



PRIED

Policy Research Institute
for Equitable Development

Solar Adoption Patterns in Pakistan

The first national snapshot of Pakistan's distributed solar boom, detailing installation trends, system sizes, connection types, and changing demand patterns.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
1. INTRODUCTION	5
2. METHODOLOGY	10
3. SURVEY ANALYSIS	17
3.1. Over 33 GW of solar installed against the 50GW of imported solar	17
3.2. Satellite Mapping by TransitionZero	18
4. RESIDENTIAL SECTOR	20
4.1. Adoption across the Residential Sector	20
4.2. Low solar adoption in Low-income Households	21
4.3. Changing Grid Energy Consumption Patterns	22
4.4. Reasons for Reduced Grid Demand	24
4.5. Reasons for Increased Grid Demand	25
4.6. Barriers to Adoption	26
5. COMMERCIAL SECTOR	28
5.1. Adoption across Commercial Sector	28
5.2. Adoption by Enterprise Scale	29
5.3. Adoption by Income Group	30
5.4. Changing Grid Demand	31
5.5. Reasons for Reduced Grid Demand	33
5.6. Reasons for Increased Grid Demand	34
5.7. Barriers to Adoption	35
6. INDUSTRIAL SECTOR	38
6.1. Adoption across the Industrial Sector	38
6.2. Industrial Solar Adoption Across Provinces	38
6.3. Changing Grid Demand	41
6.4. Reasons for Decreased Grid Demand	42
6.5. Reasons for increased Grid Demand	43
6.6. Barriers to Solar Adoption	44
7. AGRICULTURE SECTOR	47
7.1. Agricultural Solar Capacity by Province	47
7.2. Trends in Irrigation Power Sources	48
7.3. Adoption across Income Groups	48
7.4. Adoption by Scale	49
7.5. Change in Electricity Consumption from Grid	51
7.6. Reasons for Decreased Grid Demand	52
7.7. Reasons for Increased Grid Demand	53
7.8. Barriers to Adoption	54
8. IMPLICATIONS OF PAKISTAN’S SOLARIZATION TREND: A UNIFIED INTERPRETATION	56
9. CONCLUSION	59

LIST OF FIGURES

Figure 1: Trends in Solar PV Imports	5
Figure 2: Electricity sales growth trends	6
Figure 3: Pakistan's trade deficit	7
Figure 4: Pakistan's Solar Adopters	8
Figure 5: Geographic Coverage of the Survey Sample	11
Figure 6: Survey Response Counts by Area	12
Figure 7: Triangulation Framework	15
Figure 8: Provincial Distribution of Residential Solar Capacity by Connection Type (GW)	20
Figure 9: Household Solar System Capacity by Income Group	21
Figure 10: Solar Adoption Rates by Household Income Group (%)	22
Figure 11: Changes in Residential Grid Electricity Consumption Over the Last Two Years	23
Figure 12: A macro-economic overview for reduced grid demand	24
Figure 13: Reasons for Increased Electricity Consumption	25
Figure 14: Barriers to Adoption	26
Figure 15: Provincial Distribution of Commercial Solar Capacity by Connection Type (GW)	28
Figure 16: Solar Adoption by scale of enterprise	29
Figure 17: Solar adoption across income groups	30
Figure 18: Change in electricity consumption from the grid over the last two years	32
Figure 19: Reasons for reduced grid demand by income groups	33
Figure 20: Reasons for Increased Electricity Consumption	34
Figure 21: Barriers to adoption by income groups	36
Figure 22: Provincial Distribution of Industrial Solar Capacity by Connection Type (GW)	38
Figure 23: Solar Adoption by Industrial Size	39
Figure 24: Solar adopters by Expenditure groups	40
Figure 25: Change in electricity consumption from the grid over the last two years	41
Figure 26: Change in electricity consumption from the grid by expenditure groups	42
Figure 27: Reasons for increased grid electricity demand by income groups	43
Figure 28: Barriers to adoption by income groups	44
Figure 29: Provincial Distribution of Agriculture Solar Capacity by Connection Type (GW)	47
Figure 30: Distribution of irrigation sources in Pakistan	48
Figure 31: Solar adoption by expenditure groups	49
Figure 32: Solar adopters by scale of agricultural facility	50
Figure 33: Change in electricity consumption from the grid over the last two years	51
Figure 34: Reasons for decrease in grid demand	52
Figure 35: Barriers to adoption in the agricultural sector	54
Figure 36: Impact on non-solarised consumers	56

LIST OF TABLES

Table 1: Installed Distributed Solar Capacity by Region and Consumer Category (GW)	17
Table 2: Solar Capacity Estimates by Region and Sector (TransitionZero Analysis)	18
Table 3: Change in Electricity Consumption by New-Demand Status in percent (%)	31



EXECUTIVE SUMMARY

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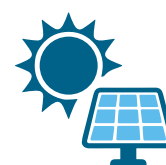
Pakistan's Scramble for Solar – Economic Necessity or Environmental Compulsion

Pakistan has experienced a dramatic solar revolution over the past nine years, with an estimated 33.34 GW of distributed solar PV capacity installed against more than 50 GW of imported solar modules. This installed capacity now exceeds the country's peak summer grid demand of 28–30 GW, fundamentally transforming the national energy landscape. The residential sector leads this transition with 16.66 GW of installed capacity, followed by industrial (7.91 GW), agricultural (5.04 GW), and commercial (3.73 GW) sectors. Provincial analysis reveals Punjab as the dominant adopter with the highest installed capacity across all sectors, followed by Khyber Pakhtunkhwa, Sindh, Balochistan, and Islamabad Capital Territory.

This solar revolution is primarily driven by economic necessity rather than environmental motivation. Electricity tariffs increased by over 150 per cent between FY2021 and FY2024, making grid electricity financially unsustainable for most households and businesses. PRIED survey findings indicate that 77 per cent of solar adopters now rely primarily on their PV systems for daily energy needs, with only 23 per cent depending significantly on the grid. Solar now meets approximately 41 per cent of residential electricity demand and 43–49 per cent of commercial and industrial demand, effectively displacing massive amounts of grid consumption.

However, this transition has exposed critical equity challenges. Solar adoption increases sharply with income levels: From 38 per cent among low-income households to 88 per cent among high-income households. Low-income consumers face high upfront costs (cited by 75 per cent of survey respondents as a barrier), limited financing access, and exposure to substandard equipment from unscrupulous vendors. Meanwhile, wealthier consumers who can afford solar systems are gradually leaving the grid, shifting cost burdens onto captive non-adopters who face escalating tariffs.

The shift is creating severe structural pressures on Pakistan's power sector. Distribution companies face declining sales revenues as consumers reduce grid dependency, while fixed network costs remain unchanged. This revenue erosion is accelerating circular debt and undermining assumptions behind market reforms. The emergence of the «duck curve», with deep midday demand dips and steep evening peaks, is complicating system operations and dispatch planning. Distribution networks designed for unidirectional power flow are experiencing voltage rise, reverse flows, and equipment stress in high-penetration areas.



Solar capacity now **exceeds** peak national demand **33.34 GW** of distributed solar installed *VS* **28–30 GW** peak summer grid demand

Electricity tariffs increased over



150%
in 3 years

Industries, once the backbone of productive electricity demand, are achieving 50–75 per cent savings through solar adoption, with rural industries reporting the highest benefits. In agriculture, solar-powered tube-wells now dominate irrigation, with Punjab showing a remarkable decline in diesel dependency from 80 per cent in 2021 to 59 per cent currently. This sector demonstrates a truly bottom-up energy transition, with even the lowest-income agricultural group showing 85 per cent adoption rates, driven by unreliable grid supply and long-term economic benefits.

Looking ahead, Pakistan faces a critical juncture. While distributed solar has delivered cleaner and more affordable energy to millions, the pace of adoption is outstripping regulatory adaptation and grid modernization efforts. Without comprehensive reforms – including advanced metering infrastructure, distribution energy resource management systems, refined tariff structures, and updated grid codes – continued solar growth risks exacerbating technical instability, financial imbalances, and planning uncertainty. The anticipated battery revolution will add another layer of complexity, requiring proactive energy storage management strategies. The challenge now is to balance consumer autonomy and affordability with grid stability and the financial health of the power sector, while ensuring equitable access to clean energy technologies across all income segments and regions.

Key Findings

1. **Massive Scale of Solar Adoption:** Pakistan has installed 33.34 GW of distributed solar capacity, exceeding the country's peak summer grid demand of 28–30 GW and total grid-connected capacity of 46 GW, representing a fundamental restructuring of the national energy system.
2. **Residential Sector Dominance:** The residential sector leads with 16.66 GW of installed capacity, comprising 5.22 GW net-metered, 9.24 GW non-net-metered, and 2.20 GW off-grid systems. Solar now meets approximately 41 per cent of residential electricity demand, with 2 out of every 5 units of household electricity coming from solar.
3. **Income-Based Equity Gap:** Solar adoption exhibits stark income disparities, rising from 38 per cent among low-income households to 88 per cent among high-income groups. Low-income consumers face barriers including high upfront costs (75 per cent), limited financing access (32 per cent), and exposure to substandard equipment, while wealthier consumers increasingly exit the grid.
4. **Dramatic Tariff-Driven Transition:** Average electricity tariffs increased over 150 per cent between FY2021–FY2024, transforming solar from an aspirational investment to a survival strategy. Across all income groups, 77–94 per cent of adopters cite solarization as the primary reason for reduced grid consumption.

5. **Significant Grid Revenue Erosion:** Residential consumers reduced grid electricity expenditure by approximately 41 per cent after solarization, commercial users by 23 per cent, and industrial users by 23 per cent. Rural industries achieve the highest savings (75–100 per cent), while 57 per cent of urban industrial adopters report zero savings, indicating system-performance disparities.
6. **Industrial Self-Sufficiency Shift:** Industries have installed 7.91 GW of solar capacity, meeting nearly 50 per cent of their electricity needs through self-generation. Industrial grid consumption has declined by approximately 20 per cent in recent years, with medium-scale industries showing the highest adoption rates (81 per cent) driven by cost optimization and supply reliability concerns.
7. **Agricultural Transformation:** The agricultural sector demonstrates a bottom-up energy transition with 5.04 GW installed, predominantly off-grid (2.09 GW in Punjab alone). Solar-powered tube-wells now dominate irrigation, with diesel dependency in Punjab declining from 80 per cent (2021) to 59 per cent, and the lowest-income agricultural group showing 85 per cent adoption rates.
8. **Provincial Distribution Patterns:** Punjab leads across all sectors with the highest installed capacity, followed by Khyber Pakhtunkhwa, Sindh, Balochistan, and Islamabad. However, household solar adoption rates are actually highest in Khyber Pakhtunkhwa, where solar meets 60–65 per cent of household demand compared to 48 per cent in Punjab and 78 per cent in Islamabad.
9. **Technical Grid Challenges:** High solar penetration is creating a pronounced «duck curve» with daytime demand dips and steep evening peaks, complicating dispatch planning. Distribution networks face voltage rise, reverse power flows, increased harmonics, and equipment stress, particularly in urban and industrial clusters, necessitating urgent infrastructure modernization.
10. **Structural Power Sector Crisis:** As high-paying consumers with large daytime loads increasingly adopt solar and reduce grid dependency, utilities face declining revenues while fixed costs remain constant. This cost-shifting onto captive non-adopters accelerates circular debt, undermines market reform assumptions, and creates a vicious cycle where rising tariffs drive further solar adoption and grid defection.





INTRODUCTION

1. INTRODUCTION

Pakistan's electricity sector is undergoing a structural shift with consumers increasingly turning to distributed solar generation to counter high electricity cost and unreliable supply. Ever-rising tariffs, and recurring power outages, have made self-generation and consumption not just a technology option but an economic necessity for households, business, and industries. The rapid decline in global solar prices, combined with policy support measures such as net metering and import duty exemptions, has further accelerated this transition.

Over the past 9 years, more than 50 gigawatt (GW) of solar modules have been imported as shown in **Figure 1**. Despite this massive inflow, no reliable, ground-verified data exists on its deployment, with the true scale and distribution of installed systems undocumented. Official deployment figures are reported for only utility-scale and net-metered systems, overlooking the majority of behind-the-meter installations that dominate the market. This information gap limits policymakers and planners from accurately integrating distributed solar into national energy planning and demand projections, and devising effective policies to make such an unprecedented transition equitable.

Trends in Solar PV Imports: Volume and Expenditure

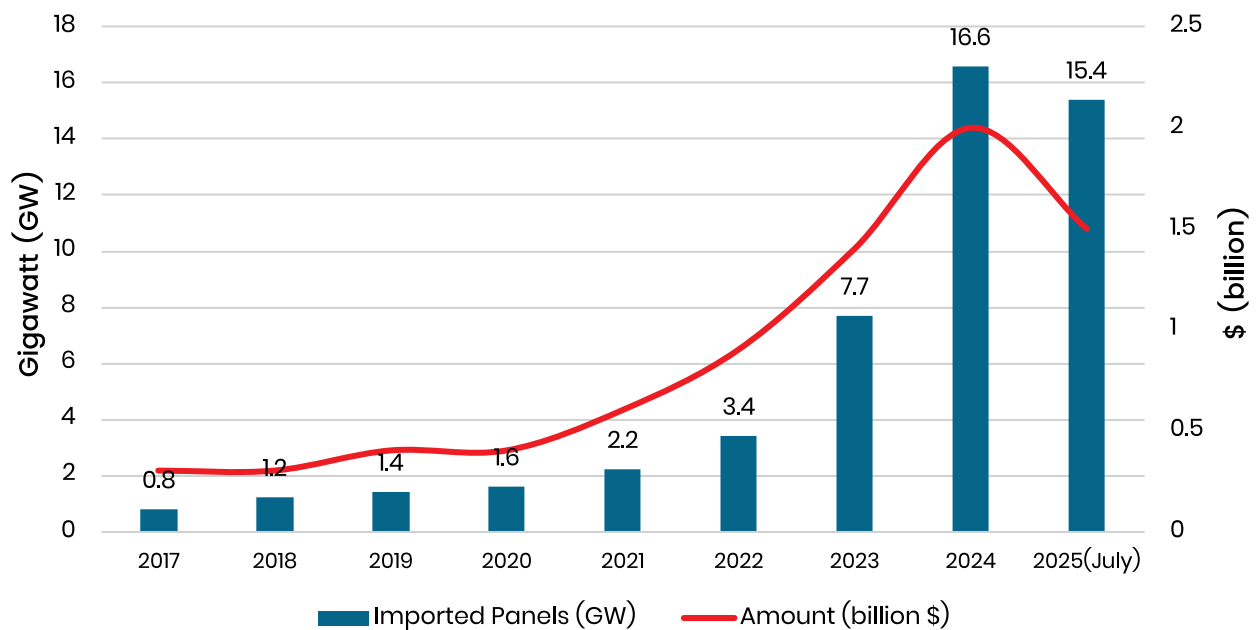


Figure 1: Trends in Solar PV Imports

The broader power sector context of Pakistan makes this question even more pertinent. Pakistan today has a surplus generation capacity of nearly 20,000 MW, yet almost 10 per cent of households remain without electricity access of any type.¹ Many urban as well as rural communities still face more than 12 hours of daily load-shedding pointing towards deep-rooted transmission and distribution issues and effective planning challenges. Meanwhile, affordability has become a pressing concern for those connected to the grid, with the domestic tariffs increasing by 155 per cent over the past three years.

In response, consumers are seeking reliable and cost-saving alternatives like solar PV to reduce their dependence on the grid and lower their electricity bills. These factors have collectively fueled a bottom-up shift toward solar adoption. However, without complete and accurate data, it is difficult to know....

1. whether this expansion is equitable,
2. whether it is truly addressing unmet demand, and/or
3. whether it places additional strain on Pakistan's national grid.

For instance, Power Distribution Companies (DISCOs) argue that widespread solar adoption has significantly reduced demand for grid electricity as illustrated in **Figure 2**, thereby widening the gap between supply and demand. Some of the DISCOs highlight the growing challenge of managing reverse power flows from distributed generation, feeding electricity back into the system. In addition, concerns have also been raised about Pakistan's net metering policy, which, according to utilities, is shifting costs to non-net-metered customers, creating further imbalances within the system.

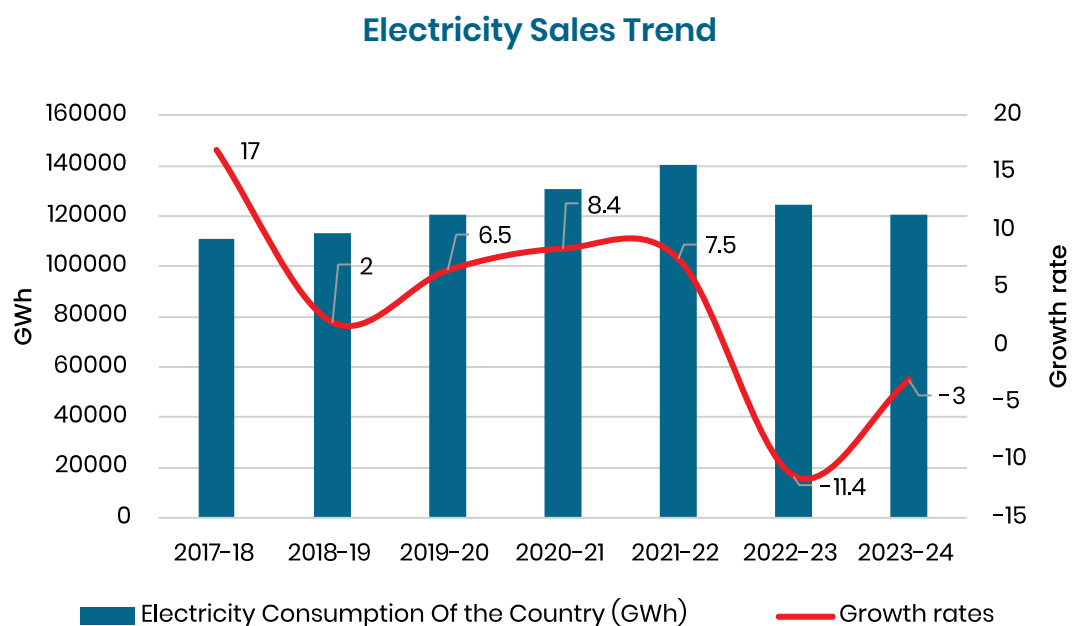


Figure 2: Electricity sales growth trends

1. https://www.pbs.gov.pk/sites/default/files/population/2023/tables/table_22_national.pdf

On the contrary, some stakeholders contend that the slowdown in electricity sales is more closely linked to reduced economic activity, particularly the decline in industrial sector productivity. This perspective is reinforced by Pakistan’s widening trade deficit in recent years, which they see as a clearer indicator of falling demand for electricity as presented in **Figure 3**.

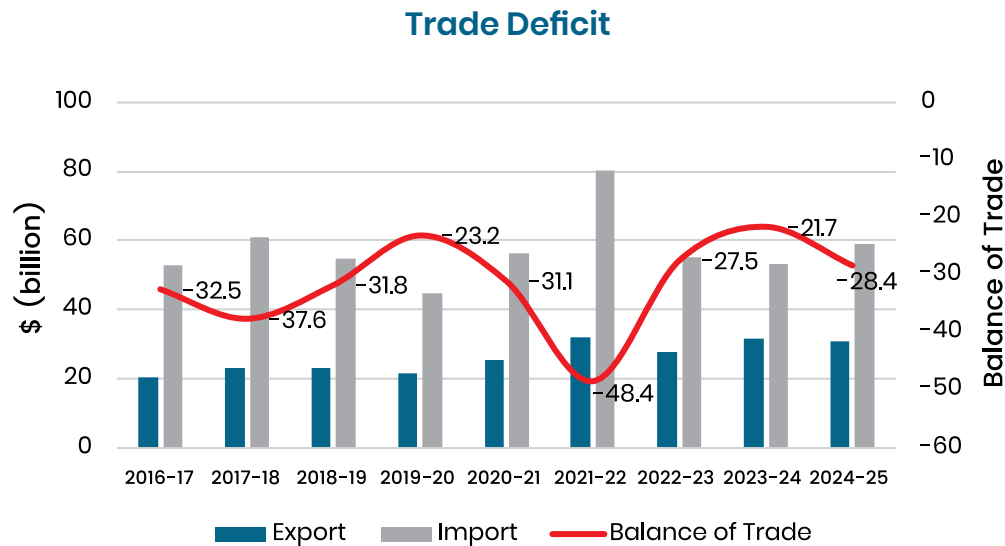


Figure 3: Pakistan’s trade deficit

Amid these conflicting claims, one problem is clear: Pakistan lacks accurate, comprehensive data on solar PV installations, particularly those outside the formal utility scale and net-metering system. *Our hypothesis is that if the utility scaled and net-metered solar PV accounts for approximately 7GW, then the huge delta of 43 GW cannot possibly be sitting in inventory; consequently, there is a significant number of solar adopters which are either behind-the-meter (BTM) or are completely off-grid.*

An argument that supports this hypothesis can be based on the number of solar households in Pakistan.

A review of census data from Pakistan Bureau of Statistics (PBS) reveals that the number of solar-equipped households far exceeds those reported under NEPRA’s *State of Industry Report* for net-metered connections. As of 2024, a total of 0.134 million households were registered under net metering system, whereas the PBS 2023 Census recorded approximately 2.96 million households using solar as a source of lighting nationwide as presented in **Figure 4**. This disparity highlights the vast share of unrecorded installations operating outside the formal grid system. The adoption ratio derived from the PBS data further indicates higher uptake in Khyber Pakhtunkhwa at 13 per cent and Balochistan at 20 per cent, compared to Punjab at 10 per cent, Sindh at 12 per cent, and Islamabad 2 per cent. These figures demonstrate that net metering data alone cannot capture the full extent of decentralized solar adoption in Pakistan, as it significantly underreports households relying on solar energy. Supporting this observation, PRIED’s rural electrification study in Naushki District, Balochistan found that approximately 66 per cent of rural households had installed solar systems to meet their basic energy needs² – underscoring the widespread and undocumented reliance on distributed solar solutions across rural Pakistan.

