Competition Commission of Pakistan
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Unlocking Green Potential

A Market Competition Study of Solar Energy in Pakistan

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CENTRE OF EXCELLENCE IN COMPETITION LAW (CECL)

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Foreword

I am pleased to share the competition assessment study titled "Unlocking Green Potential: A Market Competition Study of Solar Energy in Pakistan," prepared by the Centre of Excellence in Competition Law and Economics (CECL) of the Competition Commission of Pakistan.

Solar energy is becoming an important part of Pakistan's energy future. In recent years, the solar sector has grown rapidly due to high electricity tariffs, falling solar panel prices, and increased energy shortages. Pakistan is naturally well suited for solar power, with abundant sunlight available across most regions of the country. As a result, solar energy is increasingly being adopted by households, commercial users, industries, and agricultural consumers, particularly through rooftop installations and net metering arrangements.

Solar energy is also helping reduce dependence on imported fuels, lower pressure on the national grid, and provide cost relief to consumers. At the same time, the rapid growth of solar power has raised new challenges related to grid integration, tariff structures, regulatory approvals, and coordination between federal and provincial institutions. Addressing the challenges is essential to ensure that the solar market develops in an orderly, competitive, and sustainable manner.

The study takes a practical and evidence-based look at the solar energy market in Pakistan, including its structure, regulatory framework, and market challenges. The report highlights issues that may limit market entry, raise costs, or create unequal conditions for participants. It also identifies opportunities for regulatory improvements that can support fair competition, investment, and enable the smooth integration of solar energy into the broader power sector.

I hope this report will assist policymakers, regulators, and stakeholders in making informed decisions and contribute to the development of a competitive, efficient, and sustainable solar energy market in Pakistan.

Farid Ahmad Tarar

Chairman
Competition Commission of Pakistan

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List of Abbreviation

Abbreviation	Full Form
AEDB	Alternative Energy Development Board
ARE	Alternative and Renewable Energy
BCD	Basic Customs Duty
CCP	Competition Commission of Pakistan
CoP	Conference of Parties
CPEC	China Pakistan Economic Corridor
CTBCM	Competitive Trading Bilateral Contract Market
DCR	Domestic Content Requirement
DERs	Distributed Energy Resources
DISCOs	Distribution Companies
DMS	Distribution Management Systems
FITs	Feed-in Tariffs
GDP	Gross Domestic Product
GHGs	Greenhouse Gases Emissions
GW	Gigawatt
GWh	Gigawatt-hour
IAs	Implementation Agreements
IEA	International Energy Agency
IGCEP	Indicative Generation Capacity Expansion Plan
IPPs	Independent Power Producers
kW	Kilowatt
LNG	Liquefied Natural Gas
LOIs	Letters of Interest
LOS	Letters of Support
MW	Mega Watt
NEPRA	National Electric Power Regulatory Authority
NTDC	National Transmission & Despatch Company
PEC	Pakistan Engineering Council
PLI	Production-Linked Incentive Scheme
PPAs	Power Purchase Agreements
PPIB	Private Power & Infrastructure Board
PRIED	Policy Research Institute for Equitable Development
PSDP	Public Sector Development Programme
PSQCA	Pakistan Standards and Quality Control Authority
PSW	Pakistan Single Window
PV	photovoltaic
QESCO	Quetta Electric Supply Company
R&D	Research and Development
SCADA	Supervisory Control and Data Acquisition
SDGs	Sustainable Development Goals
SEZs	Special Economic Zones
SIFC	Special Investment Facilitation Council
SWOT	Strength, Weakness, Opportunities and Threats
TWh	Terawatt-hours
VRE	Variable Renewable Energy
WEF	World Economic Forum

Executive Summary

Energy is a critical input for economic growth and social welfare, with reliable and uninterrupted supply being essential for enhancing consumer welfare and productivity across all sectors. Over the past two decades, Pakistan has faced persistent challenges in meeting its growing energy demand. The country's energy mix remains heavily reliant on imported fossil fuels, resulting in high generation costs, significant pressure on foreign exchange reserves, and heightened exposure to international price volatility. At the same time, a substantial proportion of rural households and the farming community remains disconnected from the national grid, limiting access to a basic and essential service. Moreover, continued dependence on fossil-fuel–based energy poses serious environmental risks for Pakistan, which is consistently ranked among the world's most climate-vulnerable countries.

Against this backdrop, solar energy has emerged in recent years as a strategically important and environmentally sustainable alternative. Pakistan's geographical location strongly supports the development of solar energy. Situated between latitudes 24°–37° North and longitudes 62°–75° East, the country receives an estimated 1.55×10^{15} kWh of solar radiation annually, with average daily sunshine ranging from 8 to 8.5 hours-equivalent to more than 2,300-2,700 hours per year. Economic factors have further accelerated solar adoption: electricity tariffs from the national grid have increased sharply, while international prices of solar panels have declined substantially. In addition, government policy measures, including duty waivers on the import of solar panels, have further facilitated market expansion. These favourable geographical, economic, and policy conditions have led to rapid growth in the solar energy sector. More than 6,000 MW of capacity has reportedly been integrated into the national grid through rooftop installations and micro-grids. However, available evidence suggests that the actual scale of solarization is significantly larger, as cumulative imports of solar panels exceed 50 GW.

Given the growing importance of solar energy in shaping Pakistan's future power landscape, this study undertakes a competition assessment of the solar energy sector. The analysis focuses on identifying potential market distortions and entry barriers, particularly those arising from import dependence, certification and quality assurance mechanisms, and licensing requirements. The study also examines how frequent changes in net-metering policies and tariff structures may undermine investment incentives and slow the pace of solar adoption. Besides, the report also aims to analyze the inclusiveness of solarization as well as its compatibility with the existing power sector infrastructure.

Methodologically, the study employs a mixed-methods approach, combining quantitative and qualitative analyses. The quantitative analysis draws on published studies, official reports, and available databases, while the qualitative component is based on interviews with key stakeholders and experts from both the public and private sectors. The findings indicate strong and sustained growth in solar energy adoption, driven predominantly by private sector initiatives and household investments, with relatively limited direct policy leadership. Rising electricity costs, frequent power outages, and growing energy needs have been key demand-side drivers. On the supply side, this phenomenal growth has been supported by reduced solar panel prices, low import duties and availability of cheap services for solar installation and maintenance. However, the sector continues to face competition-related constraints, including

policy uncertainty, weak quality control and certification frameworks, heavy reliance on imports, limited availability of skilled human capital, and inadequate financial sector support—particularly for low-income households facing high upfront investment costs.

The study also identifies gaps in environmental management, notably the absence of effective systems for the disposal and recycling of expired or damaged solar panels. In addition, deficiencies in data availability and reporting limit an accurate assessment of the true scale and structure of the solar market. Based on these findings, the study proposes targeted policy and regulatory interventions to strengthen competition, improve market transparency, enhance consumer protection, and promote inclusive and sustainable growth of the solar energy sector, thereby contributing to Pakistan's energy security and the achievement of Sustainable Development Goals 7 and 13.

1. Introduction

Chapter 1: Background and Introduction

18. Energy plays a pivotal role in the smooth functioning of modern economies. In the post-industrial revolution era, global community saw a massive use of energy in all the sectors including agriculture, industry and services. One the one hand, higher use of energy directly contributes to consumer welfare while, on the other hand, economies suffering from energy poverty are also performing poorly on growth fronts. While recognizing the importance of energy in the overall economic systems, global community is investing massively in the energy sector. For instance, in the year 2025, global capital flows in the energy sector remained USD 3.3 trillion, 2% higher than in 2024.[1] However, at present, global energy mix is dominated by fossil fuels with a very small share of renewable energy in the overall energy mix. To illustrate, in the year 2018, the share of renewable energy in the global energy mix was only 15% which is likely to increase to around 25% by 2040 (Rasheed et al., 2020).

19. An excessive reliance on fossil fuels energy has created major challenges for global environmental sustainability. Environmentalists have been continuously raising concerns about the rise in global temperatures, depletion of glaciers, rising sea levels and higher concentration of greenhouse gases (GHGs) emissions. All this is not only threatening the sustainability of economic growth but also questioning the mere survival of human species on this planet. In recognition to this alarming situation, the 21st Conference of Parties (CoP 21) held in Paris, stresses the signatories to reduce the global temperature by 2°C and if possible, below 1°C.[2] As part of the global commitment to enhancing environmental quality, the 29th Conference of the Parties (CoP29), held in Baku, Azerbaijan, from November 11–22, 2024, concluded with a landmark agreement. Under this pact, developed countries pledged to allocate a minimum of $300 billion annually to emerging economies by 2035, aimed at supporting pollution reduction initiatives and strengthening climate adaptation efforts.[3]

20. For developing countries like Pakistan, this whole scenario presents a dual challenge. On the one hand, there is a pressing need to expand energy consumption for improved living standards; on the other, there is an equally urgent need to mitigate the impacts of climate change and environmental degradation. The International Energy Agency (IEA) notes that although the country's primary energy consumption increase by 87% from 2000 to 2022, the nation still needs to connect over 40 million people with the national grid[4]. Sustainable the adverse effects of climate change, Pakistan is ranked among the top five nations most affected by this phenomenon despite its meager contribution to global emissions.[5] A sustainable energy future requires a gradual and well-managed transition from non-renewable to renewable energy sources, with a particular emphasis on solar technologies. Such a shift would not only accelerate national electrification

[1] https://www.iea.org/reports/world-energy-investment-2025/executive-summary

[2] See, United Nations Framework Convention on Climate Change. (n.d.)

[3] https://www.un.org/en/climatechange/cop29

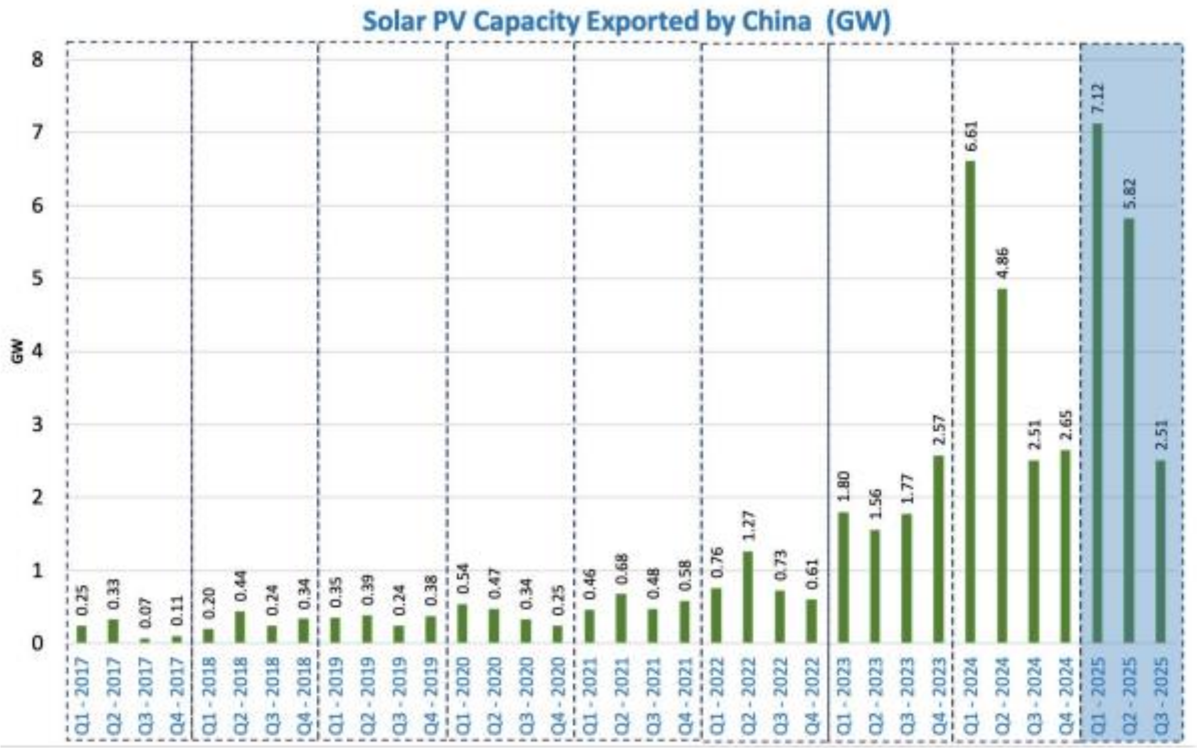
[4] https://www.iea.org/countries/pakistan

[5] https://unhabitat.org/sites/default/files/2023/06/4._pakistan_country_report_2023_b5_final_compressed.pdf

efforts but also play a crucial role in mitigating climate change. Globally, a variety of renewable energy options such as hydropower, wind, solar, biogas, geothermal, and ocean energy have been explored to reduce dependence on fossil fuels. However, recent studies indicate that solar energy is emerging as the most rapidly expanding component within this portfolio. The IEA reports that of the total 700 GW of renewable energy added in the year 2024, solar energy accounted for roughly 80 percent.[6]

21. Concerning the evolution of solarization in Pakistan, the country has observed growing adaptation of solar energy in the recent years. In fact, Pakistan presents a leading example of transition from fossil fuel to solar energy technology. As shown by Figure 1, the solar import of the nation has increased tremendously in the last few years. This massive import of solar panels can be associated with several factors including costly and unreliable grid electricity, low tariff rates on solar panels and invertors, high social acceptance and a reduction in imported solar prices from China. According to Policy Research Institute for Equitable Development report[7], the solar exports from China to Pakistan from China reached 17 gigawatts in 2024, making it the 3rd largest importer of Chinese solar panel. To contextualize, this represents 30% of the total installed capacity of Pakistan, which was around 46 GW in 2023.

Figure 1: Pakistan's Solar imports from China (2017: Q1 to 2025: Q3)



22. Solar uptake continues to rise, with some recent studies reporting even higher levels of imported and installed capacity. A recent study by the Policy Research Institute for Equitable Development (PRIED) indicates that solar imports surpassed 50 GW by

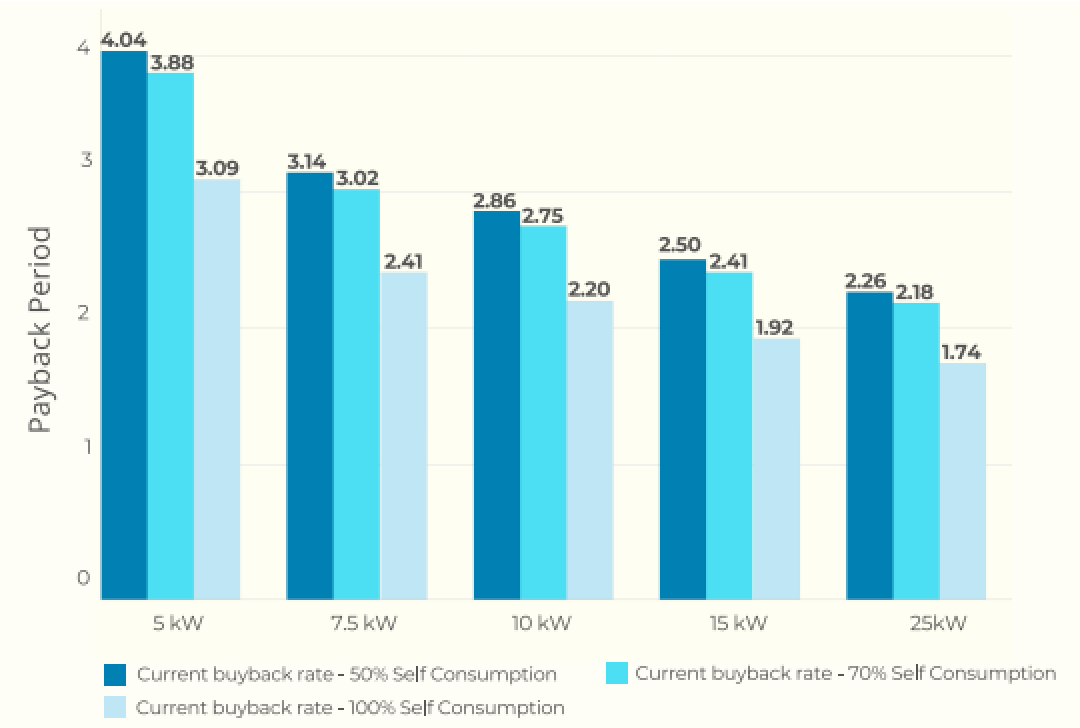
[6] https://www.iea.org/reports/global-energy-review-2025/key-findings
[7] https://www.priedpk.org/wp-content/uploads/2025/10/WHITE-PAPER-Solar-Revolution.pdf

August 2025, while installed capacity reached approximately 35 GW.[8] The import bill of this hefty solar adaption reached USD 5,226 million in total. The study also notes that a substantial portion of solar adoption remains undocumented, as net metering accounts for only 6 GW of solar generation connected to the national grid. It suggests that solarization is not only substituting conventional fossil-fuel-based energy but also generating new demand. Moreover, the primary data investigation of the study indicates that solar adoption among households increases with income, highlighting the fact that financial barriers are mainly holding back the end users from solarization.

23. This rapid transition to solar energy in Pakistan is explained by at least two important factors. First, energy prices in the country have increased significantly in the last few years, primarily because of capacity payments issues and currency depreciation. In fact, the country signed agreements with the foreign producers in the last decade where energy prices from thermal and LNG plants were indexed to the dollar (Renewables First & Herald Analytics, 2024). Moreover, the agreements also had a take or pay clause which increased the capacity payments causing a huge increase in energy price over the last few years. To illustrate, electricity prices increased by 155% in the last 3 years due to higher capacity payments and currency depreciation.[9] In many cases, these exorbitant energy prices have pushed the monthly electricity bills higher than the house rents.[10] Unfortunately, the solution to the energy crisis of the first decade came in the form of excess supply in the last decade. The country installed an overall capacity of 45000 MW when the peak time demand was hardly 30,000 MW, for a brief period of summer season. The financial impact of this excess energy supply appears in the form of capacity payments to the producers, forcing them to pay for the electricity they never used. All this provides a compelling reason to disconnect with the grid and opt for solarization. The second important reason behind solarization is a massive reduction in solar modules and battery prices which significantly decreased the payback period of rooftop and other micro plants. The payback period of solar plants is even low for utility scale plants, as shown by Figure 2 below:

[8] https://www.transitionzero.org/shedding-light-on-pakistans-distributed-solar-revolution
[9] https://www.bloomberg.com/news/articles/2024-08-13/it-can-cost-more-to-power-a-house-than-rent-it-in-pakistan
[10] https://www.bloomberg.com/news/articles/2024-08-13/it-can-cost-more-to-power-a-house-than-rent-it-in-pakistan

Figure 2: Payback Period (Years) for Solar PV Installations (5-25 Kw) in Pakistan Under Net-Metering



Source: Renewables First & Herald Analytics, 2024

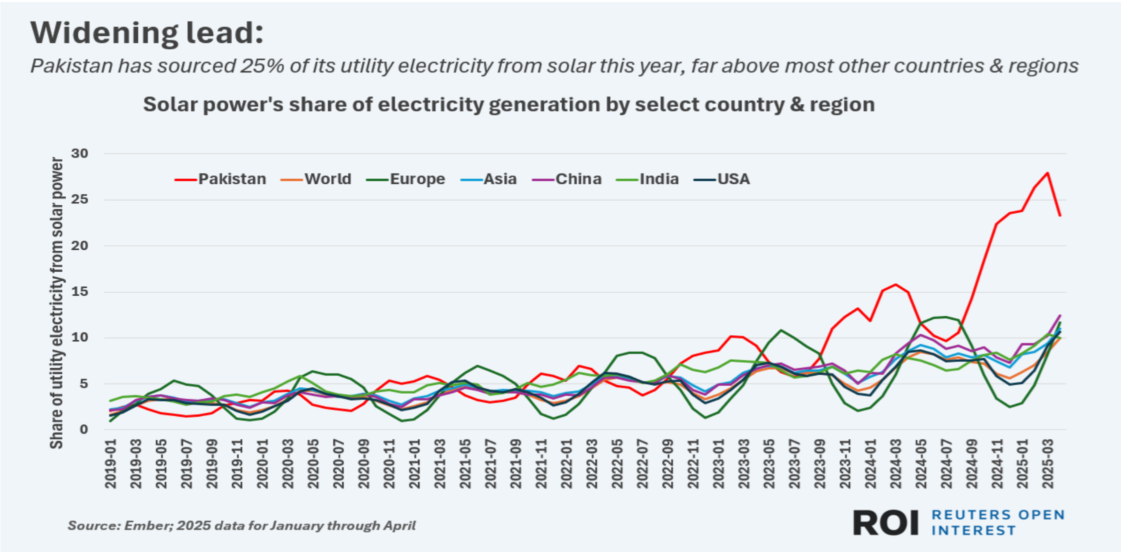
24. Effectively, for harnessing the potential of solar energy in Pakistan and making this transition smooth and financially viable, the country needs vibrant markets mechanisms, supported by clear government regulations. As noted by some previous studies (see Timilsina et al., 2012), any significant deployment of solar technologies is not possible without clear policy incentives by the respective countries. To this end, the main barriers include technical and financial constraints as well as the policy uncertainty, particularly on the net metering. Timely interventions by the state and effective regulations are urgently needed to expedite solarization.

