The Distributed Divide

How Solar Expansion Affects Non-Adopting Consumers and Utility Economics

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The name "Arzachel" honors the esteemed Islamic Golden Age astronomer and scientist al-Zarqālī (Latinized as Arzachel), whose brilliance in astronomy inspires our commitment to insight and excellence. Just as al-Zarqālī pioneered transformative discoveries in his time, we at Arzachel aim to deliver forward-thinking solutions that shape the future of energy. Bridging the expertise of the past with modern technologies, our work strives to uphold the legacy of innovation, providing impactful, effective consultancy to our clients and partners.

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Executive Summary

The increasing integration of distributed generation (DG), particularly photovoltaic (PV) solar, can either raise or lower costs in the distribution network. Tariff design plays a crucial role in allocating these costs to customers who own and operate DG resources. However, current tariff structures often either exempt DG units from paying distribution tariffs or apply tariffs that were designed for traditional grid models without DG, commonly referred to as load-based pricing. This can result in either partial recovery of the allowed distribution company revenue or create cross-subsidies between customers.

This report examines the impact of pricing mechanisms, such as net metering and pure volumetric tariffs, in the context of growing DG adoption. The analysis demonstrates significant cross-subsidies and cost shifting from consumers to prosumers, with the degree of subsidy varying based on the amount of DG connected to the grid and the characteristics of the network. Notably, low-density grids tend to experience a higher rate of cross-subsidy.

This report contributes to the net metering literature by providing a quantitative assessment of these cost shifting to the consumers does not have solar. It compares fixed cost payments avoided by the solar Behind the Meter and Net metered Consumers. Furthermore, the report offers policy recommendations, proposing a cost-reflective, volumetric tariff structure that allocates both load-driven and DG-driven network costs equitably to loads and DG units based on cost causality principles.

The net-metering experience in Pakistan

Pakistan established net-metering regulations in 2015 under the National Electric Power Regulatory Authority's Distributed Generation and Net Metering Regulations to encourage the adoption of distributed renewable energy. These regulations enable consumers to produce renewable electricity on-site, reducing grid dependence and allowing them to sell surplus power back to distribution companies (DISCOs). Consumers with net-metering systems benefit from monthly energy credits and receive quarterly commercial credits for electricity exported to the grid.

With the global decline in solar prices and rising electricity tariffs, rooftop and behind-the-meter solar installations have accelerated, especially in the past year. Currently, around 141,800 net-metering consumers in Pakistan's DISCO networks contribute roughly 2,200 MW of solar generation capacity. Behind-the-meter installations, particularly in large industrial sectors, are also growing rapidly, with limited data available from utilities and regulators. Bloomberg reports that in the first eight months of this year alone, Pakistan imported 13 GW of solar panels, potentially setting the stage for a significant shift in grid demand patterns (the "duck curve") due to solar penetration. This rapid adoption has begun to introduce grid management challenges, such as voltage rises and reverse power flows, especially in affluent areas with high solar penetration.

The costs of distribution, transmission, and ancillary services are increasingly borne by non-net-metering DISCO customers due to Pakistan's tariff adjustment mechanisms. This creates a cross-subsidy or cost shifting effect that is particularly challenging given the protections in place for low-income consumers, who are shielded from tariff increases.

Key Findings

Following are the key findings of our tariff impact analysis:

- Net-metered distributed solar systems provide significant cost savings to prosumers.
- Behind-the-meter installations are also impacting energy equity.
- Prosumers who install solar systems according to their sanctioned load can reduce their electricity bills to near zero; however, those who install systems 1.5 times their sanctioned load may even receive negative bills.
- Energy sales and demand from the grid have decreased by approximately 8% to 10%, primarily during daylight hours, indicating that this reduction is due to the increased penetration of solar energy.
- In a typical scenario, a 10 kW net-metering system allows prosumers to avoid the grid's fixed cost of 20 PKR per unit by relying less on grid electricity.
- The fixed costs avoided by behind-the-meter installations vary with solar capacity penetration, averaging around 7 PKR per unit.
- In FY 2023-24, approximately PKR 200 billion in grid fixed costs were shifted to non-solar consumers, leading to a tariff increase of around PKR 2 per kWh for these users.
- With substantial solar imports this year, it is anticipated that grid demand will decline by more than 10%, with estimates suggesting a 15% reduction; however, the exact numbers for behind-the-meter installations remain unclear. This shift is expected to result in a 17% increase in the base tariff.
- For current fiscal year, a 5% reduction in grid demand through solar integration will result in a shift of PKR 131 billion in costs to non-solar consumers annually. Doubling this reduction to 10% will shift an even larger cost of PKR 261 billion to consumers without solar energy.
- High distributed solar generation poses challenges for the grid, such as voltage instability, reverse power flows, and increased demand for ancillary services like frequency regulation and reactive power support. These changes require infrastructure adjustments and careful demand balancing to maintain grid stability and efficiency.
- If solar penetration and installation rates continue at their current pace, it is predicted that the Pakistan grid will experience a "duck curve" within the next two years.
- The grid will face significant challenges in maintaining energy stability during the coming winter, especially on clear days, due to insufficient flexible resources to manage the high levels of distributed solar generation.

Recommendations

At the moment, it is essential to address the economic burdens that net metering programs may impose on Distribution Companies (DISCOs) and non-participating electricity customers. The existing electricity balancing mechanism does not adequately account for the cost differences between electricity imports and exports for net-metered distributed generation (DG) customers, benefiting them with a premium price for their generation. This premium could either be subsidized by DISCOs or passed on to non-participating customers through increased tariffs. Furthermore, as DG penetration rises, it presents technical challenges for grid operations, necessitating infrastructure investments for grid strengthening, which carries significant financial implications for DISCOs. Therefore, developing policies that ensure a fair distribution of costs associated with net metering is critical to balance the interests of both participating and non-participating customers.

Following is the summary of recommendations:

Recommendation	Description	Key Actions
1. Introduction of Feed-In-Tariffs	Implement differentiated FiTs to promote solar and battery storage usage.	Daytime FiT: ~12 PKR/kWh
		Nighttime FiT: ~25 PKR/kWh
		Transform Net Metering to Net Billing
2. Shift to Time-of-Use (TOU) Tariffs	Transition from slab-based tariffs to TOU tariffs for all consumers.	Remove slab tariffs
		Provide alternative subsidies for low-income groups
3. Revaluation of TOU Rates	Adjust TOU rates to encourage off-peak consumption and ease peak demand.	Adjust TOU rates to reflect nighttime peak demand around 11 PM to 12 AM
4. Demand Charges and Minimum Monthly Bills	Introduce demand charges and a minimum monthly bill for net-metering users.	Non-Net Metered Residential: 500 PKR/kW/Month
		Net Metered Residential: 1,000 PKR/kW/Month
		Non-Net Metered Industrial: 1,250 PKR/kW/Month
		Net Metered Industrial: 2,500 PKR/kW/Month
5. Special Incentives for BESS Integration	Support BESS deployment, especially in high solar areas, to improve grid stability.	Offer financing schemes for BESS in solar-heavy areas
		Utility-led BESS deployment
6. Creation of Ancillary Service Market	Establish a market for ancillary services, including frequency and voltage support.	Set up an ancillary services market
		Allow BESS and DER to participate in this market
7. Locational Marginal Pricing (LMP)	Optimize grid usage by introducing LMP to reduce congestion and transmission losses.	Implement LMP to strategically place distributed generation and improve grid efficiency
8. Incentives for Data Centers and Industrial Parks	Offer fixed-rate electricity to data centers and industrial parks to utilize surplus southern grid power.	Fixed rate ~25 PKR/kWh for 10 years in areas like Port Qasim, Dhabeji, and Nooriabad
9. Revision in Distribution Code	Update the code to incorporate Distributed Energy Resources (DER) and bi-directional power flow management.	Integrate DER guidelines
		Implement control mechanisms for oversupply and curtailment
10. Distributional Equity Assessment (DEA)	Conduct DEA to ensure equitable cost distribution and protect vulnerable consumers.	Identify financial burdens on non-participating consumers
		Develop fair tariff structures

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List of Abbreviations

€	Euro
ACC	Avoided Cost Calculator
AEDB	Alternative Energy Development Board
AMI	Advanced Metering Infrastructure
AREP	Alternative & Renewable Energy Policy
ARERA	Italian Regulatory Authority for Energy, Networks and Environment
ASEAN	Association of Southeast Asian Nations
BESS	Battery & Energy Storage System
BTM	Behind the Meter
CAGR	Compound Annual Growth Rate
CCP	Common Coupling Point
CEC	Collective Self-Consumption
CfD	Contract for Difference
CHP	Combine Heat & Power
CoD	Commercial Operations Date
CPI	Consumer Price Index
CPP	Capacity Purchase Price
CPPA-G	Central Power Purchasing Authority Guarantee Limited
CPUC	California Public Utilities Commission
DER	Distributed Energy Resources
DES	Decentralized Energy Systems
DG	Distributed Generation
DISCO	Distribution Company
DLR	Dynamic Line Rating
DNSP	Distribution Network Service Provider
EEG	German Renewable Energy Sources Act
EPP	Energy Purchase Price
ESCOs	Energy Supply Company
EV	Electric Vehicles
EVN	Vietnam Electricity
FESCO	Faisalabad Electric Supply Company
FiT	Feed in Tariff
FY	Fiscal Year
GEPCO	Gujranwala Electric Supply Company
GHI	Global Horizontal Irradiation
GSE	Gestore dei Servizi Energetici
GWh	Giga-Watt Hours
HESCO	Hyderabad Electric Supply Company
HFO/RFO	Heavy Furnace Oil
HSD	High Speed Diesel
Hz	Hertz
IEEFA	Institute for Energy Economics and Financial Analysis
IESCO	Islamabad Electric Supply Company
IGCEP	Indicative Generation Capacity Expansion Plan
IOU	Investor-Owned Utilities
KWh	Kilo-Watt Hours
KWp	Kilo-Watt Peak
LC	Letters of Credit
LCOE	Levelized Cost of Energy
LESCO	Lahore Electric Supply Company

LMP	Locational Marginal Pricing
MDI	Maximum Demand Indicator
MEPCO	Multan Electric Power Company
MoIT	Ministry of Industry & Trade
MWh	Mega-Watt Hours
NAEPP	National Average Energy Purchase Price
NAP	National Action Plan
NAPPP	National Average Power Purchase Price
NBT	Net-Billing Tariff
NCCP	National Climate Change Policy
NEM	Net Energy Metering
NEP	National Electricity Policy
NEPRA	National Electric Power regulatory Authority
NLDC	National Load Dispatch Centre
PDP	National power Development Plan
PESCO	Peshawar Electric Supply Company
PG&E	Pacific Gas and Electric
PKR	Pakistani Rupee
PPA	Power Purchase Agreement
PPIB	Private Power & Infrastructure Board
PV	Photo Voltaic
QTA/QTR	Quarterly Tariff Adjustment/Revision
RECs	Renewable Energy Communities
RECs	Renewable Energy Certificates
RES	Renewable Energy Sources
RLNG	Regasified Liquified Natural Gas
SAPN	South Australia Power Networks
SBLC	Stand by Letter of Credit
SCE	Southern California Edison
SEPCO	Sukkur Electric Supply Company
SG&E	San Diego Gas & Electric
SO	System Operator
T&D	Transmission & Distribution
TESCO	Tribal Electric Supply Company
TOU	Time of Use
TWh	Tera-Watt Hours
USD	United States Dollar
VND	Vietnamese đồng
WREGIS	Western Renewable Energy Generation Information System

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1 Introduction

Renewable energy sources are gradually gaining momentum in Pakistan's electricity system. In the early 2000s, solar and wind energy barely registered within the country's energy landscape, contributing less than 1% to the national electricity generation. However, by 2024, renewable sources have started making noticeable inroads, with solar and wind generation playing an increasingly important role in the energy mix as shown in Figure 1. This shift is part of a larger trend aiming to reduce reliance on fossil fuels and increase energy security in Pakistan, aligning with the country's renewable energy targets and commitments to sustainable development.

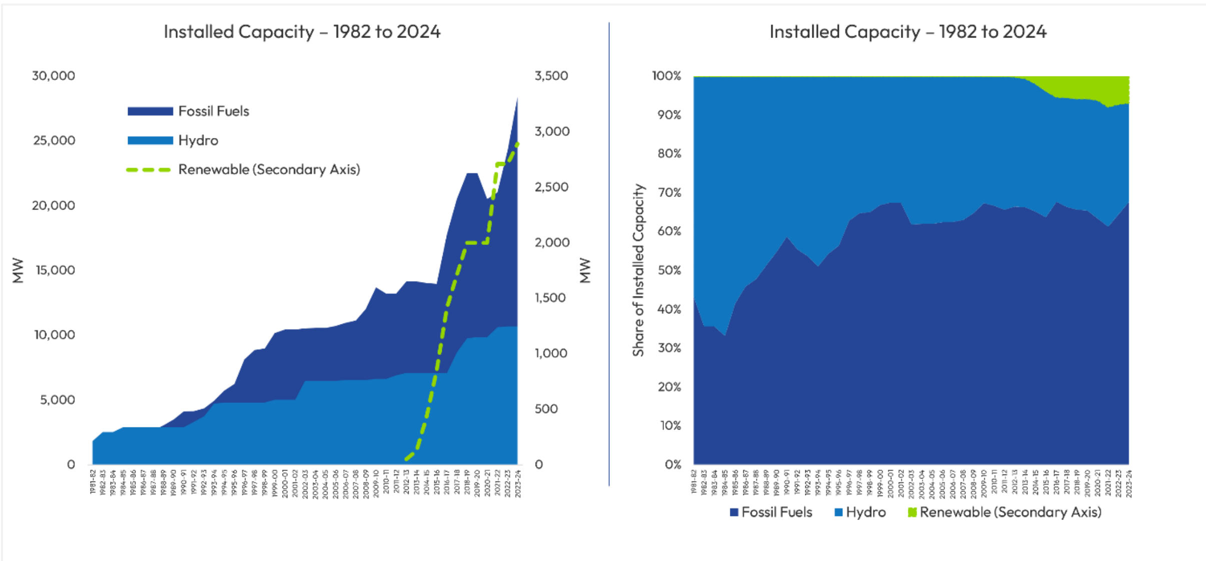


Figure 1: Renewable Injection in Pakistan

Pakistan's renewable energy sector has seen significant growth in recent years. As of 2023, renewables contribute around 7-8% to the national grid, with wind and solar capacity reaching approximately 1,800 MW and 2,000 MW, respectively. Additionally, hydropower remains the largest renewable source, contributing nearly 10,000 MW to the energy mix, which accounts for about 30% of Pakistan's total installed capacity. The country has set an ambitious target to achieve 30% of its energy from renewables (excluding large hydropower) by 2030, which translates to an estimated 20,000 MW from solar and wind alone. These developments, supported by policy reforms like the Alternative and Renewable Energy (ARE) Policy 2019, highlight Pakistan's commitment to reducing its dependency on imported fossil fuels and enhancing energy sustainability.

1.1. Purpose of the Study

The purpose of this study is to comprehensively evaluate the multifaceted impacts of solar distributed generation penetration either adding through net metering or behind the meter on the electricity landscape in Pakistan.

Tariff Shifts for Non-Net Metering Users:

The Study aims to analyze how the implementation of solar net metering affects tariff structures for consumers not participating in the program. This analysis will consider the implications for cost distribution and equity among different consumer classes, ensuring a comprehensive understanding of the broader economic impacts.

Financial Impact on Utilities:

Another objective is to assess the financial implications of solar distributed generation for utility companies, particularly focusing on potential revenue losses and shifts in operational costs. Understanding these financial dynamics is crucial for evaluating the long-term sustainability of utility operations in the context of increasing consumer-generated electricity.

Policy Gaps:

Identifying existing gaps in the current electricity tariff and renewables distributed generation and net metering policies is another key focus of the study. This will involve assessing whether these gaps hinder the further adoption of solar technologies or create disproportionate financial burdens on different stakeholders, which is essential for future policy recommendations.

Incentives and Subsidies:

The research will review the impact of government incentives, tariff shifts, and cross subsidies on the adoption rates of solar net metering. Understanding the role of these financial mechanisms is vital for promoting renewable energy initiatives effectively.

Grid Modernization:

Finally, the research will explore the necessity for grid modernization to support the integration of distributed solar generation. This includes evaluating the adoption of smart meters and advanced inverter technologies and Battery Energy Storage System - BESS, which are critical for enhancing grid resilience and efficiency.

1.2. Concept of Net Metering

Net metering serves as an incentivizing program for distributed generation, commonly utilizing renewable energy sources. Within the framework of net metering, a consumer has the opportunity to install an on-site renewable energy power plant primarily aimed at reducing their reliance on the grid. Simultaneously, the consumer gains permission to interconnect with the grid and is permitted to supply any excess energy units generated by their installation to the electricity grid. These surplus units are meticulously recorded and subsequently deducted from the total units consumed from the grid, a process known as "netting-off." Through this mechanism, net metering effectively encourages consumers to invest in decentralized renewable energy systems.

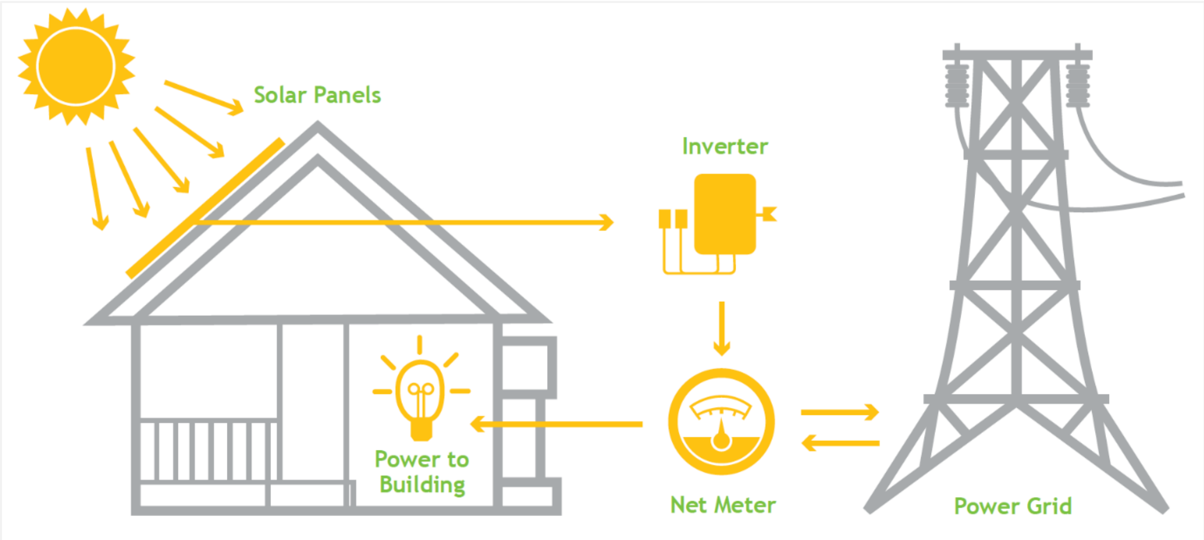


Figure 2: Concept of Net Metering

1.3. Concept of Behind the Meter (BTM)

There are two main types of solar installations: On-Grid and Off-Grid. Off-Grid systems operate independently and do not interact with or use grid for stability purpose, so they remain outside the scope of this report. Within On-Grid systems, however, there are two key configurations: Net Metering and *Behind-the-Meter installations*. In Net Metering, which we previously discussed, consumers generate electricity from their solar installations and can export excess energy back to the grid. Behind-the-Meter installations, on the other hand, connect to the grid without informing the utility and are designed to avoid exporting any surplus power. Consumers using Behind-the-Meter setups rely on solar for daytime self-generation while using the grid to stabilize their power supply, drawing on grid resources for frequency, voltage control, and reactive power support to ensure reliable operation. This configuration allows them to avoid costs during daylight hours but still benefit from grid stability and ancillary services for seamless power delivery.

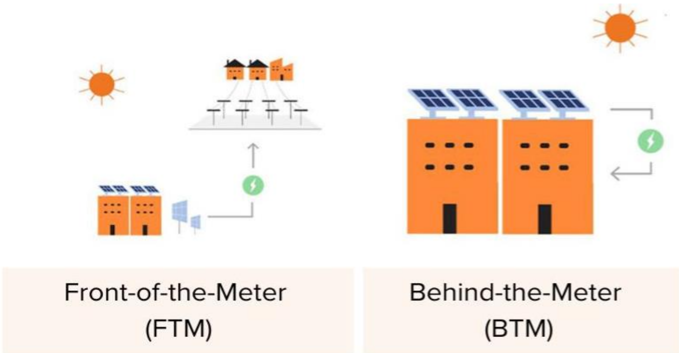


Figure 3: Behind the Meter

1.4. Setting the theme

Grid demand has been steadily decreasing as distributed solar energy, supported by net metering and behind-the-meter systems, continues to offset daytime energy consumption. The graph below illustrates this trend: while overall demand has remained relatively stable, energy sales have declined as shown in Figure 4 , underscoring the increasing role of distributed solar generation in reducing dependence on the grid.

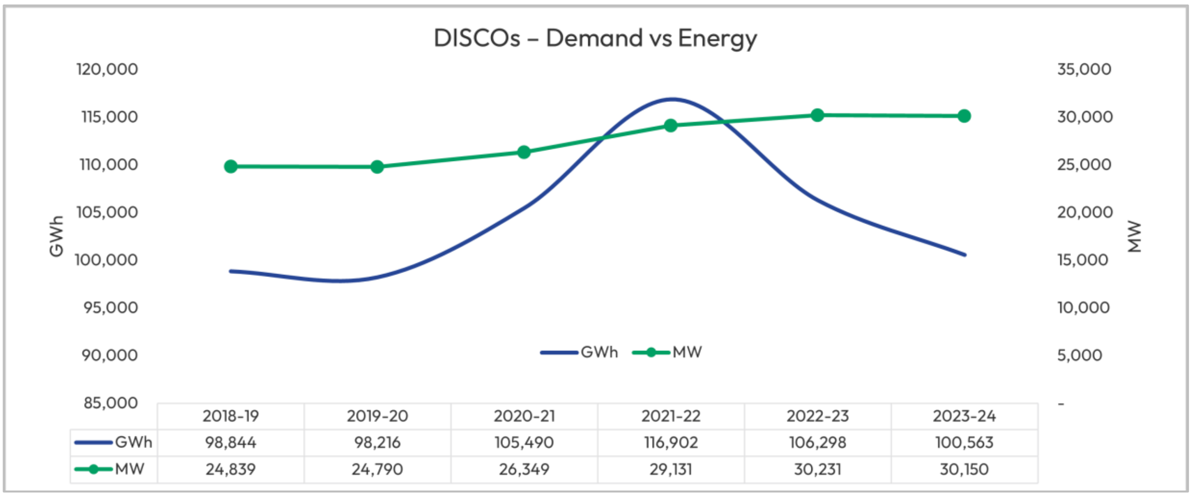


Figure 4: DISCOs Demand vs Energy

1.4.1. Same Day, Different Year

To analyze the impact of solar energy on grid demand patterns, June 30th—a typical clear summer day—was selected from the past three years for a Distribution Company (DISCO) from Punjab, Pakistan. The figure below highlights how rising distributed solar generation has reshaped daytime demand profiles, revealing a pronounced effect where grid reliance is significantly reduced during peak sunlight hours. This shift indicates that as solar injections increase, they not only offset a portion of daytime grid demand but also alter the timing and magnitude of peak load periods, leading to a more variable and complex demand profile for grid operators to manage.

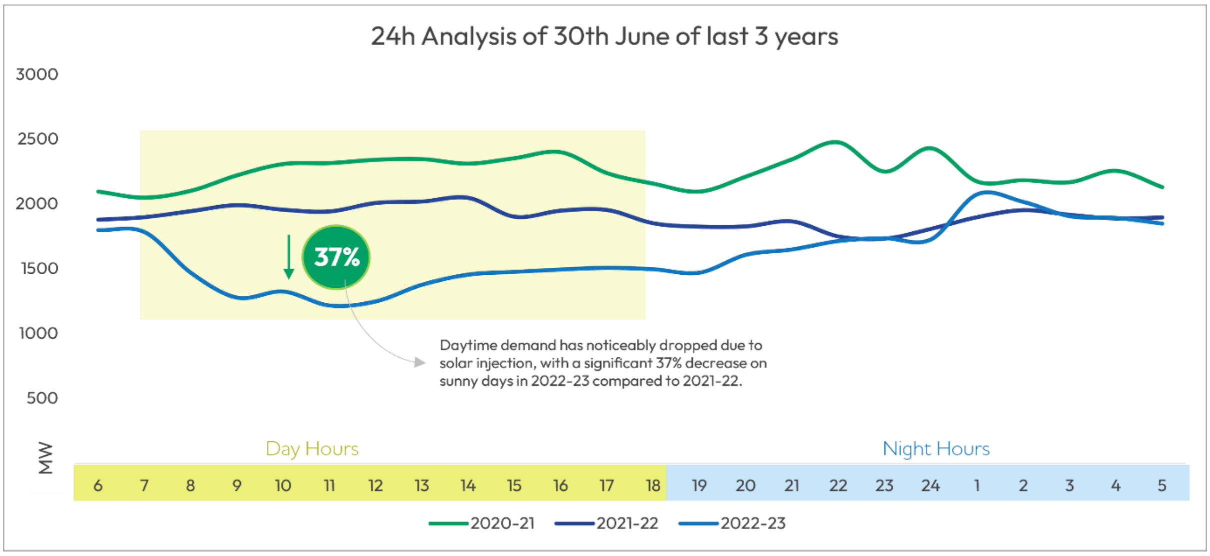


Figure 5: 24 Hour Analysis of a single day

1.4.2. The Solar Effect:

The graph below presents the sales data at the 11kV level for five key DISCOs—LESCO, GEPCO, FESCO, IESCO, and MEPCO—over a seven-year period from 2017-18 to 2023-24. Displayed in gigawatt-hours (GWh), this data tracks each DISCO's sales trajectory, with peak sales observed in the 2021-22 period, marking the highest electricity consumption before distributed solar energy significantly impacted the grid.

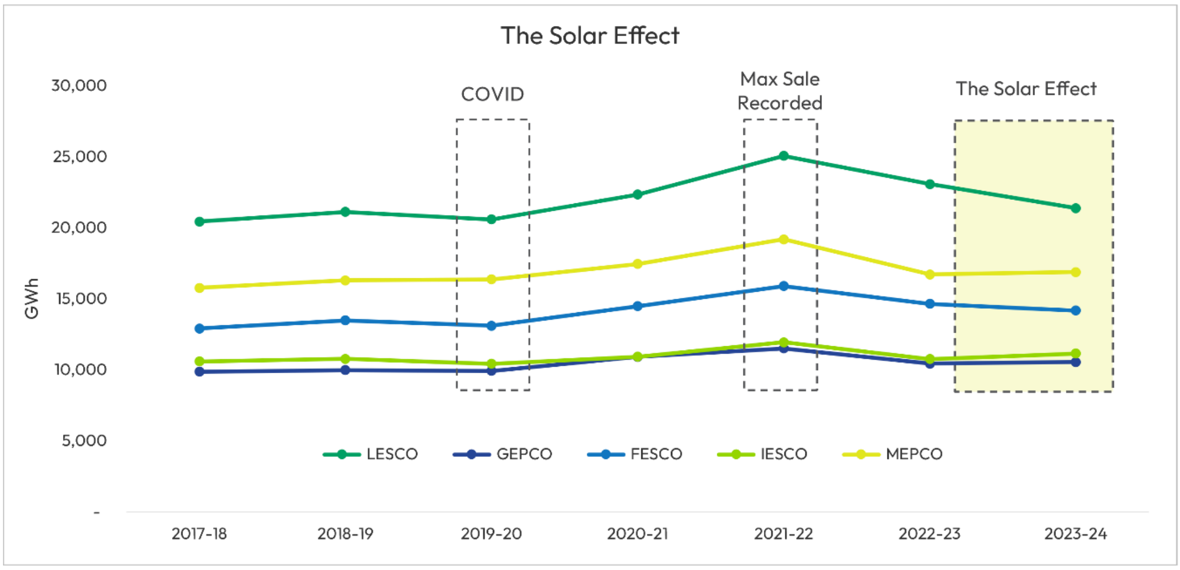
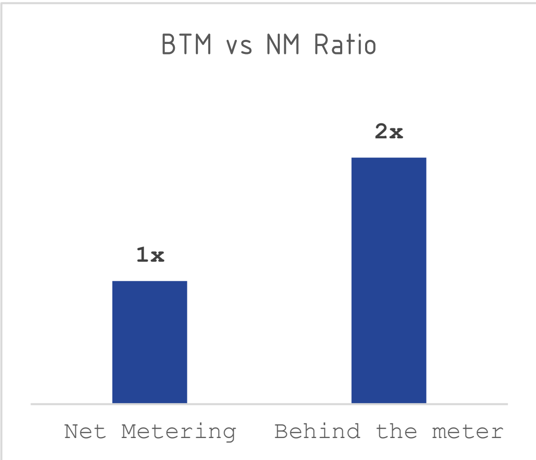


Figure 6: The Solar Effect

Since 2022-23, all DISCOs in Pakistan have witnessed a marked decline in electricity sales. While economic instability and high inflation temporarily suppressed demand, the trend continued in FY 2023-24, even as Pakistan's economy showed early signs of recovery and certain macroeconomic indicators improved. This persistent decline, despite a stabilizing economy, points to distributed solar energy as a major contributing factor.