2. <https://www.priedpk.org/wp-content/uploads/2025/11/Balochistan-Study.pdf>

Solar adoption as per Pakistan Bureau of Statistics

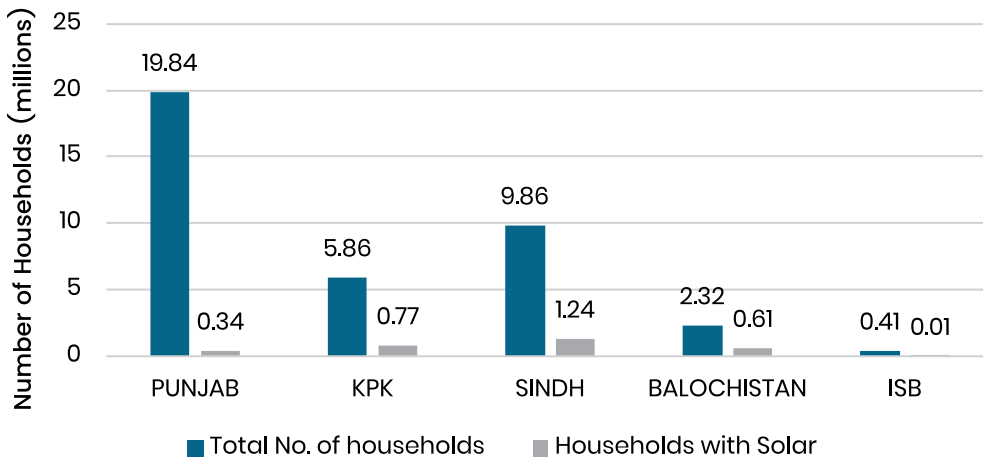


Figure 4: Pakistan’s Solar Adopters

To bridge this critical gap in data, PRIED has conducted a nationally representative survey to estimate solar adoption across all major sectors – residential, commercial, industrial, and agricultural – and across all provinces. The survey establishes the first empirical baseline of distributed solar adoption in Pakistan, detailing installation trends, system sizes, connection types, and changing demand patterns.

These survey findings have been integrated with satellite mapping of rooftop and ground mounted solar PV installations conducted by [Transition Zero](#), creating a unified and evidence-based assessment of distributed solar adoption nationwide.

The survey and mapping exercises are particularly significant because the National Transmission and Dispatch Company (NTDC) does not account for off-grid systems or behind-the-meter installations, leaving a critical data gap. To address this, official datasets from the Power Division and the Pakistan Bureau of Statistics, along with interviews with key stakeholders, have also been analyzed to provide a comprehensive and data-driven picture of Pakistan’s solar transition. In the following section, we have explained our methodology in detail.



METHODOLOGY

2. METHODOLOGY

A multi-pronged approach has been employed to perform the analysis.

Primary Objectives of our Analysis:

- Assess disparity between solar imports and documented net-metered connections.
- Identify actual on-ground deployment of solar systems – particularly undocumented behind the meter systems.
- Understand technical and socio-economic implications of rise in solar adoption.

The study has adopted a mixed-methods approach, integrating both secondary and primary data sources.

Secondary Data Sources

- **Formal Sector (Net Metering):** The adoption of grid-connected solar systems has been assessed using the NEPRA State of Industry Reports and National Transmission and Distribution Company's Power System Statistics Reports. These sources provide official statistics on installations registered under net metering, reflecting the formally documented share of the solar market.
- **Informal Sector (Behind the Meter):** To capture behind-the-meter installations where no official records exist, national census datasets (Pakistan Household Census) have been analyzed for 2017 and 2023 which provide statistics on household-level energy use, including the number of households using solar for lighting. Through these census reports, trends of reliance on different energy sources have also been identified. Overall, these sources provide a reliable basis for estimating small-scale, decentralized solar adoption. However, using these datasets, the assessment is limited to only the residential (household) levels.

Primary Data – National Survey

To complement secondary data, a nationally representative survey was conducted to assess the actual scale and diversity of solar uptake. The survey design was, in particular, meant to address the data gap for behind the meter installations at residential, commercial, industrial and agriculture sectors, along with assessment of changes in energy consumption patterns across these different categories. The survey was designed to further deepen the understanding of solar adoption trends across provinces, sectors, and socioeconomic tiers, ensuring robust coverage of Pakistan's rapidly developing solar landscape. Following subsections provide key details about the survey:

Sample Size and Design:

- The survey sample is based on stratified random sampling to ensure it is representative of the rural and urban divide in each province and population shares in each province.
- Total respondents: 5,320 (5,120 in case of provinces and 200 for Islamabad, the capital city).
- The random sample size for each province was adjusted for urban and rural shares and in accordance with PBS Census 2023 data, which resulted in hybrid allocation within each province: 50 per cent fixed (640 per province) + 50 per cent proportional (based on provincial population share, PBS Census 2023).

Coverage:

- Sectors: Residential, commercial, industrial, and agricultural.
- Strata: Urban/rural, provincial distribution, income groups, and consumer categories.
- Sectoral Allocation:
 - Urban: Residential 50 per cent, Industrial 25 per cent, Commercial 25 per cent.
 - Rural: Residential 50 per cent, Agricultural 30 per cent, Commercial 15 per cent, Industrial 5 per cent.

The **Figure 5** presents a heatmap illustrating the regional coverage of the survey:

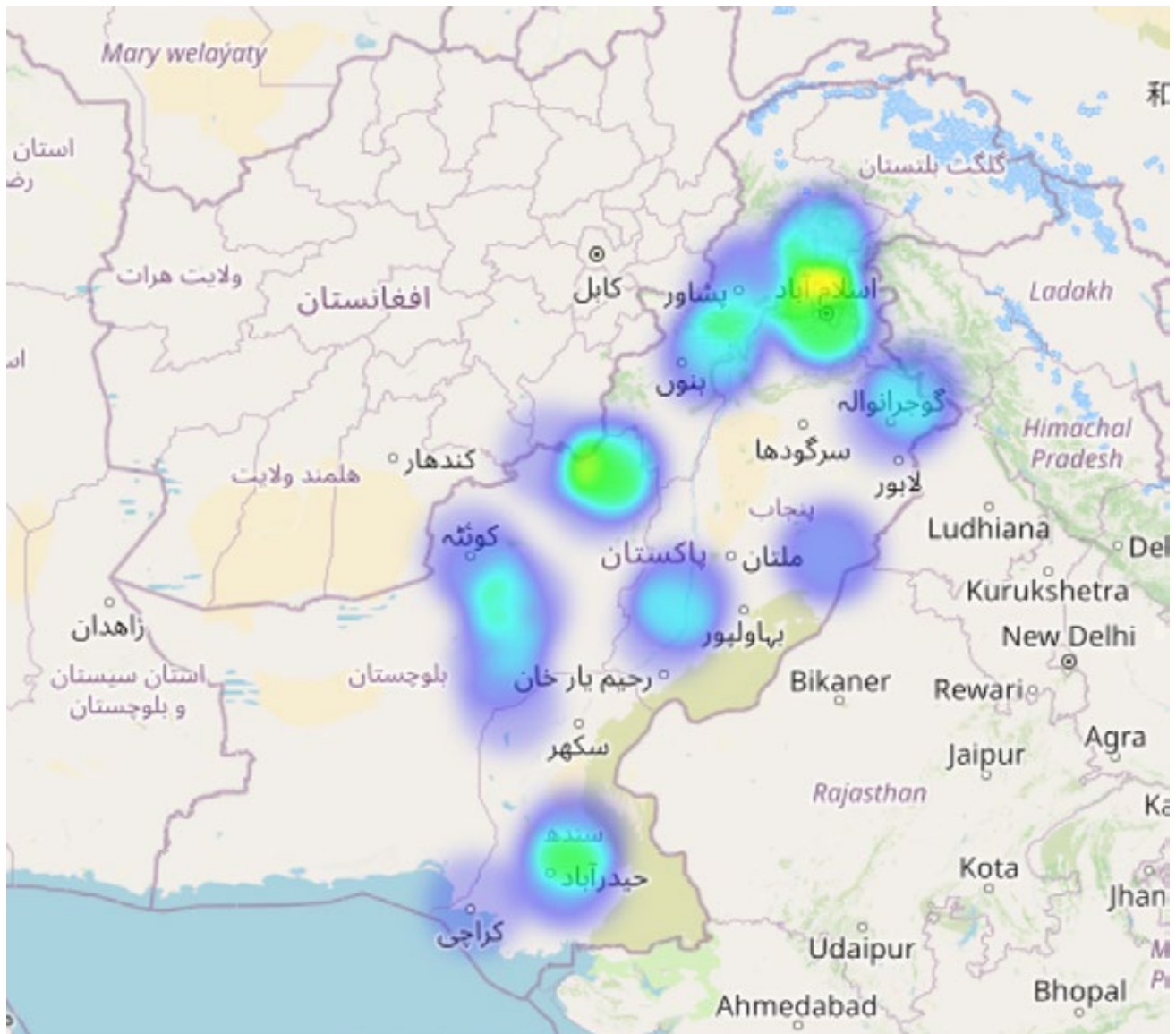


Figure 5: Geographic Coverage of the Survey Sample

Survey Implementation:

- Conducted by PRIED with support from local contacts across provinces.
- Survey Tool: KOBO Toolbox has been used for data collection.
- Pilot Testing: Initial surveys were conducted to refine the questionnaire, test survey length, and gauge public response.
- Survey was improved based on the results of the Pilot Testing

Data Quality/Credibility Assurance:

- Enumerators' GPS live locations were required for each survey as illustrated in **Figure 6**.
- The initiation and completion times of each survey form was tracked, along with geotagged survey points of each respondent. These results are visible in real time on a map.
- Verification: Random back-checks, data cleaning, and validation ensured reliability.

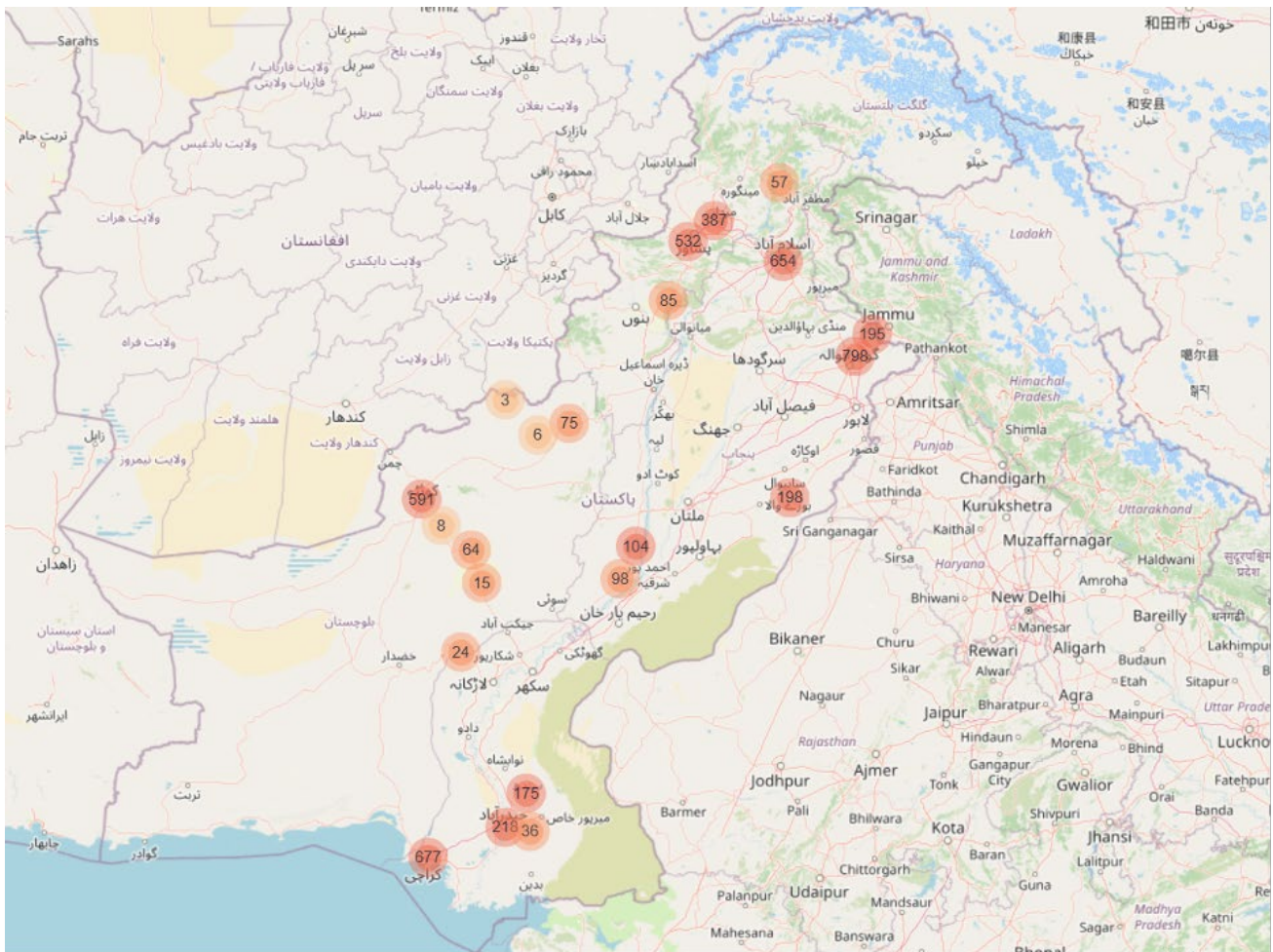


Figure 6: Survey Response Counts by Area

Statistical Validity:

- Designed to achieve national-level representation with provincial and sectoral disaggregation.
- Confidence level - of 95 per cent - and margin of error aligned with survey research standards for large national samples.

Data Cleaning, Validation and Weighting:

- A rigorous data cleaning exercise was performed.
- Validation: Removal of duplicates, detection and flagging of outliers.
- Extrapolation: To derive the final estimates, an extrapolation framework was employed to account for installations not captured in official statistics. Since the NTDC does not track off-grid consumers or behind-the-meter systems, survey data were disaggregated by province and sector and then extrapolated using consumer-base figures from the State of Industry Report 2024 and data from the PBS Economic Census. For the agriculture sector, the total number of farms reported by PBS was used as a proxy for extrapolation. This approach ensured that the analysis reflected both on-grid and off-grid solar adoption, and based on these numbers a weighting strategy was designed.

Weighting Strategy:

A multi-layered weighting strategy was applied to ensure that all estimates in this study reflect true national, provincial, sectoral, and urban/rural population patterns, while also aligning adoption and solar quantum figures with benchmarks from the NEPRA State of Industry Report (SOIR). Weighting took place at two levels:

- I. Sample Design, and
- II. Analysis and Estimation.

Design-Stage Weighting:

At the design stage, provincial weights based on Pakistan Bureau of Statistics (PBS) 2023 population shares were used to allocate the total sample (5,320 cases) across provinces. This ensured proportional representation, with Punjab receiving the largest allocation and smaller provinces represented according to their demographic size. Islamabad received a fixed sample of 200 cases. Urban/rural distributions were also integrated during district selection. These weights informed sample allocation only and were not applied in analysis.

Analysis-Stage Weighting

During analysis, a normalized composite weight ($W_{ProvSecNorm}$) was applied to correct for disproportionalities between the achieved sample and national population structures. The composite weight incorporated three adjustments:

- I Province-level (PBS 2023 population vs. achieved sample),
- II Sector-level distributions (residential, commercial, industrial, agriculture), and
- III Urban/rural composition.

These components were multiplied to generate the raw composite weight, which was then normalized to a mean of 1 to preserve statistical stability.

Adoption Estimates:

Adoption statistics (net-metered, non-net-metered, off-grid) were estimated through a dual approach:

1. Applying Weights ProvSecNorm to correct the survey structure, and
2. Anchoring totals using sectoral consumer and installation baselines from SOI/SOIR.

This ensured internal representativeness while maintaining consistency with officially reported adoption patterns in commercial, industrial, and agriculture sectors.

Solar Quantum Estimation

Total solar quantum estimation used weighted adoption rates in combination with SOIR capacity data, sector-specific scaling factors, and average system sizes (kW) derived from the survey.

This integrated framework ensured that quantum outputs (GW) remained aligned with national installed-capacity patterns and technical baselines, avoiding distortions that may arise from survey-only estimates.

Overall Rationale

This integrated weighting strategy ensured alignment with national demographic patterns, sectoral realities, and administrative records, enabling the study to generate valid and policy-relevant national estimates for solar adoption, consumption patterns, and total quantum across all four sectors.

Deliverables:

- National, provincial, and sectoral solar adoption profiles.
- Comparative analysis of solar adopters vs. non-adopters to assess the utilization gap.
- Energy consumption profiles across provinces and sectors.

Stakeholder Consultations

To complement and augment survey findings and contextualize quantitative results, PRIED team held targeted consultations with key power sector stakeholders. These engagements were conducted through a mix of focused group discussions and informal interviews, aimed at capturing institutional perspectives, operational realities, and policy considerations influencing solar deployment in Pakistan. The consultations also explored grid-level challenges, policy drivers, and sectoral adoption dynamics.

Stakeholders Engaged:

- 3 major DISCOs – representing diverse service areas across Punjab, Khyber Pakhtunkhwa and Sindh.
- Government agencies involved in energy regulation and policy.
- Private sector actors, including distributed solar installers and suppliers.

Focus Areas:

- DISCOs were specifically consulted to help understand.....:
 - Grid strain and reverse power flow issues from distributed solar.

- Their estimates of solar PV installations within respective service areas.
- Government agencies and private actors provided insights on:
 - Import data and installation records.
 - Off-grid and behind-the-meter adoption patterns.
 - Technological status quo and market developments.

Integration into Analysis:

- Findings were systematically triangulated with secondary datasets and survey results, with consultations refining assumptions for analysis and sample extrapolation as outlined in **Figure 7**.
- Importantly, these discussions also highlighted gaps in existing adoption numbers, deployment tracking, and impact assessments, allowing the PRIED team to design survey questionnaires that could fill those gaps.

