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Research Article

A SWOT Analysis for a Roadmap towards Sustainable Electric Power Generation

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During the last decade, the abundance of wind, solar, and conventional energy sources have been widely utilized in Sindh, Pakistan, to meet the energy demand-supply gap of the country. Some of these energy projects have been approved, are under constructional and operational phases and have connected to the National grid successfully. However, these energy sources are being influenced by several constraints, which keep the project developmental phases away from their technological upgradation. Therefore, the aim of the present study is to perform a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of existing energy projects in Sindh to examine its current conditions and future roadmap to promote its valuable utilization. The outcomes of the study have identified several socio-economic and environmental impacts on the sustainable development of renewable energy sources. The study concludes that energy strategic policy must contain financial profits, energy security, and environmental protection. This SWOT study will encourage local and foreign investors, researchers, and engineers to invest their financial and technical abilities towards Sindh to get benefit from the hub of energy sources. They can initiate independent power generation and distribution companies on stated sites and can provide cost-effective tariffs from green energy sources with more revenue and less payback period. It can ultimately increase profitable business as well as can boost the state's economy efficiently.

1. Introduction

The energy is a key factor for socio-economic evolution in the developing countries of the world. It has strengthened the developed countries towards their exponential development but has become challenging for developing countries to satisfy their power requirements [1]. These energy constraints have been partially minimized by consuming the available conventional and renewable energy resources to generate bulk electricity. Most of the advanced countries of the world have modified their mode of electrical power generation from fossil fuels to renewables for sustainable energy. Among developing countries of South Asia, Pakistan has a population density of 287 per.·sq.·km and has about 50% absence of electricity [2]. Besides, it has an expected annual increase rate of 8% i.e., the electrical power will be required 113 GW by 2030 [3, 4]. The country is still far behind from the development due to modern technological barriers and its implementation. These numerous issues have forced the country to consume existing conventional

and nonconventional sources, which have made the energy mix of 3 : 1, respectively [5].

According to USAID and National Renewable Energy Laboratory (NREL), Pakistan has the world's tremendous Renewable energy sources (RESs) [6]. The National Electric Power Regulatory Authority (NEPRA) had issued 27 Generation licenses for RES during 2019-20 with a cumulative capacity of 2338.14 MW [7]. In addition, oil is the leading source in Pakistan with a 35% share, followed by natural gas and coal with 30.4% and 16.3%, respectively, as stated in Development Plan Report 2020 [8]. The state has been ranked sixth among abundant coal reserves for about 186 million tonnes worldwide. The other coal reserve of 175.5 billion tonnes has also been discovered in Thar, Sindh, which will be consumed for power generation. It is an indigenous and inexpensive source for power generation [9].

Thus, it has great potential to consume existing energy sources, which have enough capability to electrify the entire country sufficiently [2]. Some of them have integrated as either individual or hybrid sources and are widely utilized for small-scale applications such as residential, agriculture, education, hospital, and military. [10]. According to IEEFA, AEDB has recently announced a 20% share of renewables into the energy mix of Pakistan by 2025 and 30% by 2030 [11].

In Pakistan, Sindh is the hub of energy sources and has an abundance of solar, wind, and coal energy sources significantly [12, 13]. These sources can take into account as a separate or integration of multiple sources. It can supply the generated power into the grid adequately, can fulfil energy deficit, and can brighten-up the entire state with bulk electricity. Sindh has enormous renewable (solar and wind) and conventional energy potential (coal, oil, and natural gas) for electrical power generation [2]. These energy sources require an appropriate roadmap for its development and implementation of mega power projects. It can only be possible by examining these sources individually and conducting a SWOT analysis effectively. Thus, the literature survey on SWOT analysis has been conducted for available energy sources in Pakistan as represented in Table 1.

It has been analysed from Table 1 that the latest and comprehensive SWOT study on energy sources available in Sindh has not been found in the literature appropriately. These energy sources have also been influenced by several constraints, which kept the project away from progressive stages and technological upgradation. The socio-enviro-economic limitations and energy policies remained undiscussed in the context of the chosen location. Thus, it motivated the authors to explore the natural occurring and abundant energies specifically.

Thus, the novelty and main objective of the paper is to conduct a comprehensive SWOT analysis for energy sources across Sindh. This study facilitated to identify the strengths, weaknesses, contemporary opportunities, and threats of existing conventional and renewable energy sources that may lower its potentials sufficiently. It highlighted the energy policies concerned with selected locations found by the latest studies to provide more energy for National socio-economic progress and to offer a future roadmap to promote its useful consumption as shown in Table 1.

Thus, the remainder of the study has structured as follows: Section 2 shows the methodology of the work and its screening process. Section 3 examines results and discussions of solar, wind, and conventional sources. Section 4 elucidates policy implications for power generation. Section 5 provides the recommendation for energy sources within the province, and finally, Section 6 concludes the study of energy sources and its future directions.

2. Methodology

This study has followed the critical process for its methodology and has used multiple search engines such as peer-reviewed journals, open access research articles, keywords, and recently published work. The process has further explored into initial and final screening methods effectively as presented in Figure 1.

2.1. Initial Screening. The preliminary screening process has been conducted on various systematic sources such as Science Direct, Google Scholar, IEEE Explore, Research Gate, Springer, and webpages. The information gathered from these sources is associated explicitly with renewable and conventional sources, its SWOT analysis, and socio-economic and environmental challenges. The particular keywords used for the present study are SWOT, Sindh, Renewable energy, solar, wind, and fuels.

2.2. Final Screening. During the final screening process, 49 references have well cited considering the journal's impact factor, indexing, and peer-reviewed processes. This article contains 27 journal articles (review and research papers), 3 Conference proceedings, 13 web pages, and 07 technical reports effectively.

3. Results and Discussions

The SWOT analysis has been conducted for frequently available wind, solar, and conventional energy sources in Sindh for electrical power generation. This section has divided into the following groups.

3.1. Wind Energy. Pakistan possesses a coastal line of 1046 km, which includes 250 km in Sindh with an area of about 9749 km^2, and each km^2 can generate electrical energy for 18 MW. The wind speed in the Sindh wind-corridor possesses from 5–12 m/s significantly. The average wind-speed of 6.63 m/s has been recorded with a power generation of 7.653 GWh per annum. The maximum average annual wind speed for Jamshoro, Noriabad, Katti Bandar, Gharo, Golarchi, Baghan, Talhar, and DHA Karachi has been computed as 8.6 7.2, 7, 6.6, 6.3, 6.3, 6.24, and 5.9 m/s, respectively, as shown in Figure 2. Wind energy contains an average capacity factor of 25%, having a gross potential of 43.8 GW, where 11 GW is useable [17, 21–26].

Table 1: Recent studies on SWOT analysis for Pakistan.

