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Article

Wind energy in Pakistan: progress, gaps, and road maps

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Abstract: Pakistan has a significant supply of wind energy, especially along the south coast; the country has been using the marginal resources, but no large-scale utilization has taken place as compared to its potential. This review is a critical analysis of wind energy development in Pakistan that has synthesized wind resource evaluation, deployment patterns, grid integration issues, and policy frameworks. As a contrast to the previous descriptive research, the article methodologically compares the estimates of the major wind potentials, examines the sources of methodological differences, and evaluates the uncertainties within the current available assessments. Based on peer-reviewed literature, reports on technical reports, and policy documents from 2000 to 2024, the review concludes that overall theoretical wind potential can be estimated at an approximate 50 GW to more than 130 GW, whereas realizable potential faces constraints as a result of grid bottlenecks, financial risk, and institutional fragmentation. Comparison to the chosen emerging wind markets, India, Egypt, and Morocco, provides a context in which Pakistan has performed and lessons which can be transferred in terms of policy and system integration. The paper ends with a synthesized roadmap that highlights grid modernization, policy uniformity, and grid diversity of deployment areas to be able to support wind energy in playing a role in the long-term energy security and decarbonization goals of Pakistan.

Keywords: wind energy; Pakistan, renewable energy; grid integration; policy and regulation

1. Introduction

The world's move towards clean and renewable energy has been on the increase, considering the growing worry of climate change, air pollution, and long-term energy security. Wind energy is unique among the renewable sources as it is mature and can be scaled, and has a cost competitiveness that is improving at a rapid rate. Wind power is one of the avenues that the developing nations that have an immediate energy requirement might consider viable, especially in countries like Pakistan, where the demand to increase power generation capacity, decrease reliance on imported fossil fuels, and alleviate environmental and health effects caused by traditional power generation are highly urgent [1].

The power sector in Pakistan is characterized by consistent problems due to the excessive demand, the reliance on imported fossil fuels and financial shocks, and the rising climate exposure. Power demand has been increasing consistently within the last 20 years due to the growth of population, urbanization, and industrialization, and domestic generation has been failing to keep pace. Consequently, Pakistan is still extensively dependent on imported oil, liquid natural gas, and coal, which subjects the economy to the volatility in fuel prices and balance of payment strains.

In this regard, renewable energy, specifically wind power, has become a strategic choice towards improving energy security and minimizing the emission of greenhouse gases. Pakistan has been blessed with large wind energy potential, particularly along the coastal strip in the south. The most promising location has been determined as the Gharo Jhimpir Wind Corridor in the Sindh Province: initial resource mapping surveys indicated a gross potential of $\approx$ 43,000 MW in the 9700 km² Wind Corridor due to an average wind speed of more than 7 m/s at an approximate 80 m hub height—conditions which are generally deemed suitable for commercial onshore wind farms [2–4]. Recent evaluations of the towns of Gharo and Jhimpir validate the feasibility of the region: the average annual wind speed is preferable, and the monthly average speed is more than 9 m/s [5]. With this possibility, it can be anticipated that wind energy will be a significant component of Pakistan's electricity supply. By 2025, however, the installed wind power in the country is still quite small: approximately 1.8 GW of wind power in 36 or so (primarily privately owned) wind farms that are in operation in the Gharo Jhimpir region [6, 7]. Though this has improved, wind energy still represents a small percentage of the national electricity mix.

This is only a small percentage of the theoretical capacity of this corridor. In fact, the estimates indicate that over 50,000 MW may be generated under ideal conditions [8]. The contribution of renewables (wind, solar, hydro, biomass, and so on) was merely 6.8% of that capacity [9]. Wind makes a significant but achieved portion among renewables. The recent data from the International Renewable Energy Agency (IRENA) suggests that the contribution of the wind capacity in Pakistan is approximately 1845 MW [10]. The gap between the potential deployment and the actual deployment begs important questions: Why has Pakistan not exploited the enormous potential of wind? What have been the technical, economic, institutional, and infrastructural obstacles to exploitation? And, above all, what strategy can be used to bridge the distance between the present humble use and the vast potential that the corridor has?

There is a large amount of literature covering the potential of wind resources in Pakistan, the policy environment, and implementation issues [7]. Nevertheless, current research tends to provide very divergent estimates of wind potential, has a diverse methodology, or addresses limited technical or policy aspects. This leaves a need to have an integrative and critical review that can synthesize existing evidence, identify sources of uncertainty, and place the experience of Pakistan in the wider context of other countries in the world.

To fill these gaps, the paper seeks to (i) critically synthesize wind resource estimates and justify the variation between reported potential estimates; (ii) track the historical development and the present state of wind energy rollout; (iii) analyse grid, financial and policy constraints to large-scale integration; and (iv) contextualize the wind energy development of Pakistan by comparison to selected emerging wind markets. In so doing, the paper aims to give a balanced and analytically sound evaluation of the role that wind energy can play in the future power system of Pakistan.

We then begin with the overview of the state of the Pakistani wind energy resources in the sections that follow: we give an overview of the geography, climatology, and resource potential to put the size of the opportunity into perspective. Next, we follow the historical and recent developments in the deployment of wind energy, pointing out milestones and technologies as well as capacities. We then discuss the facilitating factors behind the small growth of the sector to date, and then move on to a critical problem analysis of the obstacles and constraints that have persisted. Based on that analysis, we offer a future roadmap and policy recommendation that is set to unlock the full potential of wind energy in Pakistan. Lastly, we consider how expanding wind power relates to the energy security, economic resilience, and sustainability of Pakistan, as well as the sustainability of the environment. Through this detailed, current synthesis, we trust the review will be of benefit to researchers, policy makers, investors, and other interested parties, and provide a realistic yet ambitious roadmap of how to ensure a cleaner, stronger energy future for Pakistan.

2. Methodology

This is the review that takes a systematic narrative synthesis methodology to review the state of wind energy development in Pakistan. Scopus, Web of Science, IEEE Xplore, ScienceDirect, and Google Scholar were used to gather peer-reviewed journal articles, conference papers, technical reports, and policy documents. Owing to the policy-based and practical nature of the topic, official grey materials of organizations like the International Renewable Energy Agency (IRENA), World Bank, Asian Development Bank, Alternative Energy Development Board (AEDB), National Electric Power Regulatory Authority (NEPRA), and National Transmission and Dispatch Company (NTDC) were also included [11].

The literature review ranged between 2000 and 2024, which is the time frame when wind resource evaluation and commercial wind energy were developed in Pakistan. The search terms were the combinations of wind energy Pakistan, GharoJhimpir wind corridor, wind resource assessment, grid integration, and renewable energy policy. Articles were incorporated when they (i) reported a quantitative measurement of wind resources or potential, (ii) studied wind power implementation or system interlocking, or (iii) policy, regulatory, or financial models of wind energy in Pakistan. Research was filtered out when it had no methodological transparency, was operating within small and off-grid applications only, or had simply duplicated previous analyses with no new contributions of substance.

In order to allow cross-studies comparison, wind potential reports were classified based on hub height, turbine density assumptions, spatial coverage, as well as land-use limitations. This classification made it possible to conduct a clear evaluation of uncertainty and methodological deviation across the research, and this is one of the main analytical contributions of this review [12,13].

3. Wind energy potential in Pakistan

3.1. Geographic and meteorological suitability

The wind power resources of Pakistan are geographically dispersed, and the most viable conditions are located along the southern coastal stretch, stretching through Sindh and some Balochistan [14]. A combination of a coastline, relatively low topography, and enduring large-scale patterns of atmospheric circulation are advantages of this region, leading to the development of wind regimes conducive to utility-scale wind power production.

