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Turning Crisis into Opportunity: Rooftop Solar Expansion for Energy Security and Sustainable Development in Pakistan

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Turning Crisis into Opportunity: Rooftop Solar Expansion for Energy Security and Sustainable Development in Pakistan

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ABSTRACT

Pakistan's power sector is facing a combined crisis of high electricity tariffs, circular debt, underutilised generation capacity, transmission and distribution losses, and continued exposure to imported oil, LNG and coal. Recent geopolitical conflict shows that energy-importing economies remain vulnerable to international fuel price volatility and supply uncertainty. This paper develops an analytical policy framework to examine whether rooftop and distributed solar can reduce Pakistan's exposure to future geopolitical fuel shocks while supporting sustainable development. The paper constructs a Multi-Criteria Policy Index (MCPI) to rank policy options for rooftop solar expansion. Under baseline assumptions, the paper shows that one additional gigawatt of distributed solar may generate around 1.49 TWh annually, which could avoid about USD 125 million in RLNG import expenditure. The analysis shows that rooftop solar can reduce dependence on international fuel markets, but its full benefit depends on inclusive finance, stable net-metering reform, smart meters, battery storage, DISCO modernisation, vendor certification and progressive tariff design. The paper recommends treating rooftop solar as a national energy security hedge rather than only a private consumer investment.

Keywords: Rooftop Solar, Pakistan, Energy Security, Net Metering, Solar Adoption, Multi-Criteria Policy Index, Sustainable Development.

JEL Classification Codes: Q41, Q42, Q48, Q56, O13, D12

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1. INTRODUCTION

The electricity market in Pakistan has been facing persistent challenges during the last two decades. These challenges include high generation cost, structural inefficiencies across generation, transmission and distribution losses, circular debt, unreliable supply and heavy dependence on imported fuels (Harrison 2026). These constraints have significantly contributed to high electricity tariffs and periodic supply disruptions that place financial pressure on households, small businesses, industries and the agriculture sector. Nevertheless, the energy crisis in Pakistan is not just a technical issue of electricity supply but is also linked with consumer welfare, industrial competitiveness and sustainable development (Shahid et al., 2020; Khalid and Salman 2020; Malik et al., 2020).

The recent geopolitical tensions in the Middle East, especially around the Strait of Hormuz, have highlighted the vulnerability of energy-importing developing countries such as Pakistan. Since oil and LNG flows are extremely sensitive to sea transport, conflict and shipping uncertainty, Pakistan's reliance on international fuel markets translates global shocks into domestic inflation, foreign exchange pressure and higher electricity tariffs (Nyang et al., 2026). In this context, the policy question is not only how Pakistan can generate more electricity, but also how it can reduce its exposure to imported fuel and build a more resilient domestic energy system.

Due to rising electricity tariffs and unreliable grid supply, rooftop solar systems have been expanding rapidly in Pakistan. However, this transition has been consumer-led. Households, commercial users, industries and farmers have been shifting towards solar systems to reduce electricity bills, improve reliability and gain partial autonomy from the national grid (Uz and Mamkhezri 2024). This change reflects a new energy reality in which consumers are gradually becoming prosumers. Nevertheless, the transition is uneven because low- and middle-income households, small businesses and farmers face stronger financial and information barriers (Badole et al., 2024).

This paper addresses a specific gap. The claim that rooftop solar improves Pakistan's energy security is asserted across policy reports but rarely quantified, and the policy choices that would maximise that benefit are seldom ranked against one another. This paper addresses two questions. First, what is the order of magnitude of the import, foreign-exchange and emissions hedge that distributed solar provides per gigawatt installed? Second, which combination of finance, tariff, grid and regulatory measures maximises that hedge while keeping adoption inclusive and grid-compatible? The paper tests one proposition: the energy security value of rooftop solar is realised only when adoption is broad-based and grid-integrated, not when it is left to high-income self-selection.

The contribution is threefold. To the best of our knowledge, this paper provides a transparent, reproducible estimate of the avoided import, foreign exchange and CO_2 value of distributed solar for Pakistan, with every assumption stated. Lodhi et al. (2024) and Khan and Arsalan (2016) provide city level estimates of rooftop solar potential; however, limited

evidence is available on the quantification of rooftop solar in Pakistan. It builds a multi-criteria decision-analysis index that ranks eight policy options on six weighted criteria and tests the ranking for robustness. And it connects the household-adoption literature, which explains why uptake is uneven, to the macro energy security argument, which explains why that unevenness matters for the state. The study moves the discussion from description to prioritisation.

2. METHODOLOGY

This study employs an analytical approach to analyse how rooftop solar expansion can support energy security and, thereby, sustainable development in Pakistan. First, it reviews evidence on Pakistan's power sector, particularly solar market growth and net-metering policies. Second, literature on household solar adoption, willingness to pay, credit access and technology acceptance is reviewed. Third, it constructs a Multi-Criteria Policy Index (MCPI) to rank various policy options according to their contribution to energy security, affordability, equity, grid stability, implementation feasibility and sustainability. This approach moves the paper beyond descriptive discussion and provides a structured basis for policy prioritisation.

In this regard, data on the power sector, installed generation capacity, power generation and consumption, solar imports, grid sales, fuel imports and net-metering capacity are extracted from the State of Industry Reports, the Economic Survey, Pakistan Electricity Review 2025 and Mordor Intelligence (for the solar market outlook).

Methodologically, this is a mixed-methods policy analysis with a single organising method. It combines a structured narrative review of the power sector and adoption literature with a multi-criteria decision-analysis (MCDA) index, and supplements both with a transparent quantification of the energy security hedge. The analytical engine throughout is MCDA applied to documented secondary evidence.