This phenomenon, referred to as "The Solar Effect," underscores the growing influence of distributed solar on grid demand, particularly during peak sunlight hours when solar output is highest. The trend is especially pronounced in regions managed by DISCOs such as LESCO, MEPCO, and FESCO, where solar adoption and net metering are increasingly offsetting grid consumption. Consequently, this shift is not only reducing grid electricity sales but also transforming traditional demand profiles, presenting new operational challenges and opportunities for grid management.



1.4.3. The Daytime Decline:

The data in the graph below reveals a distinct decline in daytime demand across selected months of 2024 compared to 2023, despite improved economic conditions. This reduction in daytime demand aligns closely with the growth in solar generation, which reaches its peak during daylight hours. Notably, while daytime demand on the grid has decreased, overall electricity demand has held steady, underscoring the impact of solar energy in offsetting grid consumption during peak sunlight periods. This trend emphasizes the role of distributed solar in reshaping demand profiles, reducing grid reliance specifically during the day, and highlighting a shift in how electricity demand is being met across different hours.

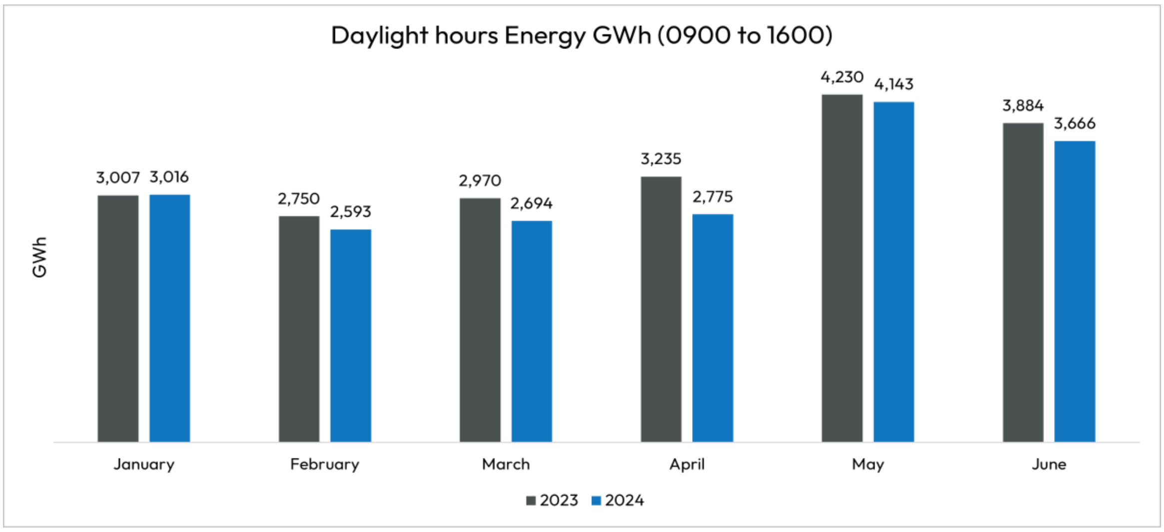


Figure 7: Daytime Decline

The comparison of monthly energy consumption data between FY 18-19 and FY 23-24 reveals a distinct decline in daytime energy use for May, June, and July in FY 23-24, despite an increase in total daily energy consumption. This trend, visualized in the graph below, indicates a shift in energy usage patterns, likely influenced by the uptake of distributed solar generation. The data highlights that while overall demand has grown, solar energy is increasingly reducing the need for grid-supplied power during daylight hours, effectively reshaping the demand profile and offsetting a significant portion of daytime grid usage.

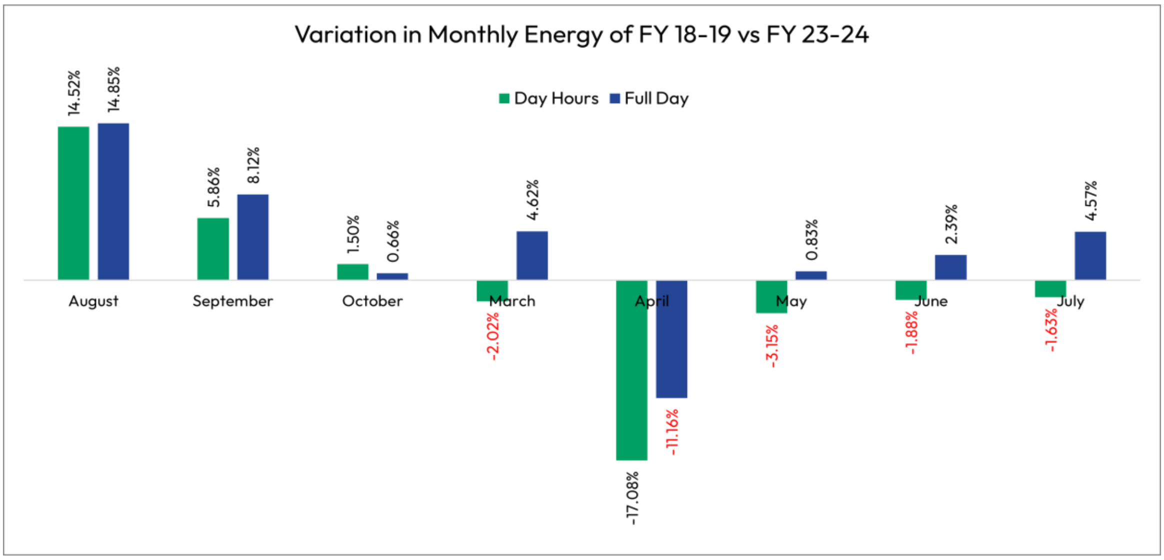
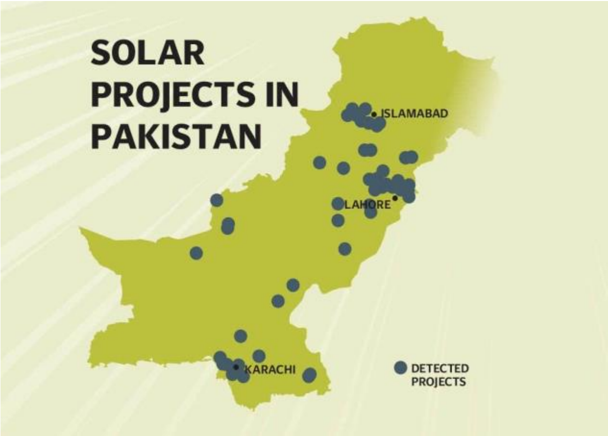


Figure 8: Variation in Monthly Energy

2

Background

The National Electric Regulatory Authority (NEPRA) announced the official Distributed Generation and Net Metering Regulations on September 1st, 2015. As per these regulations, any customer of the electric grid (three-phase connections) can avail the possibility of Net Metering for small-scale renewable energy installations.



The country is set to become the third-largest importer of Chinese solar equipment and the sixth-largest solar market globally. The solar energy boom in Pakistan is fueled by soaring power prices, declining solar costs, and growing demand, leading to an impressive import of 13 gigawatts of solar modules in the first half of 2023. BloombergNEF analyst Jenny Chase highlights that Pakistan's market has substantial growth potential, predicting the addition of 10 to 15 gigawatts of solar capacity in 2024, primarily in the residential.

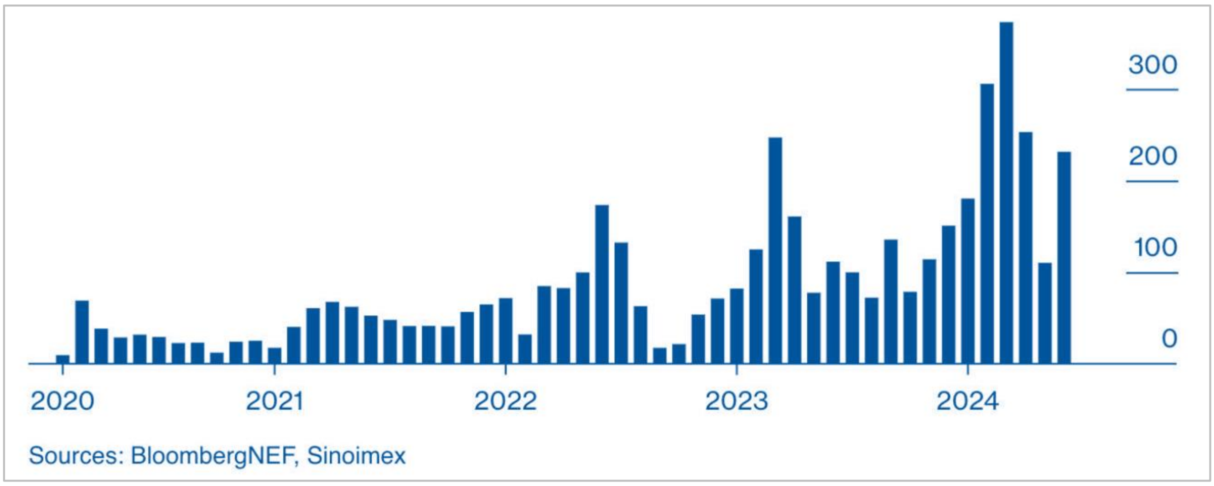


Figure 9: BloombergNEF Solar Equipment Import data

Despite the rapid growth, challenges remain. Issues such as transmission and distribution bottlenecks and losses, lack of clear policies, and intermittent solar generation can hinder the effectiveness of clean energy distribution nationwide. Nevertheless, Pakistan's abundant solar irradiance and reduction of solar and battery storage costs, present considerable opportunities for micro- and mini-grids to electrify rural communities. The government aims to generate 30% of its power from renewable sources by 2030, with recent developments in utility-scale projects illustrating the increasing interest in solar energy. The total installed solar capacity in Pakistan was reported at 1,244 megawatts as of 2023, indicating a 17% increase from 2021.

2.1. Current Status and Adaptation

Solar energy and net metering have gained significant traction in Pakistan, spurred by government initiatives, policy support, and rising consumer interest in alternative energy sources. As of recent years, solar capacity in Pakistan has expanded considerably, with over 2,200 MW of solar installations contributing to the national grid.

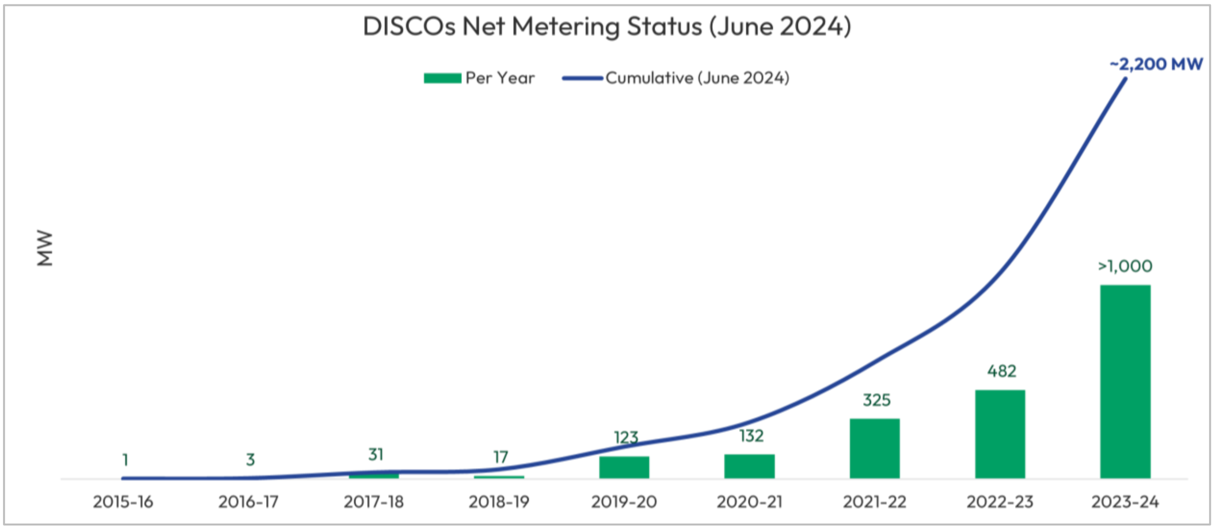


Figure 10: DISCOs Net Metering Status

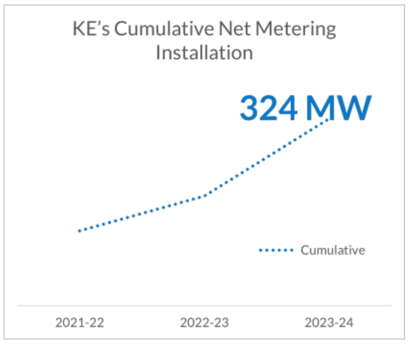


Figure 11: K-Electric Net Metering Status

Net metering, introduced by the National Electric Power Regulatory Authority (NEPRA) in 2015, has been instrumental in promoting small-scale solar adoption. By allowing consumers to feed surplus solar energy back into the grid in exchange for credits, net metering has become popular among residential, commercial, and industrial users seeking to reduce their electricity bills and reliance on the grid. As of June 2024, over 142,000 net-metering connections have been issued, reflecting growing interest across various sectors. Distribution companies (DISCOs) are experiencing reduced daytime demand due to this trend, with solar installations offsetting a significant portion of peak grid usage, especially in urban centers like Lahore and

Islamabad. K-Electric has also experienced similar impacts, with a notable reduction in daytime demand in Karachi as solar adoption increases.

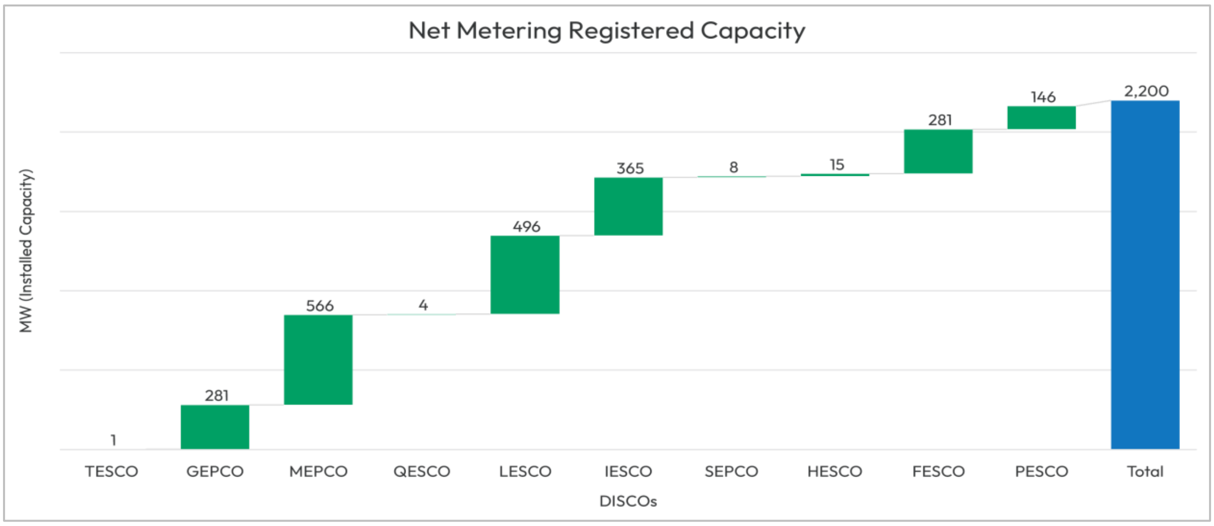


Figure 12: Net Metering Registered Capacity

2.2. Regional Insights

Pakistan has a total of 157,481 net metering consumers across various Distribution Companies (DISCOs) and K-Electric. Among the DISCOs, LESCO (34,516), MEPCO (34,187), and IESCO (34,162) lead with the highest numbers of net metering consumers, reflecting a strong preference for solar power in these regions. FESCO and GEPCO also show substantial adoption, with 17,122 and 11,242 consumers respectively, while K-Electric has 15,604 net metering consumers, indicating growing interest in renewable energy in Karachi. In contrast, regions served by TESCO, SEPCO, HESCO, and QESCO have fewer net metering consumers, likely due to variations in infrastructure and awareness. This national total (including KE) of 157,481 net metering consumers highlights Pakistan's shift towards sustainable energy solutions, supporting both environmental goals and energy self-sufficiency.

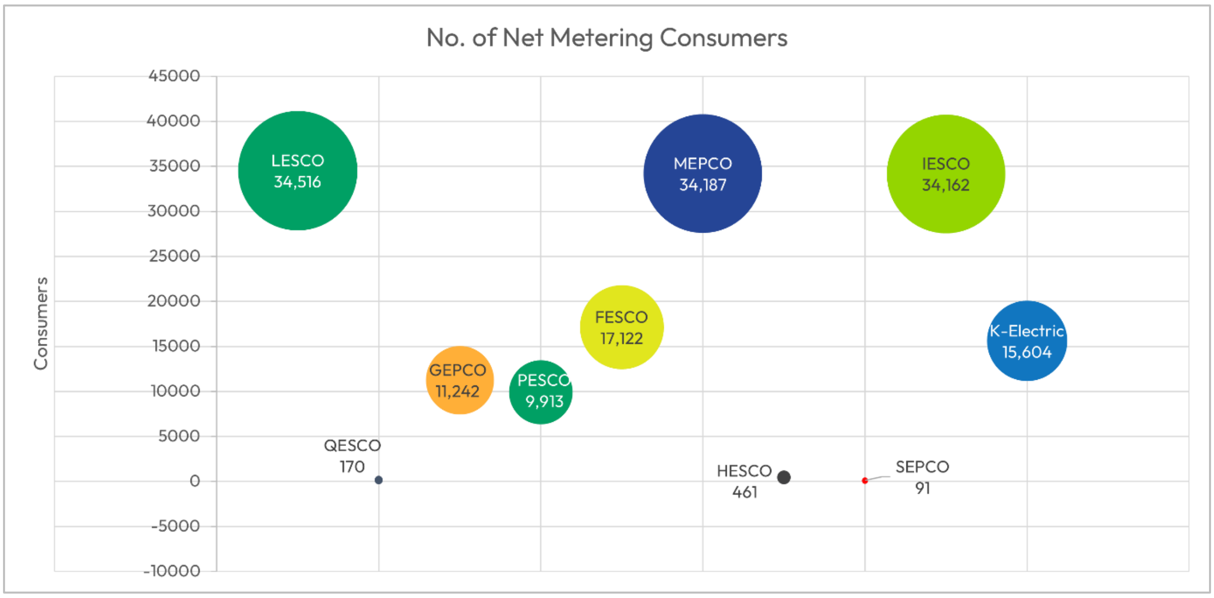


Figure 13: No. of Net Metering Consumers

In contrast, some DISCOs have significantly fewer net metering connections, such as TESCO, SEPCO, and HESCO, collectively accounting for only a fraction of the total. This disparity suggests that regions served by larger DISCOs are seeing faster adoption of solar technology, likely due to greater awareness, accessibility, and financial capacity among consumers in these areas.

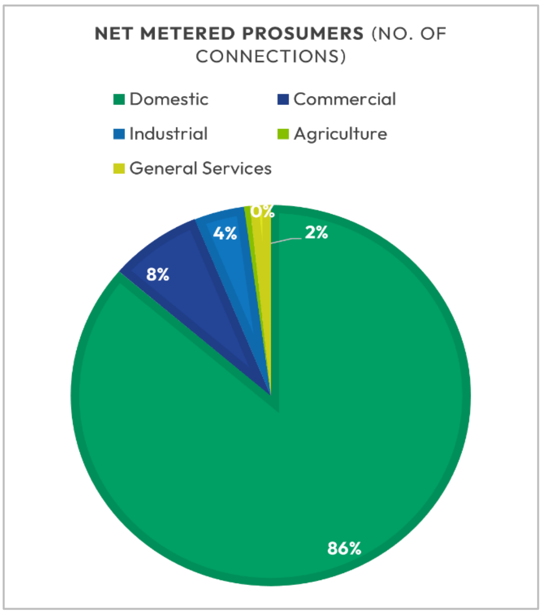


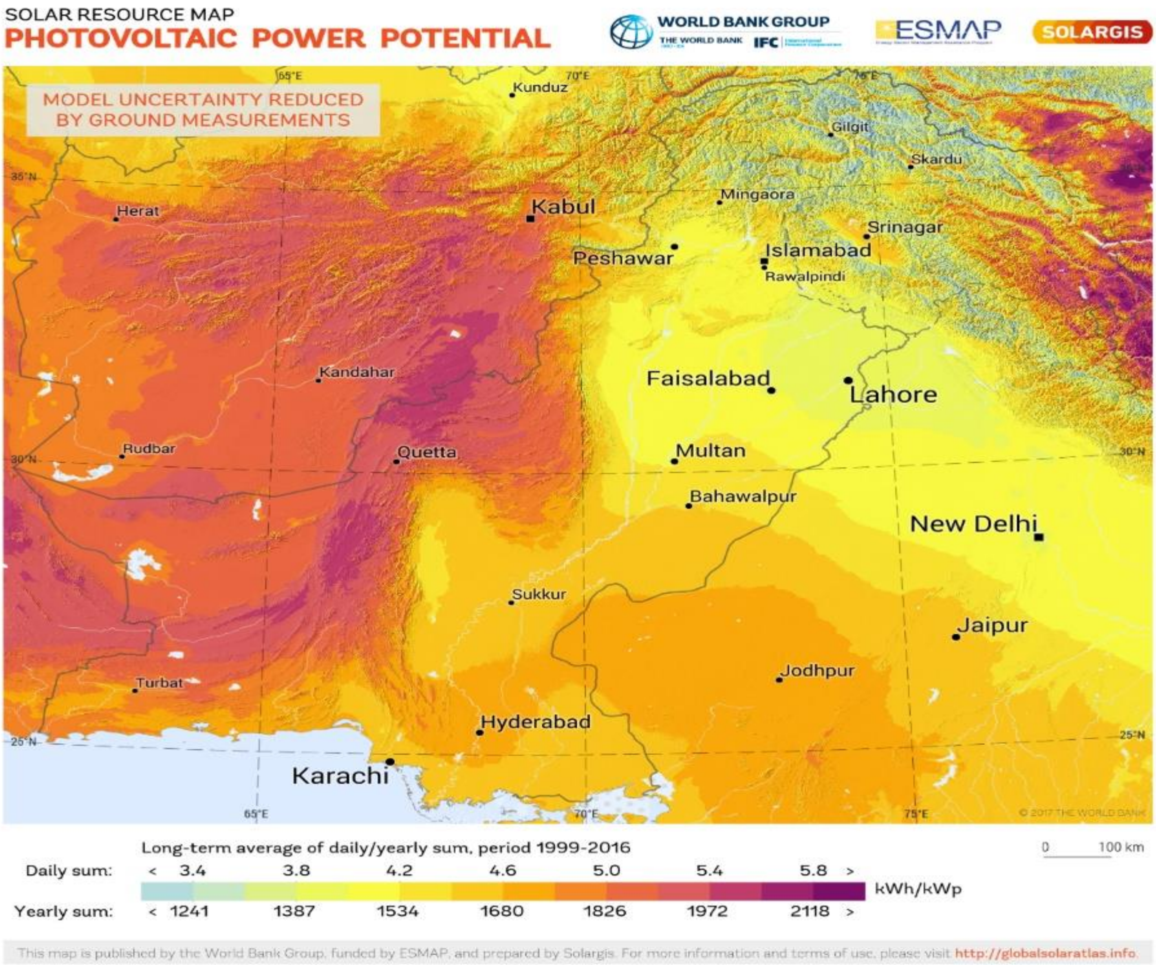
Figure 14: Percentage wise share of Prosumers

The data also highlights areas for growth and targeted support, particularly in less-served regions where net metering has not yet gained widespread traction. Addressing barriers in these areas could help expand solar adoption further, supporting Pakistan's goals for renewable energy integration and reducing dependency on grid-supplied electricity during peak daylight hours.

The chart shows that 86% of net-metered connections are from domestic users, making them the majority. Commercial users represent 8%, industrial 4%, agriculture 2%, and general services less than 1%. This indicates that residential users are the primary adopters of net metering, with limited participation from other sectors.

2.3. Solar Energy Landscape

Pakistan, strategically located in South Asia, boasts an immense potential for solar energy. With its abundant sunshine and growing energy demands, the country is poised to become a leader in solar energy production. According to recent statistics, Pakistan's solar energy market is experiencing exponential growth, driven by favorable policies, declining solar costs, and rising environmental concerns.



Pakistan receives an average solar radiation of 5-6 kWh/m²/day, making it an ideal location for solar energy generation. The country's geography, with vast deserts and arid regions, offers a unique opportunity for large-scale solar farms. This map shows long-term average daily and yearly photovoltaic output potential (kWh/kWp), demonstrating the enormous capacity for solar power generation. Areas marked in darker shades represent zones with higher solar output potential, such as parts of Balochistan, where the yearly sum exceeds 2,000 kWh/kWp.

Pakistan's energy demands are increasing rapidly, with the country facing an energy deficit of around 5,000 MW. Solar energy can help bridge this gap, providing clean and reliable power to millions of Pakistanis.

The country's coastal regions hold significant potential for wind energy, while its average 9.5 hours of sunlight per day make solar energy an attractive option. Moreover, Pakistan aims to increase its hydropower capacity from 9,000 MW to 22,000 MW by 2030

2.3.1. Demand vs GHI

In this study, data was sourced from the World Bank's platform, focusing on Lahore within the Lahore Electric Supply Company (LESCO) region, as it represents Pakistan's main load center. Lahore's selection is strategic, given its significant demand on the national grid and its role as a key urban and industrial hub.

The analysis compares Global Horizontal Irradiance (GHI) levels in Lahore with Pakistan's total electricity demand on July 14th, capturing a consistent summer date that reflects peak demand conditions driven by cooling requirements. GHI, which quantifies the total solar radiation on a horizontal surface, serves as an indicator of solar potential for the day in question.

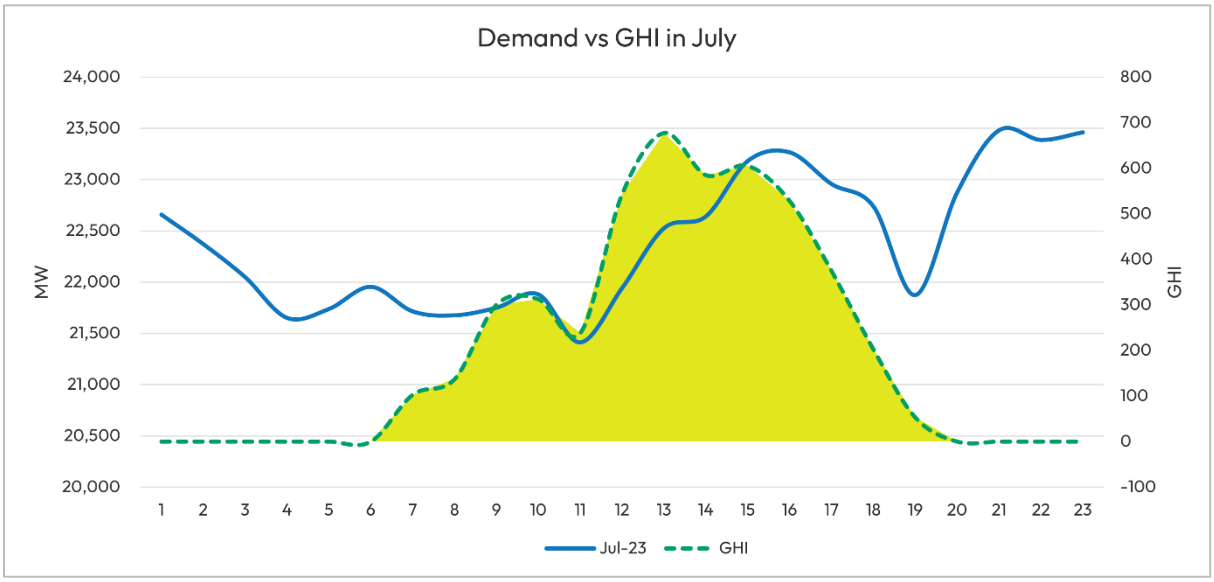


Figure 15: Demand vs GHI

The comparison between Lahore's GHI and the national demand profile provides insights into how solar energy could mitigate grid load during daylight hours, particularly in high-demand regions like Lahore. Findings indicate that higher GHI levels coincide with periods of elevated demand, highlighting the potential for solar energy to alleviate grid pressure in Pakistan's primary load center. This study underscores the value of harnessing solar resources to support peak demand, particularly in areas with concentrated energy usage such as the LESCO region.