The most researched and most commercially exploited is the Gharo Jhimpir Wind Corridor in Sindh [15]. It is found within a range of approximately 60–170 km east of Karachi and is the most promising onshore wind in the region. It has been identified [7]. The strategic value of it is based on the wind source on one hand but logistical factors on the other, such as relative proximity to existing transmission systems, road access, and industrial load centers. These are non-resource issues that have been highly important in determining early patterns of development of the project and still affect site selection.

In meteorological terms, the south Pakistani wind systems are characterized by seasonal pressure differences in the monsoon system of South Asia and also by the land-sea thermal difference along the Arabian Sea coast. Such processes help to maintain the wind flows throughout a large part of the year, and faster wind speeds are usually recorded in the months of May to September. Nevertheless, the interannual and seasonal variability has great value, and long-term datasets are important to describe the wind resources. Other coastal and near-coastal areas have been reported to be promising in Sindh. Recent feasibility studies (2022) have been conducted in Karachi, Thatta, Badin, and Jamshoro, at which the locations were also determined to be conducive to large-scale wind power generation in the wind speed and density profile [16].

Meteorologically, the regimes of wind in the southern part of Pakistan are related to the seasonal differences in pressure gradients, which relate to the South Asian monsoon system, and to the thermal differences between the land and the seas along the coast of the Arabian Sea. These processes are associated with year-long sustained wind flows, and faster winds are normally experienced between May and September. Nevertheless, interannual and seasonal variability is still important, and it is important to note that long-term datasets are important when describing wind resources.

In general, the coastal areas of Pakistan have positive geographical and climatic conditions to develop wind energy, and its spatial concentration is a combination of the quality of resources and the confidence of the data, as well as the limitations of the system itself, and not the distribution of resources. This difference is vital for the understanding of when the nationally available wind potential estimates and further extension beyond current routes are under consideration [17,18].

3.2. Wind resource characteristics

The characteristics of wind resources in the major wind zones in Pakistan have been measured using a mix of ground-based measurements, remote sensing, and numerical models. Of these, the most empirically sound to be applied in describing the behavior of the wind are the mast measurements performed in the Gharo-Jhimpir corridor, which are then extrapolated to larger spatial scales using mesoscale modeling. A report issued by a leading international energy agency indicated that the theoretical wind potential found in the southern provinces (Sindh and Balochistan) alone is in excess of 50 GW [19].

More advanced methods are usually used to estimate national potential. As an example, the 2025 estimate of the potential of wind in Sindh indicates that the overall capacity of wind energy generation in the nation may reach 132 GW at an installation density of 5 MW/km^2 in the most appropriate locations [16]. In the meantime, an earlier estimate indicates that the gross potential of the Gharo-Jhimpir corridor is approximately 43,000 MW, a figure on which policy and planning have so far been based [7].

A larger source, representing a more national outlook, estimates national realizable capacity at 131,800 MW, which is calculated by onshore projects and (where feasible) offshore or coastal ones, with maximum use of the resources and optimal deployment environment [20]. It is worth noting that according to other authors, under a high resource situation scenario, the coastal belt would be capable of producing a considerably large amount of electricity annually at full capacity, and this would be way above what the country is presently using as power. One such case is a feasibility study providing a potential of 212 TWh/year of the coastline, which would exceed and surpass twice the production of the traditional power sources available to the country then [16].

This is the potential that varies by tens of GW installed capacity to hundreds of TWh/year generation, and it emphasizes the fact that the foundation of wind resource that Pakistan has would be capable of generating a seismic effect in the energy situation in the country once harnessed properly. A summary of wind potential in different parts of Pakistan, such as the Gharo-Jhimpir corridor and offshore, is given in **Table 1**.

Table 1. Wind energy potential in Pakistan.

Region/area	Estimated wind power potential	Annual energy generation potential	Wind corridor locations
Gharo–Jhimpir Corridor (Sindh)	43,000 MW	132 TWh/yr	Gharo, Jhimpir, Keti Bandar, Thatta
Coastal Belt (Balochistan)	7000 MW	21 TWh/yr	Gwadar, Jiwani, Ormara
Inland Plains (Potential Sites)	5000 MW	15 TWh/yr	Thatta, Badin, Jamshoro
Offshore Wind (Feasibility)	12,000 MW (estimation)	36 TWh/yr	Coastal waters of Sindh and Balochistan

The distribution of wind resources in Pakistan is not even. Responding annual average wind velocities at hub heights of about 50 m are usually 6.0 to 6.8 m/s in the core sections of the Gharo-Jhimpir corridor [17]. All these values are typically deemed adequate to deploy commercial onshore wind power, especially with the current generation turbines that are optimized to moderate wind conditions. Notably, the distributions of wind speeds do not occur evenly across the corridor, and variations at the site level are associated with variations in the roughness of the surface, distance to the coastline, and topography in the area. The southern coastal belt persists to be the hot spot, whereas the rest of the regions (interior plains, North zones, mountainous areas) have relatively low wind potential as per the topography and meteorological constraints [21,22]. The estimates of wind power density (WPD) at the same hub heights are typically in the range of 250 to 360 W/m^2, and a vast bulk of the corridor is in internationally recognized classes where utility-scale turbine development can occur [17]. But the use of average values only may hide the underlying distributional properties of wind speed. Many studies thus highlight the significance of Weibull shape and scale parameters, which offer an indication of the prevalence of increased wind velocities, which disproportionately lead to the production of energy on an annual basis [23].

Vertical wind shear is important in energy yield. When it comes to extrapolating between heights of 30–50 m to taller hubs, measurements always show significant increases in wind speed and wind power density. Surveys using logarithmic and power law profiles have indicated that hub heights that are over 80 m can provide large improvements in capacity factors, especially in regions where surface roughness is low. This has significant implications for the choice of technology and implies that previous judgments with lower hub heights can be underestimated to get the actual energy output.

The other characteristic of the Pakistan wind regime is seasonal variability. The pre-monsoon and monsoon months have wind speeds that are higher, whereas the winter seasons have wind conditions that are also exploitable, although low. In contrast to the variation provided by this seasonality in generation profiles, it also provides partial complementarity to hydropower inflows and solar generation patterns, a policy of concern in system-level planning [15].

Altogether, the evidence at hand shows that the nature of the wind resource in Pakistan is widely suitable for the commercial development of wind energy. Nevertheless, site heterogeneity, the sensitivity to assumptions on hub height and seasonal variation all point to the weakness of generalized averages. All of these highlight why it is advisable to conduct site-specific evaluation and exercise special caution when utilizing aggregate estimates of wind potential, especially when converting resource units into capacity planning and project execution answers [24,25].

3.3. National and regional wind potential estimates

Several studies have been carried out to estimate the wind energy potential of Pakistan both regionally and nationally, with some estimating its potential to be as low as 1000 MW and as high as 1400 MW. Instead of reflecting a lack of consistency in the underlying wind resource, this dispersion represents disparities in methodological coverage, spatial coverage, and assumptions followed by separate assessments.

Theoretical potentials of the GharoJhimpir wind corridor. Regional studies normally indicate potentials of more than 40–50 GW relating to the wind speeds at the hub height of 30–50 m and the assumptions of the conservative turbine separation. These approximations are normally obtained through empirical mast data using some limited spatial extrapolation and thus are seen to be relatively strong within the geographic boundaries of the areas in question. Nevertheless, they fail to seize and harness the possible resources outside of the core corridor or consider technological developments in designing the turbines [26,27].

On the other hand, at the national level, which allows taking into account the entire coastal belt of Sindh and Baluchistan, along with some isolated inland areas, the values of wind potential are significantly higher. A number of studies have estimated national theoretical potential ranging between 100 and 130 GW, usually with higher turbine densities (up to 5 MW/km^2), higher hub heights, and more liberal land eligibility criteria. Although these research papers can offer a good understanding of resource availability in the long run, their findings are more prone to assumptions of land-use limitations, exclusion areas, and the availability of infrastructure [16,28,29].

