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Review

Assessing Wind Energy Projects Potential in Pakistan: Challenges and Way Forward

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Abstract: Energy is the driver of the socioeconomic growth and development of a country. In the pursuit of available and affordable sources of energy, nations around the world have forgotten the sustainability angle and are facing an energy crisis. The developing world has initiated development plans in an unsustainable way, causing a demand–supply gap and leading to very high energy prices. Renewable energy gives us a solution to this circular crisis. The recent world has seen significant investment in renewables, particularly in the wind energy sector. The investment was initiated as a government spending program, but is now taken up by the private sector. The current study presents a thorough analysis of the prospects for wind energy and the means and measures required to fully capacitate the sector in Pakistan. In Pakistan's three largest provinces, there is tremendous potential for wind energy, which requires proper utilization and exploration for sustained socioeconomic development. This study is based on the mixed-methods approach. In the first phase, content analysis was caried out using the systematic literature review (SLR) technique. Relevant content analysis was performed using the PRISMA diagram. A total of two hundred and thirty-nine (239) documents were scanned; however, only eighty-two (82) were included after the removal of duplications and irrelevant documents. Moreover, short interviews were conducted with entrepreneurs, and themes have been prescribed. The study found that commercially feasible wind energy potential is particularly abundant in Pakistan's Sindh and Balochistan regions. The country's diverse geography makes it ideal for wind turbine installations at various sites. The renewable energy policy should be revisited to incentivize the use of wind energy to ensure the nationally determined contributions (NDCs)' commitments are assured to achieve sustainable development by 2030. Pakistan has seen rapid development in the wind energy sector with around 4 percent of electric power being generated through wind farms in just over 13 years. In order to exploit the potential, there is a need for significant public and private joint efforts.

Keywords: wind energy potential; renewable energy; sustainability; Pakistan

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1. Introduction

Climate change accounts for the anthropogenic actions, effects, and damage to Earth's ecology that have put the planet and its inhabitants at risk and danger. Increasingly severe heatwaves, temperature rises, floods, sea-level rises, ice sheet melting, and other climate change indicators have served as the most evident warning signs throughout the globe [1].

To a large extent, this tragedy is caused by an ever-increasing need for energy, which is still mostly derived from fossil fuels, yet emits billions of tons worth of dangerous greenhouse gasses. The energy sector causes almost 89 percent of greenhouse gas (GHGs) emissions globally [2]. About three-quarters of the world's GHG emissions come from energy production, primarily by burning fossil fuels. Burning biomass and fossil fuels both significantly affect human health, with at least five million fatalities per year being related to air pollution [3].

Conventional energy sources are insufficient to meet the world's ever-increasing need for living, industrialization, and sustainable development. As a limited energy source, fossil fuels can only be relied upon for the next 104 years based on the current demand [4]. Renewable and non-renewable energy must be integrated to properly plan, execute, and commercialize renewable energy in the long term. Moreover, an efficient solution for utilizing and maintaining non-renewable energy resources is required to achieve sustainable development through a just transition [5].

The depletion of fossil fuels and the rise in global temperatures may both be reduced by the use of renewable energy sources (RES) [6]. There is a variety of RES that may be used to generate electric power. These include, but are not limited to, solar, wind, biomass, geothermal, and hydropower [7]. The RES are crucial in the fight against global energy shortages [8]. As a result of their environmental friendliness, RES are deemed a clean energy resource. Compared to fossil fuels, RES provide environmental protection, a pollution-free environment, energy security, and economic benefits.

Developing countries such as Pakistan must attain energy security to enable economic development in the long term [9]. Pakistan has been facing an energy security crisis for the last three decades as a result of poor contract management with private power plants, a lack of focus on RES, inconsistent and incoherent policies viz-à-viz the development and electricity infrastructure, subsidies for selected sectors, and a lack of coordination between various federating units and relevant departments. This has led to Pakistan currently having almost PKR 2.5 trillion of circular debt, which keeps on re-emerging and is creating a serious threat to the energy security of the country [10,11]. Out of these issues, the first one pertaining to the lack of focus on RES is the scope of this study.

The energy supply capacity in Pakistan has been increasing over the years during the previous decade. There has been a consistent increase in electric power generation from 2010 to 2022 with a major increase in generation during the years when the China–Pakistan Economic Corridor (CPEC) was fully active and operational. The data from the Economic Survey of Pakistan depicts that there was an 85 percent increase in installed capacity from 2010 to 2022. The details have been provided in Figure 1.

In addition to the 24.7 percent of electric power coming from hydel sources, 8.8 percent and 6.2 percent come from nuclear and renewable (wind and solar) energy sources, respectively. The remaining 59.5 percent comes from conventional fossil fuel-based sources including regasified liquefied natural gas (RLNG), residual fuel oil (RFO), coal, and natural gas. Almost 1 percent of the electric power comes from bagasse. The details are displayed in Figure 2 [12].

On the demand side, due to the focus on industrialization and the rise in the population, there has been a consistent increase in demand over the years [13]. The demand and consumption of electricity units in GWh are shown in Figure 3. As can be seen, the supply of electricity is always greater than the consumption [12]. Still, Pakistan has been faced with strong incidences of power shedding in the domestic, commercial, and industrial sectors. This is partly because of technical losses in the transmission and distribution system as well as noted incidences of electricity theft. Although numerous efforts are being made, such as reforms in the electricity market structure on the transmission and distribution end, significant efforts need to be made towards the sustainability of energy generation through the inclusion of renewable energy [11].

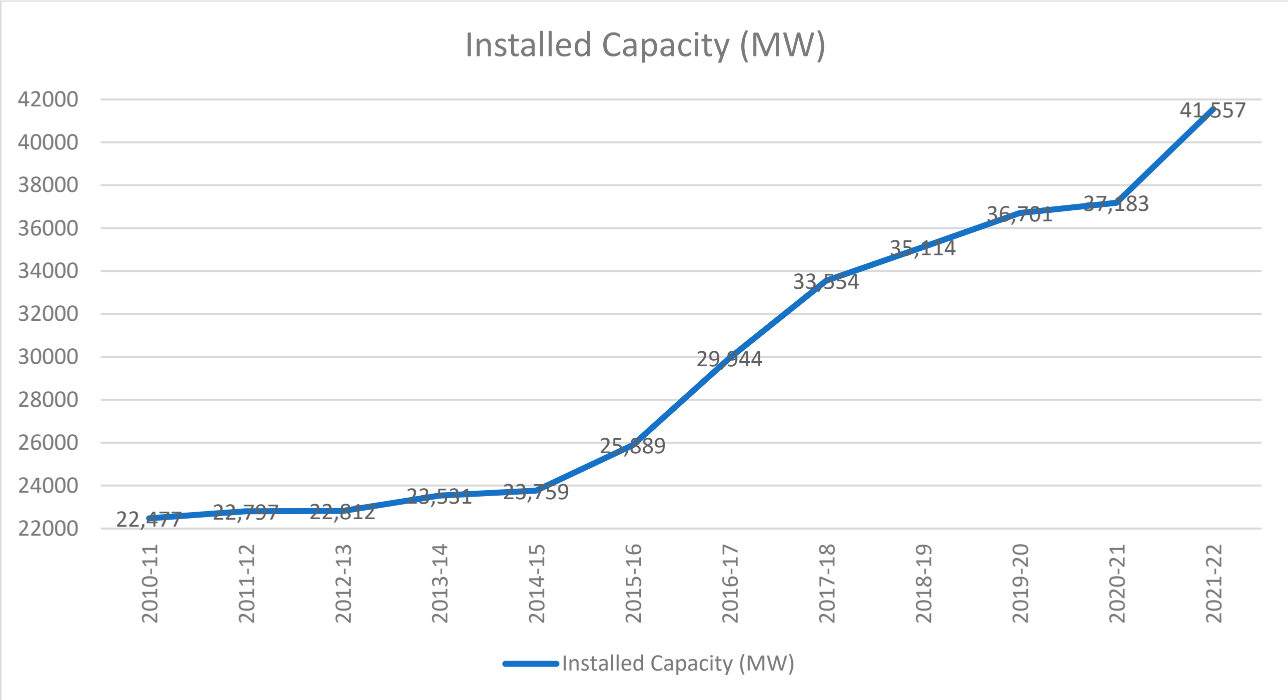

Figure 1. Installed capacity of Pakistan's electricity power sector in megawatts (2010 to 2022).

