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Policy Research Institute
for Equitable Development

From Solar Boom to Swarm Grids

Can Pakistan turn scattered solar power into a shared network?

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Introduction

Renewable energy – particularly electricity generated from the sun and wind – is transforming the way countries around the world produce and consume electricity. Solar panels and wind turbines have emerged as some of the cheapest sources of electricity generation, making renewable energy an increasingly attractive alternative to fossil fuels.

By the end of 2025, the world's total renewable energy generation capacity had reached approximately 5,000 gigawatts (GW). During 2025 alone, countries across the world added around 670 GW of new solar and wind generation capacity, highlighting the speed at which the global energy system is shifting towards cleaner sources of electricity.

Pakistan has been part of this transformation – and at a pace that is quite exceptional. By 2025, the country had imported more than 50 GW worth of solar panels, making it one of the fastest-growing solar markets in the world and the largest importer of Chinese solar panels in 2025.

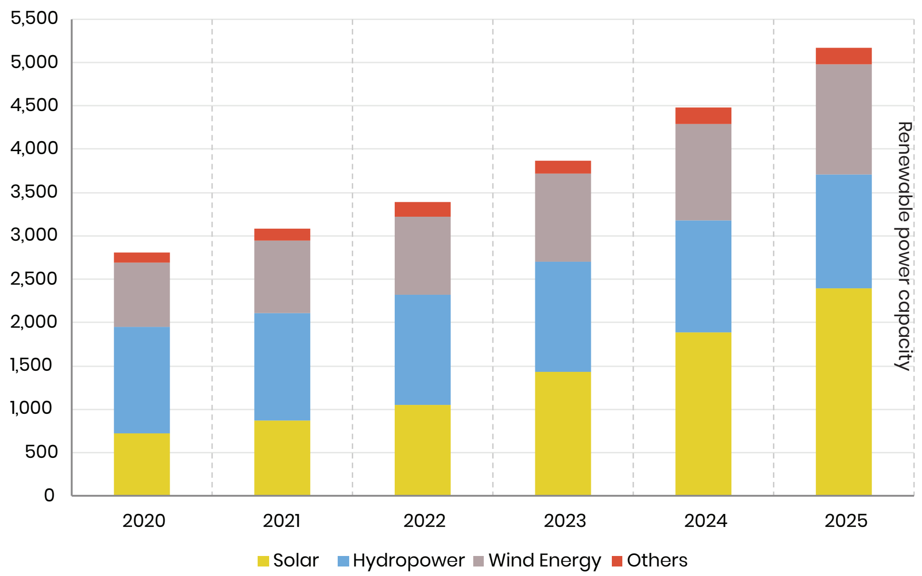
Much of this growth has come from distributed solar generation. Unlike large utility-scale solar power plants, distributed solar systems are installed close to where electricity is consumed – on the rooftops of homes, businesses, factories, schools and farms. These systems allow consumers to generate some or all of their electricity requirements themselves rather than relying entirely on the national grid.

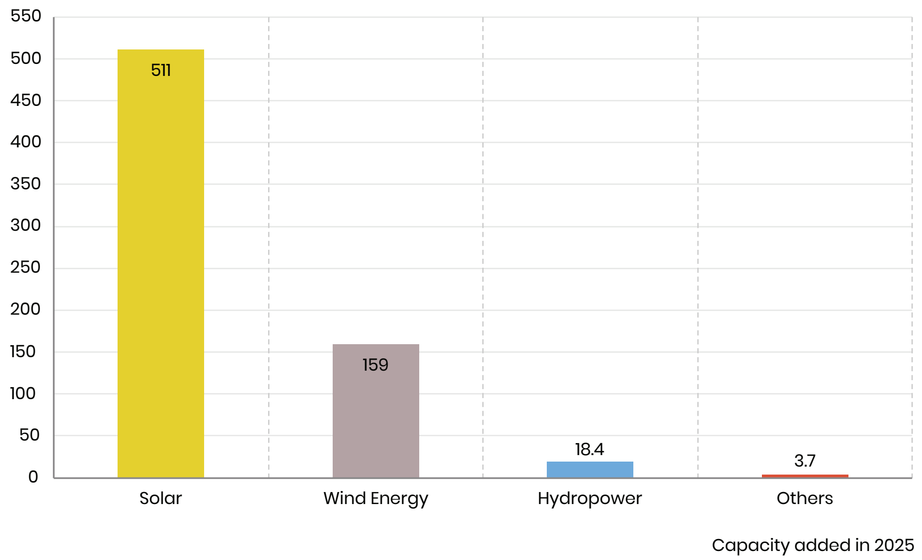
It is estimated that Pakistan now has around 33 GW of distributed solar capacity installed across the country. This represents a significant shift in the country's energy landscape. Millions of electricity consumers are no longer simply consuming electricity supplied by the grid; they are increasingly becoming electricity producers as well.