There is also another difference between theoretical wind potential, technical wind potential, and realizable wind potential. Theoretical potential represents the sum of kinetic energy that is accessible in the wind covering a specific area, and a technical potential takes into consideration the accessible turbine technology and the space limitation. Realizable potential, in its turn, adds more restrictions associated with grid connection, environmental constraints, competitive land use, and socio-economic factors. The fact that many studies do not directly distinguish these categories also adds to the lack of clarity in the result comparison or interpretation.

One should thus see the estimates of wind potential reported as indicators and not guiding values. The higher-end and the lower-end estimates point to the magnitude of the long-term opportunity under the conditions of favorable technological and institutional factors and more pessimistic assumptions, respectively, under the conditions of the short-term deployment realities. This difference should be acknowledged to reconcile resource evaluations to attain realistic planning and policy goals [30].

3.4. Methodological differences in wind potential estimates

The large spread between published wind potential estimates of Pakistan can be largely attributed to methodological differences, as opposed to disputes over the existence of favorable wind resources. The differences occur in a variety of dimensions that are interrelated, and each of these dimensions would have a considerable impact on the reporting of potential.

A significant aspect of variation is the assumed layout of spatial and turbine density. Surveys using conservative spacing principles, often within the 2–3 MW/km^2 range, report significantly lower potential than surveys using a more compact layout of 4–5 MW/km^2. Although higher densities are technically possible with current turbines and more sophisticated wake control, they can exaggerate the potential that can be achieved when implemented in the same way, without taking into consideration local losses of wakes and terrain limitations [31,32].

The choice of hub height and wind shear modeling is a second important issue. Measurement-based early condition assessments, at the height of 30–50 m, tended to employ simplified profiles of power law extrapolations and therefore created a level of uncertainty in the determination of energy yield. The newer research includes the use of hub heights above 80 m and is based on refined shear parameterizations, which estimate capacity factors higher. Nevertheless, extrapolation is still competitive with the assumption of surface roughness and atmospheric stability, which is not always explicitly recorded [26,33].

The third area of difference is associated with the quality and resolution of wind data. Empirical mast measurements have good accuracy in the specific places, but are not spatial. On the other hand, the mesoscale and reanalysis data offer more coverage, but with uncertainty in models, especially in coastal and complex terrain regions. The research based on the models may thus exaggerate continuity of resources over expansive regions.

There is also the land-use and exclusion criteria, which add to the inconsistency of results. Some do not consider urban areas, defensive zones, farmland, and bodies of water, and others make few exclusions. The variation in the treatment of setbacks, environmental buffers, and the accessibility of infrastructure may have significant impacts on the quantity of land considered good to develop wind.

Lastly, a significant number of studies fail to make a clear distinction between the gross resource potential and system-constrained potential, making an implicit assumption that all technically feasible sites can be incorporated into the power system. Such a supposition ignores grid capacity, curtailment risk, and dispatch limitations, which are especially germane in the present configuration of the Pakistani power system. Combined, these methodological variations highlight why wind potential estimates are so important they are to put them in place of the assumptions made in these estimates. Unless there is such contextualization, a comparison of numerical values on a direct basis can be deceptive. An open and common set of assessment models would thus go a long way in enhancing the value of wind resource studies in policy development and investment decisions [28,34].

3.5. Consolidated wind resource evaluation and impacts

All the national and regional estimates have shown that there is a considerable amount of wind energy potential in the country, and especially along the coastal strip of the south coast, which includes the Gharo-Jhimpir corridor and some parts of the Balochistan coastal regions. Nevertheless, these resources need to be translated into credible estimates of deployable capacity, but the methodological assumptions and constraints of the system-level must be put into seriously considered.

The claimed wind potential is widely varied, and regional evaluations of the Gharo-Jhimpir region indicate potential of over 40–50 GW, of which higher turbine densities, tall hub heights, and increased scope of land-use inclusion propose potentials of up to 100–130 GW. Considering grid integration, environmental issues, and socio-economic considerations, the achievable potential is inherently smaller, stating that the raw theoretical values should not be taken as deployment goals [1,35].

Measured site-specific values put the power densities at 250 to 360 W/m^2, and the capacity factors of operational sites range over 30 to 38%, which is in agreement with the international standards for the same onshore wind regimes. There is also added complexity of seasonal variability, as the wind speed of greater magnitude is seen in pre-monsoon and monsoon months, and less but more consistent in winter. These differences indicate the necessity of time-loving complements of other renewable resources, i.e., hydropower and solar, in the planning of integrated systems.

The dispersion of the published estimates can be predominantly explained by the variation in the assumptions of the turbine density, the height of hubs, and the sources of the wind, the exclusions of the land-use, and the limitation of taking into account the constraints of the systems. Identifying these factors is critical in the process of estimating interpretations in the realistic deployment and policy management [36,37].

Table 2, which summarizes the possible key measures, summarizes the key indicators needed based on the literature, such as the area of the corridor, wind speed, power density, and predicted electricity generation. The way these metrics are presented is an opportunity to compare the studies across studies more systematically and reveal the range of possible estimates. The possible result of such consolidation is a clear and organized basis on which further discussion involving the deployment feasibility, grid integration challenges, and policy formulation can be conducted.

Table 2. Summary of potential key metrics.

Metric/estimate	**Value/range**
Area of prime corridor (Gharo–Jhimpir)	$\sim$ 9700 km^2 [4]
Annual mean wind speed (50 m hub-height, Gharo)	$\sim$ 6.6 m/s [28]
Wind power density (50 m, Gharo)	$\sim$ 360 W/m^2 [28]
"Most probable" wind speed (30 m data, extrapolated)	$\sim$ 9.36 m/s [18]
Estimated theoretical potential (coastline, Sindh + Balochistan)	$>$ 50 GW [19]
Ambitious national potential (some studies)	$\sim$ 132 GW (at 5 MW/km^2) [16]
Upper bound national realizable potential (some reports)	$\sim$ 131,800 MW [20]
Projected annual generation (coastal exploitation scenario)	$\sim$ 212 TWh/yr [16]
Measured site-by-site power densities (selected sites)	252.8–355.6 W/m^2 [23]

The evidence gathered has been analyzed, showing that the wind resource base in Pakistan is adequate to accommodate large-scale, utility-scale deployment and that the limitations are more based on spatial concentration, system integration needs, and uncertainty in estimates, and not due to resource scarcity. The preeminence of development in the GharoJhimpir corridor minimizes the risk of exploration whilst increasing the exposure to local variability and curtailment, which underlines the importance of geographic diversification. The further effective utilization relies on the coordinated planning that would align the generation expansion with the grid capacity, transmission preparedness, and seasonal complementarities, as well as policy and investment frameworks, which consider the methodological and site-specific uncertainties by range-based assessments.

The wind resources of Pakistan can therefore be described as being strategically rich, although their successful extraction is determined by careful planning, strengthening of infrastructure, and favorable policy mechanisms. The debate identified in this section provides a logical analysis of the deployment patterns, the changing of policy frameworks, and the constraints in the system at a larger level in the sections that follow.

4. Progress in wind energy development in Pakistan

4.1. History and milestones

The use of wind energy in Pakistan started at the beginning of the 2000s with the opening of the Jhimpir Wind Power Plant in 2002. This is a US 136 million project with a capacity of 50 MW; it was the first commercial project in the production of wind power in the country [5,7,10,38–40]. It was situated on the southern coast, showing the technical feasibility of tapping the natural wind resources of the region, especially in the western Sindh province. The Jhimpir plant was used as a pilot project and served as the foundation upon which the developments in the sector were of other developments [38].