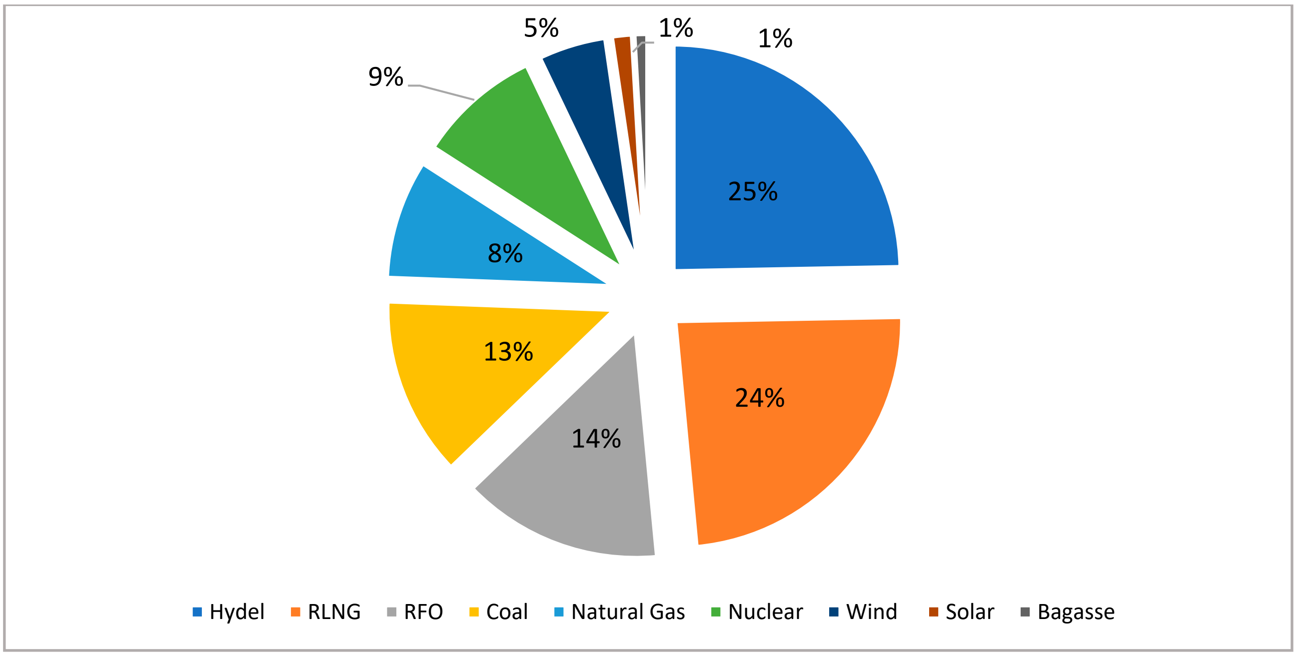

Figure 2. Energy sources in Pakistan's energy mix.

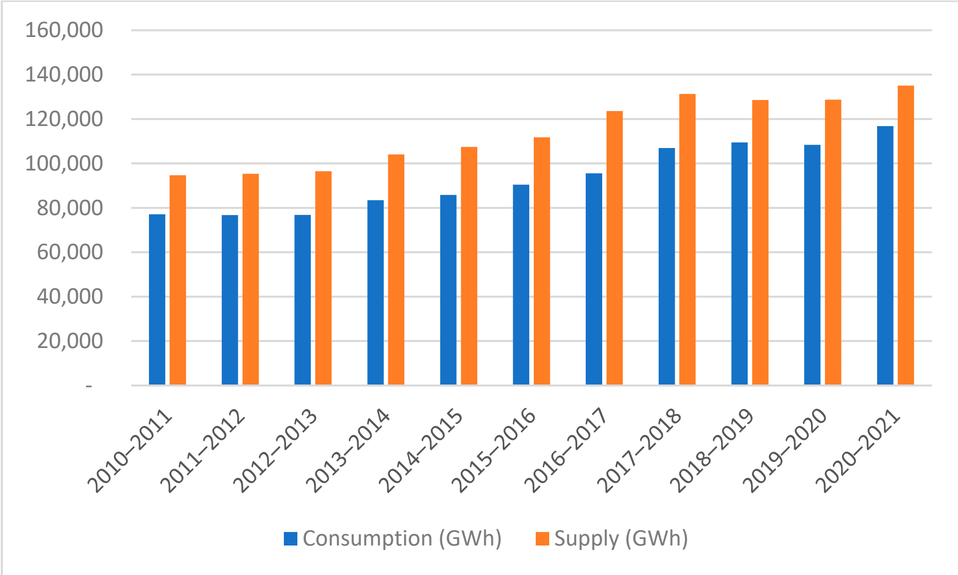

Figure 3. Supply and consumption of electricity units in Pakistan (GWh).

The aspect of sustainability in the electric power sector leads to the debate on the utilization of RES in Pakistan. Pakistan is blessed with a geography with significant RES and this enables the higher utilization of these resources [14]. It will help Pakistan not only to eliminate the circular debt, but also enable the availability, affordability, and sustainability of energy for all sectors of life in Pakistan. Further debate is around the fact that the areas abundant with RES are usually remote and have weak connectivity to the national grid. This enables another aspect regarding microgrids and captive generation [15].

Amongst the RES, wind energy has been Pakistan's most utilized resource [12]. Throughout the world, wind energy generation is based on the need for a consistent unidirectional wind, which creates motion when it impacts a rigid body (a fan-like rotor), causing the production of electricity [16]. This machinery is described as the horizontal axis wind turbine (HAWT). HAWTs are best suited for coastal areas due to the availability of consistent and unidirectional wind [17]. Additionally, for turbulent winds, vertical axis wind turbines (VAWT) are being utilized for non-commercial production [18].

Pakistan, as part of the United Nation's agenda for sustainable development 2030, has initiated nationally determined contributions (NDCs), which include aiming for 30 percent renewables by end of 2030 (https://unfccc.int/sites/default/files/NDC/2022-06/Pakistan%20Updated%20NDC%202021.pdf, accessed on 13 October 2022). The renewable energy policy 2019, Indicative Generation Capacity Expansion Plan (IGCEP), and other government policies have a mismatch, causing difficulty in the achievement of the NDCs [19].