The scale of this transformation is remarkable. The total capacity of these "behind-the-meter" solar systems – systems installed on the customer's side of the electricity meter, where electricity is consumed directly before any surplus is supplied to the grid – now exceeds Pakistan's highest level of electricity demand from the national grid at any given time.

In simple terms, Pakistan's rooftop and other privately owned solar systems now have the potential to generate more electricity than the national grid itself needs to supply during periods of peak demand. Far from being merely a change in the source of electricity generation, it represents a fundamental shift in the relationship between consumers and the electricity system: consumers who were once entirely dependent on the national grid are increasingly able to generate their own electricity outside it.

Figure 1 :Renewable power capacity growth (GW). Source: IRENA





Prosumage: From passive users to producers

The solar rush in Pakistan did not emerge overnight. For decades, people across the country faced chronic load shedding and frequent grid outages as electricity demand repeatedly exceeded available supply. Frustrated by recurrent and prolonged power shutdowns, consumers were compelled by necessity to find ways to break free from a system in which access to electricity was not only unreliable but also becoming increasingly expensive. In their search for cheaper and more reliable alternatives, consumers were also nudged along by government subsidies and incentives to adopt decentralized solar-based power generation. These systems provided a backup against daily power outages while helping households and businesses cope with increasingly exorbitant electricity bills across different income groups. Over time, this gave rise to a culture of self-generation and, more recently, to what is commonly described as "prosumage" – a shift away from the traditional model in which consumers only purchase electricity from the grid towards one in which they also produce electricity themselves and, in some cases, feed their surplus generation back into the national grid.

These solar and other backup systems took several forms, including uninterruptible power supply (UPS) systems, diesel and gas generators, DC fans and lights. An IFC report published in 2015 estimated that Pakistani households alone were spending around $2.3 billion annually on alternative lighting products, suggesting the scale of the gradual shift away from dependence on the national grid towards localized energy systems. More recently, however, it has been the sharp increase in electricity tariffs and skyrocketing electricity bills that has transformed solar photovoltaic (PV) panels from an alternative technology into a national phenomenon.

Power decentralization as an empowering logic

The rapid growth of localized solar generation has brought about a fundamental change in the conventional logic of electrification in Pakistan. For decades, electrification was understood through a centralized, top-down model in which electricity was generated at large power plants and delivered to consumers through a state-owned and operated national grid. The emerging model is increasingly decentralized and bottom-up, with consumers occupying a much more active position within the electricity system. People are no longer simply passive energy buyers. Instead of remaining entirely dependent on an unreliable national grid and paying increasingly high prices for the electricity they consume, prosumage has enabled consumers to exercise greater control over both their energy supply and their energy costs.

The proliferation of solar panels has, in this sense, delivered something that state-led infrastructure struggled to provide for decades: reliable, affordable and locally generated electricity. As a result, electrification is no longer defined solely by connecting consumers to the national grid. It is increasingly about enabling consumers to generate, manage and potentially share the electricity they produce through rooftop solar systems, including by supplying surplus generation back to the grid. This represents a fundamental shift in the structure of electricity generation and consumption. Power is becoming more distributed and participatory, creating new opportunities for consumers while simultaneously creating new coordination challenges for policymakers and power utilities.

Solarization and the duck curve

The rapid expansion of solar adoption, however, has consequences that extend well beyond individual consumers. The growth of distributed generation has begun to alter the market dynamics that have sustained Pakistan's power distribution utilities and grid operators for decades. As consumers increasingly generate their own electricity, demand for grid-supplied electricity has fallen, leaving some generation capacity underutilized or idle. Yet the financial obligations under which much of Pakistan's public and private power-generation infrastructure was established remain in place. These obligations were created on the assumption that consumers would continue to rely on the grid and that the costs of generation capacity could be recovered through electricity sales. The rapid expansion of solar generation has therefore introduced a new challenge: the electricity system must continue to finance a large centralized generation infrastructure even as an increasing number of consumers reduce their dependence on it.