After this initial success, more wind farms were set up along the southern coast with special concentration in the Gharo-Jhimpir Wind Corridor. These reports on the industry show that 36 independent wind power providers (WPPs) have helped to develop this corridor as of 2025 [5, 7]. The total installed capacity in this area has now grown to about 1845 MW, which indicates a great improvement in the Pakistani wind energy industry [10]. Another recent trend in the industry involves the Hawa Power Project, a 50 MW wind farm project in the Gharo-Keti Bandar corridor, using 29 model 1.7103 wind turbines, provided by foreign contractors [39]. During the period of 20 years, the wind energy industry in Pakistan has become a network of wind energy facilities that started with one plant of 50 MW to up to 2 GW in total capacity. This change highlights the slow but significant advancement of the development of wind energy in the country.

4.2. Installed capacity and current status

It has reached at least an approximation of 46,605 MW national electricity generation capacity in 2024–2025 in Pakistan [7, 41–43]. The contribution of wind power is about 1.8 GW [43]. This capacity is mostly located in the Gharo-Jhimpir area and is operated by privately owned producers [44]. Even though the capacity installed has been growing steadily in the last two decades, the growth has largely been stagnant in recent years. It has been reported that the wind capacity has remained at 1.8 GW over the past two years with no notable additions in this time line [43].

The real generation of electricity through wind power is still limited by technical and grid integration difficulties. According to the observations by grid operators, even in well-potential sites like Gharo-Jhimpir, low-tariff wind power is being curtailed as a routine [43]. The distortion of optimal use of installed capacity has been caused by transmission constraints, infrastructure bottlenecks, and the remote nature of wind farms to major load centers.

An overview of the key wind farms reveals the trend of the industry expansion (**Table 3**), but also reflects the difference between the installed capacity and the realized capacity. These observations suggest that, though it has created a ground on wind power, the industry is yet to attain efficient or fully optimized functioning at the national level.

Table 3. Key wind farms and installed capacity in Pakistan.

Wind farm name	Location	Installed capacity (MW)	Year of commissioning	Technology used
Jhimpir Wind Power Plant	Sindh	50	2002	Siemens Gamesa 1.4 MW
Hawa Power Project	Gharo-Jhimpir	50	2021	GE Renewable Energy
Hub Power Wind Farm	Sindh	100	2016	Suzlon 2.1 MW
UEP Wind Farm	Thatta, Sindh	150	2019	Suzlon 2.1 MW
Wind Park Pakistan Ltd.	Keti Bandar	150	2020	Nordex 3.0 MW

4.3. Contribution to national energy mix

Wind energy is a small percentage of total electricity in Pakistan, but this is a huge percentage of the renewable energy source in the country. The renewable power sources, such as wind, solar, and hydro power, have been slowly taking up a portion of the overall power supply, but the portion remains minimal compared to the traditional sources [6, 9, 44, 45]. In the renewable industry, wind energy contributes to about 1.8–1.85 GW, which is one of the dominant ones in comparison to hydroelectric [44].

Although there is this installed capacity, there is still sub-optimal utilization of wind energy. It has been analyzed that the capacity in the sector is almost 1.8 GW in capacity, but only a point of 3% of the total national electricity consumption is being delivered to the national grid [6]. This discrepancy highlights the gap between potential generation and actual output, influenced by curtailment, transmission bottlenecks, and the distance of wind farms from major load centers [45].

Figure 1 shows the difference between the total wind capacity installed and the actual generation, and **Table 4** shows the development of wind energy, its proportion in the national energy mix, and the expectancy up to 2030. The statistics indicate that, despite the fact that wind energy constitutes a significant portion of the renewable energy, the proportion of this energy source in the total electricity production is still low owing to structural and operational limitations.

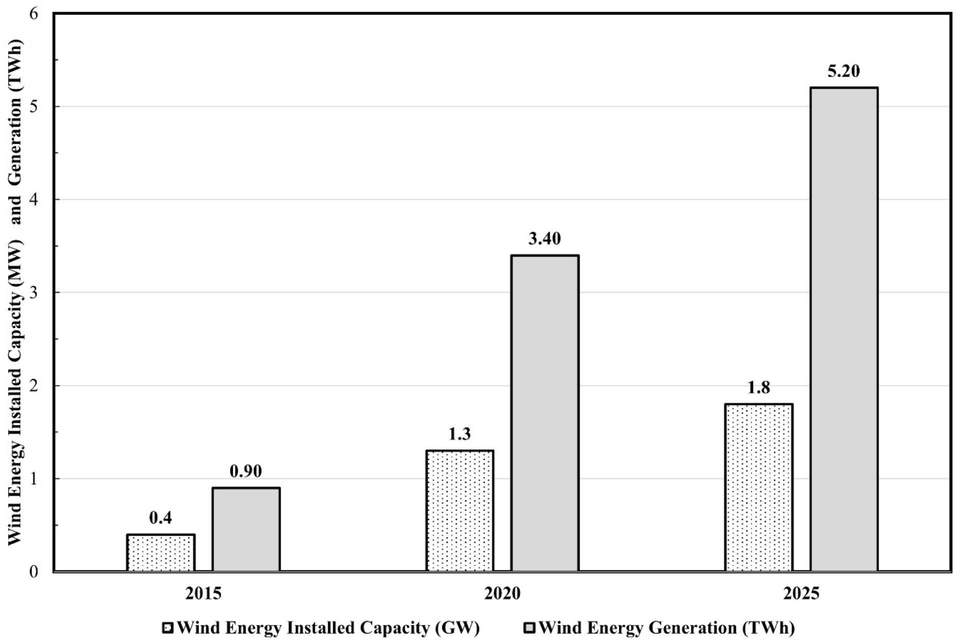

Figure 1. Wind energy generation vs. capacity in Pakistan (2025).

Table 4. Wind Energy Generation and Share in National Energy Mix.

Year	Wind energy installed capacity (MW)	Wind energy generation (TWh)	Wind share of national energy mix	Total installed power capacity (MW)
2015	400	0.9	0.5%	22,000
2020	1300	3.4	1.8%	34,000
2025	1800	5.2	3.0%	46,600
2030	6000 (projected)	16.0	7.0% (projected)	65,000 (projected)

4.4. Technology, turbines, and project portfolio

Pakistan has the largest number of wind farms, which are using onshore turbine technology with a capacity of 30 MW to approximately 60 MW for individual plants [39, 46, 47]. Hawa Power Project is an excellent example of the application of modern mid-size turbines, which employed 29 turbines of the 1.7103 type, which is optimized to work in the Gharo-Keti Bandar coastal area [39]. The situation where all the projects are concentrated in the south coast area of the Sindh region indicates a strategic selection of regions where there is a large wind potential [47].

There has been a low adoption of larger turbines of over 35 MW or offshore systems, even with favorable conditions. Recent trends have centered on small to medium onshore farms, which makes the sector quite based on small-scale projects. This mode has made it possible to build wind gradually, but has checked the massive growth of massive generation.

The current project list shows the steady presence of the private sector in the initiative, as various developers have already acquired the rights to have more plants within the corridor. The projects specify that there is still an interest in the sector despite the limited technological progress and magnitude. The focus on small and medium onshore turbines has influenced the development trend to have a moderate growth and leave the potential of large or hybrid systems untapped.

4.5. Trends, recent developments, and limitations

The private sector has remained proactive in the development of wind energy, in which various developers and energy corporations have been given licenses to set up new ventures in the Gharo-Jhimpir corridor. This prolonged attention shows that it has acknowledged the fact that there is a lot of wind potential in that region, and the long-term projections of the industry [11,43,48].