Ref. no	Energy sources						Social	Economic	Environmental	Energy policies
	Solar	Wind	Biomass	Coal	Natural gas/oil	Hydro				
[14]	✓	✓	✓				✓	✓	✓	✓
[15]	✓	✓	✓	✓	✓	✓		✓	✓	✓
[16]	✓	✓								✓
[17]		✓					✓	✓	✓	✓
[18]	✓	✓	✓				✓	✓	✓	
[19]	✓	✓	✓			✓	✓	✓	✓	✓
[20]	✓	✓		✓	✓			✓	✓	✓
Current study 2022	✓	✓		✓	✓		✓	✓	✓	✓

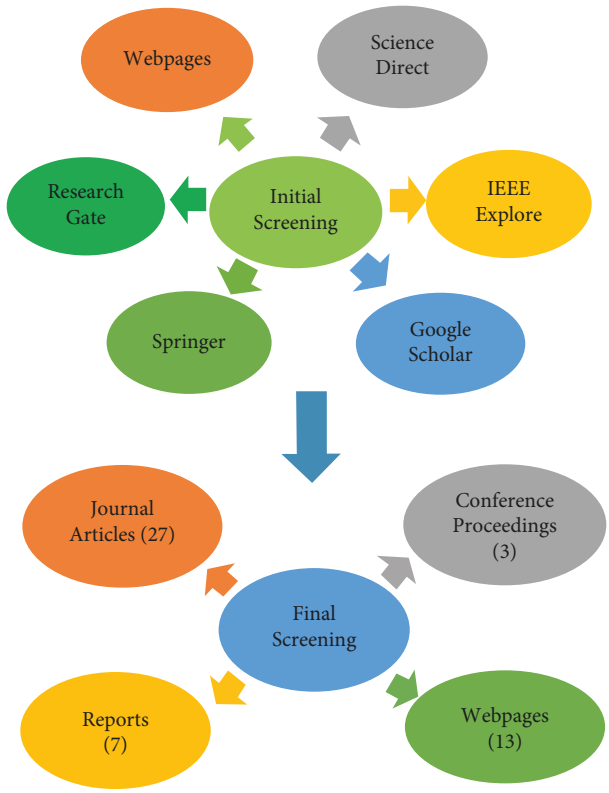

Figure 1: Methodology of the current study.

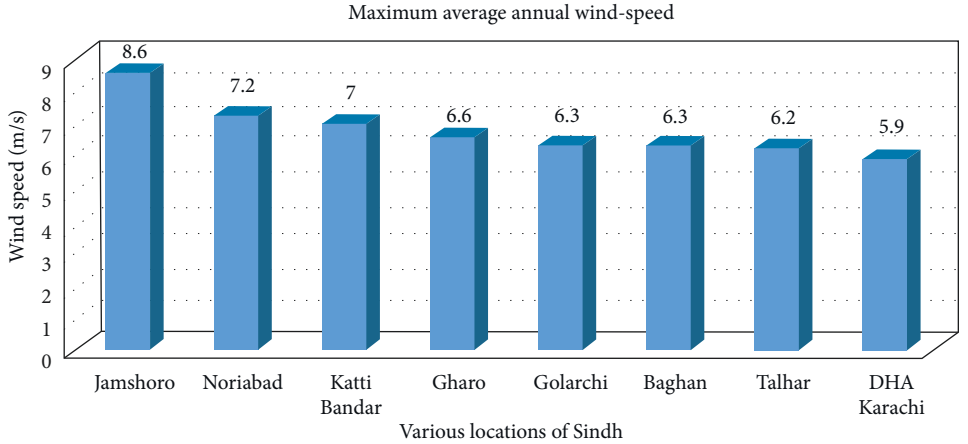

Figure 2: Wind-speeds of various locations of Sindh.

Table 2: Wind energy projects were installed in Jhimpir [19, 27–31].

S. No.	Name of projects	Capacity (MW)	COD
1.	Fauji fertilizer co. Energy Ltd	49.50	May 16, 2013
2.	Zorlu enerji Pakistan Ltd	56.40	July 26, 2013
3.	Three gorges first wind farm Ltd	49.5	November 25, 2014
4.	Sapphire wind power co. Ltd	52.80	November 22, 2015
5.	Yunus energy wind farm	50	16 September 2016
6.	Metro power co. Ltd	50	16 September 2016
7.	Tapal wind energy Ltd.	30	7 October 2016
8.	Master wind energy pvt Ltd.	52.8	14 October 2016
9.	Gul wind energy Ltd.	50	18 October 2016
10.	Sachal energy development Ltd.	49.5	18 April, 2017
11.	United energy Pakistan Ltd.	99	16 June, 2017
12.	Hawa energy Ltd.	49.6	15 March, 2018
13.	Jhimpir wind power Ltd	49.735	16 March, 2018
14.	Artistic energy Ltd.	49.3	16 March, 2018
15.	Three gorges second wind farm Ltd	49.5	30 June, 2018
16.	Three gorges third wind farm Ltd	49.5	9 July, 2018
17.	Tricon boston corporation Ltd. (A)	49.6	16 August, 2018
18.	Tricon boston corporation Ltd (B)	49.6	14 September, 2018
19.	Tricon boston corporation Ltd (C)	49.6	11 September, 2018
20.	Master green energy Ltd	50	20 August 2021
21.	Tricom wind power Ltd	50	31 August 2021
	Total capacity	1086 MW	

Table 3: Wind energy projects were installed in Gharo [19, 27–31].

S. No.	Name of projects	Capacity (MW)	COD
1.	Foundation wind energy II Ltd	50	December 10, 2014
2.	Foundation wind energy –I Ltd	50	April 11, 2015
3.	Tenaga generasi Ltd.	49.5	11 October 2016
4.	Hydro China dawood power Ltd	49.5	5 April, 2017
5.	Zephyr power Ltd.	50	27 March, 2019
	Total capacity	249 MW	