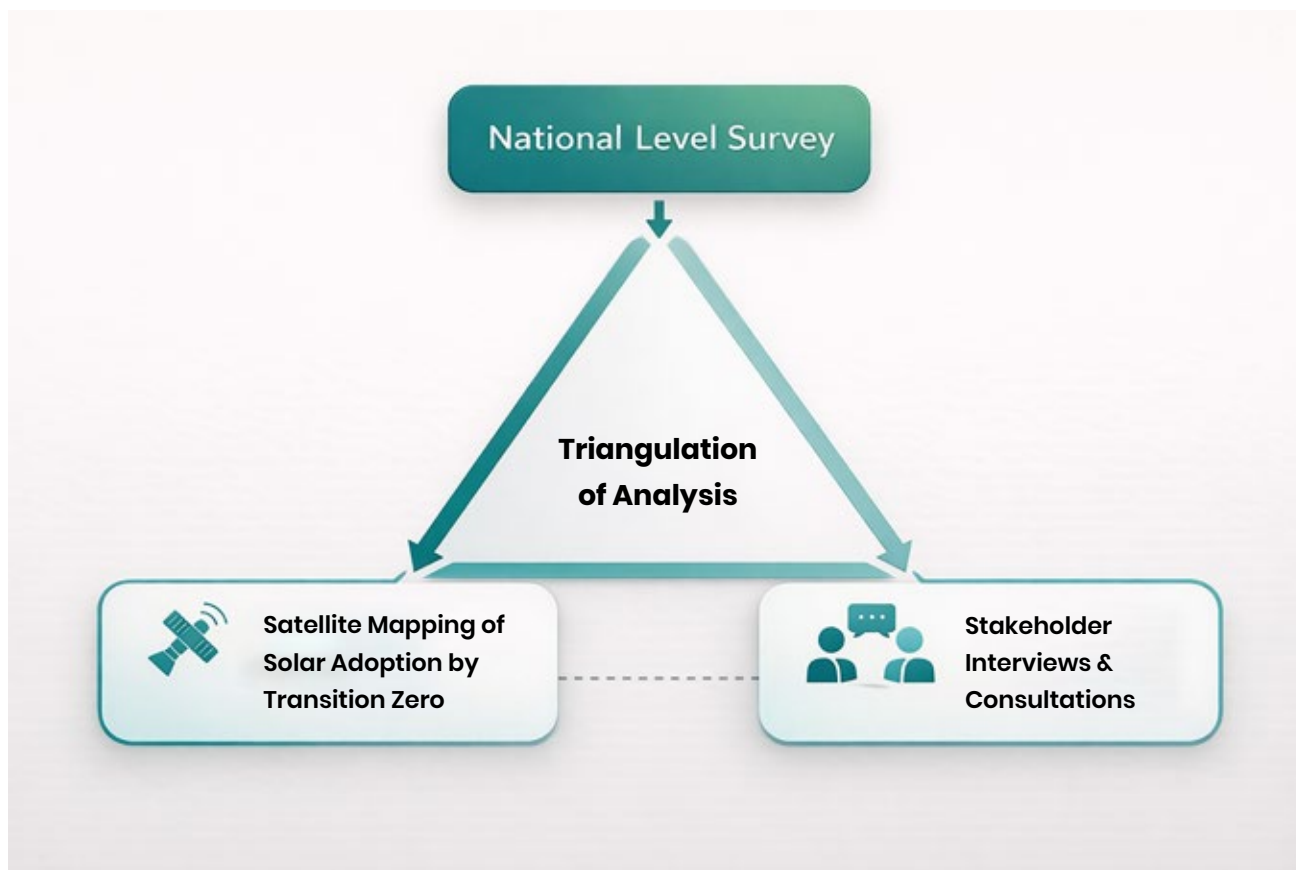
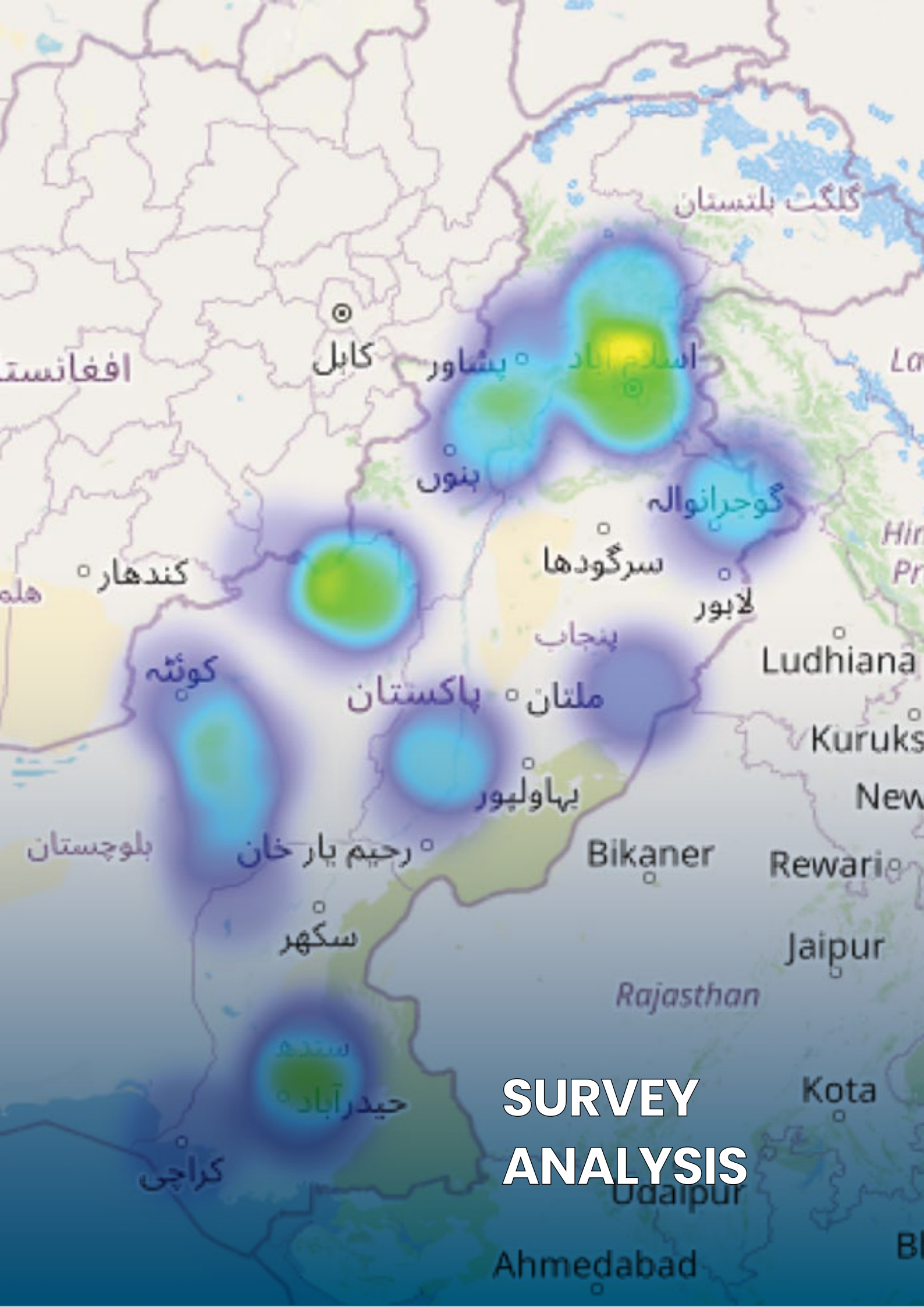


Figure 7: Triangulation Framework



SURVEY ANALYSIS

3. SURVEY ANALYSIS

3.1. Over 33 GW of solar installed against the 50GW of imported solar

As per PRIED's analysis, Pakistan has installed an estimated 33.34 gigawatts (GW) of solar PV capacity against more than 50 GW of imported solar modules over the past nine years as shown in **Table 1**. This installed capacity now exceeds the country's peak summer grid demand, which typically ranges between 28 and 30 GW, highlighting the growing contribution of distributed solar generation to the national energy mix. By comparison, Pakistan's total grid-connected installed capacity currently stands at around 46 GW.

At the provincial-level, solar adoption is highest in Punjab, followed by Khyber Pakhtunkhwa, Sindh, Balochistan, and the Islamabad Capital Territory (ICT). Among end-use sectors, the residential sector leads solar adoption, followed by the industrial, agricultural, and commercial sectors.

Survey findings indicate that a majority of solar adopters – approximately 77 per cent – rely primarily on their installed PV systems to meet daily energy needs, while only 23 per cent continue to depend significantly on the national grid, using it mainly as a backup source. This growing preference for self-generation underscores both the economic rationality and reliability advantages that distributed solar offers to consumers.

At the regional level, the share of household electricity demand met by solar is highest in urban centers such as Islamabad (78 per cent), followed by Khyber Pakhtunkhwa (60–65 per cent) and Punjab (48 per cent). In contrast, Sindh and Balochistan trail behind, with solar fulfilling roughly one-third of household energy demand on average. These variations reflect both income-based adoption disparities and differences in grid reliability and solar resource availability across provinces.

Table 1: Installed Distributed Solar Capacity by Region and Consumer Category (GW)

Regions	Net Metering/GW	Non-Net-Metered/GW	Off-grid/ GW
Punjab	4.9	8.49	4.39
Khyber Pakhtunkhwa	0.64	5.47	2
Sindh	0.03	3.53	1.44
Balochistan	0.02	0.93	0.48
Islamabad	0.44	0.57	0.01
Total	6.03	19	8.31

Residential	Commercial	Industrial	Agriculture	Total
16.658 GW	3.734 GW	7.906 GW	5.040 GW	33.338 GW

3.2. Satellite Mapping by TransitionZero³

TransitionZero estimated 27.5 GW of distributed solar capacity across Pakistan. When combined with 1.5 GW of utility-scale capacity from TransitionZero's open-access dataset of large-scale solar facilities (TZ-SAM), this brings the country's total estimated solar capacity to around 29 GW.

The **Table 2** below shows a breakdown by both province and sector.

Table 2: Solar Capacity Estimates by Region and Sector (TransitionZero Analysis)			
Rooftop systems dominate Pakistan's distributed solar landscape			
Most capacity is concentrated in Punjab, followed by Khyber Pakhtunkhwa and Sindh.			
Province	Rooftop (GW)	Ground-mounted (GW)	Total (GW)
Punjab	11.89	3.806	15.70
Khyber Pakhtunkhwa	5.62	0.535	6.16
Sindh	2.76	0.736	3.50
Islamabad	0.60	0.006	0.61
Azad Kashmir	0.53	0.013	0.54
Balochistan	0.37	0.544	0.91
Gilgit-Baltistan	0.12	0.002	0.12
Total (GW)	21.89	5.642	27.53
Calculated error bars are $\pm 18.2\%$, resulting in a final result range of 22.57 GW – 32.49 GW of total capacity. See technical methodology for details.			

To account for uncertainties such as labelling confidence, panel efficiency, sampling bias, accuracy of external datasets and panel tilt, an error margin of ± 18.2 per cent was applied. This results in a 22.57 GW – 32.49 GW range of total distributed solar capacity in Pakistan.

3. TransitionZero is a climate tech non-profit that provides energy system modelling data, software and analysis to support energy transition planning



RESIDENTIAL SECTOR

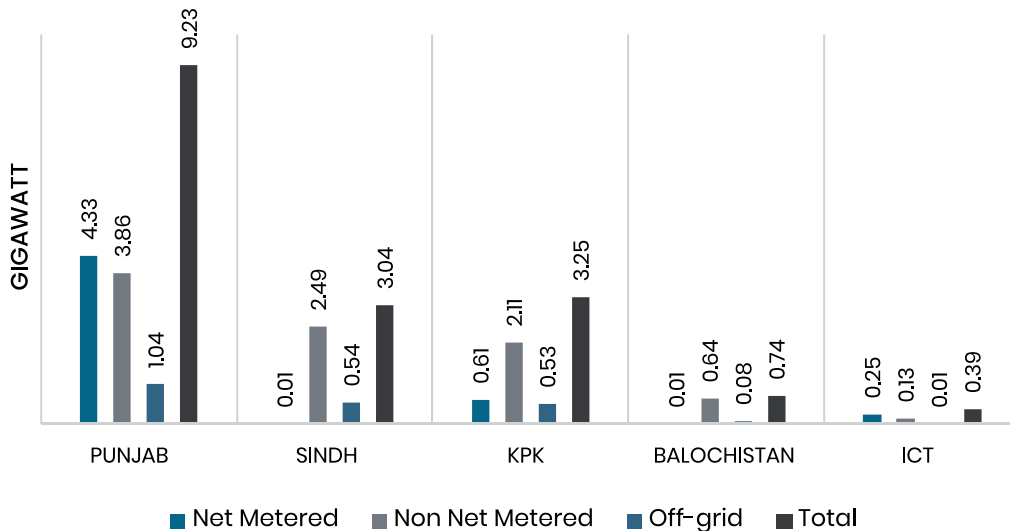
4. RESIDENTIAL SECTOR

4.1. Adoption across the Residential Sector

Our analysis estimates that 16.66 gigawatts (GW) of solar PV capacity have been installed in Pakistan’s residential sector, making it the primary driver of the country’s distributed solar revolution. Of this total, approximately 5.22 GW is connected through net-metered (NM) systems, 9.24 GW through behind the meter non-net-metered (NNM) setups ⁴, and an additional 2.2 GW through off-grid installations serving remote or underserved areas as presented in **Figure 8**.

Punjab leads the residential solar adoption with an estimated 9.23 GW – accounting for more than half of the national total for the residential sector – followed by Khyber Pakhtunkhwa (3.25 GW), Sindh (3.04 GW), Balochistan (0.74 GW), and the Islamabad Capital Territory (0.39 GW). Punjab also dominates both net-metered and non-net-metered segments, reflecting its higher household income levels, greater grid reliability, and stronger policy incentives compared to other provinces. Though the previous analysis based on the number of households using solar PV as a source of lighting as reported by the Pakistan Bureau of Statistics census survey 2023 indicates a higher adoption rate in Khyber Pakhtunkhwa, however a bigger scattered adoption in Punjab including higher total capacity installed.⁵

Residential Sector: PV Adoption



Net-Metered	Non-Net-Metered	Off-grid	Total
5.22 GW	9.24 GW	2.20 GW	16.66 GW

Figure 8: Provincial Distribution of Residential Solar Capacity by Connection Type (GW)

4. Behind-the-meter (BTM) refers to an energy generation or storage system (like solar panels and batteries) located on the customer’s side of the utility meter. A «non-net-metered» system is one where this on-site generation is not fed into the grid at all; the energy is generated and immediately used locally. This contrasts with standard net metering, where excess power is exported to the grid for credit.

5. <https://www.priedpk.org/wp-content/uploads/2025/11/Energy-Monitor-PRIED-R01-1.pdf>

4.2. Low solar adoption in Low-income Households

At lower socioeconomic levels, solar adoption is lower than at higher socioeconomic levels raising critical equity challenge.

Low-income households (electricity expenditure up to PKR 15,000) predominantly install small-scale systems—39 per cent in the 1–3 kW range and 52 per cent between 4–8 kW—reflecting limited purchasing power, constrained financing options or low electricity requirements as shown in **Figure 9**.

Additionally, this raises concerns about the widespread sale of substandard equipment and B- or C-grade solar panels by local vendors. The likelihood of such low-quality products being sold is particularly high among small-scale sellers dealing in only one or two panels. Consequently, poorer households—who are often less educated—are more vulnerable to such fraudulent practices and end up bearing the brunt of this inequitable market behavior.

This raises another critical question: **Will the upcoming market liberalization be equitable?**

In contrast, lower-middle and upper-middle income groups increasingly favor mid-sized systems (over 60 per cent and 75 per cent in the 4–8 kW range, respectively), while high-income households tend toward larger capacities (52 per cent for 9–15 kW and 6 per cent exceeding 15 kW).

A pertinent query that follows, then, is: **Are the high-paying consumers- with high demand of electricity- gradually leaving the grid?**

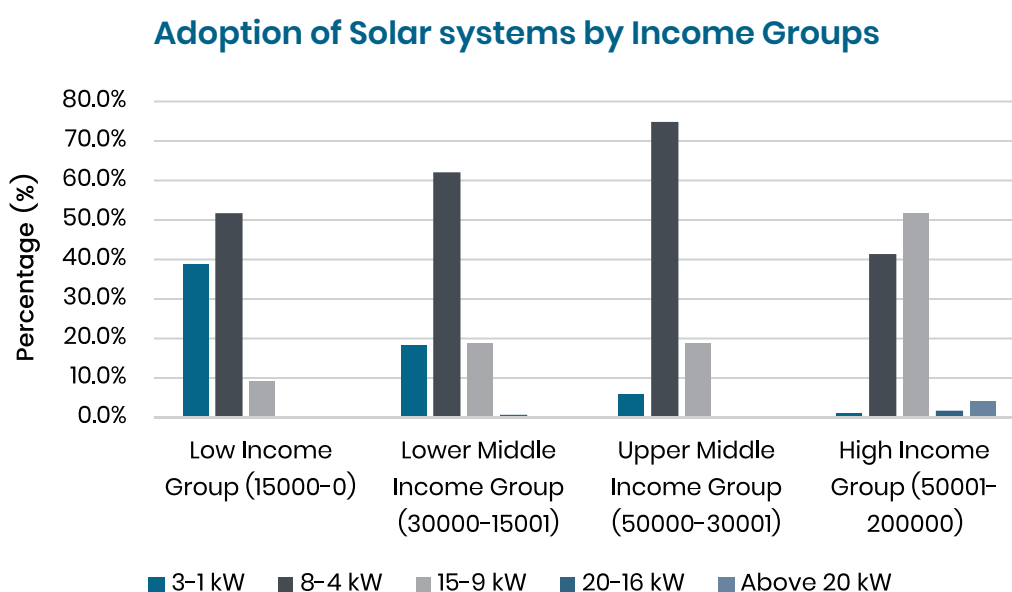


Figure 9: Household Solar System Capacity by Income Group

Solar adoption rates rise correspondingly with income: 38 per cent among low-income, 67 per cent among lower-middle, 75 per cent among upper-middle, and 88 per cent among high-income households as illustrated in **Figure 10**. This gradient underscores that affordability and capital accessibility remain the primary determinants of energy transition participation. As wealthier households increasingly adopt solar PV, their overall consumption is decreasing with some entering the protected category of consumers, therefore grid costs are redistributed to non-adopters, who remain captive to the utility system. These consumers – mostly low- and middle-income households – face escalating electricity tariffs. For many, electricity bills now consume a significant share of disposable income, constraining essential expenditures and deepening energy-related financial stress.

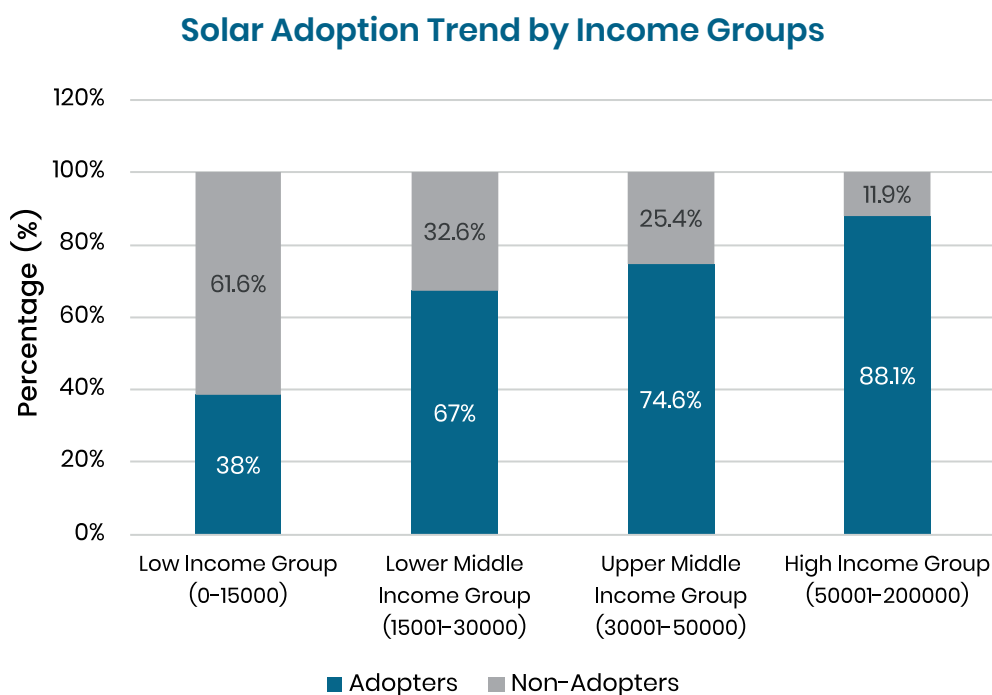


Figure 10: Solar Adoption Rates by Household Income Group (%)

Across all income groups, solarization has emerged as the dominant factor driving the reduction in residential grid electricity consumption in Pakistan. As shown in the survey dataset more than 90 per cent of middle and high-income households (93.2 per cent and 94.3 per cent, respectively) identified solar adoption as the principal reason for their decreased reliance on the grid. Even among low-income users, where affordability constraints and unreliable supply play a larger role, 83 per cent reported that self-generation through solar systems was a key contributor to their reduced grid consumption.

4.3. Changing Grid Energy Consumption Patterns

To assess the change in electricity usage from the national grid the respondents were asked how their electricity demand from the grid has changed over the past two years. The solarized households were particularly asked if they have adopted new appliances. As per the analysis most respondents have cited a decrease in their grid energy demand as shown in **Figure 11**.

The reduction in grid-based expenditure after solarization is statistically significant confirming that solar adoption substantially lowers monthly electricity costs among residential users. Here “Statistically significant” means that the observed reduction in grid electricity expenditure is very

unlikely to have occurred by random fluctuation in the data. On average, monthly electricity expenditure reduced by approximately 41 per cent after solarization for adopters.

The average monthly electricity demand for residential consumers who have adopted solar energy was approximately **612 kWh**. However, the results show that the grid supplies only 220 kWh (59 per cent), while solar covers the remaining 40.7 per cent. This means households are meeting a large share of their actual electricity needs through solar, not the grid. In simple terms: 2 out of every 5 units of electricity used in Pakistani homes now come from solar.

Households that did not install new appliances show an average 31 per cent reduction in their grid consumption, reflecting a clear decrease in electricity drawn from the grid following the shift to solar systems. Households that installed new appliances also show a 29.7 per cent reduction, indicating that even after adding appliances, their dependence on grid electricity remained lower than before solarization. The slightly smaller decrease compared with non-adopters suggests that part of the potential reduction in grid use was offset by additional household energy consumption needs after solar adoption.

Overall, both groups demonstrate that solarization effectively reduces grid electricity usage, with a modest variation between households that added new appliances versus households that did not add new appliances.

While some of the adopters as well as the non-adopters cited increased consumption as well.

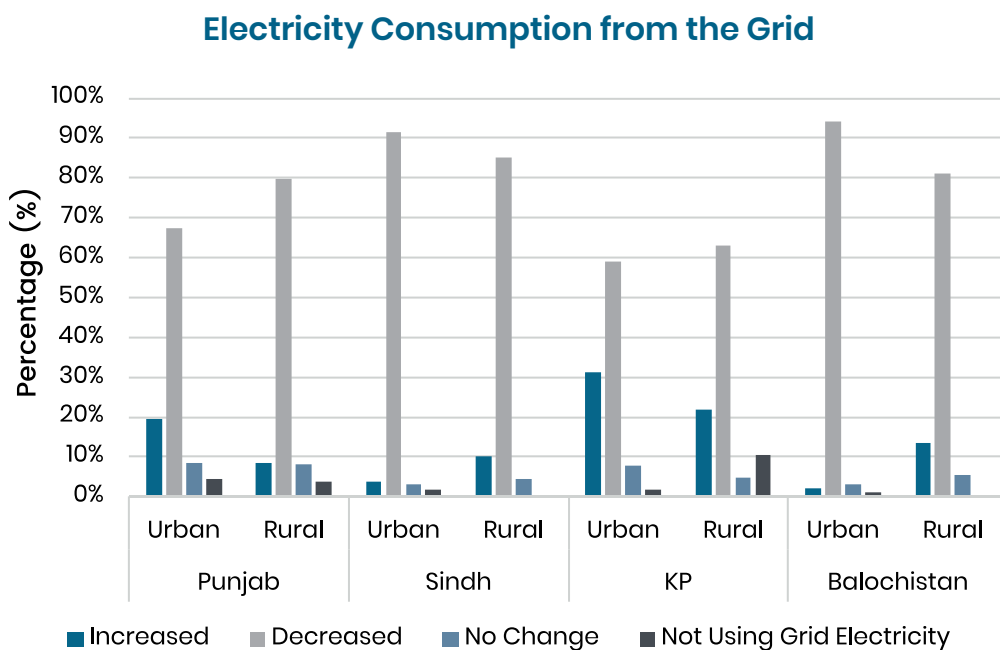


Figure 11: Changes in Residential Grid Electricity Consumption Over the Last Two Years

4.4. Reasons for Reduced Grid Demand

This trend underscores the extent to which rooftop solar has transitioned from being an aspirational or “green” investment to a cost-avoidance and survival strategy as shown in **Figure 12**. Between FY2021 and FY2024, average consumer electricity tariffs increased by over 150 per cent, largely due to rising capacity payments, rupee depreciation, and volatile fuel prices. For most households, particularly in the middle- and upper-income brackets, grid electricity has become financially unsustainable, making solar energy the most viable means to manage household energy expenditures.