The widespread deployment of distributed solar has also introduced system-level distortions and operational challenges. The concentration of solar generation in particular localities can result in reverse power flows, with electricity moving from households back into the distribution network rather than flowing in the traditional direction from the grid to consumers. At the same time, consumers that rely on solar during daylight hours often return to the grid in the evening when solar generation falls and household electricity demand rises. This creates sharp evening peaks in electricity demand and places additional operational stress on distribution networks. The resulting pattern is commonly described in the energy sector as the "solar duck curve" – a representation of electricity demand remaining after the electricity supplied by variable renewable energy sources, primarily solar, is subtracted from total demand over the course of a day.

The rapid expansion of solar generation has also been uneven and largely unregulated, raising questions about equitable access to clean energy. This is particularly important because Pakistan has made commitments to principles of equitable and sustainable energy development through the Paris Agreement and other international conventions. For the most part, access to solar technology remains concentrated among wealthier households, commercial users and industrial consumers who have the financial capacity to invest in solar panels, batteries and inverters. The benefits of decentralized energy generation are therefore not being distributed evenly across society.

Swarm electrification: Connecting the dots

The challenge Pakistan now faces is consequently not one of resource scarcity but of coordination. The physical assets required for distributed solar generation – panels, batteries and inverters – are already being installed across the country. What remains missing is the institutional, regulatory and technical layer that can connect these dispersed assets to one another and to the existing electricity grid. It is within this context that the concept of swarm electrification is gaining attention.

Swarm electrification refers to an energy system in which individual generation and storage systems are interconnected and coordinated through localized electricity-sharing networks. In simple terms, swarm grids can transform a collection of individually owned energy systems into a connected network in which electricity can be shared or traded among users. This creates opportunities not only to improve the utilization of existing energy assets but also to generate income from surplus electricity. Such systems can incorporate different forms of generation and storage rather than relying on a single source of electricity.

Instead of operating as isolated units, households and other consumers can exchange electricity, share surplus generation and collectively utilize distributed energy resources. Swarm electrification is therefore positioned somewhere between standalone solar home systems and conventional mini-grids. It seeks to unlock greater value from energy assets that consumers already own while preserving the flexibility and scalability that make decentralized energy systems attractive in the first place.

The significance of this model for Pakistan lies precisely in the fact that the country is already experiencing a rapid, largely consumer-driven transition towards decentralized electricity generation. The question is no longer whether consumers will continue to adopt solar technology. They already are. The more important question is how these increasingly dispersed generation and storage assets can be integrated into an electricity system that was designed around centralized generation and one-way flows of electricity.

This brief explores the concept of swarm electrification within this rapidly changing electricity landscape. It examines how swarm electrification compares with alternative electrification models, including standalone solar home systems and mini-grids, and assesses its potential to improve reliability, increase the utilization of existing energy assets and support more efficient forms of decentralized electrification. The brief also considers the regulatory, institutional and governance conditions that would be required for swarm electrification to scale within Pakistan's evolving energy system.

2

How swarm electrification works — Individual to shared energy network

In stand-alone solar home systems (SHS), a household may generate surplus electricity that remains unused even when households in the neighbourhood face energy shortages. Similarly, batteries are typically sized for use at the individual household level, regardless of whether spare storage capacity exists elsewhere within the community. As distributed energy adoption accelerates, with more households and businesses opting for solar power, addressing these inefficiencies and tapping the potential of distributed energy systems becomes increasingly important, particularly because of its implications for the existing grid production and power-distribution architecture.

Growing the grid, bottom up

Overall, swarm grids, or swarm electrification, are built around a simple but powerful idea: creating a network economy within a prosumer-led, bottom-up renewable electricity infrastructure comprising solar panels, batteries and inverters, while minimizing the inefficiencies associated with power production, storage and distribution. Swarm electrification builds upon the existing solar home systems (SHS) infrastructure. SHS are stand-alone solar photovoltaic systems that offer a cost-effective means of supplying "amenity power" —essentially, secondary electricity sources used for non-essential comforts, conveniences or recreational purposes rather than heavy-duty industrial or critical operations—to remote, off-grid households for lighting and appliances. By interconnecting SHS users and non-users through a bottom-up grid, surplus renewable electricity generated and stored by individual SHS can be distributed to those who need it. Due to the flexibility of the swarm grid, the number of users and loads can also be increased relatively easily, allowing the bottom-up grid to grow gradually.