Even with the continued involvement, there has been a drastic decline in the increase of wind capacity. According to reports, 2024–2025 do not include any new additions or only to a small extent, which is indicative of a stagnation in the expansion, following approximately two decades of slow development [43]. This is slowed down by structural problems such as grid integration problems, curtailment, land availability problems, and transmission problems. This is further worsened by financing and policy inertia, which have hampered the sector from exploiting its full potential.

Hydropower has remained the major share of the renewable energy mix, and the solar capacity has been growing very fast [48]. Conversely, wind energy does not benefit effectively, and the installed capacity is not proportional to the electricity generation. The current operation inefficiencies and infrastructural constraints are highlighted by high differences between the potential output and the effective delivery. The development trend of the sector shows that despite the groundwork that has been laid down and the capacity of the sector that has reached 1.85 GW, there is still a limitation in the effective utilization of the capacity due to technical, structural, and policy-related barriers.

5. Drivers and support mechanisms for wind energy growth

However, the growth of wind energy in Pakistan has not only been stimulated by the good natural resource base, but also by policy, institutional, economic, and regulatory frameworks, which, until recently, stimulated investment and development [49]. This part evaluates the major factors and facilitating forces that have seen the insignificant yet significant increase in wind energy capacity, and how they have determined the current landscape of the wind energy industry.

5.1. National renewable energy policy and government targets

The national will to use renewable energy is one of the greatest stimuli, which is manifested in official policies and capacity goals. The policy of Alternative and Renewable Energy 2019 (ARE 2019) provides general goals in the increase of the proportion of renewable energy in Pakistan. According to ARE 2019, the government hopes that renewables (wind, solar, small hydro, biomass, etc.) can provide 20 per cent. By the current electricity generation 2025, will increase to 30 per cent by 2030 [50].

The government has gone further with this in a more recent development: by 2024, Pakistan officially restated an ambition to have 60 percent of its energy produced by clean and renewable energy by 2030 [51]. This is a grandiose national objective that gives a strategic blueprint and demand guide to wind energy, among other renewables, that gives the investors and developers a long-term outlook in the market.

Following official reports, the coastal wind corridor (Sindh and Balochistan) in the south has officially been incorporated into national planning as a major area to deploy wind power, which is in line with the identified potential of the resource, as suggested by meteorological evaluations [52]. Thus, government-level commitment—through expressed targets and designation of resource zones—serves as a foundational driver for wind energy development in Pakistan. A concise summary of these drivers and government support mechanisms is presented in **Table 5**, highlighting the key factors that support growth.

Table 5. Key drivers of wind energy development in Pakistan.

Driver	Impact on wind energy	Government support/policy
Resource Endowment	High potential for wind generation, especially in the Gharo–Jhimpir corridor.	National policy support for development in coastal wind corridors.
Financial Incentives	Feed-in Tariffs (FiTs) and tax exemptions have attracted private investment.	ARE Policy 2019 guarantees tariffs, tax exemptions, and fiscal incentives.
Energy Security Concerns	Reduces dependence on imported fossil fuels, addressing balance-of-payment issues.	Inclusion of renewables in the national energy strategy (30% by 2030).
International Climate Commitments	Supports Pakistan's goals under the Paris Agreement to reduce emissions.	Policies targeting CO_2 reduction and the clean energy transition.
Private Sector Involvement	Increased participation from IPPs and foreign investors in wind projects.	Public-private partnerships and wind energy procurement mechanisms.

5.2. Regulatory instruments, incentives, and institutional support

In addition to general goals, specific regulatory and institutional facilitators assisted in the reduction of the barriers to the involvement of the private sector in the wind power industry. Since at least 2015, the national regulator, National Electric Power Regulatory Authority (NEPRA), has approved a regulatory framework permitting feed-in tariffs in commercial wind (and solar) power producers, and net metering in small (residential) installations up to the order of 1 MW [53]. Such a structure made wind projects more financially attractive, as it ensured that power generated by the project is sold to the purchaser at pre-determined tariffs —less off-taker /market risk on the side of the developer.

Pakistan has always been historically facilitated by the Alternative Energy Development Board (AEDB), which was established in 2003 and oversees and guides renewable energy schemes, giving them certificates/letters of support to access regulatory benefits [54]. After institutional restructuring, oversight and licensing have typically involved other bodies (e.g., the Private Power & Infrastructure Board, PPIB) [55]. Past policies have provided incentives to promote renewables (incentives for wind), and this has included tax exemptions, no importation of renewable energy equipment (turbines, towers, generators) through import duty, easy land allocation procedures, and simplified licensing procedures [56, 57]. Such incentives have a positive material impact on initial capital costs and administrative burden, key elements of wind project viability.

The deregulatory and institutional reforms have attracted independent power producers (IPPs) in the country and foreign investors into the industry. This led to the development of several wind farms that had the support of the private sector due to the predictable FITs, favourable policy regime, and resource potential [11]. On the whole, this regulatory institutional setting has made wind energy in Pakistan a pilot activity of a marginal and state-driven project to become a market with several players, which has facilitated capacity growth within the past 20 years. **Figure 2** shows the main drivers and major barriers to wind energy development.

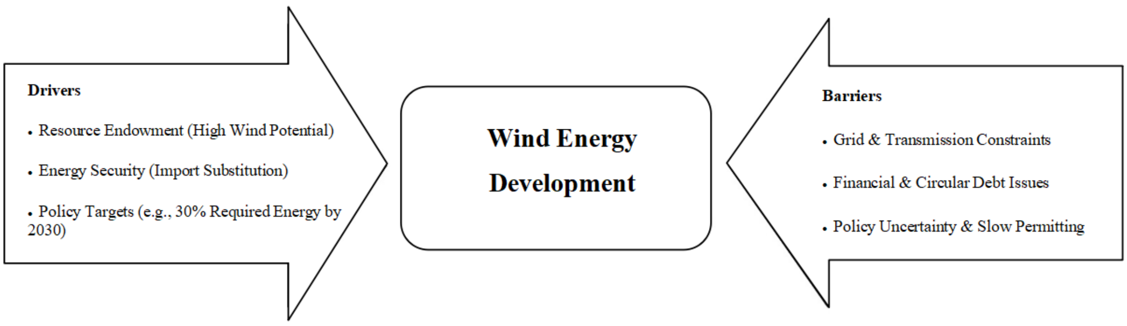

Figure 2. Drivers and barriers to wind energy growth in Pakistan.

5.3. International comparison and transferable lessons

By situating the experience of Pakistan in an international framework, one can draw attention to the lack of choices and the ways to move forward. India, which has similar climatic conditions in some parts of its western and southern regions, has used more than 44 GW of wind potential with the aid of competitive auctions, good grid codes, and local manufacturing ecosystems [58]. Morocco has surpassed 1.7 GW of set wind capacities through linking long-term power purchasing plans and proactive transmission planning. By capitalizing on concessional finance and designs of hybrid projects, Egypt has been able to expand the implementation of wind in the Gulf of Suez at a very high rate [59].

In comparison with such instances, Pakistan is less aggressive in wind deployment because of the inability of the grid to expand, financial risk management, and policy consistency, rather than resource scarcity. According to the international experience, the prompt investment in transmission infrastructure, transparent procurement processes, and sound contractual arrangements are the determining factors in the speed of wind energy adoption that can be easily transferred to the context of Pakistan.