1.1 Overview of Solar Energy in Pakistan

25. Pakistan presents a very strong case for solar energy transition due to its geographical location. The country has a huge land area of around 800,000 km^2 and abundant availability of daily sunlight making it highly suitable for large-scale solar energy production. Situated between latitudes 24°–37° North and longitudes 62°–75° East, it receives an estimated 1.55 × 10^{15} kWh of solar radiation annually (Ulfat et al., 2012). Pakistan's south-western province of Baluchistan and Northeastern part of Sindh is particularly suitable for solar energy with annual mean sunshine duration of 8-8.5h or more than 2300 to 2700h per annum (Mirza et al., 2003). Some previous studies indicate that all this potential can translate into 2.9 million MW of solar energy in the country per annum (Ghafoor et al., 2016).

26. The Government of Pakistan took its first steps toward solar energy in the early 1980s by installing 18 photovoltaic (PV) systems with a total capacity of 440 KW. Yet, due to financial and technical constraints, progress stalled, and these early initiatives had completely phased out by the early 1990s (Sheikh, 2010). The renewed momentum in Pakistan's solar sector is largely attributable to the energy crisis that emerged in 2005-06 and persisted until the inflow of CPEC-related energy investments after 2013. Although the demand-supply mismatch still exists due to the cyclical nature of electricity demand in the country, the overall condition of energy supply has improved after the formal start of CPEC related energy plants. These investments, by providing both financial and technical support, played a pivotal role in initiating the country's current solar energy transition. Some other factors contributing to the process of solarization in Pakistan include high energy prices, frequent load shedding and limited availability of fossil fuels in the country. On the availability of proven natural reserves, some recent studies indicate that Pakistan has already depleted nearly 80 percent of its proven oil reserves and about 70 percent of its proven natural gas reserves. In the absence of any major new discoveries, the remaining reserves are expected to last no more than 15 years.[11] Furthermore, declining market prices of solar technologies also contributed to a mass scale solarization in Pakistan. Here again, both local and international factors contributed to this price decline. At global level, research and development (R&D) in clean energy technologies is increasing, enhancing the accessibility of these technologies to the average users. Similarly, at the local level, Government of Pakistan has facilitated Solar technologies by removing the 17% GST on the imports of solar panels.[12] All this set the stage for massive solarization in the past five years and placed the country among the leading markets of solar panels.

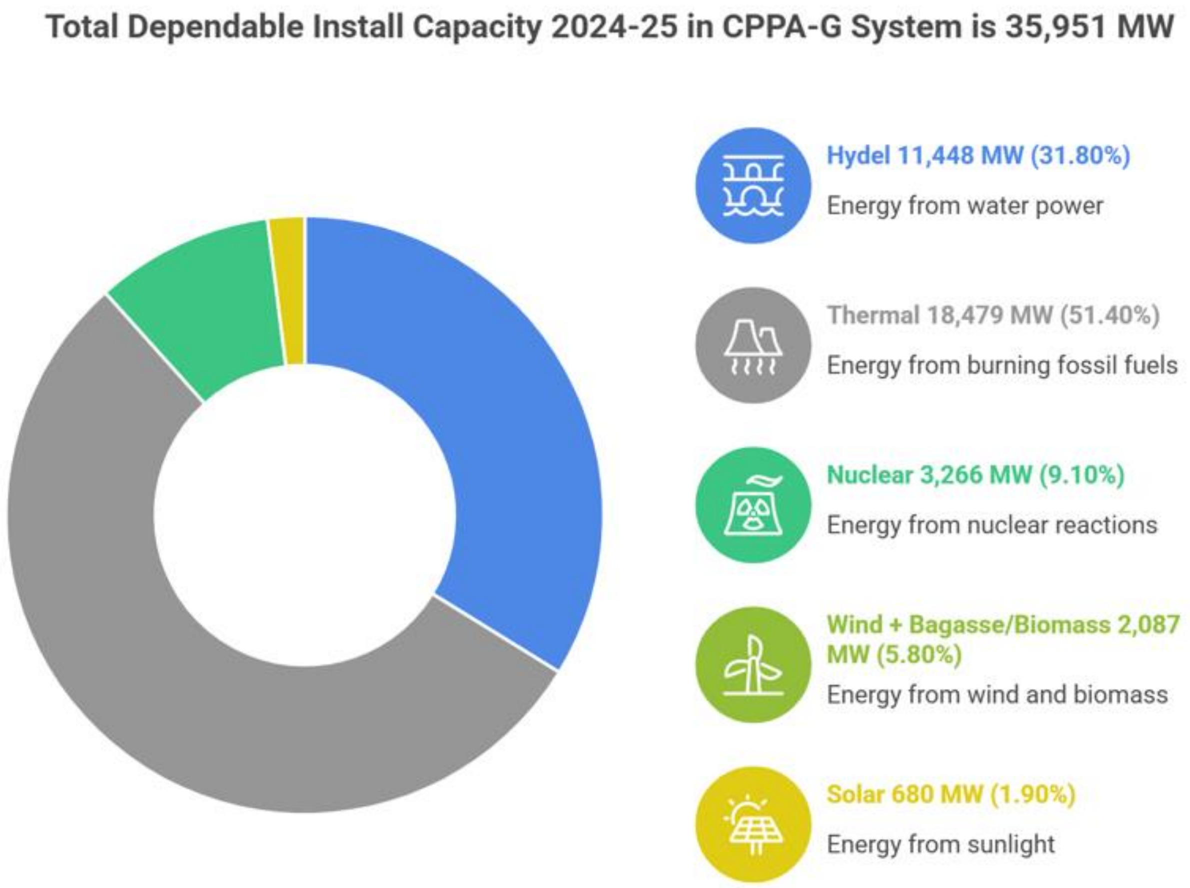
Figure 3: Solarization in Pakistan Compared to the Global Trend



[11] https://www.dawn.com/news/1964522/renewed-hope-in-the-energy-sector
[12] https://web.archive.org/web/20220521053043/https://www.dawn.com/news/1690683

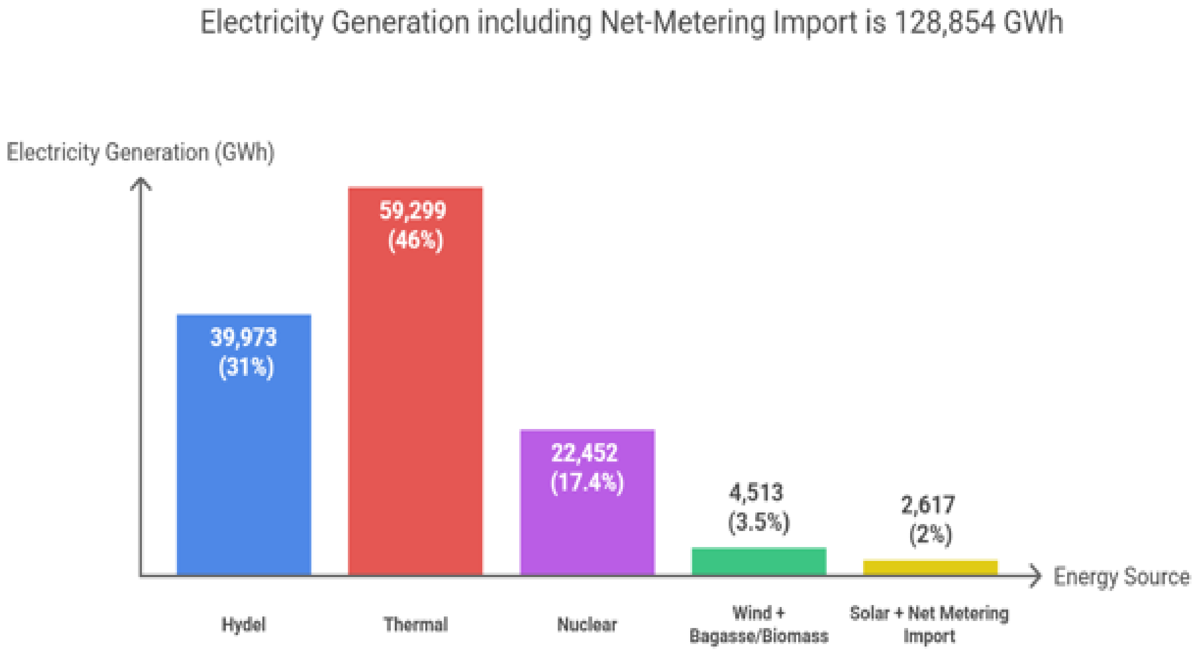
27. A diversified energy generation mix is essential for maintaining a stable, reliable, and sustainable power supply system. In terms of installed generation capacity, solar energy represented a modest share of 1.90%, reflecting its limited but growing role in the national energy landscape. Figure 3 reports a complete breakdown of country's energy-mix for the FY 2024-25. As can be seen, the largest contribution in the Pakistan's overall energy mix is thermal based (51.40%) indicating a huge scope for clean energy transition. This is particularly important when the hydro resources are dwindling due to low water availability from glaciers. By contrast, the overreliance on thermal based energy has made the prices high and volatile as global energy prices observe high fluctuation due to demand-supply factors, geopolitical environment and exchange rate fluctuations, among others.

Figure 3: Dependable Installed Capacity by Source 2024-25 Pakistan and Market Share (CPPA-G System)



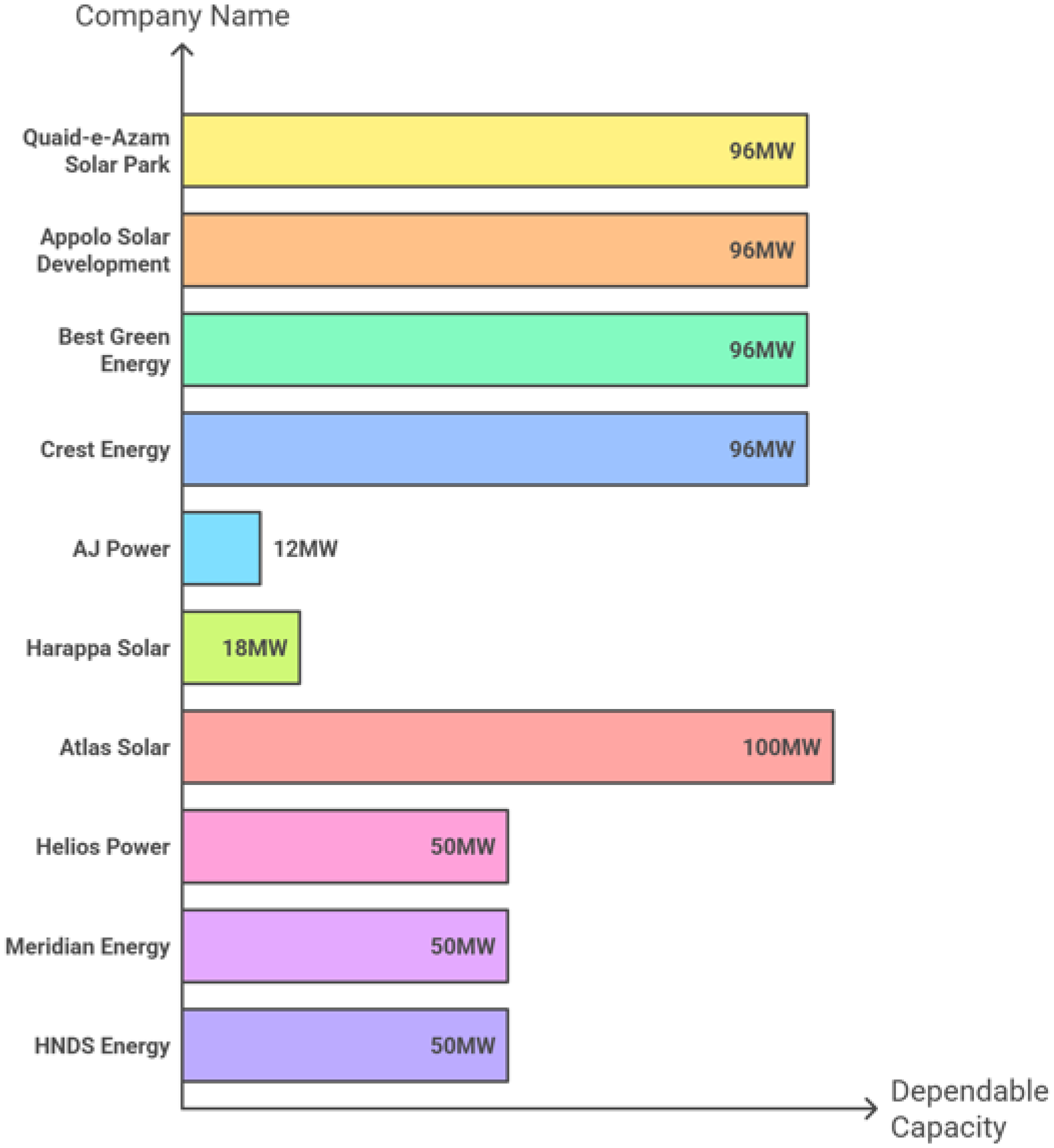
28. During 2024-25, Pakistan generated a total of 128,854 GWh of electricity including net-metering import. The power mix is dominated by traditional sources (Figure 4). Thermal power remained the largest contributor with 46%, followed by hydel power at 31% and nuclear energy at 17.4%. Other renewables such as wind and bagasse/biomass together contributed 3.5%. Solar energy accounted for only 2% (1,487 GWh) of total generation, making it the smallest source in the mix. This is very low compared to Pakistan's strong solar potential. The figures show that despite growing interest in solar power, its role in the grid remains limited.

Figure 4: Total Electricity Generation including Net-Metering Import in Pakistan 2023-24 (CPPA-G)



29. Figure 5 shows the major utility-scale solar power projects in Pakistan and their dependable capacity, which reflects how much electricity these plants can reliably deliver to the grid. Most large projects have a dependable capacity close to 96 MW, including Quaid-e-Azam Solar Park, Apollo Solar Development, Best Green Energy, and Crest Energy, indicating a fairly standardized project size in the early phase of solar development. Atlas Solar stands out with the highest dependable capacity of 100 MW, while a second tier of projects Helios Power, Meridian Energy, and HNDS Energy each contribute 50 MW. Smaller projects such as Harappa Solar (18 MW) and AJ Power (12 MW) show limited scale and impact on overall generation. It highlights that Pakistan's utility-scale solar sector is small, concentrated, and limited to a few medium-sized projects. While these projects demonstrate the technical feasibility of grid-connected solar, the modest dependable capacity across the sector explains why solar contribution to total electricity generation remains low, despite strong solar potential.

Figure 4: Dependable Capacity of Utility Scale Solar Plants in Pakistan



30. The importance of solarization can also be judged from the fact that the country needs clean energy to meet the targets related to SDGs and to combat climate change. As a matter of fact, Pakistan is widely recognized as one of the most vulnerable countries being impacted by the climate change due to its geographic location, climatic variability, and socio-economic fragility (Asian Development Bank, 2020). Despite contributing minimally to global greenhouse gas emissions, the country consistently ranks among the top five nations most affected by climate change (UN-Habitat, 2023). This heightened vulnerability has manifested in the form of recurring natural disasters ranging from floods, droughts, and heat waves to landslides while the nation's adaptive capacity remains critically limited (Stocker et al., 2013). Over the past three decades, Pakistan has faced a series of climate-induced catastrophes, including the prolonged drought of 1999-2003, the historic floods between the years 2010, 2014, 2022, and the ongoing

inundations in 2025 (Zhang et al., 2023). Projections indicate that by 2050, the country's average temperature could rise by 2-3°C, accompanied by significant variations in rainfall distribution (Gorst et al., 2015). The economic implications of climate change for Pakistan are profound. Without effective adaptation measures, annual losses could reach up to 6% of GDP by 2050, primarily through damages to agriculture, water resources, infrastructure, and public health (Asian Development Bank, 2020). One of the main reasons behind this rapid environmental degradation and climate disasters is the country's reliance on fossil fuel technologies not only to produce electricity but also for automobile, industrial and agricultural activities. To sum up, climate change alone provides an ample justification for solar and other renewable energy technologies.

31. In the case of Pakistan, the push for solarization is further strengthened by the structural challenges faced by DISCOs in supplying electricity to rural areas. Extending the grid to dispersed rural communities requires substantial infrastructure investment, while the revenue potential from these areas remains relatively low. Given that a large share of Pakistan's population lives in rural regions, this represents a vast, largely untapped market for solar energy solutions. A similar situation exists in the agriculture sector, where tube wells are widely scattered and recovery issues persist. For example, in 2023–24, electricity consumption by the agriculture sector reached approximately 8,578 GWh, generating bills worth Rs. 343.05 billion. However, DISCOs recovered only Rs. 263 billion reflecting a recovery rate of just 68.79%. Solarizing the agriculture sector would ease the financial burden on DISCOs while ensuring reliable and cost-effective energy for a sector that forms the backbone of the economy. In this way, cheap electricity would contribute to lowering food price inflation and ameliorate the situation of economic poverty in the society.

32. Furthermore, the government currently provides substantial subsidies to low-income consumers who use less than 200 units per month, creating a significant and recurring fiscal burden. Rather than continuing these perpetual subsidies, a more sustainable strategy would be to provide solar panels and storage batteries to low-income households. This would ensure long-term energy security for vulnerable consumers while easing the financial strain on the national exchequer. In addition, energy is a basic necessity, and restrictions on its use inevitably translate into a lower quality of life. Keeping households confined to below 200 units per month effectively forces them to compromise on essential energy needs, resulting in diminished living standards. A shift toward solar solutions would allow these households to meet their basic requirements without such constraints.

1.2 Objectives of the Study

33. This takes us to the main objectives of our study. While the growth potential of solar energy in Pakistan is remarkable, ensuring that the market functions in a competitive and efficient manner remains a key priority for the Competition Commission of Pakistan (CCP). Recognizing the solar sector's growing importance in the ailing energy sector and its deep inter-linkages with the broader economy, the CCP considers it essential to closely examine the evolution of this market. To this end, the present study seeks to

examine key competition-related aspects of solarization in Pakistan. It will assess the overall competition landscape of the rapidly growing solar energy sector in the country. The analysis will explore whether factors such as import dependence, certification processes, and licensing requirements pose barriers to fair competition. By examining market competitiveness and identifying key policy bottlenecks, the study seeks to develop actionable recommendations that will not only promote fair competition in the solar sector but also contribute to transforming Pakistan's overall energy landscape. A smooth transition towards solar energy, through market fairness and competition, will substantially reduce Pakistan's energy import bill, increase energy autonomy and contribute to the sustainable development goals (SDGs) 7 and 13. Briefly, our main objectives can be summarized as follows:

i. To highlight the potential of solar energy in Pakistan amidst growing economic and environmental challenges and, to link this evolution with the selected SDGs.

ii. To evaluate the competition landscape of the solar energy in Pakistan.

iii. To identify the regulatory barriers for a smooth transition towards solar energy system.

iv. To discuss the pros and cons of net metering policies and the implications of policy uncertainties on solarization.

v. To present recommendations for sustainable growth of solar energy sector.

1.3 Significance of the Study

34. A successful transition to solar energy offers numerous advantages for Pakistan. First, since a large portion of the population resides in rural areas, extending electricity through the national grid involves substantial transmission costs and significant line losses. Solar-powered micro- and mini-grids provide a cost-effective and efficient alternative for electrifying these remote regions. Second, the current centralized electricity system suffers from considerable transmission losses due to aging infrastructure and theft. These inefficiencies can be significantly reduced by adopting decentralized solar energy systems. Third, Pakistan is currently dependent upon fossil fuel energy which is mainly imported from gulf countries and other international markets. A heavy dependence on imported energy creates energy security challenges in this hostile geo-strategic environment. Hence, by reducing country's dependence on the international markets, solarization will help overcome energy security challenges. Fourth, Pakistan is geographically well-positioned to harness solar power, enjoying abundant sunshine, particularly during peak energy demand months. Fifth, shifting towards solar energy would substantially lower the annual import bill currently around USD 16 billion and thereby easing pressure on the trade balance and foreign exchange reserves (Pakistan Bureau of Statistics, 2025). Lastly, the country ranks among the top five most severely affected by climate change. The continued reliance on fossil fuels is further worsening the crisis, leading to significant human and environmental losses. Mitigating this

degradation demands a smooth transition from fossil fuel-based systems to clean energy technologies. In this regard, solar energy emerges as the most viable and sustainable option among the available renewable alternatives.