In terms of set-up, a swarm grid is similar to a microgrid; however, rather than being a centrally planned network, it is assembled in an ad hoc manner by connecting available equipment and scaled up as additional resources become available. This reduces the capital expenditure typically required for a community grid. Swarm electrification also enables owners of small solar home systems to sell excess electricity while allowing other users to gain access to electricity connections. In this way, the system offers a practical opportunity to reduce energy poverty by expanding access to electricity through the more efficient utilization of existing infrastructure. A swarm grid typically develops in three distinct stages.[1]

Phase 1: Pre-electrification

The first step, the initial requirement for swarm electrification, is the existence of stand-alone systems such as PicoPV and SHSs, used to electrify households. Pico Photovoltaic (PV) systems are very small solar systems, but large enough to meet the

1. Swarm electrification: A comprehensive literature review

most basic electricity needs of a household, typically ranging from 1–10 Watts of PV capacity. These systems primarily focus on lighting, but can also run other small electrical appliances such as mobile phone charging stations, radios and MP3 players, and can be extended by adding systems in parallel. The use of Pico PV systems allows households to substitute traditional light sources such as kerosene or battery lamps. Both Pico PV systems and SHSs can therefore provide an initial level of energy services. Due to their low complexity, these small-scale energy systems can be easily installed in rural households, supported through micro-financing. It is important, however, that long-term, locally available technical services are provided to ensure that the systems remain in a condition that allows for a transition to the next phase.

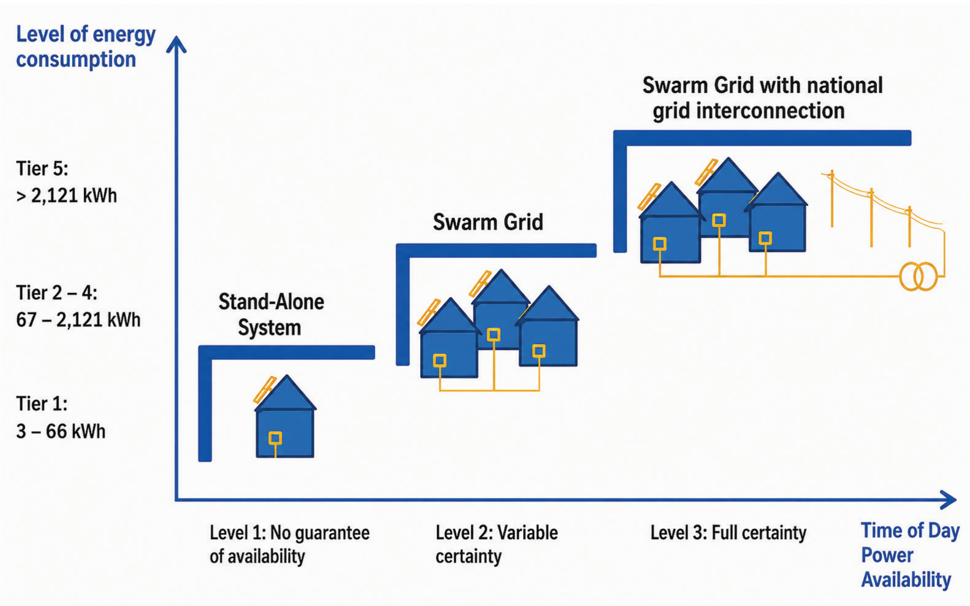
Phase 2: Swarm electrification

In the second phase, individual household systems are interconnected, allowing households to share the "swarm of generation capacity from all individual systems." This evolution enables a higher level of energy consumption as well as increased power availability.

The transition from standalone SHSs to swarm-connected systems can take place gradually, allowing households to interconnect step by step. This enables early adopters to participate first while giving other households time to build trust in the system.