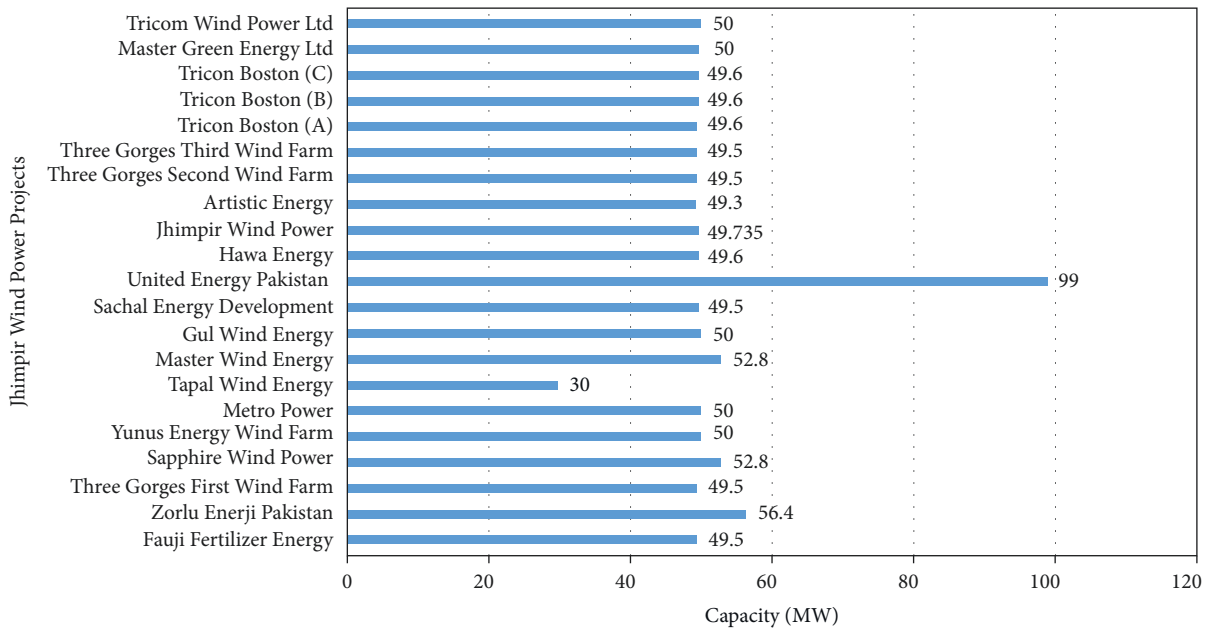

Figure 3: Wind power projects in Jhimpir.

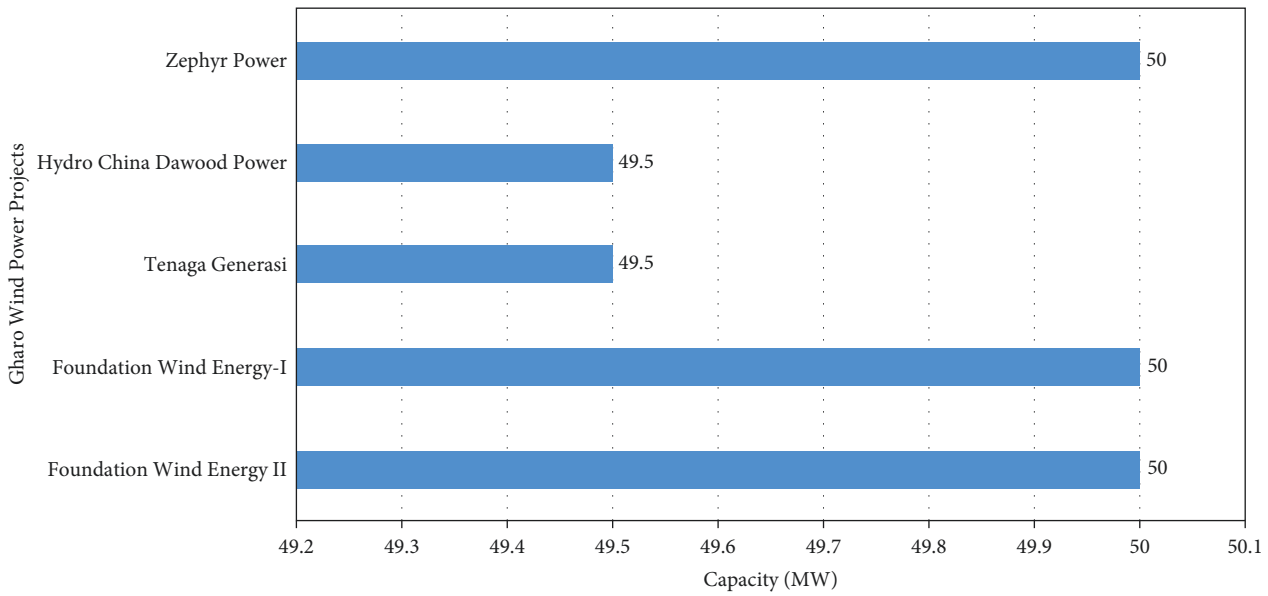

Figure 4: Wind power projects in Gharo.

Table 4: Wind projects under financial closing and construction phases [30, 31].

S. no	Name of projects	Capacity (MW)	Financial closing date
1.	Lakeside energy pvt. Ltd.	50	18 November, 2019
2.	Artistic wind power pvt. Ltd	50	
3.	Liberty wind power 1 pvt. Ltd.	50	
4.	Indus wind energy Ltd.	50	
5.	Act2 wind pvt. Ltd.	50	
6.	Metro power company Ltd.	60	
7.	Liberty wind power 2 pvt. Ltd.	50	
8.	Gul ahmed electric limited	50	
9.	Din energy Ltd.	50	
10.	Nasda green energy pvt. Ltd.	50	
	Total capacity	510 MW	

The following twenty-six wind projects of Jhimpir and Gharo having a cumulative capacity of 1335 MW have operated commercially and integrated into National Grid, as shown in Tables 2 and 3, as well as in Figures 3 and 4, respectively.

It has been observed that 21 wind projects have been placed in operation at Jhimpir, in which United Energy Pakistan Ltd., has a maximum installed capacity of 99 MW, which has came into operation on 16 June 2016. Besides, the Sachal Energy Development Ltd., has the least wind power generation of 49.5 MW, which has COD of 18 April 2017.

From Figure 4, it can be noticed that there are three projects which have a maximum installed capacity of 50 MW and the rest of the two has 49.5 MW at Gharo. These locations have presented an abundance of wind resources, which can be further utilized for bulk clean energy production in the future.

In addition, the following ten Projects having a cumulative capacity of 510 MW have accomplished financial closing and are under construction phase at Jhimpir as shown in Table 4 and Figure 5. The Metro power company will install a maximum wind power project of 60 MW and the other remaining nine wind projects will be of 50 MW. These will generate electrical energy using the available wind resource of Jhimpir, which had the financial closing in November 2019.

To explore the capability of wind energy resource that has been available in Sindh, the Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis has been conducted. These characteristics assure the possible strategies of wind power effectively.

3.1.1. Strengths

(a) *Abundant Source*. The installed projects have shown an abundance of wind potential in Sindh province for power generation. The installed and under-constructional projects have been implemented and considered for Jhimpir and Gharo, Sindh having capacities of 1335 MW and 510 MW as shown in Tables 2 to 4, respectively.