Three limitations follow from the reliance on secondary data and should be read alongside the results. First, the FY25 figures cover only July to March, and the net-metering total is the formally registered figure; a large share of adoption sits behind the meter and is unobserved, which makes the hedge estimated conservative. Second, the MCDA scores are ordinal expert judgements rather than cardinal measurements, so the index ranks options but does not price them. Third, the avoided-import estimate depends on assumed generation and price parameters that move with the fuel mix and the exchange rate. Each is mitigated: data are triangulated across NEPRA, Pakistan Electricity Review 2025 and Harrison (2026).

2.1 Multi-Criteria Policy Index (MCPI)

This paper constructs a Multi-Criteria Policy Index. The MCPI ranks policy options on six criteria: energy security impact, affordability impact, equity impact, grid stability impact, implementation feasibility and sustainability impact (Stachura and Kuligowska 2021).

Each criterion is scored from 1 to 5, where 1 indicates weak contribution and 5 indicates strong contribution. The final index is calculated as the weighted sum of criterion scores. The weights are chosen according to the policy objective of this paper, which is to reduce crisis exposure while ensuring inclusive and grid-compatible solar expansion.

$$\mathrm{MCPI_i} = \sum \mathrm{w_i} \times \mathrm{S_{ij}}$$

The MCPI formula is: MCPI = 0.25(energy security) + 0.20(affordability) + 0.20(equity) + 0.15(grid stability) + 0.10(feasibility) + 0.10(sustainability). The weights sum to one, and the MCPI is the weighted sum of the six scores. As the MCPI does not provide cost-benefit analysis or welfare outcomes but only ranks the individual measures, the ranking should be interpreted as prioritisation and not as welfare measurements. Energy security receives the highest weight because the paper is framed around future geopolitical crises. Affordability and equity receive high weights because solar adoption in Pakistan remains uneven and financially constrained. Grid stability receives a medium weight because distributed solar can create reverse power flows and revenue stress if not managed properly.

2.1.1 Criteria Selection

The literature on rooftop solar focuses on electricity market regulations, household adoption behaviour and energy security. Further, little literature is available on how the energy transition affects distributional impacts. This study reviews the literature on Pakistan and developing countries using six evaluation criteria. Studies analysing household behaviour highlight that access to finance, ownership, technological awareness and installation costs remain significant barriers to rooftop solar installation (Qureshi et al., 2017; Shahid et al., 2022; Mahn et al., 2024). These factors are associated with affordability and equity criteria.

The literature on energy security suggests that solar-based energy generation may reduce the dependence on imported thermal fuels. However, the energy security criterion reflects that the effect of solar-based generation depends on which generating units are displaced and when solar electricity is produced. The grid-stability and implementation-feasibility criteria reflect evidence that the rapid growth in rooftop solar generation affects tariff design, cost recovery and network stability (Carley and Konisky 2020; Sovacool 2021). The energy-justice hypothesis suggests that access to clean-energy technologies and electricity costs differ across socioeconomic groups, which affects grid stability. Lastly, emissions reductions and possible land and groundwater impacts motivate the assessment of sustainability as a separate criterion. Based on the literature, each MCPI criterion corresponds to an important theme in prior literature, whereas scores (1–5) are assigned on the basis of normative policy judgements.

Based on the literature, six criteria have been chosen for the MCPI ranking: energy security, affordability, equity, grid stability, feasibility and sustainability. Energy security, affordability, and equity are three key factors that have been consistently identified in the

literature on distributed energy and just transition. These factors help to determine whether a renewable transition is effective and politically durable. Along with this, grid stability, implementation feasibility, and sustainability are used to analyse supply side factors that affect behaviour in the long run. Each criterion is defined operationally. Energy security reflects the reduction in reliance on imported fuel and diesel; affordability determines consumer behaviour by affecting bills net of financing; and equity reflects the spread of benefits across income groups. Likewise, grid stability reflects the effect on voltage, hosting capacity and DISCO revenue, feasibility reflects the institutional and capital requirements, and sustainability contributes to long-run emissions and resource goals.

2.1.2 Weight Determination

The weight of each criterion is assigned normatively: the highest weight (0.25) is given to energy security because the study proposes that import exposure challenges energy security in Pakistan. Similarly, a weight of 0.20 is assigned to affordability and equity because solar adoption in Pakistan is financially constrained and uneven. The weights are not claimed to be unique, which is precisely why the sensitivity analysis re-runs the index under alternative weightings.

2.1.3 Scoring Procedure

After the weights are assigned, each policy option is scored from 1 to 5 on every criterion using anchored descriptors, where 1 refers to a negligible contribution, 2 a weak, 3 a moderate, 4 a strong and 5 a very strong contribution (Boggia and Cortina 2010). A score is assigned only where it can be tied to a documented basis such as the use of literature on affordability and equity scores for targeted finance, NEPRA and Pakistan Electricity Review 2025 for the grid-stability scores, and the avoided-import logic of quantifying the rooftop-solar hedge for the energy security scores.

2.1.4 Validation and Limitations

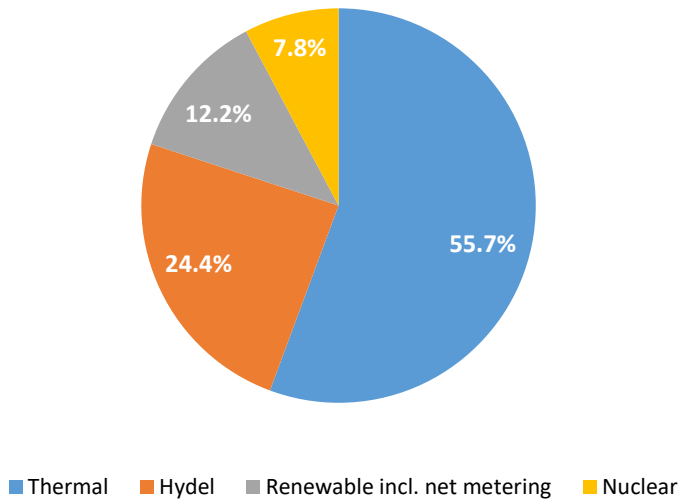
For validation, the sensitivity analysis tests the ranking and shows that the leading option is stable under plausible re-weighting. However, the index has clear limits. The scores are ordinal, so the MCPI value ranks options rather than measuring welfare. The criteria are also treated as additively separable, which understates interactions between finance and grid readiness. For these reasons the index is presented as a prioritisation aid, not a definitive cost benefit result.