Phase 3: Grid interconnection

The third and final phase involves interconnection with the national grid. This can provide greater electricity availability where grid supply is reliable. Since consumers and local distribution infrastructure are already established, this transition can



reduce the investment risks associated with grid extension. However, in many developing countries, including Pakistan, unreliable grid service and persistent load shedding often limit these benefits. Given the decreasing cost and improving performance of decentralized energy technologies, swarm grids may not necessarily transition into fully grid-dependent systems. Instead, they can expand by connecting with neighbouring community grids while retaining backup capability when linked to an unreliable national grid, thereby enhancing local energy resilience.

Since these systems rely on multiple interconnected household energy sources, mechanisms are needed to manage demand, schedule loads, and optimize the use of locally generated solar power.

A locally determined price

Unlike conventional electricity systems, where utilities and regulators set electricity tariffs centrally, swarm electrification allows energy prices to be determined locally. The simplest pricing models are Pay-as-You-Go[2] and Subscription. In the Pay-as-You-Go model, users pay only for the energy they purchase in advance. In the Subscription model, users pay a fixed fee for a chosen capacity tier, with extra charges if they exceed their limit. Commission-based pricing charges a small fee on each peer-to-peer energy trade instead of charging directly for energy use. Finally, the Hybrid model combines these approaches into a single billing system. The Dynamic Time-of-Use tariff[3] takes a different approach altogether. Instead of looking at who is trading or how much capacity they hold, it looks at when electricity is consumed. Prices rise during peak hours to discourage strain on the grid and fall during off-peak periods, thus encouraging flexibility in shifting load, adjusting supply to the peaks and lows in demand. All together, these five structures cover the full spectrum of swarm grid scenarios, from the simplest rural prepaid user to complex communities within active energy trading and battery storage context.

A model that is modular

What makes swarm grids distinct from other community grid models is how it is designed to ensure coordination between distributed solar assets in a manner that is bottom-up, electricity flowing from citizen/consumer led power generation facilities to the national grid and distribution network, without the need for a single central planner or building an upfront infrastructure solely for this purpose. In a conventional mini-grid, electricity is typically generated, stored, and managed through a centrally planned system that distributes power to connected users. Swarm electrification, by contrast, builds upon energy assets that are already owned by households as prosumers — simultaneously producing, storing, and consuming electricity —, enabling them to operate collectively through local energy-sharing arrangements, and retaining n full autonomy over investment and usage decisions. Moreover, mini grids are designed to meet a specific targeted load and built to that specification. A swarm grid has no fixed design nor an endpoint target by way of load. It starts as a

2. https://documents1.worldbank.org/curated/en/687851468320946678/pdf/93786-REVISED-LW34-fin-logo-OKR.pdf

3. https://www.researchgate.net/publication/330557459_Testing_Time-of-Use_and_Subscription_based_grid_tariff_structures_using_a_Prosumer_model#pf16

small cluster of interconnected nodes and scales organically as more households, businesses, and generators join.

To recap, swarm grids don't require significant upfront investment in centralized infrastructure. Rather, it leverages existing solar panels, batteries, and inverters already deployed by and within communities. Households remain owners of the solar assets and can participate both as consumers and providers of electricity within a swarm. As a result, the model is inherently modular, built from smaller, independent components that can be connected, swapped, or upgraded without breaking the whole system. It can expand incrementally as new users and assets join the network. In this sense, swarm electrification represents more than a technical solution; it introduces a different governance layer, one governed by consumers cum producers, within the electricity system. Its primary objective is not simply to deliver electricity, but also to coordinate distributed resources in ways that increase asset utilization, and creating value for participating households. As distributed energy adoption accelerates, this coordination function may become just as important as electricity generation itself.

3

Why Pakistan is uniquely positioned for swarm electrification

Pakistan's solar revolution has done more than accelerate renewable energy adoption. Starting as a survival strategy for people in response to longstanding systemic problems that rendered the centralized power generation model inefficient, costly and unreliable, it has reached a saturation point where it has fundamentally altered the structure of the country's electricity system. What hasn't happened, though, is for the country to tap that potential in all its myriad capacities, and possibilities. What makes swarm grid particularly significant for Pakistan is the physical foundation of assets that already exists. For the perspective of swarm grids, it means no significant new hardware infrastructure has to be installed, except for the interconnection of assets that households already own and coordination allowing surplus generation from one node to meet demand at another, rather than being wasted or curtailed.

