172605	210337	264905	344805	463840	644871	926591	1375985	2111787
Per Unit (PKR/kWh)	46.29	49.53	53.00	56.71	60.68	64.92	69.47	74.33	79.53	85.10	91.06	97.43	104.25
Electricity Savings (Million)	5.04	5.76	6.80	8.30	10.47	13.66	18.40	25.63	36.89	54.88	84.37	134.07	220.16

Year	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Annual Consumption (kWh)	108820	116233	128310	146387	172605	210337	264905	344805	463840	644871	926591	1375985	2111787
Price PKR/kWh	111.55	119.36	127.72	136.66	146.22	156.46	167.41	179.13	191.67	205.08	219.44	234.80	251.24
Electricity Savings (Million)	373.66	655.41	1188.13	2226.01	4310.23	8625.47	17839.24	38131.17	84235.37	192317.73	453789.72	1106624.95	2789052.83

6.1.1.2 Net Present Value

The net present value of the cash flows from the on-grid solar PV over a 25-year lifespan is estimated at 126 million Pakistani rupees on a discount rate of 10[1]%. The project is producing a significant return on investment. Means that after recovering the cost and discounting the future cash flows, the public institute will get the benefits of PKR 126 million. This number highlights the long-term economic advantage of substituting grid electricity. This positive NPV indicates the financial viability of the investment as the present value of benefits exceeds the upfront and wear and tear over the system's useful life.

Table 6.4: Cost-Benefit Analysis Matrices

Payback Period in Years	2.04
Discount Rate	10%
IRR	60%
NPV in PKR (Million)	126
B/C Ratio	15%

Following is the complete CBA Table.

[1]: World Bank (2021) calculated this discount factor for public sector investment projects.
https://documents1.worldbank.org/curated/en/883241610741226840/pdf/Main-Report.pdf?utm_

Table 6.5: Costs and Benefits of a Central Library 135 kW Solar PV

Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Electricity Savings	5.42	6.06	6.79	7.59	8.50	9.51	10.65	11.92	13.34	14.93	16.71	18.70	20.93
Initial Investment	(15.43)	–	–	–	–	–	–	–	–	–	–	–	–
O&M	–	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)
Disposal Cost	–	–	–	–	–	–	–	–	–	–	–	–	–
Total Costs	(15.43)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)
Cashflow	(10.01)	4.52	5.24	6.05	6.96	7.97	9.10	10.37	11.79	13.38	15.16	17.15	19.38
Cumulative Cashflow	(10.01)	(5.49)	(0.25)	5.80	12.76	20.72	29.83	40.20	52.00	65.38	80.54	97.70	117.08
Payback Period	1	1	0.4	–	–	–	–	–	–	–	–	–	–

Year	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Electricity Savings	23.42	26.21	29.34	32.84	36.75	41.13	46.04	51.53	57.67	64.54	72.24	80.85	90.49
Initial Investment	–	–	–	–	–	–	–	–	–	–	–	–	–
O&M	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)
Disposal Cost	–	–	–	–	–	–	–	–	–	–	–	–	–
Total Costs	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(1.54)	(2.04)
Cashflow	21.88	24.67	27.80	31.29	35.21	39.59	44.49	49.98	56.13	63.00	70.70	79.31	88.45
Cumulative Cashflow	138.96	163.63	191.43	222.72	257.93	297.52	342.02	392.00	448.13	511.13	581.83	661.14	749.58
Payback Period	–	–	–	–	–	–	–	–	–	–	–	–	–

PKR (Million)

Figure 6.1, given below, shows the annual and cumulative cash flows associated with the solar PV plant installation at the central library building. Furthermore, a rapid recovery of the initial investment, the project achieves payback in approximately 1.6 years based on annual cash flow. Meanwhile, the cumulative cash flow incorporates all the projected annual cash flows with a discount rate of 10% showing the full recovery of capital expenditures within 3 years. The steep upward trajectory of the cumulative cash flow curve further indicates sustained financial benefits. This early breakeven point, combined with a steadily increasing net return, underscores the attractiveness of solar PV deployment.