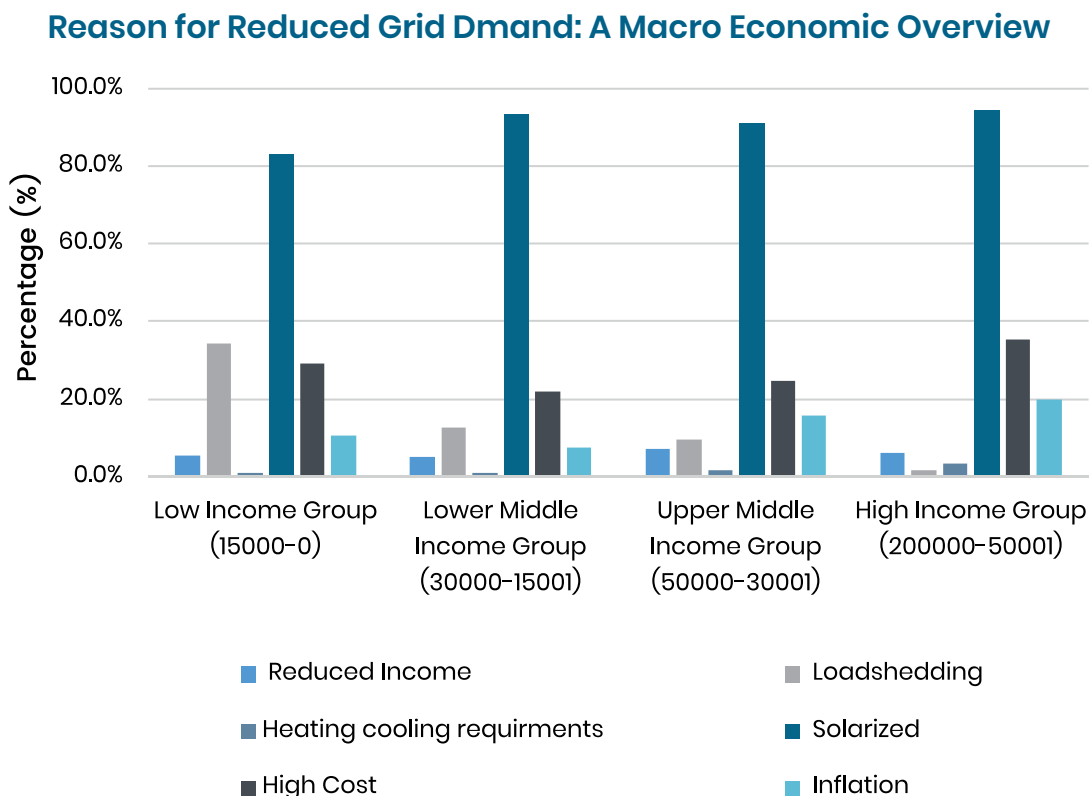


Figure 12: A macro-economic overview for reduced grid demand

At the same time, unreliable grid supply and load-shedding patterns, especially in high-loss feeders across Punjab and Sindh, have further accelerated this behavioral shift. The dataset also shows that load-shedding remains a notable driver among low-income consumers (34.2 per cent), reinforcing the perception that self-generation ensures greater energy reliability and autonomy during prolonged summer outages.

While solarization remains the primary driver of declining grid demand across income groups, secondary factors such as high electricity costs and inflationary pressures- as reported by 20 to 35 per cent of high-income and 22 to 25 per cent of middle-income households - have also contributed to consumption reductions. For low-income groups, however, the decline reflects a combination of necessity and affordability pressure, as high tariffs, reduced incomes, and poor service quality limit their ability to sustain previous consumption levels.

In summary, the dataset illustrates a clear structural transition in residential energy behavior: as economic and service reliability pressures intensify, households across all income tiers are increasingly turning to self-generation as both a coping mechanism and a long-term adaptation to Pakistan’s evolving power sector realities.

4.5. Reasons for Increased Grid Demand

Reasons for Increased Grid Demand

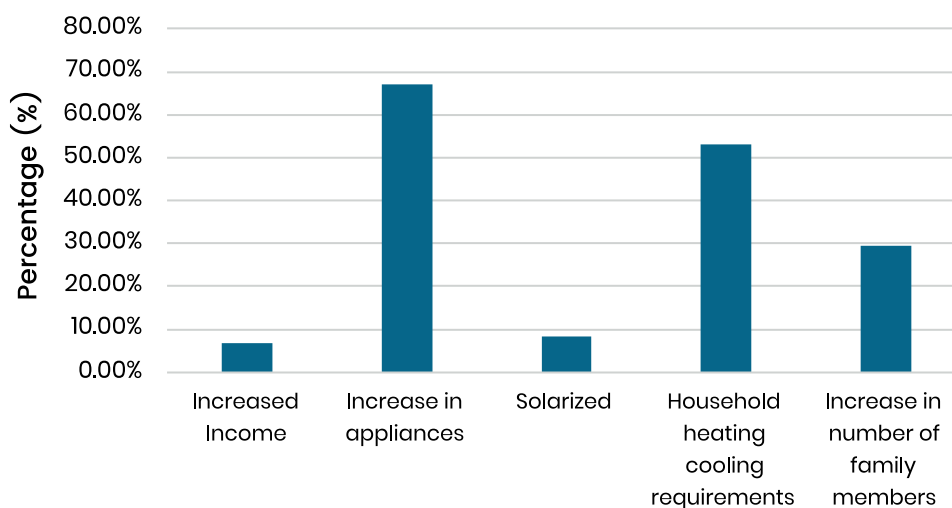


Figure 13: Reasons for Increased Electricity Consumption

Residential electricity consumption has increased due to several underlying behavioral and structural changes as shown in **Figure 13**. The largest contributor is the increase in household appliances (67.1 per cent), as families expand their appliance mix and adopt more energy-intensive devices over time. Rising heating and cooling needs (53.0 per cent) due to longer seasonal extremes also elevate electricity use, even in homes without air conditioners, as refrigerators, fans, and coolers run for extended periods. Growth in family size (29.6 per cent) adds to daily electricity-intensive activities such as cooking, laundering, and device charging, raising the baseline load. Some households that have installed solar systems (8.3 per cent) experience a rebound effect – using solar during the day but drawing more grid electricity at night or during low-generation months and added on this is the installation of new appliances since they have a cheaper electricity source available. Lastly, increased income (6.7 per cent) encourages lifestyle upgrades and comfort-oriented energy use, subtly pushing consumption upward even without major appliance purchases.

4.6. Barriers to Adoption

Despite significant reductions in solar panel prices in Pakistan, high upfront costs remain the most significant barrier to adoption among low-income households, with 75.4 per cent of respondents in this group citing it as a key obstacle as illustrated in **Figure 14**. This suggests that, although hardware prices have dropped, the total cost of installation (including inverters, labor, and other system components) still places solar systems out of reach for many poorer households.

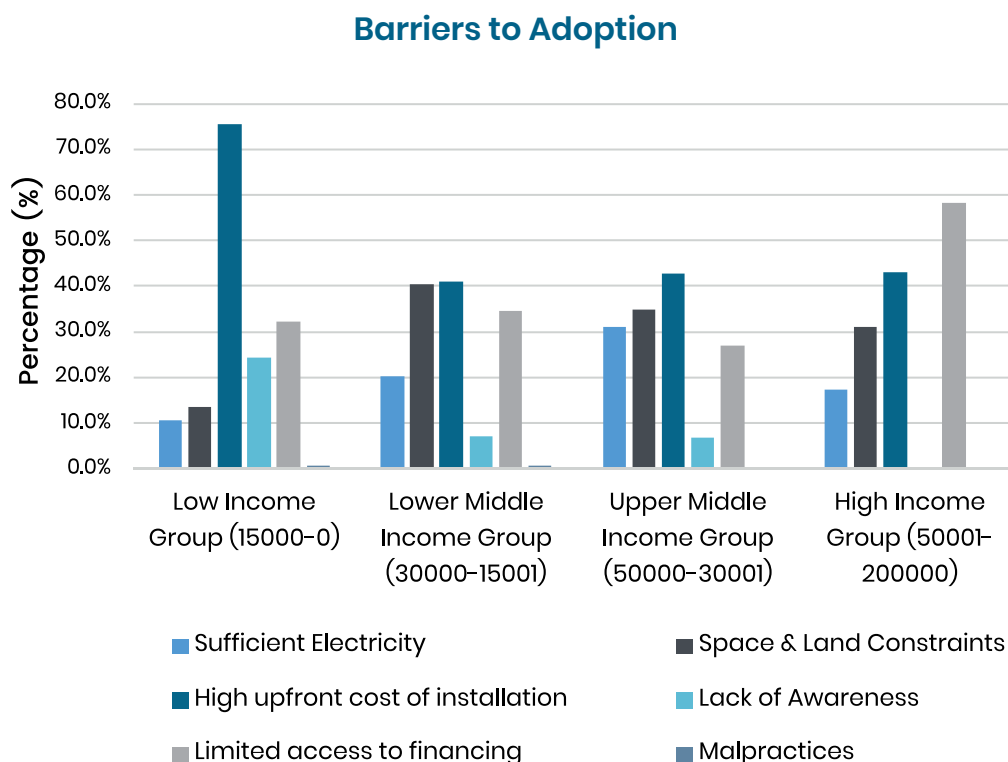


Figure 14: Barriers to Adoption

The net-metering process requires formal applications and approvals from DISCOs, along with technical constraints such as sanctioned load limits, which disproportionately affect lower-income groups with limited capacity to navigate administrative hurdles. This aligns with survey findings showing that 32.3 per cent of low-income households identify limited access to financing as a barrier, while 24.2 per cent cite lack of awareness. Additionally, 13.6 per cent reported space and land constraints, indicating physical limitations in some cases.

In contrast, middle- and higher-income groups report relatively lower concerns about upfront costs (41.0 per cent to 43.0 per cent) but face higher barriers related to financing access (up to 58.3 per cent in the high-income group) and space constraints (31.2 per cent to 40.3 per cent). These disparities underscore how financial, informational, and infrastructural barriers vary by income segment, despite falling hardware costs.

Together, these factors highlight that solar adoption in Pakistan remains constrained not only by upfront hardware expenses but also by regulatory, financing, and awareness challenges, especially among low-income households. Addressing these multi-dimensional barriers is critical for expanding equitable access to clean energy solutions.



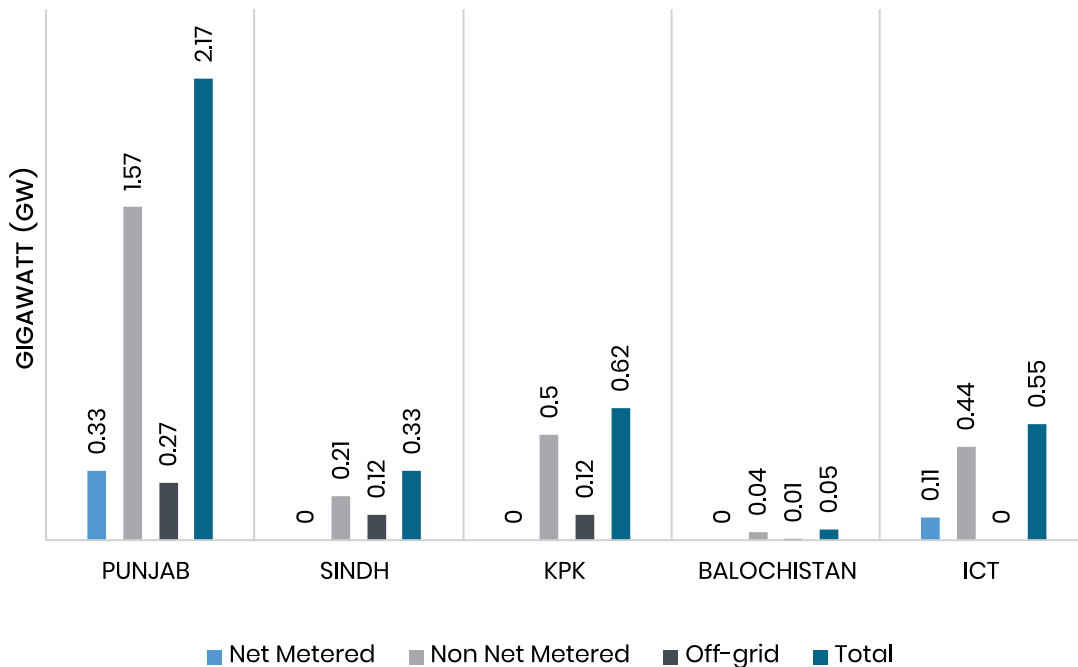
COMMERCIAL SECTOR

5. COMMERCIAL SECTOR

5.1. Adoption across Commercial Sector

Punjab leads Pakistan’s commercial solar sector with 2.17 GW of installed capacity – the highest among all provinces as outlined in Figure 15. Most of this capacity (1.57 GW) is non-net-metered (NNM), meaning systems that generate solar power for self-consumption but aren’t connected to the grid for export. The rest includes 0.33 GW under net metering (NM), where businesses sell excess electricity back to the grid, and 0.27 GW in off-grid systems, typically used in areas with unreliable grid supply. Punjab’s dominance reflects its commercial base, favorable solar potential, and relatively better infrastructure and financing access.

Commercial Sector: PV Adoption



Net-Metered (GW)	Non-Net-Metered (GW)	Off grid (GW)	Total (GW)
0.45	2.76	0.52	3.73

Figure 15: Provincial Distribution of Commercial Solar Capacity by Connection Type (GW)

Khyber Pakhtunkhwa (KP) ranks second with 0.62 GW, mostly NNM (0.5 GW) installations. This shows growing interest among local industries and businesses in reducing power costs and improving reliability, particularly where grid stability is weaker. Off-grid systems (0.12 GW) are also relatively common due to terrain and grid access issues.

Sindh has 0.33 GW of commercial solar, with a notable NNM share (0.21 GW) and NM (0.12 GW). Its potential is significant, especially around Karachi’s commercial hubs, but slower adoption may be linked to regulatory bottlenecks and limited financing for medium enterprises.

The Islamabad Capital Territory records 0.55 GW total – an impressive figure given its small geographic size. Most capacity (0.44 GW NNM, 0.11 GW NM) comes from service-oriented and retail sectors, which have both the resources and awareness to invest in solar for energy cost reduction and sustainability goals.

Lastly, Balochistan contributes only 0.05 GW, almost entirely NNM (0.04 GW) with very limited off-grid capacity. Its low adoption reflects sparse commercial activity, weaker grid infrastructure, and limited access to financing and technical expertise – despite its strong solar potential.

5.2. Adoption by Enterprise Scale

Survey results reveal a clear relationship between business size and solar PV adoption rates across Pakistan’s commercial sector.

- Medium-scale enterprises (50–249 employees) exhibit the highest adoption rate (87 per cent), indicating strong interest in self-generation to manage rising energy costs and ensure supply reliability as illustrated in **Figure 16**. These firms often have sufficient financial and technical capacity to invest in solar systems while maintaining steady operational loads that make solar economically viable.

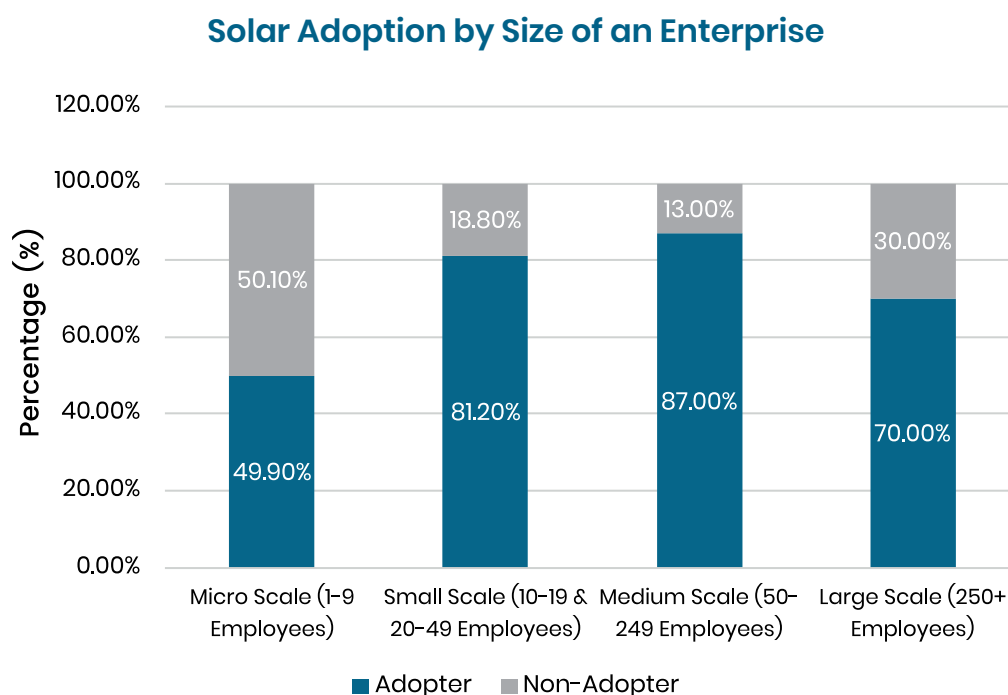


Figure 16: Solar Adoption by scale of enterprise

- Small-scale enterprises (10–49 employees) also show a high adoption rate (81.2 per cent), reflecting growing awareness and falling technology costs. Many small businesses, especially in Punjab and Sindh’s urban centers, view solar as a means to offset frequent grid interruptions and reduce electricity expenses.
- Large-scale enterprises (250+ employees) demonstrate a moderate adoption level (70 per cent). While they have ample resources, their energy use patterns are typically more complex—often involving multiple shifts or high-load industrial processes that require continuous power beyond daylight hours. Consequently, without large storage systems or net metering arrangements, solar alone cannot meet their full energy needs.

- Micro-scale enterprises (1–9 employees) show the lowest adoption rate (49.9 per cent) and the highest share of non-adopters (50.1 per cent). For such businesses, upfront cost remains the primary constraint, even when the long-term savings potential is substantial.

5.3. Adoption by Income Group

When disaggregated by income level (proxied through monthly electricity expenditure), the results show a strong positive correlation between income and solar adoption.

- High-income businesses (spending above PKR 200,000 per month on electricity) report the highest adoption rate (77.3 per cent) as shown in **Figure 17**. These entities often have access to financing and capital budgets that allow them to deploy sizable solar PV systems, sometimes with hybrid or storage components.
- Upper-middle-income groups (PKR 50,001–200,000) also demonstrate strong adoption (65 per cent), reflecting the cost competitiveness of solar against grid tariffs for commercial users in this expenditure band.

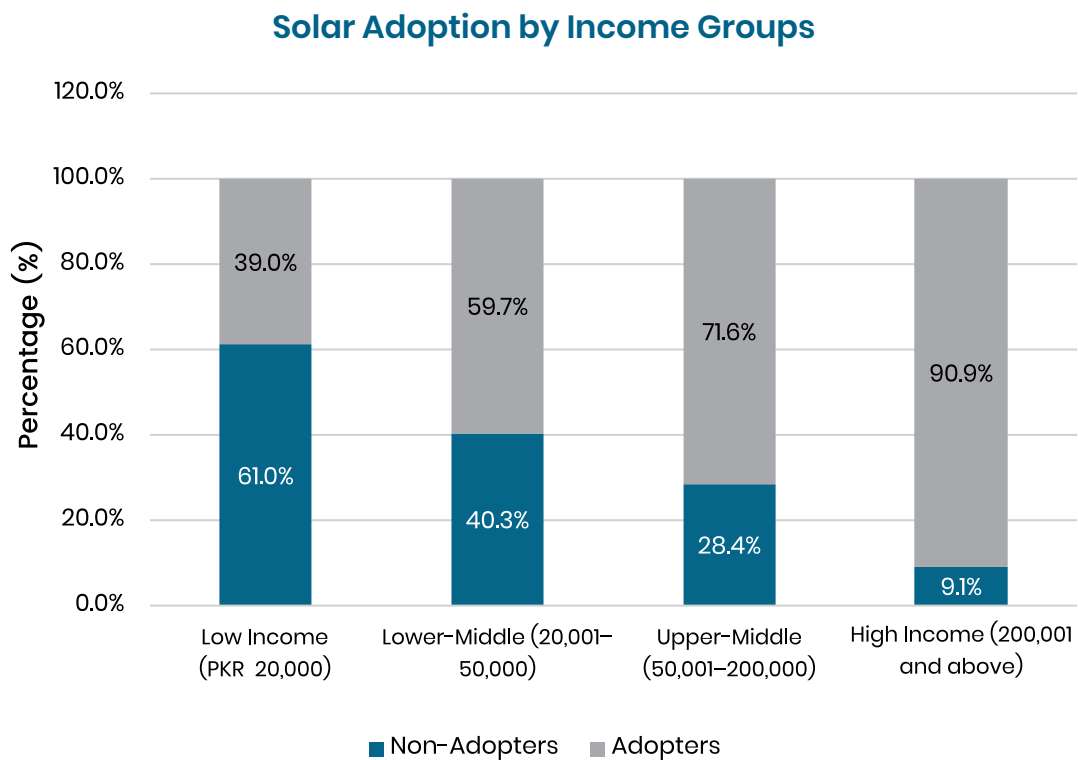


Figure 17: Solar adoption across income groups

- Lower-middle-income businesses (PKR 20,001–50,000) exhibit moderate adoption (51.2 per cent), likely reflecting budget constraints and limited awareness of financing options.
- Low-income enterprises (\leq PKR 20,000) have lower adoption (54.7 per cent), though not negligible. Many in this category rely on basic setups with smaller rooftops or limited daytime loads, making solar systems less financially attractive without targeted incentives or credit support.