Pakistan imported an estimated 1.25 GWh of lithium-ion battery packs in 2024 alone[4], suggesting that storage capacity within the country is accumulating in a fragmented manner, for fragmented solar assets installed for individual household needs. A swarm architecture could turn this installed base from a collection of isolated islands into a sea of shared functioning network.

Paying an idle grid

The need and urgency to realize the swarm potential of Pakistan becomes strikingly manifest when grid reliability is examined closely and critically. The available electricity access statistics are misleading; on paper we see electricity access of above 98 percent but the truth and reliability of that claim and statistic is open to question. A World Bank research shows that even with such a huge electrification rate, approximately 50 percent of households lie in regions with power disruptions as high as 14 hrs.[5] On top of this, there is the long-standing issue of surplus capacity where Pakistan has to pay for surplus capacity or unused electricity, the so-called "capacity payments." These are fixed, contractual charges Pakistan pays to Independent Power Producers (IPPs) to guarantee energy availability. The government pays these charges regardless of whether the electricity is actually consumed, which currently costs the national treasury around PKR 1.8–2.3 trillion annually (over USD 7 billion)[6]. Contracts with IPPs were designed to attract foreign investment by guaranteeing a set return on equity and covering debt servicing—usually protected in US dollars— for up to 25 to 30 years.

Pakistan's installed power capacity exceeds 41,000 MW, yet winter baseload demand often drops to just 12,000–13,000 MW. This leaves many power plants idle, even though fixed capacity payments still apply. As capacity costs are distributed across fewer grid consumers, electricity tariffs rise. This drives more people to shift to rooftop solar,

4. https://ieefa.org/resources/battery-storage-and-future-pakistans-electricity-grid
5. https://documents1.worldbank.org/curated/en/099062824120620952/pdf/P169313-aa11a457-32e0-.459b-bd99-b944e3711bfe.pdf
6. https://ieefa.org/articles/pakistans-pkr21-trillion-capacity-payments-crisis-triggers-power-purchase-agreement

which shrinks the billing base and triggers even higher capacity charges for remaining users. Because the national grid cannot sell enough electricity at inflated tariffs to cover these fixed capacity payments, a massive financial shortfall—known as circular debt—accumulates across the energy supply chain. These payments typically account for roughly half of the total cost on end-consumers' electricity bills.

The root cause for the unreliability, the exorbitant cost of electricity in Pakistan that almost borders on extraction, is therefore structural: a conventional grid and an outdated transmission system that lacks the ancillary services needed to stabilize the network, resulting in frequent unannounced blackouts.

This structural weakness is well-documented at the operational level. NEPRA's performance evaluation reports for July 2024 and December 2024 indicate that grid transformers were overloaded and frequently tripping. Concerns about unreliability of the national grid are also reflected in system-level interruption data across the power distribution companies or DISCOs. Unplanned interruptions are exceptionally high during summer months when electricity demand is at its peak but happen even during winter months. More importantly, though, most of the disruptions were concentrated at the 11 kV and lower voltage levels, which directly supply most of the residential consumers.[7]

Table 0 1: Feeder level interruption data 2024

	Winters/ Interruptions (Minutes)	Summers Interruptions (Minutes)
11kV dedicated	242,913	3,851,75
11kV shared	10,390,72	2,323,300

Swarm grids – A balancing act

Swarm grids could address this not by fixing the national grid — an expensive, slow, and politically complex task — but by creating a balancing layer locally; one that insulates community-level consumption from national transmission failures. When the feeder goes down, the swarm can continue to operate on locally generated and stored power, restoring the reliability that the formal grid connection promised but has not delivered.

The case for swarm grids is further strengthened when fiscal losses are factored into the argument. In FY2024 transmission and distribution losses reached 18.3 percent against a permitted 11.8 percent, adding Rs 280 billion to the circular debt. Losses in some distribution companies exceed 37 percent against the 17 percent national average. A significant portion of these losses arise from long, overloaded low-voltage feeders — the final-mile distribution infrastructure, as explained in box item here — that were never designed for the demand now placed on them. Swarm grids resolve demand locally, whereby power is generated, stored, and consumed within the same

7. https://nepra.org.pk/M&E/PER/Distribution/Performance%20Evaluation%20Report%20-%20Distribution%20Companies%20Jul-Dec%202024.pdf

neighborhood cluster rather than drawn from a distant generation plant over which the consumers have no power, with electricity stepped down through multiple transformer stages. This directly reduces the load on feeders and cuts the technical losses that are contributing to the sector's fiscal crisis. NEPRA's current load-shedding framework already recognizes feeder-level performance, rewarding feeders with lower losses with preferential supply — swarm deployment aligns naturally with this incentive structure.