3. OVERVIEW OF PAKISTAN'S POWER SECTOR

As of March 2025, Pakistan's total installed electricity generation capacity stood at 46,605 MW (Government of Pakistan, Finance Division 2025). Thermal power remained the largest component with 55.65% of installed capacity, followed by hydel at 24.39%, renewables, including net metering, at 12.18% and nuclear at 7.77% (see Figure 1). The renewable figure includes 2,813 MW from net metering, showing that distributed solar has

become a measurable part of Pakistan's installed capacity. However, this also means that Pakistan remains materially exposed to fossil fuel generation and imported fuel markets.

Figure 1: Pakistan Installed Electricity Capacity Mix



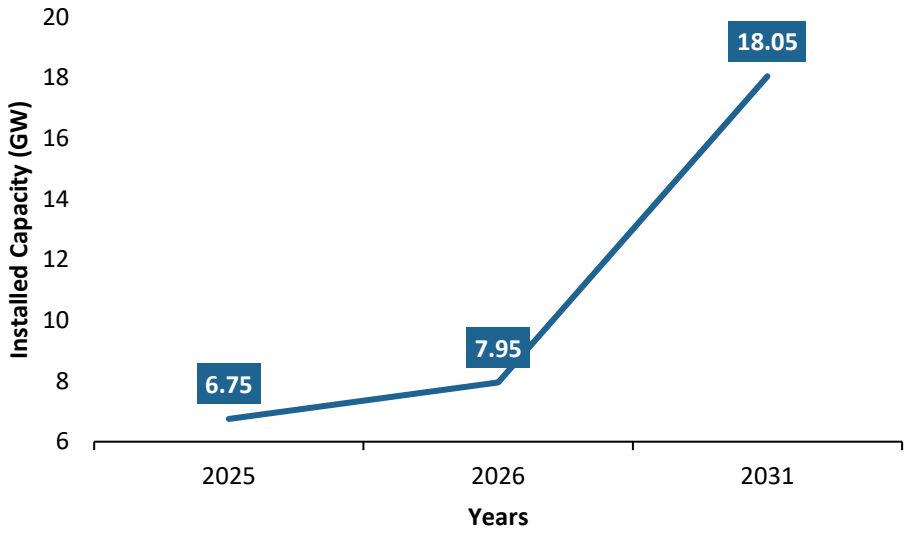
Source: Pakistan Economic Survey (2024-25).

During July–March FY25, Pakistan generated 90,145 GWh of electricity, while total electricity consumption stood at 80,111 GWh. The consumption level declined by 3.6% compared with the same period of FY24. The official explanation links this decline with energy conservation, elevated tariffs, off-grid solar solutions and subdued industrial activity. According to the Pakistan Economic Survey (2024–25), the household sector remained the largest consumer, accounting for 49.6% of electricity consumption (see Table 1). Industry accounted for 26.3%, commercial users for 8.6%, agriculture for 5.7% and others for 9.8%.

3.1 Solar Market Transformation and Demand Shift

Pakistan's solar market is expanding rapidly. Figure 2 shows that the solar market was at 6.75 GW in 2025, 7.95 GW in 2026 and 18.05 GW by 2031, with a compound annual growth rate of 17.82% during 2026–2031. Although market forecasts should be interpreted cautiously, the direction of change is consistent with observed import and net-metering data (Mordor Intelligence 2026). The solar market is no longer restricted to utility-scale projects; households, SMEs, agriculture and commercial and industrial users increasingly drive it.

Figure 2: Pakistan Solar Market Growth

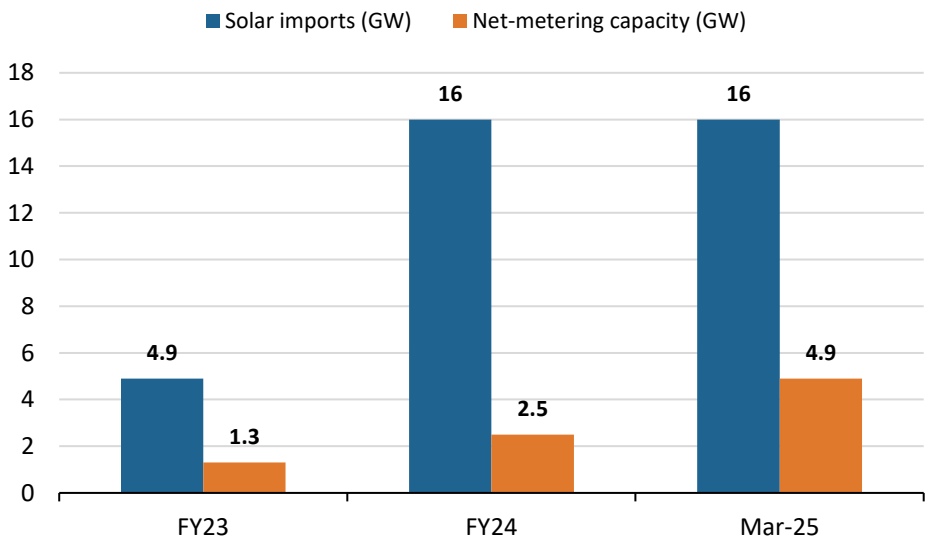


Source: Mordor Intelligence (2026).

Figure 3 shows a sharp increase in solar PV imports. Solar panel imports surged to 16 GW in FY24 from 4.9 GW in FY23, while formal net-metering capacity increased from 1.3 GW in FY23 to 2.5 GW in FY24 and 4.9 GW by the first nine months of FY25. This reveals an important analytical point: formal net-metering is only one part of the solar transition. A large part of solar adoption may remain behind the meter or off-grid and may not be fully reflected in official demand planning.