(b) *Cost-Effective Tariff*. The national electrical power company can get enough and cost-effective tariffs for their customers. The off-grid consumers can also be benefited by utilizing wind-generated power at a

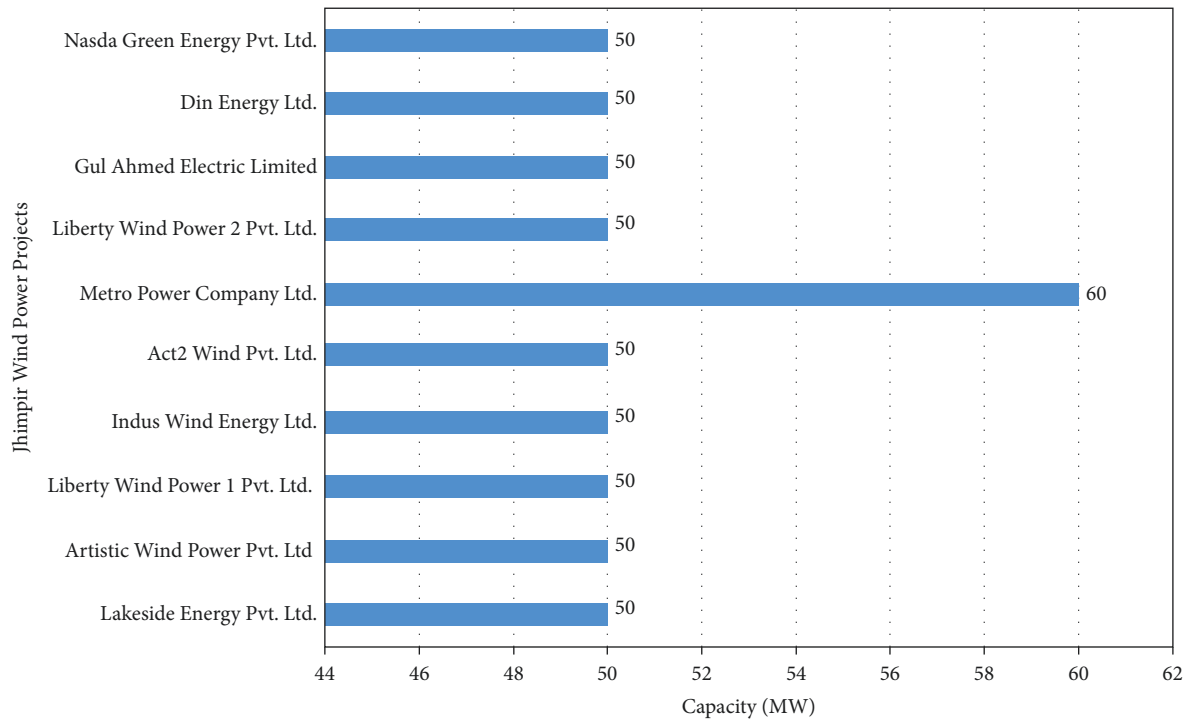

Figure 5: Wind power projects capacity.

cheap unit price, i.e., 10 cents US cents/kWh efficiently [32].

(c) *Bulk Power Generation*. Wind Power can generate 7.653 GWh energy units annually from Sindh for power utilization and integrated into an interconnected national grid [25].

(d) *Contribution of Several Independent Power Plants (IPPs) into National Grid Power*. There are several IPPs in Pakistan, which have installed projects at wind corridor to contribute to the national energy hub and provide bulk power to neutralize the energy supply and demand gap efficiently. Those wind power projects and Tables 2–4 have exposed their locations. These projects will help the government to provide incentives and cost-effective tariffs to consumers.

(e) *Reduction in Green House Gas Emissions (GHGEs)*. The wind power projects reduce GHG emissions adequately. It has been computed that 50 MW wind power can produce 110 GWh annual electrical power and can mitigate about 63620-ton CO_2 effectively [33].

3.1.2. Weaknesses

(a) *Turbine Height Increases with Capacity*. The large capacity wind turbines required great height to utilize wind resources efficiently and generate bulk electrical power. The wind power changes with variation in the altitude effectively [34].

(b) *Robust Foundation for Turbine Required*. The giant wind turbines have terrific weight, and it requires a solid foundation to sustain natural environmental challenges.

(c) *GHGE during Foundation*. During the foundations for wind turbines, the required constructional material (cement, soil, rocks, etc.) emits GHGE, which produce breathing problem to workers as well as residents of the site.

(d) *Unwanted Noise of Wind Blades and Generators*. The cutting of high-speed wind through large wind turbine blades causes unwanted and annoying noise, which disturbs the ecological peace. Along with blades, the generator converting the kinetic energy of wind into electrical energy also produces undesirable noise. Therefore, giant wind turbines have usually installed away from populated areas. The control and operation sections of power plants are used to construct as sound proof.

(e) *Proper Operation and Maintenance (O&M)*. The wind turbine has attached several auxiliary parts. If any of its components is detached or damaged, it can cause severe injury due to heightened high turbines. Therefore, it is mandatory to conduct scheduled O&M to avoid accidents and casual deaths.

3.1.3. Opportunities

(a) *Wind Power Share by 2030*. According to Energy Security Action Plan 2006, the National on-grid power generation must have at least a 5% share from wind power by 2030. The incentives will be provided to Wind IPPs by the Wind Power Project Development of Pakistan for multiple perspectives [35].

Table 5: Solar resources in major cities of Sindh.

Solar power cities parameters	Daily sum (kWh/kWp)			Yearly sum (kWh/kWp)		
	Hyderabad	Sukkur	Karachi	Hyderabad	Sukkur	Karachi
Direct normal irradiations	5.0	4.6	4.2	1826	1680	1534
Global horizontal irradiation	5.6	5.2	4.8	2045	1899	1753
Photovoltaic power potential	5.0	4.6	4.2	1826	1680	1534

(b) *CPEC Projects*. The China Pakistan Economic Corridor (CPEC) has contributed among several fields for the socio-economic development of Pakistan. Some of them such as Three Gorges Pakistan, Sachal Wind Farm, UEP Wind Farm, and Hydro China Dawood Wind Farm, have located in Jhimpir as represented in Table 2.

(c) *Employment Chances*. When wind power plants will be initiated by foreign and/or local investors, they will require local workers and engineers to fulfil their operational tasks. In this way, the local residents near planned wind projects will get employment and can manage their expenses appropriately.

3.1.4. Threats. Following are the possible threats to wind power development:

(a) *Lack of Power Management*. AEDB is responsible for renewable energy projects across the country, and the PEPCO and NEPRA are Power Company and regulatory authority, respectively. If generated power will be managed appropriately, the installed wind projects will operate efficiently.

(b) *Financial Crisis*. The country requires investors to invest and enhance its economic value in the world. If investors will contribute greatly, especially in Sindh, the bulk electrical power can be generated and reduced the capital cost; otherwise, natural wind resources will be wasted.

(c) *Landscape and Land Use*. These large wind power projects have used to install away from populated areas. It causes transportation issues of heavy equipment, and the land used for projects must be properly purchased or registered to avoid hindrances in the electrical power generation afterward.