These findings highlight a significant equity gap: As income rises, solar adoption grows, and non-adoption falls sharply. The results suggest that financial capacity and access to capital are the strongest determinants of solar uptake in Pakistan’s commercial sector. Expanding concessional financing, leasing models, or small-scale solar credit lines could therefore play a critical role in democratizing adoption among lower-income businesses.

5.4. Changing Grid Demand

New Demand Status	Increased	Decreased	No Change	Not Using Grid	Total
No New Demand Generated	0.0	76.7	12.1	11.2	100.0
New Demand Generated	100.0	0.0	0.0	0.0	100.0
Total	12.3	67.2	10.6	9.8	100.0

The **Table 3** reveals a clear distinction between commercial entities that have generated new electricity demand and those that have not:

- Among businesses with no new demand generated, a significant majority (76.7 per cent) reported a decrease in electricity consumption, indicating limited expansion or even contraction in energy use. This group also includes a notable share (11.2 per cent) of entities not using the grid, highlighting potential barriers such as unreliable supply, affordability issues, or shifts to alternative energy sources.
- Conversely, all businesses that have generated new demand (100 per cent) reported an increase in electricity consumption, reflecting active growth and expansion where barriers to electricity adoption are likely minimal or effectively managed. Though, across solarized industrial users reporting increased electricity demand, the analysis shows a statistically significant reduction in monthly grid electricity expenditure categories following solarization. Average expenditure shifted from a mean category of PKR 500,001–1,000,000 before solar installation to PKR 100,001–500,000 afterward equivalent to roughly one full expenditure level decrease. (This shift corresponds to a decline of about PKR 400,000 per month in grid electricity expenditure, equivalent to a 23 per cent reduction and roughly one expenditure band decrease after solar adoption). This downward movement represents an estimated 23 per cent reduction in grid electricity spending and confirms a meaningful decline in grid dependency. The mean solar-adopting commercial consumer’s electricity demand is estimated to be about 1,249 kWh/month. However, the results show that the grid supplies only 471 kWh (57 per cent), while solar

covers the remaining 778 kWh (43 per cent). This means commercial consumers are meeting a substantial share of their actual electricity needs through solar rather than the grid

- Overall, 67.2 per cent of commercial users experienced decreased consumption, suggesting that barriers such as cost, supply reliability, or operational downsizing are widespread and impact electricity demand negatively as shown in **Figure 18 and Figure 19**.

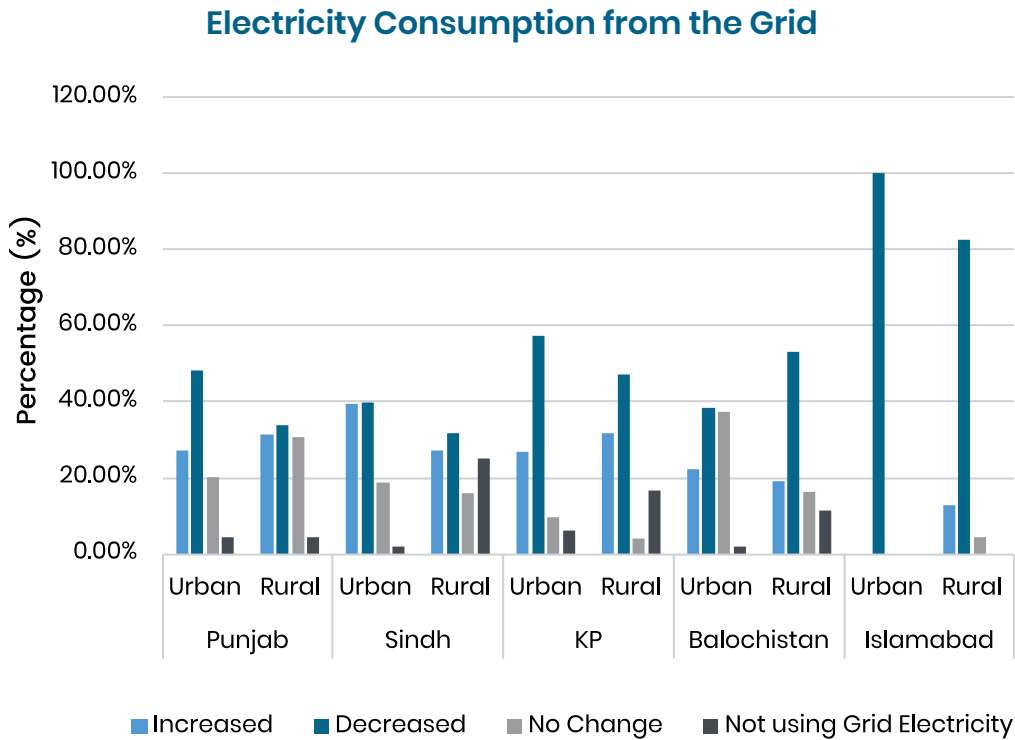


Figure 18: Change in electricity consumption from the grid over the last two years



5.5. Reasons for Reduced Grid Demand

Reasons for Reduced Grid Demand: A Macro-Economic Overview

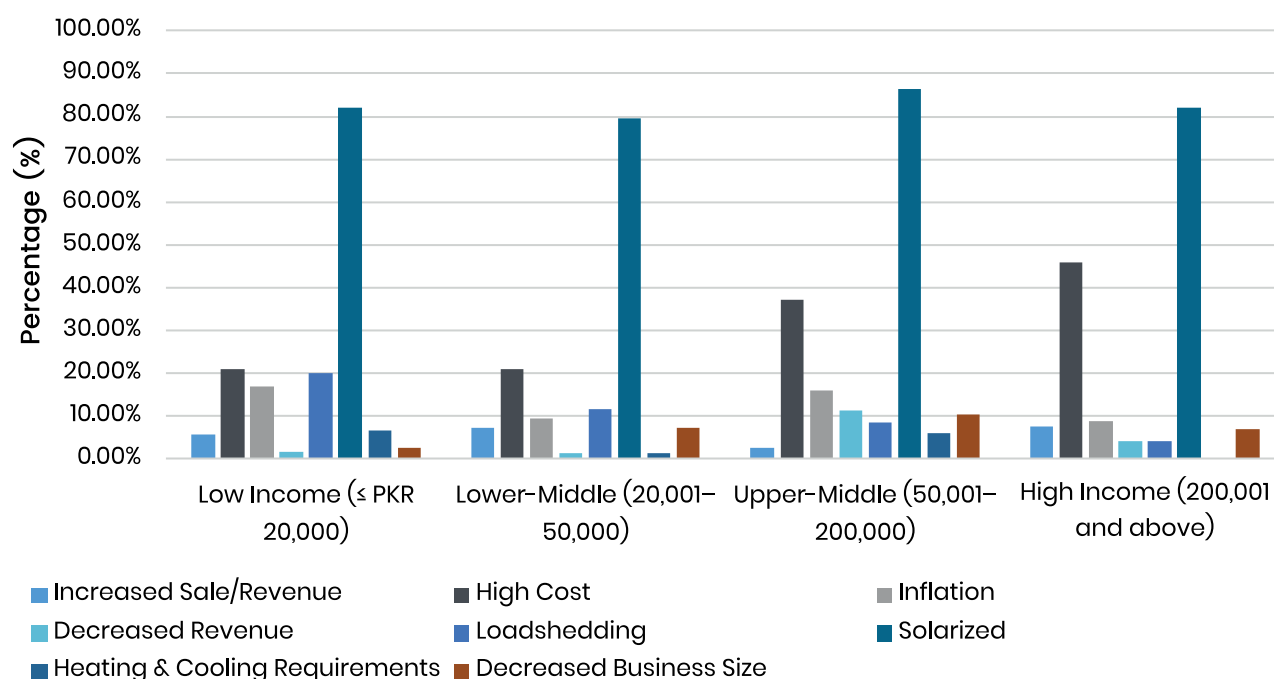


Figure 19: Reasons for reduced grid demand by income groups

Solarization as a Universal Driver

Across all income groups, solarization remains the dominant reason for decreased grid electricity demand, reported by more than 79 per cent of respondents in every category. This underscores the widespread adoption of solar PV as a key strategy for managing rising energy costs and improving supply reliability. Even among high-income businesses, 82 per cent identified solarization as the main factor behind reduced dependence on conventional grid electricity as shown in **Figure 19**.

High Costs and Inflation Pressure Upper Income Groups

“High Cost” and “Inflation” are more frequently cited by upper-middle (37.3 per cent) and high-income (45.8 per cent) groups, indicating that these segments are more sensitive to tariff escalation and macroeconomic uncertainty. These factors influence operational decisions, prompting cost-saving strategies such as solarization and energy efficiency adoption. For these groups, electricity affordability directly affects production scaling and profitability, linking energy cost management to overall business resilience.

Load Shedding, Revenue Decline, and Business Contraction Affect Lower Income Groups

Among lower-income segments, load shedding (20.0 per cent) and decreased revenue (1.6–11.8 per cent) emerge as key reasons for reduced demand, reflecting the vulnerability of small businesses to supply interruptions and economic downturns. Additionally, decreased business size—reported by up to 10.3 per cent of upper-middle and 7.4 per cent of lower-middle income firms—shows that

some enterprises have scaled down operations, thereby lowering electricity consumption. This contraction highlights the compounding impact of unreliable supply and weak demand on small and mid-sized commercial entities.

Impact of Heating and Cooling Requirements

While relatively minor compared to solarization, *heating and cooling requirements* (ranging from 1.5 per cent in lower-middle to 6.8 per cent in low-income groups) still contribute to variations in electricity demand. This reflects seasonal sensitivity, where demand reductions may partly result from lower cooling loads in certain months, particularly among small-scale service-oriented businesses with limited climate-control infrastructure.

5.6. Reasons for Increased Grid Demand

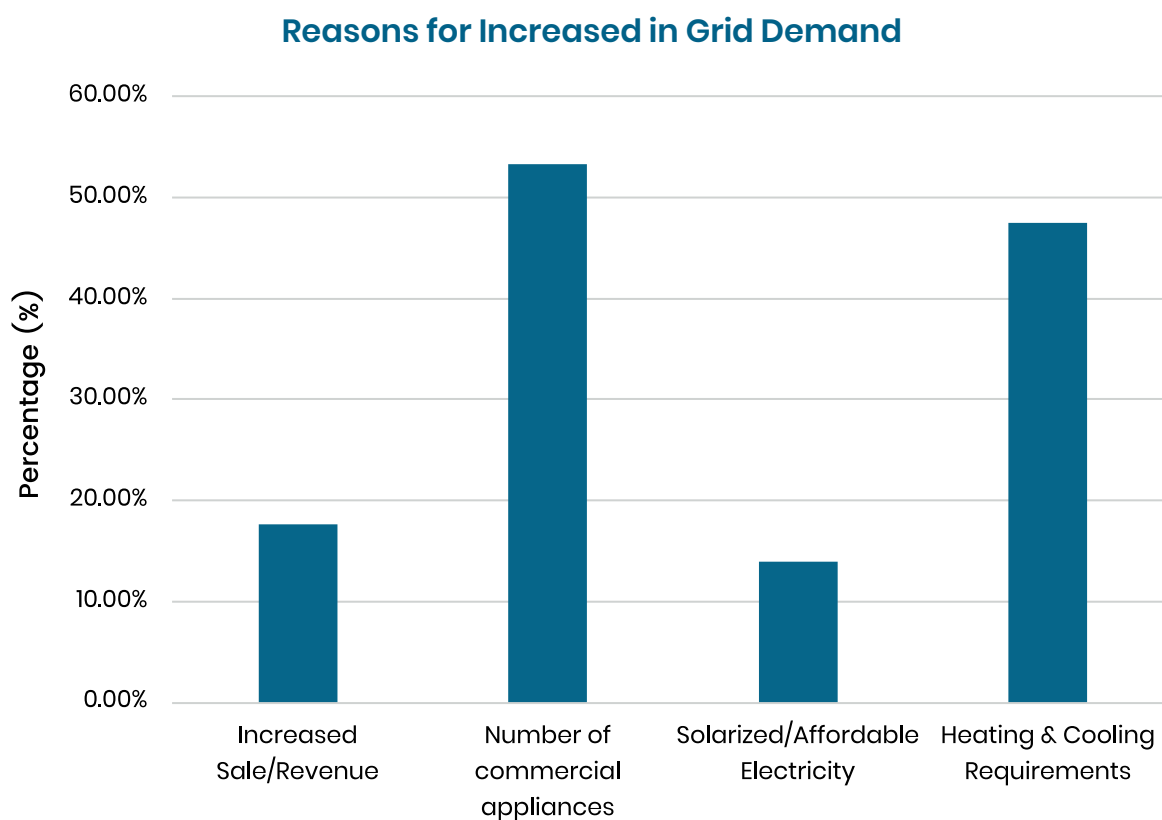


Figure 20: Reasons for Increased Electricity Consumption

Commercial electricity consumption has risen due to a combination of operational growth and changing energy-use practices as presented in **Figure 20**. The most prominent factor is the increase in commercial appliances (53.3 per cent), as businesses adopt more equipment to expand services, improve efficiency, or enhance customer experience—from additional refrigeration units to lighting, computers, and electronics. Growing heating and cooling requirements (47.5 per cent) also significantly push demand, with longer summers and higher customer footfall driving extended use of air-conditioning and cooling systems in shops, offices, and service establishments. Higher sales and revenue (17.6 per cent) indicate business expansion, which typically translates into longer operating hours, greater equipment usage, and increased electricity-intensive activities. Additionally, businesses that have installed solar or gained access to more affordable electricity (14.0 per cent) often increase their total energy consumption, using solar to offset costs during the

day while relying on the grid during peak hours or when generation drops—creating a rebound effect similar to residential users.

5.7. Barriers to Adoption

The analysis of barriers to adoption across income groups and urban-rural divides reveals important socio-economic and infrastructural dynamics shaping commercial electrification in Pakistan as shown in **Figure 21**.

Urban Commercial Sector

In urban areas, high cost stands out as the primary barrier—especially for lower-income businesses (70.5 per cent) and lower-middle-income groups (54.3 per cent). This reflects the compounding effect of urban energy tariffs, limited financial liquidity, and often tighter profit margins in smaller enterprises. The urban context, characterized by higher living and operating costs, makes upfront investments in solar or electrification technologies financially challenging without subsidies or accessible financing options.

The land and space constraints (up to 42.7 per cent in lower-middle income) are a critical urban challenge. Urban commercial businesses frequently operate in congested areas with limited rooftop or ground space, restricting the physical feasibility of installing solar PV or other electrification infrastructure. This spatial limitation highlights the need for innovative solutions such as community solar projects or shared infrastructure in dense commercial zones.

Interestingly, the relatively high percentage of lack of awareness (30.2 per cent) among high-income urban businesses suggests that even better-resourced enterprises face knowledge gaps or skepticism about solar technologies, indicating a potential disconnect between market offerings and end-user understanding. This underlines the importance of targeted awareness campaigns and demonstration projects that showcase tangible benefits and ease of integration.

Rural Commercial Sector

Rural businesses face a different set of challenges. The overwhelmingly high cost barrier (92.7 per cent for low-income groups) underscores the persistent affordability issue in less economically developed areas where financing options are scarce and income volatility high. Unlike urban centers, rural enterprises often lack access to formal credit markets, making capital-intensive investments like solar adoption prohibitive.

Moreover, limited awareness is more pronounced in rural low and upper-middle income groups (14–16.6 per cent), reflecting informational gaps exacerbated by geographic isolation and weaker extension services. Without sufficient knowledge of technology benefits or available support mechanisms, rural businesses are less likely to pursue electrification despite its potential to enhance productivity.

The lower incidence of land and space constraints in rural areas aligns with the generally more spacious commercial premises outside urban centers, but this advantage is offset by infrastructural deficits like grid unreliability and regulatory hurdles reported in some upper-middle rural businesses.

Implications

The data reveals that financial barriers—both cost and access to financing—are the primary and universal obstacles across all commercial segments, limiting the pace and scale of electrification. However, urban areas must also contend with physical constraints and awareness challenges, while rural areas suffer more acutely from affordability and information deficits.

This suggests that one-size-fits-all policies are unlikely to succeed. Instead, tailored interventions are required:

- In urban centers, promoting innovative space-efficient solar solutions and financing schemes targeted at small-to-medium enterprises.
- In rural areas, expanding awareness programs and improving rural credit facilities alongside cost-reduction strategies such as subsidies or concessional loans.

Barriers to Adoption by Income Groups

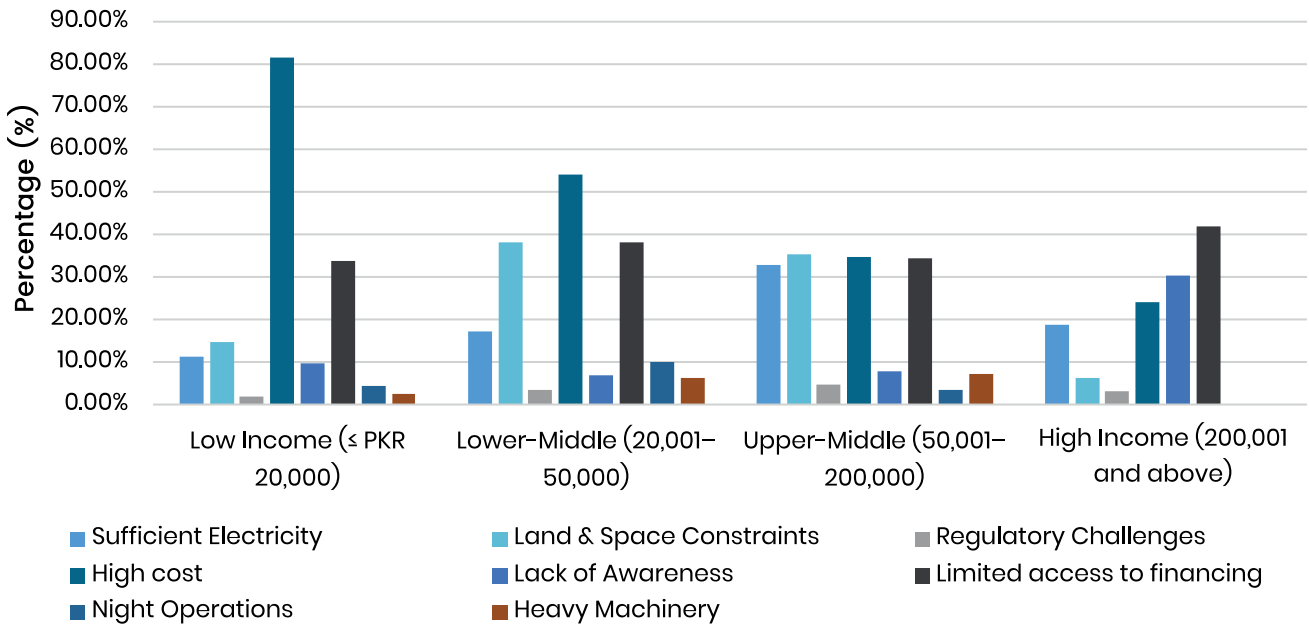


Figure 21: Barriers to adoption by income groups

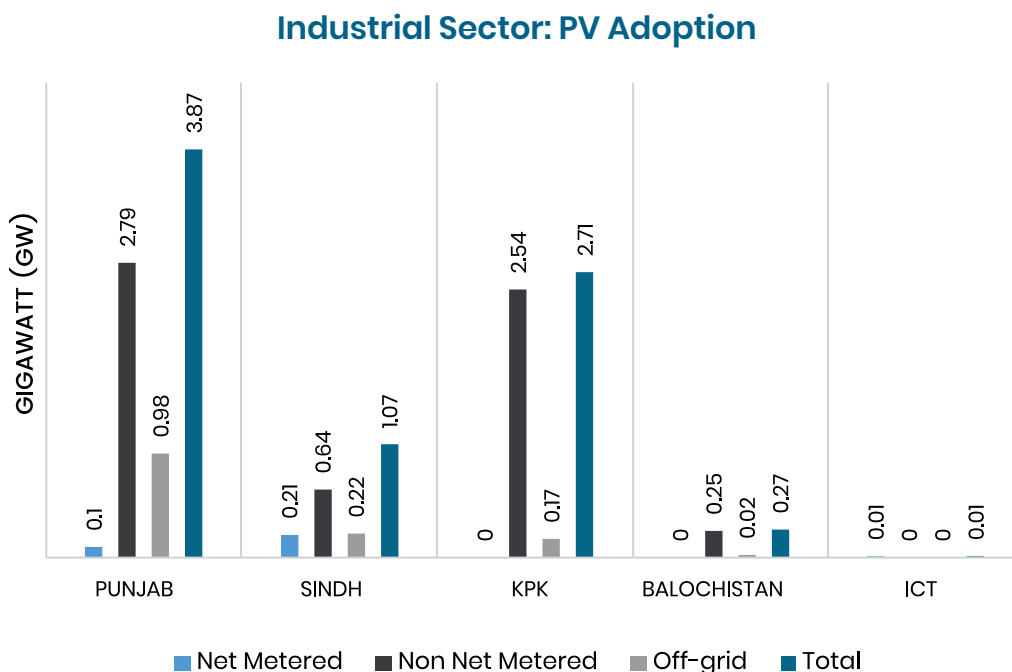




INDUSTRIAL SECTOR

6. INDUSTRIAL SECTOR

6.1. Adoption across the Industrial Sector



Net-Metered	Non-Net-Metered	Off grid (GW)	Total (GW)
0.30	6.22	1.39	7.91

Figure 22: Provincial Distribution of Industrial Solar Capacity by Connection Type (GW)

6.2. Industrial Solar Adoption Across Provinces

Punjab currently leads industrial solar adoption in Pakistan, with a total installed capacity of 3.87 GW. The majority of this capacity – approximately 2.79 GW – consists of non-net-metered (NNM) systems, highlighting industries’ growing preference for self-generation and energy independence as illustrated in **Figure 22**.

