Infrastructure of Sustainable Energy Development in Pakistan: A Review

Sidra Kanwal, Bilal Khan, and Muhammad Qasim Rauf

Abstract—**Pakistan is an energy-resourceful country with vast and untapped renewable energy sources (RESs). The wind, solar, and biomass of the country are practically capable of ending a power sector collapse caused by demand-supply variances. A significant percentage of Pakistan's population resides in rural areas. For rural population, the lack of connection to the mainstream of national development is a direct consequence of frequent power blackouts and, in certain cases, a lack of grid connection altogether. Lucrative features of smart grid are not fully incorporated into the power network yet, but policy-makers are paying attention to increase RES reliance. A comprehensive study describing the renewable energy potential of Pakistan is of importance. This research work attempts to present a collective summary of Pakistan's renewable energy potential. A statistical analysis of the proposed and installed projects in various districts are presented. This paper elaborates the pressing needs of renewable energy integration for resolving Pakistan's energy crisis. Renewable energy projects are acclaimed in this paper for affording higher living standards and better job opportunities than the fossil fuel based industry in Pakistan. Integrating RESs into the national portfolio is guaranteed to offer profound socio-economic benefits to Pakistan's rural population.**

Index Terms—**Biomass energy, geothermal energy, renewable energy source (RES), solar energy, smart grid, wind energy.**

I. Introduction

Pakistan's energy crisis is attributed to an ever-increasing population size, followed by consumers being subjected to frequent load shedding. A stable energy supply is crucial for the development of the social and economic fabric of the society. The task is feasible in terms of home-grown conventional energy reserves. Pakistan primarily relies on foreign imported fossil fuels to fulfill its energy demand, and expends approximately 20% in crude oil imports [1].

Pakistan has about 2.56% of the total worldwide population, and is the world's sixth most populous country [2]. The geographical location of Pakistan benefits international maritime trade immensely and presents a lucrative paradigm for foreign investment. Stable energy supplies to handle current and future energy demand will depend on power generation from sustainable energy sources. Imported crude for electricity generation is an established fiscal burden on the economy [3]—a situation further aggravated by depleting home-grown natural gas reserves. The country's installed power generation capacity is rated at 17000 MW, with a peak demand of 22000 MW. Figure 1 illustrates that the power demand is growing by 8% to 10% annually, in contrast with an annual supply growth of only 7% [4].

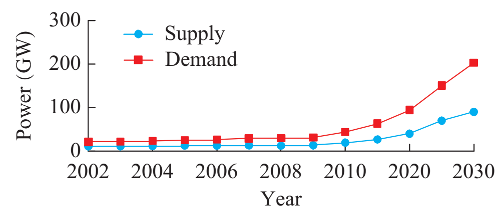

Fig. 1. Power demand-supply trends of Pakistan.

Urban areas are frequently subjected to a regular 8 to 10 hours of load shedding, while the average load shedding in rural areas is 20 hours. The contribution of renewable energy sources (RESs) in power generation was reported to be less than 1% in 2010. However, the government seeks to ramp up RES contribution by 5% until the year 2030 [5]. Residential and commercial sectors are major electricity consumers due to the significant number of indoor electricity appliances. The increase in the number of appliances is a direct consequence of the rapid technological development and urbanization of the rural community. The attention gathered by the vast and untapped renewable energy reserves in Pakistan is expected to effectively meet the country's energy requirements [7].

A summary of Pakistan's current energy resources is depicted in Fig. 2 [8]. The current energy shortfall indicates that the existing energy infrastructure is insufficient for countering the increasing energy demand. Thus, the ultimate solution of the problem is to increase the renewable energy penetration in Pakistan's energy spectrum. Pakistan has a huge potential for RES, despite little attention has been paid to its benefits. Chief sources for electricity generation in Pakistan are natural gas, oil, and coal. Hydro energy contributes 29% toward the total energy mix.

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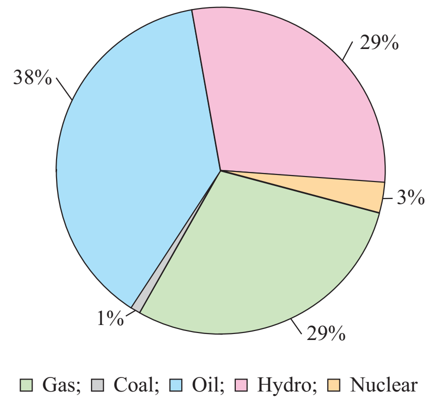

Fig. 2. Share of conventional sources for power generation in Pakistan.

Countries adopting RESs for power generation experience both positive and negative impacts. Even though RES adoption provides self-sufficiency of the energy, the country's heavy reliance on fossil fuels shows that RESs are not sufficient to phase out fossil fuels entirely. Reference [9] investigated the factors of economic growth, energy consumption, fiscal development, and relative prices for high-income organization for economic cooperation and development (OECD) and non-OECD countries. Reference [10] investigated the link between economic development and energy consumption, and indicated that economic growth increases together with renewable energy consumption. Reference [11] addressed the issues related to the electricity sector, analyzed the current regime's policies, and discussed their impact on the electricity sector. Also, it is found that the cost of fuel and the emission of hazardous gases are increasing due to the imports of fossil fuels.