The decrease in electricity consumption from the national grid can be interpreted as declining household reliance on the grid in response to rising tariffs. The decline in grid consumption may reflect a substitution effect, whereby consumers prefer to generate their own electricity rather than consume grid electricity. The CREA analysis suggests that the solar boom in Pakistan helped avoid more than USD 12 billion in oil and gas imports by February 2026 and could save an additional USD 6.3 billion by the end of 2026 if prices remain elevated (Harrison 2026). The study also showed that solar PV imports had increased from below 1 GW in 2018 to more than 51 GW by early 2026. Thus, rooftop solar should be considered a macroeconomic opportunity because it reduces demand for imported fuel.

Figure 3: Solar PV Import and Net-metering Capacity



Source: Renewables First (2025).

3.2 Pakistan's Energy Security Challenge

Energy security in Pakistan has four key dimensions. First, the country remains exposed to international fuel markets, where imported fuel (oil, LNG and coal) has shaped the cost of electricity generation. When fuel prices increase in the international market, the effect is transferred to domestic consumers via fuel adjustment charges, exchange-rate pressure, and higher tariffs, making the power sector in Pakistan highly vulnerable to global energy shocks.

Second, the power sector is financially stressed. Installed capacity was 46,605 MW by March 2025 while electricity consumption fell to 80,111 GWh during July–March FY25 from 83,109 GWh in the same period of the previous year (see Table 1). This decline reflects the affordability constraints, suppressed industrial activity and increasing off-grid or behind-the-meter solar solutions. It further creates a revenue problem for DISCOs because fixed system costs remain even when formal grid sales decline.

Third, the household sector remains central to the electricity system. Households accounted for almost half of electricity consumption during July–March FY25 (NEPRA 2025). This means that rooftop solar policy should not be treated as a niche intervention because it directly affects the largest electricity consumer category. Fourth, agriculture consumption declined sharply, implying that farmers may be reducing grid reliance, shifting to solar tube-wells, or facing affordability constraints. Agricultural solarisation can reduce diesel and grid dependence, but it must be linked with groundwater regulation.

Table 1: Power Sector and Solar Transition Indicators

Indicator	Value	Policy interpretation
Installed electricity capacity	46,605 MW	Grid has the capacity, but its utilisation and affordability weaken.
Net-metering capacity	2,813 MW (NEPRA 2025)	Distributed solar is solution
Thermal share in capacity	55.65%	Exposure to fuel markets is high
Electricity generation	90,145 GWh	Demand is high compared to installed capacity
Electricity consumption	80,111 GWh	Grid consumption reduced by 3.6%
Household consumption share	49.6%	Rooftop solar policy has system-wide importance
Agriculture consumption decline	34.3%	Solar-based irrigation and affordability constraints call for policy attention
Petroleum use in power sector	116.21 thousand MT	Large decline shows reduced oil-based generation

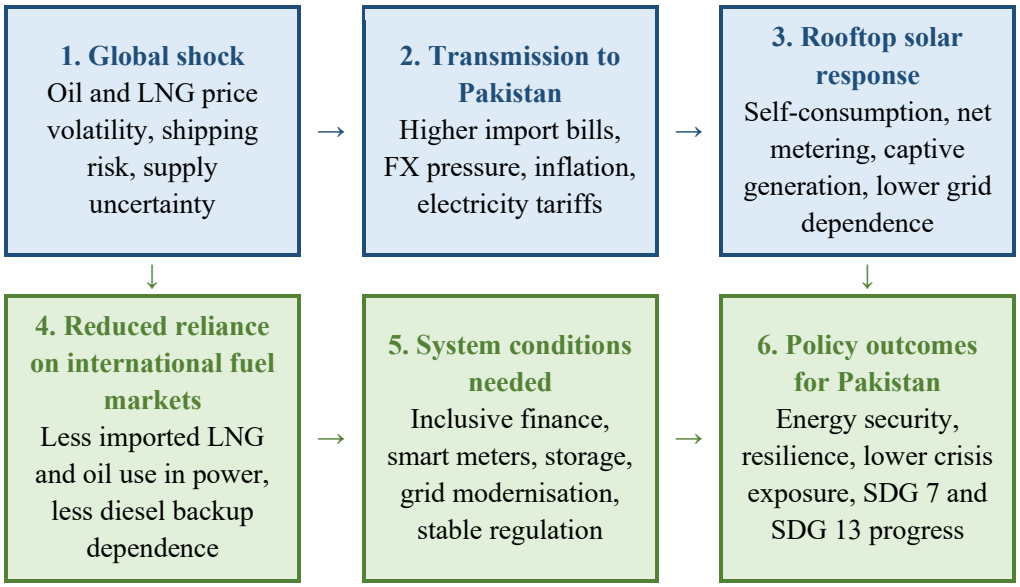
Source: NEPRA State of Industry Report (2025).

3.3 Rooftop Solar and Crisis Exposure

The key argument of this paper is that rooftop solar works as a hedge against future geopolitical energy crises. Geopolitical conflict has affected Pakistan through international oil and LNG markets. The immediate transmission channels are higher import prices, exchange-rate pressure, rising inflation, high electricity tariffs, and shipping uncertainty (Hosseini et al., 2026). Rooftop solar weakens this transmission chain by replacing part of the electricity that would otherwise be generated through imported LNG, oil-based generation or diesel backup systems (Lolai et al., 2026).

This is particularly crucial for Pakistan because consumers have been using diesel generators and battery backup during supply interruptions. When rooftop solar with batteries or self-consumption systems replaces these backup sources, it reduces household and commercial dependence on imported petroleum products (Lolai et al., 2026). At the macro level, reduced fossil fuel imports lower the pressure on foreign exchange reserves. According to Harrison (2026), Pakistan's solar boom has already helped avoid large oil and gas import costs, showing that distributed solar has value beyond private bill savings. Therefore, every additional megawatt of rooftop solar can be interpreted as a small but measurable reduction in future fuel market exposure.

