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Research Article

Renewable Energy-Based Distributed Generation in Pakistan: Status, Importance, and Electrification Opportunities

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Abstract

Renewable energy improves energy security, provides reliable power supply, and ensures fuel diversification. It also offers a solution to the problem of circular debt which has lately become a major concern for the power sector of Pakistan. At present, the share of renewable energy resources in the energy mix is significantly low and the Government of Pakistan (GoP) is urging the drivers and enablers to boost clean and green energy generation and distribution. The power sector, especially the distribution companies, are facing numerous issues in transmission and distribution of power, and recovery of losses. Distributed generation (DG) can play a vital role in overcoming these issues. The effectiveness of solar PV systems, the active role of the capital market, and environmental concerns are among the major factors that prompt the adoption of net-metered solar systems. Apart from traditional alternate energy sources through sunlight and wind, Pakistan has enormous potential for biomass fuel if it could develop proper facilities for biomass-based electrification. For issues related to grid coverage and technical losses in far-flung rural areas, mini-, and micro-hydro power-based distributed generation can serve the purpose. Distributed generation can play a vital role in steering the national power sector toward power sources that offer clean, green, and cheap energy. Huge opportunities for prosperity in rural areas can be also created through carbon-free atmosphere and a sustainable energy sector.

Keywords: Renewable Energy, Power Generation, Distributed Generation, Solar Electrification, Biomass Fuel, Hydropower Stations, Rural Electrification.

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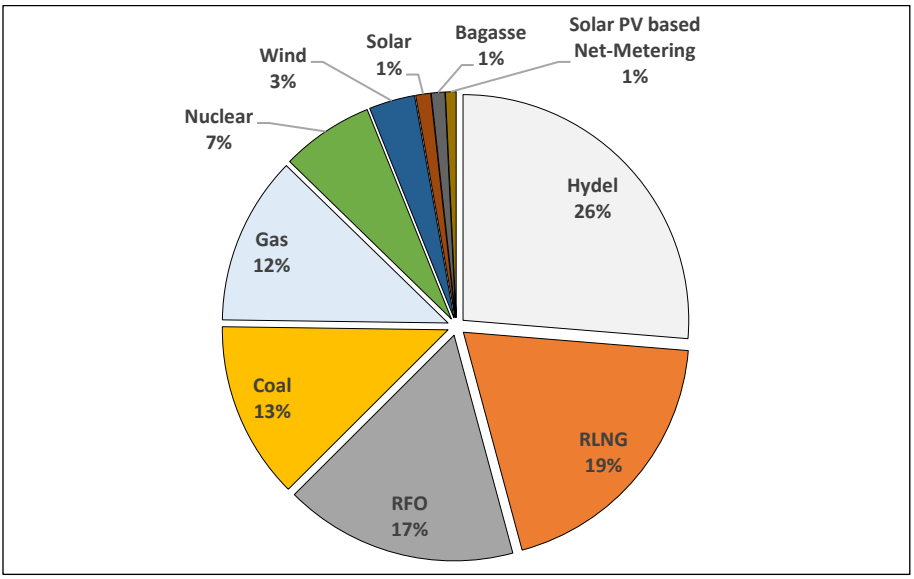
Introduction

The electric power generation in Pakistan is mostly reliant on the conventional power plants that are based on fossil fuels, and categorized in the settlement of *take or pay* mode. While the energy mix also constitutes mega-hydro power generation facilities, the share of solar, wind, and biomass technologies remains significantly low. The modern technological advancements have also demonstrated the feasibility of geothermal, tidal, waste-to-energy, and gasification methodologies suitable for grid electrification, yet their integration requires maturity of the technical integration techniques, based on generation facilities and the distribution utilities.

The power sector of Pakistan has a long-standing issue of circular debt,[1] which arises due to the capacity payments to the independent power producers (IPPs).[2] The technical transmission and distribution losses aside, the inability to recover the energy charges from the consumers is another issue faced by the power sector. While Pakistan has seen an exponential increase in the generation capacity during the last decade,[3] major rural areas are still facing electricity shortfall due to the lack of power distribution infrastructure and non-compliant recovery rates, which is a major problem faced by almost half of the rural population.

Pakistan aims to increase the share of renewable power generation by 25 percent by the year 2025 and further to 30 percent by the end of this decade.[4] To realize the integration of renewable energy sources, National Electric Power Regulatory Authority (NEPRA) has allowed and supported the installation of grid-tied roof-top solar photovoltaic (PV) systems, which have significantly increased during the year 2021.[5] Further, the captive power generation from the bagasse—i.e., sugarcane residue—and implementation of solar and wind-based independent power plants are also being adopted. Still, the share of solar, wind, and biomass accumulatively accounts for 5.36 percent as per the installed capacity in the national grid.[6] With this, the adoption of distributed generation (DG) based net-metered solar systems is on the rise, with a total capacity of 398 MW till March 2022.[7] The status of the fuel-wise installed capacity is demonstrated in Figure 1 below.[8]

Figure 1: Fuel-Wise Installed Power Generation Capacity in Pakistan (2022)



Source: National Transmission & Despatch Company, Gop, "Energy Resources in Pakistan."