Reference [12] provided statistical information about RESs in Pakistan. It is found that RESs have a huge potential, the utilization of which will overcome the energy crisis. Reference [13] inspected Pakistan's energy sector in detail by addressing the infrastructure that generates and distributes the energy. It asserted that the consumption of RESs plays a significant role in economic growth and argued that renewable energy generation should be increased. It also explained that RESs are the best alternative to overcome the energy crisis, though barriers that punctuate progress are also addressed. Reference [14] investigated the relationship between inflation and the energy crisis. It explained the situation of energy sector, both globally and in Pakistan, and inspected key factors contributing toward energy inflation. It collected annual data related to energy inflation such as the exchange rate, international oil prices, energy imports, the tax ratio, and the money supply from 1973 to 2012. Reference [15] examined various factors contributing to the energy crisis that contains reduced reserves of oil and gas, an energy gap between supply and demand, security concerns over the power supply, and energy costs. A solution to the entire problem is renewable energy generation. Reference [16] investigated the potential capacity of energy production through renewable energy technologies (RETs) within Pakistan. Current energy crisis requires balancing energy supply-demand curve with RESs as reliable solution [17]. Reference [8] explained that RETs must be utilized to fulfill energy demand and supply gap. It examined the demand and supply gap in Pakistan and inspected various geographical locations for RET installation. According to [18], solar, wind, and biomass energy potential exists abundantly in Pakistan, which can meet the energy needs. It is explained that the solar energy returns its investment cost within 5 years; the biomass energy and wind energy return their investment cost within 6 years, while parabolic trough collectors (PTC) produce returns within 17 years. Reference [19] inspected problems related to biomass energy utilization effectively and efficiently. It also deduced that local government must be considered as the main factor while establishing a biomass-based electricity plant. Reference [20] deduced that biomass can supply 42 percent of the power portfolio in Pakistan. Reference [21] studied the development for bioenergy using anaerobic digestion, and found that separate biogas plants can be installed in an area that has no electricity. Reference [22] discussed prospects of both wind and solar energy in Pakistan. Reference [21] studied the current status of solar energy generation in Pakistan and emphasized that the main hindrance is the high capital cost to install solar technologies. Reference [22] surveyed the Quetta district of Pakistan and determined rich potentials of solar energy in the area. An RET screen simulation showed that about 23.206 GWh of electricity can be produced in a year. A photovoltaic (PV) plant will generate electricity at a rate of 0.157 $/kWh, at a total cost of $50 million, and a 50 percent debt ratio. Reference [23] provided a detailed analysis of wind energy development in Pakistan, and provided guidelines for increased wind energy. A summary of some generic state-of-the-art surveys is illustrated in Table I.

All studies emphasized the need to develop alternative energy sources and challenges related to the implementation of alternative energy sources at the national level. Some research has been conducted at the regional level. Reference [24] examined the wind energy potential in Pakistan and the challenges related to the installation of such facilities. It also inspected the reserve of 1678 MWh energy, while half of the residential consumers in Karachi have installed micro wind turbines. Reference [25] conducted the research on urbanization, growth of vehicle use, energy consumption, CO_2 emission, and industrialization, and deduced that the urban area and its population increased by 1500 percent from 1947 to 2008. An investigation also revealed that the consumption of natural gas, coal, and gasoline increased by 367%, 287%, and 219%, respectively.

The main contributions of this paper are as follows:

1) A discussion of the energy crisis in Pakistan and its worsening impact on the social and economic fabric of the country is presented. Energy demand is far greater than the existing infrastructure of supply, and RES-based power generation is the ultimate solution to the problem.

2) A quantitative analysis of current and future RES power generation in Pakistan is presented at considerable length.

3) A comprehensive depiction of the dire need and status of implementing a smart grid (SG) in Pakistan is illustrated.

TABLE I
SUMMARY OF SOME GENERIC STATE-OF-THE-ART SURVEYS

Ref.	Technology	BA	FP	RDC	TP	GP	MP	TS	SA	EI	CA	SEP	GPA	GT
[26]	Renewable energy generation	×	✓	×	✓	✓	✓	×	×	×	×	×	×	✓
[27]		×	×	×	✓	✓	✓	×	✓	×	✓	✓	✓	×
[28]		×	✓	×	×	×	✓	×	×	×	✓	✓	✓	×
[29]		×	✓	×	✓	✓	✓	×	×	×	×	✓	✓	×
[30]		×	✓	✓	✓	✓	×	×	✓	✓	×	✓	✓	×
[31]		×	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓
[5]		×	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
[32]		✓	✓	✓	✓	✓	✓	×	✓	×	✓	×	✓	✓
[12]		×	×	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓
[33]		×	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓
[34]		×	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓
[35]		×	✓	✓	✓	✓	✓	×	✓	×	✓	✓	✓	✓
[34]		×	✓	✓	✓	✓	✓	×	✓	✓	×	✓	✓	×
[15]		×	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓
[13]		×	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	×
[37]		×	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×
[18]		×	✓	✓	×	×	✓	✓	✓	✓	✓	✓	✓	×
[10]		✓	✓	✓	×	×	×	✓	✓	×	✓	✓	×	×
[16]		×	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓
[38]		×	✓	✓	✓	✓	✓	×	×	×	×	✓	✓	×
[39]	Wind energy	×	✓	×	✓	✓	✓	×	×	×	×	×	✓	×
[23]		×	✓	✓	✓	✓	✓	×	✓	×	✓	×	✓	×
[40]	Biomass/biogas energy	×	✓	×	✓	✓	✓	×	✓	✓	✓	✓	✓	✓
[41]		×	✓	×	×	✓	✓	×	✓	×	×	×	✓	✓
[19]		×	✓	×	✓	✓	✓	×	✓	✓	✓	✓	✓	✓
[42]		×	✓	✓	✓	✓	×	✓	✓	✓	✓	×	×	✓
[43]		×	✓	×	✓	✓	✓	×	✓	✓	✓	×	✓	✓
[44]		×	✓	×	✓	✓	✓	✓	×	×	✓	✓	✓	✓
[45]		×	✓	✓	✓	✓	✓	✓	✓	×	✓	×	×	✓
[46]	Hydro	×	✓	×	✓	✓	✓	×	✓	✓	✓	✓	✓	✓
[47]	Solar energy	×	✓	×	✓	✓	×	×	×	×	×	×	✓	✓
[48]		×	×	✓	✓	✓	×	✓	✓	×	✓	✓	×	✓
[6]		×	×	×	✓	✓	✓	✓	✓	×	✓	✓	✓	✓
[8]		×	✓	✓	✓	✓	✓	✓	✓	×	×	×	✓	✓
[21]		×	✓	×	✓	✓	✓	×	✓	×	×	✓	✓	✓
[49]		×	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	×
[50]		×	✓	✓	✓	✓	✓	✓	✓	×	×	✓	✓	✓
[51]		×	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓
[52]		×	✓	✓	✓	✓	×	✓	✓	×	×	×	✓	×
[53]		×	✓	✓	✓	✓	✓	×	✓	×	✓	×	✓	×
Our survey		✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓

Note: ✓: explored; ×: not explored; BA: bibliometric analysis; FP: future prospects; RDC: real-time data collection; TP: theoretical potential; GP: geographical potential; MP: market potential; TS: technical study; SA: statistical analysis; EI: ecological impact; CA: cost analysis; SEP: socio-economic potential; GPA: geo-political assessment; GT: global trends.

The remainder of this paper is organized as follows. Section II presents an overview of RESs in Pakistan along with strengths, weaknesses, opportunities, and threats (SWOT) analysis of its energy system. The status of SG implementation and suggestions for RET development are discussed in Section III. Finally, Section IV concludes the paper and provides future approaches.

II. STATUS OF RES UTILIZATION IN PAKISTAN

According to an estimate, Pakistan is blessed with solar radiations of 5.5 Wh/m^2 per day. Wind speed is 5-7 m/s in the shoreline front territories of Sindh and Baluchistan. The potential of energy generation from wind is more than 20 GW [12]. Figure 3 clearly demonstrates that RESs are able to complement Pakistan's energy requirements for providing a sustainable energy base [54].

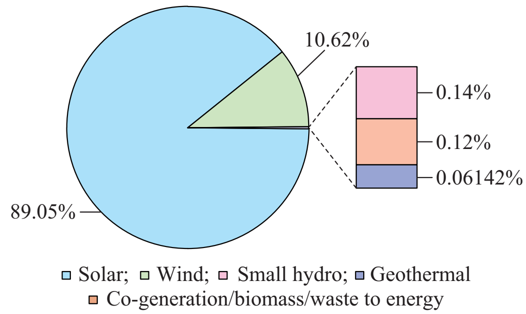

Fig. 3. Pakistan's RES potential.

The main reasons for the energy crisis in Pakistan are an imbalance in the energy mix, the non-utilization of numerous indigenous energy resources, a deficiency of investment in power, political instability, energy policy failure, and high energy production costs. Other crisis factors are political arguments over mega-energy projects, corruption by both producers and consumers, and an old transmission and distribution infrastructure [55]. The significant energy utilization sectors in Pakistan are domestic, commercial, industrial, agricultural, government, and transportation. The increase in energy consumption in these sectors are 9%, 2.8%, 3.8%, 7.1%, 1.4%, and 4.6%, respectively. The present energy deficit is around 5000 MW and the annual increase in demand is 10%, while the supply rate is 7% [13]. Table II demonstrates predictive information about peak demands, available generation, and energy gap of electricity from 2016 to 2020 [56].

TABLE II
POWER DEMAND AND SUPPLY FROM 2016 TO 2020

Year	Month	Peak demand (MW)	Available generation (MW)	Energy gap (MW)
2016	Jan.	17582	12140	−5442
2016	Jul.	23107	17285	−5822
2017	Jan.	17582	14174	−3408
2017	Jul.	23500	23436	−64
2018	Jan.	18402	20213	+1811
2018	Jul.	25145	27094	+1949
2019	Jan.	19690	22940	+3250
2019	Jul.	26905	28168	+1263
2020	Jan.	21068	25077	+4009
2020	Jul.	28788	30803	+2015

Pakistan's energy demand is predicted to increase at a rate of 9% until 2030. The government must attempt to organize, facilitate, and encourage all power generation technologies [57].

A. Conventional Energy Sources

Numerous countries of the world are completely dependent on conventional energy sources, triggering a fast depletion of these sources. The utilization of these sources pollutes the environment due to the emission of harmful gas and waste production. Figure 4 illustrates conventional and non-conventional energy sources [17]. The chief conventional energy sources of Pakistan are briefly described in this section.

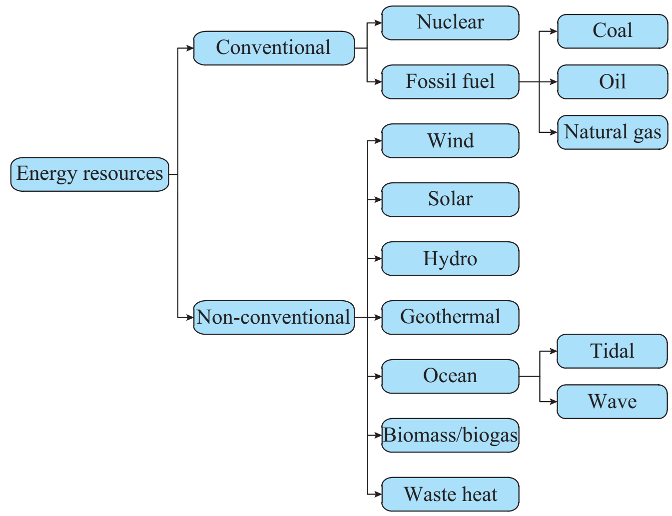

Fig. 4. Taxonomy tree of conventional and non-conventional energy sources.

1) Coal Resources

Pakistan has sixth largest coal reserves with total coal reserves of nearly 186 billion tons. The largest reserve of low-quality coal of about 175 billion tons is found in Thar, which has the capability to generate power of 50000 MW. Thar coal reserve has heating value of 6223 to 10288 Btu/lb, Jherruck and Lakhra have 106 and 244 million tons of coal, respectively. The main consumers of coal resources are the cement sector and the brick kiln industry. The share of the cement sector in the consumption of coal resources is 58%, and the share of the brick kiln industry is about 41% in 2012 [13].