Figure 4: Rooftop Solar: Hedge Against Future Geopolitical Fuel Shocks



Source: Authors' own calculations.

3.4 Quantifying the Rooftop Solar Hedge

The potential contribution of rooftop solar is estimated using conditional fuel displacement scenarios. Let K denote installed solar capacity and CF the annual capacity factor; s is the proportion of solar generation that substitutes for imported RLNG, HR is the thermal plant heat rate (MMBtu/MWh), P is the imported-RLNG price (USD/MMBtu) and EF is the emissions factor of the displaced generation (tonnes CO_2/MWh). Annual generation equals K × 8,760 × CF. Imported-RLNG-equivalent output displaced equals generation × s; associated gas use equals displaced output × HR; avoided import expenditure equals gas use × P; and avoided emissions equal displaced output × EF. For one additional gigawatt, the baseline assumes a 17% capacity factor, complete displacement of imported RLNG, a heat rate of 7 MMBtu/MWh, an RLNG price of USD 12/MMBtu and an emissions factor of 0.40 tCO_2/MWh. Table 2 shows that the resulting annual generation is about 1.49 TWh, with approximately 10.42 million MMBtu of gas-equivalent displacement, USD 125 million of potentially avoided imported-fuel expenditure and 0.60 million tonnes of potentially avoided CO_2. Illustrative low and high assumptions produce imported-fuel savings of approximately USD 35–224 million per gigawatt annually.

Avoided imported fuel expenditure should not be conflated with total avoided generation cost or definitive foreign-exchange savings. Variable domestic operating costs and fixed capacity obligations are analytically distinct. Moreover, the assumption that solar displaces imported RLNG at all relevant hours is a scenario, not an observed dispatch result. The

estimates depend on solar generation timing, the system's marginal fuel mix, network constraints, demand and fuel prices; the underlying input parameters require technical-source verification. Published aggregate avoided-import estimates cover different deployment bases and periods and should not be interpreted as direct validation of these annual per-gigawatt scenarios. Conditional scaling from either 2.813 GW or 4.9 GW must state which source is used.

Table 2: Annual Fuel Displacement and Emissions Scenarios Per Additional Gigawatt

Outcome	**Low Scenario**	**Baseline**	**High Scenario**
Additional solar capacity	1 GW	1 GW	1 GW
Capacity factor	14%	17%	20%
RLNG-displacement share	60%	100%	100%
Thermal heat rate (MMBtu/MWh)	6	7	8
RLNG price (USD/MMBtu)	8	12	16
Annual generation (TWh)	1.226	1.489	1.752
Imported gas avoided (million MMBtu)	4.42	10.42	14.02
Fuel import savings (USD million)	35.3	125.1	224.3
Avoided CO_2 (million tonnes)	0.258	0.596	0.876

Source: Authors' own calculations.

Under the stated assumptions, rooftop solar may affect sustainable development through possible fuel import savings (economic), access and tariff incidence (social), and operational emissions reductions (environmental). These outcomes depend on network integration, affordability and regulatory choices; the study does not quantify household level distributional welfare or guarantee emissions reductions in every dispatch hour.

4. DETERMINANTS OF ROOFTOP SOLAR ADOPTION

The literature on rooftop solar adoption behaviour is divided into four strands (Mahn et al., 2024). The first strand discusses rooftop solar as a decentralised energy transition rather than a consumer-specific product, implying that prosumer growth reshapes utility revenue and network planning (Brown et al., 2021). The second strand links distributed renewable energy to national energy security, indicating that import-dependent systems gain measurable resilience from domestic generation (Besant-Jones 2006; Nyang et al., 2026). The third examines net-metering and tariff reform, discussing how policy reversals depress investment in solar (Khan et al., 2024). The fourth strand focuses on energy justice and states that, without targeted finance, a renewable transition benefits wealthier households and shifts fixed network costs onto the poor (Carley and Konisky 2020; Sovacool 2021).

Together these strands frame the central claim that the security and development value of rooftop solar depends on how, and for whom, it is deployed.

The literature on household renewable energy adoption in Pakistan focuses on socioeconomic, financial, behavioural, technical, and regulatory factors (Parveen et al., 2025). In Pakistan, households have been considering rooftop solar for reliability, cost savings, and energy autonomy. However, this adoption remains uneven because of high upfront cost, financing constraints, information gaps, and housing limitations (Uz and Mamkhezri 2024).

Abdullah et al. (2017) found that about 81% of respondents in northern Pakistan showed strong interest in solar home systems. However, high cost of panels, lack of information and mistrust of providers emerged as major barriers. The study also showed that willingness to purchase increased when the government subsidised part of the cost, indicating that latent demand exists but requires financial facilitation.

Table 3: Key Household Solar Adoption Determinants

Determinant	Effects	Policy instrument
High upfront cost	Consistently lowers adoption	Targeted green loans, leasing and partial subsidies
Household income	Higher income raises adoption probability	Target support to low- and middle-income consumers
Access to credit	Enables adoption and larger systems	Green consumer finance through banks and MFIs
Homeownership	Owners adopt more than tenants	Shared/community solar and renter-friendly models
Awareness and trust	Increases willingness to adopt	Vendor certification and consumer information
Net-metering stability	Improved expected return	Avoid abrupt policy reversal
Peer visibility	Encourages diffusion	Neighbourhood demonstration projects
Battery/resilience value	Raises value under unreliable supply	Storage support for critical services and SMEs

Source: Authors' own calculations.

Qureshi et al. (2017) studied household solar PV adoption behaviour in Lahore and found that high initial cost is a crucial factor affecting solar adoption in the city. The study indicated that inadequate government financial support, problems in using electric appliances simultaneously, limited exposure to local vendors and long payback periods remained the key barriers to solar adoption. Along with this, environmental friendliness, local market availability, and energy security are crucial adoption factors. Shahid et al.