(d) *Bird's Mortality*. These wind turbine blades are giant and have enough sharpness that the bird's mortality ratio increases and creates a significant loss to ecological life.

(e) *Synchronization with Grid Power*. The wind power projects generate AC power, synchronizing with conventional grid power through proper synchronization method and efficient utilization. If the frequency of 50 Hz could not match with grid power properly, the power mismatch and fault will occur and can cause a blackout across the country.

(f) *Variable Power Source*. Wind is a natural resource and has fluctuating behaviour due to variable wind speed. It generates variable power and requires various auxiliary components to provide constant output power. It also requires an automatic brake system to protect blades from high wind speeds during thunderstorms.

Table 6: Solar PV power projects with financial closing.

S. no	Name of project	Capacity	Location
1.	Meridian Energy (Pvt.) Ltd	50	Sukkur
2.	HND Energy (Pvt.) Ltd	50	
3.	Helios Power (Pvt.) Ltd	50	

Table 7: AEDB solar PV projects under Category-III.

S. no.	Name of projects	Capacity (MW)	Location
1.	RE Solar I (Pvt) Ltd	20	Dadu
2.	RE Solar II (Pvt) Ltd	20	
3.	ET Energy Fateh Jang (Pvt) Ltd	50	Thatta
4.	ET Energy Pakistan 1 (Pvt) Ltd	25	

3.2. Solar Energy. Pakistan has a unique geographical location in the world map with a latitude of 23.45°N to 36.7°N and a longitude of 61°E to 75.5°E. It has an enormous solar potential of 2900 GW [36]. Its solar data has been collected by the World Bank Group and Energy Sector Management Assistance Program (ESMAP) using the SOLARGIS tool. The direct average irradiation, global horizontal irradiation, and photovoltaic power potential data of Pakistan have been represented by Global Solar Atlas [37]. These values have been collected of large cities of Sindh i.e., Hyderabad, Sukkur, and Karachi to present great solar potential in these places. In Table 5, can be seen solar resources in the Major cities of Sindh.

It has been observed that the direct normal irradiations are sufficient at Hyderabad, Sukkur, and Karachi, having enough potential to utilize it for 5.0, 4.6, and 4.2 kWh/kWp daily and has a yearly sum of 1826, 1680, and 1534 kWh/kWp, respectively. Besides, the global horizontal irradiation values of these selected cities (Hyderabad, Sukkur, and Karachi) have attained a daily sum of 5.6, 5.2, and 4.8 kWh/kWp and a yearly sum of 2045, 1899, and 1753 kWh/kWp, respectively. The photovoltaic power potential for these dominated cities of Sindh (Hyderabad, Sukkur, and Karachi) have also been collected. Their daily and yearly sum values have been calculated as 5.0, 4.6, and 4.2 kWh/kWp daily and have a yearly sum of 1826, 1680, and 1534 kWh/kWp, respectively. Hence, the existing solar resources have been

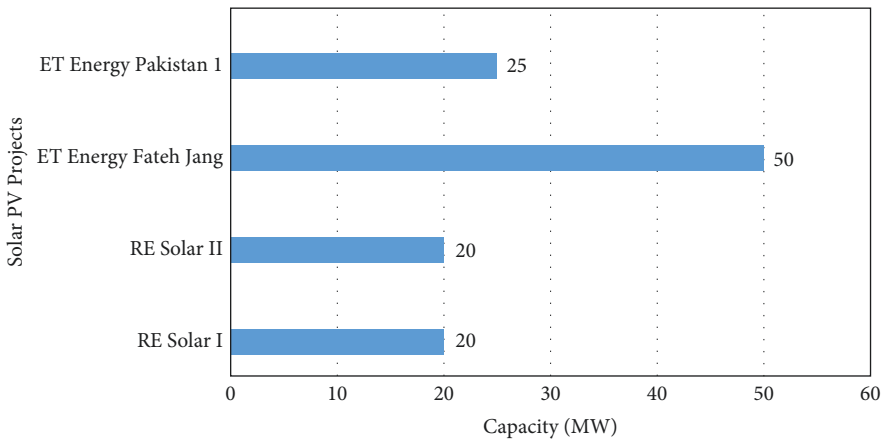

Figure 6: AEDB solar power projects in Sindh.

Table 8: Energy Departrment, Government of Sindh under Category-III [41].

Sr. No.	Name of projects	Capacity (MW)	Location
1.	New Ggeneration	200	Jamshoro
2.	MCC New Energy co. PK (Pvt) Ltd	100	
3.	China National Power Ltd	100	
4.	Technomen Kinetics (Pvt) Ltd	100	
5.	National Power & Water Co. (Pvt) Ltd	50	
6.	ACT 2 Solar (Pvt) Ltd	50	
7.	IDC (Private) Limited	50	
8.	Sindh Renewable Energy Co. (pvt) Ltd	50	
9.	MI Solar	20	
10.	Gul Ahmed Energy Ltd	50	Thatta
11.	Tricom Solar Power (Pvt) Ltd	50	
12.	Metro Solar Power Ltd	50	
13.	Sukkur Solar Park (Pvt) Ltd	20	
14.	Thatta Solar Park (Pvt) Ltd	20	
15.	Al Tariq & Laguardia	20	
16.	Siachen Energy Limited—II	100	
17.	Zhongxing Telecom (Pvt) Ltd (ZTE)	100	Shaheed Benazirabad
18.	Technomen Kinetics/ZTE	20	
19.	Siddiqsons Ltd	50	Khairpur
20.	Artistic Milliners (Pvt) Ltd	50	Sukkur

represented, which will ultimately motivate the investors to install maximum solar projects in Sindh. [38].

According to AEDB Renewable Energy Policy 2006, Sindh has high solar potential terrains. It receives about 2 MWh/m^2/year, and the annual average horizontal solar radiation/day is calculated as 5.48 kWh/m^2 [39, 40]. Consequently, various solar power projects have been systematized under the Alternative Energy Development Board (AEDB), which are in different stages of development in Sindh, as presented in Tables 6 and 7 and Figure 6 [31, 41].

Following three Solar PV Power Projects approved for Sukkur with a cumulative capacity of 150 MW have accomplished Financial Closing of December 2022 and are under constructional works as shown in Table 6.

Besides, another Solar PV Power Project i.e., Siachen Energy Ltd-I of 100 MW has been approved project for Thatta under Category-II of CCOE decision; which also has been planned project in Indicative generation Capacity Expansion Plan (IGCEP′2021–30); approved by NEPRA [42].

In addition, the following 24 Solar PV Projects have been categorized under Category-III of CCOE decisions based on IGCEP outcomes, in which 04 AEDB Solar PV Projects for 115 MW and 20 for 1250 MW Solar PV Projects approved by the Energy Department, Government of Sindh have been listed as represented by Table 7, Figure 6 and Table 8, Figure 7, respectively.