Many studies have been conducted regarding the technical and financial feasibility from a stand-along turbine or plant perspective; however, this study focuses on the awareness of and opportunity for exploitation and exploration perspectives, and devises a proposed Public–Private Partnership (PPP) model, which seems practical, viable, and implementable, and can positively impact on the socioeconomic conditions in Pakistan, especially for remote and terrorism-prone areas of Balochistan and Khyber Pakhtunkhwa.

A strong focus is required on the location, modes of development, financing mechanisms, and lifecycle assessment of the wind power plants in Pakistan. Therefore, the primary goal of the study was to evaluate Pakistan's need for and awareness of wind energy projects. The wind corridors and tiny standalone wind turbines placed in suitable areas are suggested as potential remedies for Pakistan's current energy issue. However, the initial investment cost associated with the introduction of wind powerplants is high. Moreover, the government should take some concrete steps to make the most of this potential.

In this paper, we examine the energy sector potential, needs, supply, and demand deficit in-depth in the context of wind energy. Therefore, descriptive and content analyses, along with a thematic analysis, were performed using the PRISMA approach. In parallel, brief interviews were conducted with entrepreneurs who are interested in investing in the wind energy sector. However, due to the high risk, tough regulations, and high capital requirements, they seem unable to go ahead and face the risk head-on. The need for the government to share the risk and to design an appropriate mechanism for suitability in terms of regulation may enable a smoother shift from conventional to renewable energy. According to the study findings, Pakistan has huge opportunities for wind energy. Some of these have been utilized by the private sector in Sindh province. A similar holistic PPP arrangement will be required for an extension towards Balochistan and other areas of Pakistan.

The main objectives of the research study are to:

- Map the existing literature on the wind energy potential in Pakistan.
- Identify areas of future research and policy recommendations for the wind energy sector of Pakistan.

2. Research Methodology

The study is built upon a systematic literature review (SLR). The keywords used included “wind energy”, “renewable energy”, “potential”, and “Pakistan”. The keywords were initially searched using Google Scholar to find more relevant keywords that can be utilized for a more comprehensive SLR. Once finalized, a total of six databases were utilized for the analysis including Scopus, Emerald, Dimensions AI, Science Direct, and Google Scholar. The Dimensions AI database was utilized for the analysis. The period of research was 2012–2022. Moreover, content published in research journals, books, periodicals, conferences, and by the government, published only in the English language, was selected for inclusion in the study. Similarly, literature published in social sciences, economics, and management sciences was considered for inclusion. In contrast, articles published in biological and engineering sciences that did not have any connotation to economics, social sciences, or management were excluded.

The following methodological steps were taken:

(1) The identification of keywords based on the experience of the authors, the assessment of relevant literature, and brainstorming sessions held among the authors. The identified keywords included, but were not limited to, “wind energy potential”, “Pakistan”, and “renewable energy potential”. These keywords were organized into search strings, for instance, “wind energy potential” OR “renewable energy potential” AND “Pakistan.”
(2) The search strings were used to carry out a preliminary search on Google Scholar. No additional keywords were identified during this process.
(3) The search string was used on the six databases mentioned to identify the key citation indices for review. The selection was made based on the volume of citations relevant to the basic search string.
(4) The articles were reviewed based on the inclusion and exclusion criteria mentioned in Table 1. A two-stage process was used to reduce the number of citations to be analyzed. The first stage was based on the article title and the second stage was based on the analysis of abstracts.
(5) The 82 citations that were left at the end of the second phase were analyzed for their content and organized into different categories according to the objectives of this study. A list of themes was compiled and a summary and discussion on each theme were produced in this study.

Table 1. Inclusion and exclusion criteria.

No.	Criteria	Reasons
	Inclusion Criteria	
1	Studies focusing on wind energy potential as a means of gaining sustainability in projects from a multi-stakeholder point of view and give solutions	The focus of the study is to identify issues and potential solutions available in the literature in this context. Solutions can come from multi-stakeholders including public and private stakeholders
2	Studies that have kept Pakistan in context	To keep in line with the overall context of the study
3	Studies containing conceptual, empirical, quantitative, and qualitative methodologies, and literature reviews	The aim is to include all relevant academic writing
4	Articles indexed in various databases including Scopus, Emerald, and Science Direct	The mentioned databases have all of the main journals indexed
5	Articles published in social sciences, economics, and management sciences were considered for inclusion	The article was written to contextualize wind potential from a policy and regulatory angle, particularly from a non-technical point of view
6	Articles focusing on developing countries	Since the context of this study is Pakistan, a developing country, studies that do not explicitly mention developing countries were deemed irrelevant. However, studies focused on developed countries, but gave a context of developing countries, were included
	Exclusion Criteria	
1	Studies published in related areas before 2012	The first wind powerplant in Pakistan became operational in 2013. In 2012, most of the awareness about the policy and regulatory issues concerning wind energy was made public. Literature before 2012 carries information that is not relevant in today's context [20]
2	Studies related to VAWT were not considered	VAWT products available globally have not been economically feasible on a commercial scale till now
3	Business magazine articles, editorials, or similar publications were not considered	Only journals, books, periodicals, conferences, and government-published research were considered
4	Linguistic expression	Articles published in the English language were considered. This was due to linguistic constraints
5	Articles published in biological and engineering sciences were excluded	A non-technical analysis was required to contextualize the topic from a policy and regulatory angle

A total of 239 articles were downloaded. However, 74 were excluded in the first screening, as their focus was on wind energy potential, but the main literature was from developed countries. In the second phase, 63 more articles were excluded, as they were published in biological and engineering sciences. A further 20 articles were excluded due to duplications. The study was left with 82 articles, which were cited for the related content. The detailed process is depicted in Figure 4.