(2022) found that awareness regarding net metering, solar technology and policy parameters significantly affects consumer willingness to become prosumers.

Recent survey evidence from the twin cities of Islamabad and Rawalpindi shows that only around one-quarter of households had installed solar systems, despite widespread use of backup electricity during outages (Parveen et al., 2025; Qureshi et al., 2017). Education, homeownership, peer influence, and access to finance increase adoption, while high upfront costs and unsuitable housing types restrict it. International evidence also confirms that willingness to pay varies with income, education, savings expectations, motivation, self-reliance, and battery attributes (Shahid et al., 2022).

5. MULTI-CRITERIA POLICY INDEX (MCPI)

The MCPI results presented in Table 4 show that targeted solar finance for households and SMEs has the highest score, which is consistent with the literature (Abdullah et al., 2017; Shahid et al., 2022). It is also in line with the view that high upfront cost and limited access to credit are the primary barriers to rooftop solar adoption. From an energy security perspective, financing helps to increase the number of consumers who can reduce grid and diesel-backup dependence. From an equity perspective, targeted finance can prevent the solar transition from being captured only by high-income consumers (Shahid et al., 2022).

Figure 5 shows that targeted solar finance ranks highest with a score of 4.50, whereas public-building solarisation with batteries scores 4.10, making it the second-ranked policy option. Public-building solarisation helps to reduce public electricity expenditure, improves service continuity in hospitals and schools, and provides considerable public demonstration of solar reliability. Stable net-metering reform ranks third because policy uncertainty can immediately weaken investor confidence. However, net metering alone is not sufficient because it primarily benefits those who can already afford solar systems. Therefore, it must be combined with finance, smart meters and progressive grid charges to realise the full benefits of solar. Grid charges, agricultural solarisation, local manufacturing and green skills rank relatively low.

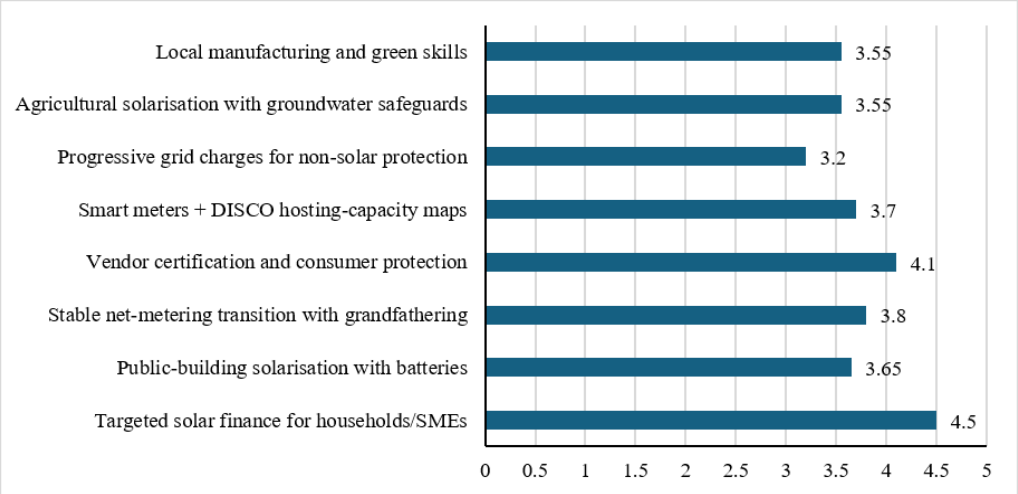
Smart meters and DISCO hosting-capacity maps score strongly on grid stability but lower on feasibility because they require investment, institutional coordination and technical capacity (see Figure 5). Moreover, vendor certification performs well in feasibility and consumer protection, but it scores lower on energy security. Local manufacturing contributes strongly to long-term sustainability, but its short-run energy security effect is relatively lower because industrial capacity takes time to develop. Lastly, agricultural solarisation has high energy security and affordability value but requires groundwater safeguards to avoid unintended resource depletion.

Table 4: Multi-Criteria Policy Index (MCPI) Scoring Matrix

Policy option	Energy security	Affordability	Equity	Grid stability	Feasibility	Sustainability	MCPI
Targeted solar finance for households/SMEs	5	5	5	3	4	4	4.50
Smart meters + DISCO hosting-capacity maps	4	3	3	5	3	4	3.65
Stable net-metering transition with grandfathering	4	4	3	4	4	4	3.80
Public-building solarisation with batteries	4	4	4	4	4	5	4.10
Vendor certification and consumer protection	3	4	4	3	5	4	3.70
Local manufacturing and green skills	3	3	3	3	3	5	3.2
Progressive grid charges for non-solar protection	3	3	5	4	3	3	3.55
Agricultural solarisation with groundwater safeguards	4	4	3	3	3	4	3.55

Source: Authors' MCPI calculations.

Figure 5: MCPI ranking of Policy Options



Source: Authors' MCPI calculations.

5.1 Sensitivity Analysis

Table 5 shows the alternative weights. Four scenarios are examined: the baseline, higher grid stability, higher equity and higher energy security. Each scenario uses a weight vector summing to one. The baseline scenario is 0.25 (energy security), 0.20 (affordability and equity), 0.15 (grid stability) and 0.10 (feasibility and sustainability).

Table 5: Alternative Weights

Criterion	Baseline	Higher Grid Stability	Higher Equity	Higher Energy Security
Energy Security	0.25	0.25	0.25	0.35
Affordability	0.20	0.10	0.10	0.10
Equity	0.20	0.20	0.30	0.20
Grid Stability	0.15	0.25	0.15	0.15
Feasibility	0.10	0.10	0.10	0.10
Sustainability	0.10	0.10	0.10	0.10

Source: Authors' own calculations.

Table 5 shows that, under the higher-grid-stability scenario, the weight of grid stability increases to 0.25 and the affordability weight falls to 0.10. Under the higher-equity scenario, the equity weight increases to 0.30 and the affordability weight falls to 0.10, whereas the higher-energy security scenario raises the weight of energy security to 0.35 and reduces the affordability weight to 0.10.