2.4. Behind the Meter

In Pakistan, the rapid adoption of solar power has been significantly shaped by behind-the-meter installations, many of which are not officially tracked by the National Electric Power Regulatory Authority (NEPRA). While NEPRA monitors only registered, grid-connected solar systems, geospatial data reveals a widespread proliferation of solar panels across diverse sectors, including factories, residential homes, and government buildings. This trend reflects an “under-the-radar” shift toward energy independence and cost savings, with businesses and individuals alike generating their own power locally and thereby reducing reliance on an often-unreliable grid. Tentative estimates indicate that by the close of FY 2023-24, around 5 GW of distributed solar capacity has been installed, with projections suggesting this figure could grow to 8 GW over the next 10-12 months, driven by increasing affordability of solar and battery storage technologies.

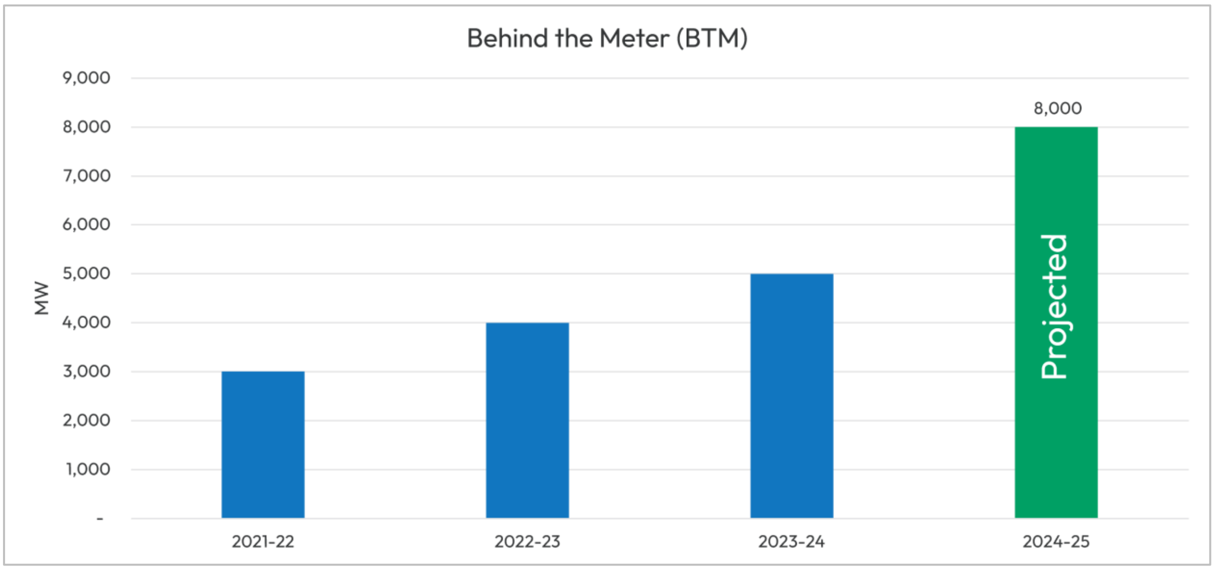
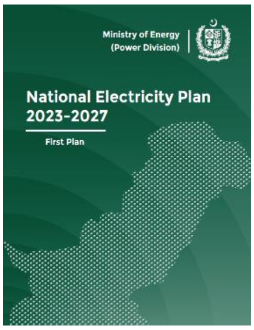


Figure 16: Behind the meter solar adoption

This has been derived from these tentative estimates, derived from import data that assumes approximately 30% of total installations are off-grid, with the remainder being behind-the-meter, yet unregistered in net metering systems.



Acknowledging this substantial yet informal adoption of Distributed Energy Resources (DERs), Strategic Directive 15 of the National Electricity Plan recommends that the Alternative Energy Development Board (AEDB), now integrated into the Private Power and Infrastructure Board (PPIB), coordinate with Distribution Companies (DISCOs) and Provincial Governments to develop a comprehensive strategy. This strategy aims to achieve visibility of DER penetration, facilitating informed system planning for both short- and long-term horizons. Key components include tracking annual DER imports through customs, quantifying installations by vendors and service providers, and establishing a mechanism for detailed data collection—covering DER type, technology, location, and quantity for on-grid, off-grid, and hybrid installations. Furthermore, the directive calls for incentive mechanisms to encourage the registration of DER systems and the deployment of bottom-up evaluations by DISCOs, using load profiles, surveys, and technology to better understand and integrate these resources.

2.5. Current Legal Framework and Policies in Pakistan

Pakistan's approach to promoting renewable energy, particularly solar power, is encapsulated in various national policies that emphasize the importance of net metering and distributed generation. These policies aim to not only diversify the energy mix but also enhance energy access, especially in rural and underserved areas. By creating an enabling environment for residential, commercial, and industrial consumers, the government seeks to stimulate investment in solar technologies and facilitate the transition towards sustainable energy solutions. The Net Metering Policy is briefly described in section 2.5.1. The key clauses from other major policies that support these objectives are outlined in sections 2.5.2 onwards.

2.5.1. Net Metering Regulations, 2015

Eligibility	Consumers of DISCOs are eligible to install net metering systems. They must have a renewable energy system (solar or wind) with a capacity between 1 kW and 1 MW.
Bi-directional Metering	A bi-directional meter is installed to allow exporting surplus energy to the grid when generation exceeds consumption. Energy imported and exported is measured separately for net calculation.
Net Billing	If production exceeds consumption, the excess energy is fed into the grid, and the consumer receives a credit. If consumption exceeds generation, the consumer pays for the net electricity consumed.
Tariff and Compensation	Consumers are compensated for excess electricity at the National Average Power Purchase Price (NAPPP). Credits can be carried forward for up to 3 months; unused credits expire after that.
System Ownership and Maintenance	The consumer is responsible for ownership, installation, and maintenance of the net metering system, while DISCOs facilitate bi-directional meter installation and operation.
Connection Agreement	A Net Metering Agreement is signed between the consumer and DISCO, detailing technical and commercial terms. The consumer must ensure compliance with safety and technical standards.
Grid Stability and Safety	NEPRA has set standards to ensure consumer-installed systems do not affect grid stability. DISCOs can disconnect a net metering system if it poses a risk to grid safety or operation.

2.5.2. Alternative Renewable Energy (ARE) Policy, 2019

✓ Clause 6.1 (Promotion of Distributed Generation and Net Metering): The policy explicitly supports distributed generation (DG) and net metering as part of its renewable energy promotion. It encourages residential, commercial, and industrial consumers to adopt DG through net metering, allowing them to sell excess electricity to the grid.

✓ Clause 6.6 (Incentives for Solar Energy): Provides incentives for small-scale solar installations, including tax exemptions and subsidies, to enhance the adoption of solar energy in distributed generation.

✓ Clause 7.2 (Promotion of Private Sector Investments in Solar): This clause incentivizes private sector investment in renewable energy, including solar PV systems, emphasizing small-scale and rooftop installations linked with net metering.

2.5.3. National Electricity Policy (NEP), 2021

✓ Clause 3.2.4 (Promotion of Renewable Energy): The NEP 2021 promotes the integration of renewable energy sources, including solar energy, into the national grid through policy support for distributed generation. It highlights the importance of enabling mechanisms like net metering to achieve energy diversification.

✓ Clause 5.1.6 (Distributed Generation and Net Metering): Reiterates the need to enhance regulatory support for net metering and distributed generation to promote solar PV and other renewable resources in the energy mix.

2.5.4. National Climate Change Policy (NCCP), 2021

✓ Clause 5.3.1 (Renewable Energy Adoption for Climate Mitigation): This clause emphasizes the role of renewable energy in Pakistan's climate mitigation strategy, promoting solar energy adoption and net metering as critical components in reducing greenhouse gas (GHG) emissions.

✓ Clause 6.2 (Distributed Generation and Decentralized Energy Systems): Supports decentralized energy solutions, particularly solar power, through mechanisms like net metering to reduce reliance on fossil fuels and combat climate change.

2.5.5. National Action Plan, 2019

✓ Clause 4.1.2 (Renewable Energy and Energy Efficiency): The action plan focuses on renewable energy promotion, particularly solar energy, as a key driver of energy efficiency in Pakistan. Net metering is presented as a tool for promoting the adoption of rooftop solar systems.

✓ Clause 4.3.1 (Distributed Generation and Off-Grid Solar Solutions): Advocates for distributed generation through net metering to improve access to renewable energy in underserved regions of the country, particularly in rural areas with off-grid solar system

2.6. Tariff Structure Overview

The electricity tariff charged to the consumers connected to the grid called consumer end tariff and comprises of Generation, Transmission, Distribution and Supply components. From these components Generation Capacity Costs, Transmission and Distribution costs are fixed cost and only Generation Energy Cost is variable in nature.

From the consumers it is charged through fixed, variable, fuel adjustment and quarterly adjustment mechanism.

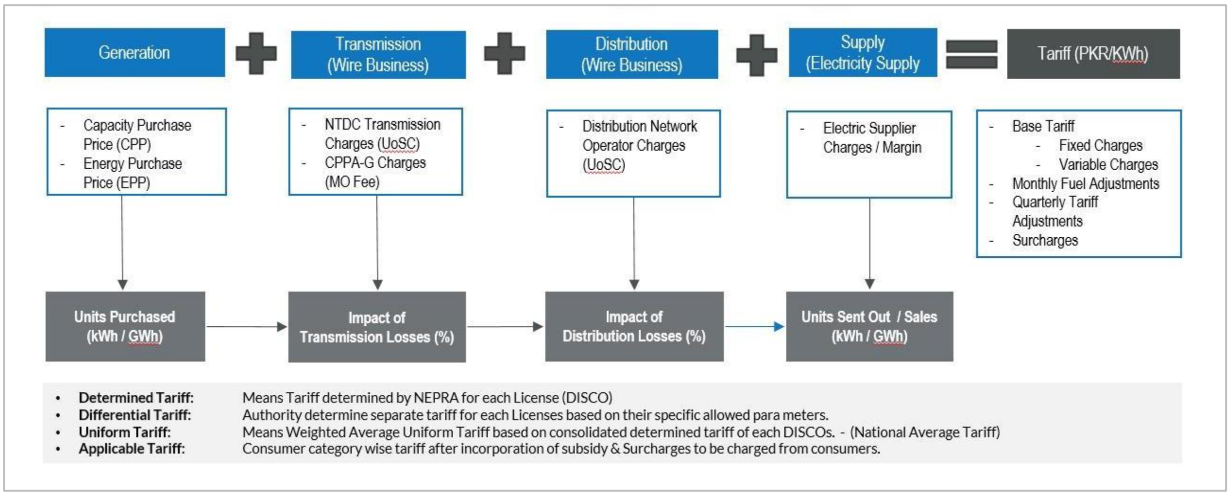
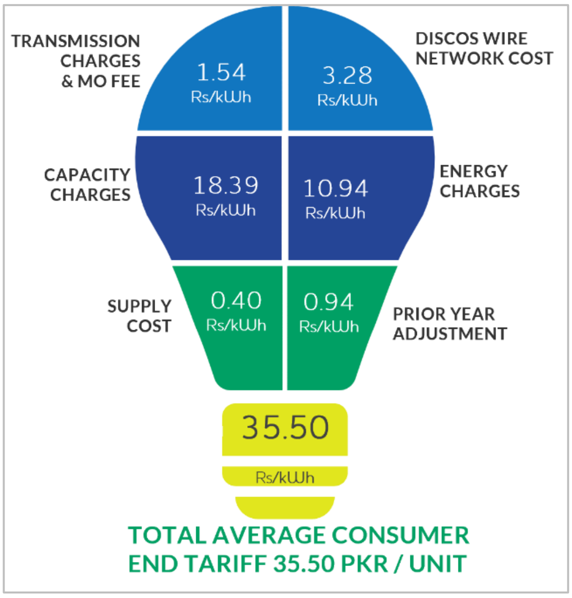


Figure 17: Tariff Structure

The electricity tariff charged to consumers, referred to as the consumer-end tariff, is primarily volumetric, meaning it is billed on a kilowatt-hour (kWh) basis. However, the true cost structure includes a significant fixed cost component.

For the financial year 2024-25, the average per unit cost estimated to be 35.5 PKR/kWh on the potential sale of 106,153 GWh. Of this, variable cost accounts approximately 11 PKR/kWh, while the remainder consists of fixed costs like generation capacity cost, transmission cost and distribution cost.

Since the tariff charged to consumers is volumetric, a reduction in sales from the grid—due to consumers not purchasing in volume—will result in an inability to recover these fixed costs.



2.6.1. Last Three Years Consumer end tariff

The last 3 years consumer end tariff approval shown in below figure shows significant reduction in demand.

Component wise tariff of FY 2022-23, 2023-24 & 2024-25

Description	FY 2022-23		FY 2023-24		FY 2024-25	
	GWh		GWh		GWh	
Projected Sales of XW-DISCOs	113,002		110,165		106,153	
	PKR Million	Rs./Unit	PKR Million	Rs./Unit	PKR Million	Rs./Unit
Energy Charge	1,152,357	10.20	840,462	7.63	1,161,257	10.94
Capacity Charge	1,250,959	11.07	1,874,334	17.01	1,952,493	18.39
Transmission & MOF	114,606	1.01	151,363	1.37	163,755	1.54
Power Purchase Price	**2,517,922**	**22.28**	**2,866,159**	**26.01**	**3,277,505**	**30.88**
DISCO Distribution & Supply Margin	244,189	2.16	341,403	3.10	390,502	3.68
PYA	42,409	0.38	73,599	0.67	999,54	0.94
Revenue Req. of XW-DISCOs	**2,804,520**	**24.82**	**3,281,161**	**29.78**	**3,767,961**	**35.50**

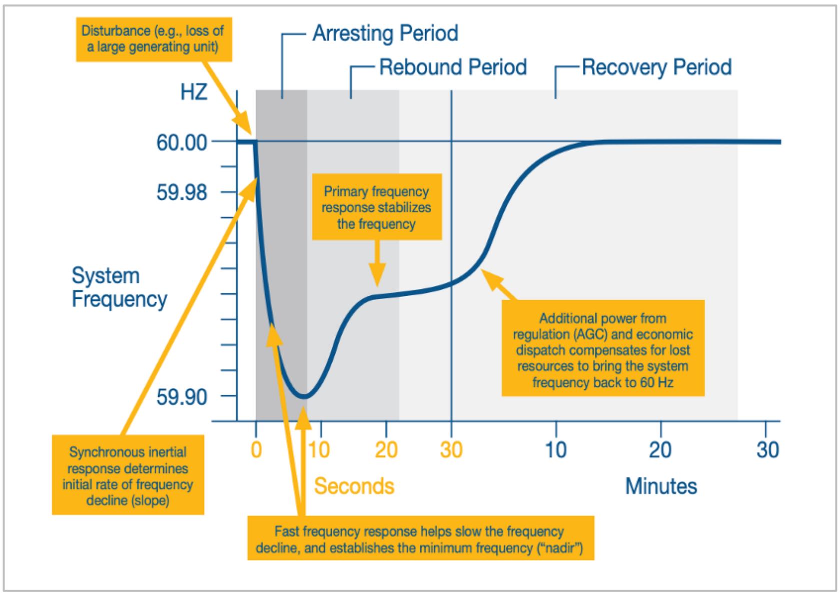
Figure 18: Last three years tariff

The per-unit price of electricity is calculated by dividing the total revenue requirement of utility companies by the total energy sales. The chart above illustrates that one factor driving the increase in per-unit prices is the declining trend in unit sales (measured in GWh). As total energy sales decrease, this reduction contributes to a higher per-unit price for consumers, affecting overall electricity costs.

2.7. Grid Reliability and Renewable Intermittency Challenge

Electric grid reliability refers to the capability of the electrical grid to consistently meet consumer demand, ensuring that electricity is available when needed, 24 hours a day, 7 days a week, throughout the year. This reliability is crucial because electricity demand fluctuates continuously, driven by variations in consumption patterns across different times of day and seasons.

The principle governing reliable grid operation is that the supply of electricity must always match the demand in real-time. In practical terms, for every megawatt (MW) of electricity required at any given moment, an equivalent amount of power must be generated and supplied instantaneously. This balance is continuously monitored by system operators using the grid frequency, which is 50 Hz in Pakistan. Maintaining this frequency is a key indicator of grid stability, and it is achieved by adjusting power generation from dispatchable sources—those that can be controlled and ramped up or down quickly as needed.



Reliable grid operation, particularly in the short term, depends on the flexibility to increase or decrease electricity generation on demand. This flexibility is primarily provided by dispatchable technologies such as natural gas, coal, or hydropower plants, which can adjust their output in real-time.

Renewable energy sources like solar and wind, while cost-effective in terms of their Levelized Cost of Energy (LCOE)—often around 4 US cents per kWh—pose challenges to grid reliability. The intermittent nature of these resources means they cannot be dispatched on demand. Solar and wind generation depend on environmental conditions, such as sunlight and wind speed, which are not controllable. As a result, the ability of these renewable sources to meet electricity demand at any given moment is uncertain, leading to the need for additional "**firming**" measures—technologies or systems that can ensure power availability when renewables cannot supply sufficient energy.

The cost of firming intermittent renewables is significant, often offsetting the low LCOE of solar and wind. These firming costs may include investment in energy storage technologies like batteries, backup generation capacity, or grid enhancements to manage variability. Without these additional investments, the variability of renewables poses a risk to grid reliability, especially during periods of high demand or low renewable output.

The incremental cost to firm intermittent resources varies regionally—as such is defined by the relevant reliability organizations using the current effective load carrying capability values and the current cost of adding new firming resources. For Pakistan Grid a separate Study is required in this required.

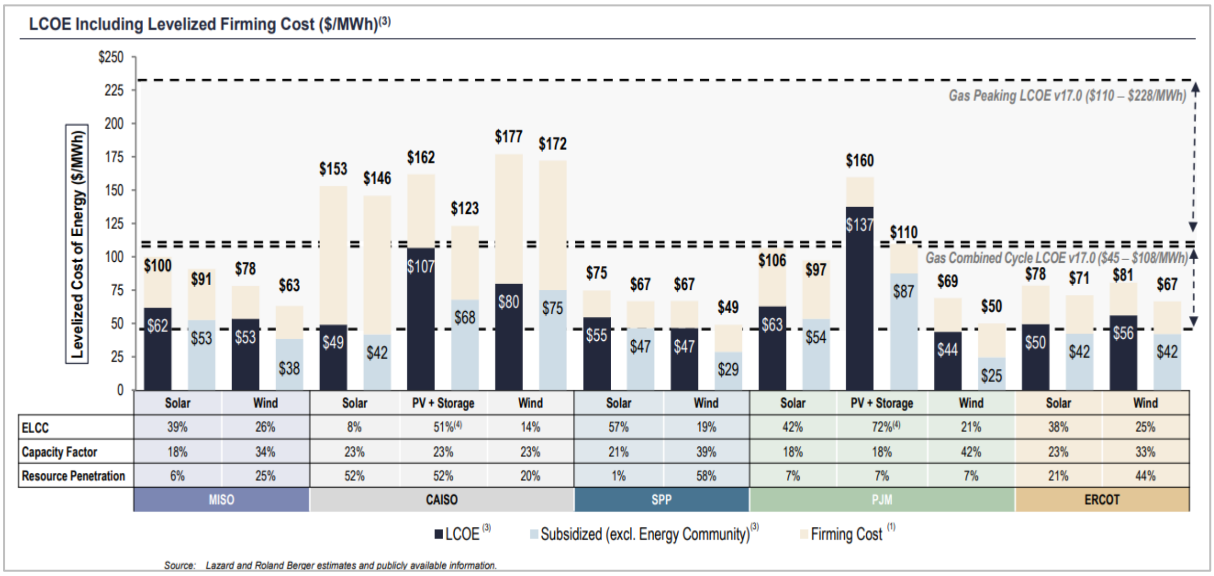


Figure 19: Lazard Study graph

The chart from the Lazard Study demonstrates that while standard solar generation has a levelized cost of electricity (LCOE) of 5.3 US cents per kWh, this increases to 9.1 US cents per kWh when firming costs are factored in for the MISO market. Similarly, in the ERCOT market, the LCOE of solar generation rises from 4.2 to 7.1 US cents per kWh with firming costs included. This indicates that achieving 24/7/365 reliable energy from a solar-based mix—when combined with other technologies for stability—effectively doubles the cost of electricity from what is typically projected based solely on solar LCOE.

3

Burden on Non-Net Metering Users

The Net Metering program offers incentives to eligible customers who install decentralized or distributed renewable energy systems like solar PV. While this program benefits participating customers by allowing them to sell excess electricity back to the grid at retail rates, it creates distinct challenges for non-participating customers.

Firstly, net metered customers are compensated for the energy they supply to the grid at the full retail rate, which includes not just the cost of energy but also transmission and distribution (T&D) costs built into electricity prices. As a result, these customers receive a premium since they are compensated for components of the retail rate that go beyond just energy generation costs.

Secondly, customers with behind-the-meter distributed generation (DG), such as solar PV systems, reduce their reliance on the grid. While this reduces their personal energy costs, they also contribute less to the fixed costs of distribution, transmission, and ancillary services that the utility (DISCO) must recover from its entire customer base. Since the utility still needs to maintain grid infrastructure and operations, the costs are redistributed among fewer paying customers, increasing the marginal cost of these services for non-net metered or non-solar customers. ***This cost shift is often handled through a tariff true-up mechanism, effectively leading to a cross-subsidy, where customers without DG systems subsidize the fixed costs of grid services for those with DG installations.***

3.1 Net Metering Prosumers Benefits

Under the current policy, net metering prosumers receive three key advantages compared to behind-the-meter prosumers, who primarily benefit by avoiding grid-supplied electricity during the day. If we exclude the grid's role in providing firming services, the benefits for net metering prosumers are as follows:

- Savings from Avoiding Daytime Grid Consumption:

Residential consumers who avoid using grid electricity during the day through solar generation save the delta of 41.68 PKR/unit base rate Grid Unit Price from PV Solar Unit Rate that is approximately 12 PKR/Unit.

- Off-Peak Savings with Net Metering:

Net metering consumers balances off-peak grid charges during the night, leading to savings of around 41.68 PKR/unit (plus taxes) from their PV Solar Generation Price. Additionally, these customers avoid the cost of installing a battery system, as the grid effectively acts as a storage mechanism.

- Selling Surplus Energy:

Net metering prosumers can sell excess electricity back to the grid at the National Average Purchase Price (NAPP), which is currently set at approximately 27 PKR/kWh. This provides an extra revenue stream, further enhancing their financial benefits compared to behind-the-meter prosumers.

3.2. Cost-Saving Potential of 10 kW Residential Net Metering

A residential consumer with a sanctioned load of 10 kW can reduce their electricity bill significantly, potentially reaching zero, by installing a corresponding 10 kW net metering system. Furthermore, by installing a system that is 1.5 times the sanctioned load, they could even generate excess electricity and earn by feeding surplus power back into the grid. For simplicity, this calculation only considers the base tariff rates, excluding any quarterly adjustments, fuel charges, or taxes. Additionally, the cost of solar PV generation is assumed to be 12 PKR/kWh, with a capacity factor of 16.5% for residential rooftop installations.

In Summers:

Based on the current residential tariff of 47 PKR/kWh for peak hours and 41.68 PKR/kWh for off-peak hours, alongside fixed monthly charges of 1,000 PKR, the estimated summer electricity bill for a consumer with a 10 kW sanctioned load is calculated. This approach highlights how homeowners can leverage solar net metering to not only reduce their reliance on the grid but also optimize financial savings, especially given the current high electricity tariffs.

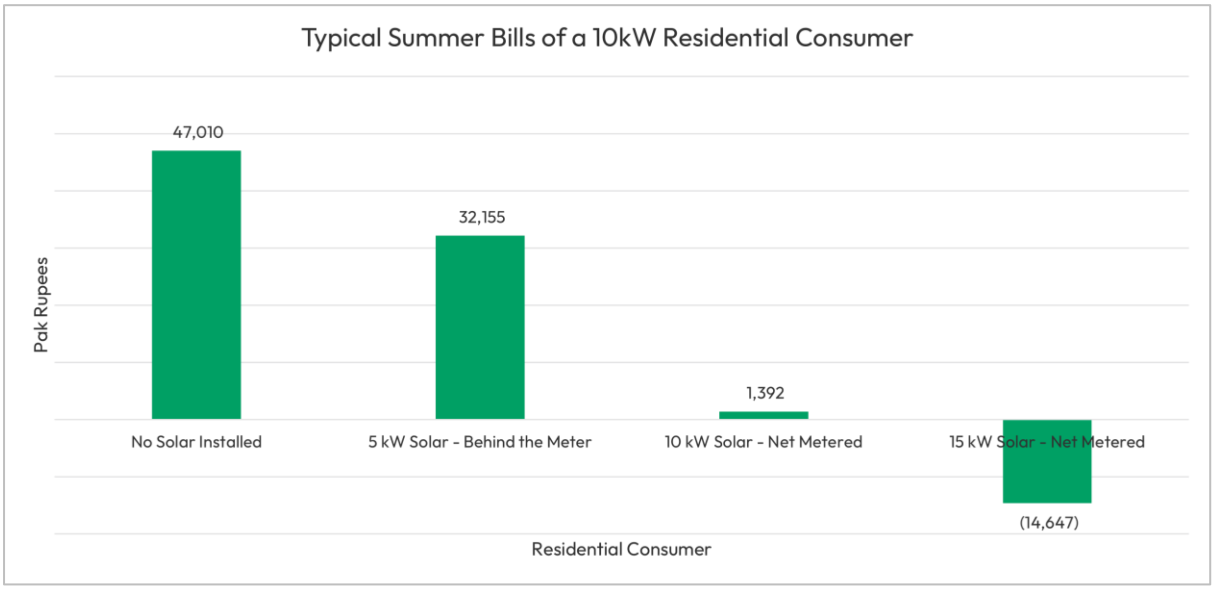


Figure 20: Summers Bill of 10kW Consumer

In Winters

During the winter months, as the cooling load decreases, consumers with solar installations will likely export more electricity back to the grid, especially on clear, sunny days, particularly in the southern regions of the country. This increased solar generation results in surplus electricity being sold to the grid, leading to negative electricity bills, where the consumer earns more from the grid than they use, further enhancing the financial benefits of net metering in regions with strong solar exposure.