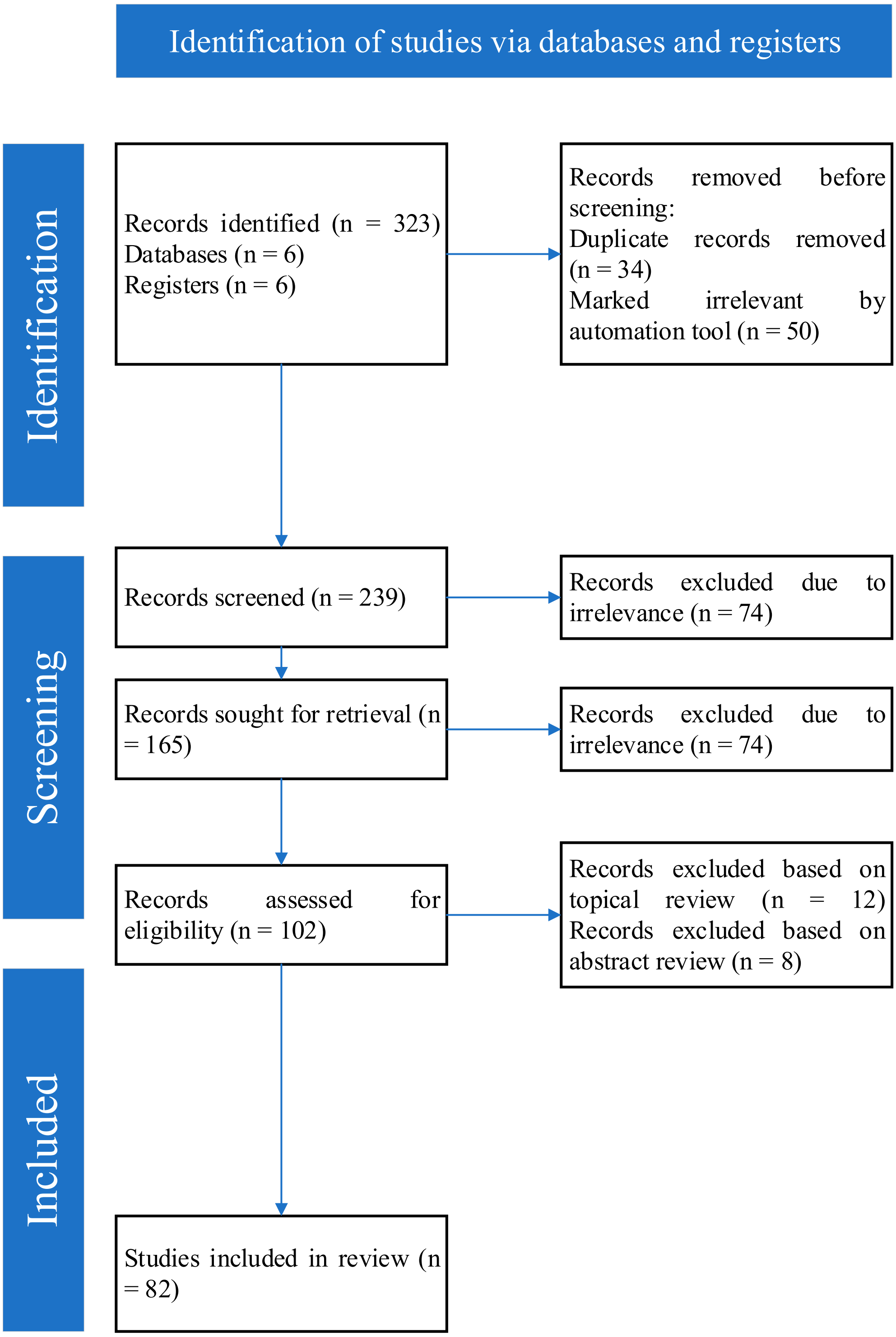

Figure 4. Screening and inclusion and exclusion criteria using the PRISMA framework.

In addition to the SLR, the authors also conducted unstructured qualitative interviews with six (6) entrepreneurs to validate the findings, enhance the recommendations, and assure generalizability. As there is very small awareness concerning the topic, fewer companies are planning to invest, therefore, the study only found a total of eleven (11) entrepreneurs relevant to the field and out of which only six (6) agreed to the interviews. The unstructured interview was maintained around the questions such as "What is your opinion regarding the wind energy projects that are needed for Pakistan?" and "How can these projects be initiated?". The follow-up questions related to "How can these projects be initiated through a Public–Private Partnership model?".

It is important to note that the private sector players who are already investing in wind energy through the International Finance Corporation (IFC) or other international financiers were excluded, and only local entrepreneurs were selected to be interviewed, just to gauge the local and indigenous investment potential of wind energy in Pakistan [21].

3. Descriptive Analysis

In this section, the results of the review of the 82 publications will be presented. Out of these publications, 93 percent were journal articles, 3 percent were conference proceedings, and 4 percent were book chapters, as displayed in Figure 5.

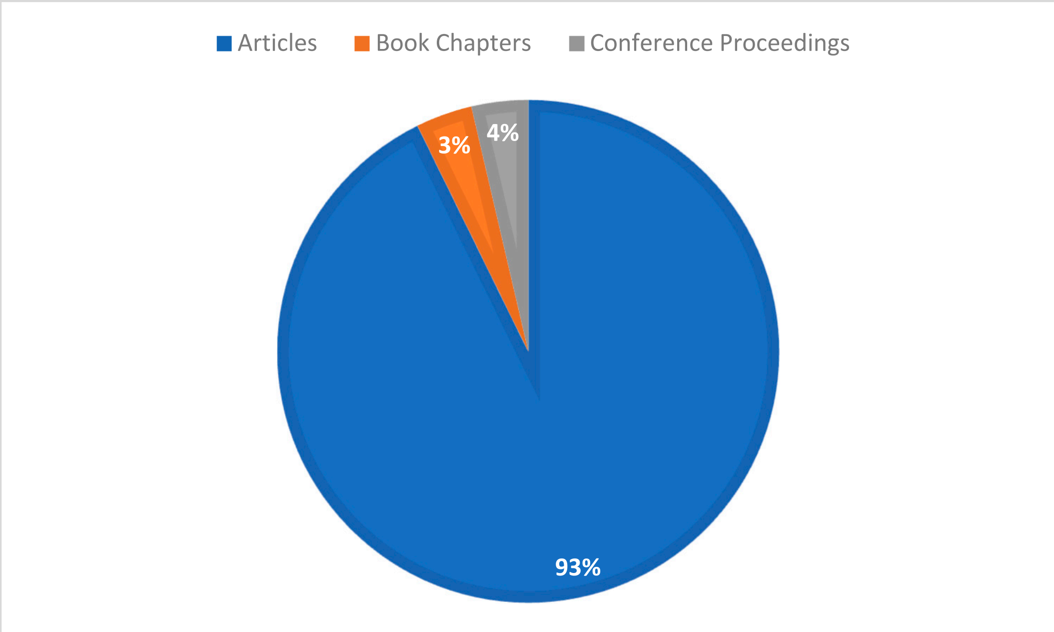

Figure 5. Publication types in the study.

The number of publications over the years is displayed in Figure 6. The academic debate on wind energy in Pakistan took a tangent somewhere around 2012, close to the commercial operation date of the initial two projects in early 2013. The publications in the area have seen steady growth, but the majority of the publications focused on the technical and engineering aspects. The publications that we considered were more focused on the potential and relevant policy efforts and the potential feasibility of introducing wind energy projects [20].

Another aspect that is worth mentioning is the citations per annum in the publication record, as depicted in Figure 7. This shows that publications after 2016 have received more traction. This is probably due to the maturity of the wind energy market, as around 12 projects had already been completed before the end of 2016 and around 10 more were in the construction phase [20].

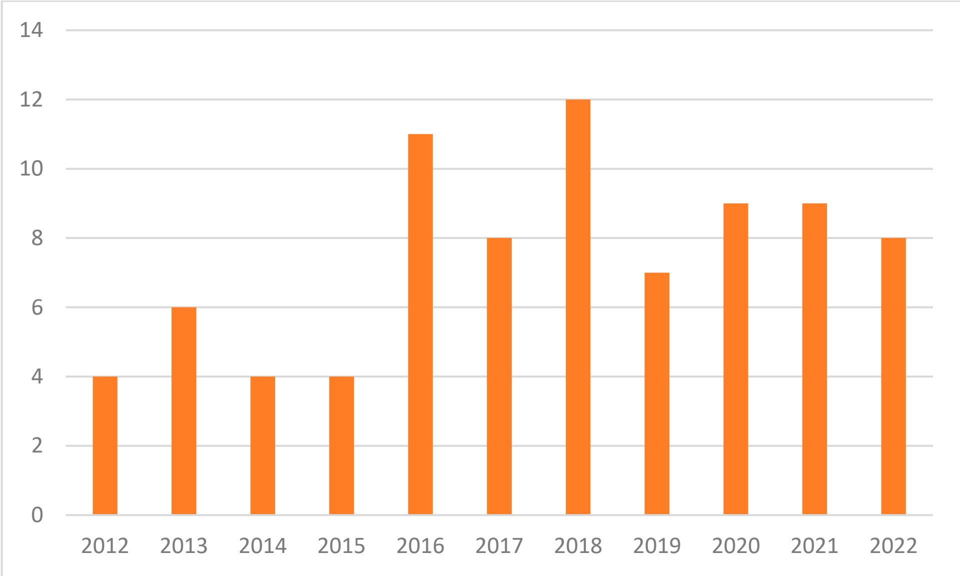

Figure 6. Number of studies year-wise.