Beyond reliability and efficiency, however, the most consequential argument for swarm grids is equity. Pakistan's solar surge risks creating a two-tiered energy system: reliable, clean power for those who can afford to go off-grid, and deteriorating, fossil-fuel-dependent supply for the vast majority still reliant on the conventional grid. Research carried out by Policy Research Institute for Equitable Development (PRIED) shows that wealthy urban households and businesses are defecting from the unreliable and expensive national grid, gravitating towards solar, a move duly encouraged through government policies. This erodes the revenue base that cross-subsidizes poorer consumers, causing deepening financial distress for DISCOs as high-paying users exit and leave behind those who can least afford rising tariffs. Swarm grids offer a structural alternative: rather than allowing clean energy to become a private good for those who can afford a full SHS installation, swarm architecture enables households with partial or low-capacity systems to participate in — and benefit from — a shared network. In rural areas, poorer households often install only one or two panels — enough, at best, to power a single DC fan for the whole family. Under a swarm model, such households can both contribute to and benefit from a collective network whose quality improves as more nodes connect, without waiting for a top-down infrastructure build.

Pakistan's final mile electricity distribution architecture is heavily state-managed, operating through 10 regional DISCOs and the vertically integrated K-Electric in Karachi. It steps down power from the National Grid to end-users via 11 kV and 400 V lines, but is historically plagued by massive transmission and distribution (T&D) losses.

The Hierarchical Distribution Network

The journey of electricity to the final consumer in Pakistan follows this architectural sequence:

High Voltage (HV) Transmission: Power leaves the National Transmission & Despatch Company (NTDC) grid stations at 500 kV, 220 kV, or 132 kV. [1]

Primary Distribution (11 kV): The 132 kV lines step down at local grid stations into 11 kV High Tension (HT) lines, which carry power across local neighborhoods and industrial zones.

Secondary Distribution (400 V/Phase): Pole-mounted or pad-mounted transformers step down the 11 kV to Low Tension (LT) levels: 400 V for three-phase commercial/industrial usage, and 230 V for standard domestic lines.

Key Utility Operators

The final mile delivery falls under the jurisdiction of a few core entities:

Public DISCOs: 10 government-owned corporations under the Water and Power Development Authority (WAPDA) unbundling. Examples include IESCO, LESCO, and PESCO, which are all regulated by NEPRA.

K-Electric (KE): A privatized utility in Karachi that manages generation, transmission, and final-mile distribution.

Major Network Challenges

The final mile is the weakest link in Pakistan's power sector, suffering from several critical issues:

High T&D Losses: Technical and commercial losses routinely exceed 18%, primarily caused by aging transformers and rampant electricity theft (kunda connections).

Voltage Fluctuations: End-of-line users, particularly in rural or densely populated urban areas, often experience severe voltage drops and load-shedding.

Circular Debt: Distribution companies frequently fail to recover billed amounts, generating circular debt that cascades upstream to power producers.

Modernization Efforts: The government has begun deploying Advanced Metering Infrastructure (AMI) and integrating IT systems to refine billing and reduce power theft.

Reining in scattered power

Perhaps most importantly, swarm electrification aligns with the direction in which Pakistan's electricity system is already evolving. The country's energy transition is becoming increasingly decentralized, consumer-driven, and asset-rich. The question is no longer whether distributed energy resources will play a major role in Pakistan's future electricity system. That transition is already underway. The more important question is whether these assets will continue to operate as isolated investments or whether they can be connected in ways that create greater value for households, communities, and the wider energy system. Swarm electrification offers one possible answer.

4

The regulatory challenge: Enabling peer to peer energy sharing

While Pakistan has made important progress by instituting laws that enable distributed generation of power. Current regulations remain largely focused on the relationship between individual prosumers and distribution companies. The 2015 Net Metering Regulations, notified under SRO 892(I)/2015, established Pakistan's first formal legal framework for connectivity of distributed power to the national grid. The regulations governed solar photo-voltaic, wind, and biogas systems with installed capacities between 1 kW and 1 MW connected to a distribution company's network. These regulations turned from net-metering to net-billing in 2026[8] - the former being a billing mechanism that credits solar energy system owners for the electricity they add to the electric grid, and the latter a solar compensation mechanism where electricity imported from the grid is billed at the standard retail rate, while the excess solar energy exported is credited at a separate, lower buyback rate set by the regulator.