It can be noticed that the ET Energy Fateh Jang Solar project has an installed capacity of 50 MW situated at Thatta based on its feasible location and energy output. The two RE Solar projects have installed of the capacity of 20 MW each at Dadu Sindh, where the future expansion of solar projects is possible.

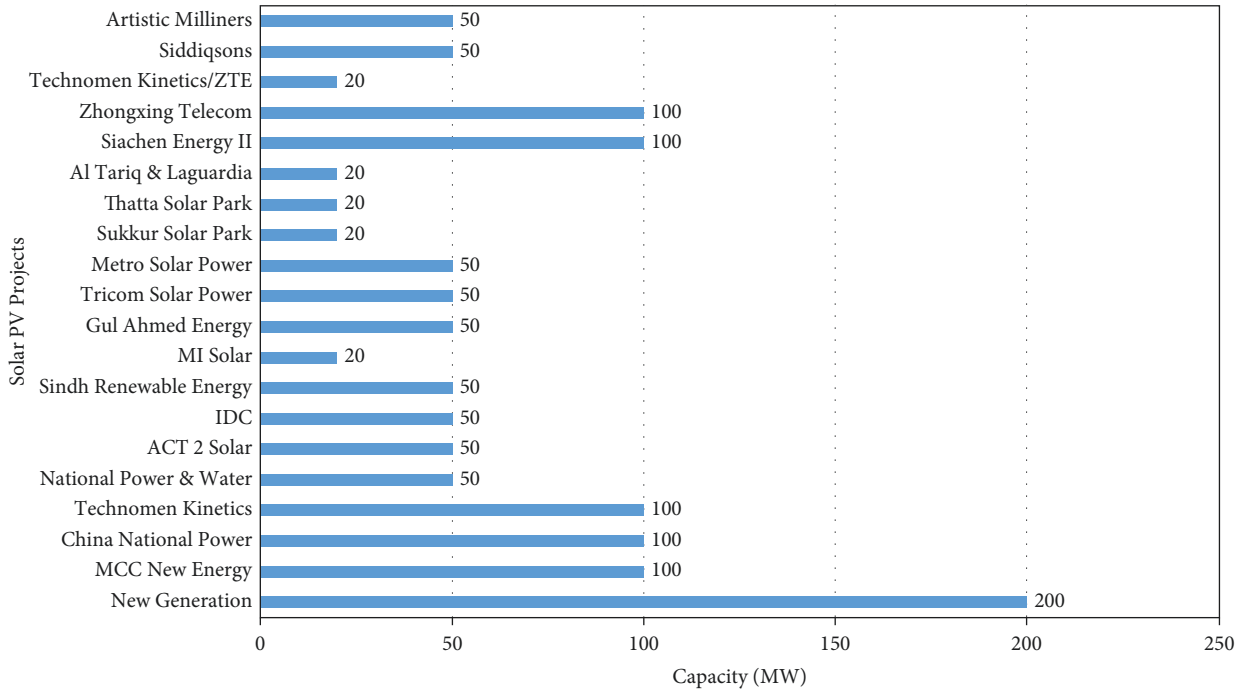

Figure 7: Energy department solar power projects in Sindh.

It can be observed that New Generation Solar PV Power Project installed in Jamshoro circumstances have a great installed capacity of 200 MW initiated by the Energy Department due to high solar irradiations and solar power at this location. Among the other projects, 20 MW is the minimum installed capacity of Solar Power, which also can be extended further as per requirements.

The above-stated projects and their locations have sufficient solar radiations, which can generate bulk power and can be integrated into grid power. Therefore, SWOT analysis for available solar resources in Sindh has shown favorable outcomes to influence the investors to participate into the financial development of Pakistan.

3.2.1. Strengths

(a) *Solar Resource Potential*. It is a natural and abundant source of energy available in Sindh. Proper utilization of solar energy sources can lead to enough power generation for the country and reduce the electrical burden on the national transmission line system.

(b) *High Solar Radiations*. Sindh has enough solar radiations and perfect solar maps presented by World Bank and ESMAP. [43] These maps will lead the consumers for proper utilization of solar resources and assist them during the installation of short-term and long-term solar projects.

(c) *Several Applications*. The solar resource can be utilized for numerous applications such as electrical power generation for all types of consumers, heating, cooking, agricultural uses, electric vehicles, and off-grid and grid-connected solar projects.

(d) *Environment Friendly*. Solar energy is a clean and sustainable energy source, and it uses Photovoltaic (PV) panels or Collected Solar Power (CSP) technology for various applications. It only emits GHG emissions from 26 to 217 gCO_2, among the other renewable energy sources [19].

(e) *Lowest O&M*. The solar project requires only 1% of running costs of capital costs because it contains static components for solar power utilization. Therefore, no significant O&M costs are required. The cost required in solar projects is to clean panels and replacement of any damaged component [44].

3.2.2. Weaknesses

(a) *High Initial Cost*. The solar projects require high initial capital investment for its installation due to the cost of PV panels and their supporting components. These costs increase the cost of generated energy per Watt.

(b) *Large Area Requirements*. The large capacity solar power plants require a vast area for their installation due to the size of PV panels. Therefore, large solar power plants have avoided for bulk power generation.

(c) *Feasibility and Forecasting of Projects*. The appropriate forecasting, feasibility, and planning are mandatory for long-term solar projects. These aspects will be beneficial to energy departments in utilizing the available solar resources of Sindh as well as implementing large-scale solar projects accordingly. It will reduce extra expenses during the project

Table 9: Thermal power generation projects of Sindh [49].

Description	Operational power generation projects in sindh			
GENCO	I		II	IV
Names	Jamshoro Power Company Limited (JPCL)		Central Power Generation Company Limited (CPGCL)	Lakhra Power Generation Company Limited (LPGCL)
Locations	Jamshoro	Kotri	Guddu, Kashmore	Jamshoro
Plant details	1 × 250 MW (S.T) + 3 × 210 MW (S.T) + 2 × 660 MW)	(4 × 25 MW (G.T) + 1 × 44 MW (S.T)	16 [2 × 110 MW (S.T.) + 2 × 210 MW (S.T.) + 4 × 100 MW (G.T) + 2 × 100 MW (S.T.) + 2 × 136 MW (G.T) + 1 × 143 M.W (S.T) + 2 × 261.0 MW (G.T.) + 1 × 225 MW (S.T.)]	3 × 50 MW (S.T.)
Plant types	Thermal Power Plants		Combined Cycle (C.C.)	Thermal
Fuel types	Natural gas, residual furnace oil (RFO), coal		Natural gas, residual furnace oil (RFO)	Coal
Gross capacity	2344 MW		2431.70 MW	150 MW

lifetime and provide optimal and efficient electrical power generation, and it can be integrated into the national grid properly.