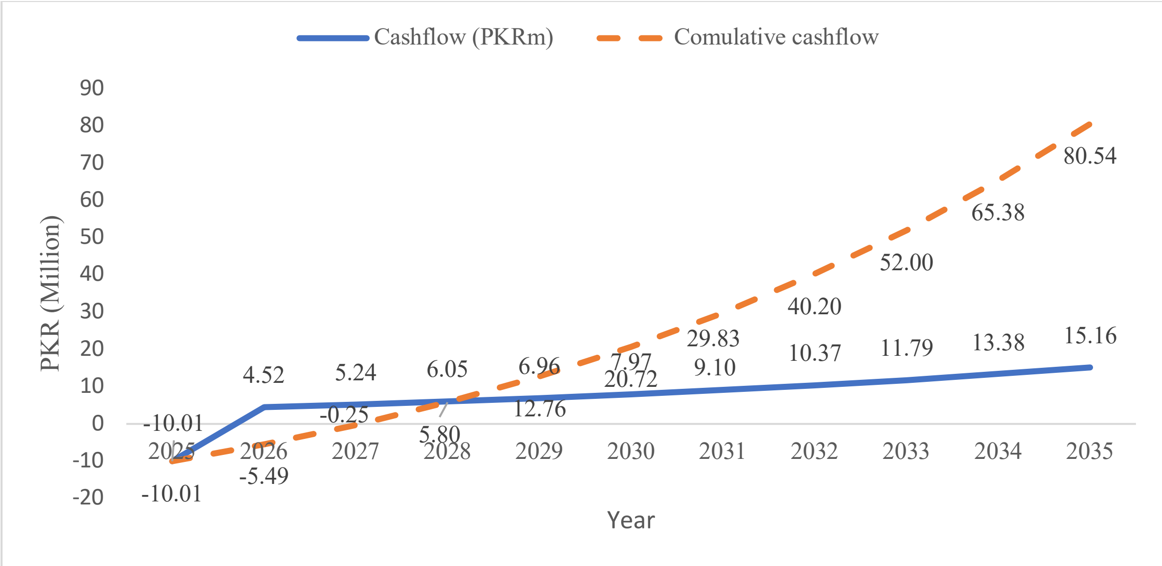

Figure 6.1: Projected Cash Flows of 135 kW On-Grid Solar PV System

6.1.2 Off-grid Solar PV

This sub-section of the chapter evaluates the feasibility of a 30 kW off-grid solar PV plant. This system serves as the backup for the same required load in case there is an interruption in the grid power supply. Off-grid solar PV plant works independently of the national grid, as it holds sufficient battery storage capacity to ensure an uninterrupted power supply. An off-grid solar PV plant incurs a high upfront cost compared to an on-grid system because it requires extra batteries and inverters. It offers strategic advantages in terms of energy autonomy and reliability. These attributes become particularly valuable in contexts where grid supply is unreliable or where public services cannot be disrupted. The CBA examines the cost structure and financial viability of the off-grid system. This analysis includes metrics such as NPV, IRR, and B/C ratio. Moreover, a comparative analysis is used to examine off-grid and on-grid solar PV systems. To capture a more holistic understanding of their relative trade-offs. This comparison is intended to inform the adoption of a solar PV investment decision in government infrastructure. Specifically, in the context of climate adaptation, decentralization, and energy resilience.

Table 6.6: Key Differences Between On-Grid and Off-Grid Solar PV

Parameter	On-Grid System	Off-Grid System
PV Capacity	135 kW (full building load)	30 kW (essential load coverage)
Battery Storage	Not required	8 lithium ion battery banks
System Autonomy	None	3 days backup for critical services
Inverter Type	Grid-tied inverter	2 Hybrid inverters with charge controller
Net Metering	Enabled	Not applicable
Energy Consumption	Net-metered with grid export/import	Full self-consumption
Capital Expenditure	PKR 18.49 Million	PKR 8.97 Million
System Objective	Cost reduction via net metering	Uninterrupted supply

6.1.2.1 Cost and Benefit Estimation

The total capital cost of the 30 kW off-grid solar PV system is PKR 8.96 million. With comparison to the on-grid system, its cost is high due to additional requirements of the system, including battery storage and hybrid inverters. The annual operating and maintenance costs are calculated as 5% of the capital cost because the battery replacement is expected every 5-10 years. The electricity generated is consumed on site, which offsets the revenue from the exports to the national grid. On the bright side, it is beneficial for the environment and can reduce the estimated total carbon emissions by 2653.9 tCO_2 over the life of 25 years.