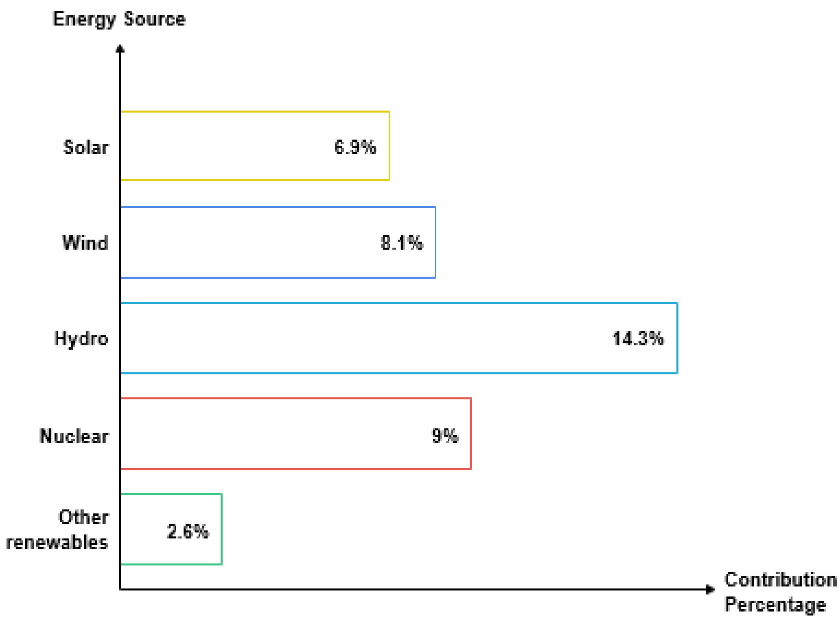
35. The remaining of this study is structured as follows: Chapter 2 discuss an overview of solar energy in Pakistan. Chapter 3 discusses global perspectives on solar energy. Chapter 4 describes market structure and value chain of solar energy. Chapter 5 elaborates the regulatory environment of solar energy markets in Pakistan and elaborate on government's net metering policy. Finally, Chapter 6 concludes this report with policy recommendations.

2. Global Perspective of Solar Energy

Chapter 2: Global Perspective of Solar Energy

36. In 2024, the world saw an increase in renewable energy, led mainly by solar power. At the same time, nuclear energy output also rose. Together, the developments pushed the share of clean electricity to 40.9% of global electricity, compared to 39.4% in 2023. It marks an important milestone, as it was the first year since the 1940s that low-carbon sources provided more than 40% of the world's electricity. Notably, the electricity system today is about 50 times larger than it was in the 1940s. Wind and solar energy continued to expand rapidly. In 2024, their combined share reached 15% of global electricity generation (wind at 8.1% and solar at 6.9%), surpassing hydropower for the first time. Despite this shift, hydropower still remained the single largest source of clean electricity, contributing 14.3% of the global supply. Nuclear energy followed closely, providing 9.0% of electricity worldwide. Other renewables, such as bioenergy and geothermal power, contributed 2.6% of global electricity in 2024.[13]

Figure 5: Share of renewable energy sources in the world (2024)

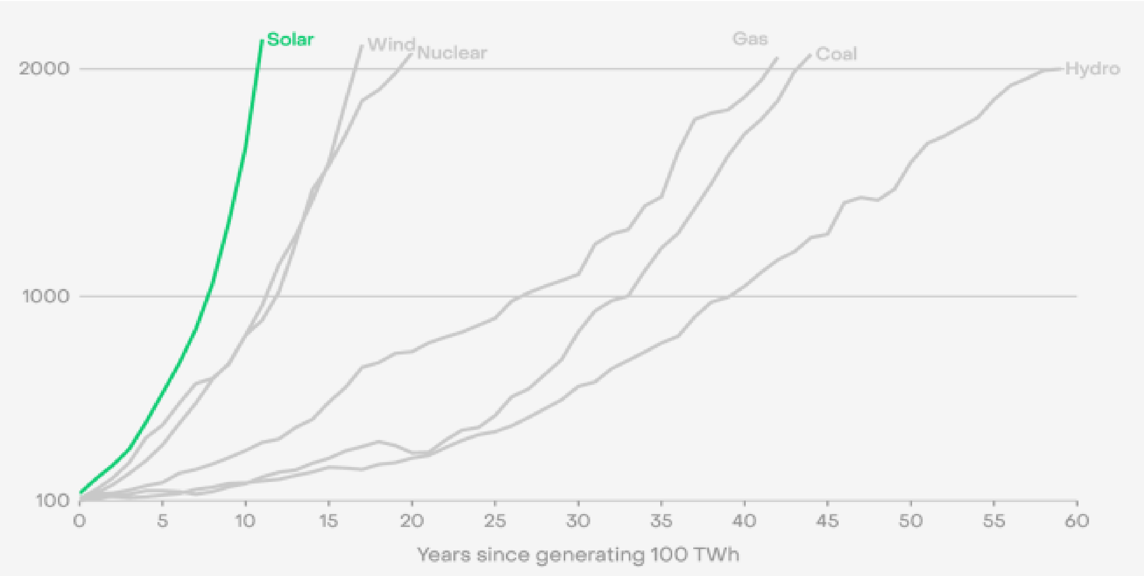


37. In 2024, solar power supplied more than 2,000 terawatt-hours (TWh) of electricity globally. It represented an increase of 474 TWh (29%) compared to the previous year, the largest annual increase in electricity generation from any single power source during the year. Solar energy has now been the leading source of new electricity generation worldwide for three consecutive years. The pace of growth has been remarkable: while global solar generation expanded from 100 TWh to 1,000 TWh over an eight-year period, it required only three years to double again from 1,000 TWh to 2,000 TWh. The trend shows the exponential growth trajectory of solar energy, with its output effectively

[13] Record rise in renewables pushes clean power generation above 40% of global electricity. See online at https://ember-energy.org/latest-insights/global-electricity-review-2025/2024-in-review/

doubling every three years. Such rapid expansion give emphasis to solar central role in the global energy transition and its growing importance in meeting rising electricity demand. China remained the principal driver of this global expansion. In 2024, the country added 250 TWh of solar generation, accounting for more than half (53 percent) of the worldwide increase. The growth was four times higher than that of the United States, which recorded the second-largest increase of 64 TWh.

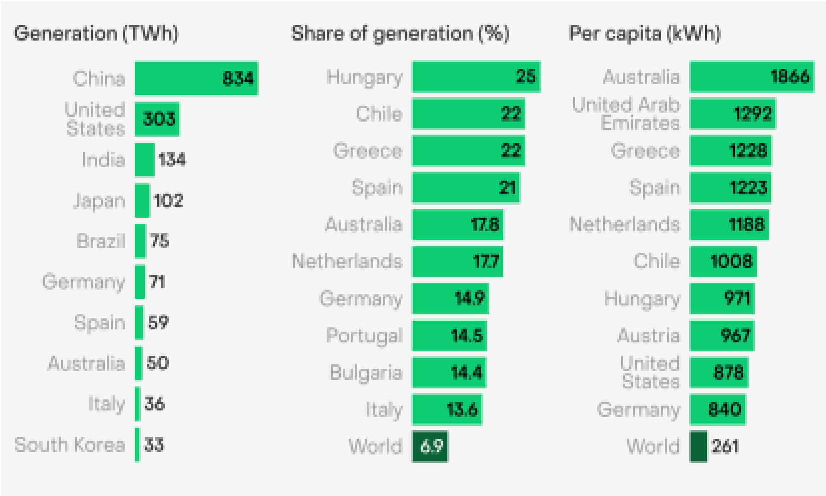
Figure 6: Global Energy Generation per Source, by years since passing 100 TWh



38. In absolute terms, China remained the global leader in solar power generation that produced 834 TWh in 2024. The figure alone was greater than the global solar output just five years earlier in 2019. As a result, China accounted for 39% of the world's total solar generation in 2024. At the same time, the global rankings shifted. Brazil, which stood at 58th place in 2015, rose to become the fifth-largest solar generator by 2024, surpassed Germany despite Germany also achieving record growth. In terms of electricity mix, 42 countries now generate at least 10% of their electricity from solar. Among them, Hungary and Chile stand out. Hungary generated a quarter (25%) of its electricity from solar in 2024, while Chile followed closely at 22%. Both countries had solar shares below 2% in 2015. On a per capita basis, Australia remained the world leader, producing 1,866 kWh of solar electricity per person in 2024, more than seven times the world average. The developments demonstrate that solar power is no longer confined to a few advanced economies; rather, it has become a global phenomenon, reshaping electricity markets across both developed and developing countries.[14]

Figure 7: Global Solar Electricity Rankings 2024

[14] Record rise in renewables pushes clean power generation above 40% of global electricity. See online at https://ember-energy.org/latest-insights/global-electricity-review-2025/2024-in-review/



2.1 Cross-Country Comparison of Solar Energy Sector

39. The growth of solar energy around the world depends on how each country supports and develops this sector. To strengthen the report, we compared the progress of China, India, Brazil, and Pakistan to understand how different countries are promoting solar energy. The comparison is based on five main areas: income per capita, electric power consumption (kWh per capita), business electricity rates in USD/kWh, 2023–2025 average, the share of solar power in the total electricity mix, domestic manufacturing capacity, and policy incentives including net metering, subsidies, feed-in tariffs, and tax breaks.

40. As shown in Table 1, the sample economies vary significantly in income levels, energy consumption, and solarization rates. The statistics on GDP per capita and electricity use reveal some interesting patterns. Countries with higher per-capita income tend to consume more electricity. This relationship reflects two key points: first, higher income enables households to allocate more resources toward electricity, which is a necessary good; and second, greater energy use often supports higher production of goods and services, since electricity is a critical input for economic activity. Against this backdrop, Pakistan ranks lowest among the selected countries both in per-capita income and per-capita electricity consumption. This gap highlights a strong case for accelerating solar adoption, as increasing access to affordable energy can contribute to higher productivity and income generation.

41. The next two rows present business-sector electricity prices and solarization rates across the four sample economies. Since energy is a fundamental input in the production function, lower electricity prices are particularly critical for firms operating in export-oriented sectors. Once again, electricity prices for businesses are lowest in China and highest in Pakistan. This disparity helps explain why Pakistan's exports have remained stagnant over the years, whereas China has emerged as a global export leader. Similarly, the share of solar energy in Pakistan's overall energy mix remains the lowest among the sample countries, as shown in Table 1. Increasing the contribution of solar energy would enhance export competitiveness by reducing production costs, ease pressure on the local

currency by lowering dependence on imported fuels, and ultimately support broader macroeconomic stability.

42. China stands far ahead of the other three countries. With the highest income per capita and very high electricity consumption, it has built a fully integrated solar manufacturing ecosystem covering panels, inverters, and batteries. Almost the entire supply chain is local, supported by strong government policies such as tax incentives, subsidized financing, feed-in tariffs, large-scale R&D funding, and clear long-term planning. As a result, solar power contributes more than 12% to China's electricity mix. India has also made progress by combining policy incentives with a push toward domestic manufacturing. It's Production-Linked Incentive (PLI) Scheme and customs duties on imported solar equipment have helped expand module manufacturing capacity to over 100 GW. India's solar share is close to 10%, and its policies encourage both local production and consumer adoption through net metering, domestic content rules, and "Make in India" preferences.

43. Brazil, despite having a higher income level than Pakistan, relies almost entirely on imported solar modules 99% of panels are sourced from abroad. However, Brazil has achieved solar penetration (nearly 15% of its electricity mix) because of tax exemptions, affordable credit lines, and social programs that enable even low-income households to install solar systems. Its system shows that even without large-scale domestic manufacturing, well-designed incentives can drive widespread adoption. On the other hand, Pakistan has the lowest income per capita, lowest electricity consumption, and the highest business electricity tariffs among the four countries. Solar energy contributes just 1.15% to the national electricity mix, and around 99% of solar panels and equipment are imported. Unlike China, India, or Brazil, Pakistan lacks targeted manufacturing incentives, long-term policies, and supportive financing structures. However, the share of off-grid solar installations such as household and commercial rooftop systems are relatively higher compared to other countries.

Table 1: Cross-Country Comparison of Solar Energy Performance

Variables	China	India	Brazil	Pakistan
Income Per Capita (USD)	13,303	2697	10,280	1485
Electric Power Consumption (kWh per capita)	6,524	1,182	2,916	606
Business Electricity Rates in USD/kWh, 2023–2025 average	0.096	0.125	0.129	0.156

Solar Share in Electricity Mix (%)	12.4%	9.8%	14.9%	1.15%
Domestic Manufacturing Capacity	China has developed strong domestic manufacturing of solar panels, inverters, and batteries through concentrated industrial clusters that gives it a competitive advantage. The majority of the supply chain is localized.	India's module manufacturing capacity has expanded from about 72 GW in March 2024 to nearly 118 GW by July 2025.	Approximately 99% of the solar modules installed in Brazil are imported. Only 1 to 2 percent are domestically produced (2024).	99% imported.
Policy Incentives (Net Metering, Subsidies, FITs, Tax Breaks)	China has become a global leader in solar energy by providing a range of incentives to encourage growth in the sector. They supported the industry through R&D funding, tax incentives such as exemptions from corporate income tax and reductions in VAT, clear regulatory frameworks, and training programs. Consumers are also encouraged through feed-in tariff schemes. In addition, the Ministry of Finance increased its subsidy for solar in 2024, raising subsidies from 100 million yuan to 1 billion yuan (around US$137 million).	India is implementing a Production Linked Incentive (PLI) Scheme under the National Programme on High Efficiency Solar PV Modules with an outlay of Rs. 24,000 crore to boost domestic manufacturing at gigawatt scale. The scheme provides incentives for five years post-commissioning and is being implemented in two tranches: Tranche-I (Rs. 4,500 crore) awarded to three bidders for 8,737 MW capacity, and Tranche-II (Rs. 19,500 crore) currently under process. Complementary measures to support domestic solar manufacturing include Domestic Content Requirement (DCR) in subsidy-linked schemes, preference to 'Make in India' in public procurement, Basic Customs Duty (BCD) on imports of solar cells and modules (from April 2022), and withdrawal of customs duty concessions (since	The growth of solar energy in Brazil is supported by public policies, including tax exemptions (ICMS (Tax on Commerce and Services) and PIS/Cofins (federal tax paid by companies on their gross revenue, and the money goes into social programs such as unemployment benefits and allowances for workers)), facilitated credit lines for easier financing of solar systems, and government programs like Minha Casa, Minha Vida that promote solar adoption among low-income families.	Net-metering business is open to residential consumers.

		Feb 2021). Also net metering in place.		

China: https://ember-energy.org/latest-updates/wind-and-solar-generate-over-a-quarter-of-chinas-electricity-for-the-first-month-on-record/#:~:text=Share%20of%20generation%20(%25),set%20in%20August%20of%202024.
https://www.mdpi.com/1996-1073/18/5/1227 https://www.pvknowhow.com/news/china-solar-subsidies-stunning-10x-boost-in-2024/
https://iea-pvps.org/wp-content/uploads/2025/01/IEA-PVPS-Task-1-NSR-China-2023.pdf
India: https://www.iea.org/data-and-statistics/charts/electricity-generation-from-solar-power-in-india
Germany: https://ember-energy.org/latest-insights/global-electricity-review-2025/2024-in-review/
Pakistan: https://nepra.org.pk/publications/State%20of%20Industry%20Reports/State%20of%20Industry%20Report%202024.pdf
India: https://www.pv-magazine.com/2025/02/07/india-hits-10-gw-of-solar-cell-capacity/#:~:text=India's%20module%20manufacturing%20capacity%20reached%2060%20GW,this%20fiscal%20year%20from%2045%25%20in%202024.
https://www.pib.gov.in/Pressreleaseshare.aspx?PRID=1909958#:~:text=The%20Government%20of%20India%20is,24%2C000%20crore.
Brazil: https://www.pvknowhow.com/countries/brazil/solar-supply-chain-brazil/#:~:text=While%20the%20demand%20for%20finished,are%20imported%2C%20primarily%20from%20Asia .

Table 2: Comparison of the Countries on different Variable of Solar Energy

Variables	China	India	Brazil	Pakistan
Income per Capita (USD)	High	Medium	Medium	Low
Power Use (kWh/capita)	Very High	Moderate	High	Very Low
Business Electricity Price	Low	Medium	Medium	Highest
Solar Share in Energy Mix	High	Growing	High	Very Low
Domestic Manufacturing	Strong, full supply chain	Expanding rapidly	Very limited	Almost none
Policy Incentives	Heavy R&D + subsidies + FITs	Strong PLI scheme + DCR + BCD	Tax exemptions + credit schemes	Net metering, limited incentives

3. Regulatory and Institutional

Chapter 3: Regulatory and Institutional Framework

44. Pakistan's energy landscape is undergoing a gradual transformation, with solar energy emerging as one of the promising sources to meet the growing electricity demand. The abundance of sunlight across most regions of Pakistan, high cost of grid electricity and decreasing price of solar panels make solar power an option for both grid-connected and off-grid solutions. Over the past decade, several initiatives have also been taken to promote solar energy through supportive policies (National Electric Power Regulatory Authority (Alternative & Renewable Energy) Distributed Generation and Net Metering Regulations, 2015), financing schemes, and facilitation of private sector participation.

45. A strong and coherent regulatory and institutional framework is therefore important to accelerate the growth of solar energy in Pakistan. Effective regulation ensures transparency, fair competition, and consumer protection, while institutional coordination among federal and provincial entities helps streamline project approvals and implementation. As the country transitions toward a diversified and sustainable energy mix, the roles of institutions such as NEPRA, PPIB, AEDB, NTDC, and provincial energy departments become essential to ensure that policy objectives are translated into on-ground results.

46. The section aims to examine the regulatory and institutional setup governing the solar energy sector in Pakistan, which will highlight the policies, laws, and institutions responsible for its development. The chapter seeks to provide a clear understanding of how the current framework supports or constrains solar energy growth and what reforms could enhance efficiency, competitiveness, and investment in the sector.

3.1 Policy and Legal Framework

47. Over the past two decades, Pakistan's policy and legal framework for solar energy has gradually evolved in response to rising electricity demand, growing dependence on imported fuels, and the need for a cleaner and more affordable energy mix. The government has shown a commitment to promoting renewable energy, and that is reflected through a series of national policies, regulatory reforms, and legal instruments. Together, these measures define the structure, direction, and functioning of the solar energy market in Pakistan, providing the foundation for both public and private sector participation in the country's transition toward sustainable energy.

3.1.1 Alternative and Renewable Energy (ARE) Policy 2019

48. The Alternative and Renewable Energy (ARE) Policy 2019 provides a framework for promoting renewable energy in Pakistan, with solar energy identified as one of the key technologies for diversifying the national power mix. The policy envisions solar power as a central component of Pakistan's long-term energy strategy, which aims to increase the share of renewables particularly solar and wind to at least 30 percent of the total generation capacity by 2030.

49. For grid-connected (utility-scale) solar power, the policy encourages private sector investment through transparent and competitive bidding processes. It replaces the earlier

upfront tariff regime with a competitive system. The policy empowers the PPIB and Provincial Energy Departments to facilitate project approvals, land acquisition, and coordination with relevant agencies. It also emphasizes the need to integrate solar projects into the Indicative Generation Capacity Expansion Plan (IGCEP) to ensure grid stability and optimal capacity planning. The policy recognizes the importance of strengthening transmission and grid infrastructure to accommodate variable renewable generation such as solar. It requires the National Transmission and Despatch Company (NTDC) and distribution companies (DISCOs) to plan network upgrades, adopt modern grid management tools, and introduce smart technologies to improve solar integration.

50. For distributed and off-grid solar applications, the policy promotes small-scale solar installations, including rooftop systems, mini-grids, and hybrid solutions, particularly in remote and underserved regions. It directs NEPRA and AEDB (now merged with PPIB) to develop frameworks for net metering, technical standards, and consumer protection. The government also encourages the participation of public institutions and private investors in expanding decentralized solar systems to enhance access to clean energy and reduce dependence on the national grid. Fiscal and financial incentives form another important aspect of the policy. The Policy provides for customs duty exemptions, tax incentives, and concessional financing to promote investment in solar technologies. It also encourages the local manufacturing of solar equipment such as panels, inverters, and batteries to build domestic capacity and reduce reliance on imports.[15]

3.1.2 National Electric Power Regulatory Authority (Prosumer) Regulations, 2026

51. NEPRA (Prosumer) Regulations, 2026, provide the updated regulatory framework governing distributed renewable energy generation in Pakistan. These regulations replace the earlier net metering regime and introduce a net billing mechanism for prosumers. It applies to distributed generation facilities based on solar, wind, or biogas energy sources with an installed capacity of up to 1 MW. Eligible participants include domestic, commercial, industrial, agricultural, and bulk consumers connected at 400V or 11kV. The capacity of the distributed generation facility cannot exceed the sanctioned load of the consumer, and for systems of 250 kW or above, a load flow study is required to ensure technical feasibility and grid stability.