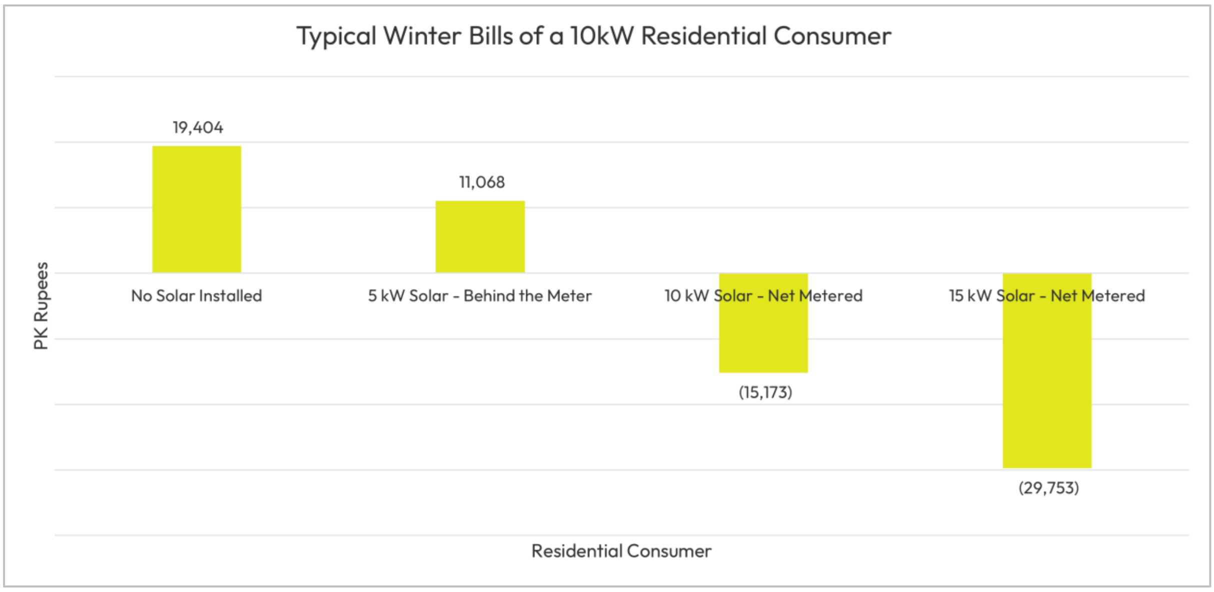


Figure 21: Winters Bill of 10kW Consumer

3.3. Shifting of Costs

In the fiscal year 2023-24, the projected energy units expected to be delivered to DISCOs (Distribution Companies) after accounting for transmission losses were estimated at 124,860 GWh. However, the actual units delivered reached 134,523 GWh, reflecting a shortfall of 8.7%

compared to the anticipated figures. If we apply the same transmission and distribution loss factor used in the PPP (Power Purchase Price) and uniform tariff determination, which stands at 18.11%, the actual sales of units would amount to 100,563 GWh. These figures are derived from Monthly Fuel Adjustments and Quarterly Adjustment documents and may vary slightly due to some provisional submissions.

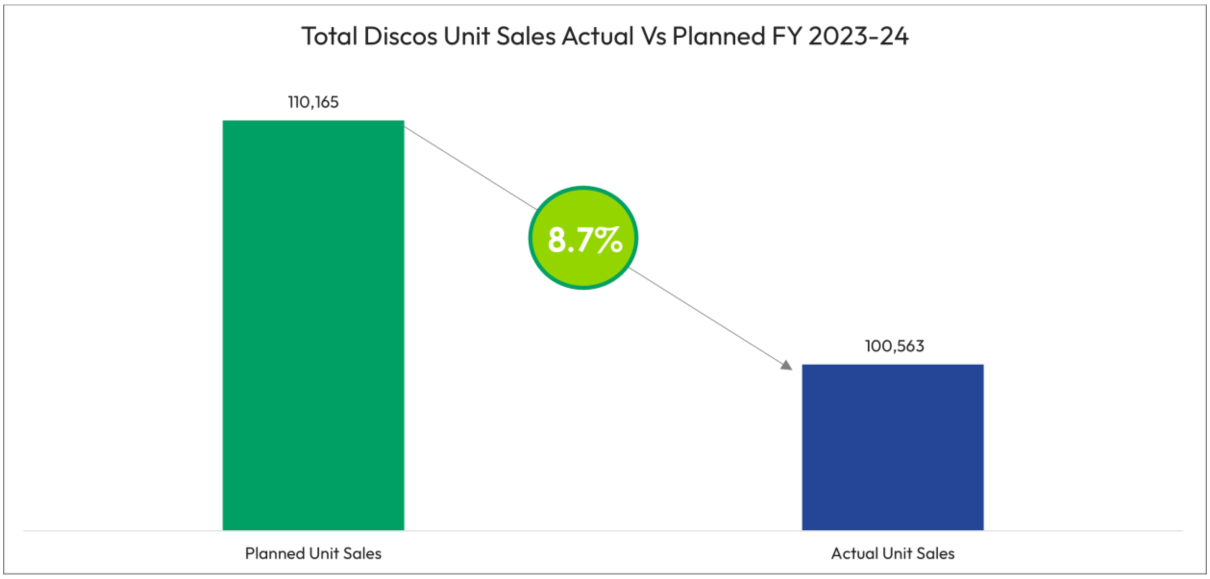


Figure 22: Actual vs Planned Sales

The uniform consumer-end tariff for FY 2023-24 was calculated at 29.78 PKR/kWh, of which 22.15 PKR/kWh represents fixed costs. Due to the reduction in delivered units, this fixed cost has increased to 24.27 PKR/kWh. The reduction of 9,602 GWh in units creates a gap of 2.12 PKR/kWh in the recovery of fixed costs, which will need to be compensated through quarterly adjustments. As highlighted in Section 1.4, the primary reduction in demand occurred during the morning and daytime hours. Given that the broader macroeconomic indicators remain relatively stable, the increased costs will largely be borne by non-net metering consumers through higher charges on their total consumption. While behind-the-meter (BTM) consumers also faces a disproportionate burden as well particularly during nighttime.

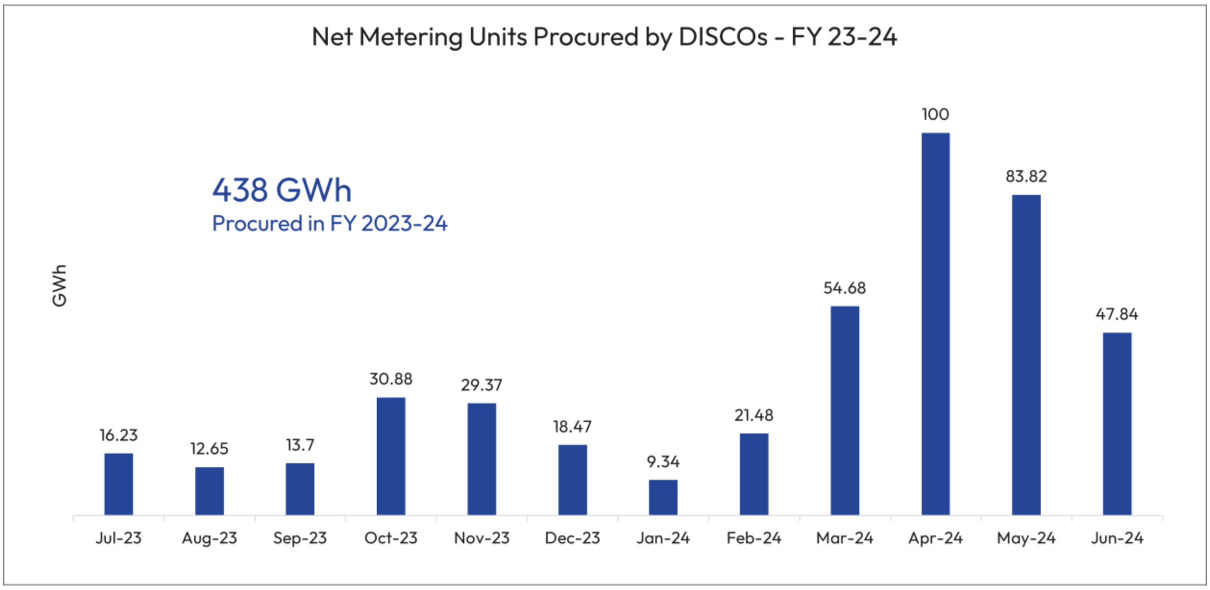


Figure 23: FY 23-24 Procured Net Metering Units

DISCOs have procured a total of 438.46 GWh through Net Metering during FY 23-24, but this figure does not account for the daytime units displaced by Net Metering prosumers or the behind-the-meter (BTM) consumption by prosumers during the day. According to an IEEFA report, by June 2024, approximately 2,200 MW of solar capacity was installed under Net Metering. Assuming a consistent average installed capacity throughout the year, and applying a utilization capacity factor of 16.5%, the system would generate an estimated 3,180 GWh annually.

Due to limited monthly data, it's assumed based on recent trends that 30% of the solar energy generated is exported to the grid, while 70% is self-consumed by prosumers during the day. In residential households, the trend often shows more export and lower self-consumption, whereas in industrial and commercial sectors, self-consumption is higher during daytime hours.

If we conservatively estimate that an additional 5,000 MW of PV Solar was installed behind the meter over the past year, it would have displaced approximately 7,200 GWh of grid electricity during the day. This means that nearly 9,942 GWh of grid demand has been displaced due to both Net Metering and BTM solar generation. These indicative calculations highlight a significant reduction in grid demand during daytime hours.

In FY 2023-24, approximately PKR 200 billion in grid fixed costs were shifted to non-solar consumers, leading to a tariff increase of around PKR 2 per kWh for these users. Future assessments could also explore the impact of fuel costs shifted due to increased PV solar procurement at NAPPP (National Average Power Purchase Price), as well as grid ancillary charges incurred by distributed solar generation (DG) users who leverage the grid for stability and storage, effectively using it as a backup battery system.

3.4. Fixed Cost Avoidance

For the purpose of analyzing fixed costs, we are excluding the base tariff, which includes cross-subsidies among different tariff categories, and instead focusing on the uniform consumer-end tariff for our calculations. For FY 2024-25, NEPRA has determined an average consumer-end tariff of 35.5 PKR/unit. Out of this, approximately 11 PKR/kWh accounts for variable costs, while the remaining 24.5 PKR/unit represents fixed costs, calculated on a per-unit basis against a predefined sales target.

In this analysis, we evaluate a typical 10 kW sanctioned load residential consumer under various scenarios involving net metering and solar installation. The key observation is that through net metering, consumers effectively avoid a significant portion of these fixed costs. The per-unit savings from fixed costs under the net metering tariff amounts to approximately 20.93 PKR per unit, highlighting the financial benefits for net metering consumers when compared to those who solely rely on the grid.

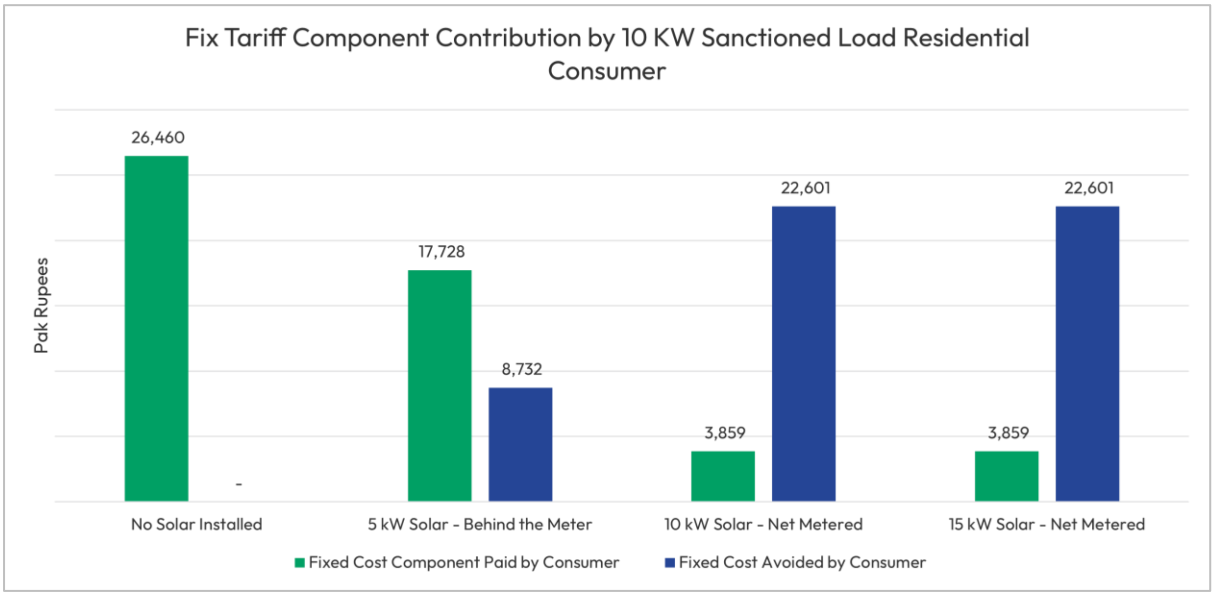


Figure 24: Fix Tariff Component – Residential Consumer

Consider another typical scenario involving an industrial facility with a 5,000 kW (5 MW) sanctioned load, operating at full capacity 24/7, with an assumed load factor of 45% and a Maximum Demand Indicator (MDI) at 90% of the sanctioned load. In this scenario, four cases of behind-the-meter solar penetration are modeled to illustrate how the industrial consumer can significantly reduce fixed costs.

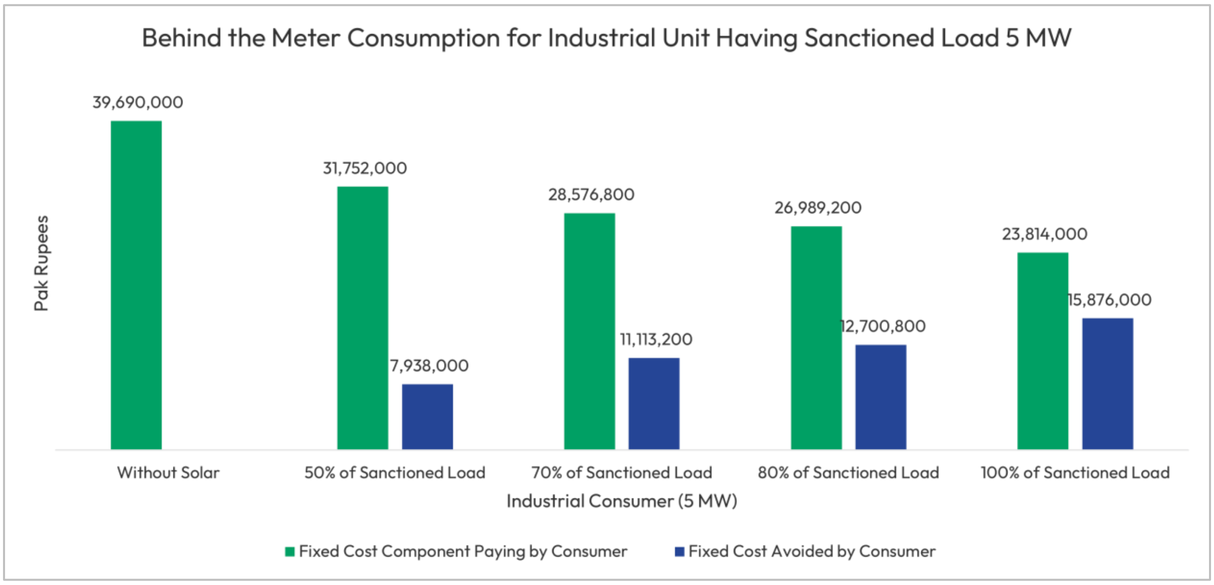


Figure 25: BTM Solar effects of Industrial Consumer

For simplicity, we use the fixed cost component of 24.5 PKR per unit from the uniform consumer-end tariff of 35.5 PKR/unit, as discussed previously. The calculations assume a solar capacity utilization factor of 18% with no curtailment. Although the exact results will vary depending on the specific industrial setup, this model shows how solar adoption can provide considerable savings by reducing dependency on the grid and avoiding fixed cost recovery by the utility.

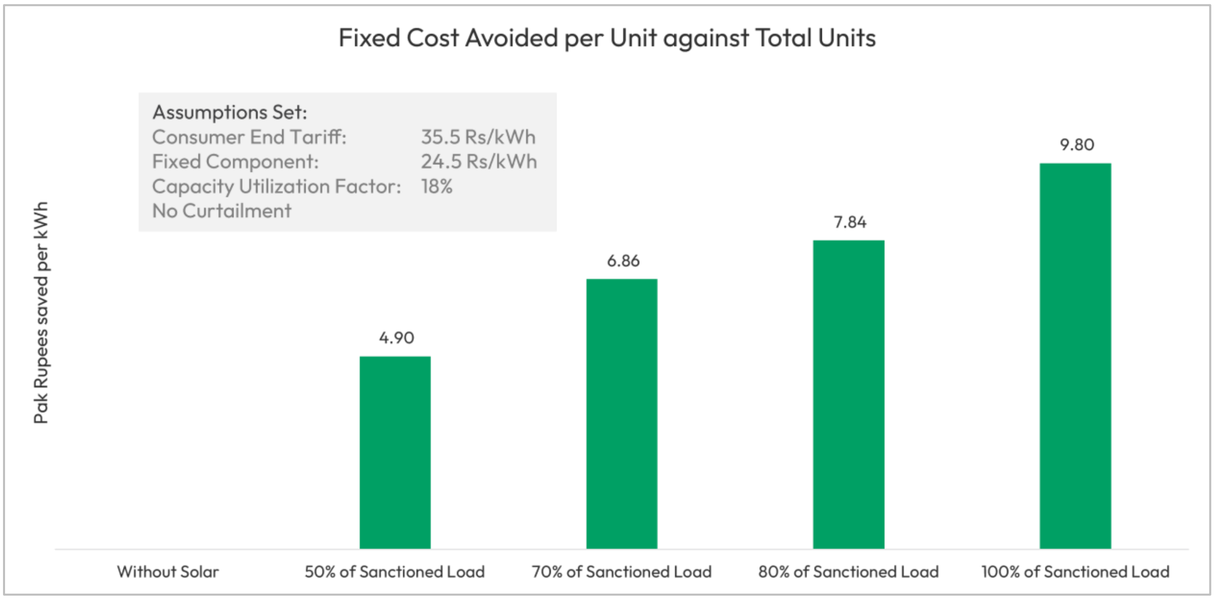


Figure 26: Fixed Cost Avoided per Unit

3.5. Tariff Adjustment - Low Vs High Prosumption Scenarios

Increasing penetration of distributed solar generation and self-consumption will impact grid-based sales, with three scenarios projecting reductions of 5%, 10%, and 15% in sales. Alternatively, solar penetration within the grid has caused the base tariff for FY 2023-24 to rise by nearly the same percentages. While impact calculations here consider only the fixed cost component, higher daytime solar generation also pressures large central power plants to operate at partial load, incurring additional costs due to part-load operations.

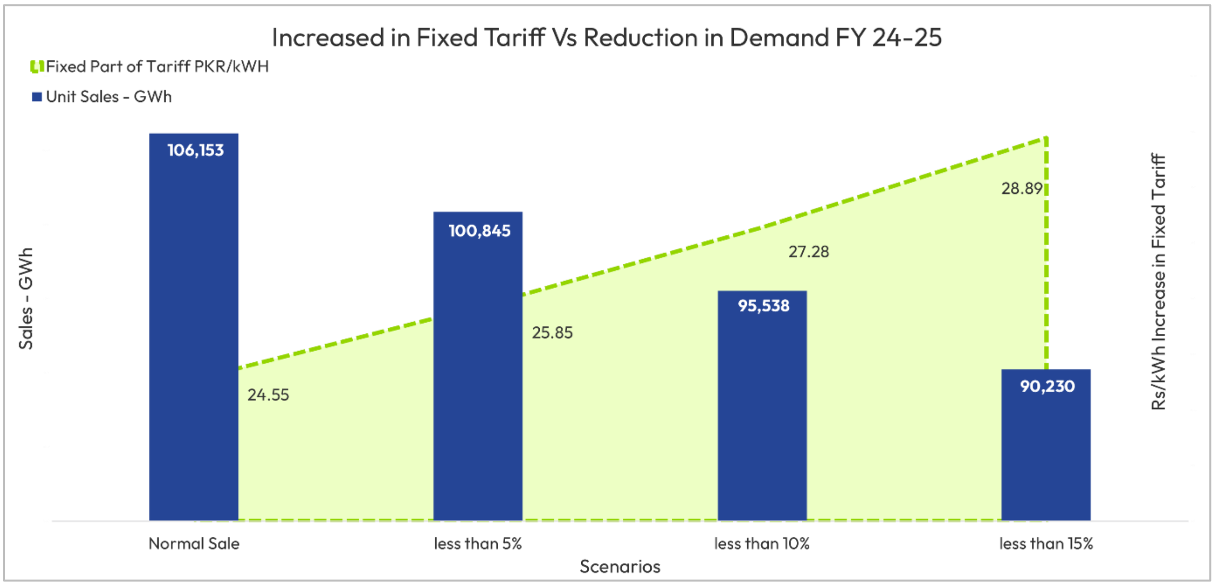


Figure 27: Tariff and Demand Relation

For the current fiscal year, a 5% reduction in grid demand through solar integration will result in a shift of PKR 131 billion in costs to non-solar consumers annually. Doubling this reduction to 10% will shift an even larger cost of PKR 261 billion to consumers without solar energy.

The methodology illustrated in the figure outlines the approach used to manage tariff adjustments and illustrates how these adjustments have contributed to an increased cost burden for consumers.

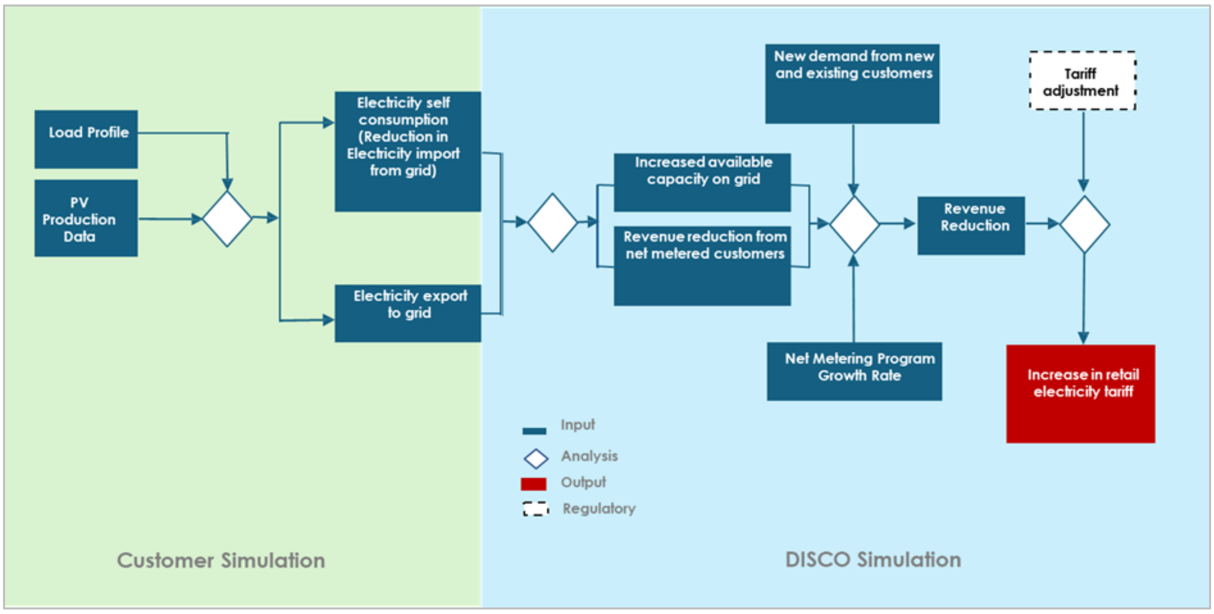
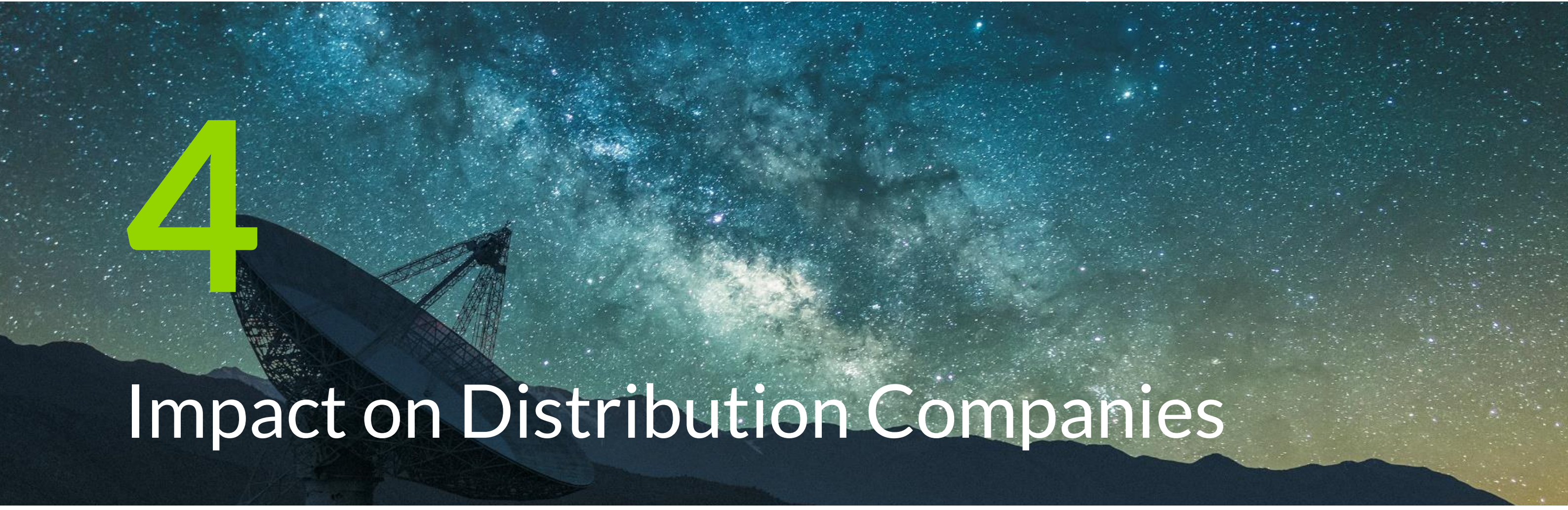


Figure 28: Methodology for Tariff Adjustment



4

Impact on Distribution Companies

The penetration of PV solar distributed generation (DG), whether through net metering or behind-the-meter systems, presents significant challenges for DISCOs (Utilities), particularly in managing grid stability and ensuring a balanced supply and demand.

1. Grid Stability and Demand Ramping:

One of the most prominent challenges arises from the variability of solar generation throughout the day. Solar power production peaks during daylight hours, but as the sun sets, this generation quickly falls off. This sudden reduction in solar output, often referred to as the "duck curve," requires utilities to rapidly ramp up other forms of generation to meet the shortfall in demand. Conventional power plants, particularly those running on fossil fuels or hydropower, are often called upon to fill this gap, but not all plants are designed for rapid scaling of output, making it difficult to maintain grid reliability during these transition periods.

2. Over-Generation and Grid Overload

High solar penetration also poses the risk of over-generation during peak sunlight hours. When solar installations, particularly on a large scale, produce more electricity than is being consumed locally, utilities must either curtail the excess generation or export it to other areas. Without effective grid management or storage solutions, this over-generation can lead to grid imbalances, forcing utilities to implement measures such as curtailing solar output or even paying customers for their excess power, thus affecting the utility's profitability.

3. Utility Revenue Loss and Cost Recovery

The widespread adoption of behind-the-meter solar systems, especially through net metering, results in reduced energy purchases from utilities, leading to significant revenue losses. As more consumers generate their own electricity and rely less on grid power, utilities face the challenge of covering fixed infrastructure costs, such as transmission and distribution maintenance, with a reduced customer base. This often leads to increased electricity tariffs for non-solar users, exacerbating equity issues and possibly creating resistance to further solar adoption.

4. Voltage Regulation and Grid Infrastructure

Another technical challenge is maintaining voltage stability and quality across the grid. Solar DG systems, particularly those connected behind the meter, can cause fluctuations in voltage levels, especially in areas with high solar penetration. Utilities must invest in grid upgrades, including voltage regulators and advanced metering infrastructure, to monitor and manage these fluctuations. This also requires more sophisticated grid management systems, increasing operational costs for utilities.

In conclusion, while PV solar DG provides clean, cost-effective energy, its integration into the grid presents utilities with complex challenges in managing grid stability, maintaining revenue streams, and ensuring that the infrastructure is capable of handling fluctuating and distributed generation sources. These challenges highlight the need for advanced grid management solutions and supportive regulatory frameworks.

4.1. Prosumers' Effect on Energy Sales

In Pakistan, solar prosumers behind the meter or net-metered consumers significantly reduce their energy purchases from utilities by generating their own electricity, typically through solar power. During daylight hours, these consumers generate excess energy, which they can export back to the grid, leading to a reduced reliance on grid electricity. This displacement of daytime electricity demand lowers the amount of energy utilities need to supply, particularly during day hours.

From the utility's perspective, this results in a reduction in revenue, as energy tariffs are mostly volumetric, meaning that utilities collect revenue based on the amount of electricity sold. When net-metered consumers produce and consume their own energy, the grid demand decreases by approximately 8%. This decrease in demand directly impacts the utility's ability to collect revenue. Since fixed costs for maintaining grid infrastructure (transmission and distribution) do not decrease with reduced consumption and same for generation capacity in Pakistan case due to single buyer model.