5.4. Economic and environmental drivers

The economic and environmental necessities have also contributed to the growth of wind energy. The conventional production of electricity in Pakistan has depended on the importation of fossil fuels (oil, gas, and coal). Volatility of the global fuel prices, in addition to the foreign exchange and energy security risks, saw renewables, and more so indigenous wind energy, as an appealing alternative to ensure less dependence on imports and pressure on the balance of payments [60]. With the maturation of wind turbine technology around the world, and the rise of economies of scale, the cost per kilowatt hour (kWh) of wind energy would start to be much more competitive compared to traditional fossil-based generation, particularly when the long-term fuel prices and the externalities of the environment are factored into the equation. This price point is a boost to the wind business case. Several energy economics studies contend that the deployment of large-scale wind can be important in stabilizing and reducing the cost of electricity production in Pakistan in the long run and medium term [61].

To achieve its national climate change interests, and based on international commitments (e.g., in the Paris Agreement), Pakistan is becoming more driven to cut greenhouse gas emissions in the power sector. The need to decarbonize electricity production gives a good environmental justification for the promotion of wind energy [62]. Therefore, there is a strong case for wind energy in terms of macroeconomics and sustainability, as the combination of economics (saving the cost of fuel, decreased reliance on imports), long-term cost stability, and environmental/climate policy makes a solid argument.

5.5. Policy coherence, strategic planning, and integration

Besides reduced incentive mechanisms, wind energy development has been enhanced by more integrated energy sector planning and long-term strategies. Pakistan has used capacity expansion planning devices, which integrate renewables in an energy mix of diversification, where a mix of hydro, wind, solar, among other sources, is aimed to be balanced. In these plans, wind power corridors in Sindh and Balochistan are singled out as a priority area in which renewable growth is to be targeted [63]. The national renewable energy plan has realized that there is a need to integrate various renewable sources (wind, solar, hydro, etc.) to provide a more reliable and stable energy supply, in particular due to the intermittency of wind and solar [64]. It has been noted by analysts that this kind of hybridization, as well as flexible system planning, enhances the viability of large-scale renewable implementation and makes wind energy a major part of a diversified, clean-energy portfolio.

The trend behind the promotion of wind energy is a larger energy and environmental policy change in Pakistan, which is in line with climate objectives (reduction of CO_2 emissions), sustainable development concerns, and energy security objectives. This alignment enhances political dedication, mobilization of donor and foreign funding interest, as well as enhances the institutional legitimacy of the renewable projects [65].

5.6. Recent momentum and emerging drivers (post-2020)

Although the growth of wind energy has been a bit stagnant over the past few years, new drivers, as well as market indicators, give a case for the possibility of a re-acceleration. The target of the government of renewable energy of 60% by 2030 (mentioned above) announced in 2024–2025 gives a new boost to wind, together with solar [66]. New trends in grid modernization and variable renewable energy (VRE) integration. Increasing transmission infrastructure, making it adaptable, which international observers and domestic stakeholders report is becoming a priority, needed enablers should wind (and solar) capacity scale [49, 67]. Increased appreciation (in policy, as well as scholarly circles) of the role of wind in lowering long-term generation costs, enhancing energy security, and helping to decarbonize, which could lead to further investment, such as international financing, particularly as global climate finance opportunities expand [49]. These new trends support the opinion that wind energy is still a strategically important part of the future energy of Pakistan. To conclude, wind power in Pakistan was enabled by a combination of desirable policy objectives, a regulatory framework of incentives (FiTs, net metering), institutional structures to encourage private investment, economic and environmental forces, and strategic energy planning. These drivers resulted in the attraction of the private developers, promoted the initial capacity increase (up to 1.8 GW in the coastal corridor), and made wind a recognized and accepted portion of the national electricity mix.

Nonetheless, although they provide the reasons why wind energy has taken off, the fact that deployment remains small in comparison to its potential implies that the enablers have been needed, but not yet sufficient, i.e., policy and incentives have preconditioned the growth, but other constraints (technical, infrastructural, financial, governance - will be discussed in following sections) have kept the growth limited and slow.

6. Challenges, gaps, and roadmap for wind energy expansion in Pakistan

6.1. Key challenges and gaps

The potential of wind energy is high in Pakistan, but the rate of growth of wind power is still low. There have been several issues that have limited large-scale implementation, in both technical, financial, regulatory, and institutional aspects [6,68]. All these issues have contributed to the viability of projects, investors' trust, and integration of wind energy into the national power industry at the system level.

Technical constraints are mainly a result of the constraints in the current electricity infrastructure, which was developed historically, where centralized thermal and hydropower generation was a focus [69]. There is also the challenge of financial pressures that complicate development, which are supported by the instability of macroeconomic stability, the capital requirements, and liquidity in the power industry. The slower progress can also be associated with regulatory and institutional aspects, since processes of project approval and policy continuity are still inconsistent [70, 71].

These gaps have to be identified to comprehend the structural circumstances that developed wind power in Pakistan. A grid limitation, financial and institutional barriers, system integration issues, geographic concentration, and policy uncertainty are analytically examined, which offers a ground to consider the ways of reaching a more effective use of wind resources [6, 68].

6.1.1. Grid infrastructure, transmission bottlenecks and curtailment

One of the main limitations on the Pakistan wind energy development is the limitation in the transmission infrastructure. The national power grid was not initially intended to support large and centralized thermal and hydropower facilities, which restricts its capability to handle the variability and spatial dispersion of wind energy production [69]. This structural mismatch has become increasingly evident as wind capacity has expanded in specific regions.

The positioning of wind farms on the coastline of the south, especially in the Gharo-Jhimpir region, has increased the transmission issues. These locations are many miles away from the major load centers in the central and northern parts of the country, which is causing continuous choke points in the electricity transmission [69]. Transmission congestion limits the capacity of the grid to take in wind-generated power, particularly when there is a high supply of wind conditions and a low demand on the system.

These limitations have resulted in the rise of curtailment. Experimental measurements and industry monitoring show that under some operating circumstances, curtailment rates in wind farms can be very high, especially when too little capacity has been built into the grid, or when the system demand is not high [67, 72]. These decreasing outputs mean underutilization of the wind resources available and defeat the financial performance of wind projects. Structural inefficiencies in the power system are also supported by the fact that the use of wind energy to contribute effectively to the national energy mix is curtailed because of its prevalence [67, 69, 72].

6.1.2. Financial, economic, and institutional barriers

The economic and financial situations create a strong impact on the growth of wind energy projects in Pakistan. The high capital commitment needs, such as turbine purchases, installation, and ancillary infrastructure, pose another significant limitation, and this is especially true when the price of other macroeconomic volatility is taken into consideration. The exposure to currency volatility, inflation, and high financing costs increases the risk of investment and makes long-term planning of a project difficult.

In the power industry, liquidity issues further restrict the viability of the project. The circularity of debt, which is defined as arrears of payments between the electricity producers, distributors, and the state institutions, has diminished the economic status of the utility owned by the state [73]. The delays in payments to wind power producers disrupt the stability of revenues and decrease the ability of the government and non-government actors to start new projects [73]. By 2024, the magnitude of circular debt had risen to the extent that it severely limited the funding in the electricity sector [74].

There are also institutional and regulatory processes that have hindrances in the timely development of a project. The processes of permitting, licensing, and land acquisition are usually characterized by lengthy legal processes and bureaucracy. Uncertainty is also caused by policy inconsistency and the constant back-and-forth changes made to regulatory frameworks, which lower investor confidence. These institutional requirements, coupled with a lack of finances, have retarded the rate of wind energy development even when there has been a good resource potential [73–75].

6.1.3. System integration and resource adequacy concerns

A combination of changing renewable power, especially wind power, poses a consistent challenge to the Pakistani power system [69, 76]. The historical organizational structure of existing grid operations was based on the predictable output of large thermal generation units, and restricted the flexibility of the system in the conditions of variable generation. This feature of the structure limits the ability of the grid operators to adjust supply and demand when wind production is changing.