52. A reform introduced under the 2026 regulations is the shift from net metering to net billing. Under this mechanism, electricity imported from the grid is billed at the applicable retail tariff, while electricity exported to the grid is purchased by the DISCO at the National Average Energy Purchase Price (NAEPP). Settlement is conducted in monetary terms rather than through one-to-one unit adjustment. If the monetary value of exported electricity exceeds the cost of imported electricity in a billing cycle, the surplus amount is either credited to subsequent bills or paid quarterly. The Authority also retains the power to revise the export purchase rate during the subsistence of the agreement.

[15] Alternative & Renewable Energy Policy, 2019. Ministry of Energy (Power Division). https://www.ppib.gov.pk/policies/ARE_Policy_2019_-_Gazette_Notified.pdf

53. The regulations establish a defined application and interconnection process. Applicants must submit a request to the relevant distribution company (DISCO), which is required to review the application within specified timelines. Interconnection approval depends on technical feasibility and transformer capacity constraints, with distributed generation limited to 80 percent of a transformer's rated capacity. After signing an interconnection agreement with the DISCO, the applicant must obtain formal concurrence from NEPRA. The prosumer is responsible for all interconnection costs, including metering and any necessary distribution system upgrades. The interconnection agreement is valid for five years and may be renewed upon mutual consent.

54. The regulations further prescribe technical and operational standards to ensure safe integration of distributed generation into the grid. Prosumers must comply with approved protection systems, voltage and frequency limits, inverter standards, and disconnection mechanisms. Distribution companies retain the right to limit or disconnect a facility in cases of fault, maintenance requirements, or regulatory non-compliance. Existing distributed generators operating under the repealed 2015 regulations will continue under their current agreements until expiry, after which renewals will be governed by the 2026 framework.[16]

3.1.2 National Electric Power Regulatory Authority (Alternative & Renewable Energy) Distributed Generation and Net Metering Regulations, 2015.

55. The Net Metering Regulations 2015, issued by NEPRA, established the first formal framework for distributed solar and wind power generation in Pakistan. The regulations enabled residential, commercial, and industrial consumers to generate their own electricity using solar or wind systems up to 1 MW capacity and connect them with the respective Distribution Company's (DISCO) network. Under the framework, eligible consumers referred to as "Distributed Generators" can install rooftop or on-site solar systems and export surplus electricity to the grid. A net metering mechanism is used, where electricity imported from the grid and electricity generated and supplied back to the grid are offset over a monthly billing cycle. If generation exceeds consumption, the excess units are credited to the next month's bill or paid out quarterly by the DISCO at the off-peak tariff rate of the respective consumer category.

56. The regulations also set procedures for application and interconnection. When a consumer submits a complete application, the DISCO must process it within specific timelines, including technical feasibility reviews and installing bi-directional metering equipment. NEPRA issues licenses to distributed generators after the agreement is signed. For the protection of grid stability and safety, technical standards are mandated, including inverter compliance with international certifications and installation of protection systems to prevent grid interference. Distributed Generators bear the cost of interconnection, metering, and any required upgrades specific to their connection. The

[16] National Electric Power Regulatory Authority (Prosumer) Regulations, 2026. https://www.nepra.org.pk/Legislation/3-Reg/3.35%20NEPRA%20%20Prosumer%20Regulations%202026/NEPRA%20Prosumer%20Regulations%20(SRO%20251(I)2026)%2009-02-26.PDF

regulations sets the rights and obligations for both parties. DISCOs must allow qualified consumers to interconnect and cannot unreasonably withhold approvals. They may disconnect systems only under defined conditions, such as safety faults. Distributed Generators must operate their systems safely, in line with the Grid and Distribution Codes. The regulatory framework also includes mechanisms for dispute resolution, NEPRA's authority to issue directions and seek information, and penalties for non-compliance.[17]

3.1.3 Regulation of Generation, Transmission and Distribution of Electric Power Act, 1997 (NEPRA Act)

57. The Regulation of Generation, Transmission and Distribution of Electric Power Act, 1997, commonly known as the NEPRA Act, serves as the cornerstone of power sector regulation of Pakistan. The primary objective of the NEPRA Act is to promote a transparent, competitive, and financially sustainable power sector by setting out clear rules for licensing, tariff determination, performance standards, and consumer protection. Under this Act, NEPRA has the exclusive authority to:

    (i). Issue licenses for the generation, transmission, and distribution of electricity to both public and private entities;

    (ii). Determine and approve tariffs for all categories of electricity consumers and producers;

    (iii). Set technical standards for grid operations, safety, and service quality; and

    (iv). Enforce compliance through monitoring, inspections, and penalties where necessary.[18]

3.1.4 National Electricity Policy 2021

58. The National Electricity Policy 2021 lays out vision for a power sector that is affordable, secure, sustainable and efficient. It put emphasis on universal access to electricity, diversification of the fuel mix, and integration of modern market mechanisms. The goals are underpinned by guiding principles such as transparency, competition, financial viability, local manufacturing (indigenization), and environmental responsibility.

59. In the generation, the policy instructs that new capacity additions should follow a least-cost and competitive basis, with increasing reliance on local resources including hydropower and renewables. Specifically, it calls for the development of a "sustainable renewable energy market" and prioritizes renewable zones for evaluation and

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[17] National Electric Power Regulatory Authority (Alternative & Renewable Energy) Distributed Generation and Net Metering Regulations, 2015. https://nepra.org.pk/Legislation/3-Reg/3.13%20NEPRA%20(Alternative%20&%20Renewable%20Energy)%20Distributed%20Generation%20and%20Net%20Metering%20Regulations,%202015/NOTIFICATION%20SRO%20892%20-2015.pdf

[18] The Regulation of Generation, Transmission and Distribution of Electric Power Act, 1997. https://nepra.org.pk/Legislation/1-Act/2022/1.%20[Updated]%20NEPRA%20Act%20All%20Amendments%20incorporated%20upto%20december%202021.pdf

procurement. In this context, solar energy is recognized as a key component of the renewable mix; the policy explicitly mentions “distributed generation, including net-metering additions” as part of integrated planning. On the grid and system operations side, the policy acknowledges the technical challenge of absorbing high shares of renewables and calls for upgrades to SCADA systems, better forecasting, and transparent grid operation practices measures which are especially relevant to solar PV integration. Under the tariff, subsidies and distributed generation section, the policy states that the regulator will prepare guidance for registering distributed generation facilities (such as rooftop solar) and that cost-recovery measures should take into account distributed generation and open access.

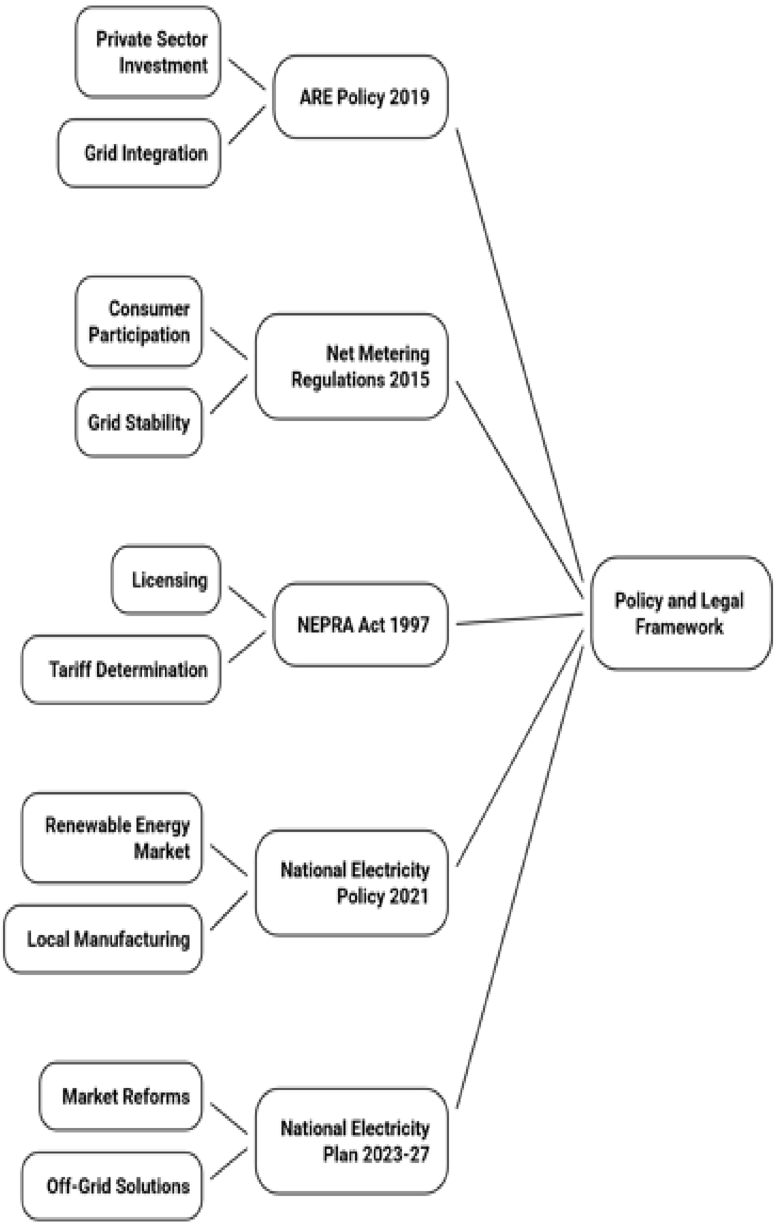
60. The policy also underscores indigenization, research & development as a guiding principle calling for promotion of local manufacturing, technology transfer and R&D across the energy value chain. For solar-industry stakeholders, this opens opportunities for domestic component manufacturing (solar panels, inverters, and batteries) and value-chain development. In terms of implementation and monitoring, the policy mandates that a five-year “National Electricity Plan” and rolling generation/transmission expansion plans (IGCEP and TSEP) be developed, with annual updates.

3.1.5 National Electricity Plan 2023-27

61. The National Electricity Plan 2023-2027 provides medium-term policy direction for the power sector and sets a regulatory foundation that influences solar energy development. The Plan prioritizes diversification, affordability, financial viability, and sustainability, with a shift towards increasing the share of renewable and distributed energy resources (DERs) including solar PV. It encourages more use of solar power both utility scale and rooftop systems and aims to make the energy mix cleaner and more affordable. The Plan introduces market reforms (Competitive Trading Bilateral Contract Market) that allow solar companies to sell electricity directly to consumers instead of relying only on the government’s single-buyer system, which increases competition and choice. It also works on improving the transmission and distribution network so the grid can handle more renewable energy without disruptions. Tariff changes are meant to make prices more transparent, though they may affect the savings for rooftop solar users depending on future policies. The Plan further supports off-grid solar solutions for remote areas through the Universal Electrification program.[19]

[19] National Electricity Plan 2023-2027. Ministry of Energy (Power Division). https://power.gov.pk/SiteImage/Policy/National%20Electricity%20Plan%202023-27.pdf

Figure 8: Pakistan's Policy and Legal Framework for Solar Energy



3.2 Institutional Framework

62. The institutional framework of solar energy sector operates within multi-layered institutional framework that brings together federal, provincial, and supporting organizations. Each institution plays a distinct and complementary role in shaping policies, regulating activities, private investment, and implementing projects across the country. At the federal level, the Ministry of Energy (Power Division), NEPRA, and the PPIB provide policy direction, regulation, and investor facilitation. Meanwhile, provincial departments and energy development boards are responsible for planning and executing solar initiatives within their respective jurisdictions. Because the

responsibilities of the institutions often intersect, effective coordination among them is essential. Clear communication and alignment between federal and provincial entities help prevent policy overlaps, procedural delays, and regulatory inconsistencies that can discourage investment or slow project implementation. A well-coordinated institutional framework not only ensures smoother execution of solar projects but also supports the long-term goal of building a competitive, transparent, and sustainable solar energy market in Pakistan.

3.2.1 Federal Institutions

3.2.1.1 Ministry of Energy (Power Division)

63. The Ministry of Energy (Power Division) was established in August 2017, when the former Ministry of Water & Power was split and the Power Division was moved under the newly formed Ministry of Energy. The Division's mandate covers the full spectrum of the electricity value chain in Pakistan namely, generation, transmission, distribution along with policy formulation, regulation liaison, and institutional oversight. It is responsible for steering the country's power sector toward greater efficiency, reliability, affordability, and sustainability. In line with the Government of Pakistan's Rules of Business (1973), the Power Division's assigned functions include:

    a. Promoting and developing the country's power resources (including generation).

    b. Overseeing electric utilities and associated institutions.

    c. Liaising with international engineering organizations and bodies for power-sector studies and development.

    d. Administrative control over federal statutory bodies in the power sector, such as the PPIB and the AEDB, now merged in PPIB.

64. More specifically, the Power Division is structured through several functional wings which cover:

    e. Dealing with circular debt, tariff and subsidy management, financial stability of the sector.

    f. Planning and oversight of transmission infrastructure, generation company oversight, integration of large-scale power projects.

    g. Coordination and oversight of distribution companies (DISCOs), public sector power-sector entities, and renewable energy agencies.

    h. Management of development projects under the Public Sector Development Programme (PSDP), donor-funded initiatives, and special projects (including renewables).

    i. Dealing with tariff setting, subsidies, and coordination with the regulator (NEPRA).

j. In addition, the Division supports the Government's strategic shift toward renewable and alternative energy sources such as hydropower, wind, solar to diversify the energy mix and bring electricity costs down for consumers.[20]

3.2.1.2 National Electricity Power Regulatory Authority (NEPRA)

65. NEPRA is electricity regulator in Pakistan, created under the *Regulation of Generation, Transmission and Distribution of Electric Power Act, 1997 (the NEPRA Act).* The mandate of NEPRA is to ensure that the power sector runs transparently, efficiently and fairly by licensing generators and distributors, setting and approving tariffs, enforcing technical and service standards, and protecting consumer interests.[21] In the context of solar energy, NEPRA issued the *Distributed Generation and Net Metering Regulations, 2015*, a legal framework for rooftop and small solar generators to connect to DISCO networks and to offset their bills by exporting surplus energy. The regulations set application procedures, technical and safety requirements, billing rules (net energy billing) and dispute resolution paths, enabling the spread of behind-the-meter solar in Pakistan.[22] For utility-scale solar projects, NEPRA evaluates tariff petitions (whether from competitive bids or cost-plus arrangements) and issues tariff determinations that form the basis for power purchase agreements and project bankability. As more solar capacity (utility and distributed) connects to the network, NEPRA enforces grid and interconnection standards to manage variability, protect grid stability and require appropriate protection and inverter standards. NEPRA supports competitive procurement (ICBs) and transparent tariff discovery for renewables that encourage lower costs and fair market access for solar developers. Its regulatory approvals and auction frameworks are enablers of competitive solar markets.[23]

3.2.1.3 Private Power and Infrastructure Board (PPIB)

66. PPIB works under the Ministry of Energy (Power Division) and acts as the federal government's main organization for facilitating private investment in the power sector. It was established in 1994 to attract IPPs and promote partnerships between the public and private sectors to help meet Pakistan's energy needs. Over time, PPIB has become an institution that connects investors, government bodies, and regulators to ensure smooth and timely development of power projects across the country. A major shift in PPIB's role came in 2023, when the Alternative Energy Development Board (AEDB) was merged into it. The merger brought all renewable and alternative energy activities including solar and wind power projects under one organization. The goal was to

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[20] Ministry of Energy (Power Division), Year Book 2023-24. https://power.gov.pk/SiteImage/Publication/YEARBOOK%202023-2024%20final.pdf
[21] National Electric Power Regulatory Authority. https://nepra.org.pk/About.php
[22] National Electric Power Regulatory Authority (Alternative & Renewable Energy) Distributed Generation and Net Metering Regulations, 2015. https://nepra.org.pk/Legislation/3-Reg/3.13%20NEPRA%20(Alternative%20&%20Renewable%20Energy)%20Distributed%20Generation%20and%20Net%20Metering%20Regulations,%202015/NOTIFICATION%20SRO%20892%20-2015.pdf
[23] Ibid

simplify processes, avoid duplication, and create a single national platform for both conventional and renewable energy investment.

67. In the solar energy sector, PPIB plays a role in turning government policies into real projects. It works with NEPRA, NTDC, provincial governments, and the Power Division to implement the Alternative and Renewable Energy (ARE) Policy 2019. The Board helps investors by issuing Letters of Interest (LOIs) and Letters of Support (LOS), coordinating with relevant agencies for approvals, and assisting in agreements such as Power Purchase Agreements (PPAs) and Implementation Agreements (IAs) that make projects financially viable and bankable. PPIB also leads efforts to introduce competitive bidding for renewable projects, replacing the old cost-plus tariff system with a more transparent and market-based approach. It works with the Special Investment Facilitation Council (SIFC) to attract local and foreign investors for large-scale solar initiatives, and with NTDC to ensure that solar projects are properly integrated into the national grid and aligned with the IGCEP. After the merger, PPIB has also inherited AEDB's technical expertise, data, and project pipeline that allows to handle renewable energy projects more efficiently. Its unified structure now serves as a one-stop institution for renewable and solar energy, which helps streamline project approvals and improve coordination among stakeholders.[24]

3.2.1.4 National Energy Efficiency & Conservation Authority (NEECA)

68. The National Energy Efficiency and Conservation Authority (NEECA) is a federal body established under the Ministry of Energy (Power Division) pursuant to the National Energy Efficiency and Conservation Act, 2016[25]. It serves as the national focal institution for promoting, coordinating, and implementing energy efficiency and conservation initiatives across different sectors of the economy. The Act provides the legal basis for the establishment of relevant institutions and sets out the mechanisms and procedures required to ensure the conservation and efficient use of energy in Pakistan.