The share of energy generation into the national grid from renewable energy sources (solar, wind, and biomass) is significantly low compared to thermal-based power generation. Energy generation from renewable sources stands at around 2.23 percent, while thermal power plants contribute 60 percent; while the mega hydropower stations make a contribution of around 30 percent to the energy mix.[9]

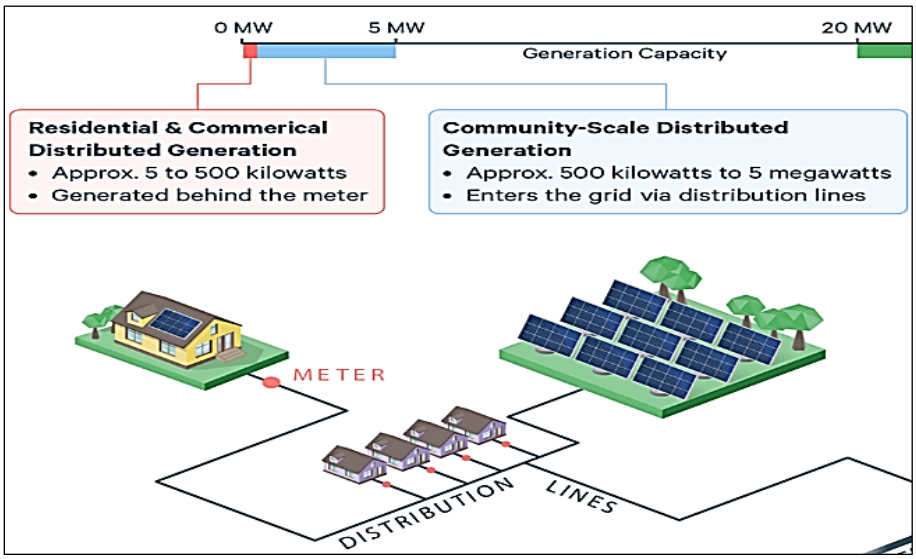
To efficiently enhance the share of renewable energy sources in the mix, the Government of Pakistan (GoP) is emphasizing the development of clean energy. With the imminent and already obvious concerns of climate change and high generation costs, the tilt towards the development of clean and cheap energy projects has been evident. The significance of reliance on renewable energy leads to more energy security, cost-effectiveness, and penetration of investments. The GoP is emphasizing upon the drivers and enablers of green energy to boost market orientation in favor of its adoptability.[10] Still, there are certain areas where practical measures are lacking.

This paper shows the importance of decentralized and distributed power generation, which is based on renewable energy sources and is aimed at cheap and clean electrification. Pakistan has significant potential for solar, wind, biomass, and hydropower generation, which is the focus of this paper for its distributed generation. DG facilities can be defined as the utilization of small, integrated/ standalone energy-producing units which are installed in the proximity to the load centers. While the consumers of the grid are opting for electricity generated through the scheme of solar-based net metering, this paper gives an appraisal of the progress in the installation of roof-top solar systems with the associated economical levers. Further, the distributed generation methods based on biomass have been discussed which are potentially viable for rural communities and electrification in the non-compliant areas of the grid infrastructure. The electrification methods based on mini and micro-hydropower are mentioned for the facilitation of the far-flung communities in the mountainous regions. The distributed generation based on renewable energy sources also faces some barriers, which are assessed in the later section while policy recommendations are proposed for the proper uptake of these electrification facilities.

Distributed Generation Based on Renewable Energy Sources

The distributed generation facilities are usually connected to the distribution utility and provide energy at the point of connection where the low voltage grid infrastructure is available. Categorically, the distributed generators can be divided into '*behind the meter'*, and '*front of the meter'* installation.[11] 'Behind the meter' installation is majorly governed by the tariff regime of net-metering and net-billing, which have been instrumental in driving the consumer of the grid towards the adoption of clean and cheap renewable energy. The 'front of the meter' installation is usually suitable for community-scale electrification of the society, which can include industrial zones, commercial enterprises, military zones, and college/university campuses. Figure 2 demonstrates the technical definition and configuration of categories of DG facilities that can be incorporated.[12]

Figure 2: Behind the Meter and Front of Meter Installation



Source: Cleary and Palmer, "Renewables 101: Integrating Renewable Energy Resources into the Grid."