This mechanism, known as the Quarterly Tariff Adjustment (QTA), allows utilities to pass on the cost increases to all grid-connected users, compensating for the revenue lost due to net-metered solar consumption and exports. This creates a feedback loop where the burden of distributed solar energy adoption indirectly falls on non-solar users through tariff increases, raising concerns about fairness in cost distribution.

4.1.1. Shifting of Peak

It has been discussed in the previous sections that energy consumption has mainly reduced in the daytime due to penetration of Solar Distributed Generation. This graph shows a shift in electricity demand patterns between July 2015 and July 2023. In 2015, peak demand occurred during the day, around 3 PM, at just above 22,500 MW. By 2023, the peak shifted to nighttime, around 8-9 PM, with demand exceeding 23,500 MW. This shift highlights both a change in consumption timing and an increase in overall peak demand over the 8-year period.

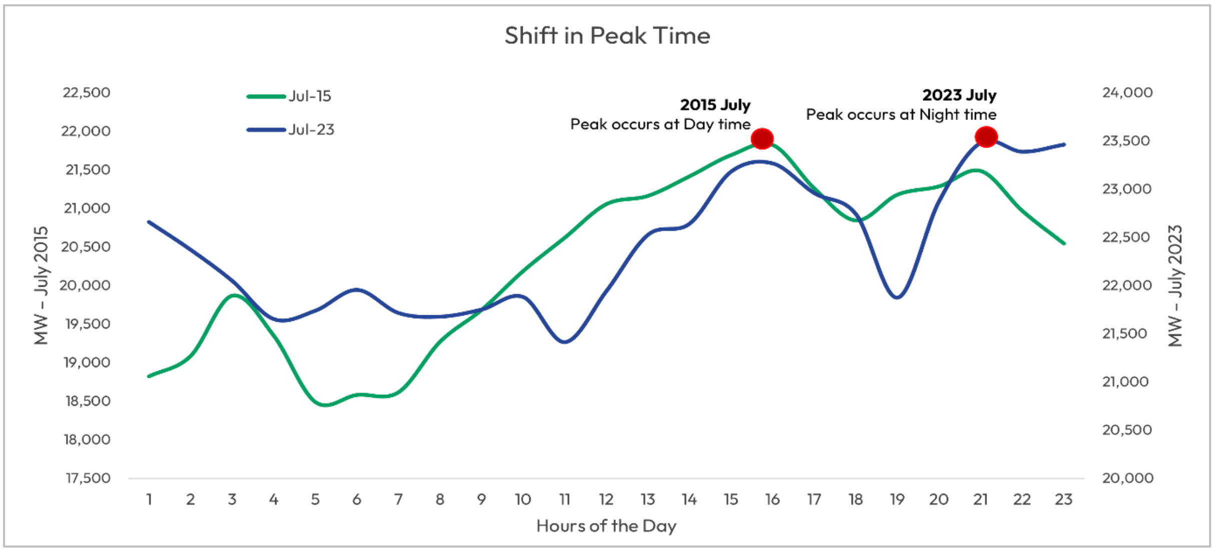


Figure 29: Shift in Peak Time

4.2. Quarterly Adjustment:

Quarterly Adjustment is a mechanism designed to recover any revenue shortfall that wasn't initially met, typically due to various factors. While these adjustments encompass multiple components, the primary impact for FY 2023-24 observed from reduced unit sales. For FY 2023-24, despite the exchange rate averaging around 280 PKR/USD and Consumer Price Index (CPI) inflation showing a downward trend, adjustments still resulted from reduced energy sales. Notably, non-solar consumers bear the brunt of these adjustments, as net metering customers largely avoid these costs due to their capacity to offset grid consumption through self-generated solar power, resulting in lower utility expenses under the net metering adjustment mechanism.

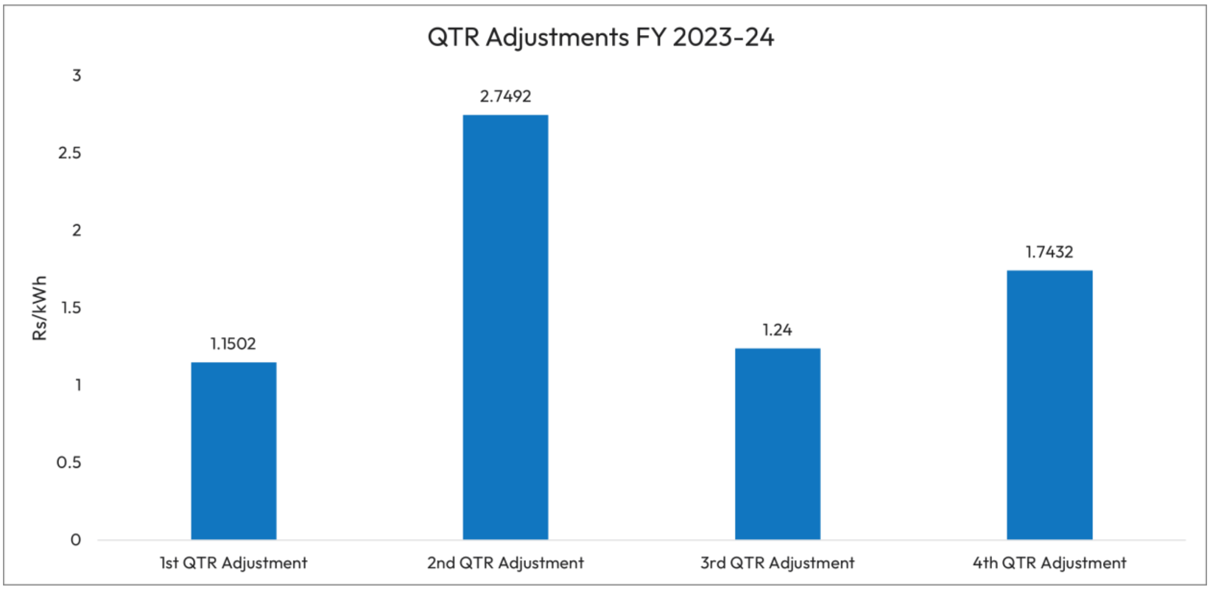


Figure 30: QTR Adjustments

All calculations have been based on the uniform base tariff. Typically, in consumer-end tariffs, higher residential and commercial users cross-subsidize lower-end users. However, with consumers shifting away from traditional grid sources, this additional cross-subsidy burden along with the fixed cost component, has now been transferred to the remaining consumers.

4.3. Revenue Loss Calculations

Distributed solar installations can introduce several new costs to DISCOs (Distribution Companies), such as investment in upgraded distribution infrastructure, the administrative expense of managing the Distributed Solar Net Metering Program, and compensating for excess electricity exported to the grid.

Our revenue analysis for DISCOs focuses solely on the costs from compensating distributed solar exports and avoided maintenance costs. Quantifying other cost and benefit elements would require extensive grid power flow analysis and loss reduction assessments, which are outside the scope of this study.

In Pakistan, most grid costs are fixed; however, recovery is largely volumetric. For FY 2023-24, the Distribution Wire Revenue Requirement is 358 billion PKR (or 3.28 PKR/kWh), and the Transmission Business Revenue Requirement is 164 billion PKR (1.54 PKR/kWh), based on projected sales of 106 TWh. This analysis excludes fixed capacity costs.

Consumers using behind-the-meter generation (e.g., self-generation or net metering) reduce their contributions to grid maintenance, which lowers DISCO revenue, affects cash flow, increases borrowing costs, and reduces profitability. Additionally, this study does not include the costs associated with ancillary services or technical stresses on the grid, which are typically recovered through quarterly tariff adjustments, as previously discussed.

Based on historical trends and recent data on PV solar panel imports, we conservatively estimate that Net Metering installations in Pakistan could increase by 1,330 MW, bringing the cumulative total to approximately 3,500 MW. Meanwhile, Behind-the-Meter installations are expected to rise from an estimated 5,000 MW to nearly 9,000 MW. Assuming a solar capacity factor of 16.5% and that 30% of Net Metering generation is exported to the grid, overall grid sales could experience a 15% reduction. This reduction will likely impact utility companies (DISCOs) in the following ways:

1. Revenue Loss Due to Unrecovered Network Costs

Unrecovered costs are expected to be approximately 16,500 GWh x 4.82 PKR/kWh, totaling around 79.5 billion PKR.

2. Balancing Cost Losses from Net Metering Exports

With 1,520 GWh exported by Net Metering consumers at a rate differential of 13 PKR/kWh (assuming 40 PKR/kWh consumer tariff and 27 PKR/kWh pool price), losses could reach 19.7 billion PKR.

While these losses could be further refined using hourly marginal costs for electricity delivery, here they are estimated based on average pool prices and consumer tariffs. These unrecovered costs are typically passed on to non-solar consumers through adjustments in tariffs to maintain revenue balance.

4.4. Impact on DISCOs Operations including Grid Stability

As highlighted in Section 2.6, renewable energy sources like solar and wind are inherently intermittent, which creates a need for dispatchable generation resources to ensure a stable balance between supply and demand on the grid. Grid stability can only be maintained through the availability of sufficient capacity, which allows power generation to be adjusted up or down quickly to meet real-time demand fluctuations. The increased penetration of renewables exacerbates these challenges, as the grid must frequently compensate for the unpredictable nature of renewable energy output.

This reliance on dispatchable generation to manage the variability of renewable energy increases the cost of ancillary services—those additional services required to maintain grid stability, such as frequency regulation and voltage control. Moreover, thermal power plants operating below full capacity to provide rapid response services must absorb part-load inefficiencies, further driving up operational costs. These adjustments add to the financial strain on the system.

In Pakistan, the capacity costs of maintaining this grid flexibility are already significant, totaling around 195 billion PKR annually. When distributed across an expected annual sales volume of 106 TWh, this translates to a cost of approximately 18.4 PKR per kWh. Although the exact cost of ancillary services has not yet been fully quantified by the market operator, rough estimates suggest that about 5 PKR of this 18.4 PKR per kWh is attributed to the capacity needed for balancing the grid.

A critical concern is that prosumers—those who generate their own electricity through net metering or behind-the-meter solar systems—are not contributing to these capacity and ancillary service costs. As a result, the financial burden of maintaining grid stability and capacity is shifted onto non-solar consumers, who must cover the shortfall through higher tariffs on the electricity they purchase from utilities. This cost shift highlights the economic strain that large-scale renewable adoption places on traditional utility business models and the importance of designing fair compensation mechanisms to ensure equitable cost distribution.

4.5. Marginal Price and Solar Buyback Rate

Renewable resources like solar power are typically valued based on their energy cost (EPP) alone, without any associated capacity cost (CPP), as they provide intermittent rather than dependable, on-demand power. The Energy Purchase Price (EPP) for solar is significantly lower than the National Average Power Purchase Price (NAPPP) of 27 PKR per kWh, a rate that includes both EPP and CPP to ensure capacity reliability.

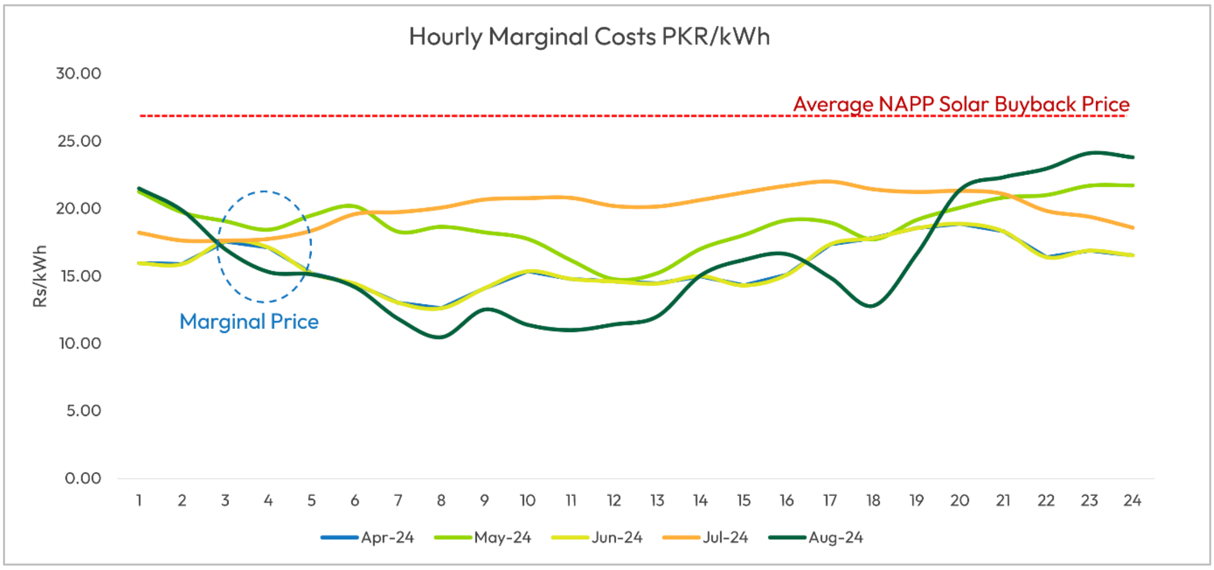


Figure 31: Marginal Price vs NAPP

Since solar power generation fluctuates with sunlight availability and cannot consistently contribute to the grid's capacity needs, assigning a capacity price to solar Distributed Generators (DGs) lacks practical or financial justification. Paying a capacity price to solar DGs would be inefficient, as these resources do not contribute dependable capacity and are intended to supplement the grid only when sunlight is available. Therefore, compensating solar purely on the basis of EPP reflects a more rational approach, aligning with their actual contribution to the energy mix.

4.5. Future Forecast

With the rapid penetration of distributed solar and the decreasing costs of solar panels and battery energy storage, it is expected that solar adoption will continue to grow in the coming years. Historical data indicates a compound annual growth rate (CAGR) of 1.268 for net metering in DISCOs, which is used here to project future penetration rates.

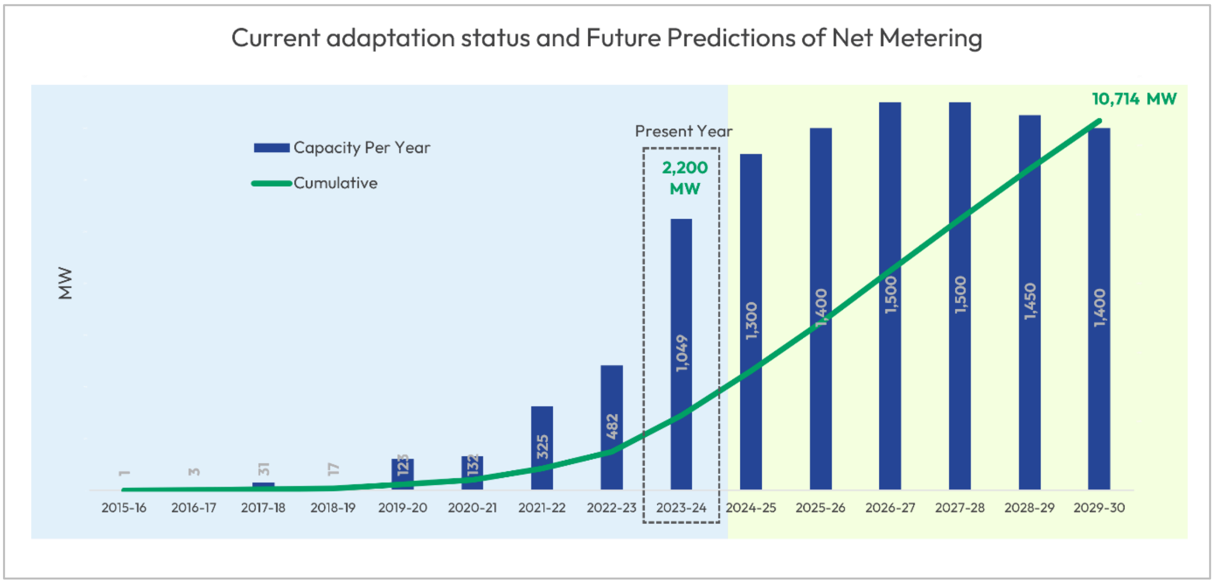


Figure 32: Current Adaptation and Future Prediction of Net Metering

In a low-demand scenario, IGCEP forecasts peak demand to reach 30,444 MW with total energy consumption estimated at 158,555 GWh for FY 2026-27. It is projected that by this time, behind-the-meter installations will increase to approximately 14,000 MW, with net metering capacity reaching around 7,300 MW. This growth in distributed solar generation is likely to lead to a "Duck Curve" effect in Pakistan, presenting significant challenges for grid management, particularly in the winter months following this period.

4.6. Early Signs of Duck Curve in Pakistan

The "Duck Curve" illustrates the challenges posed by the integration of renewable energy into power grids, particularly solar power. Named for its shape, which resembles a duck's body and head, the Duck Curve shows the pattern of net electricity demand (total demand minus renewable energy generation) throughout a day. As solar energy generation peaks during midday, the demand for power from conventional sources drops significantly, creating a "belly" in the curve. However, as the sun sets and solar generation decreases, demand for other energy sources rapidly increases, leading to a steep "neck" in the curve.

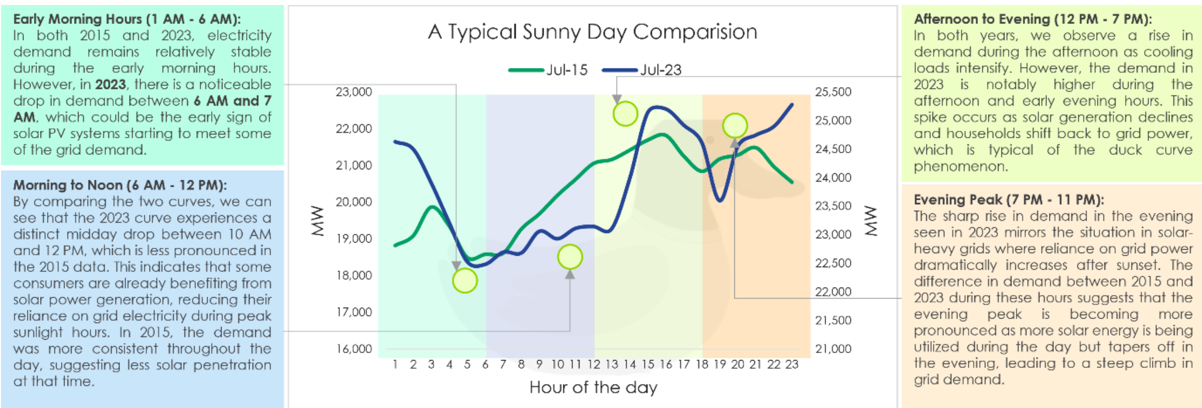


Figure 33: Early Signs of Duck Curve

In this analysis in figure above, we have compared electricity demand data for the summer months of 2015 with that of 2023 to examine how solar power adoption and changing energy patterns impact grid demand throughout a typical sunny day in Pakistan. The resulting "duck curve" reflects the shifts in demand due to solar generation, highlighting differences in usage and reliance on grid power across these two years.

- Early Morning Hours (1 AM - 6 AM)

The data shows that from 1 AM to 6 AM, electricity demand in both 2015 and 2023 remains relatively stable. However, in 2023, a noticeable dip occurs between 6 AM and 7 AM, suggesting a potential impact of solar PV systems. As dawn approaches, solar generation could be contributing to grid demand reduction, as some solar installations start to generate power, albeit at lower levels. This drop likely represents the early signs of a shifting energy profile as renewable sources begin to play a role in offsetting morning grid demand.

- Morning to Noon (6 AM - 12 PM)

The period from 6 AM to 12 PM highlights a more substantial midday reduction in demand in 2023 compared to 2015. The 2023 curve displays a clear dip around 10 AM to 12 PM, indicating that consumers are increasingly benefitting from solar power generation during peak sunlight hours, thus reducing dependency on grid electricity. In contrast, the 2015 curve remains more consistent, suggesting limited solar penetration at that time. This divergence points to growing solar adoption, allowing daytime grid demand to be lessened as solar-generated electricity fills a portion of the demand during these hours.

- Afternoon to Evening (12 PM - 7 PM)

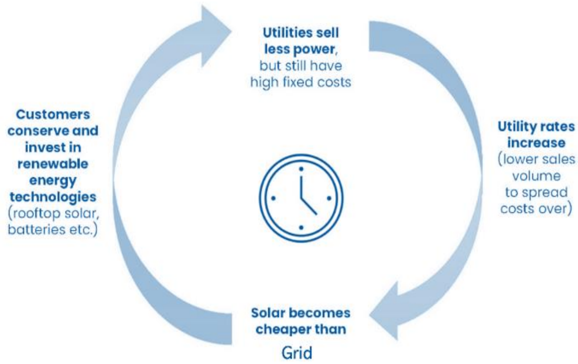
From noon to 7 PM, both 2015 and 2023 data illustrate a rising demand trend, corresponding with increased cooling loads as temperatures peak in the afternoon. However, the 2023 curve shows a significantly higher demand in the afternoon and early evening than in 2015. This uptick coincides with the decline in solar generation as the sun sets, leading households and businesses to shift back to grid power. This behavior aligns with the classic "duck curve" phenomenon, where demand drops midday due to solar input but sharply increases later as solar fades. The higher overall demand in 2023 also suggests a growing reliance on cooling and other power-intensive activities in Pakistan's rapidly developing urban landscape.

- Evening Peak (7 PM - 11 PM)

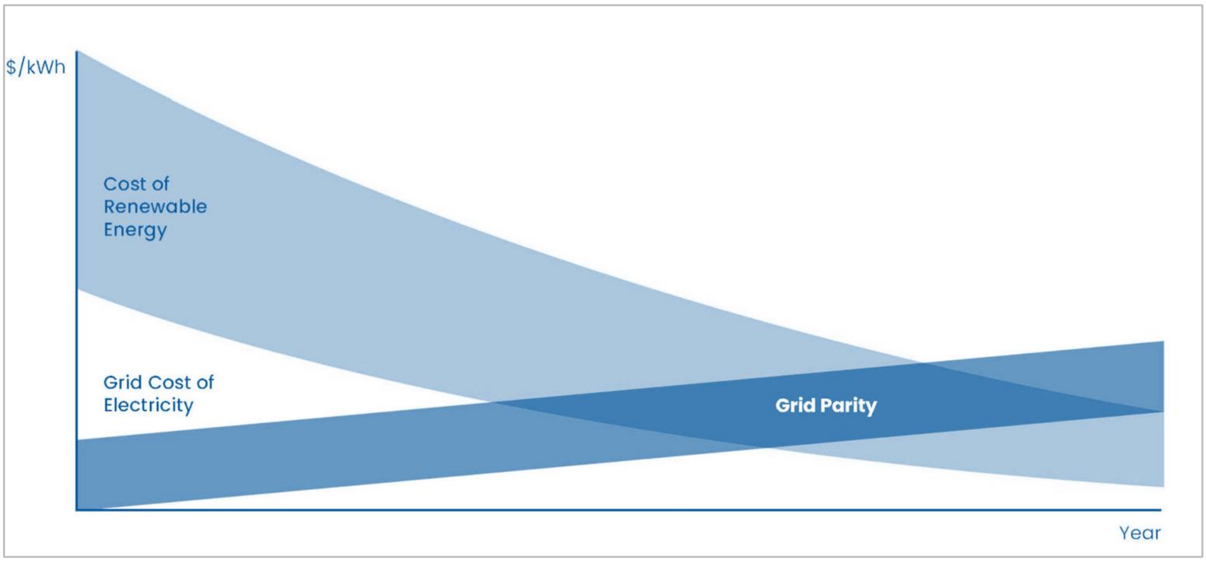
The sharp increase in demand observed in the evening hours from 7 PM to 11 PM in 2023 is characteristic of solar-heavy grids. As solar energy ceases to contribute, reliance on the grid surges, driving up demand. This evening peak in 2023 is steeper than in 2015, implying that as solar penetration rises, the dependence on the grid intensifies once solar supply is no longer available. This trend highlights an important challenge: while solar energy alleviates some of the daytime load, it can inadvertently intensify the evening peak demand. Addressing this shift may require storage solutions or demand response mechanisms to smooth the transition from solar to grid power as the sun sets.

4.7. DISCOs Death Spiral

As more homeowners adopt solar panels, they generate their own electricity, reducing their dependence on utility companies. While consumer solar adoption benefits the environment, it simultaneously diminishes utility companies' revenue from consumers. To offset this revenue loss, utilities often raise electricity prices, which, in turn, encourages more consumers to switch to solar, further reducing demand for grid-supplied power. This cycle, known as the 'utility death spiral,' can lead to escalating prices for consumers and financial instability for utility providers.



This scenario exemplifies the 'death spiral' concept previously considered mostly theoretical within the industry. With grid maintenance costs rising and the capital costs of renewable energy falling, more customers are expected to disconnect from the grid. In Pakistan, this cycle has already begun, necessitating urgent action to break the spiral and stabilize both consumer costs and utility operations.



5 International Perspective

Net Billing, Net Metering, Feed-in tariff and other programs like Gross-Metering, designed to encourage the adoption of renewable energy by allowing consumers to sell excess electricity back to the grid, have yielded varied results across countries. Their implementation has led to significant financial and operational impacts that highlight both opportunities and challenges for grid management and energy policies:

5.1. Vietnam:

Vietnam has experienced remarkable growth in its rooftop solar sector, primarily driven by an attractive feed-in tariff (FiT) program. Starting in 2019, the installed capacity of rooftop solar ballooned to approximately 16,500 MW by 2020, the highest among the ASEAN states. This rapid expansion was fueled by a FiT rate that incentivized consumers to adopt solar energy. The **Circular 16/2017 TT-BCT** of 2017 introduced the landmark net-metering policy in Vietnam to promote solar power. This policy set a distinct net-metering tariff of 9.38 US cents per kWh, which allowed settlement with the VND-USD exchange rate. It also included a comparable feed-in tariff (FIT) for ground-mounted solar installations, with a purchase guarantee from the national utility, EVN. A suite of policy measures such as highly competitive FITs/net-metering terms, land acquisition exemptions, and extended tax breaks created a conducive environment for large-scale adoption of solar energy, making the program a notable regional success. The program turned into a remarkable success, with rooftop solar capacity alone surpassing 9.5 GW by January 2021, as reported by Vietnam Electricity (EVN). An astounding 101,996 installations were recorded, with an incredible 6 GW of that total being added in a single month—December 2020.