69. Under its mandate, NEECA is responsible for formulating energy conservation programs in major energy-consuming sectors and planning and initiating energy efficiency actions at the national level. Its role also includes developing and maintaining database on energy conservation opportunities, supporting capacity-building and training activities related to energy efficiency applications, and undertaking field research and pilot demonstration projects for specific conservation technologies and solutions. In addition, NEECA monitors the implementation of energy conservation programs carried out by public and private sector entities to ensure alignment with national energy efficiency objectives.[26]

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[24] Discussion during the meeting with PPIB

[25] National Energy Efficiency and Conservation Act, 2016.
https://neeca.gov.pk/SiteImage/Misc/files/NEEC%20Act%202016.pdf

[26] NEECA Overview.
https://neeca.gov.pk/Detail/MzZiMGJmMDMtZGRiNS00OTNhLWE1M2ItMGZkN2U4NWZiZDM1

3.2.2 Provincial Institutions

3.2.2.1 Energy Department, Government of Punjab

70. The Energy Department, Government of Punjab, is responsible for overseeing the province's electricity-related functions, including regulation, coordination with distribution companies, and enforcement of technical standards. It supervises Electric Inspectors, manages billing and metering disputes, and regulates licensing for electrical contractors and supervisor. A major part of the department's role is to support the development of new power projects, including solar and other renewable energy sources. Through entities like Quaid-e-Azam Solar Power and the Punjab Power Development Company, the department helps plan and promote large solar projects and encourages private companies to invest in clean energy. It also works on off-grid solutions for remote areas and promotes energy-saving measures through better appliances, building codes, and awareness programs. The department is responsible for making energy policies for Punjab, monitoring electricity tariffs, and working with the federal government on licensing and electricity charges. It also supports public-private partnerships, new technologies, and faster approvals for investment in energy projects.[27]

3.2.2.2 Pakhtunkhwa Energy Development Organization (PEDO)

71. PEDO is executing body of the Energy & Power Department KP, mandated for development of energy sector in the province. Solar energy sector is being looked by the Renewable Energy/Private Powers (RE/PP) section for both Public and Public Private Partnership project. The core mandate is to plan, promote and execute energy projects especially in hydropower, solar, wind, and biomass to increase clean and affordable electricity supply. From a solar energy perspective, PEDO plays a role in:

    a. Identifying and developing solar project sites across KP, including utility-scale solar parks and distributed solar solutions for off-grid or remote communities.

    b. Implementing government-funded and donor-supported solar initiatives, such as solarization of schools, health facilities, tube wells and public buildings.

    c. Facilitating private sector investment in solar projects by offering clear guidelines, support in approvals, and coordination with provincial and federal.

    d. Promoting clean energy adoption through policy support, feasibility studies, project implementation and public-private partnerships.

    e. Supporting energy access and rural electrification where solar is the most practical and cost-effective option.[28]

[27] Energy Department, Government of Punjab. https://energy.punjab.gov.pk/functions
[28] Pakhtunkhwa Energy Development Organization (PEDO). Annual Report 2021-22. https://pedokp.gov.pk/wp-content/uploads/2024/04/PEDO_Annual_Report_2021_22.pdf

3.2.2.3 Directorate of Alternative Energy Sindh

72. The Directorate of Alternative Energy under the Energy Department, Government of Sindh works to promote renewable energy in the province, especially solar power, along with wind, biomass, waste-to-energy, and other natural energy sources. Its main role is to explore Sindh's potential for renewable energy and help the government and public understand the benefits of shifting to cleaner sources. The Directorate studies both the technical and economic feasibility of renewable energy projects, including solar. It provides information and awareness to communities, government bodies, and private companies about how renewable energy can reduce costs and improve energy access. It also supports the Sindh Government in making policies, rules, and regulations for the renewable energy sector. The Directorate helps implement national ARE Policy 2019. Another key function is to facilitate private investors who want to develop renewable energy projects in the province, including solar power plants. Additionally, the Directorate participates in research, development, and training programs to promote innovation and build capacity in the renewable energy sector across Sindh.[29]

3.2.2.4 Energy Department of the Government of Baluchistan

73. The Energy Department of the Government of Baluchistan is in charge for developing the province energy resources, including oil, gas, and especially renewable energy. One of its roles is planning and promoting new energy projects that can help meet the province growing electricity needs in a sustainable way. A major focus of the department is village electrification through renewable sources, such as solar energy. By using off-grid solar systems and other clean technologies, the department aims to provide reliable electricity to underserved communities. The department also works closely with Quetta Electric Supply Company (QESCO) to implement government-funded power development schemes. It has an attached department Baluchistan Energy Company Limited, which manages the production, sale, and distribution of oil, gas, LNG, LPG, and other fuels, along with renewable energy initiatives.[30]

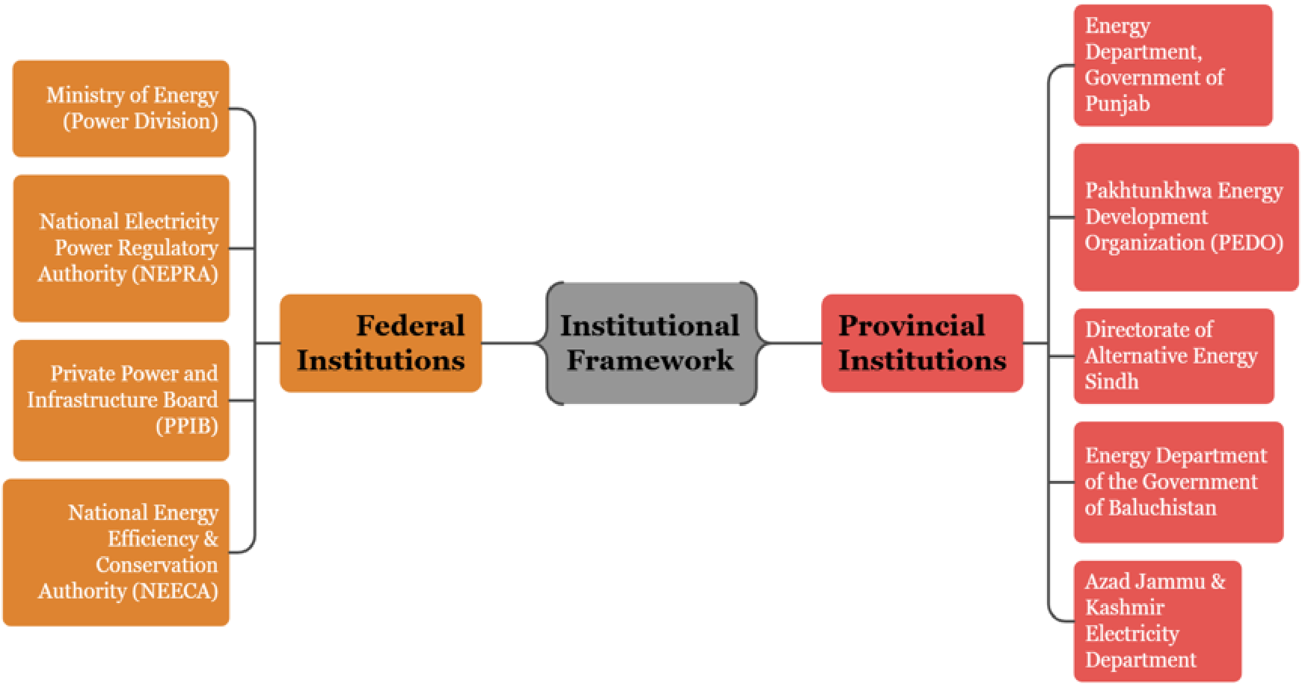
3.2.2.5 Azad Jammu & Kashmir Electricity Department

74. The Azad Government of the State of Jammu & Kashmir introduced the AJ&K Distributed Generation (Alternative & Renewable Energy) and Net Metering Regulations, 2022 to encourage the use of renewable energy and allow consumers to connect small-scale generation, mainly rooftop solar, to the electricity grid. Under these regulations, the AJ&K Electricity Department (AJKED) is the main authority responsible for implementing net metering. Its role includes processing applications, approving system designs, ensuring compliance with technical standards, installing bi-directional meters, and managing billing and energy settlement. AJKED also regulates and oversees approved vendors and installers, carries out inspections, and coordinates grid connectivity to ensure that distributed generation is integrated safely and efficiently. The regulations provide consumers with a structured pathway to adopt renewable energy

[29] Directorate of Alternate Energy, Sindh. https://sindhenergy.gov.pk/directorate-of-alternate-energy/
[30] Energy Department, Government of Baluchistan. https://energy.balochistan.gov.pk/?page_id=39

while helping the electricity system accommodate distributed generation in an orderly manner.[31]

Figure 9: Institutional Framework of Solar Energy Sector in Pakistan



3.3 Net-Metering Situation in the Country

75. Net metering is an electricity policy for consumers who own renewable energy facilities which allows them to use electricity whenever needed while getting credit for contributing their production to the grid. Producing electricity partly for own consumption, and partly for sale to the DISCO, provided anyone has a roof suitable for solar energy. Solar Energy is a long term power solution. The Solar PV Technology gives access to affordable electricity supply during system life. Residential, industrial, agricultural and commercial customers can switch their electricity load to solar energy and can slash their power bills. As mentioned earlier, 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 energies installations. Below figure shows flow of steps involve in Net Metering Process along with the timeline.[32]

[31] Azad Government of the State of Jammu & Kashmir, AJK Electricity Department. See online at https://ajked.gok.pk/wp-content/uploads/2023/09/AJKED-Net-Metering-Reference-Guide.pdf
[32] Net-Metering Reference Guide for Electricity Consumer and Installers. https://www.ppib.gov.pk/Netmetering/Net-Metering_Reference_Guide_for_Electricity_Consumer.pdf

Figure 10: Net-Metering Process and Timeline in Pakistan

	Description	Timeline
Application	Submit application with documents to DISCO.	As soon as requirements are met
Acknowledgement	DISCO acknowledges receipt and completeness.	Within 5 working days
Incomplete Application	Applicant provides missing information/documents.	Within 7 working days
Initial Review	DISCO reviews application for interconnection.	Within 20 working days
Technical Infeasibility	DISCO returns application with reason.	Within 3 working days
Agreement	DISCO and applicant enter into agreement.	Within 10 working days
Generation License	DISCO sends agreement to NEPRA for license.	Within 7 working days
Connection Charge Estimate	DISCO issues CCE for interconnection.	Right after the agreement
Payment of CCE	Applicant pays CCE and notifies DISCO.	Within 20 days
Installation	DISCO installs interconnection facility.	Within 30 days

76. Net-metering applications for systems with a capacity of less than 25 kW are handled directly by the DISCOs. Amid rising grid tariffs, ongoing concerns about supply reliability, and higher electricity prices driven by structural inefficiencies in DISCOs and broader macroeconomic pressures, Pakistan has witnessed a rapid expansion in distributed generation (DG), particularly rooftop solar PV systems. While this shift supports national goals related to sustainability and consumer empowerment, it also presents technical, commercial, and financial challenges for DISCOs. The following table gives the data of the number of consumers of different categories in FY 2024-25.

Table 3: Net-Metering Consumers FY 2024-25

Company	No of Consumers as of 30th June 2025
PESCO	20,952
TESCO	83
IESCO	72,332
GEPCO	37,658
LESCO	105,959
FESCO	27,844
MEPCO	83,548
HESCO	1,261
SEPCO	250
QESCO	320
KE	28,132
Total	**378,339**
Source: State of Industry Report 2025 (NEPRA)	

4. Market Structure and Value Chain

Chapter 4: Market Structure and Value Chain

77. In the competition assessment studies, the market structure of any commodity or service describes the organizational features and competitive dynamics that govern how transactions take place. It helps explain how buyers and sellers interact within a given market environment. Key factors that determine market structure include the number and size distribution of buyers and sellers, the nature of the product, supply chain and pricing practices, profitability levels, entry and exit barriers, and the strategies adopted by the market participants. A clear understanding of these elements is crucial for evaluating competitive behavior and assessing the overall efficiency and performance of a market. This chapter analyzes the market dynamics on both demand and supply sides of the solar panels and describes the actual size of this market.

4.1 The Relevant Market

Our definition of the relevant market is based on two elements: 1) relevant product market and 2) relevant geographic market. While the energy markets are quite vast and contain a range of fossil fuel and clean energy products, our study focuses only on solar technology with a particular emphasis on solar panels. Our geographic markets are the entire country as the adoption and use of solar panels is homogenous across Pakistan. It is important to mention that although solar panels being used everywhere in the country, the intensity of use is highest in Khyber Pakhtunkhwa, followed by Punjab, Sindh and Baluchistan. Likewise, the highest penetration of net metering is in Lahore.

4.2. Supply and Demand Dynamics

78. The current structure of the solar energy market comprises a diverse set of participants on both the supply and demand sides. On the supply side, key players include manufacturers, installers, and providers of complementary services such as maintenance, repair, and replacement. Similarly, the demand side participants include solar users such as households, industrial and commercial entities, farmers and government departments. This section provides an overview of the major actors on both demand and supply sides of the market and outlines the competition dynamics of the solar market.

4.2.1 Product Specifications

79. Concerning the type of solar panels mostly used worldwide, they can be divided into three categories: monocrystalline, polycrystalline and thin film solar panels. These three types differ with respect to the content used in their manufacturing, price and energy produced by each of these categories. For example, monocrystalline are made of single crystal of silicon, making them efficient due to uninterrupted flow of electrons. By contrast, polycrystalline and thin-film panels use multiple crystals that cause interruptions, causing lower efficiency. Monocrystalline panels are also considered more efficient in low-light conditions and hence can be used for a larger span of time a day. However, they are more costly to produce compared to the other two varieties. The panel technology that is currently available in Pakistan is N-type Bifacial panels which is

monocrystalline technology offering relatively high performance and short payback period.

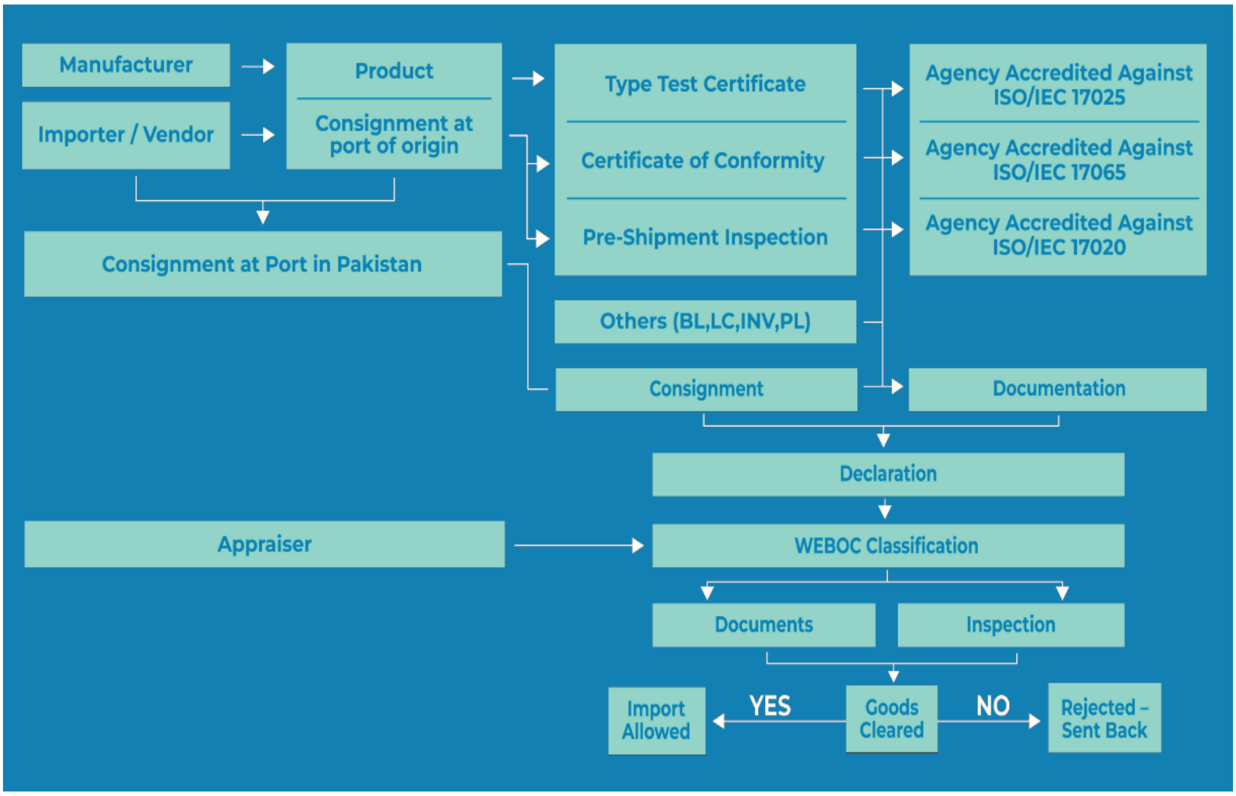
4.2.2 Import Process and Quality Control

80. Concerning the origin of solar panels imports, almost entire supply of this product coming to Pakistan is manufactured in China. In fact, the global supply is predominantly captured by Chinese companies (Cui et al., 2025) where substantial government subsidies, lower energy and labor cost, and sustained investment in R&D have enabled the producers to supply around 80% of the world's total output (International Energy Agency, 2022). In case of Pakistan, this dominance is even more pronounced as Chinese manufacturers only compete with one another. While some Chinese manufacturers have shown interest in setting up production in Pakistan[33], the materialization of these plans may take some time. Although the cost of Chinese-made solar panels has declined in recent years – mainly because of overproduction and tariffs from the Western economies – such heavy reliance on a single country raises concerns regarding supply chain resilience and geopolitical vulnerabilities. Moreover, for countries like Pakistan, job creation and the effective utilization of domestic resources are critical policy priorities. Developing local manufacturing capacity can generate employment opportunities and foster skill enhancement throughout all stages of the solar value chain. It can also help ensure better quality control, which is more difficult to enforce when relying heavily on imported products. In line with these objectives, the Government of Pakistan in 2024 raised the import duty on solar panels from zero to 10 percent as a policy measure to encourage domestic production.[34]

81. Just like the production of any conventional product, the import process starts with placement of order by the importer. Following the SRO 604, issued in 2019, solar imports must follow quality and safety standards approved by Pakistan Standards and Quality Control Authority (PSQCA). As per the said regulation, the product needs to pass different certification and inspection tests before the import is allowed (see Figure 4). Furthermore, the laboratory providing accreditation on the quality of the product must also be certified by ISO/IEC 17025. Once the panels and other related products arrive in the country, the custom department examines all the documents including invoices, certificates, Letter of Credit (LC) copies, etc. before the consignment is handed over to the importer. Failing to provide these documents leads to rejection and the product is sent back to the country of origin. To facilitate the import of solar panels, government of Pakistan brought them under Pakistan Single Window (PSW) where the importer must register, upload the required documents and clear customs for the delivery of the product.

[33] https://www.pvknowhow.com/news/longi-to-set-up-solar-panels-plant-in-pakistan/
[34] https://www.energyupdate.com.pk/2024/05/11/ppib-proposes-10-duty-on-solar-pv-module-imports-for-a-decade/

Figure 11: The Solar Import Process Flow



Source: Renewable First and Herald Analytics (2024)

4.2.3 Installation and After Sale Services

82. Once the import process of solar panels is complete, the subsequent phase is its installation at both utility and consumer levels. At this stage, utility scale installation is generally done by established brands. According to the Pakistan Solar Association, over 800 solar companies are registered in the country[35]; however, other sources suggest that more than 2,000 solar companies are currently operating in Pakistan.[36] The installation process of solar panels by the established brands includes several steps starting from the import of solar panels and equipment, maintaining their own warehouses, and carrying out installation and after-sales services using in-house teams. However, the installation of rooftop or farm-level plants is mostly done by the informal market participants as they offer lower service charges. This market is generally unstructured and informal with no clear product tracking. Over the last few years, this informal installation and maintenance market has grown exponentially with the addition of many players who have had prior experience of working with registered/branded installation companies. While the informal installation market reduces both upfront and maintenance costs, the market operates with higher risk and imprecision as the suppliers do not strictly follow engineering and quality standards. In fact, in many cases, they prefer low quality products since they do not have to offer any warranty claims. Moreover, the dominance

[35] Members Directory 2025. See online at https://www.pakistansolarassociation.org/members-directory/

[36] List of Solar energy contractors in Pakistan. See online at https://rentechdigital.com/smartscraper/business-report-details/list-of-solar-energy-contractors-in-pakistan?

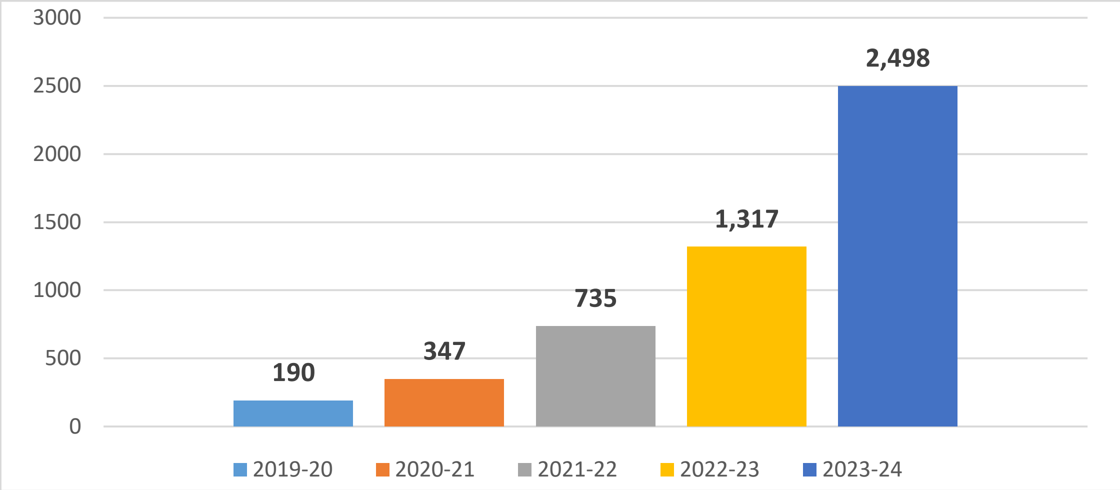
of informal agents is leaving less space for the formal agents who pay taxes and meet the regulatory requirements, set by PEC and PPIB.

83. Generally, these panels come with two types of warranties: the first is the Workmanship Warranty which is typically for 12 years and covers the physical qualities of the solar panel, protecting against physical defects, deterioration of components, hotspots etc. Secondly, the solar panels are covered by a Performance Warranty of 25 years, with some manufacturers offering 30 years, which warrants that the solar panels will only degrade at a specific rate (typically 1% in the first year and 0.4% every year after that) and will have a minimum efficiency at the end of the warranty period. While the import mechanism, detailed above, clearly mentions the quality related aspects of products, it is general perception in the market that the country receives a variety of products with different quality standards. In fact, as mentioned by one stakeholder, the recent influx of solar panels resulted in several sub-standard imports from China. This has created a challenge of quality control and increased the number of fire accidents.