Importance and Significance of RE-Based DG Facilities

Some of the crucial problems faced by the power sector of Pakistan are associated with inefficiencies in the power generation and distribution sector despite enhanced power generation capacity in the country owing to the immense potential of RE. To overcome this gap, interventions and policy directives are much-needed especially in reducing the burden of circular debt, making improvements in the power distribution sector, and bringing in electrical power to the far-flung rural commodities without the grid access. In this context, the DG facilities based on cheap and clean power generation mechanisms are projected to address some key issues.

Pakistan is blessed with several renewable energy resources that can be utilized for power generation. On the one hand, high mountain ranges and glaciers surround the northern regions of Pakistan, which are best suited for installing mini and micro-level hydropower projects.[13] On the other hand, plains and desert surfaces receive abundant sunshine and are ideal for exploiting solar energy, while Southern provinces—Sindh and Balochistan—have rich resources for wind energy. Pakistan being an agricultural country has huge amounts of agricultural residue produced by sugar, rice-refining, and

other agro-industries, which can also be optimized for clean and cheap energy generation.

The energy crisis has been a major impediment to Pakistan's economic development, and the DG of renewable energy technologies seems to offer the solution i.e., cheap, clean, and green resource. Devising effective policies and plans along with efficient governance to undertake extensive plans of DG of renewable energy can prevent large-scale power outages and steer the country towards progress. Many factors have to be considered in developing a reliable policy, such as energy demand and effective project management.

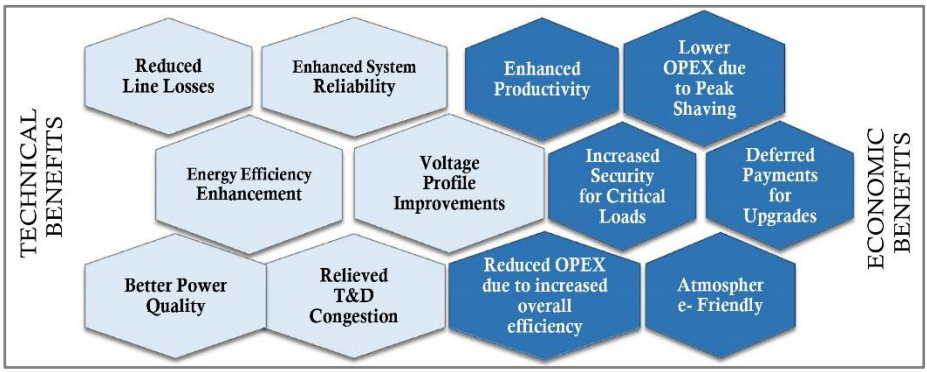
Among the measures for efficiently increasing renewable energy generation, the liberalization of the local electricity market is crucial. Facilitating power generation business in a competitive environment can help resolve the longstanding problems of electricity shortage. The issues related to the inefficient infrastructure of the power distribution companies (DISCOs) can also be addressed by incorporating DG. In this context, a 2021 study by NEPRA assessed the performance of four DISCOs across the country, namely Hyderabad Electric Supply Company (HESCO), Quetta Electric Supply Company (QESCO), Sukkur Electric Power Company (SEPCO), and Tribal Areas Electric Supply Company (TESCO) and revealed inconsequential losses comprising of technical high-loss infrastructure and inadequate recovery rates.[14] Also, these DISCOs have uneven geographical distribution amid the integration of DG facilities.[15] The table 1 below demonstrates the technical and recovery losses with the financial fallout encountered due to these issues.[16]

Table 1: Technical Losses in PESCO, HESCO, SEPCO, and QESCO and Financial Fall-out in Amount

DISCOs	**Reported Losses (%)**	**Financial Cost of Losses (Rs. Millions)**
PESCO	38.18	32,280.01
HESCO	38.5	22,844.30
SEPCO	35.27	10,017.92
QESCO	27.92	13,309.39

Source: National Electric Power Regulatory Authority, GoP, *Performance Evaluation Report of Distribution Companies of FY 2020-21*.

Figure 3: Technical and Economic Levers for Distributed Generation based on Renewable Energy Sources

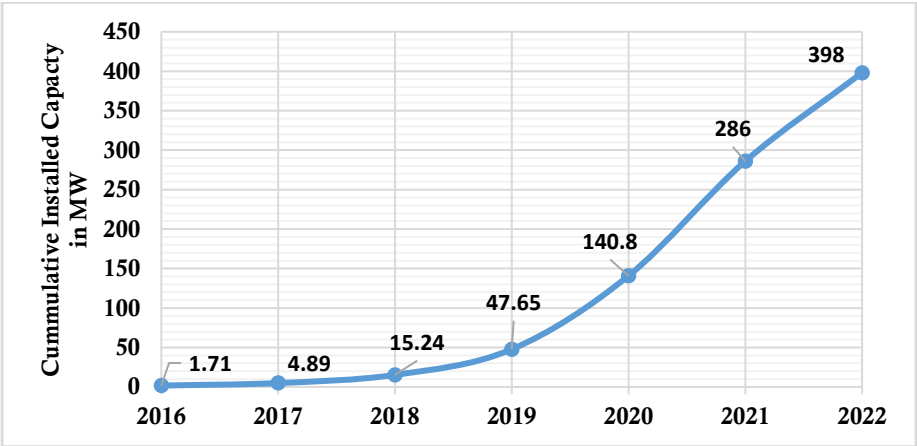


Source: Authors' own.