2) Oil Resources

The oil resources of Pakistan are about 27 million barrels. Daily oil production is about 66032 barrels. Thirteen companies are working to produce crude oil from 133 oil fields. The transportation and power sectors are the main consumers of petroleum products. The consumption of petroleum products by the transportation sector in 2010-2011 is 48.9%; by the power sector, 41.3%; and by the industrial sector, 7.1% [13], [17].

3) Natural Gas Resources

The total natural gas reserves of Pakistan are about 282 trillion cubic feet (TCF). Daily natural gas production is about 4 billion cubic feet. Fifteen companies are working to produce gas from 190 gas fields, of which 44 are associated (a natural gas reservoir with petroleum deposits) and 146 are non-associated (a natural gas reservoir without crude oil deposits). The largest reserve of natural gas is found in Sui, with potential of about 12.7 TCF. The power sector is the largest consumer of gas in 2012-2013, consuming 27.5%; the industrial share is 22.6%, and the household share is about 23.2% [13], [17].

4) Nuclear Energy Resources

The development and operation of nuclear power plants are the responsibility of the Pakistan Atomic Energy Commission (PAEC). Table III depicts the information on the country's nuclear plants [58]. Chashma Nuclear Power Plant Units 1 and 2 (C-1 and C-2) and the Karachi Nuclear Power Plant (KANUPP) are working with a capacity of 787 MW. The government directed PAEC to increase its capacity of electricity production to 8800 MW by 2030. PAEC has decided to build a huge civilian enrichment plant to expand the program. These plants, when successfully installed, will provide the employment and will resolve the energy demand issue to a great extent [13].

TABLE III
OPERATIONAL NUCLEAR POWER PLANTS (2016)

Plant	Contractor	Capacity (MW)	Construction started	Commercial operation
KANUPP	CANDU Owners Group (COG), Canada	137	Aug. 1996	Dec. 1972
C-1	China National Nuclear Corporation (CNNC), China	325	Aug. 1993	Sept. 2000
C-2	CNNC, China	325	Dec. 2005	May 2011

B. RESs

The accessible potential and status of RESs in Pakistan are discussed in the following subsections.

1) Solar Energy

Solar energy has a huge share in fulfilling worldwide energy demand with the least unfavorable environmental consequences. According to a solar map prepared by the National Aeronautics and Space Administration (NASA), Pakistan is the second highest area to receive solar irradiation [59]. The annual solar irradiance received by Pakistan is around 1900-2200 kWh/m^2 [3]. These enormous solar radiations make solar a highly recommended energy generation source. Solar resource potential in Pakistan is demonstrated in Table IV [60]. The descriptions for KESC, HESCO, SEPCO, MEPCO, FESCO, LESCO, GEPCO, IESCO, FATA, KP1, KP2, AJK can be found in [60].

The total estimated energy that can be generated from solar is 8084.72 TW. Bahawalpur has the maximum number of annual sunshine hours, an average of 3300 hours per year. The regions of Gilgit and Chitral receive the least amount of solar radiation, 2400 hours per year. The first solar generation plant went into operation in September 2016 in Bahawalpur with a potential to produce 400 MW of energy. The second phase of this project, with a generation capacity of 600 MW, went into operation in 2017. Details of projects under implementation, completed, or with a letter of intent (LOI) issued, are listed in Table V [61].

TABLE IV
SOLAR RESOURCE POTENTIAL IN PAKISTAN (2014)

Sub region	Maximum average instant solar insolation	Solar resource capacity (TW)
KESC	0.90	202.83
Baluch 1	0.94	1518.25
Baluch 2	0.95	948.89
Baluch 3	0.95	1981.90
Baluch 4	0.89	451.19
HESCO	0.91	776.61
SEPCO	0.96	210.07
MEPCO	0.97	519.49
FESCO	1.00	319.62
LESCO	0.92	8.68
GEPCO	1.16	9.13
IESCO	1.04	555.90
FATA	1.11	482.67
KP1	1.16	7.11
KP2	1.10	22.34
AJK	1.11	8084.72
Gilgit	1.18	22.34
Total	17.25	16121.74

TABLE V
LIST OF SOLAR POWER PROJECTS (2016)

Project	Status	Location	Capacity (MW)
Quaid-e-Azam Solar Park	400 MW operational; 600 MW will be operational in 2017	Bahawalpur	1000
Conergy Solar Project	Under implementation	Bahawalpur	50
Bakhsh Energy Solar	LOI issued	Lodhran	20
First Solar	LOI issued	Punjab	2
Wah Industries Limited Solar	LOI issued	Taxila	1
Scatec Solar Project	Set up starts	Sindh	150
Solar Energy Pakistan Limited	LOI issued	Thatta	35
DACC LLC Solar	LOI issued	Sindh	50
CWE Solar	LOI issued	Cholistan	50
Pakistan Parliament	Under implementation	Islamabad	80
Tech Access Solar	LOI issued	Punjab	10
SSJD Bagasse Energy	Under implementation	Jhimpur	50
Roshan Power Solar	LOI issued	Kasur	10

Pakistan is an agrarian country. Most people living in rural areas are deprived of electricity, and the maximum energy demand of every house is 50-100 W. The extension of transmission lines is impracticable and uneconomical for such a small load. Solar energy can help electrify these areas [45]. Thus, the project was initiated, and about 3000 solar home systems were installed in 49 villages of Thar Parker, Sindh. The second phase of this program has been approved, and it will provide solar home systems to 51 and 300 villages in Sindh and Baluchistan, respectively.