Khyber Pakhtunkhwa (KP) ranks as the second-largest industrial solar adopter, with 2.54 GW of NNM capacity. Although net-metered (NM) installations in KP’s industrial sector remain limited, the province demonstrates a notable 2.71 GW in total industrial photovoltaic (PV) capacity. This trend underscores an increasing inclination among KP’s industries toward self-sufficiency and reduced grid dependence.

Sindh stands third in industrial solar uptake, accounting for a total of 1.07 GW in installed PV capacity.

Overall, industrial solar adoption now exceeds that of the commercial sector, reflecting industries’ strong motivation to minimize operational costs, improve supply reliability, and mitigate exposure to grid inefficiencies and tariff fluctuations.

In industries, a positive correlation between industrial scale and solar adoption

The observed data reveals a clear positive correlation between industrial scale and solar adoption, underscoring significant inequities in access to renewable technologies across firm sizes as shown in **Figure 23**. Adoption rates rise markedly from 38 per cent among micro-scale industries to 80.9 per cent among medium-scale industries, indicating that expanding enterprise size enhances capacity for investment in solar systems. Likewise, large-scale (74.2 per cent) and heavy industries (69 per cent) exhibit strong adoption trends, reflecting both financial capability and operational incentives for energy diversification.

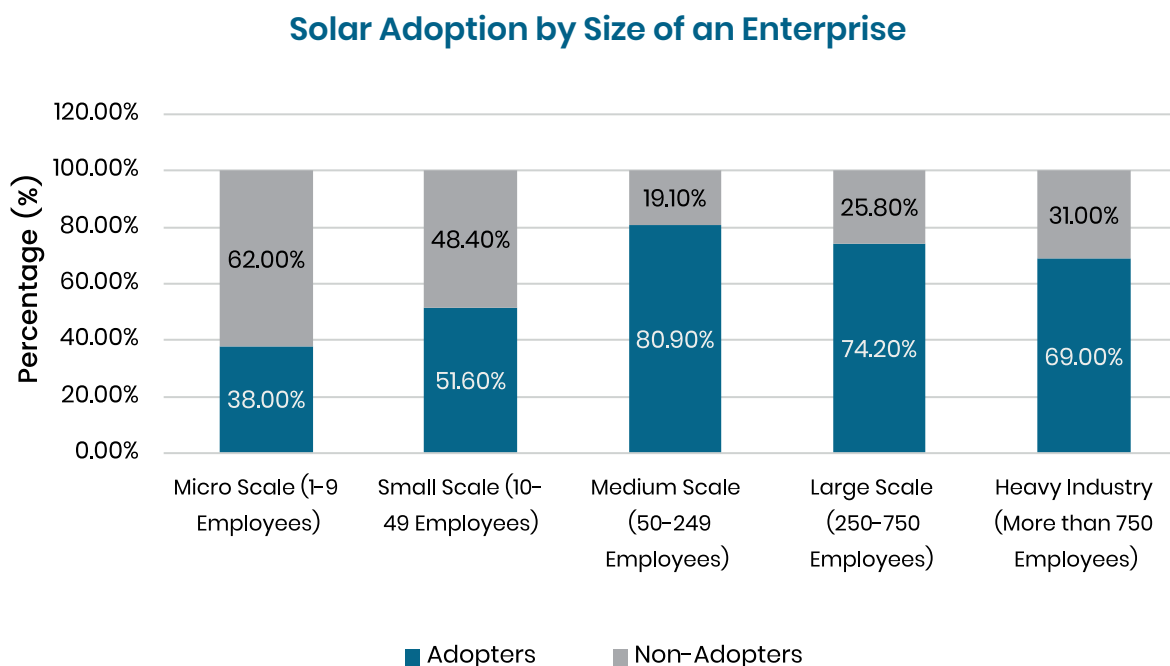


Figure 23: Solar Adoption by Industrial Size

From an equity perspective, this pattern exposes a structural disparity in the energy transition: smaller and lower-capacity industries face greater financial, technical, and procedural barriers to solar integration. High upfront costs, limited access to credit, lack of technical expertise, and bureaucratic hurdles (such as licensing and net-metering approvals) restrict smaller firms from fully participating in the renewable energy shift. Consequently, while industrial solarization advances national sustainability goals, it may also exacerbate inequalities between industrial tiers, privileging firms with greater capital and institutional support.

When analyzed by monthly energy expenditure, the relationship becomes more nuanced as illustrated in **Figure 24**. High-revenue industries (energy spending > PKR 1 million) show the highest adoption rate at 76.3 per cent, leveraging solar as a cost-optimization strategy. Conversely, low-revenue industries (\leq PKR 100,000) also demonstrate a relatively high adoption rate of 57 per cent, likely driven by necessity – to mitigate high grid tariffs, reduce operational downtime, and ensure reliability amid inconsistent supply. However, lower-middle (32.6 per cent) and upper-middle (27.8 per cent) groups exhibit the lowest adoption levels, caught between affordability constraints and limited economies of scale.

Solar Adoption by Income Groups

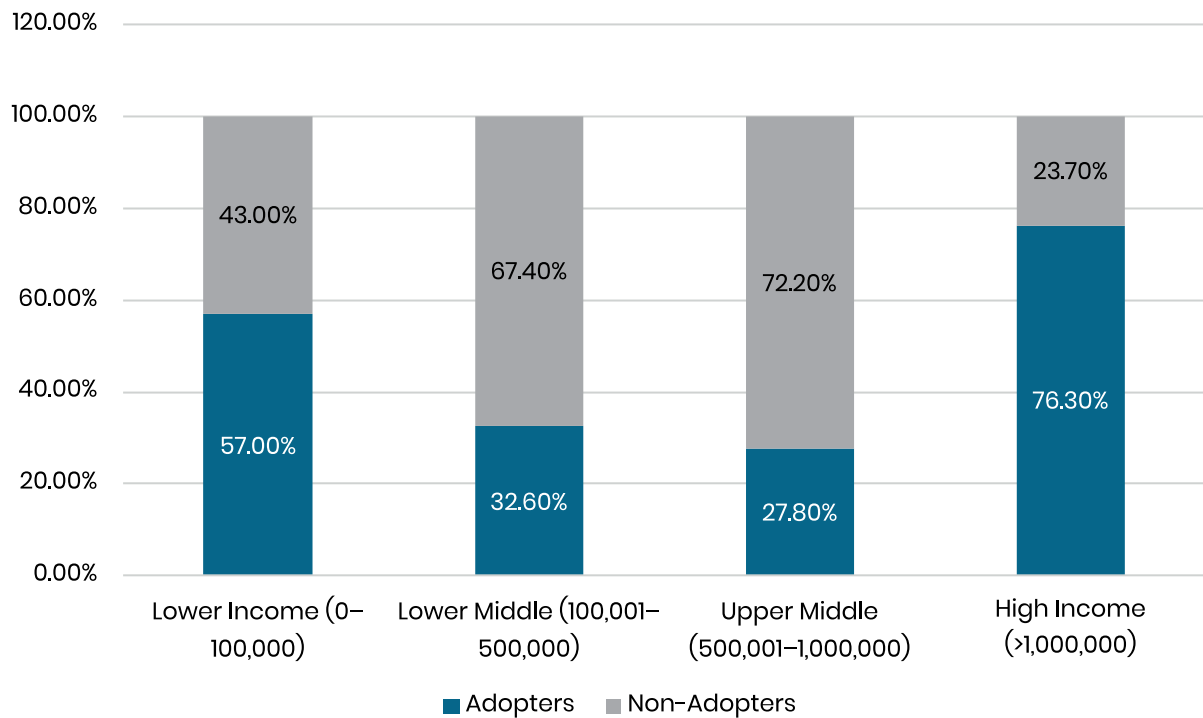


Figure 24: Solar adopters by Expenditure groups

This pattern forms a U-shaped relationship between financial scale and solar adoption. On one end, resource-constrained firms adopt solar as a survival mechanism; on the other, capital-rich enterprises adopt it as an efficiency and competitiveness strategy. Those in the middle – neither resource-poor nor resource-rich – often lack both the incentive and the financial headroom to transition.

In equity terms, this suggests that current market and policy structures disproportionately benefit the extremes, while medium-tier industries remain under-supported. Addressing this imbalance will require targeted financial instruments, simplified procedural frameworks, and capacity-building initiatives that enable inclusive access to solar technologies across the full spectrum of industrial participants.

6.3. Changing Grid Demand

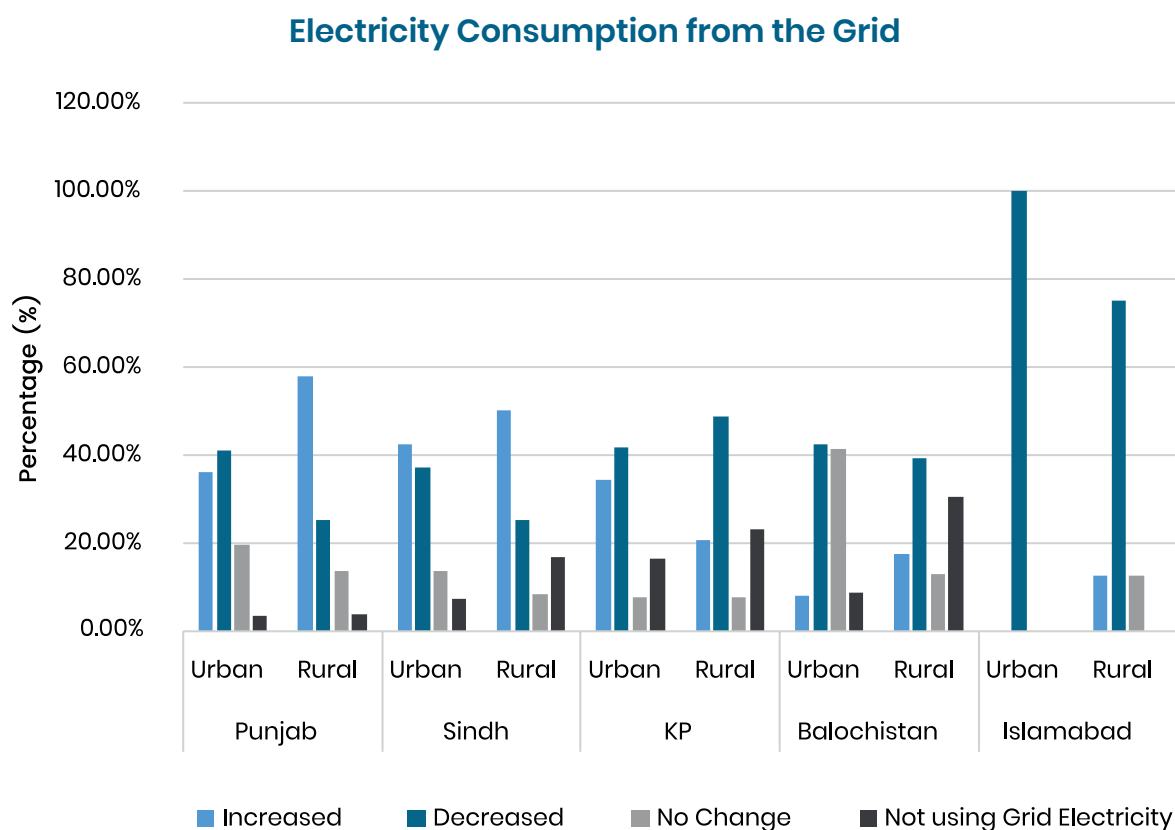


Figure 25: Change in electricity consumption from the grid over the last two years

The data shown in **Figure 25** indicates that grid electricity consumption among industries has largely declined over the past two years, particularly within lower-middle (81.5 per cent) and upper-middle (86.4 per cent) revenue groups. This trend suggests that medium-scale industries—those with moderate revenues and energy expenditures—are increasingly reducing reliance on the grid, likely due to rising electricity tariffs, improved solar economics, or efficiency retrofits. In contrast, lower-revenue industries (46.3 per cent) also show substantial decline, but a notable 32.7 per cent are not using grid electricity at all, reflecting limited affordability or access constraints, possibly forcing them towards off-grid or curtailed operations. High-revenue industries, however, display more diversified energy behavior: while 63.3 per cent report decreased grid usage, 20 per cent maintained stable consumption, implying that larger firms possess greater flexibility and resilience—either through hybrid energy systems or better financial capacity to absorb rising costs.

6.4. Reasons for Decreased Grid Demand

Change in Electricity Consumption by Income Groups

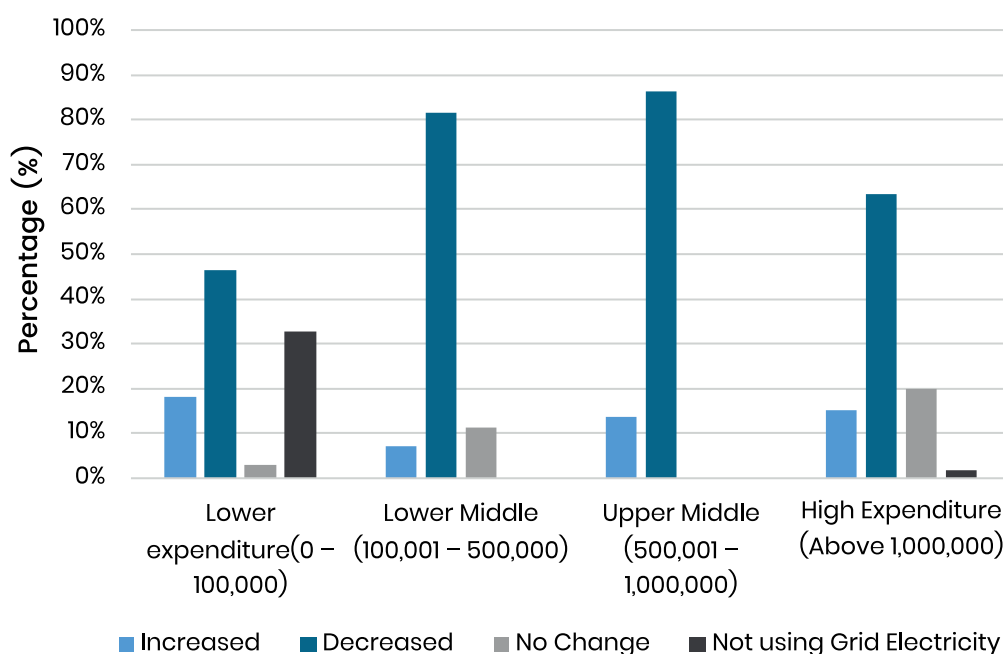


Figure 26: Change in electricity consumption from the grid by expenditure groups

Grid electricity consumption trends vary significantly across industrial earning groups, reflecting both macroeconomic pressures and the rapid adoption of self-generation technologies as outlined in **Figure 26**.

Lower-middle and upper-middle earning industries show the sharpest declines in grid demand—81.5 per cent and 86 per cent, respectively—corresponding with the highest solarization rates (80–86 per cent) among all categories. These findings suggest that mid-scale industries are leading the transition toward self-sufficiency, primarily driven by rising grid tariffs, inflation, and improved cost-efficiency of solar systems. Notably, 39.5 per cent of upper-middle industries cited high electricity costs as a key factor, underscoring that economic constraints, rather than capacity limitations, are steering this shift.

Lower-earning industries also show reduced grid dependence (46 per cent decreased usage) and a substantial off-grid share (33 per cent). While 66 per cent of them have adopted solar systems, a considerable portion (33.5 per cent) report being impacted by high costs and 18 per cent by inflation, indicating that cost burdens and limited access to affordable finance restrict their ability to maintain grid reliance or expand operations.

Among high-earning industries (electricity expenditure above PKR 1 million), consumption patterns are more diversified: 63 per cent reported decreased grid usage, 15 per cent increased, and 20 per cent remained unchanged. Despite a relatively high solarization rate (79.9 per cent), this group exhibits more balanced energy behavior, likely reflecting strategic energy portfolio diversification—combining on-site solar, backup generation, and continued grid connectivity to maintain reliability.

Overall, the data reveal a systemic decline in grid dependence across all industrial tiers, most pronounced in the middle-income segments, where firms have both the economic incentive and

technical feasibility to invest in solar. Conversely, lower-tier industries face access and affordability constraints, while higher-tier firms pursue hybrid optimization rather than complete grid withdrawal.

Across solarized industrial users reporting increased electricity demand, the analysis shows a statistically significant reduction in monthly grid electricity expenditure categories following solarization.

Average expenditure shifted from a mean category of PKR 500,001–1,000,000 band before solar installation to PKR 100,001–500,000 band afterward equivalent to roughly one full expenditure level decrease. (This shift corresponds to a decline of about PKR 400,000 per month in grid electricity expenditure, equivalent to a 23 per cent reduction and roughly one expenditure band decrease after solar adoption). The mean solar-adopting industrial consumer's electricity demand is estimated to be about 22,754 kWh/month. However, the data show that the grid supplies only 3,071 kWh (50.7 per cent), while solar covers a much larger 19,503 kWh (49.3 per cent). This means industrial consumers are meeting nearly half of their actual electricity needs through solar rather than the grid.

This downward movement represents an estimated 23 per cent reduction in grid electricity spending and confirms a meaningful decline in grid dependency. The strong pre-post correlation indicates that while industries maintained proportional consumption behavior, solar adoption generated consistent cost savings across the sector, enhancing overall energy efficiency and operational resilience.

6.5. Reasons for increased Grid Demand

Reasons for Increased in Demand by Income Groups

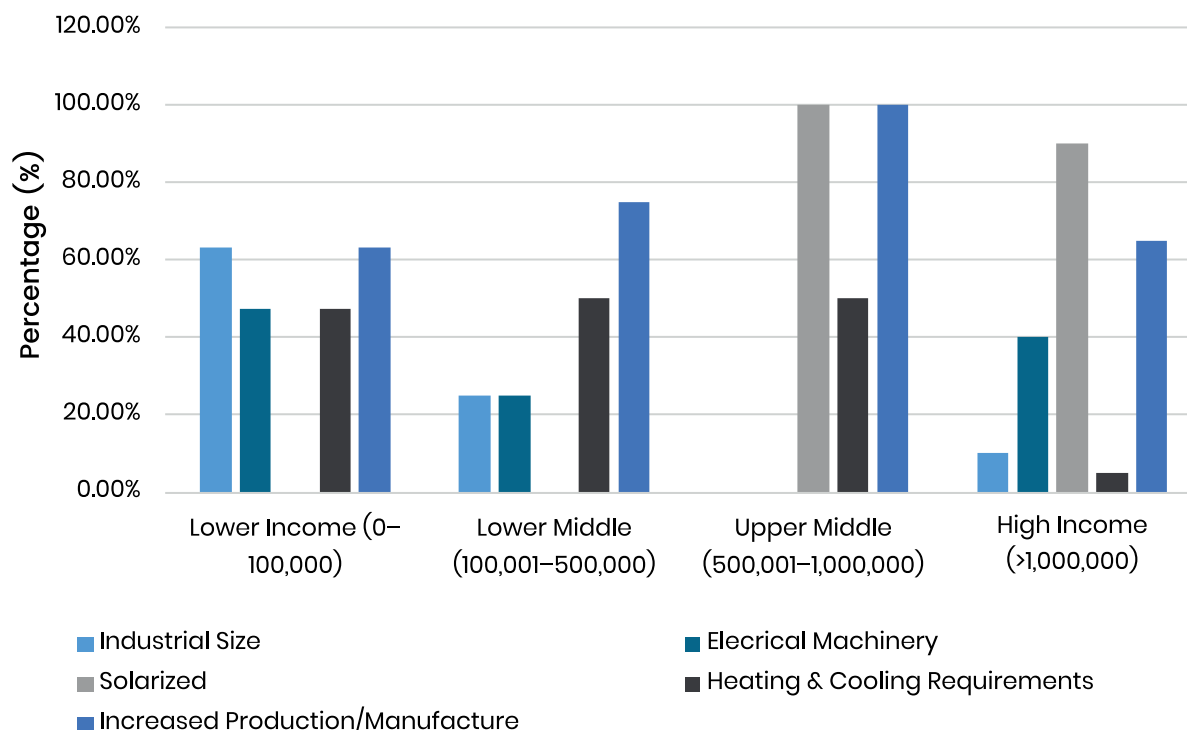


Figure 27: Reasons for increased grid electricity demand by income groups

A minority across all groups have reported increased grid electricity demand, driven by the following specific operational factors:

- Among lower-income industries, the largest share of increased demand is linked to industrial size (63.2 per cent), increased production or manufacturing activity (63.2 per cent), and heating & cooling requirements (47.4 per cent) as outlined in **Figure 27**. Despite zero solarization in this group for increased demand cases, these firms are expanding operations or upgrading machinery, thus relying more on the grid.
- Lower-middle industries with increased grid demand similarly report manufacturing growth (75 per cent) and heating/cooling needs (50 per cent) as key drivers, alongside operational scale (25 per cent) and electrical machinery use (25 per cent).
- For upper-middle industries showing increased grid demand (though a smaller group), 100 per cent report solar adoption - indicating that these firms are generating new electricity demand overall, with solar supplementing rather than replacing grid supply. This reflects business growth where self-generation and grid consumption expand in tandem. These firms also cite manufacturing growth (100 per cent) and heating/cooling requirements (50 per cent).
- Among high-income industries, 90 per cent of those with increased grid demand are also solarized, and 65 per cent point to production scale-up as the cause. Notably, only 5 per cent cite heating/cooling requirements here, indicating more diverse and possibly efficiency-optimized operations.