To reduce the impact of the issues of technical and recovery losses, the concentration of DG facilities can be enhanced towards business models and the incentivized schemes, which in turn can also be very beneficial to address the technical and economic fallout of the issues associated with the distribution companies.[17] Figure 3 demonstrates some of the technical and economic benefits which can be obtained by the integration of DG. Some of the factors that encourage the incorporation of DG facilities are:

a. They facilitate a clean and green environment.
b. The installation and commissioning of distributed power generation facilities require less infrastructure and time.
c. The generation facilities attract the investor's interest in project development and offer adequate returns.
d. The installation of the power generation facilities near the load centers reduces the congestion in the transmission system and minimizes the impacts of technical transmission and distribution losses.

Figure 4: Cumulative Grid-Connected Solar PV Systems (2016-2022)



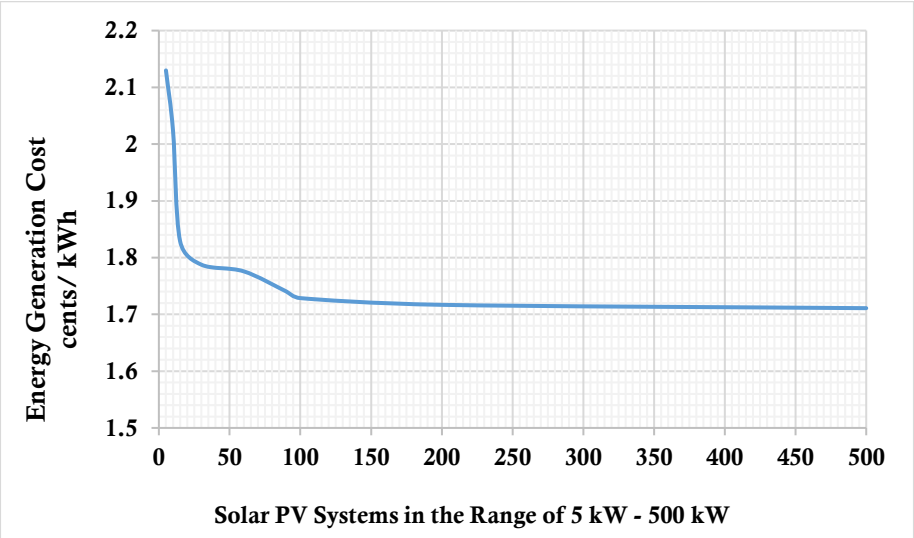
Source: Prepared by authors from data taken from Alternative Energy Development Board (AEDB) till March, 2022.

Appraisal of Solar PV Based Distributed Generation in Pakistan

With the ambitious motives of the renewable energy adoption by Pakistan, the facility of grid-tied solar PV systems was allowed in 2015 through NEPRA (Alternative & Renewable Energy) Distributed Generation and Net Metering Regulations. Such systems have demonstrated a significant rise in the year 2021. Some of the drivers of high uptake are: cost-effectiveness of the solar PV technology, independence from the costly grid energy, and environmental aspects.[18] The incentivized schemes other than net-metering are non-existent, which, if introduced, might have caused further uptake of RE in the country. The primary driver of installing net-metered solar PV systems has been the rising power tariff, where the cumulative capacity has been raised to 398 MW.[19]

Furthermore, concise on-site construction, cost-effectiveness of solar PV systems, active role of the capital market and environmental concerns are other factors that have contributed in the adoption of net metered PV systems. To assess the cost-effectiveness of grid-tied PV systems, it is projected that the returns on investments ranging from 390 percent to 500 percent can be achieved with a payback period of 3.2 to 4.1 years.[20] Figure 5 shows the energy generation cost which is incurred by the PV systems in the range of 5-500 kW.

Figure 5: Energy Generation Cost of PV systems (cents/ kWh) (2021)



Source: Authors' own.