Production of wind energy is time-varying depending on patterns of meteorology and seasons. This variability makes operation planning more difficult, and more balancing mechanisms are required in the power system. The lack of forecasting tools and enough flexibility in operations increases the risks of imbalance between supply in situations of rapid alteration of wind generation.

The issue of resource adequacy arises when the proportions of wind power are increased without incremental upgrades to the systems. Analytical tests point to the fact that grid stability may be impaired in the situation of the rise in wind penetration unless compensatory measures are taken. Increased grid flexibility in the form of better forecasting, flexible generating capacity, and coordination at the system level is widely recognized to be needed to ensure reliability. The existing constraints within these regions limit the magnitude to which wind energy can be used to incorporate the electricity system on a nationwide scale [69, 76–78].

6.1.4. Geographic concentration and lack of diversification

Pakistan is still heavily focused on the coastal belt in the south in the development of wind energy, and especially in the areas of Gharo, Jhimpir, and Keti Bandar. These regions have good wind potentials, but the dependence on a narrow geographical region creates structural limitations. Project concentration along the same line of action enhances the vulnerability to the localized challenges, such as land-use, social acceptance, and local environmental issues.

The resilience of the wind energy sector is also limited by limited diversification. There is quantifiable potential in the wind in other parts of the country, but there is little systematic mapping of resources and potential feasibility studies. There are also high exploration costs and infrastructure needs, which discourage development outside the developed corridors, which have strengthened regional imbalances in the deployment of wind energy.

The underutilized potential takes another aspect in the form of offshore wind resources. There is evidence of potential conditions in the coastal areas of Sindh and Balochistan, but commercial development is still pending [79, 80]. Offshore wind deployment has been limited because of high initial investment fees, technological complexity, and inadequate policy assistance. This under-diversification (both geographically and technologically) is still influencing the direction of the development of wind energy in Pakistan [79,80].

6.1.5. Policy uncertainty and lack of long-term strategic commitment

The development of wind energy in Pakistan is determined by policy and regulatory conditions. There has been uncertainty in the sector due to variability in policy direction and a lack of consistency in the regulation. Several renewable energy programs have been developed over time, such as incentive-based programs, but more often than not, these programs have been revised and changed in terms of the implementation frameworks, and this has curtailed their effectiveness in the long run.

The problem of strategic planning is further hindered by institutional fragmentation. Energy planning, regulation, and project facilitating roles are shared by several government agencies, which makes coordination a problem. Lack of a clearly defined and enforced long-term wind energy roadmap has diminished the predictability in the policy, which impacts the confidence and continuity of investment in the private sector [70,71].

The question about the sustainability of the support systems and regulatory obligations has shaped the conduct of investors. The extended development horizons that come with wind projects make them susceptible to policy risk, especially when there is a change of administration and shifting political priorities. The combination of these reasons limits the long-term growth of the wind energy capacity and is one of the reasons behind the stagnation in the growth of the sector. **Table 6** presents the challenges of wind energy development in Pakistan and the solutions that are advised in the field of infrastructure, finance, among others [70,71].

Table 6. Challenges in wind energy development in Pakistan.

Challenge	Impact on wind energy development	Recommended solutions
Grid Infrastructure Constraints	Transmission bottlenecks, leading to curtailment of generated wind power.	Upgrade transmission lines and improve grid connectivity.
Financial Barriers	High upfront costs, limited access to financing.	Explore green financing options, low-interest loans, and guarantees.
Regulatory and Policy Uncertainty	Inconsistent policies and frequent changes reduce investor confidence.	Ensure long-term policy stability, clear regulatory frameworks.
Lack of Storage and Flexibility	Difficulty in managing intermittency of wind energy generation.	Integrate energy storage solutions and enhance grid flexibility.
Geographic Concentration	Over-reliance on the Gharo–Jhimpir region for wind power generation.	Diversify wind deployment to new regions and consider offshore.

6.2. Roadmap and recommendations: How to overcome the gaps

The weaknesses that have been determined in the technical, financial, institutional, and policy sectors demonstrate that a concerted and systematic effort should be made concerning the development of wind energy in Pakistan. Analysis of these gaps has proposed that development is tied to the need to synchronize infrastructure planning, regulatory frameworks, financial mechanisms, and system-level integration strategies. The road map-based approach allows the analysis of how specific interventions can be used to overcome the consistent limitations and enhance the performance of the sector in the long run.

Some of the key strategic focus areas encompass transmission and grid upgrades, financial and institutional reforms, diversification of areas of wind resource, and improved system planning in view of integrating variable renewable energy. These domains are interrelated because when one area is improved, it affects the performance in other areas. **Figure 3** provides a graphic representation of priority areas of actions, which emphasizes the leads to the scaling of wind energy via integrated infrastructure, regulatory, and investment actions.

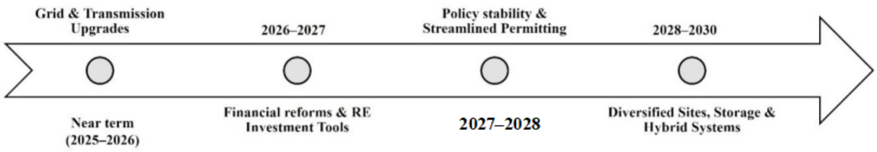

Figure 3. Recommended Action Areas for Wind Energy Expansion in Pakistan.

A detailed roadmap, describing the main steps, the timeline, and the institutions, is described in **Table 7**. This framework will allow the examination of how both incremental and system-wide actions could help to make the use of wind resources more effective and enable the role that wind energy plays in the national power system.

Table 7. Proposed Roadmap for Overcoming Challenges in Wind Energy.

Action area	Priority actions	Timeline	Responsible entities
Grid Infrastructure & Transmission	Upgrade and expand grid capacity, reduce bottlenecks, integrate smart grids.	2025–2030	NEPRA, AEDB, Provincial Governments, Transmission Companies
Financial Support and Investment	Introduce green bonds, risk-sharing mechanisms, and incentives for IPPs.	Immediate to 2025	Ministry of Finance, State Bank of Pakistan, AEDB
Regulatory and Policy Stability	Ensure long-term, consistent policy frameworks and establish clear guidelines.	2025–2030	NEPRA, Ministry of Energy, AEDB
Resource Mapping and Regional Expansion	Expand wind resource assessments, promote offshore wind development.	2025–2030	AEDB, International Partners, Provincial Agencies
System Integration and Flexibility	Deploy energy storage systems, introduce flexible grid management solutions.	2025–2030	NTDC, AEDB, Private Sector Investors

6.2.1. Grid modernization and transmission expansion

In Pakistan, modernization of the national grid and its expansion are essential to allow increased integration of wind energy. There is a constraint within the present transmission infrastructure to move electricity through the southern wind corridors to the major load facilities in the north and central areas. These bottlenecks limit the provision of power generated by wind and lead to curtailment in times when the wind produces high power.

The efficiency of electricity transfer over long distances can be enhanced through improvements in transmission capacity, such as the introduction of high-voltage delivery systems (HVDC and HVAC lines). Integration of smart grid technologies can also contribute to the real-time control and management of the variable generation to allow greater responsiveness of the control of the power flows and address the operational imbalances.

A combination of storage systems, such as pumped-hydro and battery storage systems, enables more flexibility as excess energy is stored during peak production and discharged when demand is high [81]. All these enhance the capacity of the grid to support variable renewable generation, eliminate losses related to curtailment, and guarantee a higher level of system reliability [81,82].

6.2.2. Diversification and resource-zone expansion

The energy production of wind energy in Pakistan is still in the southern coastal belt, which makes the sector vulnerable to site effects and restricts resilience. The ability to expand into other geographical areas would improve the dependability as well as the volume of wind power production. The systematic analysis of wind potentials in areas outside the conventional corridors, such as parts of Baluchistan, interior Sindh, and prospective offshore areas, can give an idea of underutilized potentials.