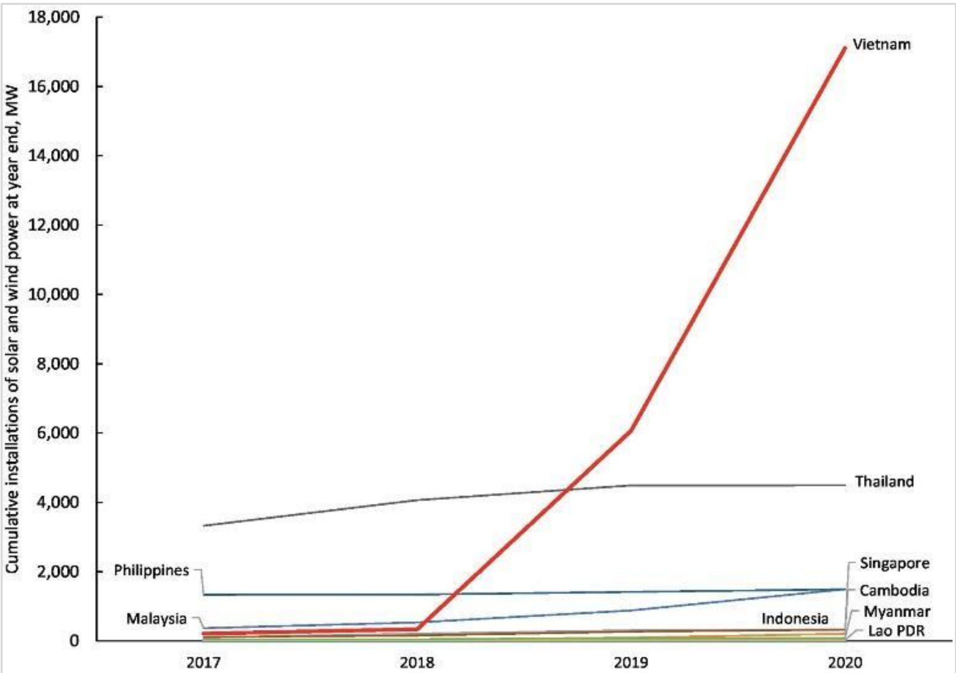


Figure 34: Vietnam Renewable Installations

The Transition

<table>
<tr><th colspan="4">FIT I – Solar Scheme 2019 – April 2020</th></tr>
<tr><td>FEATURES</td><td>ROOFTOP</td><td>GROUND MOUNTED</td><td>FLOATING</td></tr>
<tr><td>Surplus Tariff
US Cents/kWh</td><td>9.3</td><td>9.3</td><td>9.3</td></tr>
<tr><td>Tax Holidays</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Land Cost</td><td>Exempted</td><td>Exempted</td><td>Exempted</td></tr>
<tr><td>Purchase Guarantee</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Exchange Rate Cover</td><td>100 %</td><td>100 %</td><td>100 %</td></tr>
<tr><td>Licensing less than 1 MW</td><td>Registration with Local Company</td><td>Registration with Local Company</td><td>Registration with Local Company</td></tr>
<tr><td>Licensing 1 MW & Above</td><td>License Required</td><td>License Required</td><td>License Required</td></tr>
<tr><td>Licensing Duration All System Size</td><td>20 years</td><td>20 years</td><td>20 years</td></tr>
<tr><td>Surplus Billing Cycle</td><td>Annual</td><td>Annual</td><td>Annual</td></tr>
<tr><td>Program Cap</td><td>No</td><td>No</td><td>No</td></tr>
<tr><td>Min Efficiency Allowed</td><td>15 %</td><td>15 %</td><td>15 %</td></tr>
<tr><td colspan="4">FIT II – Decision 13/2020 -22 May 2020</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Surplus Tariff
US Cents/kWh</td><td rowspan="2">8.35</td><td>7.09
Rest of Vietnam</td><td rowspan="2">7.69</td></tr>
<tr><td>9.35
For Ninh Thuan province Projects COD till Dec 2020</td></tr>
<tr><td colspan="4">*All remaining incentives remained the same</td></tr>
<tr><td colspan="4">FIT III – Roof Top Solar FIT Cut April 2021</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Surplus Tariff
US Cents/kWh</td><td>5.8
Residential</td><td rowspan="2">No Change Reported</td><td rowspan="2">No Change Reported</td></tr>
<tr><td>5.2
Commercial</td></tr>
<tr><td colspan="4">*No other change was reported</td></tr>
<tr><td colspan="4">In 2022 the National Load Dispatch Centre (NLDC) banned all future uptake in the Country</td></tr>
<tr><td colspan="4">Till 2024, various proposals have been put forward by the Ministry of Industry & Trade (MoIT)</td></tr>
</table>

Grid Curtailments due to High Intermittent Generation Volume:

However, this rapid growth outpaced the development of the necessary grid infrastructure, leading to significant congestion and curtailment issues. In 2020, approximately 364 GWh of solar energy was curtailed, leading to considerable economic losses and wasted power resources.

The concentrated rise in rooftop solar installations overwhelmed Vietnam's transmission system, resulting in ***a 14% curtailment rate*** *(1.6 GWh in one month)* in some regions during solar's midday generation peak and during the evening rush from 5:30 to 6:30 PM, when energy demand spiked and solar output began to dip.

364 GWh of Solar Generation curtailed in 2020!!!

This situation highlighted the critical need for improvements in grid capacity and management systems alongside renewable energy promotion efforts. In 2022, all future uptakes were banned in the country.

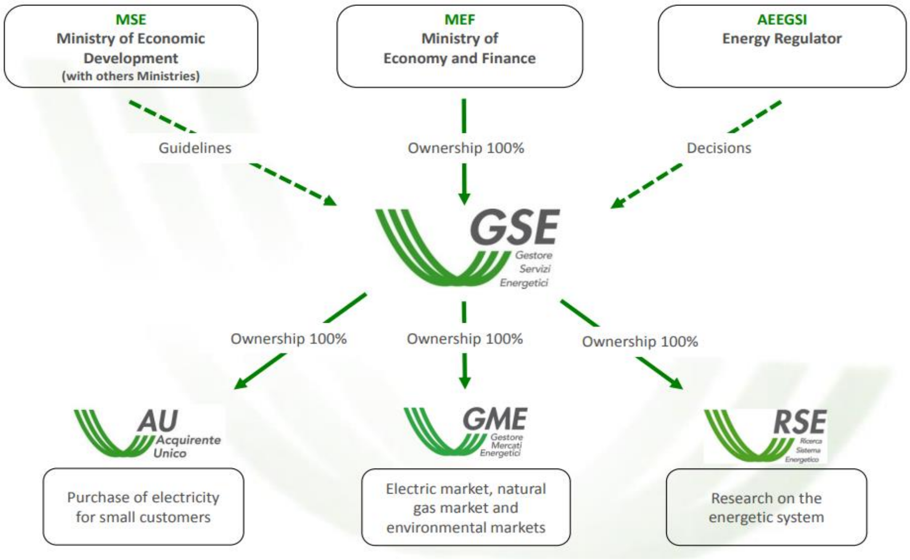
Reviving Net-Metering in Vietnam:

In July 2024, the Ministry of Industry and Trade (MoIT) proposed a tariff of VND 671 (2.6 cents)/kWh for 10% offtake of surplus solar power. Later in September of the same year, another proposal was put to the Prime Minister proposing a 20% surplus offtake of installed system size. At present, Vietnam hosts approximately 103,000 rooftop solar installations, with a combined capacity surpassing 9,500 MW. According to the National Power Development Plan for 2021-2030 (PDP VIII), this figure is projected to increase by an additional 2,600 MW by 2030, with a broader strategic outlook extending to 2050.

5.2. Italy:

Italy, another leader in solar and wind energy, encountered similar challenges with grid congestion. To address these issues, the country introduced Dynamic Line Rating (DLR) systems. The Italian transmission operator started deploying Dynamic Line Rating (DLR) on select critical lines, with the long-term goal of using the data for optimal power dispatch. In the meantime, DLR has been utilized as a temporary solution to meet demand while awaiting further network upgrade. These systems utilized real-time environmental data—such as temperature and wind speed—to dynamically adjust the transmission capacity of power lines, thereby optimizing the grid's ability to handle fluctuating renewable energy inputs. This technological adaptation proved crucial in reducing curtailment and preventing grid overloads, demonstrating the importance of smart grid technology for integrating intermittent renewable energy sources efficiently. Additionally, Italy has expanded its focus on energy storage technologies, reinforcing the need for flexible systems that can store excess renewable energy when generation surpasses demand. Terna, Italy's grid operator, is planning a €16.5 billion investment over the next half of the decade to modernize the country's transmission infrastructure and advance the shift to decentralized energy. The initiative will prioritize expanding grid capacity, relieving congestion, and incorporating renewable energy like solar. Approximately €10.8 billion will be directed toward projects such as high-voltage direct current lines and submarine cables.

Additionally, enhancing cross-border electricity connections will be a key objective, reinforcing Italy's position as a key energy hub in the Mediterranean.



Gestore dei Servizi Energetici (GSE), a state-owned company in Italy, operates as the Energy Service System Operator. It is responsible for acquiring energy from producers and prosumers and redistributing it in the market, facilitating the flow of energy within the national system.

CLEAN ENERGY PROMOTION SERVICES RENDERED BY GSE
Support Schemes for RES Electricity
CIP 6/92 (a kind of feed-in tariff).
Green Certificates For plants achieving COD by 2012 (with glide period).
Feed-in Tariff for gensets up to 1 MW.
Fixed Feed-in Premium for PV & RES plants.
Sliding Feed-in Premium for PV & RES plants.
Energy Services for RES & CHP Electricity
Net-Metering scheme for RES & CHP plants up to 500 kW.
Dedicated Electricity Procurement for procurement at market average price from plants selling through GSE.
Support Schemes for Thermal RES & Energy Efficiency
Renewable Heat Incentive.
White Certificates.
Biofuels Support Schemes (Blending Obligation)
Biofuels Certificates, sustainable biofuels to enter with a blending mix obligation.

In 2009, the Italian government implemented net metering regulations known as **"Scambio sul Posto."** This framework imposed a **capacity limit of 500 kW** on individual power generation systems, regardless of the technology employed. Prosumers—those who both produce and consume energy—are eligible for financial compensation when their electricity production exceeds their usage. The **compensation** is calculated using the formulas **outlined in Article 6 of Regulation 570/2012**. Tariffs are adjusted annually, with each net metering agreement incurring **a fixed fee of EUR 30**, and a **variable charge of EUR 1 per kilowatt for systems**

between 20 kW and 500 kW. Additionally, systems with a **capacity greater than 3 kW** are required to pay a **fee to GSE** to cover administrative, verification, and oversight expenses.

The net metering program **"Scambio sul Posto" ("On-site Exchange")**, which allowed prosumers to offset the value of the energy they supplied to the grid against their consumption, and receive financial compensation if their energy contribution exceeded usage, was discontinued after 2023. This phase-out was also applied to other programs like the Credit Transfer scheme, which allowed credits to be sold to third parties such as ESCOs, banks, or companies. The idea was to replace these by new measures designed to encourage self-consumption of energy. However, certain ***financial incentives*** remained intact, including:

House Bonus (Bonus Casa): A tax deduction of up to 50% on IRPEF (personal income tax) for the purchase of photovoltaic (PV) systems.

Super bonus 110%: Initially offering a 110% tax deduction on related expenses, this incentive has been reduced to 90% as of 2023.

In addition, various regional financial instruments were kept intact to cover all or part of investment costs for photovoltaic (PV) systems in regions such as Friuli-Venezia Giulia, Basilicata, Sardinia, Marche, Puglia, Lazio, and Sicily. In ***April 2023, the Ministry of Agriculture introduced incentives for rooftop solar PV*** installations in the agricultural and agro-industrial sectors, ***offering funding for up to 80% of the costs*** through the Recovery and Resilience Fund. In ***November 2023***, the government also created a ***€200 million fund to assist low-income families in installing PV systems***. This fund was to be available for 2024 and 2025 and managed by the Gestore dei Servizi Energetici (GSE), a state-owned company under the Ministry of Economy and Finance.

Overall, numerous mechanisms support the adoption of residential PV systems. However, the highly impactful 110% tax deduction that significantly boosted small-scale PV installations over the past two years has been reduced to 90%, and the option for credit transfer has been eliminated.

Energy Sharing (P2P):

In Italy, the public grid currently supports collective self-consumption (CEC) and energy sharing through two main models:

Collective self-consumption, where the scope is limited to a single building.

Renewable energy communities, where the area covered extends to the primary electricity substation that converts power from high to medium voltage, potentially serving up to 30,000 to 40,000 users.

Collective self-consumption involves at least two prosumers within the same building who share energy resources. A typical case is a multi-family residential building with a shared photovoltaic (PV) system. The electricity generated by the system partially meets the residents' energy needs, with any surplus fed back into the grid.

According to ***the Italian Regulatory Authority for Energy, Networks, and Environment (ARERA)***, energy sharing *incentives in 2022 amounted to €0.11 per kilowatt-hour* for energy generated and consumed within the community, along with additional market premiums. As reported by the Gestore dei Servizi Energetici (GSE), Italy has recognized 74 groups engaging in collective self-consumption to date.

Commitment to a Higher Share of Clean Energy:

Italy has incorporated the definitions of Renewable Energy Communities (RECs) and Collective Self-Consumption (CEC) into its national legislation. The law stipulates ***that REC projects must not exceed a capacity of 1 MW per project***, and defines geographical proximity as consumption points connected to the same medium voltage substation. In November 2023, the European Commission officially approved the executive decree for ***Italy's plan to promote renewable electricity*** production and self-consumption. The scheme was designed to encourage the growth of energy communities and ***supports the installation of renewable energy systems up to 1 MW***. It offered ***two forms of financial aid,*** which can be combined:

1. A ***premium tariff*** on self & community consumption paid over a **20-year** period. *This initiative, with a total* ***budget*** *of* ***€3.5 billion,*** *intended to be* ***funded by a levy*** *on the electricity bills of all consumers*.

2. An investment grant covering 40% of costs, with a budget of €2.2 billion, through the Recovery and Resilience Facility (RRF).
   Eligibility: Projects CoD by June 30, 2026, and located in municipalities with fewer than 5,000 inhabitants

5.3. Germany:

As Germany's clean energy transition accelerated, the installed capacity of photovoltaic (PV) systems grew rapidly, driven by incentives from the German Renewable Energy Sources Act (EEG). Although these PV systems were connected to the low-voltage grid, their widespread adoption began to impact the larger power system, introducing new risks that hadn't been encountered before. Germany, with one of the highest solar capacities in Europe, faced challenges not only related to grid congestion but also grid frequency stability. Excess solar power generation caused frequency deviations that could potentially destabilize the grid. In response, Germany enacted stricter regulations for solar inverters, requiring them to adjust output based on real-time grid frequency. This regulation—known as frequency-sensitive inverter technology—allowed for better control of distributed solar power, ensuring that solar generators could curtail their output when necessary to maintain grid stability. Germany's experience underscores the need for regulatory frameworks that address both the volume and the variability of renewable energy.

When examining Germany's total energy load for the years 2015 and 2023, with a focus on the share of renewable energy and residual load (demand minus variable renewable generation), it becomes clear that as renewable energy increases, the residual load decreases. However, over time, the fluctuations in residual load become more volatile and extreme.

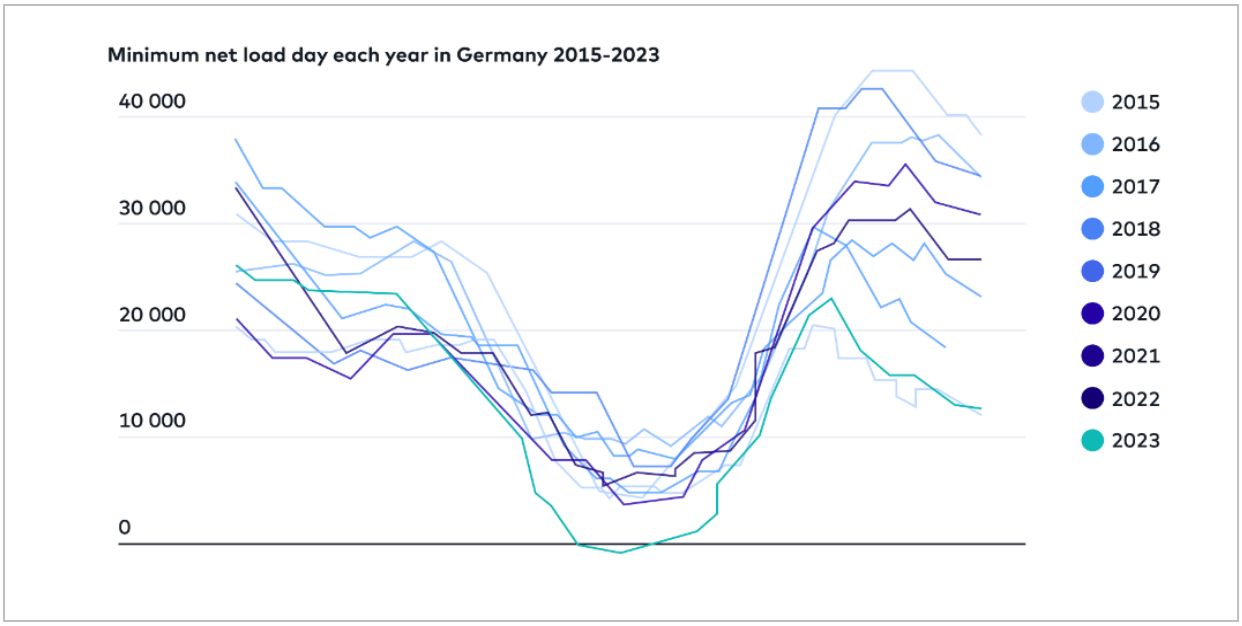


Figure 35: Comparison of Residual Load in Germany from 2015 - 2023

While not as smooth as California's, Germany's net-demand curve follows a similar trend, with a deeper "belly" and a more pronounced duck curve evolving into a canyon. As these dips grow steeper, the demand for grid flexibility rises. In 2023, Germany's net-demand formed a much deeper dip compared to 2016, and on April 10, 2023, the residual load even turned negative. This highlights the increasing challenge of balancing supply and demand as the share of renewables grows.

5.4. Australia:

Australia has one of the highest levels of rooftop solar penetration globally. However, its rapid growth in distributed solar generation has resulted in similar grid congestion and energy export issues. Australia responded by introducing ***time-based tariffs and export limits***, also known as **'Two Way Pricing'** to manage the inflow of excess solar generation during peak sunlight hours. As of May of 2024, Ausgrid, the largest electricity distributor on Australia's east coast, is implementing this pricing model charge of ***a 1.2 c/kWh*** to encourage maximum self-consumption from PV systems between ***10 AM and 3 PM***. During these hours, solar exports will incur a charge, while ***exports during peak demand (4 PM to 9 PM)*** will be rewarded with ***credits of 2.3 cents/kWh***. Additionally, a "free threshold" will allow electricity in the range of 192 kWh to 212 kWh to be exported without charges during the midday period. In contrast, other Distribution Network Service Providers (DNSPs) are adopting a different approach to manage congestion. For instance, South Australia Power Networks (SAPN) is introducing dynamic solar exports, ***enabling remote adjustment of solar inverters based on network conditions.*** Similarly, in Victoria, new inverters must be capable of adjusting solar export limits dynamically and remotely. These policies encourage solar owners to invest in battery storage, allowing excess power to be stored for later use instead of overwhelming the grid during peak generation times. The integration of battery storage systems helps mitigate grid stress and reduces the likelihood of curtailment.

5.5. California, United States:

In the U.S., net metering policies vary by state, with some states like California leading the way in integrating distributed solar. However, California has faced its own challenges, including duck curve issues, where excess solar generation during midday results in steep ramping requirements for non-renewable energy sources in the evening.

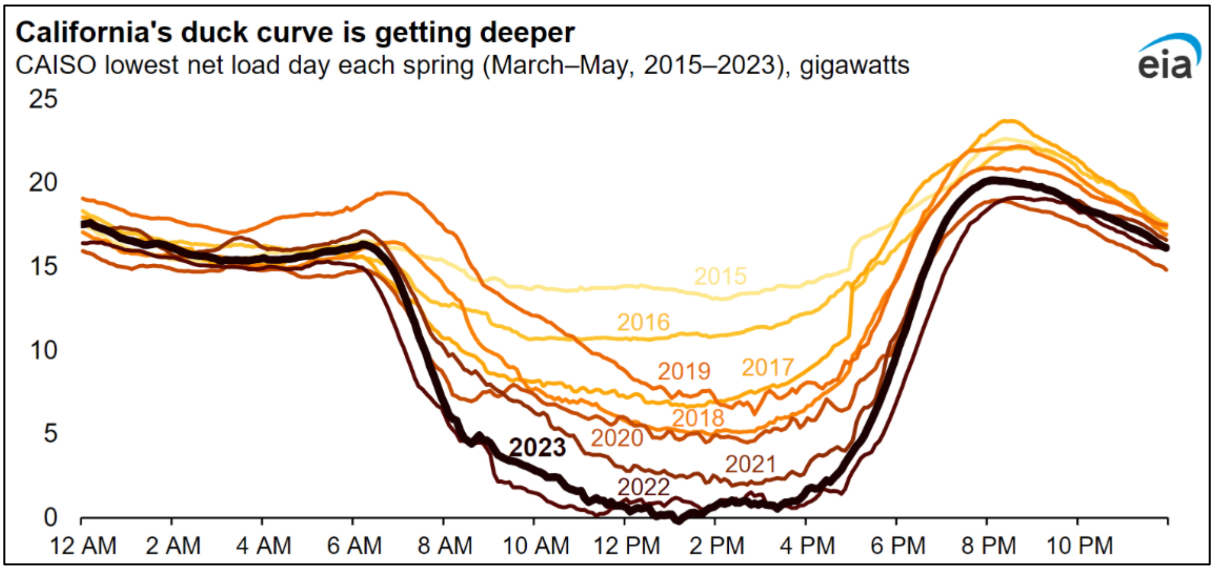


Figure 36: California Duck Curve

This has led to the proposal & implementation of **time-of-use (TOU) rates**, in 2016 which incentivize consumers to use energy during off-peak hours or store solar energy for later use. California is also advancing the development of **grid-scale battery storage** solutions to address these imbalances.

Net-Metering in the State of California:

Senate Bill 656.28 marked the official launch of net metering in California as early as 1995. This program, known as Net Energy Metering (NEM) 1.0, was accessible to small-scale solar, wind, biogas, and fuel cell generators with a capacity of up to 1 MW within the service areas of the state's three major investor-owned utilities: Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E). The NEM program enabled customers to use the energy they generated to reduce their electricity bills while also providing financial compensation for any surplus electricity that was sent back to the grid.

Salient features of the Program **NEM 1.0** included:

1. Monthly billing credits for surplus generation at the retail tariff, which encompasses generation, transmission, and distribution components (ranging from $0.02/kwh to $0.03/kwh).
2. Annual net surplus compensation at an average market rate following the conclusion of the billing cycle. Additionally, customers can earn renewable energy credits by registering with the Western Renewable Energy Generation Information System (WREGIS).
3. A virtual net metering initiative that enables property owners to equitably allocate billing credits among multiple tenants.

4. The net metering aggregation feature allowing agricultural customers to obtain NEM credits for multiple meters associated with the same property through a single renewable generation system.
5. Renewable Energy Self generation bill credit transfer (RES-BCT) enabling entities to share NEM credits earned at only generation point of one system with billings at any other location owned by the same entity with system size up to 5 MW.

On January 28, 2016, the California Public Utilities Commission (CPUC) transitioned the NEM1 program to NEM 2.0 via **Decision (D.) 16-01-44**[22]. This new version introduced several modifications to the original program, while ensuring that current users were not impacted by these changes.

NEM 3.0

Following years of deliberation and discussion, the California Public Utilities Commission (CPUC) via **Decision 22-12-056** on December 15, 2022, approved the third iteration of California's net metering program, known as NEM 3.0 which came into effect on April 14th, 2023. Users who filed applications before April were grandfathered into NEM 2.0. This new NEM 3.0 featured:

- **Switch to Net-Billing**: For the first time, Net metering was replaced by a **Net Billing Tariff** Scheme which saw the compensation rates cut down by 75% on average. Retail export compensation rates are determined using hourly values (**TOU- Tariff**) from the 'Avoided Cost Calculator', averaged over the days of the month, and differentiated between weekdays and weekends/holidays.

- During the first five years, referred to as the 'glide path transition period', retail export compensation rates for residential and non-residential net billing tariff customers will follow a nine-year schedule of hourly values derived from the most recent Avoided Cost Calculator. These values are established as of January 1 of the calendar year in which the customer's system is interconnected. This is also known as the lock-in period. After the locked-in period, retail export compensation rates will be determined using the average hourly avoided cost values from the most up-to-date Avoided Cost Calculator, set as of January 1. Customers enrolling after the 'glide path' will not be allotted any 'lock-in' period.

- **Transition Support Adders:** For further supporting the transition, Pacific Gas and Electric (PG&E) and Southern California Edison (SCE) customers are eligible for additional export rate adders during the first five years of the NEM 3.0 program. *(SDG&E customers are excluded because their solar systems generate more bill savings due to SDG&E's higher electric rates)*.

- Known as the Avoided Cost Calculator Plus (ACC Plus) adder, these are calculated in cents per kilowatt-hour of exported energy. This adder will be available to net billing tariff customers for the first five years of the successor tariff as part of the glide path transition. Once applied, the ACC Plus adders, as shown in the table below, will remain fixed for each customer for nine years from their interconnection date. Customers transitioning from NEM 1.0 or NEM 2.0, and those owning a building with a solar system will not be eligible for these.

- The adder will decrease by 20% annually for newly enrolled tariff customers, starting from the initial rate, until it is fully phased out. It will be listed as a separate item on the customer's utility bill, applicable to all charges, and will carry over to future bills until the credit is entirely used. Funding for the adder will come from all ratepayers through the Public Purpose Program charge.

Adopted Avoided Cost Calculator Plus Adders			
Customer Segment	**PG&E**	**SDG&E**	**SCE**
Residential	$0.022/kWh	$0/kWh	$0.040/kWh
Low Income	$0.090/kWh	$0/kWh	$0.093/kWh
Non-Residential	$0/kWh	$0/kWh	$0/kWh

- For the above table, low-income customers are categorized as any of the following: (i) residential customers participating in the California Alternate Rates for Energy and Family Electric Rates Assistance programs; (ii) resident owners of single-family homes located in disadvantaged communities (as defined in Decision (D.) 18-06-027); and (iii) residential customers residing in California Indian Country (as defined in D.20-12-003).

- **System Size:** Customers **may oversize their generation systems by up to 50%**. This is subject to two conditions: first, the oversizing measurement will be based on the past 12 months of usage, unless the customer has less than 12 months of usage or attests to an increase in usage. In such cases, the customer must expect to increase their usage to match the system size within 12 months of interconnection. Second, net surplus generation will be compensated at the current net surplus compensation rates. A virtual net billing tariff (VNB) was also introduced in November, 2023 via **Decision D.23-12-068** however the focus of the study is only on NEM 3.0 Net Billing.

<table>
<tr><th></th><th>NEM 1.0</th><th>NEM 2.0</th><th>NEM 3.0</th></tr>
<tr><td rowspan="2">INTERCONNECTION FEE</td><td rowspan="2">None</td><td>Different fee strucutres for utilties:</td><td>Different fee strucutres for utilties:</td></tr>
<tr><td>PG&E: $145, SCE $75 and SDG&E $132</td><td>PG&E: $94-$145</td></tr>
<tr><td rowspan="5">NON-BYPASSABLE CHARGES</td><td rowspan="5">Applicable on the netted off kWh of electricity consumed annually</td><td rowspan="5">Applicable on netted of kWh of electricity consumed in a recorded interval i.e., 1 hour for residential users and 15 min for non-residential customers</td><td>All energy imports.</td></tr>
<tr><td></td></tr>
<tr><td>Public</td></tr>
<tr><td>Purpose program, Nuclear decommissioning, Competition transition, and the Wildfire</td></tr>
<tr><td>Fund non-by passable Charge</td></tr>
<tr><td>TIME OF USE RATE (TOU)</td><td>Not Applicable</td><td>Applicable</td><td>Specific Electrification TOU Rates</td></tr>
<tr><td>BASIS OF CREDITS FOR RETAIL</td><td>Import Rate</td><td>Import Rate</td><td>CPUC Avoided Cost</td></tr>
</table>

ENERGY EXPORTS BEFORE TRUE-UP			Calculator values (mostly less than import rates)
BILLING AND TRUE-UP PERIOD	Annual billing, annual true-up (Both charges and credits roll over for 12 months)	Annual billing, annual true-up (Both charges and credits roll over for 12 months)	Monthly billing (pay monthly); Annual true-up (credits roll over for 12 months)
SYSTEM SIZE CONSTRAINT	1 MW	No constraint user can at maximum deploy system size equal to his/her annual load	Annual electricity Load of Customer and 50% additional if attest to need.
IOU PROGRAM CAP	5 % of IOU's aggregate peak demand or July 1st, 2017	No cap	No Cap
TERM OF AGREEMENT	20 Years	20 Years	9 Years

Lessons & Potential Solutions from International Utility Practices

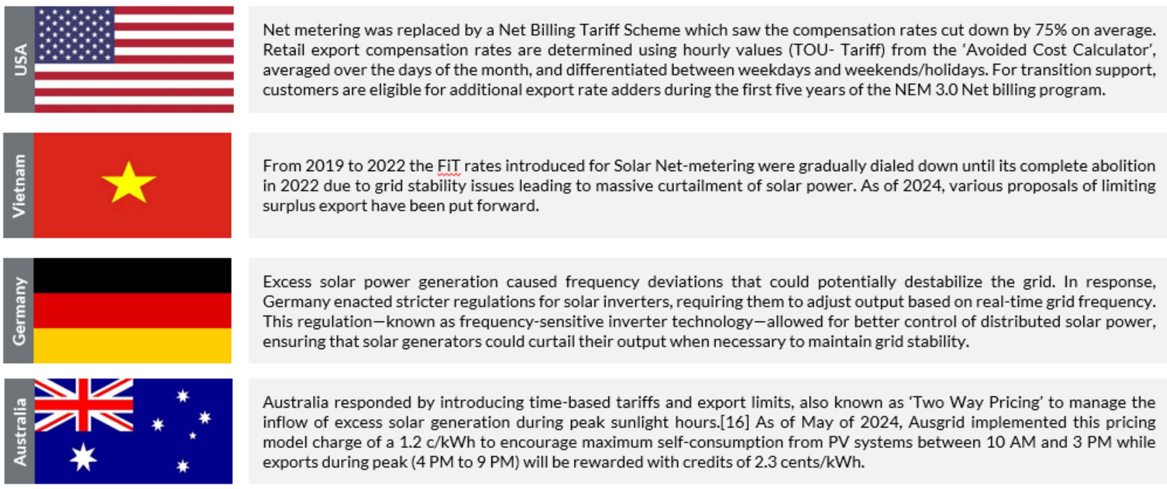


Figure 37: International Perspectives

The experiences of these countries emphasize several key lessons for regions looking to expand net metering programs:

Grid Infrastructure:

The rapid growth of distributed energy resources (DERs) requires grid upgrades to avoid bottlenecks, as seen in Vietnam and Italy. Advanced management systems like DLR in Italy show how real-time monitoring can prevent grid overloads.