Opportunities in Biomass to Energy Conversion Techniques

Pakistan has been richly endowed with biomass resources with an estimated energy potential of 0.5 million GW/year.[21] The country has currently biomass power plants, constituted as 'captive co-generation' where bagasse is used as fuel with a cumulative capacity of 400MW.[22] Being an agricultural country, it has an enormous potential where the residue of crops can be efficiently used for power generation through incineration and gasification of the biomass. The table shows the assessed quantity and prices of the agro-industry biomass fuel in Pakistan.

Table 2: Biomass Quantity Assessed and Prices of Different Fuels in Pakistan (2019)

Fuel Source	Assessed Quantity	Price per Tons	
Bagasse	2.4 million Tons per year	Rs. 4500-5000/Ton	$ 28 Per Ton
Rice Husk	1.3 million Tons per year	Rs. 8000-9000/Ton	$ 45 Per Ton
Corn Cobs	Not assessed	Rs. 7500 /Ton approx.	$ 42 Per Ton
Wheat Straws		Rs. 12000/ton approx.	$ 68 Per Tons

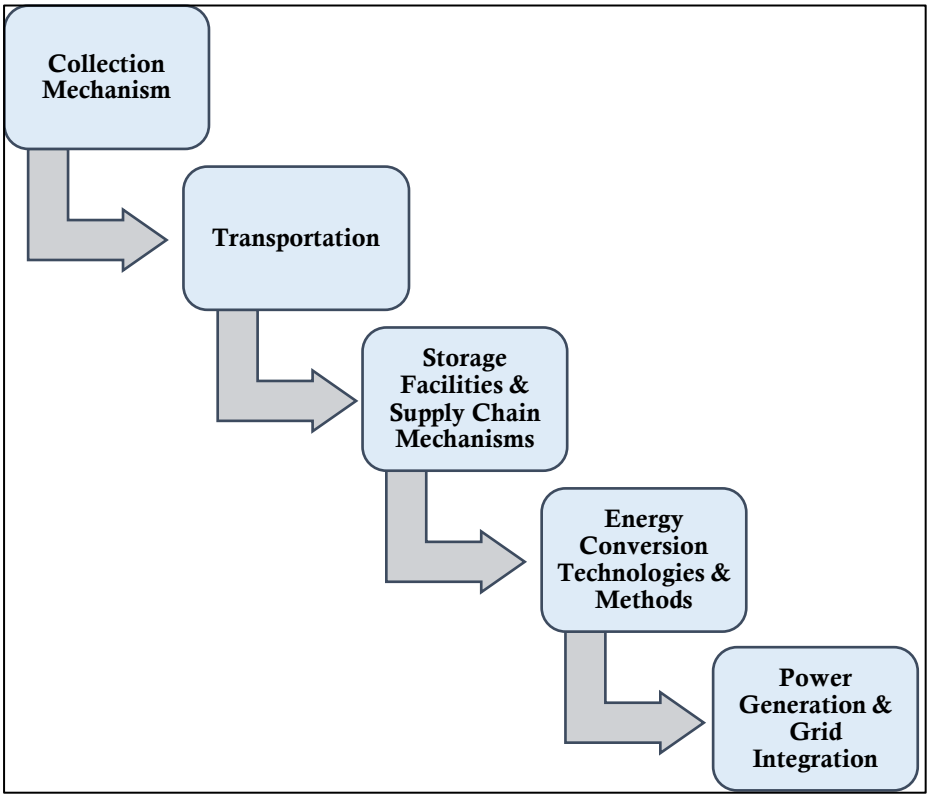
Source: Assessed and recorded by authors from country-wide surveys and interviews with biomass traders

Agricultural residue such as stalks, straws, agri-trash, rice husk, shells, woodchips, barks, and trims are some of the abundantly available fuels. The biomass fuel can further be classified into *agri-industry residue* and *agri-crop residue*.[23] The agro-industry residue is leftover after the processing of food crops through industrialized techniques and is more commonly acquired from the sugar industry, and rice and corn processing units. On the other hand, the agri-crop residues are the leftovers of the crops from the fields. Wheat straws, crop stalks, woodchips, and barks are common examples.

Renewable energy electrification through biomass fuels has experienced some barriers in Pakistan. As biomass fuel requires adequate collection and transportation techniques, their development is an urgent requirement. Figure 6 demonstrates the electrification methodology for the biomass energy conversation techniques.

This has been implied from the detailed field visits that the availability of the proper collection facilities is crucial for biomass-based electrification. The collection centers link up the trade of biomass from the primary source of production to the biomass power plants. Biomass collection centers, exclusively for the collection of fuels, rarely exist in Pakistan. These facilities can offer better economic levers for the rural community as well as the population of the area where such installation is projected.