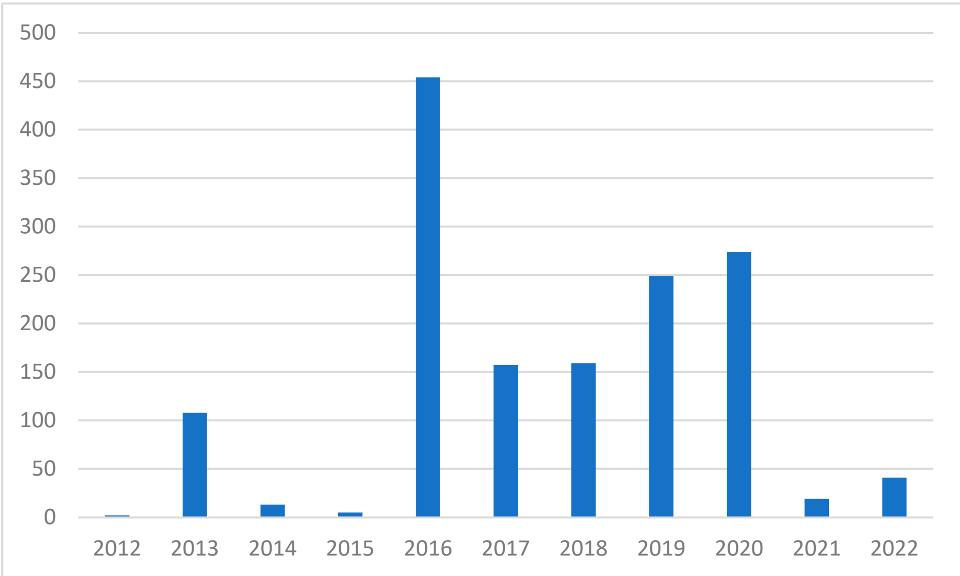

Figure 7. Number of citations year-wise.

The publications with more than 50 citations are listed in Table 2. This table, combined with the year-wise citation details in Figure 7, explains the reason for the high citations in 2016, as four out of the nine records with more than 50 citations are from 2016. Another important aspect is that the highest citation for a paper published in 2020 is based on the logic that most of the published work in 2021 and 2022 focuses on using the analysis presented in that publication. They have also cited it because of the methodology and critique on the alternate and renewable energy policy presented in 2019 and the World Bank's energy atlas [11,12,15,22,23].

Table 2. Details of records with more than 50 citations.

Sr. No.	Title	Authors	Source Title	Year	Times Cited
1	Strategic renewable energy resources selection for Pakistan: Based on SWOT-Fuzzy AHP approach [24]	Wang, Ying; Xu, Li; Solangi, Yasir Ahmed	*Sustainable Cities and Society*	2020	171
2	Evaluating the strategies for sustainable energy planning in Pakistan: An integrated SWOT-AHP and Fuzzy-TOPSIS approach [25]	Solangi, Yasir Ahmed; Tan, Qingmei; Mirjat, Nayyar Hussain; Ali, Sharafat	*Journal of Cleaner Production*	2019	148
3	Current status and overview of renewable energy potential in Pakistan for continuous energy sustainability [26]	Ghafoor, Abdul; Rehman, Tanzeel ur; Munir, Anjum; Ahmad, Manzoor; Iqbal, Muhammad	*Renewable and Sustainable Energy Reviews*	2016	115
4	Renewable energy technology acceptance in Peninsular Malaysia [27]	Kardooni, Roozbeh; Yusoff, Sumiani Binti; Kari, Fatimah Binti	*Energy Policy*	2016	114
5	Current scenario of the wind energy in Pakistan challenges and future perspectives: A case study [28]	Baloch, Mazhar H.; Kaloi, Ghulam S.; Memon, Zubair A.	*Energy Reports*	2016	81
6	Evaluating wind energy potential in Pakistan's three provinces, with proposal for integration into national power grid [29]	Shami, Sajjad Haider; Ahmad, Jameel; Zafar, Raheel; Haris, Muhammad; Bashir, Sajid	*Renewable and Sustainable Energy Reviews*	2016	64
7	Evaluation of wind power potential in Baburband (Pakistan) using Weibull distribution function [30]	Shoaib, Muhammad; Siddiqui, Imran; Amir, Yousaf Muhammad; Rehman, Saif Ur	*Renewable and Sustainable Energy Reviews*	2017	62
8	Towards empowerment of the renewable energy sector in Pakistan for sustainable energy evolution: SWOT analysis [31,32]	Kamran, Muhammad; Fazal, Muhammad Rayyan; Mudassar, Muhammad	*Renewable Energy*	2020	60
9	Greener energy: Issues and challenges for Pakistan wind power prospective	Bhutto, Abdul Waheed; Bazmi, Aqeel Ahmed; Zahedi, Gholamreza	*Renewable and Sustainable Energy Reviews*	2013	53

The major sources, as described in Figure 6, are journal articles. The highest number of articles are from *Renewable and Sustainable Energy Reviews* [7,26,29–44], the *Journal of Basic & Applied Sciences* [45–48], and *Environmental Science and Pollution Research* [15,49,50]. The details are provided in Figure 8. This signifies that the focus of the study is beyond energy and has a tilt towards the environmental implications of energy.

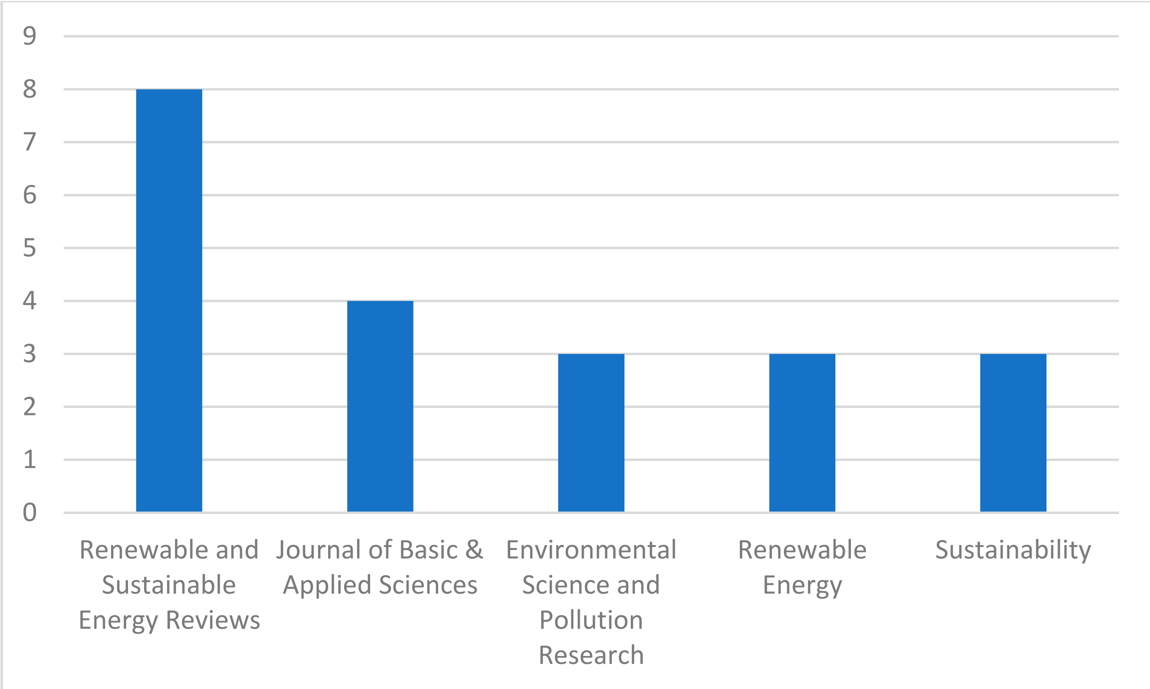

Figure 8. Top sources of the analyzed records.