2) Hydro Energy

Annual surface flow rate of water in Pakistan is 145 million acre feet (MAF) [59]. Hydro power plants are suitable for Pakistan because of its abundant water supply and low generation cost. Most of the hydropower resources are in the northern areas of Pakistan. Table VI demonstrates the details of hydropower generation for operational projects, under-implementation projects, and projects with completed feasibility analyses [62]. Northern areas of Pakistan have numerous sites, where energy generation is possible in the form of mini and micro hydel power plants. The hydro power generation potential for micro hydel plants is about 1200 MW [12].

TABLE VI
SUMMARY OF HYDRO POWER RESOURCES IN PAKISTAN (2016)

Region	Power of operational projects (MW)	Power of under implementation projects (MW)			Power of solicited sites (MW)	Power of projects with raw sites (MW)	Total (MW)
		Public sector	Private sector				
			Provincial	Federal			
KPK	3849	9482	28	2370	77	8930	24736
Gilgit Baltistan	133	11876	40		534	8542	21125
Punjab	1699	720	308	720	3606	238	7291
Azad Jammu Kashmir	1039	1231	92	3172	1	915	6450
Sindh					67	126	193
Baluchistan					1		1
Total	6720	23309	468	6262	4286	18751	59796

3) Geothermal Energy

Pakistan lies on the intersection of seismic-tectonic plates. Thus, the country has plentiful geothermal resources. The geo-pressurized system, the seismic-tectonic system, and the Neogene-Quaternary system are three environments where geothermal resources can be found. It is estimated that Pakistan can produce 240 GW of electrical energy from geothermal sources [63].

Numerous geysers, hot springs, and mud volcanoes are available, with temperatures ranging from 30 °C to 170 °C. No locality has yet been introduced for the direct or indirect use of geothermal energy [64]. No attempt has been made to utilize geothermal energy in the Himalayan range of Pakistan [65]. Currently, there is no power plant for geothermal energy, but there are many locations where the electricity generation is possible. Details of the geothermal resources in various locations of Pakistan, along with the temperature category, the surface temperature, and weather geothermal energy are categorized in Table VII [63].

Geothermal power plants can provide power grid support, as it produces constant output power because of its day-and-night availability. Both the private and public sectors of Pakistan should contribute to the practical implementation of geothermal power plants to overcome the energy crisis [66].

4) Wind Energy

Wind is another significant source of RESs. The radiation and rotation of the earth affect the direction and speed of the air. The heat difference between the land and sea also affects wind flow. Consequently, the region that lies near water and coastal areas has more wind energy potential [30]. Wind power is classified into 7 different classes. Class 1 is poor, class 2 is marginal, class 3 is moderate, class 4 is good, and the remaining classes are excellent. According to the National Renewable Energy Laboratory (NREL), classes 3 and above are appropriate for the installation of wind turbines to generate energy. Class 2 is suitable for rustic claims [67]. Pakistan is installing wind energy plants in Gharo, Bin Qasim, Keti Bandar, and Jhimpir. The first wind energy plant was installed in 2013. Sindh and Baluchistan have the potential more than 50000 MW, whereas the wind energy potential of Punjab is only 1000 MW [13].

The Pakistan Meteorological Department has done surveys throughout the country to determine the potential of wind energy. After collecting data from 20 sites, the potential of wind energy was estimated, and it was found that a 9700 km^2 area at the coastal belt is suitable for wind energy production, and can produce 43000 MW of power [30]. Table VIII shows that about 9% land of Pakistan is suitable for wind turbines, giving the country a wind energy potential of 349000 MW [67].

Table IX illustrates that 12.55% of total area of Sindh lies in an adequate-to-outstanding wind power class. Wind energy potential is about 88460 MW. Eighteen wind independent power projects (IPPs) received land from the Alternative Energy Development Board (AEDB) to implement wind production plants, and each plant will have a capacity of 50 MW. Eight IPPs have received licenses from the National Electric Power Regulation Authority (NEPRA), and four IPPs received tariffs from NEPRA [67]. The total land area of Khyber Pakhtunkhwa (KPK) is over 74521 km^2. Table X shows that a 11709 km^2 area, or more than 15% of the total area, lies in a moderate-to-excellent wind power class [67].

TABLE VII
SURVEY OF GEOTHERMAL ENERGY SOURCES OF PAKISTAN (2016)

Location	TC	ST (°C)	GR	PPT	IP	DP	PPG	CPG
Hunza	Low	50-91	Hot spring	RCP	NP	P	P	×
Hakuchar	Low	49-50	Hot spring	RCP	NP	P	P	×
Chagai Volcanic Arc	Low	64	Mud volcano	RCP	NP	P	P	×
Karakoram Granodiorite	Moderate	172-189	Hot spring	BCP	P	P	P	×
Mashkin	Moderate	86-169	Hot spring	BCP	P	P	×	×
Murtazabad	Moderate	172-212	Hot spring	BCP	P	P	P	×
Tatta Pani	Low	85	Hot spring	RCP	NP	P	P	×
Darkut Pass	Low	62	Hot spring	RCP	NP	P	P	×
Budelas	Moderate	172-212	Hot spring	BCP	P	P	P	×
Gilgit Region	Low	24-71	Hot spring	RCP	NP	P	P	×
Koh-e-Sultan	Moderate	150-170	Mud volcano	BCP	P	P	×	×
Chicken Dik	Low	29.9	Hot spring	×	NP	P	×	×
Dadu District	Low	41	Hot spring	RCP	NP	P	×	×
Mango Pir	Low	71-98	Hot spring	BCP	NP	P	P	×
Garam Chashma	Moderate	85-252	Hot spring	BCP	P	P	×	×
Salt Range Mianwali	Low	30	Hot spring	×	NP	P	×	×

Note: ×: not explored; P: possible; NP: not possible; RCP: ranking cycle plant; BCP: binary cycle plant; TC: temperature category; ST: surface temperature; GR: geothermal resource; PPT: power plant type; IP: indirect applications; DP: direct applications; PPG: proposed power generation; CPG: current power generation.