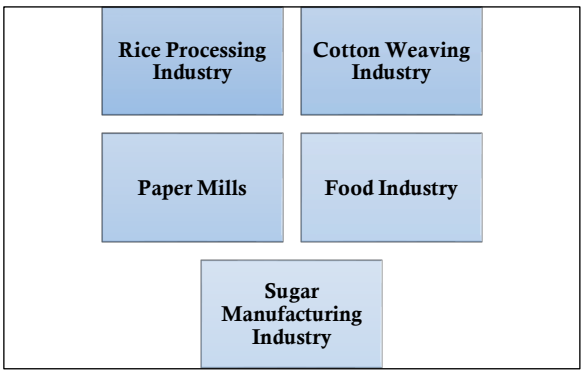
Figure 6: Electrification and Power Generation Methodology through *Biomass Fuels*



Source: Authors' own.

The potential alternate electrification of many associated industrial sectors and small and medium enterprises (SMEs) can be realized by the adoption of biomass. The biomass fuel resource can be adequately utilized for the industries where the biomass is sufficiently produced and processed, rather it converges biomass to energy generation without the requirement of collection methods. Some of the sectors where biomass-produced power can be used are mentioned in Figure 7.

Figure 7: Industrial Sector Potential to Adopt Biomass Fuel-Based Distributed Generation



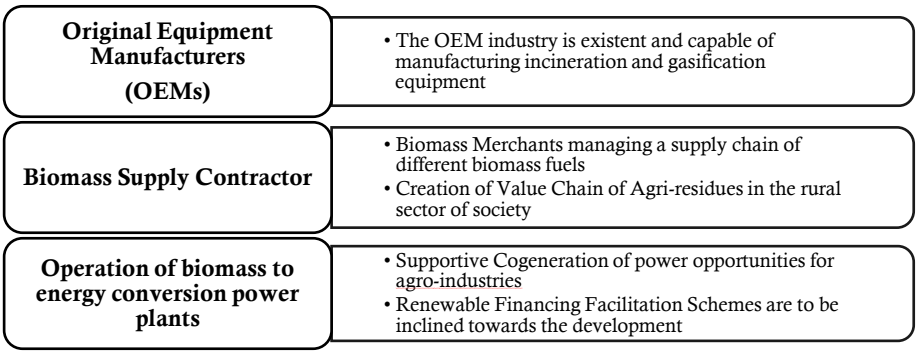
Source: Authors' own.

Market Prospects and Commercial Viability

The biomass fuel can be utilized and processed through two combustion techniques, i.e. incineration and gasification.[24] Both the conversion techniques require burning fuel, which provides enough heat energy to produce electric power. The exhaust heat energy after the power generation can be efficiently utilized for the operations of combined heat and power (CHP) mechanisms. The industries with the CHP generation have the ideal alternative to fossil fuels –where the less carbon enriched biomass fuel can be burnt. The commercial viability of the biomass-based energy generation facilities is dependent on the association of engineering advancement, market orientations, fuel supply chain and collection, and policy framework. Figure 8 shows the role of necessary ingredients for biomass-based energy generation mechanisms.

Biomass fuel is a green and suitable alternative for CHP cogeneration in industries. The industrial sector is already dependent on fossil fuels, which can be replaced with biomass fuels with some technological advancements. The rural commodities located in the non-compliant areas with the issues of technical losses and inadequate recovery rates can be efficiently electrified through the biomass sources. The implementation of biomass-based power generation facilities near the load centers of the rural areas shall decrease the losses which incur due to the power dispatch and shall increase the reliability.

Figure 8: Biomass-Based Distributed Generation: Role of OEMs, Trading, and Operations



Source: Authors' own.

The power generation facilities based on biomass have a high ramp rate and capacity factor. This implies an increase in energy security and shall improve the electrification and grid support. Due to the indigenous manufacturing of the equipment and production of the fuel, the overall generation cost is very minimal compared to the other conventional sources. Author estimated that the cost incurred was around 4.3-5.9 cents/kWh in 2019, which made this source of energy cheap and cost-effective.

Prospects of Mini- and Micro-Hydropower-based Distributed Generation

The segregated populated areas in the mountainous regions of Pakistan face issues in electrification in terms of inaccessibility and inefficient grid infrastructure, which enhances the technical losses.[25] In this context, the installation and implementation of the generation facility near the load centers create electrification opportunities that can provide a sustainable solution for the rural communities.

The populated areas in the mountainous regions of Pakistan are ideally suited to be fed by the utilization of small and medium-sized hydropower stations. It is estimated that about 60 GW of the power capacity potential is existent in Pakistan.[26] The table 3 below demonstrates the potential assessment of sites suitable for mini-hydro and micro-hydropower stations.[27]

Table 3: Potential Sites and the Capacity for Power Generation from Micro Hydropower and Mini Hydropower Plants

Province	Total Potential for Distributed Hydropower Stations (MW)	Potential Strengths for Implementation	No. of Potential Sites
Khyber Pakhtunkhwa	750	Small / Micro based on Natural Falls / Flow	125
Gilgit Baltistan	1300	Natural Falls	200
Azad Jammu & Kashmir	280	Natural Falls	40

Source: AEDB, "Potential and Progress in Small Hydropower."