4.2.4 Market Size and Demand Side Dynamics

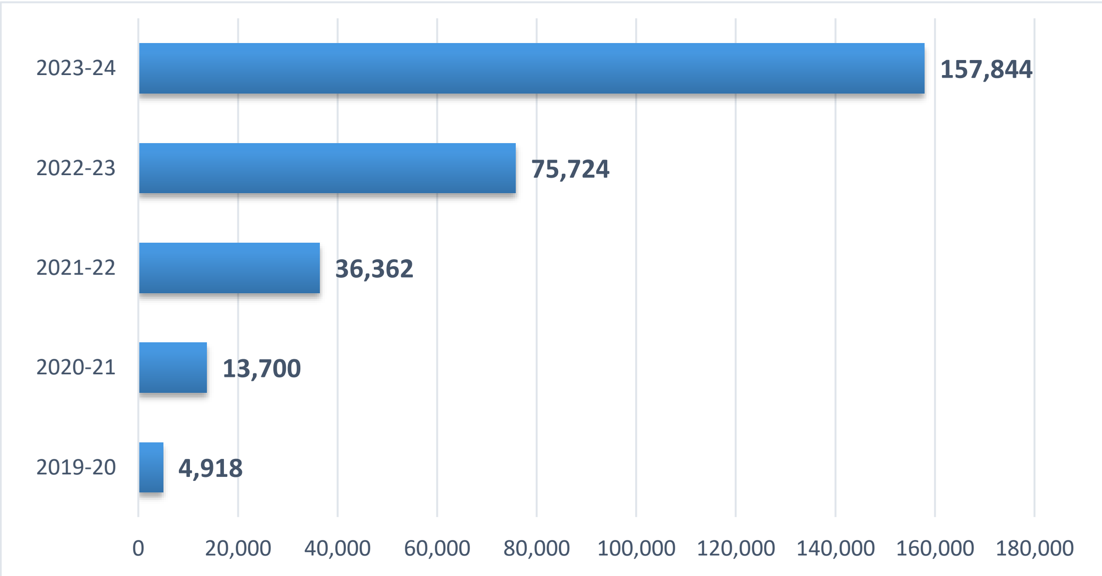
84. The above discussion highlights the supply side of Pakistan's solar market. Turning to the demand side, recent trends in solar adoption reveal some important insights. Official government statistics primarily based on DISCOs' net metering data capture only on-grid systems and therefore overlook a substantial portion of off-grid solar generation. Despite this shortcoming, the numbers showing installed capacity of net metering have improved significantly over the last few years. As shown by Figure 5, the total installed capacity during FY 2019-20 was around 190 MW which increased more than twelve times to reach 2498 in FY 2023-24. The IGCEP 2022-31 set the target of adding 3420 MW till 2031. However, the current trends suggest that this target will be achieved well before the deadline. Likewise, the number of net metered households also increased from merely 4,918 to 157,844 during the same period.

Figure 12: Installed Capacity of Net-Metering Consumers in DISCOs and KE (2019 – 2024)



Source: State of the Industry Report 2024, NEPRA

Figure 13: Net-Metering Consumers in DISCOs and KE (2019 – 2024)



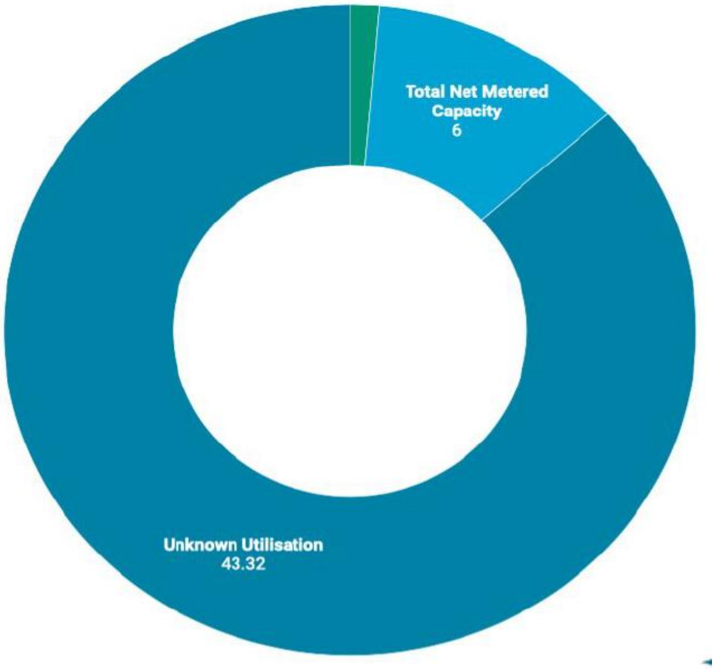
Source: State of the Industry Report 2024, NEPRA

85. Notwithstanding these impressive numbers, these figures still provide an incomplete picture of the magnitude of solarization in the country. These numbers also fail to explain the surge in solar panel imports over the past several years, particularly during the last two fiscal years. All stakeholders consulted on this matter confirmed that actual adoption rates are significantly higher than what official data suggests. More importantly, a recent study by the PRIED highlights stark discrepancies between government-reported solarization levels and the country's actual solar energy output[37]. The report confirms that during the year 2025, net metered capacity has increased up to 6 GW whereas the cumulative import of solar panels reached 50 GW. This huge gap

[37] https://www.priedpk.org/wp-content/uploads/2025/10/WHITE-PAPER-Solar-Revolution.pdf

cannot be explained by inventories, it explains off-grid solar installations largely practiced by rural areas and disconnected communities.

Figure 14: Solar Import versus Official Adoption Level



Source: PRIED Study

86. Conducted jointly by PRIED and TransitionZero[38], the study uses satellite imagery combined with household survey data to provide more accurate estimates of national solar energy production. The study mentions that a significant portion of solar energy is behind-the-meter and hence does not become part of national grid. More precisely, while the official net-metering estimates show 6 GW of electricity produced by solar technology, the satellite data results, complemented also by the consumer surveys, show around 33.35 GW of solar-based electricity in the country. The study divides the overall production into four main economic sectors, namely, the residential sector, industrial sector, agriculture sector and commercial sector. Among these sectors, household constitutes 50% (16.6 GW) of installed capacity followed by 7.9 GW for industrial sector, 5.4 for agriculture and 3.7 GW for commercial sector. This increasing reliance on solar energy is explained by lower solar prices, higher cost of grid electricity, extended power blackouts and a lack of connectivity with the grid of around 10% population.

4.2.5 Pricing, Cost Components and Seller Margins

87. Pricing trends are a key determinant of market expansion and sectoral growth. In the case of solar panels, prices are shaped by factory production costs, import duties, transportation expenses, and the profit margins of wholesalers and retailers. In recent

[38] https://www.transitionzero.org/shedding-light-on-pakistans-distributed-solar-revolution

years, global factory prices have declined significantly, largely due to excess supply in China and reduced Chinese solar exports to Western economies. For importing countries like Pakistan, however, domestic prices are also sensitive to exchange rate movements. The substantial depreciation of the PKR in recent years pushed up the cost of all imported goods, including solar panels. That said, relative stability in the dollar–rupee exchange rate over the past two years has helped facilitate a surge in solar panel imports from China. Additionally, in FY2025 the Government of Pakistan introduced a 10% import duty on solar panels, adding another cost component for local buyers. At the same time, the sharp rise in imports has squeezed the profit margins of wholesalers and retailers-particularly in an environment where much of the market operates informally and sellers typically work on thin margins. Overall, these factors point to a highly competitive solar market in Pakistan, with no evidence of monopolistic conduct or cartelization.

4.2.6 Solarization and Inclusive Energy Markets

88. An important aspect of solarization is its lack of inclusiveness. Solar adoption rates rise with household income levels, indicating that socio-economic conditions largely determine the extent to which families can adopt solar technologies.[39] Higher-income households not only install solar systems more frequently, but also tend to opt for larger capacities that support energy-intensive appliances such as refrigerators and air conditioners. In contrast, low-income households typically rely on small systems that meet only basic needs, particularly in remote areas that are not connected to the national grid. The relatively lower adoption rates among poorer segments underscore the financial constraints that remain a major barrier to widespread solar uptake. Moreover, because the payback period decreases as system capacity increases (see Figure 2), the solar transition becomes far more attractive for affluent households, particularly those residing in well-developed urban areas.

4.2.7 Geographic Location and the Efficiency of Utility Scale Projects

89. While the utility scale solar plants have been on the rise to cater energy challenges in Pakistan (Figure 5), some previous studies have reported deficiencies related to geographic location of these projects (Khosa et al, 2020). It is pertinent to mention that in case of solar energy, several factors affect its feasibility and lifetime returns. These include solar irradiance, sunshine hours, weather conditions, dust and rainfall, different types of energy losses and plant degradation over-time. Any miscalculation to future climate change or unpredictable changes in it will alter the cost – benefit analysis and internal rate of return (IRR) on these projects. In Pakistan, the first utility scale solar plant was Quaid-e-Azam Solar Park (QASP), located in Cholistan desert, district Bahawalpur. The project started with an initial electricity generation capacity of 100 MW which had then to be raised to 400 MW in the second phase and up to 1000 MW in the third phase. So far, the project has already completed the first two phases and hence works at 400 MW capacity. However, the project received some criticism in earlier

[39] Ibid

years, particularly related to its geographical location and climate in the project area, raising doubts not only about the performance of this plant.

90. The feasibility assessment of utility-scale solar projects typically relies on key parameters such as high solar irradiation, long sunshine hours, availability of unused desert land, and predominantly clear skies throughout the year. The Quaid-e-Azam Solar Park (QASP) site was evaluated against these criteria and was found to satisfy all fundamental feasibility requirements. The climate of Bahawalpur is characterized by hot and arid conditions, with average annual rainfall of approximately 200–220 mm. The upper soil layer at the site is very loose, non-cohesive, and friable, with minimal moisture content. A major concern associated with the project, however, is the high level of atmospheric dust, which adversely affects the performance of photovoltaic (PV) systems by limiting the amount of solar radiation reaching the cells. It has been noted by the previous literature that in extreme duty environment, the performance of solar system can reduce by up to 85% (Al-Sharafi et al., 2024). The loose soil structure further exacerbates this issue by increasing dust suspension, particularly in an area prone to frequent dust storms. In addition, limited groundwater availability constrains regular panel cleaning, thereby posing an operational challenge and potentially leading to sustained efficiency losses over time.

4.2.8 Data Related Issues and their Implications for Competition

91. A key deficiency related to Pakistan's solar energy market is the absence of reliable and comprehensive data on both the demand and supply sides. Such data are crucial for assessing market transparency, competitiveness, and contestability. On the supply side, market size is typically inferred from solar panel import statistics, net metering figures, or specialized research efforts, such as TransitionZero's recent satellite imagery–based study, mentioned above. On the demand side, most solar adoption occurs either off-grid or through hybrid systems in which consumers rely on solar power during daylight hours and switch to the national grid after dark. This makes it difficult to obtain accurate estimates of the true extent of solarization. The data gaps also prevent analysts from determining whether solar energy is substituting grid electricity or simply adding new consumption-particularly among energy-poor households. Despite these limitations, the market continues to exhibit competitive characteristics, supported by the large number of buyers and sellers operating across various stages of the supply chain.

4.2.9 Weak Human Capital, low R&D expenses and Informal Labor Market

75. Some other important factors hampering the growth of solar markets include weak human capital, low expenses on research and development (R&D) and informal arrangements in the labor markets. To this end, one important supply side factor is the availability of trained staff across all the parts of solar market. Pakistan currently faces a shortage of trained engineers and technicians for installation, operation and maintenance (O&M), and related services, as mentioned by various stakeholders. Addressing this gap requires targeted government investment and formal MoUs with China to facilitate exchange programs and technical internships. Training human capital in this sector is essential for achieving a partial or complete shift of the solar

supply chain into the country. At present, countries such as Malaysia, Thailand and Vietnam, manufacture various components used in solar production. India has started solar panels domestically to meet its demand. Pakistan can leverage this opportunity and align solar manufacturing with its broader industrialization goals under CPEC. Doing so would not only help meet domestic demand but also lay the groundwork for a solar-equipment export industry.

76. Similarly, labor market practices in the solar sector-particularly in micro-grids and small-scale installations-are largely informal. These informal arrangements often bypass fair labor standards, including compliance with national minimum wage requirements. Workers engaged in this emerging segment also lack clear pathways for career advancement or opportunities to acquire advanced technical skills. From the government's perspective, the informal nature of this work limits revenue collection, as these activities generally fall outside the income tax net. Additionally, given the hazardous nature of installation and maintenance work, laborers operating in informal settings remain excluded from safety protections and life insurance coverage. Overall, this environment discourages investment in skill development and undermines the broader growth and professionalization of the solar markets.

77. Net metering has emerged as a policy tool for promoting solar energy adoption in Pakistan. It enables electricity consumers, residential and commercial users, to generate their own electricity through solar systems and export excess energy back to the national grid. The concept of net metering in Pakistan was formally introduced under National Electric Power Regulatory Authority (Alternative & Renewable Energy) Distributed Generation and Net Metering Regulations, 2015 which allowed consumers with a three-phase connection and solar systems of up to 1 MW to participate.[40] Till 30th June 2024, the number of net-metering consumers within the country was 157,844 compared to 75,724 in FY 2022-23. The total capacity added from net-metering during FY 2023-24 was 1,181 MW, compared to 583 MW added during FY 2022-23 raising the total net-metering installed capacity to 2,498 MW within the country.[41]

4.2.10 Absence of solar panels recycling mechanisms

78. The rapid expansion of solar energy in Pakistan and other emerging economies is largely occurring in the absence of adequate recycling mechanisms. As noted earlier, the average solar panel has a lifespan of 25–30 years, after which its output declines by nearly 80 percent, necessitating replacement. Although the current wave of solarization is relatively recent and large-scale recycling needs will emerge only when the first installations reach the end of their operational life, the associated waste challenge

[40] National Electric Power Regulatory Authority (Alternative & Renewable Energy) Distributed Generation and Net Metering Regulations, 2015. See online at https://www.ke.com.pk/download/other_sros_tariff/NOTIFICATION-NET-METERING-REGULATIONS-SRO-892-2015.pdf

[41] State of Industry Report 2024. See Online at https://www.nepra.org.pk/publications/State%20of%20Industry%20Reports/State%20of%20Industry%20Report%202024.pdf

appears imminent. Recent studies estimate that cumulative solar photovoltaic waste could reach as much as 78 million tons by 2050.

79. This situation creates a clear dilemma whereby a technology that is inherently environmentally friendly may itself give rise to significant environmental externalities. A substantial share of this future waste is expected to originate from countries such as Pakistan, which are at the forefront of the global solar expansion. In the absence of proper recycling mechanisms, end-of-life solar panels can cause serious environmental damage, including soil and water contamination, air pollution, and biodiversity loss. From an economic perspective, inadequate recycling infrastructure also implies a loss of valuable recoverable materials embedded in expired panels. Moreover, the country would forgo potential employment opportunities that could otherwise be generated through the development of a dedicated solar recycling industry. It is worth noting that the developed countries including Germany, France and Japan have already established recycling facilities where around 95% of the materials are recycled.

5. Barriers to Market Contestability and Efficiency

Chapter 5: Barriers to Market Contestability and Efficiency

80. The solar energy sector in Pakistan is growing faster than ever before that offers people a cleaner and more affordable alternative to traditional electricity. However, the growth is not without challenges. For solar markets to function well, they must allow fair competition, easy entry for new players, and equal opportunities for consumers and businesses. These qualities known as market contestability and efficiency are essential for innovation, lowering prices, and service quality. Unfortunately, a number of barriers still prevent the solar market from reaching its full potential. In this chapter, we look closely at the impediments that stand in the way of a competitive solar market. These barriers limit consumer choice, discourage investment, and slow down the shift toward renewable energy. Understanding the challenges is important because it helps identify where policy improvements, regulatory clarity, and institutional support are needed. A stronger and more competitive solar market will not only help reduce electricity costs, but also support Pakistan's long-term energy security and sustainable development goals.

5.1. High Upfront Cost and Capital Requirements

81. A barrier to the adoption of solar energy in Pakistan is the high upfront capital cost associated with installing solar systems for both households and utility scale. Though, cost of solar technology has been declining over the years, the initial investment remains substantial relative to the income levels of many consumers in Pakistan. In addition, the payback period of solar systems is comparatively long, which reduces their appeal for lower-income households and small businesses that already face liquidity constraints. As a result, many potential users are unable to justify or afford the initial expenditure despite the long-term savings that solar power offers.[42] On the utility scale, the cost comparison between solar technologies and conventional energy sources further weakens the competitive position of solar energy. Traditional power technologies benefit from decades of industry maturity, well-established supply chains, extensive research and development, and economies of scale. Moreover, the environmental and health externalities associated with fossil fuel-based power generation are not fully reflected in market prices, making conventional energy appear more cost-effective than it actually is. The structural imbalance makes solar energy less competitive on financial grounds, even though it is cleaner and more sustainable. Government preferences and policy choices further compound the problem. Public-sector investment in renewable energy, particularly solar, has remained limited, and the energy mix continues to be dominated by fossil fuels (around 60%). For example, under the China-Pakistan Economic Corridor (CPEC), the majority of energy projects have been thermal or coal-based, with only a small proportion allocated to solar initiatives. Also, other social aspects have also not been considered while making the policy decisions.

[42] Solar Energy Development in Pakistan: Barriers and Policy Recommendations. https://www.mdpi.com/2071-1050/11/4/1206

5.2. Inadequate Grid Infrastructure and Smart Metering Gaps for Solar Integration

82. The transmission and distribution (T&D) network of the power sector of Pakistan remains one of the bottlenecks constraining the growth of the solar energy market. The existing grid was designed primarily to accommodate conventional, centralized power generation and therefore lacks the flexibility and technological capacity required to integrate variable renewable energy (VRE) such as solar. The mismatch between generation trends especially after the on-grid uptick in the country and grid readiness has emerged as an impediment to market contestability, sectoral efficiency, and investor confidence. Also, the T&D losses, recorded at 17.55% for FY 2024-25 compared to the allowed 11.43%, have, added Rs. 265 billion to the circular debt during the year.

83. Another challenge is the limited capacity of transmission lines in several regions, particularly in areas where solar generation potential is high. Congestion and limited capacity on existing lines restricts the ability of new utility-scale solar projects to secure grid interconnection approvals. Furthermore, distribution networks in many urban and semi-urban areas are outdated and technically weak, making them ill-equipped to manage power flows from distributed generation, including rooftop solar. Concerns about “back-feeding” where excess electricity flows from consumer systems into the grid have led distribution companies (DISCOs) to adopt conservative or restrictive approaches to net metering and interconnection approvals. The limitations disproportionately affect small-scale solar providers and households.

84. The pace of grid modernization and reinforcement remains slow, with delays in upgrading substations, transformers, and protective systems. The absence of advanced technologies such as automated control systems, smart meters, and real-time grid monitoring further reduces the system’s capability to absorb renewable energy without risking instability. As a result, the sector experiences curtailment risks, operational uncertainty, and loss of potential generation all of which deter new entrants and limit economies of scale.

5.3 Low Consumer Awareness and Rising Sub-standard Solar Products

85. A structural barrier to the development of a competitive and efficient solar energy market in Pakistan is the limited awareness among consumers combined with the absence of accredited testing and certification facilities for solar equipment. As discussed by the stakeholders that despite the rapid growth of solar installations in recent years, consumer awareness regarding system sizing, panel efficiency, life-cycle costs, warranties, after-sales services, and safe installation practices remains low. Households and small businesses depend on informal market advice, which often lacks technical accuracy. The information asymmetry enables opportunistic market behavior, including overselling of system capacity, misrepresentation of product specifications, and installation of substandard components. As a result, consumers struggle to make informed decisions, and reputable firms face unfair competition from low-cost, low-quality suppliers.

86. Another problem is that Pakistan does not have any internationally accredited or government-backed testing laboratories for solar panels and related equipment. Because of this, there is no reliable system to check the quality of solar products, ensure they meet international standards (like IEC standards). Currently, the only requirement is a pre-shipment certificate provided by the importer. During consultations, stakeholders shared an issue: some companies copy the unique serial numbers of well-known global brands and print them on low-quality panels manufactured by unrelated vendors in China. These counterfeit products easily enter the Pakistani market and are sold as “A-grade” panels. The situation harms fair competition, as genuine companies that import high-quality equipment find it difficult to compete with cheaper, fake products. It also exposes consumers to poor-quality systems and reduces overall trust in the solar market.