3.2.3. Opportunities

(a) *Global Attention towards Solar Power*. Solar power plants have widely been implemented in various parts of the world. It has enhanced several opportunities for investors as well as consumers to improve the usage of solar power in their daily life. Consequently, AEDB has initiated various renewable energy projects for Sindh to improve the socioeconomic development of the country [45].

(b) *Solar Plants as an Alternate Solution to Power Consumers*. Due to inconsistent oil prices, the consumers of conventional grid power have moved towards a clean and cost-effective source of energy. These off-grid solar plants have become more accessible for residential customers to meet their load demands efficiently.

(c) *Source of Employment*. It has opened opportunities for technical and nontechnical individuals due to extensively installing solar power projects across the country.

(d) *Net Metering*. Through solar power projects, the prosumers can install projects on their sites and can sell power to distribution companies through a net metering system as approved by NEPRA [46].

3.2.4. Threats

(a) *Immature Technology*. The solar power plants require additional time to become mature and feasible to install their technology accessibly in the country as of conventional power plants.

(b) *Lack of Incentives for Off-Grid Small Solar Plants*. The customers are decreasing conventional generated power requirements indirectly by utilizing their generated solar power. However, no such incentives have been provided to them to reduce national energy demand.

3.3. Conventional Energy Sources. The electrical power generation in Pakistan is mainly relying on fossil fuels. According to Paris Agreement 2015, Pakistan targets to minimize GHGE by 20% until 2030 and improve the energy mix with renewable energy sources [47]. The fossil fuels primarily contain coal, residual furnace oil (RFO), and natural gas (NG) energy sources, which are the most consumed conventional sources due to their availability and generation companies (GENCOs) as shown in Table 9. Besides, the largest coal mines of Pakistan as well as Asia are available in Tharparkar, Sindh. It has ranked seventh in the world and covers 9000 km^2 with around a coal reserves of 175 billion tons [48].

Table 9 represents the various installed Generation Companies (GENCOs) of Pakistan, in which all these three GENCOs have been installed across Sindh due to its location and easy availability of resources. Table 9 has presented the installed plant details, fuel types, and gross capacity for electrical power generation. The CPGCL has the maximum gross capacity having 2431.70 MW in Sindh using CC plant type and NG, and RFO as energy sources effectively. Following Jamshoro Power Company Ltd (JPCL) having a gross capacity of 2344 MW with NG, RFO, and coal sources, LPGCL has placed in the last with only the gross capacity of 150 MW and consumes coal power.

3.3.1. Strengths

(a) *Conventional Thermal Plants since Decades*. These plants have mature technology that the issues concerned to them can easily handle. They can be modified with the latest equipment to enhance their operational efficiency.

(b) *Frequency Synchronization*. These power plants generate electrical power in AC voltage and at a

Table 10: CPEC energy projects [50].

S. no.	Names of projects	Capacity (MW)	Location	Status
1.	Coal-fired Power Plant	1320	Port Qasim Karachi	Operational
2.	Engro Thar Coal Power Project	660		
3.	Surface Mine Block II Thar Coalfield	660	Tharparkar	Operational
4.	SSRL Thar Coal Block-I	1320		
5.	HUBCO Thar Coal (Thar Energy)	330		
6.	Thal Nova Thar Coal Power Project	330	Tharparkar	In process
7.	Thar Mine Mouth Oracle Project	1320		

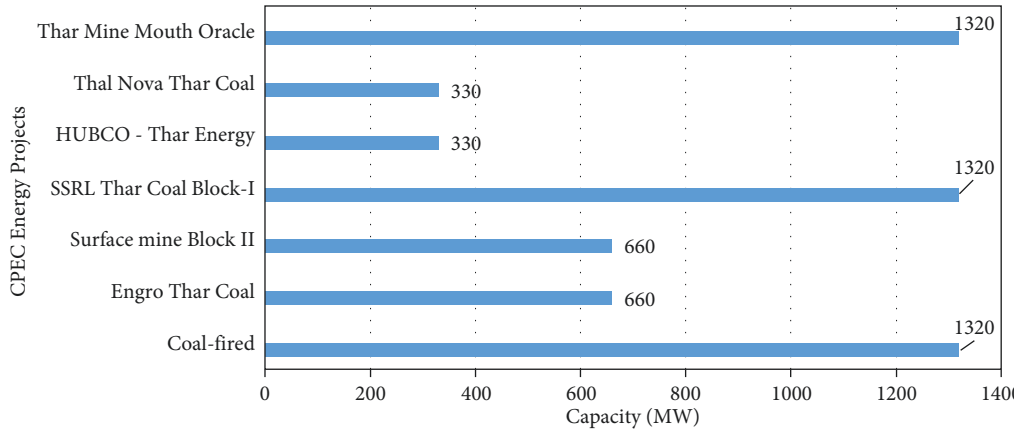

Figure 8: CPEC energy projects.

standard frequency of 50 Hz. It becomes easy to integrate power generation into the national transmission system without any other auxiliaries.

(c) *CPEC Coal Projects*. The available coal resources of Sindh have been utilized efficiently with the collaboration of CPEC projects. China Pakistan Economic Corridor (CPEC) has initiated the following coal energy projects. Among them, some are in the operational phase, and some are in the construction phase, as listed in Table 10 and shown in Figure 8.

3.3.2. Weaknesses

(a) *Power Blackout*. When a significant fault occurs in an interconnected grid system, it will travel in an entire power system and results into a power blackout. Afterwards it becomes challenging to re-energize the power system again.

(b) *Fuel Transportation*. Transportation of conventional energy fuels (Crude oil, coal, and diesel) from dealer to requisite location increase project expenditure.

(c) *Environmental Hazards*. Air pollution and global warming increases with conventional sources [51].

3.3.3. Opportunities

(a) *Cost Minimization*. Consumption of available sources in the province minimizes the import of costlier sources from other parts of the country efficiently

(b) *Job Openings*. The opportunities for unemployed graduates can enhance through newly installed and upcoming power projects

(c) *Electrical Power Production*. Bulk power generation and integration into the national power pool may decrease the energy supply-demand gap

(d) *Socio-Economic Development*. China has initiated their great investments for power projects, which can improve the socio-economic development and represents the country globally for having coal in abundance

3.3.4. Threats

(a) GHG Emissions. Expect a rise of CO_2 emissions for 55.2 million metrics by 2030 from the utilization of these sources [52]

(b) *Food Security*. The food security issue can be increased due to the utilization of largely cultivated lands

(c) *Water Security*: The water security concerns for residents can be attained due to the consumption of water resources for thermal power generation sufficiently

(d) *Fuel Price Variation*. Variable oil prices and fuel adjustment prices has resulted from fossil fuels into an expensive source of electricity

Table 11: Detailed SWOT analysis for preferred energy sources in Sindh.