The rapid expansion of variable renewable energy (RE) in Vietnam, coupled with limited grid and energy storage infrastructure, led to congestion and curtailment issues. The lack of an adequate grid system hindered the full utilization of renewable power in the Central and Southern regions and prevented it from addressing the power demand in the North. The rapid growth of RE in Vietnam during 2019-2020 exposed significant challenges related to transmission infrastructure. Grid congestion problems stalled the development of utility-scale solar projects for two years, causing curtailment and financial losses for existing solar installations. As a result, the swift expansion of variable RE in South-Central Vietnam caused issues like grid congestion and energy curtailment. In 2020, approximately 364 GWh of solar energy was curtailed, leading to considerable economic losses and wasted power resources.

Integrated Energy Planning:

Reforming planning strategies can enhance the deployment of new generation capacity by preventing congestion and situating generation facilities closer to load centers. This can be accomplished through initiatives such as establishing ***Renewable Energy Zones*** and developing **integrated provincial energy plans.**

Risk Sharing/Mitigation Mechanisms:

Proposed here are three key recommendations to tackle grid related problems due to intermittent generation. First, governments should reform the structure of **power purchase agreements (PPAs)** to better balance risks between investors and off-takers. Second, the implementation of more advanced economic incentives, such as **reverse auctions**, is essential to establish equitable market conditions for renewable energy. These auction mechanisms should include protective measures like **'contracts-for-difference,'** which are gaining traction in PPAs to reduce the risks linked to variable renewable energy for both sellers and buyers. Finally, there should be a concerted effort to streamline and improve the efficiency of **permit procedures** that are currently outdated and unnecessarily complex.

Regulatory Adaptations & Equitable Cost Sharing:

Germany's inverter regulations and Australia's time-based tariffs demonstrate the importance of adaptive regulations that can manage the variability of renewable energy, ensuring both grid stability and fairness for all consumers.

As net metering expands, the financial burden on non-net metering consumers can increase. Policies must ensure that costs associated with grid maintenance and upgrades are distributed equitably between prosumers (those generating energy) and traditional consumers. **Time-based tariffs** and **export limits** are examples of mechanisms that can help achieve this balance Time-based tariffs and export limits are essential features for enhancing control over net metering programs. Time-based tariffs incentivize energy generation and consumption during peak demand periods by varying rates based on the time of day. This encourages users to optimize their energy usage and production, leading to a more balanced grid. Meanwhile, export limits help manage the amount of excess energy that can be fed back into the grid, preventing congestion and ensuring grid stability. Together, these mechanisms allow utilities to better align renewable energy generation with demand, fostering a more efficient and reliable energy system while maximizing the benefits of net metering.

The **transition of net metering policy programs** is crucial as it allows utilities to adjust compensation rates and modify program features based on evolving energy market conditions and technological advancements. This flexibility enables utilities to better manage grid stability, promote renewable energy integration, and address cost concerns associated with compensation for excess energy. By refining these policies, utilities can encourage greater adoption of renewable technologies while ensuring fair cost-sharing among all customers, ultimately leading to a more sustainable and efficient energy system.

Energy Storage & Electric Vehicles an Opportunity in a Crisis:

Integrating energy storage is critical for handling excess generation and reducing curtailment, as evidenced by policies in Australia and the U.S. This allows for better energy use during non-generation periods and helps balance the grid. The reduction of greenhouse gas emissions and the enhancement of electric energy security have gained significant momentum in recent years. The integration of intermittent renewable energy sources (RESs), such as solar photovoltaic (PV) and wind, into the existing grid has surged over the past decade. However, this integration presents numerous operational and control challenges that can hinder the reliable and stable functioning of the grid. Key issues include generation uncertainty, voltage and angular stability, power quality concerns, reactive power support, and fault ride-through capability.

Control systems: Control theory, a well-established field within engineering, has emerged as a crucial tool for tackling the intermittency associated with renewable energy sources. Recent advancements in this discipline have enhanced our understanding of control methodologies that can effectively manage fluctuations in energy generation. Furthermore, these developments have enabled the application of control systems to optimize the performance of power grids that integrate renewable resources. Integrating a variety of storage methods into the power infrastructure enhances grid stability and facilitates the smooth incorporation of renewable resources.

Given the variability of renewables, energy storage systems (ESS) play a vital role in balancing the grid by providing essential flexibility.

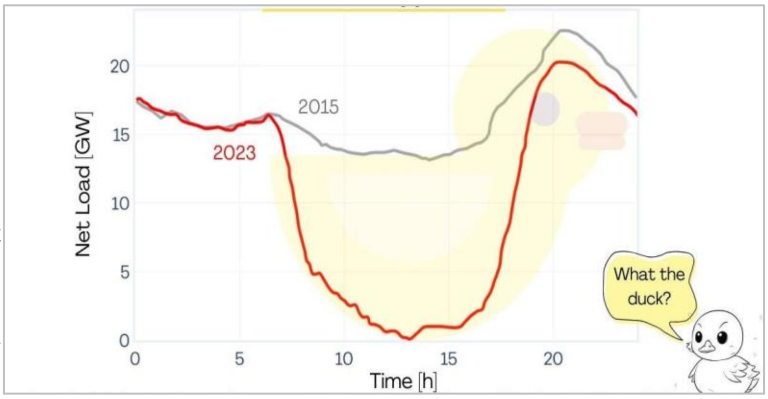
Energy storage systems (ESS) play a crucial role in maintaining grid stability. They provide energy during low-demand periods and support the grid during peak consumption, ensuring a continuous power supply. This coordination helps prevent potential grid overloads and frequency fluctuations, thereby enhancing reliability. ESS facilitates the integration of renewable energy sources by addressing their inherent unpredictability. By storing excess renewable generation, a consistent energy stream is ensured, mitigating the effects of renewable variability on the grid. Through strategic energy conservation and coordinated dispatch, ESS optimizes energy distribution, improving deliverability and reducing strain on the grid.

EV for Increasing Grid Demand: Electric vehicles (EVs) can play a significant role in helping developing countries manage grid demand and ***reduce the impact of the duck curve***. By serving as mobile energy storage units with bidirectional charging, EVs can store excess renewable energy during periods of low demand (such as midday when solar production is high) and release it back to the grid during peak demand hours. This helps ***balance supply and demand, smoothing out the duck curve***. Additionally, widespread EV adoption boosts overall electricity demand, which can further incentivize the development of renewable energy infrastructure. Fully charged EV batteries could provide a distributed network of backup power through vehicle-to-grid (V2G) programs, supplying electricity to homes and communities during peak demand. Once demand stabilizes, the EVs can recharge, ready to supply power again the next day.

Addressing the Duck Curve Problem

Demand Side & Load Flexibility management programs: These are important to handle the capacity constraints imposed by the grid architecture and renewable energy sources. The best-known example of these constraints is the ***"duck curve,"*** which occurs because of the increasing effect of a large PV share on the energy generation, which effectively turns off other dispatchable sources of electricity like gas during the day. This midday dip in net load for the conventional sources is getting lower with increasing PV share and that presents at least two challenges for grid operators. The first challenge is grid stress since the conventional sources of energy must ramp up production very quickly. The second challenge is economic. The dynamics of the duck curve can challenge the traditional economics of dispatchable power plants because the factors contributing to the curve reduce the amount of time a conventional power plant operates, which results in reduced energy revenues.

Load shifting: Encouraging consumers to use energy during optimal times is key to promoting load shifting. This can be achieved by introducing time-of-use and dynamic tariffs to help balance demand curves.



Home storage: Utilizing household batteries more effectively can turn consumers into prosumers, allowing them to sell surplus electricity back to the grid. Electric vehicles (EVs) can also serve as storage systems through bidirectional charging, making them valuable assets for grid flexibility. Regulations need to keep pace with technology to support these demand-response initiatives.

Utility storage: Large-scale batteries contribute to grid stability with their rapid ramp-up capabilities, helping to maintain balance.

Sector coupling: Connecting different sectors enables the use of excess clean energy, such as storing surplus electricity in hydrogen. Likewise, waste heat from industrial processes can be repurposed to generate electricity when demand rises and renewable output falls.

Virtual power plants: Using combination of DERs, virtual power plants act as a single dispatchable unit. This creates a substantial opportunity to provide flexible power, particularly when solar generation decreases.

Data Centers Build-up to Increase Grid Consumption: The International Energy Agency reports that datacenters consumed 460 TWh of energy in 2022, with projections suggesting this could exceed 1000 TWh by 2026. For comparison, Germany, the world's third-largest economy, used 507 TWh in 2022. The positive aspect of datacenter computational workloads is their flexibility, both in terms of when and where they can be processed. ***The U.S. is experiencing an unprecedented rise in data center power demand, which is expected to double by 2030, reaching 35 GW—about 7.5% of the country's total electricity consumption***. This level of demand is equivalent to powering nearly a third of American homes (40 million). A record-breaking 4.3 GW of new data center projects were initiated in 2023, driven by the ***growing demands of cloud computing, cryptocurrency mining, and AI workloads, including power-intensive large language models***. This rapid expansion of data centers for technology advancement can be a huge opportunity for developing countries like Pakistan to capitalize upon and substantially boost their grid capacity usage effectively bringing down their unutilized capacity charges. The technology build up can be shifted to the developing countries if provided the right price signals & the availability of the critical infrastructure required

6

Policy & Regulatory Challenges The Way Forward

Distributed solarization can lead to revenue loss for utilities as consumers generate their own power, reducing demand from the grid. This decline in traditional energy sales may drive up fixed costs per customer, as utilities must still maintain infrastructure with fewer contributing users. Large-scale Power Purchase Agreements (PPAs) become more costly to manage, as fluctuating demand and increased renewable integration require complex grid balancing solutions. **These financial pressures can ultimately shift costs onto non-solar customers, creating equity challenges.**

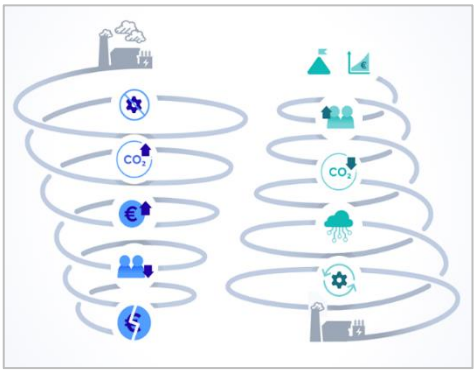
This chapter builds on the findings of the preceding report, providing recommendations to the respective Authorities and utility companies on adjusting the tariff structure to reduce disparities between distributed solar generation users (either behind the meter or net meter) and non-solar users. Furthermore, it advocates for policy adjustments that harmonize the promotion of renewable energy, particularly solar PV, with the need to preserve the financial viability of distribution companies.

6.1 Revamping the Utility Business Model

Sustainability of Current Tariff Structures

The power sector in Pakistan has largely followed a rent seeking model since its inception with the GoP picking up any deficit created by inefficiencies of the system. This has continued till date and *the existing tariff structure—encompassing cross-subsidies, surcharges, fuel and quarterly adjustments, along with additional taxes—is not sustainable for any grid company and gradually started to trigger a phenomenon known as 'the utility death spiral'* as explained in more detail in the report above.

The utility death spiral refers to a critical case in which the conventional utility business model risks becoming unviable. This trend emerges as consumers take a more active role in both using and generating their own energy, driven by a desire to lower costs and support decentralized, sustainable energy. *If conventional utilities fail to adjust their services to accommodate this shift toward "prosumerism," they risk losing customers.* This loss of customers forces utilities to raise prices to meet fixed expenses, which, in turn, makes alternatives like rooftop solar more appealing, intensifying the downward spiral.



6.1.1. Fixed Mode of Recovery & the NAPPP Conundrum

Besides the lucrative covers, the *tariff structure in Pakistan is generally designed for a volumetric recovery* where the consumers are *charged* for all fixed and variable costs *through a per kWH consumption* configuration. Although since July 2024, the GoP has increased fixed charges share in Industrial and Commercial Tariffs and also imposed fixed charges per the consumption slab for residential consumers as well, yet the total percentage for fixed mode of recovery is only 6% compared to the volumetric portion of 94%.

Moving forward, another challenge arises with the current net metering policy. In Pakistan, the tariff for surplus energy from prosumers is based on the ***National Average Power Purchase Price (NAPPP)***, which includes both capacity (fixed) charges and variable costs. This setup creates an inequitable and disproportionate incentive for prosumers, who not only offset the high energy purchase price (EPP) of grid-supplied electricity but also receive compensation for fixed charges they do not actually incur. Consequently, this additional cost is passed on to non-solar consumers, adding an estimated 1.5 to 2 PKR per kWh.

The proposed solution does not involve raising tariffs, as this would only drive more consumers to leave the grid. Adjusting tariffs will not slow the growth of renewables and Distributed Energy Resources (DERs), given that the costs of solar and battery technologies have sharply declined, making investment in these areas an obvious choice.

To break this cycle, innovative pricing models should be developed, such as reducing the buyback rate for excess solar power and introducing a subscription fee for solar users. These approaches aim to more equitably distribute costs between solar and non-solar consumers. Given that solar users rely on utility transmission and distribution infrastructure to both import and export power, a subscription fee can enable utilities to recoup fixed costs without disproportionately increasing rates across the board.

An immediate priority should be a comprehensive redesign of the tariff structure to accommodate the growing integration of Distributed Energy Resources (DERs), whether behind-the-meter or net-metered. A new framework is needed to recover costs for network and ancillary services while leveraging advanced technologies to strengthen grid support. For more details on rate design philosophy, please see **Annexure A**.

6.1.2. Tariff Slabs

Pakistan is currently caught in a vicious cycle of capacity surplus, where the growing Distributed Energy Resources (DERs) continues to reduce demand on the national grid, feeding into a fiscal deficit and will act as one element to increase in Circular Debt now reaching an immense 2.6 trillion PKR. Despite an excess power supply, DISCOs (distribution companies) struggle to boost grid consumption, operating at persistent losses. This issue stems partly from inadequate, short-term planning but, ***more critically, from the economic challenges intensified by a tariff slab structure that discourages high consumption & offers subsidized packages for the lower end of the consumer chain***.

6.1.3. Policy Lacuna - A Bottleneck Left Unchecked

On the Policy level, the National Electricity Policy of 2021 Clause 5.5.2 (f) puts a strong emphasis on ***'providing a level playing field to all market participants through uniform application of cross-subsidization and other grid charges to consumers of all suppliers***.

This discourages any premium for enhanced operational efficiency of market players and distorts competition by creating an easy way out for underperformers in the market. Such interventions must be dealt at policy level to overhaul the tariff structure completely.

6.1.4. Establishing an Ancillary Services Market

Ancillary Services are the essential, behind-the-scenes functions that uphold the electricity grid's stability, reliability, and security. Unlike the primary task of delivering electricity from generators to consumers, these services function much like the backstage crew of a performance—vital yet largely invisible elements that keep operations running smoothly. They address aspects beyond mere power generation, focusing on ***sustaining grid balance, managing voltage levels, and controlling frequency.*** Specific types of these services vary by region and grid operator, but core functions typically include Frequency Control, which keeps the grid's alternating current (AC) frequency steady.

According to a report by Verified Market Research, the ***global ancillary service market valued at USD 9.29 billion in 2024, is expected to grow at a CAGR of 7.97%, reaching USD 17.16 billion by 2031.***

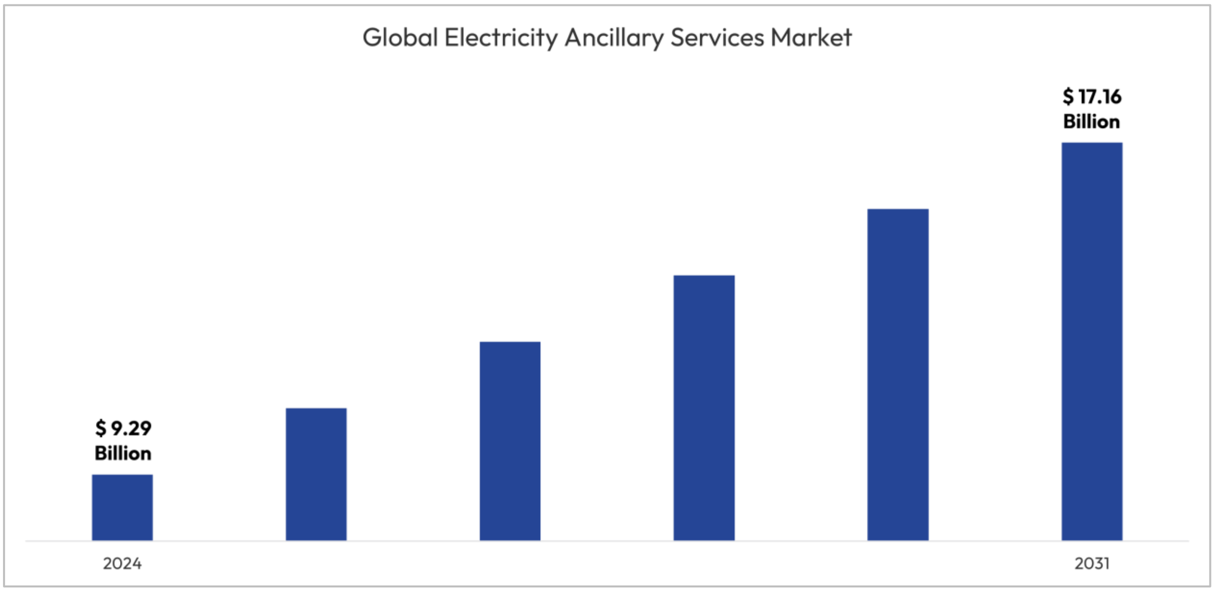
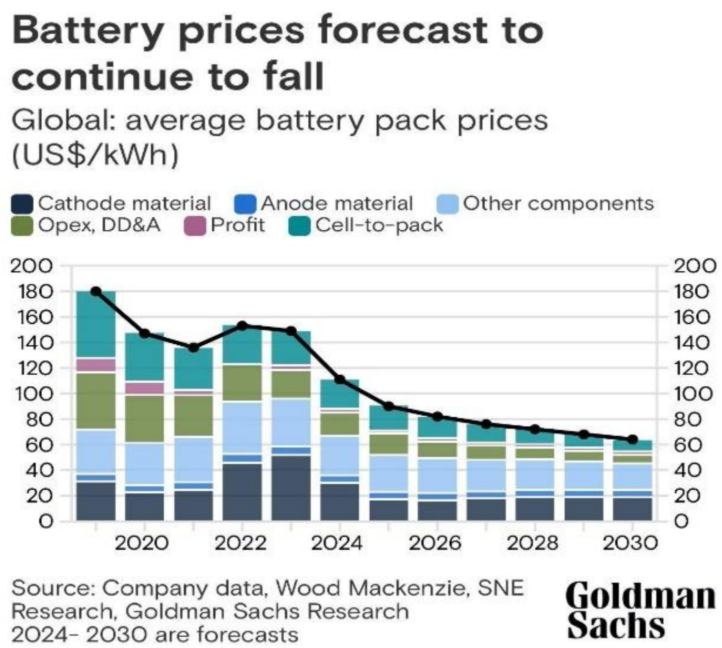


Figure 38: Global Electricity Ancillary Services Market

Furthermore, our ***Grid & Distribution Codes will need to be revised to accommodate a fair charge for any ancillary services*** provided by the wire network particularly for the intermittent electrons. At present there are no clauses or provisions for DER integration in our Distribution code which is currently being revised. Moreover, due consideration must be given to the obligation of every generator entering into the system to ensure system stability at the point of common coupling (CCP). As the market matures gradually, this ancillary services market can be opened up for private participants ***especially small to medium scale BESS owners*** that can participate for grid requirements or individual market player services. BESS can play a vital role in fulfilling short to medium term ancillary requirements. The declining trend in BESS prices all over the world, most countries are progressing towards even large-scale BESS systems for stability requirements and where possibly to offer price signals for incremental consumption.



The early adoption of behind-the-meter (BTM) solar photovoltaic and energy storage systems (PVESS) has been largely motivated by concerns over affordability, reliability and resilience. The growing adoption of BTM systems with battery energy storage (BESS) could significantly disrupt grid utilities' revenues if they fail to seize the current opportunity. Countries like Pakistan where the technical losses are high can deploy small to medium scale modules for loss recovery which can be charged with the surplus provided by the solar prosumers and utilized as per the requirements.

More solutions such as utilizing Electric Vehicles for creating grid supply demand and serving as mobile battery storages have been discussed in detail in the International Case Studies Chapter of this study.

6.2 Bottlenecks due to Solar Surge

Pakistan currently has approximately 3000 MW of net metered capacity but is encountering significant technical challenges, such as high voltage issues, transformer overload, and unauthorized rooftop solar installations. More than net metered, behind the meter installation is threatening the grid stability in day time as it has ballooned at a significantly greater pace with Bloomberg NEF reporting Pakistan on track to becoming the 6th largest solar market globally this year, installing a staggering (estimated) 10-15GW in 2024. As explained in the previous chapters of this study, Pakistan is rapidly moving towards achieving the Duck Curve phenomenon that is bound to create stress on the grid both technically and financially. There is a need for greater adaptability of flexible solutions to accommodate technological advancements in the system. These challenges must be addressed to ensure a seamless integration of solar energy into the national grid.

6.2.1. Reverse Power Flow Risks:

The reverse power flow from net metered solar systems primarily occurs during shoulder months, and poses risks to transformers. Implementing transformer monitoring & early warning and detection systems and alarms is crucial to prevent potential burnouts.

6.2.2. Equity in Installation Limits:

Allowing solar installations to exceed sanctioned loads by up to 1.5 times creates inequity among consumers. Experts recommend aligning installation limits with the sanctioned load, following best practices from countries like Bangladesh and India.

6.2.3. Excess Energy Carry Forward Policy:

The existing policy allows excess energy to be carried forward for three months, which incentivizes the over installation of solar capacity. Experts advocate for a transition to a monthly carry-forward system to promote self-consumption and enhance battery storage utilization, if authorities want to retain Net Metering Mechanism.

6.2.4. Imbalance in Tariff Regime:

The current tariff regime benefits net metered consumers while imposing a disproportionate burden on non-net metered consumers. A new tariff mechanism should be developed to rectify this imbalance, potentially incorporating fixed charges for all consumers. Also renewables are considered with only energy price rather than capacity so compensation shall be adjusted as per marginal cost of energy generation.

6.2.5. Impact of Captive Solar:

The rise of non-metered solar installations especially at industrial scales (captive solar) is leading to a decline in overall energy demand. This trend requires careful consideration to maintain a balance between energy demand and generation.

6.2.6. Foreign Currency Outflow - Taxing the Luxury

The surge in solar panel imports is also contributing to the depletion of Pakistan's foreign reserves, a recurring concern for the country. To manage this, the government should consider implementing import taxes on panels and limiting the issuance of Letters of Credit (LCs) to a set volume per month or year. While panel prices have dropped, they still represent a luxury for many in Pakistan, especially for middle-income groups in densely populated urban areas—such as high-rise residents in Karachi—who often lack access to solar solutions. Additionally, the upfront costs remain prohibitive for others. Policymakers need to evaluate these factors comprehensively to establish a fair and balanced regulatory framework.

6.3 The Way Forward

Based on the findings in the report the following recommendations are proposed in two separate perspectives priority wise:

6.3.1. First Priority Actions:

- **Introduction of Feed-In-Tariffs**
  Implement differentiated Feed-In-Tariffs (FiT) for solar power generation:
  - **Daytime FiT**: Set at 12~15 PKR/kWh, aligned with the latest solar power plant tariffs to encourage daytime solar generation.
  - **Nighttime FiT**: A higher rate (~25 PKR/kWh) during evening hours to incentivize the use of Battery Energy Storage Systems (BESS) and reduce reliance on costly thermal generation from RLNG or HFO plants.
  - Net Metering scheme has to be transformed to Net Billing scheme under Feed-In Tariff Mechanism.
- **Demand Charges and Minimum Monthly Bills**
  - **Introduction of Demand Charges**: Charge consumers based on peak usage to ensure that all users, including prosumers, contribute fairly to grid infrastructure and fixed costs.
  - **Minimum Monthly Bill**: Propose a minimum bill for net-metering users, ensuring that they contribute to the cost of grid maintenance even if they offset most of their consumption through self-generation.
  - For. E.g.
    - Non-Net Metered Residential Consumers = 500 PKR/kW/Month
    - Net Metered Residential Consumers = 1,000 PKR/kW/Month
    - Non-Net Metered Industrial Consumers = 1,250 PKR/kW/Month
    - Net Metered Industrial Consumers = 2,500 PKR/kW/Month
    - Same for Commercial Consumers

- **Special Incentives for BESS Integration**
  - **BESS for Solar Areas**: Policy makers should introduce financing schemes and policies to integrate BESS, especially in areas with high solar PV penetration.
  - **Utility-Led BESS Deployment**: Utility companies should deploy BESS in regions with high solar adoption to balance intermittent generation and improve grid stability.

Action Required	Benefit
Introduction of Feed-In-Tariffs (FiT)	Encourages daytime solar generation and incentivizes BESS use at night, reducing reliance on expensive thermal generation Balance the cost shift to non-solar consumers by paying NAPP instead of marginal price to solar consumers.
Demand Charges and Minimum Monthly Bills	Ensures fair contribution to grid costs from all users, including prosumers, and helps maintain grid infrastructure. Balance the fixed cost of grid that is shifting to non-net metering users from net metering users.
Special Incentives for BESS Integration	Enhances grid stability in areas with high solar adoption and encourages investment in energy storage systems. Replace expensive fuel generation and operation of part load of generators.

6.3.2. Second Priority Actions:

- **Shift to Time-of-Use (TOU) Tariffs**
    - **Removal of Slab Tariffs**: Transition from slab-based tariffs to TOU tariffs for all consumers, enabling more accurate reflection of grid usage and energy costs.
    - **Low-Income Support**: Subsidies for lower-income groups should be distributed via alternative mechanisms, not through energy tariff structures, to maintain a fair system.
- **Reevaluation of TOU Rates**
    - Encourage behavioral changes by shifting energy consumption to off-peak hours through reassessed TOU tariffs. This helps utilities manage load more efficiently and minimize peak demand challenges.
    - Now peaks at the grid has observed in the Night time around 11:00 PM and 12:00 AM.
- **Revision in Distribution Code**
    - Revisions to the Distribution Code should incorporate the integration of Distributed Energy Resources (DERs), detailing guidelines for managing bi-directional power flow and implementing advanced control mechanisms to regulate distributed generation. Techniques for curtailment in instances of oversupply are also necessary to ensure that grid stability and reliability are maintained as DERs expand in capacity and variety.

Action Required	Benefit
Shift to Time-of-Use (TOU) Tariffs from Slab tariffs	Allows for fairer billing by reflecting actual usage patterns, reduces peak demand, and provides a better cost structure for consumers.
Reevaluation of TOU Rates	Encourages consumers to shift usage to off-peak hours, reducing peak demand and helping utilities manage loads more efficiently.
Revision in Distribution Code	Facilitates integration of Distributed Energy Resources (DERs) and ensures grid reliability through advanced controls and bi-directional power flow.

6.3.3. Third Priority Actions:

- **Creation of Ancillary Service Market**
    - **Establish a Transparent Ancillary Services Market**: Develop a structured ancillary services market to set clear price signals for services like frequency and voltage support, ensuring all costs and incentives are transparent and aligned with grid needs.
    - **Promote BESS & DER Participation**: Enable Battery Energy Storage Systems (BESS) and Distributed Energy Resources (DER) to participate in the ancillary market, leveraging their capabilities for reliable, cost-effective grid support and stability.
- **Incentives for Data Centers and Industrial Parks**
    - Leverage surplus generation from the southern grid, where marginal costs are around 15 PKR/kWh, by offering a fixed electricity price (~25 PKR/kWh) for 10 years to **Data Centers and Industrial Parks** in regions such as Port Qasim, Dhabeji, and Nooriabad. This would cover network costs and contribute to ancillary service charges.