Overall, while grid reliance is declining across the industrial spectrum, driven primarily by solar adoption and economic pressures, increased grid demand in some segments underscores that grid and self-generation sources often coexist in evolving energy portfolios.

6.6. Barriers to Solar Adoption

Barriers to Adoption by Income Groups

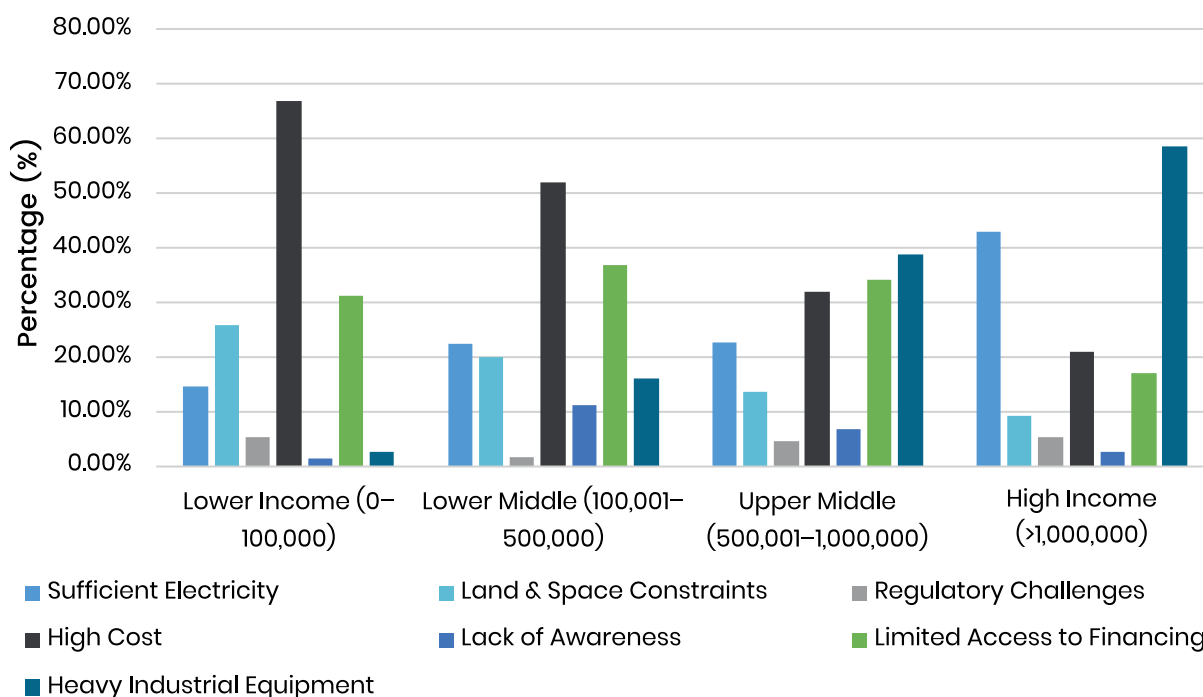


Figure 28: Barriers to adoption by income groups

Barriers to solar or self-generation adoption vary notably across industrial income groups, reflecting distinct financial and technical challenges at each level as illustrated in **Figure 28**.

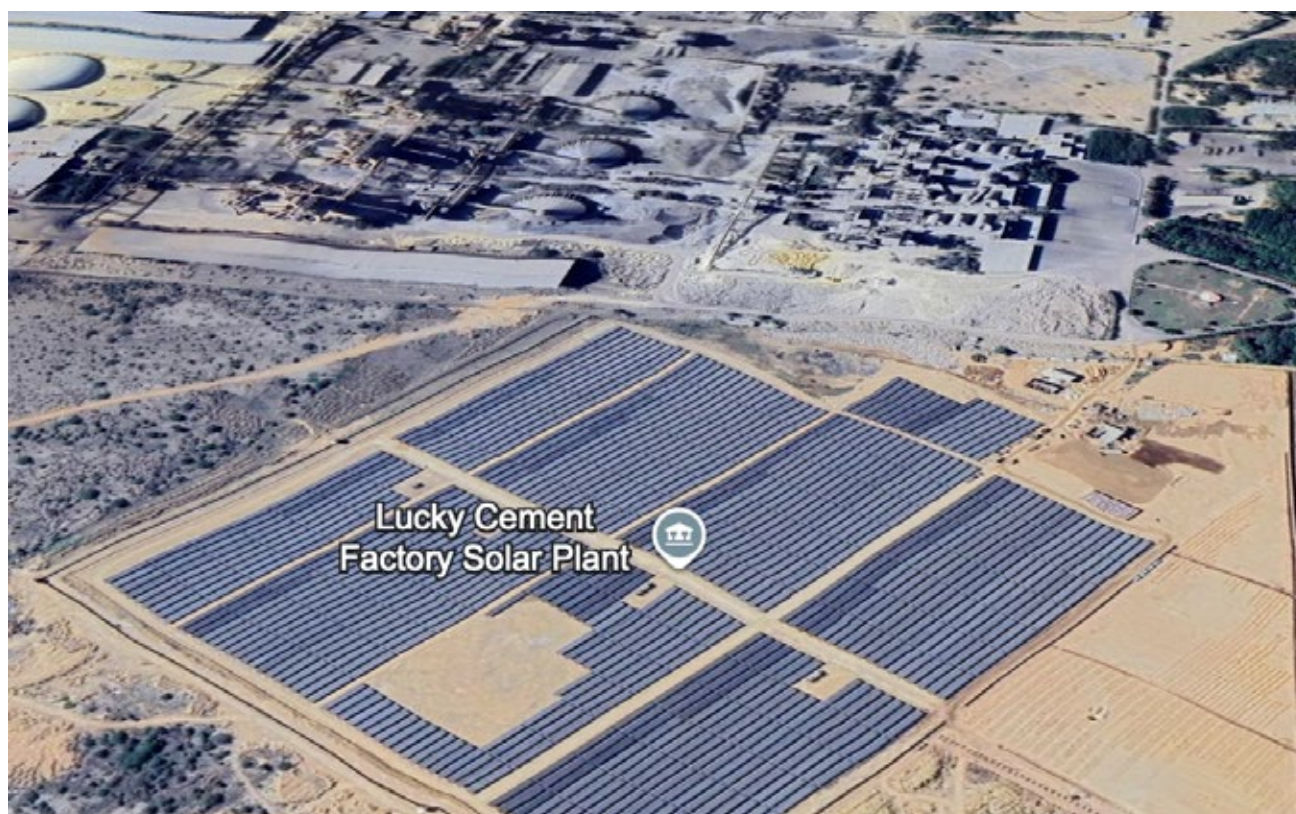
Among lower-income industries (electricity expenditure up to PKR 100,000), high installation costs (66.9 per cent) and limited access to financing (31.1 per cent) are the most significant hurdles. This highlights that upfront capital requirements and lack of affordable credit are the primary deterrents for smaller or low-revenue firms. Other barriers such as land and space constraints (25.8 per cent) also affect this group, though awareness issues remain minimal (1.3 per cent).

In the lower-middle income group (PKR 100,001–500,000), financial barriers remain prominent, with 52 per cent citing high costs and 36.8 per cent limited financing access. Additionally, land and space constraints (20 per cent) and lack of awareness (11.2 per cent) emerge more strongly, indicating that these firms face both economic and informational challenges in adopting new technologies.

For upper-middle industries (PKR 500,001–1,000,000), financial barriers diminish somewhat (31.8 per cent report high cost), while technical challenges grow more important. Specifically, compatibility with heavy industrial equipment (38.6 per cent) and limited financing (34.1 per cent) are key concerns, reflecting the complexity of integrating solar or alternative energy with larger-scale, specialized machinery.

In the high-income group (expenditure above PKR 1 million), financial factors play a smaller role—only 20.8 per cent cite high cost and 16.9 per cent limited financing—while sufficient electricity supply (42.9 per cent) and heavy equipment compatibility (58.4 per cent) dominate as barriers. This indicates that larger firms' hesitation to adopt new energy solutions primarily stems from technical and operational constraints, such as ensuring reliable power quality and seamless integration with existing infrastructure, rather than affordability.

Overall, the data shows a clear progression: financial barriers predominate among lower-revenue industries, while technical and operational issues become the main challenges for larger, higher-revenue firms to install solar panels.





AGRICULTURE SECTOR

7. AGRICULTURE SECTOR

7.1. Agricultural Solar Capacity by Province

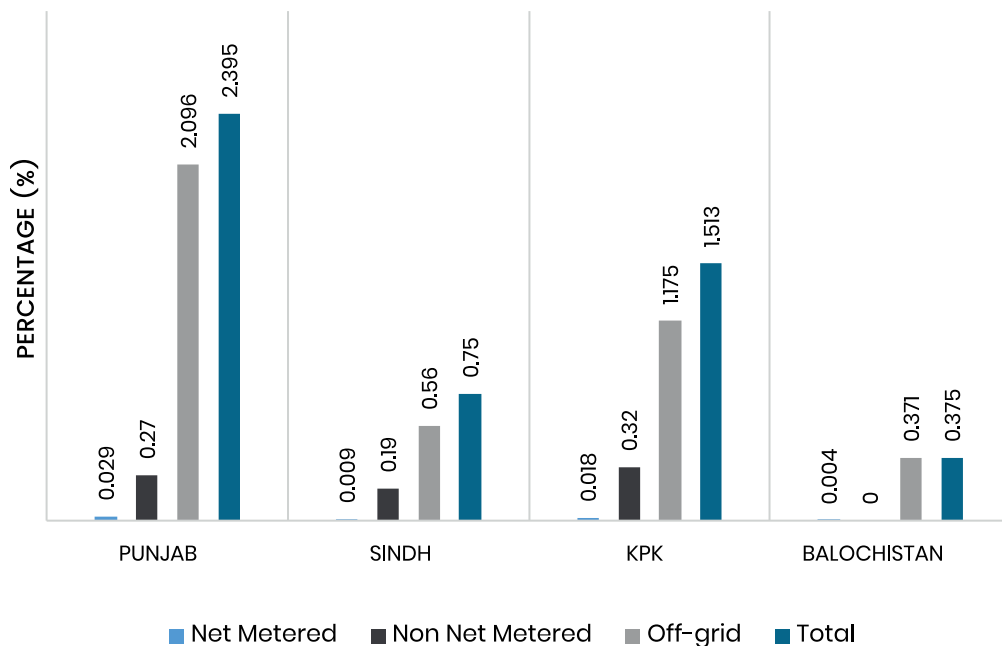
Punjab leads the country with a substantial installed agricultural solar capacity totaling 2.38 GW as shown in **Figure 29**. This capacity is primarily composed of 2.09 GW off-grid systems, 0.27 GW non-net-metered (NNM) installations, and a marginal share of net-metered (NM) solar systems.

Following Punjab, Khyber Pakhtunkhwa (KP) holds the second position with a total agricultural solar capacity of 1.51 GW. This comprises 1.17 GW off-grid, 0.32 GW NNM, and a minor 0.018 GW NM capacity, reflecting a strong preference for decentralized solar solutions.

Sindh reports an aggregate capacity of 0.76 GW, with a diversified mix including 0.56 GW off-grid systems, 0.19 GW NNM, and 0.09 GW NM installations. This distribution indicates a balance between grid-connected and standalone solar applications in the province.

Balochistan accounts for a total installed capacity of 0.38 GW, predominantly driven by 0.37 GW off-grid systems. The negligible presence of net-metered and non-net-metered capacities underscores the province's heavy reliance on localized and decentralized photovoltaic systems, a necessity shaped by limited grid accessibility.

Agriculture Sector :PV Adoption



Net-Metered	Non-Net-Metered	Off grid	Total (GW)
0.06	0.781	4.203	5.045

Figure 29: Provincial Distribution of Agriculture Solar Capacity by Connection Type (GW)

7.2. Trends in Irrigation Power Sources

Nationally, solar-powered tube-wells dominate the agricultural irrigation landscape, marking a significant shift from traditional energy sources as illustrated in **Figure 30**. Despite this transition, diesel-powered tube-wells remain the primary irrigation method in Punjab, accounting for approximately 59 per cent of tube-well systems. However, this figure reflects a substantial decline in diesel dependency. According to a Government of Punjab report (2021), nearly 80 per cent of tube-wells were diesel-based at that time, highlighting notable progress towards solarization in recent years.

This trend underscores an ongoing energy transition within Punjab’s agricultural sector especially, with increasing adoption of sustainable, solar-powered irrigation solutions contributing to reduced diesel reliance and improved energy security.

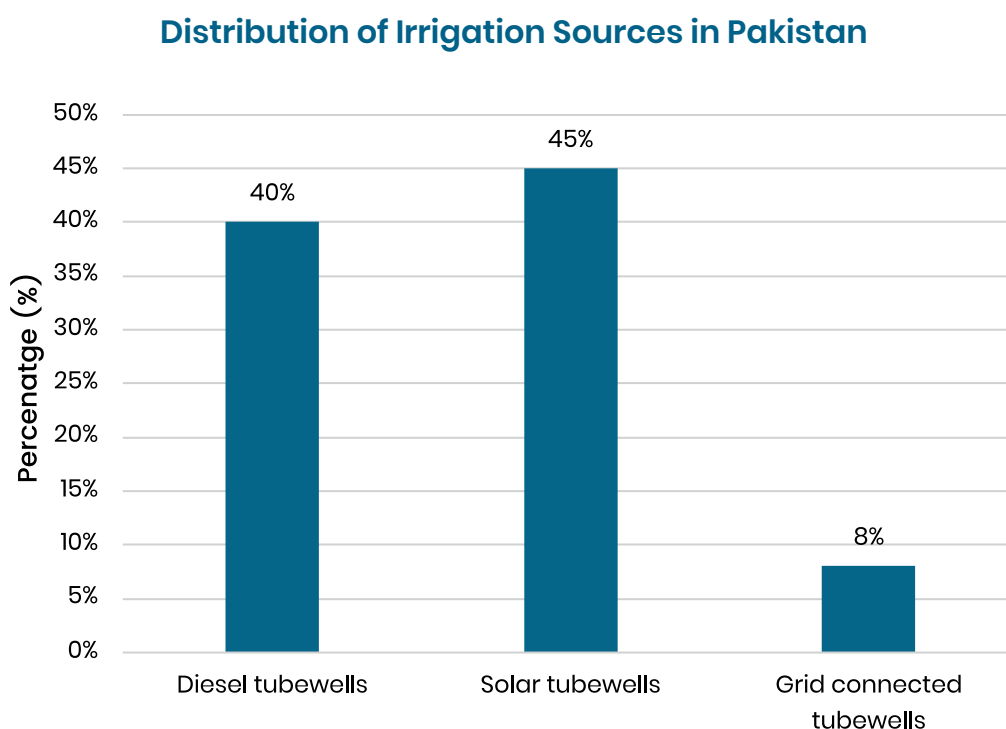


Figure 30: Distribution of irrigation sources in Pakistan

7.3. Adoption across Income Groups

The adoption of solar technology varies considerably across different income (expenditure) groups as shown in **Figure 31**. The highest adoption rate is observed among the lower expenditure group (PKR 1–20,000), with 84.7 per cent of households adopting solar systems. This suggests that even low-income agricultural households are increasingly turning to solar, likely motivated by unreliable grid supply and the long-term economic benefits of self-generation.

Solar Adoption by Income Groups

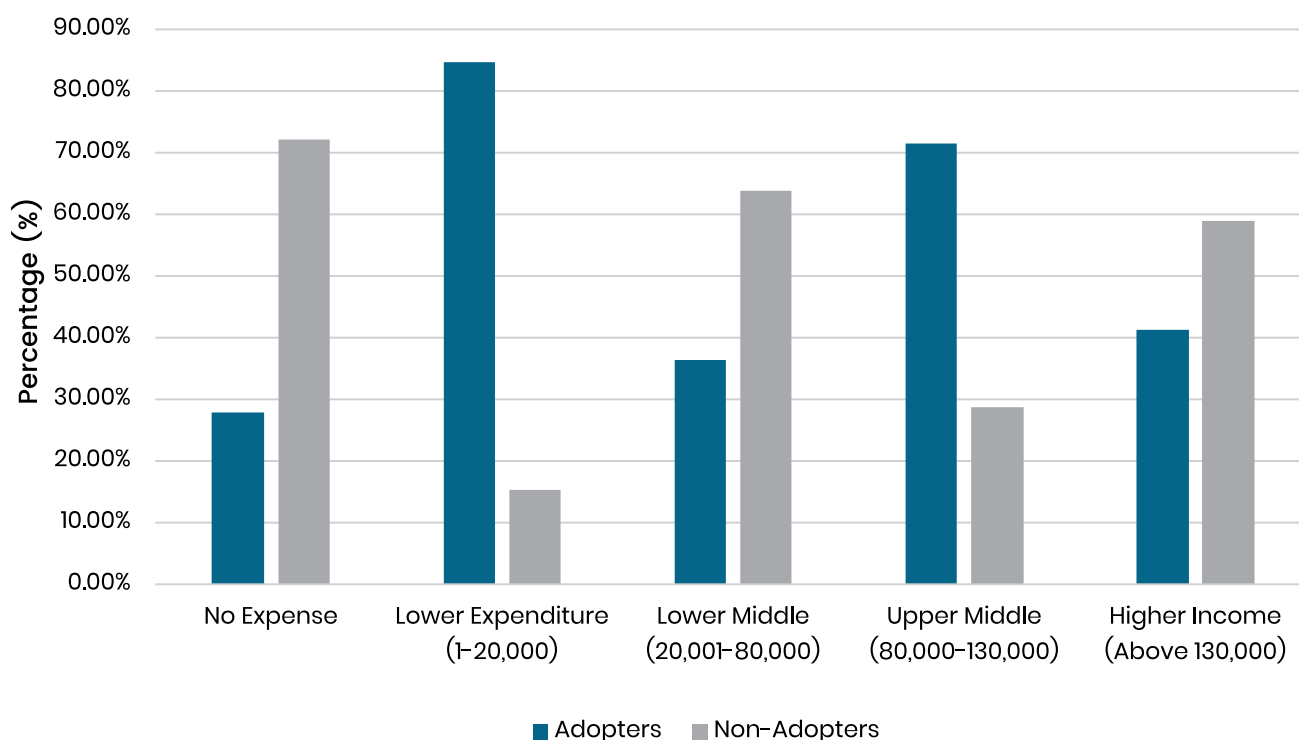


Figure 31: Solar adoption by income groups

Similarly, the upper-middle expenditure group (PKR 80,000–130,000) reports a strong adoption rate of 71.4 per cent, indicating both affordability and a preference for stable, clean energy sources within this segment. Conversely, adoption rates are lower among the no-expenditure group (27.9 per cent) and lower-middle group (36.3 per cent), reflecting possible financial or access constraints. The higher income group (above PKR 130,000) shows a moderate adoption rate of 41.2 per cent, suggesting different energy preferences or alternative arrangements at this level.

7.4. Adoption by Scale

Solar adoption also exhibits a clear relationship with the size of the agricultural facility as outlined in Figure 32. Adoption rates increase steadily with farm size up to the 6–10 acre range: from 18.8 per cent among farms smaller than one acre to 46.4 per cent among those spanning 6–10 acres. This trend suggests that medium-scale farms are the most active adopters, likely due to higher energy demands and greater financial capacity to invest in solar technology.

Solar Adoption by Scale of Agriculture Facility

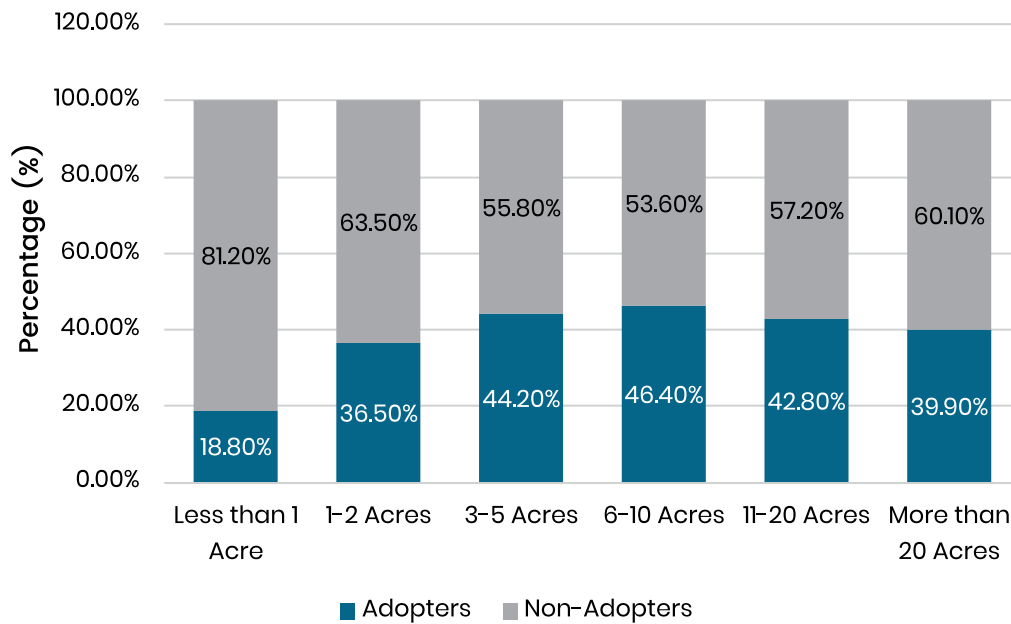


Figure 32: Solar adopters by scale of agricultural facility

Beyond 10 acres, adoption slightly declines, with 42.8 per cent among 11–20 acre farms and 39.9 per cent for farms exceeding 20 acres. This decrease may reflect alternative energy strategies or differing operational priorities among larger farms.