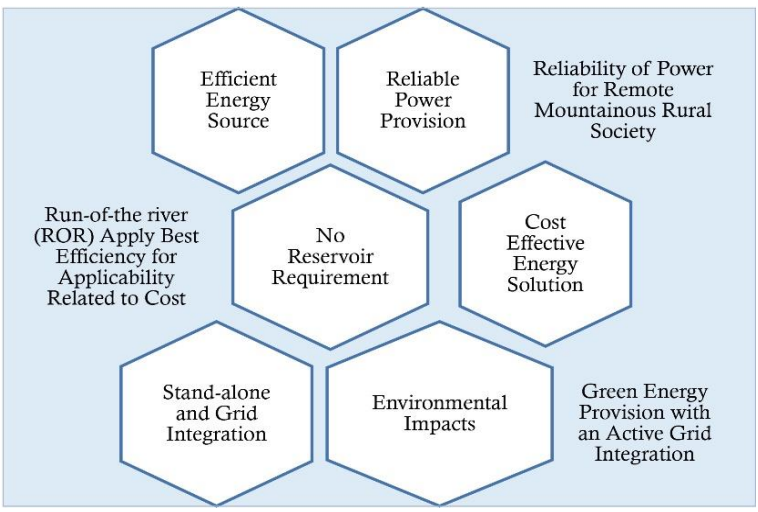
The hydropower-based DG is possible in two categorical arrangements; installation of mini-hydropower (100-500 kW capacity) and micro-hydropower (5-100 kW capacity) facilities. Both of these arrangements do not require the construction of reservoirs and dams for the operation, rather they can be operated on the run-off river. The technical configuration of the mini- and micro-hydropower stations allows the integration with the utility grid. Mini-hydropower facilities can feed the power into the grid at 11 kV or a greater voltage, and may also act as the generation facility for either standalone or grid-connected systems. Mini-hydropower for community-based electrification has enough potential to partially reduce power shortage if implemented properly; both community, as well as the distribution utility, can take steps for its promotion. On other hand, segregated installation of micro-hydropower station facilitates the power generation for standalone systems, like agricultural installations, cottage industries, and small communities of the rural population. The power generation can be carried out at low voltages, requiring a cost-effective configuration of technical setup. This installation technique is ideally suited for the villages and far-flung populations in the mountainous regions where the grid accessibility lacks.

Some of the coverage areas of the distribution companies in the mountainous regions have low voltage transmission and dispatch systems.[28] This leads to an increase in technical losses. The infrastructure is also responsible for the inadequate power quality. This causes economic fallout on the consumers as well as the distribution companies. To address the technical issues and provide an uninterrupted and secure power supply, the proposed

installation is ideally suited. Certain remote communities are not accounted for bill recovery due to the resource constraints of these populations. In fact, subsidies are poured in to support such areas. In such cases, it is likely that these areas do not receive adequate power provision and the electric supply is interrupted to decrease losses. To efficiently cater to these issues with rural electrification, distributed generation near the load centers decreases the technical losses and manages the billing mechanism.

The hydropower generation facilities can be ideally suited for peak-shaving of the maximum demand during the summer season as they offer maximum capacity output. The efficiency of the hydropower facilities is considered to be adequate in terms of technological and economic options for rural electrification.

Figure 9: Drivers Behind Applicability and Adoption of Hydropower-Based Distributed Generation



Source: Authors' own.

Barriers Surrounding the Distributed Generation Uptake

With the promise of sustainable development models, renewable energy-based distributed generation has gained importance worldwide. In Pakistan, due to a set of hiccups, the required push for the promotion of renewable energy from distributed generation is lacking. The common barriers and the obstacles have been assessed to facilitate the renewable energy uptake, and are provided below:[29]

Technical Issues with the Integration of Distributed Generation Facilities

The issues related to technical integration techniques of the distributed generation facilities with the grid call for attention. The resources available with the grid infrastructure are obsolete and pose barriers to technical connectivity. Furthermore, the lack of awareness and methodology for the installation is another issue. The requirements for improvements in grid infrastructure and amendments in grid codes are mandatory for the successful integration of distributed generation facilities at respective nodes.

Inertia of DISCOs

One of the major barrier related to the promotion and uptake of these generation facilities lie in the inertia of the distribution companies. It is falsely believed that the distribution companies would be facing more financial shortfall if the power is fed by the distributed generation. Whereas in reality, it would be beneficial to them as it would bring cost-effective and cheap energy to the utility grid. Moreover, the dependence on the expensive fossil fuel-based generation could be reduced if enough capacity for distributed generation can be integrated with the grid.