- **Locational Marginal Pricing (LMP)**
  - Implement **LMP** to optimize grid usage, manage congestion, and reduce transmission losses. This encourages distributed generation to be more strategically located and enhances overall grid efficiency.
- **Distributional Equity Assessment (DEA)**
  - A focused Distributional Equity Assessment (DEA) should be initiated to promote energy equity across Pakistan. DEA would help in systematically identifying and addressing the uneven financial burdens distributed energy resources (DER) can impose on non-participating consumers. Through DEA, stakeholders can assess cost allocations, ensuring that policies consider fair tariff structures, equitable access to clean energy, and protections for vulnerable consumers within the national energy strategy.

Action Required	Benefit
Creation of Ancillary Service Market	Improves grid stability by enabling BESS and DERs to provide services like frequency and voltage support, enhancing grid reliability. It would also attract investments in flexible energy resources like battery storage, improving grid resilience and reducing overall operational costs.
Locational Marginal Pricing (LMP)	Optimizes grid usage by managing congestion and reducing transmission losses, promoting efficient distributed generation placement.
Incentives for Data Centers and Industrial Parks	Supports industrial growth by leveraging surplus generation and ensuring stable energy prices for data centers and industrial parks.
Distributional Equity Assessment (DEA)	(DEA) would help identify and address inequities in energy access, ensuring all consumer segments benefit fairly from energy policies and pricing.

Energy equity is crucial in the current landscape, as non-solar consumers bear the burden of cross-subsidies by financing net-metering solar users through higher tariffs. Additionally, early solar adopters will likely reach transformer capacity limits (80%), potentially preventing later users from accessing net metering benefits. A new policy grounded in energy equity principles is essential to ensure fair and inclusive access across all consumer segments.

To explain further the LMP (Locational Marginal Pricing); there is surplus generation at south with marginal cost of 15 Rupees/kWh and this can be leverage by introducing a long term 10 year policy for Data Centers and Industrial Parks. For E.g. any IT Park / Industrial Park in the area of Port Qasim / Dhabeji / Nooriabad will have Electricity Prices locked at 25 Rupees/kWh in dollar term that will recover 5 rupees network cost and 5 rupees to pay additional capacity at grid and for ancillary services.

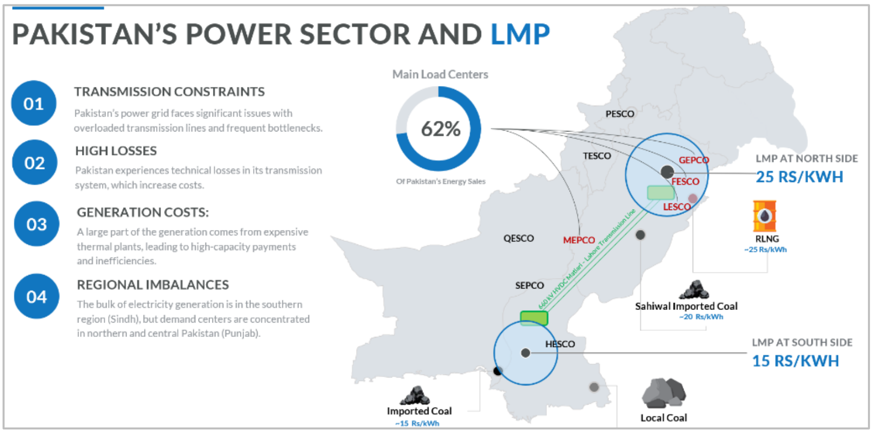


Figure 39: Locational Marginal Price

6.4. Special Recommendations for Regulator

Regulatory policy investigations are essential in shaping the future of the energy landscape. As new technologies, market conditions, and societal expectations evolve. Following are special recommendations for Regulator regarding policy investigations to shape the future of the energy landscape in immediate and medium-term actionable items:

6.4.1. Recommended Actions for Regulator – Immediate Term:

Category	Action Required	Benefit
Rate Design	Explore rate designs to accommodate DER and fair rates for all customers.	Ensures rates reflect energy production/consumption patterns, benefiting traditional and DER customers.
Time-of-Use (TOU) Rates	Implement TOU rates to shift consumption to cheaper, renewable energy times.	Reduces grid stress and promotes energy use during periods with abundant renewable generation.
Demand Charges	Introduce demand charges based on peak usage.	Ensures fair cost-sharing for grid infrastructure and incentivizes peak demand reduction.
DER Program Design	Design programs for DER integration (e.g., rooftop solar, EVs).	Supports smooth integration of DERs, enhancing grid stability and consumer options.
Incentives for DER Adoption	Offer incentives for solar, storage, and EV adoption.	Encourages wider adoption of DERs, contributing to grid reliability and clean energy goals.
Advanced Metering Infrastructure	Investigate AMI for better control over energy use.	Improves consumer control and grid management, enabling more efficient energy distribution.
Broad Stakeholder Involvement	Engage utilities, consumers, and experts in policy decisions.	Ensures inclusive policy-making that addresses the needs and insights of all stakeholders.
Public Comment Proceedings	Gather public input through comment periods.	Provides transparency and ensures policies reflect public interest.

6.4.2. Recommended Actions for Regulator – Long Term:

Category	Action Required	Benefit
Equity Initiatives	Develop programs for underserved and low-income communities.	Ensures clean energy benefits reach disadvantaged communities, promoting environmental justice.
Community Solar Programs	Create community solar options for low-income households.	Increases clean energy access for those unable to install rooftop solar.
DER Aggregation	Investigate DER aggregation for grid services (e.g., frequency regulation).	Enhances grid stability by utilizing aggregated small-scale DERs.
Cross-Subsidization Mechanisms	Design mechanisms to prevent cost shifts from DG penetration.	Maintains fair cost distribution, protecting non-DG customers from bearing undue costs.
Smart Grid or Grid Modernization	Prepare grid infrastructure for high DER penetration.	Ensures reliable grid operation with increased DER and improved response to supply/demand shifts.
Cost-Reflective Tariffs	Implement tariffs that reflect actual service delivery costs.	Balances utility cost recovery with consumer fairness by including only prudent, useful assets.
Revenue Decoupling	Decouple utility revenue from electricity sales.	Protects utility financial health as solar adoption grows and grid energy sales decrease.
Grid Fees and Shared Cost Models	Implement grid usage fees and shared-cost approaches.	Ensures fair contribution to grid costs from prosumers and traditional consumers alike.

For more on utility business models please refer to **Annexure C.**

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ANNEXURES

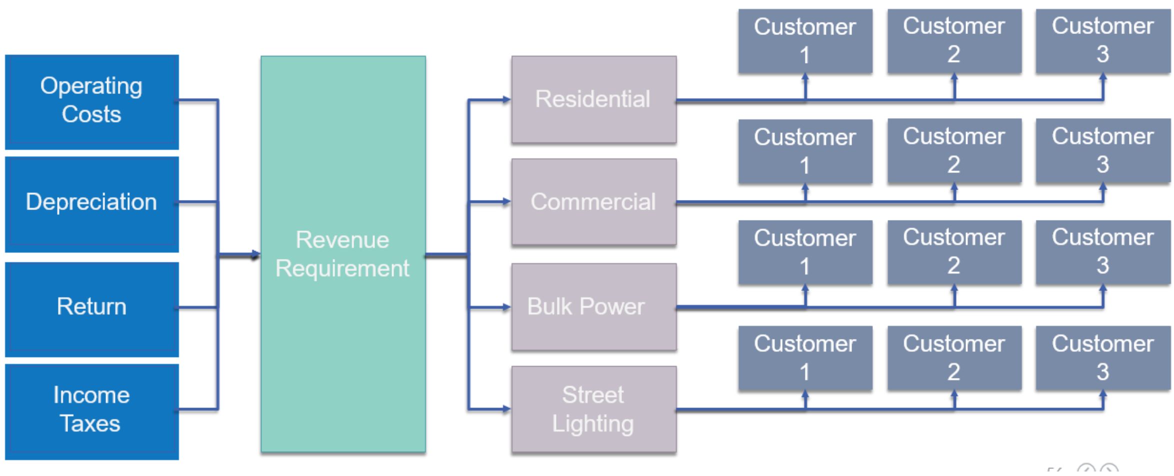
Annexure A: Rate Design

Overview of Cost of Service – Rate Making

Regulators aim to set utility rates that accurately reflect the true costs of services provided, ensuring that only prudently incurred expenses are included. For inclusion, assets covered by these rates must be both “used and useful” in delivering utility services. Fairness and reasonableness are essential, as rates should not only allow utilities to cover their expenses but also to earn returns comparable to similar utilities. This balance between recovery of costs and fair profit is fundamental to maintaining service quality and financial stability for utilities.

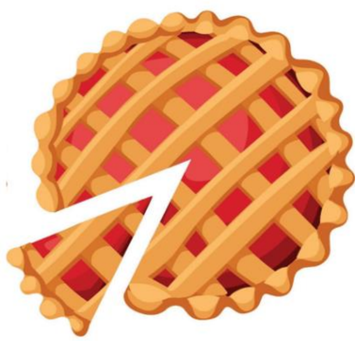
Elements of a cost of service (COS) study

A Cost of Service (COS) Study is essential for determining the costs associated with serving utility customers. It begins by calculating the total annual costs, including operating, capital, fixed, and variable expenses. Next, it allocates these costs among different customer classes—such as residential, commercial, and industrial—based on their unique usage patterns, utilizing various allocation methods. Finally, the study designs utility rates that ensure each class contributes fairly to the overall revenue requirements, aligning with regulatory standards. This structured approach helps utilities manage their financial obligations while promoting equitable service to all customers.



Test Year (TY) Revenue Requirement (RR) analogy

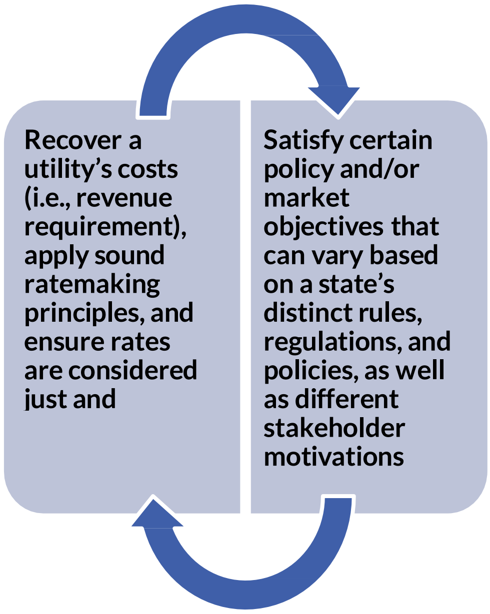
- The annual revenue requirement amount can be compared to the size of a pie that is needed to serve all of the utility’s retail customers over a year.
- The “Test Year” RR is the amount used to design rates in the general rate case. This may be a recent historical value or a future projected value.
- The revenue requirement allocation determines the revenue requirement amount that each customer class is responsible for.



- This is analogous to dividing the pie into slices that correspond to the revenue responsibility for each customer class.
- Rate design determines how each slice of the revenue requirement pie is collected.
- The rate design step allocates revenue responsibility to each customer in each class.
- Ideally, the entire slice of pie is collected from customers annually.

Retail rates are designed based on two broad concepts

Retail rates for utilities are primarily designed based on two broad concepts. First, they aim to recover the utility's costs, which includes the revenue requirement necessary to cover operational expenses, infrastructure investments, and maintenance while applying sound ratemaking principles. This ensures that rates are deemed just and reasonable for consumers, reflecting the actual costs of providing service. Second, retail rates must satisfy specific policy and market objectives that can differ from state to state. These objectives may be influenced by local regulations, environmental goals, and stakeholder motivations, such as promoting renewable energy or enhancing energy efficiency. By balancing cost recovery with policy goals, utilities can create equitable rates that support both their financial viability and broader community interests.

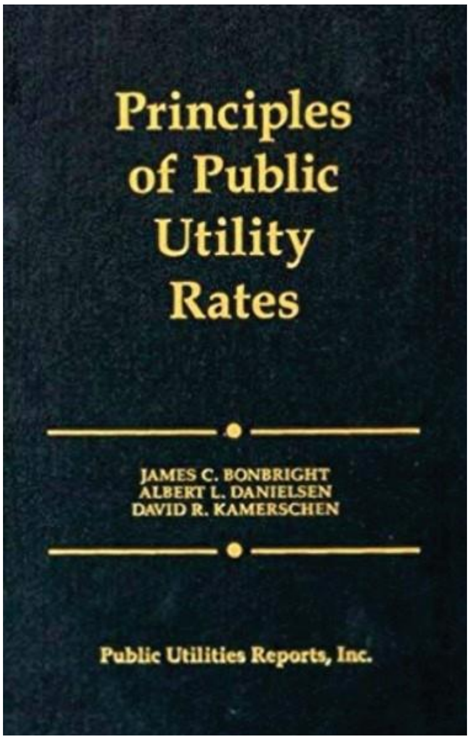


Rate Design Criteria (Bon-bright principles)

The Bon-bright principles outline key criteria for effective rate design, aiming to balance financial stability, customer equity, and ease of understanding. These principles typically include:

1. **Customer Understanding**: Rates should be straightforward and easily understandable for customers, allowing them to recognize how their consumption patterns impact their bills.
2. **Ease of Implementation**: Rate structures should be feasible for both utilities and regulatory bodies to administer and enforce without unnecessary complexity.
3. **Cost Recovery**: Rates need to cover the utility's cost of service, ensuring the utility can maintain its financial integrity by generating sufficient revenue to support operations, maintenance, and investment needs.
4. **Fair Apportionment of Costs**: Costs should be fairly distributed across different customer classes, reflecting each class's contribution to the utility's cost of service.
5. **Avoidance of Undue Discrimination**: Rate designs must avoid unfairly burdening one customer group over another without clear justification related to cost of service or usage.

These guiding principles, collectively known as the Bonbright criteria, help ensure that rate designs are just, reasonable, and aligned with both utility financial needs and customer fairness. They encourage transparency, fairness, and efficiency, which are essential in modern utility rate structures.



Balancing rate design principles has evolved from a straightforward cost-recovery focus to a more dynamic, nuanced approach, especially with the rise of distributed energy resources (DERs). Today, finding the right balance is increasingly about prioritizing economic efficiency, aligning with state policy goals, and fairly apportioning costs across a wide variety of customer profiles—ranging from net-metered solar users to those with behind-the-meter (BTM) battery energy storage systems (BESS) and electric vehicles (EVs).

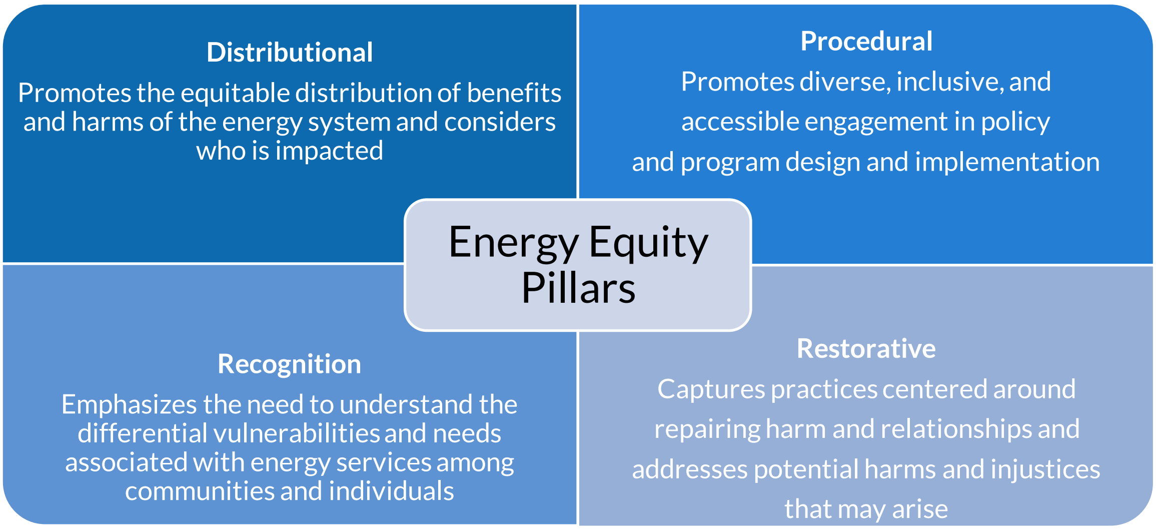
In an era where consumers both draw from and contribute to the grid, rate structures must not only provide clear price signals that encourage efficient energy use but also support the equitable distribution of grid costs across all types of users. This approach requires rate designs that accommodate the varied behaviors and grid impacts of DER users, recognizing that traditional, one-size-fits-all pricing models may no longer be sufficient.

Annexure B: Energy Equity Pillars

Energy equity is a broad concept structured around four foundational pillars: distributional, procedural, recognitional, and restorative equity (as illustrated in the below figure). Achieving comprehensive energy equity typically requires addressing these pillars system-wide to ensure that inequities are mitigated across all four dimensions (Woolf et al., 2024). A Distributional Equity Assessment (DEA), however, focuses primarily on distributional equity by examining how the benefits and burdens of the energy system are shared across different customer groups, though it may also touch on other aspects of equity.

The **Distributional Equity Analysis** (DEA) is an analytical framework that allows for the evaluation of the distributional equity of utility resource investments in combination with benefit-cost analysis (BCA). Compared to the BCA framework which assesses equity across a system, the DEA focuses on the differential impacts of investments across different customer groups.

The DEA framework assesses the distribution of costs and benefits among customers with varying characteristics. It works alongside benefit-cost analyses in evaluating utility investments in Distributed Energy Resources (DERs) and helps answer essential questions such as: whether to initiate or invest in a new DER program, whether to sustain an existing one, whether adjustments are necessary for existing or proposed programs, and how to best allocate investments across multiple DER initiatives. This approach supports a fair and equitable transition to sustainable energy by guiding the development of programs that address both customer needs and systemic inequities.



Distributional equity is an urgent focus as the energy transition unfolds, raising concerns that existing social inequities may worsen if benefits from cleaner and more resilient energy sources are unevenly distributed. For example, net-metered consumers with rooftop solar often save on electricity costs and enjoy energy independence, whereas non-net-metered customers must rely solely on grid power and may see rising costs. Additionally, underserved and rural areas frequently face issues like poor power quality and extended load shedding, which restrict access to reliable power and economic opportunities. Addressing these disparities is essential to ensure the energy transition is both equitable and inclusive, reaching all communities with cleaner energy benefits and robust infrastructure.

Annexure C: Utility Business Models

As distributed energy resources (DERs) such as solar photovoltaics (PV) and other forms of renewable generation continue to penetrate the grid, traditional utility business models must adapt to remain financially sustainable while maintaining grid stability and ensuring fair cost distribution. Below are some strategic recommendations and suggestions for how utilities can adjust their operations and performance metrics to better align with the new energy landscape:

1. **Shift to a Services-Based Utility Model**

Traditional utilities operate on a volumetric model, where revenue is tied to the amount of energy sold. As more consumers adopt distributed generation, utilities should shift towards a service-based model, where revenue is based on the services, they provide rather than just energy sales. This can include:

- **Grid Access Fees**: Implement fixed or semi-fixed charges to ensure all grid users contribute to the cost of maintaining and upgrading grid infrastructure, regardless of their energy consumption.
- **Subscription Models**: Utilities can offer subscription services for DER users, providing grid services such as backup power, voltage regulation, and energy storage at a fixed monthly rate.

2. **Differentiated Pricing and Time-of-Use (TOU) Tariffs**

Utilities can adopt **differentiated pricing** to reflect the true costs of energy generation and grid maintenance:

- **Time-of-Use Pricing**: Implement TOU tariffs that incentivize consumers to use electricity during off-peak hours and reduce demand during peak hours. This encourages better load balancing and aligns consumer behavior with grid needs.
- **Dynamic Pricing**: Adjust electricity prices in real-time based on supply-demand conditions, particularly to address fluctuations caused by solar generation and renewable intermittency.
- **Net Billing or Reduced Net Metering Credits**: Instead of traditional net metering where solar users receive full retail credit for the energy they export to the grid, utilities could switch to a **net billing** system where exported electricity is credited at a lower rate, reflecting the cost of grid services they still use.

3. **Grid Modernization and Digital Infrastructure**

To cope with the increasing complexity of managing distributed energy resources (DERs), utilities need to invest in modernizing the grid:

- **Smart Grids**: Deploy advanced metering infrastructure (AMI) to enhance monitoring, control, and flexibility. Smart grids enable real-time data collection on generation and consumption, improving the utility's ability to balance supply and demand.
- **Energy Storage Integration**: Utilities should invest in energy storage systems (such as batteries) to mitigate the intermittency of renewable energy and provide ancillary services like frequency regulation and grid balancing.

- **Demand Response Programs**: Utilities can incentivize consumers to shift or reduce their electricity usage during peak periods or times of grid stress through demand response programs, helping to smooth demand without needing to ramp up dispatchable generation.

4. **Performance-Based Regulation (PBR)**

Utilities have traditionally been regulated based on the cost-of-service model, which rewards them for capital investments like building new power plants. To encourage utilities to embrace DERs and renewable energy, regulators can transition to **Performance-Based Regulation (PBR)**, which links utility compensation to specific performance metrics, such as:

- **Grid Reliability**: Incentivizing utilities to maintain high reliability standards despite increased DER penetration.
- **Emissions Reductions**: Rewarding utilities for reducing carbon emissions through the integration of renewable energy.
- **Customer Satisfaction**: Metrics that reflect how well the utility is meeting the evolving needs of both DER and non-DER customers.

5. **Establish DER Integration Programs**

To better manage and optimize the increased use of DERs, utilities should develop dedicated programs:

- **Virtual Power Plants (VPPs)**: Aggregate DERs such as rooftop solar, batteries, and electric vehicles (EVs) into a "virtual power plant" that can be dispatched as a unified resource, providing grid services and enhancing resilience.
- **Community Solar Programs**: For customers unable to install solar themselves (e.g., renters, apartment dwellers), utilities can offer access to shared solar projects, allowing broader participation in renewable energy while generating revenue.
- **DER Management Systems (DERMS)**: Develop systems that manage the flow of energy from distributed sources, ensuring that DERs contribute to grid stability instead of creating disruptions.

6. **Enhance Utility-Consumer Partnerships**

With the rise of prosumers (consumers who both produce and consume energy), utilities must foster stronger relationships with their customers:

- **Educational Campaigns**: Help consumers understand their role in grid stability, the value of ancillary services, and the importance of paying for grid access even if they generate their own electricity.
- **Incentives for Storage and Demand Management**: Provide financial incentives for consumers who install energy storage or participate in demand-side management programs, ensuring that they contribute to grid stability rather than exacerbating variability issues.

7. **Cost Recovery Mechanisms**

To address the financial challenges posed by reduced energy sales due to DER adoption, utilities must implement fair cost-recovery mechanisms:

- **Fixed Charges**: Implement modest fixed charges to ensure that all consumers, including those with DERs, contribute to the cost of grid maintenance and services like ancillary support.
- **Grid Service Fees for Prosumers**: Prosumers who use net metering still rely on the grid for backup power and exporting excess energy. Utilities can introduce grid service fees or connection fees to cover these costs without discouraging solar adoption.

8. **Regulatory Support for DER Integration**

Finally, utility adaptation requires close coordination with regulators:

- **Adjusting Tariff Structures**: Regulators should allow utilities to implement tariffs and grid access fees that reflect the true cost of service while avoiding unfair cost shifts between solar and non-solar users.
- **Promote Transparent Pricing**: Ensure that tariff structures are transparent and understandable, so consumers can make informed decisions about energy consumption, DER investment, and the overall cost implications.

Adapting to increased solar and DER penetration requires utilities to fundamentally change their business models and performance metrics. By shifting from volumetric sales to service-based models, leveraging advanced technology, and partnering with regulators, utilities can maintain grid stability, ensure fair cost distribution, and continue to support the transition to a cleaner, more distributed energy future.

9. **Incentives for Solar Adoption**

While the levelized cost of electricity (LCOE) for solar PV has significantly decreased, making it a highly attractive option for consumers and industries, the next wave of focus should be on overcoming the intermittency of solar energy. Incentivizing allied technologies like battery energy storage systems (BESS), green hydrogen, and advanced energy storage options will help integrate higher levels of solar into the grid and ensure stable, round-the-clock energy availability.

Here are some recommendations on how to incentivize these allied technologies:

- **Incentivize Energy Storage Solutions**

Energy storage systems, especially BESS, are crucial for addressing the intermittency of solar PV and maintaining grid reliability. To promote adoption, the following strategies can be used:

- **Tax Credits and Subsidies**: Provide tax incentives, subsidies, or grants to both residential and commercial users who install energy storage systems alongside solar PV. These financial incentives can help reduce the initial capital costs and improve the return on investment.
- **Time-of-Use (TOU) Tariffs**: Introduce TOU pricing structures that reward consumers who use stored energy during peak demand hours. This will encourage the installation of storage systems to store excess solar generation during the day and discharge it during the evening peak.
- **Ancillary Service Payments**: Establish markets where battery storage owners can get paid for providing grid services such as frequency regulation and spinning reserves. This

would allow storage owners to benefit financially from participating in stabilizing the grid.

10. Expand Energy Storage Options

To overcome solar intermittency, a wide range of storage technologies needs to be explored. Incentivizing the development and deployment of diverse energy storage technologies can help bridge the gap:

- **Thermal Energy Storage**: Provide incentives for systems that store excess solar energy as heat, which can be used for industrial processes or converted back into electricity during peak demand periods.
- **Mechanical Storage (Pumped Hydro, Compressed Air)**: Expand support for large-scale mechanical storage systems like pumped hydro and compressed air energy storage. These can store vast amounts of energy over longer durations compared to batteries.
- **Chemical Storage**: Encourage the development of advanced chemical storage technologies, such as flow batteries and fuel cells, which offer longer-duration storage solutions and can support grid stability over hours or days.

11. Hybrid Solar Systems

Hybrid systems that combine solar PV with other renewable or dispatchable energy sources can mitigate intermittency challenges:

- **Solar + Wind + Storage**: Provide incentives for utility-scale hybrid projects that combine solar, wind, and storage. These projects can smooth out the variability in renewable energy supply, as wind often generates during non-solar hours.
- **Solar + Hydrogen**: Incentivize the development of hybrid solar and green hydrogen plants, where surplus solar energy can be used to produce hydrogen during the day, which can then be stored and used to generate electricity or power industrial processes.

12. Enhancing Grid Flexibility and Demand-Side Management

Integrating a larger share of distributed energy resources like solar requires a more flexible grid. Strategies to enhance grid flexibility include:

- **Grid Modernization Investments**: Invest in smart grids, advanced metering infrastructure (AMI), and automated demand response systems that allow better management of distributed energy resources and ensure the efficient use of solar energy.
- **Demand-Side Incentives**: Offer financial incentives for consumers who participate in demand response programs, adjusting their energy usage based on solar production levels. This could involve shifting energy-intensive activities (like EV charging or industrial processes) to periods of high solar generation.

13. Community Solar and Storage Programs

Community solar projects allow consumers who cannot install their own rooftop solar to participate in clean energy production. These projects should also be paired with energy storage:

- **Community Storage Incentives**: Encourage community storage projects where solar energy generated in neighborhoods is stored collectively and used during periods of high demand.
- **Co-ownership Models**: Promote co-ownership models where consumers can buy shares in larger solar-plus-storage facilities, making solar more accessible and inclusive.

14. Public-Private Partnerships and Financing Mechanisms

Encourage collaboration between public entities and private companies to develop innovative financing models for solar and storage technologies:

- **Green Bonds and Climate Finance**: Expand the use of green bonds and climate finance to support large-scale solar and energy storage projects, particularly in regions with high solar potential.
- **Energy-as-a-Service (EaaS) Models**: Develop EaaS models where third-party companies finance, install, and maintain solar-plus-storage systems for consumers, charging only for the energy services provided, thus reducing upfront costs for adopters.

Incentivizing allied technologies such as BESS, green hydrogen, and advanced storage systems is crucial to ensuring the seamless integration of solar PV into the energy system. With a comprehensive approach that includes financial incentives, regulatory reforms, and investment in grid modernization, we can overcome solar's intermittency challenges and pave the way for a cleaner, more resilient energy future.

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