Using the visualization tool VOSviewer, the reference co-citation network by the author is shown in Figure 9. We analyzed the co-authorship with authors as the unit of analysis. The minimum number of papers per author is set to 1 and the minimum citation to 0. The analysis displayed all eligible records from our SLR to be linked with the highest one from Gul, who has authored three publications [51–53].

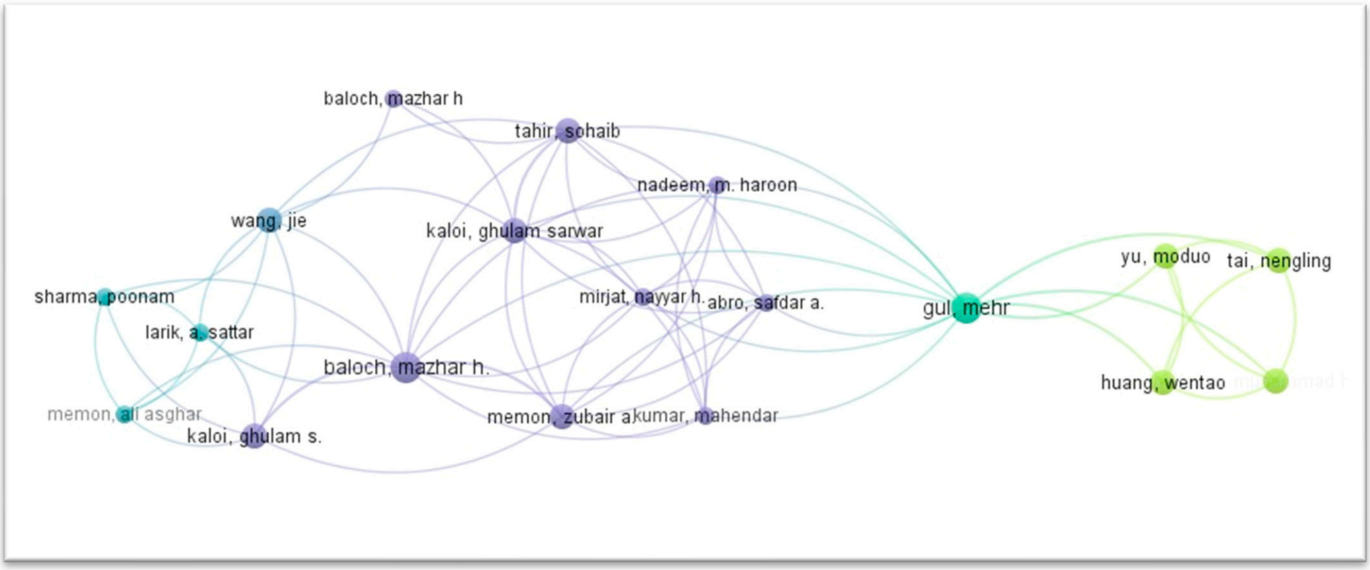

Figure 9. Co-citation network by authors.

Lastly, as discussed in the introduction, the focus towards renewables in general and wind, in particular, has a lot of credit towards the sustainable development goals (SDGs). While all of the records in the SLR relate to SDG 7 (affordable and clean energy), 34 percent also relate to SDG 13 (climate action), as shown in Figure 10. This creates a direct link between energy and sustainability, as discussed in the Introduction section.

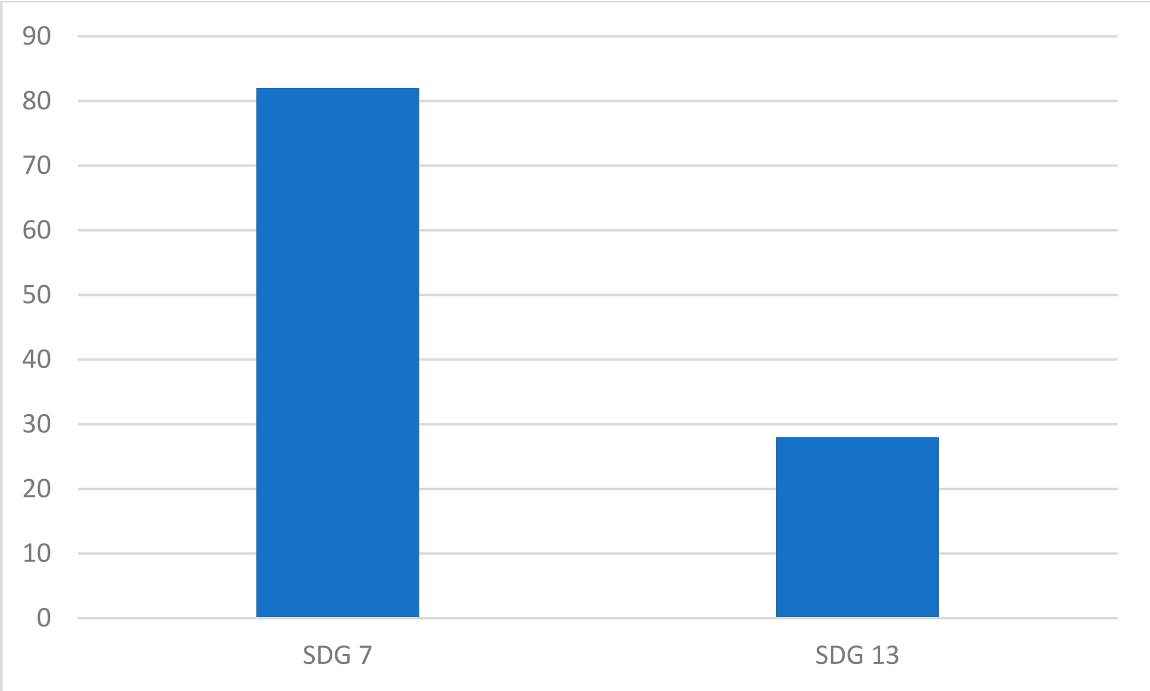

Figure 10. SDGs discussed in the records.

4. Content Analysis

The majority of the publications that were part of the SLR used quantitative methods and secondary data analysis to come up with potential zones of wind energy deployment in an optimal manner. However, around 12 studies used qualitative methods, including three case studies, and the remaining approaches were interviews and focus group discussions. The majority of the publications considered wind energy potential towards the southern region of Pakistan including the provinces of Sindh and Balochistan. This is attributable to the coastal line discussed earlier, which gives unidirectional and consistent wind for around six months per annum.