Likewise, The NEPRA Licensing (Microgrid) Regulations, 2022 were promulgated under the Regulation of Generation, Transmission and Distribution of Electric Power Act, 1997, to facilitate the electrification of unserved or underserved areas through public or private investment, using indigenous or any other energy resource. Together, these instruments support distributed generation and local electricity provision. However, they do not fully address a key feature at the heart of swarm electrification: the direct exchange of electricity between users within a localized energy eco system. Both the 2015 Net Metering Regulations and the 2026 Prosumer Regulations restrict third party access to the grid thereby constraining the development of swarm electrification in Pakistan. For instance, the 2015 Regulations state that: "The Distributed Generator shall not have any right to utilize Distribution Company's [interconnection facilities] for the sale of [electricity to any party other than the Distribution Company]." The 2026 Regulations further entrenches this regulatory hurdle, stating that “the prosumer shall not have any right to utilise the licensee's interconnection facilities for the sale of electricity to any third party.” Additionally, another critical point, and potentially a hindrance to the development of swarm grids, is the one stating that “a microgrid is not allowed to serve an area served by the host distribution company”. Though this is for microgrids, such a regulation essentially affords DISCOs the legal position and precedent to penalize P2P sales, should they feel so inclined.

These provisions, therefore, create fundamental regulatory barriers to swarm electrification. The fact that there is currently no clear legal framework that enables peer-to-peer energy exchange between neighboring users is just as compounding when it comes to creating a level playing field to realize swarm grids. As a result, the commercial and operational mechanisms that underpin swarm electrification remain largely absent from Pakistan's regulatory architecture. In a nutshell, the foundational commercial mechanism to motivate public or private interests in favour of swarm grids has no legal basis within the current regulatory framework.

8. On 9 February 2026, NEPRA notified the (Prosumer) Regulations, 2026 which took immediate effect and repealed the 2015 Net Metering Regulations in their entirety.

5

Conclusion: From concept to implementation

The solar boom in Pakistan indicates a major social, and economic shift. The ongoing revolution could become a rare policy moment to leapfrog renewable energy pursuit into one that delivers meta-dividends that go beyond basic power-generation - such as social equity and energy democratization, economic and local development, climate resilience and sustainability, and infrastructure evolution in keeping with local needs, from the standpoint of energy security and sovereignty. Pakistan's distributed solar expansion has created the physical preconditions for a more organised, resilient local energy system. The assets — panels, inverters, and in some cases batteries — are already deployed at scale. What the country currently lacks is the institutional will and support that would allow fragmented installations to function as a cohesive, shared network.

Swarm grids represent one potential pathway towards a sustainable energy eco-system both for Pakistan and its people. They are technically compatible with the installed base, do not require significant new capital investment, and could address several concurrent challenges including local reliability and equitable access by minimizing distribution-level inefficiencies. However, realizing this potential would require political will and regulatory intervention. As highlighted in the previous section, the existing framework pertaining to distributed energy resources explicitly prohibits the peer-to-peer electricity trading that swarm architecture depends on

The emergence of swarm electrification within the global and local context of energy scarcity, just and equitable energy transition and climate concerns raises questions that extend beyond the exigencies of technical interconnection within the power sector. If swarm electrification is to be enabled, it would necessitate frameworks allowing for peer-to-peer exchange and establishing pricing and settlement mechanisms for smooth operational responsibilities. It would mean developing frameworks for local energy sharing, peer-to-peer electricity exchange, and community energy networks to help unlock greater value from investments that consumers have already made, while supporting a more flexible and resilient electricity system.

The technical and economic case for enabling peer-to-peer energy trade is reasonably strong for Pakistan. The next stage of that evolution may require policymakers to move beyond a narrow focus on individual prosumers and begin considering how local energy communities, peer-to-peer electricity exchange, and decentralized energy networks can be accommodated within the broader electricity system. Pilot projects, regulatory sandboxes, and targeted experimentation could provide an important first step in generating the evidence needed to inform future policy decisions.

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