TABLE VIII
PAKISTAN WIND RESOURCES ASSESSMENT

Class	Potential	Capacity (MW)	Wind land area (km^2)	Percent of wind land area (%)
7	Outstanding	2725	545	0.07
6	Outstanding	12570	2514	0.33
5	Outstanding	26600	5320	0.69
4	Good	97095	18219	2.36
3	Adequate	216325	43265	5.16
Total		349315	69863	9.06

TABLE IX
SINDH WIND RESOURCE ASSESSMENT (2016)

Class	Potential	Capacity (MW)	Wind land area (km^2)	Percent of wind land area (%)
7	Outstanding			
6	Outstanding			
5	Outstanding	3515	703	0.50
4	Good	23200	4640	3.29
3	Adequate	61745	12349	8.76
Total		88460	17692	12.55

The area of Baluchistan is over 347190 km^2. Table XI shows that 29229 km^2 (8.14% of the area) are in a moderate-to-excellent class. The potential of wind energy production of Baluchistan is nearly 146145 MW. It is obvious from Table XI that the potential area of classes 6 and 7 is larger than other provinces [67].

Table XII indicates that the Sindh province of Pakistan is suitable for the installation of wind energy projects [68]. Six projects are in operation, and the total power generation is 308.2 MW. Nine projects are under construction and the total power generation is 477 MW. Thus, 1140 MW will be added to the national power system upon successful completion of these projects.

TABLE X
WIND RESOURCE ASSESSMENT OF KPK (2016)

Class	Potential	Capacity (MW)	Wind land area (km^2)	Percent of wind land area (%)
7	Outstanding	90	18	0.020
6	Outstanding	645	129	0.170
5	Outstanding	3515	703	0.394
4	Good	15525	3105	4.170
3	Adequate	38770	7754	10.410
Total		58545	11709	15.710

5) Biomass/biogas Energy

Pakistan has self-sufficient biomass resources. Punjab province is capable of producing 15.777 TWh electricity annually from extra and accessible crop biomass of about 27.86 million tons [12]. The number of animals in Pakistan is over 72 million, plus about 785 million birds in poultry farms. Plant residues are about 81 million tons per year. Animals produce 360 million kg of 50% collectable dung per day. Birds produce 39.2 million kg of 50% collectable dung per day. In all, 27.5 million cubic meters of biogas are achieved daily, which generates the power of 1900 MW from crop residues. Moreover, 1012 MW of energy is produced from 14.68 million cubic meters of biogas daily in Punjab. Biogas plants produce biogas as well as organic fertilizer in slurry form.

TABLE XI
BALUCHISTAN WIND RESOURCE ASSESSMENT (2016)

Class	Potential	Capacity (MW)	Wind land area (km^2)	Percent of wind land area (%)
7	Outstanding	2100	420	0.12
6	Outstanding	9455	1891	0.54
5	Outstanding	13610	2722	0.78
4	Good	38545	7709	2.22
3	Adequate	82435	16489	4.75
Total		146145	29229	8.41

Table XIII illustrates that the potentials of biogas in Pakistan and Punjab are about 27.5 million cubic meters per day and 14.68 million cubic meters per day, respectively [12]. Different sectors utilize natural gas to fulfill their energy needs. Biogas can be an alternative to natural gas at negligible cost. The government is beginning to install 25000 biogas plants throughout the country to fulfill the power demand of the country [69]. Due to financial restraints, only 2000 biogas plants have been installed so far. The remaining 500 plants are still in the process of installation.

TABLE XII
WIND PROJECTS IN SINDH PROVINCE OF PAKISTAN (2016)

Status of project	Project	Location	Capacity (MW)
Operational	Three Gorges I Wind Farm	Jhimpir	49.50
	Sapphire Wind Power Company	Jhimpir	52.80
	FFC Energy	Jhimpir	49.50
	Foundation Wind Energy I	Gharo	50.00
	Zorlu Enerji	Jhimpir	56.40
	Foundation Wind Energy II	Gharo	50.00
In pipeline	Three Gorges II Wind Farm	Jhimpir	49.50
	Burj Wind Energy	Gajju	14.00
	Tricon Boston Consulting Organization	Jhimpir	50.00
	Western Energy	Jhimpir	50.00
	Tricon Boston Consulting Organization	Jhimpir	50.00
	Shaheen Foundation PAF	Jhimpir	50.00
	Hawa Energy	Jhimpir	50.00
	Trans-Atlantic Energy	Jhimpir	50.00
	Three Gorges III Wind Farm	Jhimpir Jhimpir	49.50
	Jhampir Wind Power	Jhimpir	50.00
	Zephyr Power	Gharo	50.00
	Tricon Boston Consulting Organization	Jhimpir	50.00
	China Sunec Energy	Nooriabad	50.00
	Hartford Alternative Energy	Jhimpir	50.00
Under construction	Tenega Generasi	Gharo	49.50
	Hydro China Dawood Power	Gharo	49.50
	Yunus Energy	Jhimpir	50.00
	Gul Ahmed Wind	Jhimpir	50.00
	Tapal Wind	Jhimpir	30.00
	United Energy	Jhimpir	99.00
	Metro Power Company	Jhimpir	50.00
	Master Wind	Jhimpir	49.50
	Sachal Energy Development	Jhimpir	49.50

TABLE XIII
POTENTIAL OF BIOGAS IN PUNJAB AND PAKISTAN (2016)

Location	Accessible animal	Dung (kg/d)	Biogas from dung (0.05 m^3 per kg dung) (m^3)	Poultry bird	Poultry dropping (kg/d)	Biogas from poultry (0.13 m^3 per kg poultry) (m^3)	Annually crop scum (tons)	Biogas from crop scum (m^3/d)
Punjab	3.9×10^7	3.9×10^8	9.75×10^6	3.90×10^8	3.90×10^7	2.54×10^6	4.4×10^7	2.39×10^6
Pakistan	7.2×10^7	7.2×10^8	18.00×10^6	7.85×10^8	7.85×10^7	5.10×10^6	8.1×10^7	4.40×10^6

Initially, cooking was the only purpose of biogas plants. However, the commercial use of biogas has been advertised to farmers for the operation of tube wells. Biogas plants have been installed and are in operation at different sites of

Sialkot, Jhang, and Narowal in Punjab [16]. Pakistan has the potential to generate 5000 MW of power from agriculture and municipal solid waste (MSW) [12]. Energy generation from MSW is comparatively low but is capable of reducing the energy crisis. According to a survey, about 108.9 tons of combustible MSW are generated per day in Peshawar. The energy produced from 108.9 tons of MSW is 12.4 MW [69].