6.1.2.2 Net Present Value

The NPV is calculated at PKR 127 million using a discount rate of 10%. This yields a highly favorable result, indicating the long-term financial gains over the useful life of the project. The IRR of 38% shows the profitability of the investment because it is higher than the discount rate. The payback period is calculated at approximately 3.49 years, after which the system starts to generate a net positive cash flow. Furthermore, the B/C is estimated at 56; the interpretation is that every 1 rupee invested will generate a return of 56 rupees, showing a high return. NPV metrics highlight that the off-grid solar PV has the potential not only as a resilient energy solution but also as an attractive investment. While the upfront cost is higher compared to on-grid, the long-term benefit significantly outweighs the costs. These results underscore that the off-grid is a suitable option for those public institutions that require an uninterrupted electricity supply or in remote areas.

Table 6.7: Comparative Financial Summary of On-Grid and Off-Grid Solar PV Systems

Financial Indicator	**On-Grid System (135 kW)**	**Off-Grid System (30 kW)**
Capital Cost (PKR)	15.43 million	8.97 million
Net Present Value (NPV)	PKR 126 million	PKR 127 million
Internal Rate of Return (IRR)	60%	38%
Payback Period (Years)	2.04 years	3.49 years
Benefit-Cost Ratio (B/C)	15	56
Net Metering	Enabled	Not applicable
Grid Dependence	Dependent	Independent
Energy Resilience	Limited	High

6.2 What if to solarize all government buildings?

The estimation evaluates the broader financial and environmental impacts of solarizing public buildings nationwide. The results of the central library CBA are used to scale based on overall load data. According to the NEECA, government buildings required load nationwide is 5,227 MW. These buildings often operate an average of 8 hours per day over 240 days each year. Deploying solar PV is expected to offset an estimated 1000 MW of load, leading to an estimated annual savings of 1.92 million MWh. Using the central library as a case study, where a 135 kW on-grid solar PV system produces approximately 73,000 kWh annually, the average yearly savings amount to PKR 2.55 million. Extrapolating the result, the total savings from solarizing 1000 MW of public sector load are estimated at PKR 67 billion, assuming a uniform tariff of 46.29 per unit. Also, it can prevent an estimated 5.1 million tons of CO_2 emissions annually. Actual results might vary depending on building specifics, usage, and location. This analysis offers a measurement of the strategic potential for solarization across public buildings.

Chapter 7

CONCLUSION

The ToC and CBA findings are presented in this chapter. A comprehensive overview of the results is presented, offering a unified and clear depiction of this study. And have two primary objectives: first, to conduct a cost-benefit analysis of a solarized central library building located at Quaid-i-Azam University; second, to evaluate the fidelity of policy implementation through the process evaluation technique.

For this first objective, the adoption of solar PV in government-owned buildings is common practice worldwide due to climate-resilient and cost-effectiveness. However, in Pakistan, a complex interplay of policy ambitions, institutional capacity, and fiscal pressures exists which causes problems in effective execution of the policy. This study scrutinizes both the quantifiable benefits of solarization, as well as the qualitative aspects. It offers valuable insights for policy formulation aimed at enhancing energy security, increase resource utilization efficiency, and environmental stewardship. By doing so, this study contributes to the broader discourse on affordable and clean energy (SDG-7) and climate action (SDG-13) of the SDGs.

The findings from the CBA show that solarizing the central library building results in significant long-term savings of Rs 4,699 billion over the project's 25-year life span. Also, it reduces energy-related emissions of 2,567 tCO_2. Even with a discount rate of 10%, the NPV of the investment for both on-grid and off-grid scenarios is approximately Rs 126.5 million, with a payback period of 2.04 years for on-grid PV and 3.46 years for off-grid solar PV systems. While the internal rate for on-grid is 60% and for off-grid is 38%, this shows the financial feasibility. It suggests that adopting off-grid solutions is beneficial for remote areas or for those facilities that require an uninterrupted electricity supply.

Contrariwise, the process evaluation shows several implementation gaps. Although the policy is well-articulated in terms of its objectives, its execution is hindered by several factors, including policy barriers, financial constraints, and limited stakeholder engagement. The factor of policy barriers shows the absence of coherent institutional coordination and regulatory clarity. Effective policy execution depends on both the quality of policy design and the bureaucratic actors responsible for its implementation (Fernández-I-Marín et al., 2024). Financial constraints identified the misalignments in funding mechanisms that impede the effectiveness of the intervention. The objective behind this intervention is to attract private sector investment, for which they designed a lease model. The SBP initiated low-interest-rate loans at 6%, still the private sector is losing confidence due to the country's ongoing political instability. Another reason for low confidence is tariffs, which are the price at which the electricity is purchased from solar power producers, denominated in PKR. Previously, under the net-metering policy, it was in dollars, which was more beneficial for the private sector, and as a result, attracted 280 solar PV projects in the government building sector. These issues in the financial models limited the scalability of this initiative. While on the technology side, it presents its own challenges, such as the outdated grid infrastructure and the inability to afford a significant transition towards solar. Kranenburg & Groenleer (2025) argue that technological advancement in the energy sector must be aligned with institutional readiness and regulatory coherence.