Financial Barriers and High Upfront Costs

One of the most pressing barriers is the high upfront cost associated with developing and commissioning technologically advanced facilities. To overcome this barrier, the financial support for the development of renewable energy sources has been planned by the government through the State Bank of Pakistan financing schemes for renewable energy. However, the adoptability rate of these schemes is yet to be seen.

As the major component of the equipment is imported, cost overruns may occur in project development for which the financial instruments are mandatory for proper uptake.

Lack of Reasonable Planning

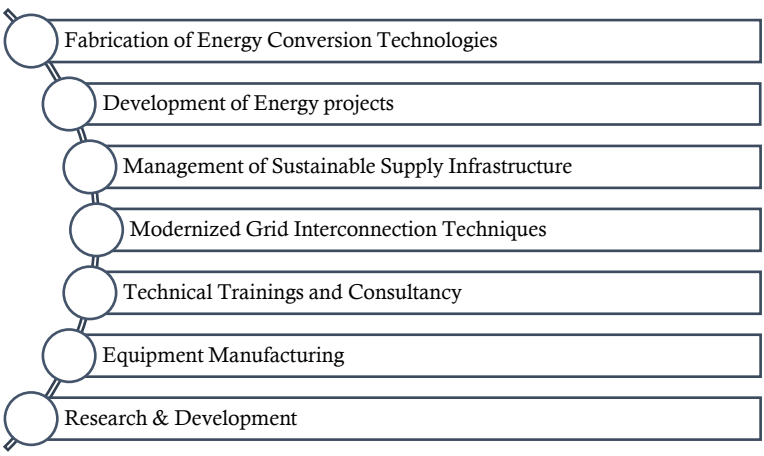
The planning for overcoming the shortfall of power had been tilted towards the installation of mega-power generation plants, where no interest had been lent towards community-based and distributed generation facilities. With the improvements in the market dynamics of renewable energy sources, Renewable Energy Technologies (RETs) have proven to be cost-effective for which the integration of these sources is needed to be planned and mapped for

the areas where these facilities can decrease the impacts of losses, inadequate rural electrification, and power quality.

Lack of Incentive Regimes and Policies

There is an eminent requirement to develop the policies and incentives for the uptake of renewable energy amid the distributed generation. The only available regime of net-metering is facilitating the solar-based distributed generation, while the inclusion of feed-in tariff (FIT), BOOT model, and third party framework shall create more opportunities. The business opportunities are lacking in this regard where the liberalization of the power markets would boost the distributed generation uptake.

Figure 10: Business Opportunities Through the Distributed Generation Mechanisms



Source: Authors' own.

Electrification Opportunities and the Way Forward

The need for public-private partnerships is an essential element where lucrative business opportunities can arise. For proper and efficient utilization of distributed generation-based infrastructure, an insight into energy demand, effective project management, and forecasting of future demand based on past trends, require attention.

The development of renewable energy projects will improve energy security, environment, economy, mechanical manufacturing, construction, transportation, and industry, as well as help to create new jobs. Solar, wind,

and biomass energy can meet local energy needs while helping to improve environmental indexes. Modernized grid interconnection techniques to boost distributed generation via small-integrated energy units can help the country address its energy crisis. Technical training and consultation are required in the field of renewable energy to investigate, understand and develop the technical mechanisms properly. And finally, indigenous research, development, and manufacturing techniques are required in the field of renewable energy, in addition to spreading awareness of its applicability.

Notes

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[14] National Electric Power Regulatory Authority, GoP, *State of Industry Report 2021* (Government of Pakistan, 2021), https://nepra.org.pk/publications/State%20of%20Industry%20Reports/State%20of%20Industry%20Report%202021.pdf.

[15] Through the concentration of the net-metered PV systems, it is evident that the solar prosumage has been concentrated only in resourceful society of the country, rather the installation lacks in the high-losses areas of four distribution companies.

[16] National Electric Power Regulatory Authority, GoP, *Performance Evaluation Report of Distribution Companies of FY 2020-21* (Government of Pakistan, 2021), https://nepra.org.pk/Standards/2022/NEPRA%20PER%202021%20Distribution%20Companies%20.pdf.

[17] Since distributed generation facilities are installed at the proximity of the load centers, it reduces or eliminates the 'line loss' (wasted energy) that happens during transmission and distribution in the electricity delivery system.

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[28] The northern areas of Pakistan are required to be electrified through the low-voltage network, due to less population density.

[29] The assessment has been made by the authors themselves through various consultative dialogues, meetings, interviews and sessions with National Electric Power Regulatory Authority (NEPRA), Alternative Energy Development Board (AEDB), GIZ Pakistan and various distribution companies.