Concerning the topics discussed in the studies, the themes based on the research objectives and patterns emerging from the studies were developed. The details of the studies in each theme are provided in Figure 11. The majority of the studies are related to wind energy potential and feasibility, but around 47 percent are relevant to either renewable energy potential in general or the policy and development implications of the benefits of wind energy. Most of the studies utilize secondary data from met masts placed on various points by the Pakistan Meteorological Department (PMD), but some studies use data from geographical information system (GIS) mapping, NASA, and other sources.

The data are collected at various heights to ensure more data richness and easy extrapolation. The data are usually measured on a 10 min average and include values such as wind speed, temperature, wind density, and wind direction. The potential of the wind energy areas will depend on statistical analysis.

The statistical analysis used in most of the studies includes Weibull distribution-based analysis, but a few studies employ Lindley's distribution as well as various software including MATLAB and others. The theme-wise studies are provided in Table 3.

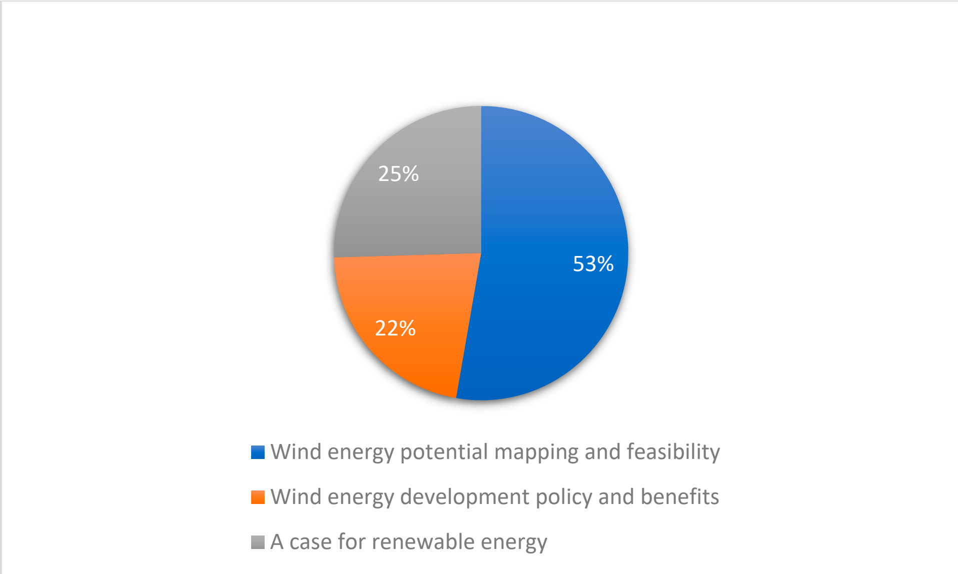

Figure 11. Themes and publications in each theme.

Table 3. Theme-wise studies.

Theme	Studies Included
Wind energy potential mapping and feasibility	[15,24,29,30,34,36,37,45–49,51–75]
Wind energy development policy and benefits	[10,25,28,32,33,42–44,59,76–78]
A case for renewable energy	[15,26,27,31,70–73,79–84]

5. Discussion

With 837 GW of wind energy installed worldwide, the planet currently saves 1.2 billion tons of CO_2 emissions annually. The wind turbines are usually installed onshore (on land), but some recent projects are employing off-shore territories as well. The leading countries in wind energy are the United States of America and China. Wind energy is the second-largest source of electricity in the world in terms of capacity and is the cleanest energy technology [85].

All of the studies agree that wind energy is one of the most promising RES in Pakistan. Pakistan is blessed with wind energy through a more than one thousand kilometer-long coastline [47,48,58,61,86]. The benefits of wind energy include it being clean, socially justified, financially viable, and environmentally friendly [87].

The GHGs emitted by a wind turbine amount to 8–20 g per kWh, which is only 2.2 percent of the GHGs emitted by coal [88]. However, recently, some researchers have started including the full lifecycle approach to GHG emission calculations, which may increase the GHGs for wind energy due to inefficient construction and development processes as well as the methods employed for decommissioning of the plant [89]. Pakistan, being one of the top five countries most affected by the climate change crisis, needs to be socially and environmentally responsible and shift its energy needs to renewables, particularly wind energy projects [90].

The success of every wind energy development project primarily depends on precise resource assessments. It is fundamental to explore sites that may be suitable for wind turbines [91]. To make the most of the significant capital expenditure connected with wind energy projects, the appropriate strategy is to start with an economic cost analysis. The wind's annual frequency and net speed are crucial factors that determine a wind turbine's net output. Wind gust speed can change from 40 to 192 km/h in 3 s; this makes wind speed highly fluctuating in both a time-based and a spatial sense, proving to be a challenge for engineers designing wind turbines. The collection, recording, and storing of wind data is far more expensive than it seems. It is required for the national meteorological departments to provide wind turbine installers and researchers with this type of information or facilities to collect detailed data or purchase expensive data sets [5,14,17,26,29,30,33,35,36,41,44–47,49,52–54,56,57,60–62,64–68,74,75,77,79,81,83,92–98].

Pakistan's conducive geographic position makes it a good option for offshore wind projects. It will take a great deal of time and effort to fully understand Pakistan's offshore wind potential. Offshore wind farm foundations are frequently constructed in shallow waters, which makes it easier to construct the structures. Pakistan's current offshore exclusive economic zone (EEZ) covers 290,000 km^2 [61].

The total potential of Pakistan's wind energy based on the data available amounts to around 350 GW in the northern and southern provinces of Khyber Pakhtunkhwa, Balochistan and Sindh, respectively. However, due to the turbulence in the wind and other land-related abnormalities, only 120 GW seems to be feasibly exploitable. The two provinces with the greatest wind potential are Sindh [36,45,57,62,67,74,96,97] and Balochistan [29,46,51,98].

The typical wind speed in Sindh's and Balochistan's coastal regions has been recorded as 7 to 8 m/s, as per Pakistan Meteorological Department, which directly relates to the International Electrotechnical Commission (IEC) 2 and 3 wind class (https://www.lmwindpower.com/en/stories-and-press/stories/learn-about-wind/what-is-a-wind-class, accessed on 13 October 2022) [43]. The availability of wind speed at a sustainable rate for operating wind turbines along the Arabian Sea coast in the provinces of Balochistan and Sindh has been the subject of a feasibility study. Balochistan province's Lasbella district is an ideal location for wind turbines with far less variation in wind speed (5 m/s in the winter and 8 m/s in the summer) [47,48,58,61,86].

The prospective places for Sindh's 88.4 GW of wind energy include Hyderabad, Kotri, Jerruck, Gharo, Jhimpir, Lakha, Khuttikun, and Bhambore. Compared to other provinces, Balochistan has a significant amount of wind energy potential with an estimated 146,145 MW of power capacity. Over 50 GW of power-generating capacity lies in Pakistan's coastal belt, which may be exploited through the use of proper wind turbines. The authors suggest local manufacturing in parts or full to save foreign exchange. This region has good wind speed and can produce cost-effective wind energy despite the enormous potential of wind energy [57].

Some authors debate that wind energy can be sequestered in desert areas. Turbines may also be installed in the desert regions of Punjab and Sindh, mostly because of the ample space available [57]. However, the potential seems to be inadequate since, after the initial data collection, the Punjab government did not go ahead with the project in Rajanpur. This may be due to the high accumulation of dust causing defects in the wind energy equipment [99,100]. Similarly, the debate around the wind energy potential in Khyber Pakhtunkhwa province has theoretical acceptance, such that the estimation in this regard amounts to around 500 MWs, but the wind in this province is turbulent and more suited for VAWT rather than commercial HAWT [70].