87. During the discussion with stakeholders, concerns have emerged about the import of low-quality solar panels, inverters, batteries, and related equipment is harming the solar market. The products are often sold at very low prices, which makes them attractive to buyers, especially low-income households. However, because these items do not meet quality standards, they perform poorly, break down quickly, and fail to deliver the expected benefits. As a result, the people who suffer the most are those who can least afford it. Many families invest their limited savings in these cheap solar systems, hoping to reduce their electricity costs or overcome load-shedding. Instead, they end up with systems that stop working, have safety risks, or require frequent repairs, which turns the investment into a financial burden rather than a relief. In 2025, several incidents were reported in which fires broke out in rooftop solar installations in Rawalpindi and Lahore.

5.4 Delayed Rollout of CTBCM and Its Impact on Solar Market Development

88. Another competition issue is the delay in implementing the CTBCM. Although CTBCM was approved in 2020 and is a key part of both the National Electricity Policy 2021 and the National Electricity Plan 2023-27, its rollout has been slow. The delay has held back the development of a competitive wholesale electricity market. Under CTBCM, power generators including large solar projects would be able to sell electricity directly to bulk power consumers through bilateral contracts. The model is important for the solar sector because it allows developers to build large utility-scale projects and supply electricity directly to industries or other major consumers without going through the government as the sole buyer. However, the slow progress on CTBCM has created costs for industrial consumers who are waiting for these competitive options. Without CTBCM, they remain dependent on the government as the only seller, limiting their ability to access cheaper, cleaner energy. The delay not only restricts market competition but also discourages investment in large-scale solar projects that could contribute to energy diversification and cost reduction.

5.5 Policy Uncertainty

89. Policy uncertainty in this sector has become a barrier to stable market development. Frequent and sometimes abrupt changes to rules on net-metering, import duties, and

tariff treatment create an unclear business environment for investors, developers, banks and consumers. For example, recent proposals to cut the net-metering buyback rate and to impose import taxes on panels were widely reported and sparked strong market reaction, illustrating how policy signals can quickly alter investor and consumer behavior.[43] Pakistan uses a single-buyer, take-or-pay system to buy electricity from both renewable and non-renewable power plants, which means the government guarantees to buy the electricity they produce, even if it is not used. Because of the guaranteed payment, large power projects face fewer financial or market risks, and investors consider them safe and "creditworthy." However, small-scale solar systems, especially residential rooftop setups, do not get any similar guarantees. There is no assurance that the electricity they send to the grid will always be bought at a fair or stable rate. Net metering policies can change, tariffs can be reduced, and new restrictions can be imposed without warning.[44]

5.6. Reluctance of DISCOs toward Net-Metering

90. One of the key drivers of rapid solarization has been the government's net-metering policy, which reduced the payback period for small investors. In addition to generating low-cost electricity for household consumption, the policy allows consumers to sell surplus power to DISCOs and purchase electricity from the grid during non-generation hours. During FY 2024-25, the number of consumers have reached to 378,339. The shift has been driven by rising grid tariffs, ongoing concerns about supply reliability, and higher electricity prices driven by structural inefficiencies in DISCOs and broader macroeconomic pressures. Given the proven advantages of net metering, there is a need to promote rooftop solar installations as they provide low-cost solution to energy deal with energy crisis. However, it has been noted that despite the clear advantages of net metering, DISCOs in several instances appear to treat net-metered solar generation as a substitute for the national grid rather than as a complementary support from small-scale producers. Consequently, applicants for net-metering connections have frequently reported delays in the processing of their applications.

91. Delays in the provision of net-metering connections continue to be a serious issue, with wide-ranging consequences for both households and businesses. The delays largely stem from shortages of materials, inadequate infrastructure, and operational inefficiencies within DISCOs. For residential consumers, prolonged delays cause hardship and disrupt daily life. For businesses, untimely connections impede operations, lower productivity, and discourage investment particularly by new market entrants thereby constraining economic growth. Persistent inefficiencies also weaken public trust in DISCOs and contribute to declining electricity sales. A particularly concerning aspect is the unjustified cancellation of connection applications by DISCO staff, often without valid reasons and, in some cases, reportedly linked to demands for

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[43] Shift to solar comes at a price for Pakistan's national grid. Financial Times. https://www.ft.com/content/91116c44-bacf-43f4-9b6f-63a6c738ef4e?utm

[44] Enhancing Renewable Energy Integration in Developing Countries: A Policy-Oriented Analysis of Net Metering in Pakistan amid Economic Challenges. https://www.mdpi.com/2071-1050/16/14/6034?utm

financial incentives. Such practices appear to be aimed at artificially reducing the number of pending applications rather than addressing the underlying capacity and governance issues. Table 8 below presents complaints data on application processing delays submitted to NEPRA against different DISCOs.

Table 4: Total Number of Net-Metering Pending Applications during 2024-25

Company	Total Number of Pending Applications
PESCO	2,624
TESCO	7
IESCO	6,132
GEPCO	7,464
LESCO	28,984
FESCO	25,715
MEPCO	34,926
HESCO	580
SEPCO	100
QESCO	626
KE	20,945
Total	128,103

5.7. Lack of Credible Data Solar Adoption Rates

92. A key competition-related concern in the solar energy sector is the limited availability and fragmentation of data. As illustrated in Figure 11, a significant share of solar panels imported from China does not appear in statistics capturing the country's solar energy contribution through net metering. This obscures the actual extent of solarization in Pakistan and creates uncertainty for potential entrants regarding the sector's outlook and market potential. For policymakers assessing the welfare implications of this clean energy technology, comprehensive data-particularly on access across income groups and regions is essential. In practice, the high upfront cost of solar installations is likely to result in greater adoption by higher-income households, both in off-grid and net-metered systems. However, this hypothesis requires empirical validation to enable the design of evidence-based policies that promote inclusive growth.

93. At present, solarization-related data are primarily derived from customs records on solar panel imports and NEPRA's information on net-metered, grid-connected systems. The Pakistan Bureau of Statistics (PBS) also reports the proportion of households benefiting from solar energy. Nonetheless, these data sources are dispersed, reported at irregular intervals, and collectively provide only a partial view of the sector. Information on off-grid installations remains largely unavailable, while data gaps along the solar value chain further impedes assessments of transparency and fair market practices. Improving the

availability, consistency, and integration of data would help reduce information asymmetries, lower entry barriers, and support the overall development and competitive growth of the solar energy sector.

5.7 SWOT Analysis of the Solar Market

94. In the competition assessment studies, SWOT (Strength, Weakness, Opportunities and Threats) model is used to study the internal and external factors of a sector's growth (Irfan et al., 2020). This methodology helps the researchers in identifying the factors that encourage or curb the growth of an industry. The findings based on this methodology provide actionable insights for the policymakers. In the field of sustainability and clean energy transition, several studies have used this tool to assess competitiveness of different energy technologies (Jaber et al., 2015). Our SWOT analysis is based on different studies. Moreover, it includes the opinion of key stakeholders from different public and private sector organizations. A key advantage of this methodology is that here we present the same picture of industry's strong points, its struggling areas, windows of opportunity and threats under the same umbrella. The analysis, however, does not present clear prioritization on the problems and opportunities, reflecting the major flaw of this methodology.

Table 5: SWOT Analysis of Solar Markets

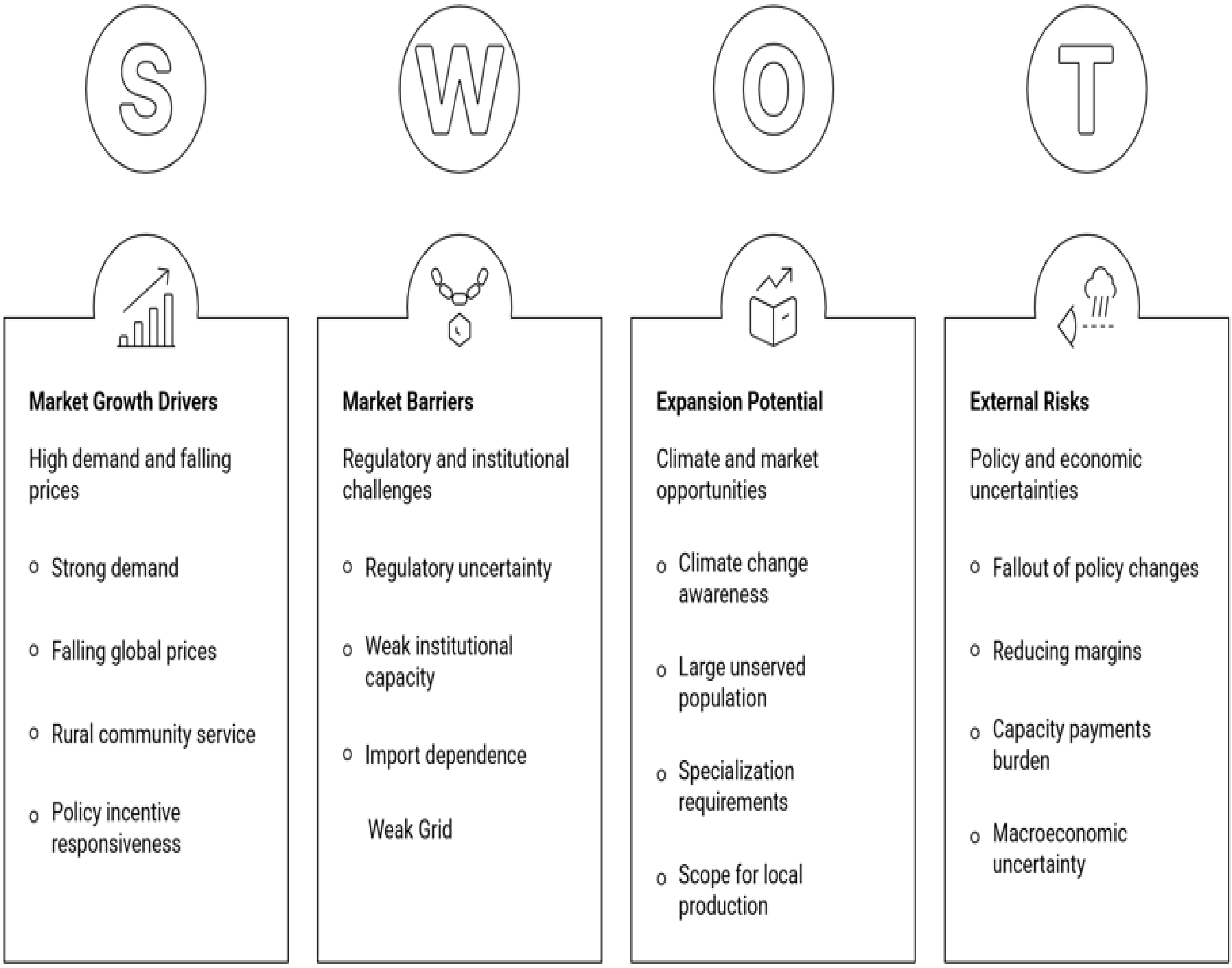
Strengths		
1	**Strong Demand**	The sector has grown exponentially over the past few years, as can be viewed from the solar import data and net metering statistics.
2	**Falling global prices and reducing payback periods**	An important part of solar evolution is the falling world solar panel prices. This defines a key strength of this sector and has contributed to the success of solarization in recent years.
3	**Solar's role to serve the disconnected rural community**	In case of Pakistan, solar becomes the most feasible option for our disconnected rural community for which transferring power through national grid becomes too expensive and comes with several challenges.
4	**Solar's responsiveness to policy incentives**	The incentives given to the solar sector in recent past including zero import duty, low-interest rate policy by the SBP and net metering have contributed to its growth. This shows the responsiveness of this sector to incentive structure.
Weaknesses		
1	**Regulatory uncertainty and volatile net metering rules**	Lower rates on net metering and proposals to shift towards net billing policy have created a regulatory uncertainty, presenting a regulatory barrier to entry.
2	**Weak institutional capacity and reluctance of DISCOs**	An impressive growth of solar energy has created surplus energy for many DISCOs. In this situation, they feel threatened about the stability of the system and are resultant to buy more power from the roof top solar systems.
3	**Import dependence**	The country mainly uses Chinese made solar panels with no domestic production. This presents a weakness and vulnerability of local system to the external geo-political environment.
Opportunities		
1	**Climate change awareness**	Given Pakistan's acute vulnerability to climate change, the expansion of clean energy particularly solar photovoltaic (PV) technology offers a critical opportunity to strengthen climate resilience and support a sustainable energy transition.

2	**Large unserved population and commercial use**	Despite the recent increase in solarization, the country still ranks very poor on energy consumption fronts with around 10% of consumers not connected with the national grid. Likewise, commercial sector also faces problems due to power cuts. Solar energy can fulfill all these energy needs.
3	**Specialization requirements and after sale services**	The expansion of solar sector will create need to specialize in batteries, invertors and O&M services.
4	**Scope for local production**	A massive domestic demand creates scope for domestic output of panels and other complementary products. The market is sending signals to investors about the long-term investment prospects in this sector.
Threats		
1	**Fallout of recent policy changes**	The success reaped so far has been partially associated with conducive public policies for this sector. The recent policy reversals on import duties and net metering may pose a threat to this transition.
2	**Reducing margins of the service providers**	Strong competition and presence of informal sector have reduced margins of the service providers. While this is good news for consumers, it does not guarantee good quality service, especially when regulatory controls are weak.
3	**Solar transition and burden of capacity payments**	A large scale solarization is disconnecting people from the national grid. In this situation, the financial burden of line losses and capacity payments only falls on the remaining consumers. This not only creates social injustice but also questions the survival of our centralized national grid.
4	**Macroeconomic uncertainty e.g., inflation, currency depreciation and high interest rates**	Another potential threat to solarization is macroeconomic uncertainty present in the country which includes high inflation and interest rates and currency depreciation over the last few years. These factors limit capital investment in the solar energy sector. By increasing the cost of capital, higher interest rates make it less feasible to fund the solar projects through financial institutions.

95. The SWOT analysis highlights several avenues for solar-sector expansion and investment, driven largely by the sector's growth potential. The potential is further reinforced by state-sponsored investment in China, which has helped reduce global solar panel prices. Moreover, the transition to solar energy is facilitated by its flexible and decentralized generation model; system sizes can range from small rooftop units to large-scale solar parks and can be installed across diverse locations.

96. However, as the SWOT findings indicate, the potential can only be fully realized if policymakers and researchers proactively identify the risks associated with rapid solar growth and design policies to mitigate them. In Pakistan's case, these risks particularly relate to grid stability and the burden of capacity payments stemming from existing power-generation commitments. The results underscore the interdependence of multiple factors and point to the need for a holistic, coordinated approach to the development of the solar sector.

Figure 15: SWOT Analysis for Solar Energy Market in Pakistan



5.7 Solarization: A PESTLE Analysis

97. To study the opportunities and challenges of the solar sector, our empirical investigation first relies upon a PESTLE analysis. PESTLE stands for **(**Political, Economic, Social, Legal, Technological & Environmental) assessment is mainly used in strategic management whenever an organization needs to acquire deep knowledge and critical thinking about external factors that influence organizational activities' potential.[45] The PESTLE framework is a simple yet powerful tool for scanning the external environment across Political, Economic, Social, Technological, Legal, and Environmental dimensions. It helps distinguish between factors that policymakers can directly influence and those that lie beyond their control, while also highlighting the policy levers and market risks that shape strategic decision-making. The framework provides a structured lens for examining macro-environmental forces that influence an industry's growth,

[45] Mostafaeipour A, Sedeh AS, Chowdhury S, Techato K. Ranking potential renewable energy systems to power on-farm fertilizer production. Sustainability (Switzerland) 2020; 12:1–27. https://doi.org/10.3390/SU12197850.

competitiveness, and long-term trajectory. Its strength lies in enabling policymakers, analysts, and industry stakeholders to understand how external forces interact to shape the operating environment of a sector such as the automobile industry. By mapping these factors, decision-makers can better identify risks, anticipate opportunities, and design policies or strategies that align with evolving national and global realities. In this way, PESTLE supports evidence-based planning by clarifying both the external constraints that are difficult to alter and the levers of change that can be shaped through consistent and well-targeted policies.[46] Lastly, although PESTLE analysis is highly correlated with SWOT, yet it provides systematic analysis of the issues which is not possible under SWOT. Besides, the PESTLE framework provides a better understanding of the external environmental factors of the business.[47]

Table 6: PESTLE Analysis of Pakistan Solar Market

	Political factors	
1	**Policy Support and financial incentives**	Government initiatives in the last few years, particularly net metering, import duty waivers and utility scale RE targets have helped boosting solarization
2	**Regulatory Uncertainty**	Policy shifts related to import duties (from zero to 10% in FY2025) and net-metering policy created challenges for the smooth transition.
3	**Energy Security Goals**	Excessive reliance on imported fossil-based energy creates a conducive environment for solar energy initiatives.
	Economic factors	
1	**Rising electricity prices**	Rising electricity prices from the national grid provide incentive to shift to solar energy.
2	**Declining global solar prices**	Solar panels have become cheap, reducing both the upfront cost as well as pay-back period for the new entrants.
3	**Low margins in domestic market**	The widespread existence of solar installers and distributors has reduced their margins by creating a competitive environment.
4	**Currency Depreciation**	Solar panels are imported items and hence their prices are impacted by PKR-USD parity.
5	**Import Dependence**	Almost the entire quantity of solar panels used so far are imported. This state of dependency can undermine the sustainable long-run growth of the sector.
	Social & Demographic factors	
1	**Public Awareness**	Growing awareness among public fosters investment in the solar project
2	**Energy autonomy**	Frequent power black outs force people to go for autonomy and reduce dependence from the national grid
3	**Informal market**	The market is evolving in an informal way where internationally followed SoPs are not being practiced by the installers.
4	**Urban-rural divide**	Although the power black outs are severe in rural areas, compared to the urban zones, solarization and particularly, net metering is more prevalent in the urban areas, aggravating the problem of energy poverty among rural households.
	Technological factors	

[46] https://www.competitiveintelligencealliance.io/how-to-do-pestle-analysis/
[47] Massihi N, Abdolvand N, Rajaee Harandi S. A business environment analysis model for renewable solar energy. International Journal of Environmental Science and Technology 2020. https://doi.org/10.1007/s13762-020-02826-6.

1	**International dependence**	Absence of solar production technology is creating an international dependence for the country and limiting the growth potential of this sector.
2	**Rapid innovation at global level**	Globally, technology has seen rapid improvements, resulting in lower costs and reduced payback period.
3	**Low quality control**	The presence of informal market reduces quality control and permits the inflow of inferior products in the market.
4	**Limited local R&D**	In the local markets, public and private spending on R&D activities is negligible, creating a long-run dependence on imported solar panels.
	Legal & Regulatory factors	
1	**Uncertain regulatory framework**	Rules related to net metering, licensing and safety standards are not strictly followed.
2	**Import duties**	In FY2025, import duties increased from zero to 10%, increasing the upfront cost of solar panels.
3	**Consumer protection gaps**	Weak enforcement and illegal markets increase the chances of faulty products with no warranty claims.
4	**Labor protection gaps**	The labor force working in informal solar market is not protected by occupational safety laws and lack insurance benefits.
	Environmental factors	
1	**High solar irradiation**	Pakistan's geographical location makes it ideal for solar energy.
2	**Abatement targets of CO2 emissions**	The country is observing an increasing trend in CO2 emissions and is among the most severely affected nations due to climate change.
3	**Recycling and waste of solar panels**	Currently, the country lacks clear framework for recycling solar panels. This may create an environmental problem in the long run.
4	**Climate vulnerability and resistance of solar infrastructure**	Extreme weather such as thunderstorms can damage solar infrastructure.

98. The PESTLE analysis presented above underscores several decisive factors shaping the future trajectory of solar energy in Pakistan. Long-term sectoral growth will hinge on consistent policy direction and a supportive financial ecosystem that can encourage widespread adoption of this clean technology. The expansion of solar solutions is driven by both push and pull dynamics. On the push side, rising electricity tariffs and persistent load-shedding are compelling households and businesses to seek alternative energy sources. On the pull side, declining global solar panel prices and continuous technological advancements are making solar solutions increasingly attractive and accessible. At the same time, a comprehensive public awareness campaign is essential-particularly to integrate currently underserved rural communities. Doing so would not only raise per-capita energy consumption but also stimulate broader economic activity. However, the rapid and unregulated expansion of the informal solar market poses risks. It can weaken the formal sector, which complies with safety standards, provides worker training, and ensures social protection for employees.

99. The PESTLE assessment also highlights the need for domestic investment in solar panel manufacturing to reduce import dependence and potentially develop an exportable surplus. Establishing robust quality-control laboratories and certification infrastructure is equally important to filter out substandard products and to foster more structured, formalized growth in the sector. Finally, the most pressing requirement for the sector's

sustainable development is a clear, stable, and transparent regulatory framework. Such clarity is vital for market participants to make informed, long-term investment decisions and for the solar industry to realize its full potential.