In particular, there is a large and unexploited potential of offshore wind resources. Feasibility tests show that wind can be favorable along the coasts, yet start-up costs and technology are still expensive. In the long run, these barriers can be decreased because of the progress in offshore wind technologies in international markets, which can make future development feasible.

The geographical diversification of wind projects can help in averting challenges that are local, including land-use issues, environmental issues, and social acceptance issues. Strategic diversification will help to make the sector sturdier and help to create a structure that will allow for the incorporation of wind energy into the national electricity system more efficiently.

6.2.3. Financial and institutional reforms to stimulate investment

The feasibility and growth of the wind energy projects in Pakistan are also greatly affected by financial and institutional conditions. Both the capital demands made at the beginning of the business and the macroeconomic instability pose significant risks to investments. Policies that stabilize the financing processes may lower obstacles to the establishment of projects and enhance confidence in the sector.

The challenge of liquidity, especially the fact that it continually remains in the form of circular debt, is essential in sustaining predictable revenue streams in the hands of independent power producers. Early payment and better management of finances in the power industry will facilitate the ability of both government and corporate players to initiate new projects.

Project development can also be accelerated by institutional reforms to simplify the permitting and licensing process and land acquisition. Regular and uniform regulatory frameworks assisted by coherent institutional control help in creating a more predictable environment for investment. These measures help to minimize the uncertainty in the administration, increase investor confidence, and help to promote the long-term development of wind energy capacity.

6.2.4. System-level planning and integration of renewables

Planning on a system-wide level should be done effectively to incorporate wind energy as part of the national power system. Integration of the variable renewable energy sources requires an integrated strategy that takes into account both supply- and demand-side resources such as storage, flexible generation, and alternative generation resources.

Increased grid flexibility incorporates increasing grid forecasting, demand-response, and integration with other sources of renewable energy, including solar energy. These will affect the impact of the intermittency of wind and the supply of electricity. Operational strategies such as flexibility of generation and integration with complementary sources of energy offer the means of balancing variable generation and reliability of the system.

The system-level planning helps in the efficient use of the available infrastructure as well. The overall effectiveness of the electricity network is enhanced due to the coordinated availability of wind resources in addition to the technical and operational enhancement of the network. This type of planning is the way to get more wind energy penetration without affecting grid stability or reliability.

6.2.5. Diversified stakeholder engagement and institutional capacity building

The elements of institutional capacity and coordination of stakeholders are very important in advocating the development of wind energy in Pakistan. Planning, permitting, and monitoring functions can be enhanced through the strengthening of operational and regulatory capabilities of key agencies, including the Alternative Energy Development Board and the National Electric Power Regulatory Authority. Capacity-building programs addressing the local engineers and technicians in the area of turbine operation, maintenance, and grid integration also boost the technical base of the sector.

The interaction with local communities and stakeholders in areas where wind projects are developed is something that is involved in making decisions in a transparent and informed manner. Social conflicts can be minimized by integrating community views in land acquisition and environmental management processes, and improving the acceptability of the project.

Institutional and stakeholder involvement can be used in a more effective manner to achieve the implementation of wind energy projects. Empowered capacity and inclusive decision-making make wind energy grow, and take into consideration social, technical, and regulatory aspects of the sector growth.

6.3. Why this roadmap matters—strategic implications

The proposed roadmap can have a considerable impact on the development path of wind energy in Pakistan with its implementation. Optimal coordination of infrastructure, financial, institutional, and policy actions can enhance the use of the available wind resources as well as expansion to underdeveloped regions.

The greater utilization of wind energy can also lead to a stronger energy security as it will decrease the reliance on imported fossil energy and eliminate the swings in the electricity supply. The implications of a wider adoption of renewable energy sources can also be useful in maintaining the stability of electricity prices, as well as mitigating the environmental consequences of the problem, such as greenhouse gases.

Planning of wind energy is in line with national and global goals of sustainable energy change. Planned coordination, capacity development, and infrastructure improvements offer the basis for incorporating variable renewable energy into the electricity system, which facilitates the resilience and efficiency of operations. Embracing such strategies can reinforce its role in ensuring long-term energy security, economic stability, and environmental sustainability of the sector.

7. Conclusions

The Pakistani wind energy is a tremendous opportunity to revamp the energy sector of the nation, decrease reliance on imported fossil fuel, and help Pakistan to achieve its goal of environmental sustainability. Pakistan has enormous potential for wind energy, particularly in the southern coastal belts, which can become central in changing its future to a cleaner and more sustainable energy. Nevertheless, even with this huge potential, the actual implementation of this potential has been constrained by a set of technical, financial, institutional, and regulatory issues. The wind energy sector in Pakistan has been making a big step forward. Since the inception of the Jhimpir Wind Power Plant in 2002, the country has put in place a small yet developing wind farm fleet that is mainly located in the Gharo-Jhimpir belt in Sindh. By 2025, the practical wind power in place was about 1.8 GW, which offered a minor yet significant contribution to the overall mix of electricity production in the country. But even this capacity is not enough to match the 43 GW theoretical potential of the Gharo-Jhimpir region alone, which was determined in resource appraisals.

The factors that slow down the growth of wind energy in Pakistan are complex. There is still poor grid infrastructure to integrate large-scale wind power, and this has resulted in curtailment and poor utilization of the resources. The barriers that face large-scale integration are transmission bottlenecks, the old system of managing the grid, and the intermittent process of wind energy. There are also financial factors that make the situation tougher, including the expensive initial capital investment of wind projects and the circular debt of the energy sector in Pakistan. Moreover, uncertainty to the investors is caused by policy instability and inefficiency of the regulations that deter both local and international investors from investing in renewable energy projects.

The challenges notwithstanding, wind energy has a bright future in the energy contributes to the energy future in Pakistan. The nation has established high goals in its Alternative and renewable energy policy, where a 30% portion of renewable energy is to be met by 2030, and wind power is one of the main sources of this. To achieve this potential, Pakistan needs to cover the serious lack of grid infrastructure, financial structures, and institutional coordination. Modernization of transmission lines, deployment of smart grid systems, and enhancing the adaptability of the grids are some of the necessary measures to increase the integration of wind energy. Also, the expansion of wind energy implementation to offshore and inland locations would contribute to the reduction of geographic concentration risk and enhance resilience.

The future roadmap should take into consideration consistency in policies and long-term support of regulations to ensure that the private investors are convinced to invest in the large-scale wind projects. The support provided to international investment by green bonds and the risk-sharing agreements, as well as the solutions of domestic financing, will be essential to address the initial capital barriers. Moreover, the incorporation of wind power into the range of renewable energy sources, such as solar energy and hydro, and energy storage, will assist in stabilizing the power supply and making the grid more reliable.

An international juxtaposition to the chosen emerging wind markets of India, Egypt, and Morocco puts into perspective the Pakistan performance and draws lessons to be transferred with regard to policy and system integration. The right technical innovation, financial and consistent policy means that the nation will be able to tap the potential of its wind resources, and this will contribute to the energy security of the country, economic stability, and environmental sustainability. Wind energy as a source of energy has the potential of providing a sustainable source of energy to Pakistan at little cost, in addition to making the country a leader in white energy in South Asia, should the full potential of such energy be tapped. The wind energy still has a long way to go, but it requires the concerted effort on the part of all the stakeholders, i.e., the government, the private sector, and the local communities, that the promise of wind energy is the way to go, so that it will benefit all.

Author contributions: SH, XL, and IUK conceived the idea, SH and XL collected data and wrote the first draft. IUK carried out data analysis and revised the manuscript. The whole project was administered and supervised by IUK. All authors have read and agreed to the published version of the manuscript.

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