Solar PV significantly reduces energy poverty in the lower-income agriculture sector fostering energy independence and a true people-led ‘just energy-transition’.



7.5. Change in Electricity Consumption from Grid

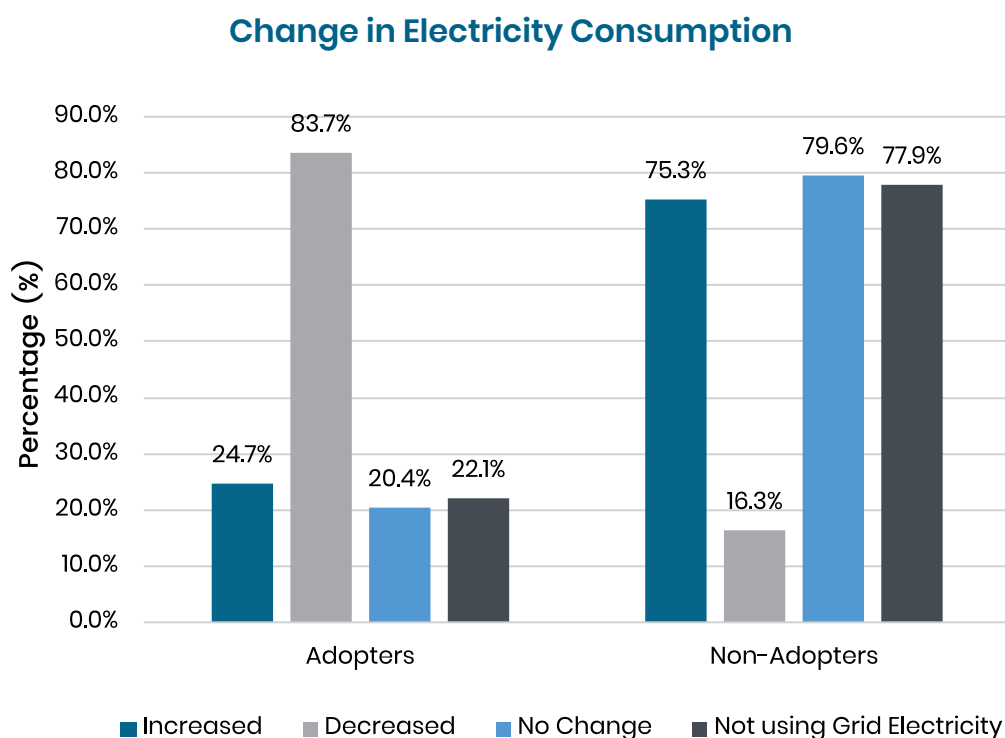


Figure 33: Change in electricity consumption from the grid over the last two years

The data reveals clear differences in electricity consumption trends between solar adopters and non-adopters within agricultural facilities as shown in **Figure 33**. Among solar adopters, a substantial 83.7per cent reported a decrease in grid electricity consumption, highlighting the effectiveness of solar installations in reducing reliance on the grid and lowering energy costs. Conversely, 24.7per cent of adopters noted an increase in consumption, likely due to expanded operations or increased mechanization enabled by affordable solar power.

Among non-adopters, the majority experienced either no change (79.6per cent) or an increase (75.3per cent) in electricity consumption, indicating limited energy efficiency improvements or diversification. Additionally, 22.1per cent of adopters are not using grid electricity at all, underscoring solar's role as a standalone or hybrid energy solution in off-grid agricultural setups.

7.6. Reasons for Decreased Grid Demand

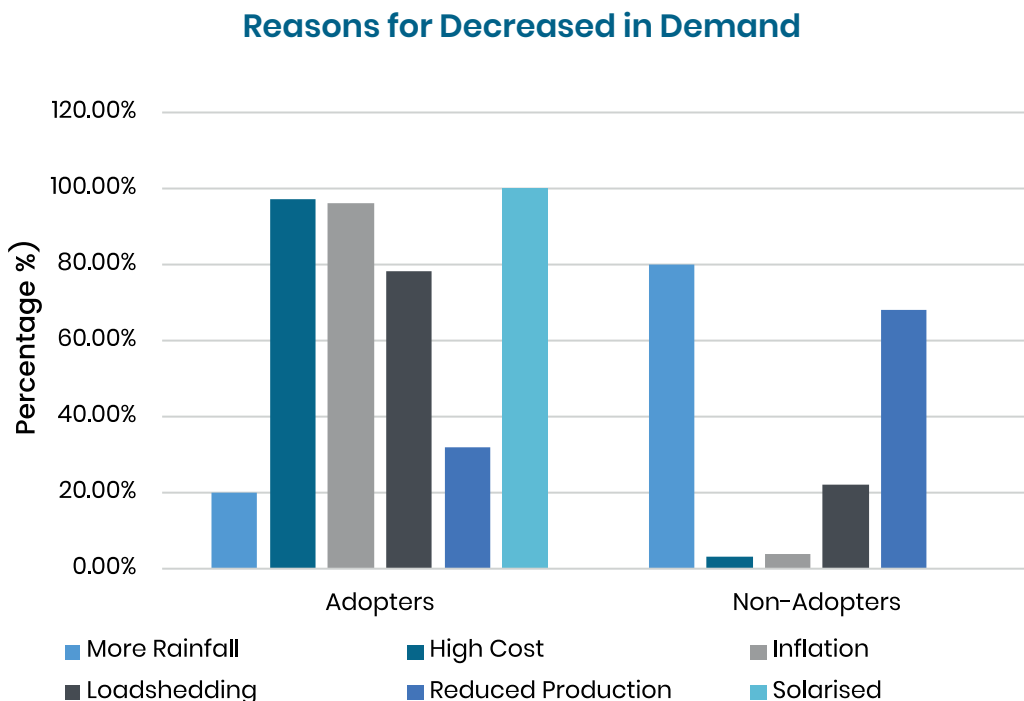


Figure 34: Reasons for decrease in grid demand

For those reporting decreased electricity consumption, solar adopters overwhelmingly cite high electricity costs (98.5 per cent) and inflation (96.4 per cent) as the primary drivers as illustrated in **Figure 34**. Additionally, load shedding (75.3 per cent) and reduced production (32.4 per cent) contributed to lower consumption. Importantly, 100 per cent of adopters indicated a reduced dependency on grid electricity or increased use of solar power, emphasizing solar adoption as a critical factor in consumption decline.

Among non-adopters, decreases in consumption are more frequently linked to more rainfall (80.8 per cent) and reduced production (67.6 per cent), rather than cost-related or technological factors.

The findings demonstrate that solar adoption significantly reduces grid electricity consumption among agricultural users, primarily driven by the economic pressures of high electricity costs and inflation. Solar power enables greater energy independence, with many adopters decreasing or entirely eliminating their reliance on grid supply. In contrast, non-adopters’ consumption changes are more influenced by environmental factors and production levels, indicating limited technological or economic shifts.

Among agricultural facilities that installed solar systems, the average grid electricity expenditure dropped by roughly 60per cent.

The difference indicates a statistically significant decline, confirming that solar adoption has led to a substantial technical reduction in grid demand within the agriculture sector.

Trends in Decreased Electricity Demand from the Grid Across Income Groups

The reasons for decreased electricity demand from the grid vary notably across agricultural income groups, reflecting different economic and operational dynamics:

- Among the no-expenditure group, decreased demand is largely driven by load shedding (75.3 per cent) and a reduced dependency on the grid or solar adoption (76.5 per cent). This suggests that these households face frequent power interruptions and have shifted significantly toward self-generation or off-grid solutions. Inflation (20.2 per cent) and high cost (16.6 per cent) are also contributing factors, albeit to a lesser extent.
- The lower expenditure group (PKR 1–20,000) shows a very high reliance on less dependency on grid/solar (92.4 per cent) as the primary reason for decreased demand. Other factors such as rainfall, cost, inflation, and load shedding play minimal roles, indicating that this group's reduction is predominantly due to shifting energy sources rather than external economic pressures or weather variations.
- In the lower-middle income group (PKR 20,001–80,000), decreased demand is more influenced by increased rainfall (34.8 per cent) and load shedding (17.5 per cent), alongside a notable reduced dependency on grid or solar (40.3 per cent). Additionally, reduced production (10.8 per cent) and high cost (7.0 per cent) contribute moderately, indicating a mix of environmental and economic reasons behind demand reduction.
- The upper-middle income group (PKR 80,000–130,000) shows a balanced distribution of decreased demand reasons: load shedding (26.7 per cent), less grid dependency or solar adoption (50.7 per cent), and increased rainfall (19.0 per cent) are prominent. Inflation and high cost have relatively lower impacts, suggesting this group manages decreased demand through a combination of technical adaptation and environmental factors.

7.7. Reasons for Increased Grid Demand

The data indicates several key factors driving increased electricity consumption from the grid among both solar adopters and non-adopters in agricultural facilities.

In terms of specific drivers:

- Increased water requirements for agriculture account for 19.9 per cent of increased consumption among adopters, compared to 80.1 per cent among non-adopters. This indicates that irrigation expansion remains a major factor for increased electricity use, particularly for non-adopters who rely solely on grid power.
- Increased crop yield contributes to higher consumption in 15.0 per cent of adopters and 85.0 per cent of non-adopters, reflecting intensified agricultural productivity demanding more power.
- The number of tube-wells or water pumps has risen in 42.0 per cent of adopters and 58.0 per cent of non-adopters, demonstrating expanded infrastructure that drives higher electricity demand.

Notably, no respondents in either group reported an increase in the number of tube-wells alone – without accompanying factors.

7.8. Barriers to Adoption

The analysis of barriers to solar adoption among non-solar users in agriculture reveals significant variation across income groups, highlighting the multifaceted challenges these farmers face as shown in **Figure 35**.

High Cost is the most prominent barrier across all income levels, but its impact varies markedly. Among the upper-middle expenditure group (PKR 80,000–130,000), an overwhelming 97.1 per cent cite cost as a barrier, indicating that despite relatively higher income, affordability remains a critical obstacle. Similarly, the lower-middle group (PKR 20,001–80,000) reports 57.9 per cent facing cost challenges, while the lower expenditure group (PKR 1–20,000) shows a comparatively lower figure of 46.3 per cent. The no-expenditure group reports a high cost barrier at 73.1 per cent, reflecting severe affordability constraints.

Lack of Awareness is a significant barrier particularly for the lower expenditure group (63.7 per cent) and the no-expenditure group (46.2 per cent), suggesting that information gaps and limited exposure to solar technologies hinder adoption among lower-income farmers. This barrier diminishes considerably in higher income groups, with only 2.9 per cent of the upper-middle group citing it.

Limited Access to Financing is another major constraint, especially pronounced in the lower-middle group (66.5 per cent) and the no-expenditure group (50 per cent), indicating difficulties in securing affordable credit or loans to finance solar investments. The upper-middle group (51.7 per cent) and lower expenditure group (35.9 per cent) also report notable financing barriers.

Space and Land Constraints and Regulatory Challenges appear less frequently cited across all income groups, with the highest being 11.9 per cent for space constraints in the lower-middle group and minimal concern for regulatory issues.

Barriers to Solar Adoption

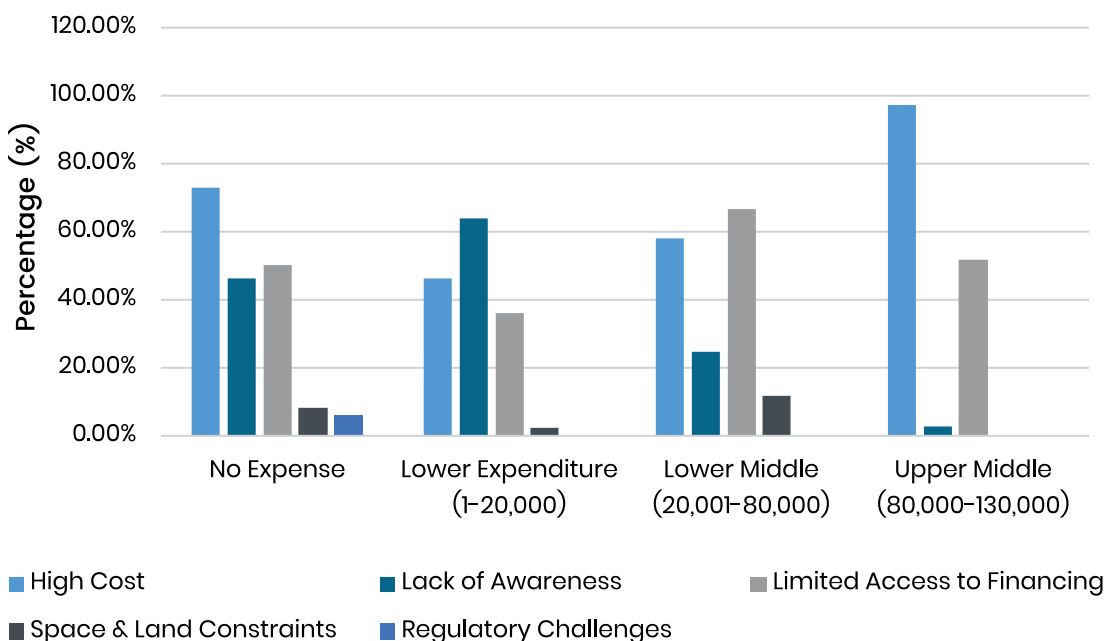


Figure 35: Barriers to adoption in the agricultural sector



**IMPLICATIONS OF
PAKISTAN'S SOLARIZATION
TREND: A UNIFIED
INTERPRETATION**

8. IMPLICATIONS OF PAKISTAN’S SOLARIZATION TREND: A UNIFIED INTERPRETATION

Pakistan’s accelerating shift toward distributed solar- across households, commercial establishments, and industries - is reshaping the country’s electricity system in fundamental ways. The most immediate impact is the transformation of load profiles, with self-generation significantly reducing daytime demand while leaving evening peaks unchanged. This widening gap between midday dips and steep evening ramp-ups has intensified the “duck curve,” complicating system operations, dispatch planning, and demand forecasting for both ISMO and DISCOs.

High solar penetration is also driving technical challenges on distribution feeders, particularly in urban and industrial clusters. As more consumers export excess generation, distribution networks face voltage rise, reverse power flows, increased harmonics, and stress on equipment designed for one-way power flow. These conditions heighten the need for feeder-level hosting capacity assessments, smart inverters, automated voltage control, and stronger protection schemes.

Simultaneously, solar adoption is triggering structural financial pressures on utilities. As residential, commercial, and industrial consumers offset large portions of their daytime consumption - often through non-net-metered (NNM) or off-grid systems- utilities see declining sales and reduced recovery of fixed network costs. This results in cost shifting onto non-solar consumers, erodes DISCO revenues, and amplifies circular debt risks as shown in **Figure 36**. In the residential sector, rising tariffs accelerate this shift even further, encouraging more consumers to defect partially or fully from grid reliance.

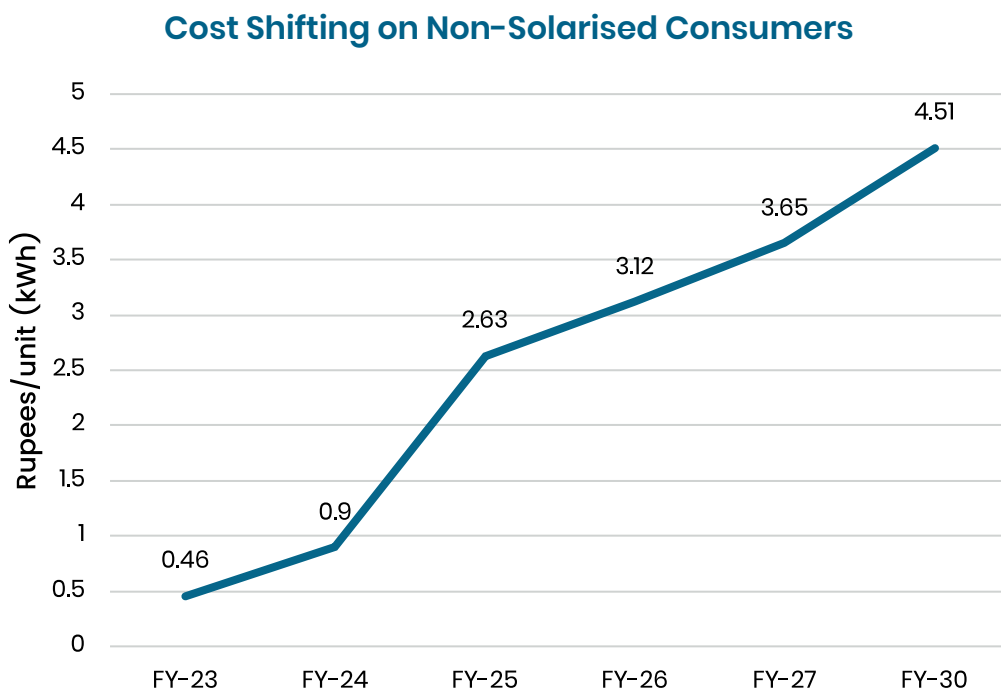


Figure 36: Impact on non-solarised consumers

Industries, once the backbone of productive electricity demand, are increasingly prioritizing self-sufficiency through large-scale solar and battery systems. This is reducing grid-based industrial consumption by nearly 20 per cent in recent years, weakening the revenue base for utilities and undermining assumptions behind market reforms such as CTBCM. As industrial and commercial entities adopt solar paired with storage, grid interaction becomes more limited, flattening load curves and further reducing system visibility and predictability.

Overall, Pakistan’s solarization wave is pushing the grid toward a future where millions of distributed generators operate in parallel with centralized assets. This transition demands modernization of planning, regulation, and system operations—including advanced metering, DERMS, flexible reserves, refined tariff structures, and updated grid codes. Without these reforms, continued growth in distributed solar risks exacerbating technical instability, financial imbalances, and planning uncertainty across the power sector, even as it delivers cleaner and more affordable energy to consumers.

Reduced Electricity Expenditure likely reducing the overall grid revenue	
Consumer Category	Detailed Empirical Findings (Savings Outcomes indicating decreased expenditure on electricity from grid)
Residential – Urban	<ul style="list-style-type: none"> • Around 2 per cent of adopters experience negative savings (higher expenditure after solar). • A significant 33 per cent report zero savings, indicating limited financial benefit for one-third of urban households. • A large share falls in the 50–100 per cent savings range, reflecting strong gains for well-sized and well-utilized systems. • High variability suggests uneven system performance and differences in consumption patterns.
Residential – Rural	<ul style="list-style-type: none"> • Very low negative savings (0.3 per cent), indicating little downside risk. • However, 64.5 per cent show zero savings, largely because many rural households have low baseline grid consumption, making solar less financially impactful. • Among households with higher loads, 50–100 per cent savings are substantial, reflecting strong benefits for productive or higher-consuming rural users.
Commercial – Urban	<ul style="list-style-type: none"> • 3.4 per cent negative savings, indicating minimal downside. • 40 per cent of businesses report zero savings, suggesting misalignment between system size and consumption or tariff structures. • Most urban commercial users fall in the 25–75 per cent savings range, indicating moderate yet meaningful financial relief through solar.

<p>Commercial – Rural</p>	<ul style="list-style-type: none"> • 45 per cent zero savings, slightly higher than urban areas. • Rural commercial adopters see stronger mid-to-high-range savings, with 30–100 per cent savings categories better represented than in urban settings. • Some rural firms show significant benefit, especially those with day-time loads aligning with solar generation.
<p>Industrial – Urban</p>	<ul style="list-style-type: none"> • Extremely low negative savings (0.8 per cent). • However, 57 per cent of urban industrial adopters report zero savings, the highest among industries. • Only a minority achieve high (75–100 per cent) savings, reflecting constraints such as limited rooftop space or high evening demand.
<p>Industrial – Rural</p>	<ul style="list-style-type: none"> • Only 23 per cent report zero savings, far lower than urban industrial users. • A remarkable 57.5 per cent achieve 75–100 per cent savings, the highest of any category across the entire dataset. • This shows that rural industries are extracting maximum financial value from solar, likely due to high day-time loads and system scalability.



9. CONCLUSION

Pakistan's transition toward distributed solar generation is reshaping the relationship between consumers and the grid. Solar adoption serves as a universal indicator of decentralization trends, while macroeconomic conditions and ongoing grid reliability issues also contribute to reduced grid demand. In sectors like agriculture, adoption is truly bottom-up, driven directly by local needs and self-reliance, whereas wealthier groups across other sectors benefit disproportionately, highlighting inequities in access and benefits.

When government support or reliable supply is lacking, consumers increasingly take power into their own hands, accelerating decentralized energy adoption. This results in increasing revenue erosion for the power suppliers. While solar has lowered energy costs and provided greater autonomy, it has also created revenue pressures for DISCOs and obscured the true scale of national electricity consumption.

The wide variation in savings across consumer categories underscores the need for sector-specific policies, improved system sizing practices, and tariff reforms that reflect a rapidly decentralizing energy system. Looking ahead, a battery revolution is on the horizon, and proactive planning for energy storage management will be critical to ensure that its growth complements the pace of solarization as well as the electricity demand from grid rather than creating new challenges. Effective planning and regulatory adaptation will be essential to balance consumer benefits, grid stability, and the long-term financial health of the power sector.



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