Table 6: Sensitivity Analysis of Policy Priorities

	Baseline	Higher Grid Stability	Higher Equity	Higher Energy Security
Targeted solar finance for households/SMEs	4.50	4.30	4.50	4.50
Smart meters + DISCO hosting-capacity maps	3.65	3.85	3.65	3.75
Stable net-metering transition with grandfathering	3.80	3.80	3.70	3.80
Public-building solarisation with batteries	4.10	4.10	4.10	4.10
Vendor certification and consumer protection	3.70	3.60	3.70	3.60
Local manufacturing and green skills	3.20	3.20	3.20	3.20
Progressive grid charges for non-solar protection	3.55	3.65	3.75	3.55
Agricultural solarisation with groundwater safeguards	3.55	3.45	3.45	3.55

Source: Authors' own calculations.

The sensitivity analysis shows a similar ranking of policy options across scenarios, with targeted finance remaining the highest-ranked option with a score of 4.50. However, in the higher-grid-stability scenario its score falls from 4.50 to 4.30, although it still ranks first, followed by public-building solarisation. Under the higher-equity weights, the score of progressive grid charges rises to 3.75, whereas targeted finance and public-building solarisation retain their positions. Similarly, the higher energy security scenario does not change the positions of the options except for smart meters and vendor certification. It is pertinent to note that two options remain unchanged in all scenarios, showing conformity with the MCPI ranking in Table 4.

6. CONCLUSION

Rooftop solar expansion in Pakistan has the potential to reduce electricity-sector exposure to international fuel markets. However, the magnitude depends on the generation displaced, system conditions and regulatory arrangements. The analysis of fuel displacement scenarios reveals that one additional gigawatt of distributed solar could, under the baseline assumptions, avoid approximately USD 125 million in annual imported-RLNG expenditure and 0.60 million tonnes of CO_2. The MCPI prioritises targeted solar finance, public-building solarisation and stable net-metering reform. The two leading options remain unchanged under the alternative weight scenarios examined, although other positions vary. The MCPI analysis reveals that targeted solar finance, public-building solarisation, stable net-metering reform and grid modernisation should be the core reforms that help to accelerate the potential benefits of solar to the power sector and to welfare in general. These policies address energy security, affordability, equity and system stability. Pakistan should not resist rooftop solar; it should govern it as a strategic transition that reduces dependence on international fuel markets and strengthens sustainable development.

7. POLICY RECOMMENDATIONS

The recommendations below are organised into four clusters: energy security planning and inclusive finance; tariff and net-metering reform; grid and storage readiness; and market integrity, productive use and development integration. Each cluster maps to one of the higher ranked options in Table 4.

Given the external shocks and vulnerabilities, Pakistan should consider rooftop solar expansion as a strategic response to international conflicts and external energy shocks rather than only as a private solution for reducing electricity bills. Such a crisis may affect Pakistan by raising oil and LNG prices, creating uncertainty, foreign-exchange pressure, inflation and electricity tariff increases. Rooftop solar could weaken this transmission channel by reducing dependence on imported fuels for power generation, lowering the need for diesel backup, supporting decentralised energy generation and improving the resilience of households, firms and public services. However, these benefits can be realised only if solar expansion is supported by stable regulation, inclusive finance, grid modernisation and consumer protection.

7.1 Recognise Rooftop Solar as an Energy Security Hedge

The Ministry of Energy, Planning Commission and NEPRA should formally include rooftop solar in Pakistan's national energy security planning. At present, rooftop solar is mostly discussed as a consumer level investment, mainly because it reduces monthly electricity bills. However, in the context of global energy-market instability, rooftop solar has a wider macroeconomic role. It can reduce Pakistan's exposure to imported oil, LNG and diesel by replacing part of grid electricity demand with locally generated renewable electricity.

During a future geopolitical crisis, Pakistan may face higher fuel import costs, pressure on foreign exchange reserves and rising electricity tariffs. If a larger share of household, commercial, industrial and agricultural demand is met through rooftop and distributed solar, the country will require less imported fuel for electricity generation and less diesel for backup power. Therefore, annual energy planning should estimate the contribution of distributed solar in terms of avoided imported fuel, avoided foreign-exchange outflow, reduced diesel-generator use and reduced peak demand from the national grid.

This will shift the policy discourse from 'solar as private saving' to 'solar as national resilience.' A Distributed Solar Energy Security Assessment should be prepared every year to quantify how rooftop solar reduces exposure to international fuel markets. This assessment can help the government design import strategies, tariff planning, climate commitments, and future power-sector investments on a more realistic basis.

7.2 Targeted Rooftop Solar Finance Facility

The State Bank of Pakistan, commercial banks, microfinance institutions, and development partners should create a dedicated rooftop solar finance facility for low- and middle-income households, SMEs, schools, clinics and small farmers. High upfront cost is one of the most important barriers to solar adoption. Without affordable finance, rooftop solar will remain concentrated among high-income consumers, while poor and lower-middle-income households will continue to depend on expensive grid electricity.

A future global fuel crisis would affect these vulnerable groups the most because higher imported fuel costs are usually transferred into electricity tariffs and inflation. Targeted solar finance can protect these groups by allowing them to generate part of their electricity from solar before the next crisis occurs. Loans should be instalment-based and linked with electricity bill savings, so that the repayment burden remains manageable. Partial credit guarantees should be introduced to reduce lender risk and encourage banks to finance small consumers.

This policy will make solar adoption more inclusive and will prevent the energy transition from becoming an elite transition. By expanding solar access to households, SMEs and farmers, Pakistan can reduce aggregate grid demand, lower imported-fuel requirements and

increase the number of consumers protected from tariff shocks during future geopolitical crises.