The studies recommend having a long-term approach to wind energy planning. The policy focus and consistency can lead to the development of the wind energy market in Pakistan through local and indigenous investment [101]. Since wind energy projects are going to be implemented in more than one province in the future, the provincial and federal governments must come together and coordinate accordingly to facilitate market development [102]. One such point of confusion between the federal alternate energy development board (AEDB) and the government of Sindh was the provision of the letter of support for land acquisition and leasing of wind farms in Nooriabad and Gharo [103].

Along with this, Pakistan needs to consider making an effort to improve the geopolitical environment, especially around the Balochistan province to convince local investment [46,98]. This can be achieved through increased government spending for training the local population, creating opportunities for local assembly and manufacturing, and creating incentives including, but not limited to, tax breaks for the investing firms. Government spending and local buy-in can create the environment required for the investor's confidence [104].

The next step can be public–private partnership (PPP). This methodology can especially support Pakistan's case because of the lack of government capacity to spend [105]. Several successful PPP models exist in the context of Pakistan. The most successful of these models is being followed in the Thar coal extraction project. Although the project is facing environmental impediments under the PPP arrangement, known as the Sindh Engro Coal Mining Company (SECMC), the social upholding of the Thar district, especially the Mithi areas, has been astounding. This is particularly noted from an employment generation and women empowerment perspective [106]. A similar model can be used in identified areas of Balochistan. Coupled with the local buy-in and the development agenda, these PPP-based wind farms can change the dynamics of the socioeconomic landscape of these less developed areas of Pakistan.

Another aspect that the studies recommend is with regard to a focus on local manufacturing, research, and development. This will not only support the additional burden on the federal reserves of Pakistan, but also have a significant impact on technology transfer and job creation. Another aspect highlighted in some of the studies is a lack of public access to met mast data of relevant heights. The extrapolation of data from 50 m to 80 m or higher has significant errors, causing deviations in academic and practical potential studies and feasibilities [98]. The government departments may include more met masts in the areas identified as having feasibility to ensure that private investors are able to access the data and become aware of the feasibility of the sector.

A lifecycle-based view of the wind energy sector requires capacity enhancement in all phases of the wind energy lifecycle. The phases of the wind farm lifecycle are classified into development, construction, operations, and decommissioning [107]. The cost in the development and construction phase is the capital expenditure (CAPEX) and the remaining costs are operational expenditures (OPEX). Due to the rapid development of the relevant vendor industry regarding the wind energy sector, Pakistan has been able to reduce the CAPEX significantly from $2 million per MW to around $1 million per MW in the construction phase. More focus on developing capacities can enhance this reduction in CAPEX. The OPEX is estimated to be around $1 million per MW per annum, which is still on the higher side owing to the lack of local capacity and manufacturing capability. It is worth noting that maintenance requirements of the wind farms are relatively higher in the Gharo region than in Nooriabad due to climatic impacts causing corrosion and weak soil conditions [108].

Pakistan is yet to see the decommissioning of any wind power plant. The first decommissioning, as per contract, will take place by 2033 in the case of 20-year contracts and in 2038 in the case of 25-year contracts. This will enable the cost of decommissioning and the lifecycle cost of operations and maintenance for the wind farms in Pakistan to be ascertained [109]. Furthermore, the employment of clean development mechanisms (CDMs) for the construction phase and maintenance may enable the environmental footprint of the wind energy sector to further decrease [110].

Additionally, going beyond the generation, as can be seen in Figure 3, Pakistan has surplus generation capacity [12]. The issues that need immediate redressal are linked to the transmission system and the tariff differentials. Pakistan introduced a very high tariff for wind power plants and has reduced the per-unit tariff accordingly, which is most appreciated. This tariff for wind power plants should be balanced with the tariff of the demand side such that significant efforts can be employed towards the reduction of the circular debt. This can be achieved through electric market reforms if the policy merits of the reform measures are taken into account [11].

6. Discussion of the Interviews

Respondent 1 (R1) explained that "wind energy is the future of the whole world. Developing countries like Pakistan can maintain and sustain their social and economic stability without it. This year, due to the war between Russia and Ukraine, the whole world is suffering from an energy crisis. If European countries can't meet the expenses of the other energy resources, who are stable financially and economically, how we may be able to cope with these challenges in near future? We must sort out using local resources and knowledge for renewable projects. Although it needs heavy investment, however, through PPP, Pakistan can achieve it". Similarly, R2 added that "Pakistan's three provinces are suitable and viable for the wind energy projects, although it needs investment, however, at the same they are too cost-effective. It needs initial investment, and in very less time, it can pay back all invested money. As Pakistan is facing more financial crises, so they can invite private partners for investment". In the same way, R3 added to the above that "the more is needed in Pakistan, is the legislative support from the parliament, then entrepreneurs can invest if they feel that their investment will not be doomed".

Moreover, R4 was too optimistic. He added that "like China, Germany, and other European country, we have installed small-scale turbines in the hilly areas, and we have received remarkable results. Therefore, we have all the practices and processes, and experiences and we can do it easily at the public level, private level, and also through PPP". R5 and R6 held an almost equal stance, remarking that "although, the government is facing financial crises, however, the per capita income of the public is increasing, so we have the money to invest in these projects through PPP, or we can fully privatize the sector. But the more we need legislative support from the government agencies".

7. Conclusions

The study found potential opportunities and suggested possible recommendations at the policy level regarding wind energy potential exploitation in Pakistan. Based on the descriptive and content analyses, discussion, and interviews, the study concludes that for the proper utilization of the huge wind energy potential, the use of a suitable PPP model is the best way forward. The institutional memory of various models available around Pakistan may be capitalized to establish an optimal, viable, feasible, and suitable option to develop wind energy project opportunities in Pakistan for its social and economic development. Similarly, there is a dire need for policy and legislative support, in addition to ancillary policy actions and consistency, so that investor confidence can be built.

The study also discusses the need for wind energy sector capacity development in terms of technology, software, capacity for local production, and the application of mechanisms such as CDM for a more effective sector. The study also confirms that the requirement for a more robust and modern transmission infrastructure and the provision of microgrids and captive plant arrangement will ensure that significant improvements in the energy security scenario in terms of availability, affordability, and sustainability can be achieved.

For a country such as Pakistan, which has high debt and diminishing foreign reserves, wind energy sector development will enable a drop in imports and focus on indigenous study. This can become the policymaker's motivation to enable the full exploitation of all of the available wind energy sites in the country, particularly for the commercially viable HAWT.

Energy policies should be designed and reviewed in a way to be convergent with Pakistan's NDCs and SDGs. This can be incentivized through relevant changes in tax codes for products and services involved, import duty reductions, subsidies, and loans. A focus on local investors should enable a more localized version of wind farm development leading to a low lifecycle-based cost.

Based on the analysis, the study found the following gaps in the literature. Technically, while statistical data analysis has been utilized in the studies to assess the potential, which was the main aim of our study, there was very little focus on the ground conditions. The assessment that needs to be carried out using local wind and ground data is the micro-siting arrangement of turbines and rows of turbines. Furthermore, the techno-economic and feasibility analyses missed out on the lifecycle-based approach and did not consider CDM or other relevant methodologies. Other aspects concerning the quality of energy services [111], energy efficiency and conservation, and awareness among consumers [112] require significant focus. This will help neutralize the load on the grid and efficiency in consumption patterns.

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