In Pakistan, the average calorific value of MSW is 6.872 MJ/kg. The total energy generation in the capital cities of Pakistan from MSW are 13594 GWh per year. Table XIV demonstrates the calorific values of MSW and the related moisture contents, according to area classifications [12].

TABLE XIV
CALORIFIC VALUES OF MSW (2016)

Classification	Calorific value (MJ/kg)	Moisture content (%)
Commercial area	6.67	64
Low income residential area	6.25	67
Medium income residential area	6.98	63
High income residential area	7.27	60
Industrial area	7.19	61

6) Tidal Energy

Tides originate from the gravitational forces between the earth and the astronomical bodies of our solar system. The current energy demand of the world will be successfully met if less than 0.1% of the energy in the oceans is converted into electricity. Delta creek areas of Pakistan have the capacity to produce approximately 900 MW energy from tidal currents. According to surveys by the National Institute of Oceanology (NIO), creeks that spread from Korangi Creek to Kajhar Creek near the Pakistan-India border have a great capacity for tidal energy. The value of the current velocity recorded at these creeks is from 4 to 5 knots, but can be as high as 8 knots. The heights of tidal waves are from 2 to 5 meters. The Kalmat Khor and Sonmiani Hor creeks of Baluchistan are considered as good sources of tidal energy in Pakistan [13], [70].

7) Wave Energy

Waves result from wind action on ocean surfaces, and wind is, in turn, caused by the heat of the sun [71]. Waves produced on the surface of the water have energy travelling across it. Every wave has various characteristics such as wind speed, water depth, wind duration, wind sliding distance, and fetch (the distance it blows over open water) [72]. The fluctuation in energy production from wave resources causes a nonlinear energy supply to power system. Grid integration problems can be solved by a linear supply of energy, using an energy storage system (ESS). Numerous storage technologies have been inspected such as flywheels, superconducting energy storage, and super capacitors. However, few findings technically and economically validate the ESS requirement for the integration of wave plant grid [73]. Wave power stations are in operation in many countries like Portugal, Spain, and Israel. The world's largest wave power station is in Portugal, with a generation capacity of 2.25 MW [74]. Pakistan is rich in sea-related wave energy due to the existence of a 1000 km long coastal area. However, Pakistan is not utilizing wave energy. Proper planning, management, and motivation are required to exploit wave energy sources to overcome the energy deficit [59].

8) Waste Heat Energy

The emission of air pollutant gases can be controlled by the implementation of waste heat power plants (WHPPs). WHPPs are green energy producers and minimize overall environmental pollution [75]. A thermoelectric generator (TEG) is used to convert waste heat into electrical energy. The characteristics of TEG such as it does not have moving parts, does not require input power, can transfer reflexive heat, is small in size, and is lightweight, make it feasible for commercial and industrial use [76]. The three main technologies used in electricity generation from waste heat are the steam-based Rankine cycle system, the organic Rankine cycle system, and the Kalina cycle system [77]. Clinker production in the cement industry emits 40% of produced heat into the atmosphere, causing environmental pollution. Thus, the installation of a TEG helps minimize air pollution and can also contribute some proportion to the electrical load [77]. Numerous industries in Pakistan are potentially capable of installing WHPP to get the benefit of their waste heat. Table XV displays the information on waste heat recovery plants in several industries. WHPP can minimize the dependency of industry on the national grid as well.

TABLE XV
WASTE HEAT RECOVERY POWER PLANTS

Ref.	Industry	Region	Output (MW)
[78]	Bestway Cement Limited	Chakwal	15.0
[79]	Bestway Cement Limited	Hattar	6.0
[79]	Bestway Cement Limited	Farooqia	7.5
[80]	D.G.K. Cement Company	D.G. Khan	10.4
[80]	D.G.K Cement Company	Khairpur	8.6
[81]	Fauji Cement Company	Attock	12.0

C. SWOT Analysis of Pakistan's Energy System

An SWOT analysis is a common practice used by both industry and academia for strategic planning purposes. It highlights the strengths and weaknesses of a fundamental energy system. Moreover, it explores the opportunities for investment, and the probable threats of delay in achieving the target. An SWOT analysis will help propose actions and measures that can be recommended for the roadmap. The major outcomes of an SWOT analysis of Pakistan's energy system are depicted in Fig. 5.

III. STATUS OF SG IMPLEMENTATION IN PAKISTAN

The social and economic development of any country is estimated from its energy utilization. Pakistan is unable to tackle its increasing energy demands due to the limited number of explored energy sources. Consequently, most people in the country are deprived of the electricity. The existing power infrastructure depends heavily on hydro power generation.

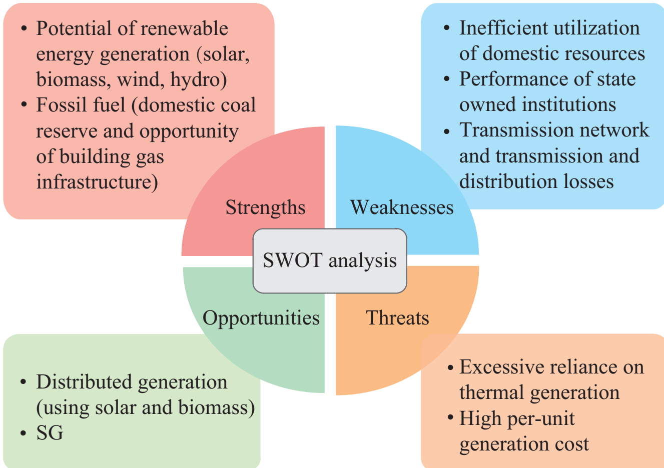

Fig. 5. SWOT analysis of Pakistan's energy system.