7.3 Reforming Net Metering Policy

Net metering has become a crucial factor affecting rooftop solar investment in Pakistan. However, the abrupt policy changes regarding net-metering create uncertainty among consumers while reducing investor confidence and slowing down solar adoption. Existing solar consumers might be protected by offering a clear grandfathering timeline while new consumers should be shifted gradually toward a revised net-metering framework. In this regard, it is important to note that the buyback rates should be transparent, predictable and should be based on clear principles. If net-metering uncertainty discourages solar investment today, Pakistan will remain more dependent on imported fuels during the next global energy shock. Therefore, a stable net-metering framework will motivate consumers to invest in solar, thereby reducing future grid demand and fuel import exposure.

7.4 Protect Non-solar Consumers

NEPRA should consider designing a progressive grid charge based on sanctioned load, consumption category and ability to pay. One of the risks associated with rooftop solar expansion is that high-income households have been reducing grid purchases whereas low-income consumers remain dependent on the grid. In such a situation fixed costs are recovered from vulnerable consumers (non-solar households) in the form of higher tariffs. This can create social resistance against solar rooftops and weaken the legitimacy of the energy transition. This implies that, in a future crisis, poor households will bear inflation, higher food prices and higher electricity costs at the expense of richer households. Therefore, lifeline and protected consumers should remain shielded. Higher-load consumers who continue using the grid as backup should contribute fairly to grid maintenance and reliability. A progressive tariff design could address this while expanding rooftop solar and protecting social equity.

7.5 Battery Storage

Battery support should not be limited to high-income households. It should initially target hospitals, schools, telecom towers, SMEs, water systems and other critical services. Rooftop solar produces electricity mainly during the day, while Pakistan's peak electricity demand often occurs in the evening. Without storage, the value of solar for crisis resilience remains incomplete. Battery storage allows daytime solar electricity to be shifted to evening demand. This reduces pressure on the grid during peak hours and lowers the need for expensive imported fuel-based generation. The stored solar electricity can help reduce dependence on thermal generation and diesel generators. A targeted battery policy can improve the reliability of the solar transition. Battery incentives should be linked with priority sectors rather than luxury backup consumption. Essential public services, SMEs and productive users should be prioritised because their uninterrupted electricity use has

wider social and economic benefits. Time-of-use tariffs can further encourage consumers to store solar electricity during the day and use it when grid demand is high.

7.6 Support SMEs and Agriculture

Solar finance should be expanded to SMEs and farms because these sectors are highly sensitive to electricity costs and fuel-price shocks. SMEs face high production costs when electricity tariffs rise, while farmers often depend on grid electricity or diesel for irrigation. During a future global energy crisis, higher fuel prices can increase production costs, reduce competitiveness and affect food security.

Solar systems can help SMEs lower energy costs and maintain production during tariff shocks. For export-oriented SMEs, solar adoption can also support compliance with green supply chain requirements. Similarly, solar irrigation can reduce dependence on diesel and unreliable grid electricity in agriculture.

However, agricultural solarisation must be linked with safeguards. If solar pumps make irrigation too cheap without regulation, groundwater extraction may increase. Therefore, solar pumps should be linked with efficient irrigation systems, smart controllers, drip irrigation and groundwater monitoring. This will ensure that solar adoption improves energy security without worsening water insecurity.

7.7 Build Local Manufacturing and Green Skills

Policymakers in Pakistan should consider promoting the domestic manufacture of items such as smart meters, cables, inverters and batteries. Although rooftop solar reduces the reliance on imported fossil fuels, heavy reliance on imported solar equipment might create another form of external dependence. To make the energy transition more resilient, Pakistan should gradually develop local value chains by empowering its local manufacturers because geopolitical crises may disrupt not only fuel markets but also global supply chains. If Pakistan continues to depend entirely on imported solar panels, batteries and inverters, its energy transition may face delays and cost increases. Local manufacturing, in such a situation, can reduce these risks by creating employment and supporting industrial development.

7.8 Integrate Rooftop Solar with Climate and Development Planning

Policymakers in Pakistan should link rooftop solar with its climate commitments, SDG targets and development planning. The integration of rooftop solar contributes to SDG 7 by improving access to affordable and clean energy. Similarly, it will help in reducing emissions from fossil-fuel based power generation and thereby achieving SDG 13. It should be noted that the integration of rooftop solar will only be beneficial if it targets vulnerable groups, SMEs, agriculture and public services. MCPI analysis reveals that in future energy crises, countries with decentralised renewable energy will be more resilient than countries dependent on imported fuels. Therefore, Pakistan should integrate rooftop solar into its

Nationally Determined Contributions, provincial development plans and public investment programmes.

Table 7: Rooftop Solar for Future Crisis Resilience

Policy Area	Crisis-Risk Addressed	Solar Policy Response	Expected Resilience Outcome
Energy security planning	Oil/LNG price shocks and import uncertainty	Treat rooftop solar as an energy security hedge	Lower imported-fuel dependence
Solar finance	Poor households remain exposed to tariff shocks	Targeted loans and credit guarantees	Inclusive solar adoption
Net metering	Policy uncertainty discourages investment	Gradual and predictable reform	Sustained solar growth
Tariff design	Cost shifting to non-solar consumers	Progressive grid charges	Socially fair transition
DISCO modernisation	Grid unable to absorb distributed solar	Smart meters and feeder maps	Reliable solar integration
Public buildings	Essential services exposed to outages and high tariffs	Solar plus battery backup	Service continuity during crises
Battery storage	Solar generation not available during evening peak	Storage support for critical users	Lower peak pressure and diesel use
Vendor certification	Poor-quality systems reduce trust and performance	Certified vendors and standard warranties	Higher consumer confidence
SMEs and agriculture	Production costs rise during fuel shocks	Solar finance with water safeguards	Lower business and farm energy costs
Local manufacturing	Dependence on imported solar equipment	Domestic solar value chain development	Industrial resilience and green jobs
Climate-development integration	Energy crisis worsens development vulnerability	Link solar with SDG and climate plans	Long-term sustainable resilience

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