SWOT sources	Strengths	Weaknesses	Opportunities	Threats
Wind	1. Abundance 2. Cheap tariff 3. Bulk power 4. GHG reduced	1. Large height for large capacity WT 2. Strong foundation required 3. GHGE production during groundwork 4. Noise pollution 5. High O&M required 6. Conductor cost increased	1. Wind power share by 2030 2. CPEC projects 3. Employment chances	1. Lack of power management 2. Financial crisis 3. Landscape and land use 4. Bird's mortality 5. Synchronization with grid power 6. Variable power source
Solar	1. Solar resource potential 2. High radiation 3. Numerous applications 4. Environmental friendly 5. Least O&M	1. High capital cost 2. Large area required 3. Feasibility and monitoring of projects	1. Centre of attraction globally 2. Alternate solution to customers 3. Source of employment 4. Net metering	1. Immature technology 2. Lack of incentives for mini off-grid systems
Conventional sources	1. Coal abundance at tharparkar 2. Several conventional power plants have installed 3. Efficient utilization of resources 4. CPEC projects	1. Chances of blackout due to interconnected system 2. Fuel transportation issue 3. Air pollution	1. Consumption of available sources reduces import costs 2. New opportunities with new projects 3. Generated bulk power will minimize demand-supply gap 4. Socio-economic development	1. Rise of CO_2 emissions 2. Installation of mega projects causes water and food security issues for local residents

The comprehensive SWOT analysis of the current study has presented in Table 11. It has been investigated from the latest and relevant research studies that the wind, solar and conventional energy sources exist in Sindh effectively. Therefore, its SWOT constraints have shown below with their key significance.

4. Policy Implications for Power Generation

(a) According to the Vision 2025 report, the power generation of Pakistan must be double i.e., 45,000 MW, to provide continuous and cost-effective electricity. The electricity access must increase from 67% to 90% among the population of the country. The overall installed generating capacity of about two-thirds is thermal in Pakistan, which has raised the cost of electricity. Therefore, the average cost/kWh must reduce to 25% by enhancing the generation mix among oil, gas, hydro, coal, nuclear, solar, wind, and biomass energy sources.

(b) The overall share of indigenous energy sources in the power generation must improve by 50%, keeping their financial viability, scalability, ecological impacts, and risk assessment aspects into consideration.

(c) Increase the energy-efficient appliances that must organize the Demand Side Management (DSM) up to 80% adequately.

(d) The power distribution efficiency must maximize, and its losses must reduce by 10%. The budgetary losses concerned with transmission and distribution systems must diminish to enhance country's economic development.

(e) The official reforms and regulatory frameworks must be introduced to enhance transparency and efficacy in the energy sector of the country.

(f) In Pakistan, about 1200 MW of energy has been lost due to system inefficiencies. The baseline efficiency standards must be established and supervised to motivate new investments for a well-organized system across the country [53].

These policy implications can be satisfied by the proposed SWOT analysis along with existing sources in the current study for Sindh and inexpensive electricity can be provided all across the country satisfactorily.

5. Recommendations for Energy Sources

(a) Improvement of subsidies and incentives are mandatory to increase the installation of RE projects in Sindh

(b) The awareness and benefits should be informed to local residents of the province to fulfil their basic electricity needs

(c) Facilitation centre should be established for the future contribution of investors into energy projects

(d) International standards must be implemented during energy projects for optimal operation

(e) According to World Bank, wind and solar power should be expanded up to 30% by 2030 in the national electrical power generation i.e., equivalent to 24000 MW [43]

(f) The energy expansion will ultimately minimize electricity cost/kWh, attains energy securities, mitigate carbon emissions and save $5 billion for 20 years

(g) The share of conventional fossil fuels into the generation mix must reduce for an optimal and economic electricity

The conducted study has discussed the most consumed and copious energy sources, which are either available generally or at least any one source is present in every country. The socio-enviro-economic constraints have been elaborated, which occurs along with these energy sources broadly. The strategic policies for electric power generation have also been listed, which may be relevant to the energy policies of every progressive country. For the implementation of power projects, the various countries can also take a quick vision about the least or averaged capacity installed energy projects in Sindh for their respective regions and/or designated purposes. This SWOT analysis of energy sources will open the chances for other researchers to explore more benefits and purposes in this scope.

6. Conclusion and Future Directions

The present study has provided a comprehensive SWOT analysis on existing abundant energy sources of Sindh, which generates bulk electricity for the country. Among the sources, wind, solar, and conventional sources (coal, natural gas, and oil) have been widely utilized. During the investigation, it has analysed that several energy projects have either become operational and connected to the National grid or under different stages of the projects to achieve an efficient roadmap of sustainable electric power generation. The various stated energy projects have represented great potential in Sindh, which can ultimately mitigate the electrical power crisis across the country. Moreover, the socio-enviro-economic constraints have also been elaborated and can achieve useful results by considering the state's financial profits, energy security, ecological protection, zero carbon projects, and smart hybrid microgrid systems. It has been concluded that the SWOT study of these renewable energy projects have great worth in the future for power generation and several stakeholders and individuals (researchers and engineers) can contribute their capabilities in a unique way. These sources can also be utilized in a different way which consumes more RE sources, offer maximal prosumers, and least electricity tariff to generate revenue significantly.

Abbreviations

AC: Alternating current
AEDB: Alternative energy development board
CC: Combined cycle
COD: Commercial operation date
CO_2: Carbon dioxide
CPEC: China pakistan economic corridor
CSP: Collector solar power
DHA: Defence housing society
DRE: Distributed renewable energy
DSM: Demand side management
ESMAP: Energy sector management assistance program
FFC: Fauji fertilizer company
GENCO: Generation company
GHGE: Green house gas emissions
GT: Gas turbine
HUBCO: Hub power company ltd
IEEFA: Institute for energy economics and financial analysis
IPPs: Independent power plants
IPS: Integrated power solution
IRENA: International renewable energy agency
NEPRA: National electric power regulatory authority
NG: Natural gas
NREL: National renewable energy laboratory
O&M: Operation and maintenance
PEPCO: Pakistan electric power company
PV: Photovoltaic
RE: Renewable energy
RES: Renewable energy source
RFO: Residual furnace oil
ST: Steam turbine
SWOT: Strengths weaknesses opportunities threats
UEP: United energy Pakistan.

Data Availability

All data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Asadullah Shaikh did the Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing, original draft, and Resources; Pervez Hameed Shaikh did the Formal analysis, Investigation, and Supervision; Laveet Kumar did the Formal analysis, Writing, review and editing, and Resources; Nayar Hussain Mirjat did the Investigation and Validation. Zubair Ahmed Memon did the Investigation and Supervision. Mamdouh El Haj Assad did the Methodology, Writing, review and editing, Resources, and Validation. Reza Alayi did the Formal analysis, Investigation, Supervision, and Resources. Behrouz Eskandarpoor did the Formal analysis, Investigation, Supervision, and Resources.

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