Moreover, fossil fuel based power generation is unreliable due to the power demand that is increasing day by day. Pakistan is thus trying to exploit indigenous energy sources of solar, wind, and biomass on a commercial scale. The SG needs to be introduced to overcome transmission and distribution challenges and losses [82].

The SG is not in full operation in Pakistan, but power generation from RESs is in practice. Moreover, NEPRA issued smart meters and tariff guidelines in 2015 for the electricity demand of consumers. Consumers can sell their surplus electricity back to the grid by generating their own energy from solar or biomass resources. Smart meters record electricity flow both in and out, and only the net amount is charged. The incentive of selling surplus electricity to the grid motivates people to generate their own electricity utilizing RESs. Electricity crises can be handled in this way. Smart meters record various electrical parameters in different time slots ranging from minutes to hours. Recorded data gives a proper understanding of load consumption and a more thorough picture of particular event occurrences. Lately, most of Pakistan's traditional power system relies on manual energy meter reading. Consequently, there is severe energy theft and much corruption in the recorded data. The flawed data leads to defective load consumption information, thus affecting on-demand management approaches.

The government is motivating people to install smart meters due to the meters' credibility. Moreover, they can generate alarms in various monitored situations like identifying grid energy losses. Smart meters can store data, so it can be retrieved from the meter in case of poor communication. This feature is conspicuous for Pakistan's energy theft issues. The load control feature of smart meters allows the energy generation side to meet peak demand. However, the available smart meters in Pakistan lack the control of individual loads, and the implementation of efficient demand response plans requires intervention by computers or human beings. Bidirectional energy flow measurement meters are installed mostly for industrial consumers. The government is planning to install prepaid energy meters. In this way, the timely identification and elimination of power theft and losses can be made possible by incorporating smart meters into the energy mix [83].

The implementation of SG is challenging due to the unreliable transmission network in Pakistan. SG can only be integrated in the main grid under the compatible and synchronized phase conditions and the constant voltage from distributed energy sources. The reliability of any transmission system is estimated by its duration and the number of outages. Pakistan's power grid has encountered many unplanned and forced outages. Thus, attention is directed toward the integration of RETs in the energy mix. The aforementioned detailed description of RESs shows that distribution generation is the last resort to overcome declining energy economy of Pakistan [82].

The following suggestions are made for RET development and the effective utilization of RETs in Pakistan.

1) Ending the fossil fuel dependence of the economy and embracing renewable alternatives are daunting tasks. It is crucial to devise laws and policies to encourage investment in RETs. RET investment should be facilitated by energy policies that encourage tax rebates and financial leasing through banks.

2) Following international quality assurance standards is important during the project installation and operation of RETs. Public health safety is an important issue that merits devising proper security protocols and subsequent implementation.

3) The corruption is reportedly a major roadblock for RET promotion. Financing an RET project is as important as overseeing original capital utilization in a project. Ensuring the transparency of mechanisms at the governmental scale is a prerequisite for effectively monitoring and evaluating these projects.

4) Human resource development in the renewable energy domain is a necessity to prepare the next generation of engineers and scientists to undertake the associated challenges. Introducing renewable subjects at graduate or post-graduate levels and offering lucrative scholarships and stipends in renewable research are also important.

5) The government must benefit from international collaboration in RET research and development. No barrier has been reported on the transfer of technology (TOT) for RETs internationally. The only barrier is the lack of coordination, planning, and diplomatic drive to explore TOT possibilities.

IV. Conclusion and Future Work

The global drive to abandon fossil fuel based electricity and opt for renewable alternatives is imperative. The devastating environmental impact of the fossil fuel industry is a huge reason for the world to mount a concerted campaign for renewable alternatives. The Fukushima Daiichi nuclear disaster was a watershed moment for the power industry to evaluate the ecological repercussions of producing unsafe electricity. Developed nations have accelerated the enterprise to tap as much of the renewable energy potential as feasible. China, Japan, the USA, and the European Union in particular lead on the renewable energy front. Denmark nearly eliminates foreign fuel imports by employing 100% wind-generated electricity, and Germany credits 30% of its electricity to renewable means.

Pakistan is a developing country, and a sustainable electricity supply plays a pivotal role for the economic growth of the country. Besides hydro power, fossil fuel-fired power plants are a major source of electricity generation. There is insufficient fuel in Pakistan, so electricity production exclusively relies on foreign imported fossil fuels. However, floods in 2010 and Kashmir earthquake in 2005 exposed the vulnerability of centralized power generation and distribution of the country after natural catastrophes. Pakistan's nuclear power plants are situated on a seismic fault line and are threatened by a potential meltdown. The development of China-supplied nuclear plants near Karachi is capable of jeopardizing the health and safety of a coastal population of 20 million people. All these facts lead to a singular conclusion: a sustainable, decentralized, and secure power source is imperative for the collapsing energy infrastructure of the country. RES offers a promising future, considering Pakistan's dynamic climate and geographical location. Hydro power projects serve as the second largest energy source of the country, after fossil fuel based power facilities. The coastal areas of the country possess a natural wind corridor with immense power production capability. The solar irradiation received by Bahawalpur region is sufficient to overcome the persistent energy deficit of the country. The national agenda of priority-based renewable energy generation is of paramount importance in overcoming the power deficit in the near future. This comprehensive review serves as an extensive guide for RES development in Pakistan's energy context.

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