Overall, it shows the fidelity of implementation error, compromising the effectiveness of the public building solarization initiative. It emphasizes the need for adaptive policy instruments and real-time monitoring mechanisms that can respond to emerging issues during implementation. Likewise, the analysis suggests that ground-level actors often reshape policy outcomes in ways not foreseen by policy designers. This necessitates stronger institutional safeguards and clearer accountability structures. These insights contribute to the broader discourse on the adoption of renewable energy worldwide. Future initiatives must account for contextual realities, anticipate systemic constraints, and prioritize fidelity to ensure that theoretically sound interventions can achieve meaningful impact.

The key contributions to the existing literature are that it provides an integrated evaluation framework that combines both CBA and process evaluation. Provide empirical evidence on the economic and environmental feasibility of solar PV deployment in public sector infrastructure, thereby informing the ongoing discourse on the clean energy transition. Furthermore, the study offers a structured lens for assessing the implementation gaps in renewable energy polices.

While this study offers valuable insights, it is also subject to some limitations. Notably, a few estimated values are employed in the CBA due to the lack of real-time data, stemming from limited access to detailed financial and technical records of public institutions. The findings are based on a case study, which may not be generalizable across the broader spectrum of public buildings with varying energy use. Additionally, although the process evaluation is guided by the ToC, it may not fully capture the informal dynamics, political influences, and inter-agency complexities that shape policy implementation in practice.

The CBA is based on data from a single public building, which, while representative, may not capture the full diversity of government infrastructure. Similarly, the process evaluation relied primarily on qualitative data from stakeholders, which, although rich in insight, may be subject to interpretive bias. Additionally, uncertainties in future fuel prices, technological advancements, and exchange rate fluctuations may impact the generalizability of the financial results.

The policy implications of the study are significant. The solarization policy to be effective must be accompanied by reforms in institutional coordination, budget allocation, and technological advancement. Moreover, a centralized monitoring and evaluation mechanism helps bridge the gap between policy design and implementation. Scaling up solarization could help reduce import bills, mitigate circular debt, and improve energy security. The transition to solar energy in public buildings has economic and environmental benefits, but its success depends on institutional and governance bottlenecks. Strengthening implementation frameworks can accelerate progress toward national energy security and SDG-7.

7.1 Policy Recommendation

- Quaid-i-Azam University should consider reallocating the surplus electricity generated by the Central Library's solar PV system to meet the energy needs of other buildings on campus. This internal utilization would enhance institutional energy self-sufficiency and contribute to a more sustainable and resilient campus energy system. Selling excess electricity to the national grid under the existing net metering framework may be less financially advantageous, as the grid purchase rate is significantly lower (PKR 25/unit) than the retail consumer tariff (PKR 46.23/unit), resulting in limited economic returns.
- In parallel with solarization efforts, prioritizing energy conservation measures is essential. Evidence from energy audit reports of public sector buildings by GIZ indicates that strategic conservation practices could reduce electricity costs by up to 35%.
- Policy monitoring and evaluation mechanisms should be institutionalized to minimize cost overruns and enhance the efficiency of implementation. Regular monitoring and evaluation can help identify delays, inefficiencies, and deviations from planned activities, enabling timely corrective actions.

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Appendix A

Interview Guide

1. What do you see as the main objectives of this initiative?
2. In your opinion, how important is solar energy for public buildings? Why?
3. What resources are critical for the success of the initiative?
4. Are there any challenges in obtaining the necessary resources? If yes, please elaborate.
5. What key activities do you believe are essential for implementation?
6. What are the outputs of this initiative?
7. What short-term outcomes do you think will result from the successful implementation of this initiative?
8. In your view, what are the long-term benefits of solarization for public buildings?
9. What external factors do you think impact the success of the initiative?
10. What financing options have been most effective in supporting solar projects?
11. Based on your experience, what recommendations would you make for improving this solarization process?

Thank you for your time and valuable insights.