Figure 16: PESTLE Analysis of Solar Energy Market

6. Conclusion and Recommendations

Chapter 6: Conclusion and Recommendations

100. Energy is central to economic growth, social well-being, and long-term development. While global investment in energy continues to rise, most of the world including Pakistan relies heavily on fossil fuels. The dependence has created environmental challenges, contributing to rising temperatures, extreme weather events, and climate vulnerability. For a developing country like Pakistan, the challenge is two-fold: expanding energy access for millions of people while also reducing the harmful impact of conventional energy sources. With its rich solar potential, Pakistan has a strong opportunity to transition toward cleaner energy in a way that supports both economic and environmental goals.

101. In recent years, Pakistan has seen rapid growth in solar adoption, driven by high electricity prices, unreliable grid supply, falling solar equipment costs, and supportive import policies. Solar imports and installations have reached record levels, helping households and businesses reduce their energy costs and dependence on fossil fuels. However, the share of solar energy in the national generation mix remains small, and the country continues to face challenges such as high upfront costs, financial barriers, and policy gaps. Given Pakistan geographic advantage and climate risks, expanding solar energy both at household and utility scale is no longer optional. It is essential for achieving energy security, affordability, environmental sustainability, and resilience against future climate shocks.

102. The global comparison shows that Pakistan is lagging behind countries like China, India, and Brazil in developing its solar energy sector, mainly due to limited local manufacturing, weaker policies, and low investment. China leads the world because of strong government support and a complete domestic supply chain, while India is rapidly expanding its solar industry through incentives that promote local production. Brazil has grown by offering tax exemptions and easy financing to households and businesses. Pakistan, however, still relies heavily on imported solar equipment and has only a small share of solar in its total electricity mix. Nevertheless, net metering, off-grid and increasing private-sector interest show that Pakistan solar market grows and has the potential more if policies and long-term support are provided.

103. The policy and legal framework for solar energy has strengthened over the past two decades, shaped by rising electricity demand, reliance on imported fuels, and the urgent need for cleaner and more affordable power. Key national policies and regulations such as the ARE Policy 2019, Net Metering Regulations 2015, the NEPRA Act 1997, the National Electricity Policy 2021, and the National Electricity Plan 2023-27, collectively provide the foundation for developing both utility-scale and distributed solar energy. These instruments outline clear procedures for investment, licensing, grid integration, tariff determination, and consumer participation, while also promoting competitive procurement, local manufacturing, and technological modernization. Although gaps remain in implementation, grid readiness, and consistency of policy direction, the overall framework demonstrates a growing national commitment to supporting solar energy as an essential component of Pakistan’s sustainable and diversified energy future.

104. The solar energy market has strong potential, but several barriers continue to slow its growth and limit competition. High upfront installation costs, long payback periods, and limited financing options make solar systems difficult to afford for households and small businesses. At the same time, utility-scale solar struggles to compete with traditional power technologies that benefit from long-standing government support, mature supply chains, and hidden cost advantages. Weak transmission and distribution infrastructure further restricts the expansion of solar energy. The national grid was designed for conventional power and lacks the flexibility, capacity, and smart technologies needed to integrate distributed and utility-scale solar projects. These gaps lead to delays, technical constraints, and lack of investor confidence. Low consumer awareness, widespread availability of substandard equipment, and absence of accredited testing labs also undermine the market. Poor-quality products especially harm low-income users, who often invest their limited savings in systems that fail prematurely. Additionally, delays in reforms such as the CTBCM and frequent policy changes particularly related to net metering and import duties create uncertainty for both investors and consumers.

Recommendations to improve the sector

6.1 Modernization of Distribution Networks to Support Distributed Solar Generation

105. DISCOs should undertake a phased modernization program to reinforce aging distribution feeders, transformers, and substations, particularly in cities and semi-urban areas with high rooftop solar potential. Many existing distribution networks in solar-rich regions are outdated and technically weak that makes them vulnerable to voltage fluctuations and back-feeding issues. Investment plans should explicitly include components for voltage regulation equipment, anti-reverse-flow protections, and automated grid management tools to safely manage two-way power flows. It will reduce technical losses and address concerns around back-feeding and wider adoption of net metering.

6.2 Introducing Advanced Grid Automation and Digital Control Systems

106. A national smart metering roadmap may be developed with clear timelines, technical standards, and implementation responsibilities. The rollout should begin with high-consumption feeders, industrial clusters, and regions where rooftop or utility-scale solar installations are increasing. Prioritizing these areas will immediately improve data accuracy and help DISCOs manage two-way power flows more effectively. Smart meters enable real-time measurement of both imported and exported electricity, which is essential for accurate billing, transparent net metering settlements, and consumer trust. They also reduce manual errors, electricity theft, and delays in data processing. Globally, countries that expanded renewable energy such as India, China, and several EU states achieved faster solar integration after adopting advanced metering infrastructure (AMI) at scale.[48] Pakistan can benefit from similar gains by deploying interoperable, tamper-proof smart meters across all DISCOs.

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[48] Transition and Impact of Smart Meters on Renewable Energy Integration in India. International Journal for Multidisciplinary Research.

107. In addition to metering, the installation of real-time monitoring and automated control systems is necessary to strengthen grid stability. Technologies such as Supervisory Control and Data Acquisition (SCADA), Distribution Management Systems (DMS), and remote sensing equipment should be expanded in both transmission and distribution networks. Such systems improve grid visibility, help operators forecast demand and solar generation more accurately, and reduce the risk of voltage fluctuations, reverse power flows, and unplanned outages.[49]

6.3 Unlocking Solar Investment Through Effective CTBCM Implementation

108. To address the delays in implementing the CTBCM, the government should prioritize and fast-track the rollout through a time-bound action plan. The government may introduce interim measures such as pilot bilateral contracts for renewable energy, especially solar so that early projects can begin operations while the full CTBCM framework is being finalized. Allowing selected industrial clusters and Special Economic Zones (SEZs) to purchase power directly from large solar projects can test the system, build market capacity, and reduce dependence on government-supplied electricity. The updated guidelines on licensing, grid access, wheeling charges, and settlement procedures to ensure that developers and consumers understand the rules and costs of bilateral trading. The targeted incentives such as reduced wheeling charges for renewable energy, guaranteed grid access protocols, and streamlined approvals for utility-scale solar plants will encourage private sector investment during the transition. Fast and predictable CTBCM implementation will help unlock cheaper solar energy for industries, increase competition, reduce government financial burden, and accelerate Pakistan's shift toward a cleaner and diversified energy mix. 800 MW addition

6.4 Reliable and Competitive Solar Market Through Standards, Testing, and Consumer Outreach

109. To protect consumers and improve the solar market in Pakistan, the government may establish accredited solar testing laboratories to ensure that all panels, inverters, and batteries meet international (IEC) standards. The labs should be government-backed, internationally recognized, and testing should be mandatory for all imported and locally assembled equipment. A digital verification system such as QR codes or a central serial-number database should also be introduced to help identify genuine products and prevent forged items from entering the market. The current pre-shipment certification system may be replaced with stricter testing and post-import checks. Standardized labeling for efficiency, durability, and warranty should be made compulsory, supported by customs inspections and penalties for mislabeled products.

110. Alongside quality control, a national awareness campaign should be launched to educate consumers about system sizing, efficiency standards, warranties, and safe

https://www.ijfmr.com/papers/2025/5/55075.pdf#:~:text=Advanced%20Metering%20Infrastructure%20(AMI):%20Advanced%20Metering%20Infrastructure,functions%20in%20residential%2C%20commercial%2C%20and%20industrial%20facilities.

[49] Digitalization and Automation of Power Distribution. Adelat. https://adelat.com/wp-content/uploads/2024/11/Executive-Summary-Digitalization-Automation-of-Power-Distribution.pdf

installation practices. The campaign should use print media, digital platforms, community outreach, and local languages to reach all regions. Simple buyer guides and checklists should be published to help people make informed choices. Finally, low-income consumers must be protected from low-quality solar products. The government may introduce targeted financing options such as micro-loans to help poor household's access reliable systems. Partnerships with reputable suppliers can ensure that vulnerable communities receive verified or subsidized solar kits.

6.5 Bridging the Urban-Rural Divide in Solar Energy Benefits

111. To reduce the growing inequality between urban and rural consumers, relevant authorities should work towards extending the benefits of solar net-metering and clean-energy incentives to rural areas. At present, most on-grid solar systems and therefore most net-metering benefits are concentrated in cities, while rural households rely mainly on off-grid systems due to weak, load shedding or non-existent grid infrastructure. It creates an uneven playing field where urban consumers can lower their electricity bills and sell excess power to the grid, but rural communities already facing higher levels of energy poverty remain excluded from these opportunities.

112. To address the gap, the government may introduce off-grid solar systems in high T&D loss regions, particularly in rural and remote areas. In these rural communities, grid extension is neither technically efficient nor commercially sustainable. Policies should also prioritize targeted subsidies (through BISP) and concessional financing for rural households. By making solar benefits accessible to everyone, Pakistan can reduce energy poverty, promote inclusive economic growth, and move closer to meeting SDG-7 (Affordable and Clean Energy), SDG-10 (Reduced Inequalities), and SDG-1 (No Poverty). Ensuring that rural consumers are not left behind is essential for a fair, competitive, and people-centered renewable energy market. Most of the on-grid system are taking place in urban population of Pakistan. Rural segment of the country is adopting off-grid systems because of low level of grid electricity to rural consumers. They cannot enjoy the benefit of net-metering. The situation arises an inequality for the rural people, because the benefit of net-metering is enjoying by urban consumers.

6.6 Promote Battery Storage to Reduce Grid Pressure and Support Industrial Consumers

113. As the use of solar energy/on-grid increases in Pakistan, the government has been considering reducing net-metering benefits because the national grid is unable to absorb large amounts of renewable energy flowing back into it and the reduce payments. It has created uncertainty for consumers and may discourage further adoption of clean energy. However, the rapid global development of battery storage largely driven by electric vehicle (EV) technology offers the country an opportunity to ease pressure on the grid while expanding competition in the energy market.

114. Battery technology is improving quickly, with longer backup times, falling prices, and stronger performance. Pakistan already has a domestic battery manufacturing base, which can be strengthened to support the solar market. As better and more affordable batteries enter the market, many households and businesses will prefer solar + battery

systems to meet their energy needs. It will allow them to store excess electricity during the day and use it later, reducing their dependence on the grid and avoiding high electricity tariffs. If more consumers shift to solar-plus-storage systems, the government can redirect national grid electricity toward industries, SMEs, agriculture, and other productive sectors that need reliable power to grow the economy. It will help reduce load-shedding for industrial users, lower operational costs, and improve overall competitiveness. To support this transition, the government may:

a. Promote solar + battery systems through incentives, concessional financing, and awareness campaigns.

b. Support domestic battery manufacturing with tax incentives, research programs, and quality-control frameworks.

c. Create clear regulations for safe installation, standards, and performance of battery-based systems.

d. Encourage hybrid and off-grid solar solutions to reduce pressure on the national grid.

e. Educate consumers on long-term savings and reliability of integrated solar-and-storage setups.

6.7 Promotion of Domestic Manufacturing of Solar Panels in Pakistan based on Global Practices

115. Pakistan can take strong and practical steps to develop its own solar panel manufacturing industry so the country can reduce dependence on imports, lower costs, create jobs, and strengthen competition in the energy market. At present, Pakistan relies almost entirely on imported solar panels. Developing local manufacturing will make the market more competitive, stable, and affordable in the long run. One of the effective ways to achieve this is by introducing a Production-Linked Incentive (PLI) Scheme, similar to successful models used in India[50], China, and the United States. Under a PLI scheme, manufacturers receive financial incentives based on how much they produce and how efficiently they operate. The approach encourages production growth, technology adoption, and competition among manufacturers. Pakistan can also build on its existing partnership with China especially under CPEC by encouraging joint ventures between Pakistani and Chinese companies. China is the global leader in solar panel technology, and such collaborations would accelerate skill transfer, technology transfer, and local capability development. To make domestic manufacturing even more attractive, Pakistan can pair the PLI scheme with supportive policies, including:

a. Tax exemptions for new solar manufacturing units.

[50] India's module manufacturing capacity has expanded from about 72 GW in March 2024 to nearly 118 GW by July 2025, while cell capacity has grown from 8 GW to about 27 GW. Wafer manufacturing remains limited at 2 GW.

b. Special Economic Zones (SEZs) dedicated to renewable technology, offering facilities such as 10-year tax exemptions, subsidized industrial land, and reliable utilities.

c. Research and development (R&D) support for improving panel efficiency and developing new technologies.

d. Export rebates and local content requirements (LCRs) that encourage both competitiveness and domestic value addition.

e. Easy financing for manufacturers through banks and development finance institutions.

6.8 Establish a National Solar Registration System

116. Any sound policy framework for promoting solar energy requires a centralized and comprehensive data system that not only records all imported and domestically manufactured solar panels but also captures the actual number of solar users and the sector’s effective contribution to the power system. In this regard, it is recommended that a national solar registry be established, covering both net-metered and off-grid users. Data from NEPRA, the Pakistan Bureau of Statistics (PBS), and AEDB/Ministry of Energy should be reconciled and integrated to develop a publicly accessible, anonymized database.

117. Such a centralized dataset would help reduce information asymmetries, improve transparency, lower barriers to entry, and deter unfair practices across the solar value chain. Moreover, proper tracking of solar installations and equipment life cycles would facilitate systematic recycling and safe disposal of expired or damaged panels, thereby addressing emerging environmental concerns associated with solar waste. Given that solar panel imports benefit from tax concessions and draw on scarce foreign exchange reserves, improved data availability would also enable policymakers to align the quantity of solar panels deployed with import volumes. This, in turn, would facilitate more accurate demand forecasting for alternative energy sources and better-informed investment decisions across the energy mix. Additionally, compiling data on provincial adoption rates would allow policymakers to assess regional trends and evaluate the effectiveness of solar-related incentives and interventions across provinces.

References

Al-Sharafi, A., Ahmadullah, A. B., Hassan, G., Al-Qahtani, H., Abubakar, A. A., & Yilbas, B. S. (2024). Influence of environmental dust accumulation on the performance and economics of solar energy systems: A comprehensive review. Cleaner Energy Systems, 8, 100125.

Asian Development Bank (2020). *Climate risk country profile: Pakistan*. https://www.adb.org/publications/climate-risk-country-profile-pakistan

Bradford T. Solar revolution. The economic transformation of the global energy industry. Cambridge, MA: The MIT Press; 2006.

Cui, C., Lonergan, K. E., & Sansavini, G. (2025). Policy-driven transformation of global solar PV supply chains and resulting impacts. *Nature Communications*, 16, Article 6742. https://doi.org/10.1038/s41467-025-61979-

Ghafoor, A., Rehman, T. U., Munir, A., Ahmad, M., & Iqbal, M. (2016). Current status and overview of renewable energy potential in Pakistan for continuous energy sustainability. In *Renewable and Sustainable Energy Reviews* (Vol. 60, pp. 1332–1342). Elsevier Ltd. https://doi.org/10.1016/j.rser.2016.03.020

Goldman, D. P., McKenna, J. J., & Murphy, L. M. (2005, October). *Financing projects that use clean-energy technologies: An overview of barriers and opportunities* (Technical Report No. NREL/TP-600-38723). National Renewable Energy Laboratory. https://docs.nrel.gov/docs/fy06osti/38723.pdf

Gorst, A., Groom, B., Dehlavi, A., 2015. Crop Productivity and Adaptation to Climate Change in Pakistan. Centre for climate change economics and policy Working paper No. 214.

Hoogwijk M. (2004) On the global and regional potential of renewable energy sources. Faculteit Scheikunde, Universiteit Utrecht.

International Energy Agency. (2022). *Special report on solar PV global supply chains.* OECD Publishing. https://www.iea.org/reports/solar-pv-global-supply-chains

International Energy Agency. (2024). *Renewables 2024: Analysis and forecast to 2030.* Paris: IEA. https://www.iea.org/reports/renewables-2024

Institute for Energy Economics & Financial Analysis. (2024, August). *The future of net-metered solar power in Pakistan*. IEEFA. https://ieefa.org/sites/default/files/2024-08/IEEFA%20-%20updated%20-%20The%20Future%20of%20Net-metered%20Solar%20Power%20in%20Pakistan_August%202024_2.pdf

Jacobsson, S., & Johnson, A. (2000). The diffusion of renewable energy technology: An analytical framework and key issues for research. *Energy Policy*, *28*(9), 625-640. https://doi.org/10.1016/S0301-4215(00)00041-0

Malik, A., & Rehman, A. (2024, August). *An Enigma of Net Metering* (PIDE Knowledge Brief No. 2024:124). Pakistan Institute of Development Economics. https://file.pide.org.pk/pdfpideresearch/kb-124-an-enigma-of-net-metering.pdf

Mirza, U. K., Mercedes Maroto-Valer, M., & Ahmad, N. (2003). Status and outlook of solar energy use in Pakistan. In *Renewable and Sustainable Energy Reviews* (Vol. 7, Issue 6, pp. 501–514). Elsevier Ltd. https://doi.org/10.1016/j.rser.2003.06.002

NEPRA. (2024). *STATE OF THE INDUSTRY REPORT 2024*. https://www.nepra.org.pk/publications/State%20of%20Industry%20Reports/State%20of%20Industry%20Report%202024.pdf

Pakistan Bureau of Statistics. (2025). *Pakistan trade in goods data FY2025 vs. FY2024*. Pakistan Bureau of Statistics. https://www.pbc.org.pk/wp-content/uploads/Pakistan-Trade-in-Goods-Data-FY25-Vs.-FY24.pdf.

Rasheed, R., Rizwan, A., Javed, H., Yasar, A., Tabinda, A. B., Bhatti, S. G., & Su, Y. (2020). An analytical study to predict the future of Pakistan's energy sustainability versus rest of South Asia. *Sustainable Energy Technologies and Assessments*, *39*. https://doi.org/10.1016/j.seta.2020.100707

Renewables First & Herald Analytics, "The Great Solar Rush in Pakistan", 2024, www.renewablesfirst.org

D. Rose, O. Koehler, N. Kaminar, B. Mulligan and D. King (2006), "Mass Production of PV Modules with 18% Total-Area Efficiency and High Energy Delivery Per Peak Watt," *2006 IEEE 4th World Conference on Photovoltaic Energy Conference*, Waikoloa, HI, USA, 2006, pp. 2018-2023, doi: 10.1109/WCPEC.2006.279898.

Sheikh, M. A. (2010). Energy and renewable energy scenario of Pakistan. In *Renewable and Sustainable Energy Reviews* (Vol. 14, Issue 1, pp. 354–363). https://doi.org/10.1016/j.rser.2009.07.037

Smith C. (1995) Revisiting solar power's past. Technology Review (July):38–47.

Stocker, T.F., Dahe, Q., Plattne, G., 2013. Climate Change 2013: the Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers (IPCC, 2013).

Szaro, J., & Ventre, G. (2000, March 1). *Florida Photovoltaic Buildings Program: Status Report, Observations and Lessons Learned* (FSEC-CR-1150-01). Florida Solar Energy Center, University of Central Florida. https://publications.energyresearch.ucf.edu/wp-content/uploads/2018/06/FSEC-CR-1150-01.pdf

Timilsina, G. R., Kurdgelashvili, L., & Narbel, P. (2012). Solar energy: Markets, economics and policies. *Renewable and Sustainable Energy Reviews*, *16*(1), 449-465. https://doi.org/10.1016/S1364-0321(11)00419-9

Ulfat, I., Javed, F., Abbasi, F. A., Kanwal, F., Usman, A., Jahangir, M., & Ahmed, F. (2012). Estimation of solar energy potential for Islamabad, Pakistan. *Energy Procedia*, *18*, 1496–1500. https://doi.org/10.1016/j.egypro.2012.05.166

UN-Habitat. (2023). *Pakistan Country Report 2023*. United Nations Human Settlements Programme. Retrieved from https://unhabitat.org/sites/default/files/2023/06/4._pakistan_country_report_2023_b5_final_compressed.pdf

United Nations Framework Convention on Climate Change. (n.d.). *The Paris Agreement*. Retrieved [date you accessed], from https://unfccc.int/process-and-meetings/the-paris-agreement

Zhang, D., Liu, X., Wang, Y., & Li, J. (2023). *Climate change impacts on crop yield and adaptation strategies in the Indus Basin of Pakistan*. **Land**, *12*(1), 140. https://www.mdpi.com/2073-445X/12/1/140