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Statistical Energy Information and Analysis of Pakistan Economic Corridor Based on Strengths, Availabilities, and Future Roadmap

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ABSTRACT In Pakistan, the performance of conventional electrical grids is inefficient, resulting in severe energy crises. To overcome the alarming challenges persisting in the energy grids, Pakistan must focus on system protection, grid reliability, distribution and transmission, and power quality. The inefficiencies in grid protection and management signify an overall problematic energy scenario. The solutions to these problems include the improvement of domestic, commercial, and industrial demand-side management and the reduction in distribution network losses. A smart grid (SG) is a critical requirement as it can overcome the shortcomings of the existing grid owing to its promising features, enhanced consumer empowerment, utmost security; efficient and optimized energy flow; and demand-supply management. Thus, the SG is essential to overcome the energy crisis in Pakistan and achieve the standards of other developed nations in the energy sector. This study aims to highlight the significant prospects of SGs within Pakistan with the key objectives of its availability requirements. We compare the energy scenario in Pakistan with that of other countries and recommend various aspects that require improvement through SG implementation. Additionally, we discuss the incorporation of renewable energy resources and present a market analysis regarding SGs to illustrate the SG scenario and its implementation in Pakistan. Moreover, we analyze and evaluate detailed taxonomies of energy generation, energy projects, renewable energy assessment, power market trends in Pakistan, and the basic requirements of SGs. Furthermore, a critical analysis of the energy sector in Pakistan is elaborated, which describes the possibilities, requirements, and strengths pertaining to the transformation of the modern electric grid with respect to the China–Pakistan Economic Corridor. Thus, we believe that our work is more versatile in improving the energy system of Pakistan for the implementation of the SG.

INDEX TERMS CPEC, energy forecast, energy resources, Pakistan energy market, SG.

NOMENCLATURE

Acronym	Definition
SG	Smart Grid
CPEC	China–Pakistan Economic Corridor
DSM	Demand-side Management
NEPRA	National Electric Power Regulatory Authority
PEPCO	Pakistan Electric Power Company
IPP	Independent Power Producer
PESCO	Peshawar Electric Supply Company
PEC	Pakistan Engineering Council
PCRET	Pakistan Council of Renewable Energy Technologies
WHRPP	Waste Heat Recovery Power Plant

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RE	Renewable Energy
ADB	Asian Development Bank
IESCO	Islamabad Electric Supply Company
HV	High Voltage
AEDB	Alternative Energy Development Board
LESCO	Lahore Electric Supply Company
GDP	Gross Domestic Product
FIT	Feed-in Tariff
GoP	Government of Pakistan
DR	Demand Response
DRP	Demand Response Program
AMI	Automatic Metering Infrastructure
ITA	International Trade Administration
T&D	Transmission and Distribution
MTOE	Million Tons of Oil Equivalent
NTDC	National Transmission and Dispatch Company
LPG	Liquefied Petroleum Gas
PAEC	Pakistan Atomic Energy Commission
KSGI	Korean Smart Grid Institute
KPK	Khyber Pakhtun Khwa
MCFD	Million Cubic Feet per Day
PMA	Power Market Analysis
KESC	Karachi Electric Supply Company
SSRL	Sino-Sindh Resource Limited
PESCO	Peshawar Electric Supply Company
WAPDA	Water and Power Development Authority
TCEB	Thar Coal Energy Board
CMEC	China Machinery Engineering Corporation
SEPCO	Sukkur Electric Power Company
COD	Commercial Operation Date
HESCO	Hyderabad Electric Supply Company
KV	Kilovolt
PHWR	Pressurized Heavy Water Reactor
PWR	Pressurized Water Reactor
WHRPG	Waste Heat Recovery Power Generation
MMT	Main Mantle Thrust
MKT	Main Karakoram Thrust
MW	Megawatt

I. INTRODUCTION

Pakistan is an energy-deficient country and is confronting an alarming energy crisis. Consumers are facing power outages for several hours on a daily basis [1]. Over the past few years, energy demand has drastically increased. However, in contrast to the demand, the generating capacity has not improved proportionally. By 2050, the energy requirement of Pakistan is estimated to witness a three-fold increase [8]. However, the energy demand is significantly more than energy production [5], [6]. Between 2013 and 2020, the growth rate in electricity demand was 7.8%. This demonstrated an increase in the entire electricity demand to 27,840 MW by 2017 and 31,900 MW by 2020 [29]. Fig. 1 illustrates the total system capacities and power demands for different electricity suppliers in Pakistan in the year 2015. The Pakistan Electric Power Company (PEPCO) revealed that the average power deficit in Pakistan is considerably more than 5,000 MW, and this shortfall is consistently increasing. Operational inefficiencies, such as electricity theft and line losses, are predominant in the present electricity system. The total power loss in the current system is 19.7% of the total electricity generated in Pakistan. Consequently, Pakistan faces continuous power failure on a daily basis. These power failures directly affect state economies [2]. To support electricity generation, the import of oil has increased, thereby increasing the import costs significantly over the past few decades. This has added an extra burden on the state economy. The gross domestic product (GDP) of Pakistan is reduced by 3–4% owing to electricity outages, resulting in a loss of approximately $13.5 billion per year to the economy of the state [4]. Pakistan spent roughly $14.5 billion on conventional energy resources, which constitute 40% of the overall imports of the country. Various energy resources for electricity generation are depicted in Fig. 2, where conventional energy resources are at a higher percentage than non-conventional energy resources.

The increase in production capacity and energy management, including demand-side management (DSM), is achieved using smart grids (SGs), which are considered to be a promising solution to the energy crisis [1]. SGs are fundamental to the accomplishment of the energy efficiency objective. Local systems work with microgrids to consolidate the electricity power system on a small scale. SG application will help the energy system of Pakistan to overcome its transmission and distribution (T&D) losses [10]. The engineering and scientific methodology of Pakistan is to seek out energy management prospects and integrate surplus renewable energy (RE) sources into the energy mix [1].

Pakistan is a resourceful country and has a vast amount of different RE sources. According to [7], the conventional energy usage rate is high and is not efficiently utilized. Conventional and RE frameworks were analyzed in [13], [14], [21], which provided suggestions for the effective use of renewable technologies. The total power production in Pakistan was analyzed by [13], [15]. The DSM solutions recommended fulfilling energy deficiency was typically proposed for domestic and industrial customers. Currently, the common DSM method practiced in Pakistan is complete load shedding. However, several DSM programs are significantly more malleable and amenable in terms of load restraints. Demand response programs (DRPs) were discussed in [15], [29]. The power production by independent power producers (IPPS) was discussed in [25], [33]. Waleed *et al.* discussed the scopes, technology, constraints, and opportunities for smart meters in Pakistan [2]. The SG policies implemented globally were overviewed in [2], [17], [120]. The communication infrastructure in Pakistan was elaborated in [15], [28], [121].

In the cities of Multan, Vehari, and Khanewal, 40,000 smart meters were installed in 2015 at the cost of US$ 69,172. This project was initiated in 2010 to improve the utility billing system [9]. The Lahore Electric Supply Company (LESCO) has 17 feeders, out of which 12 feeders are main load generators. LESCO replaced the conventional energy

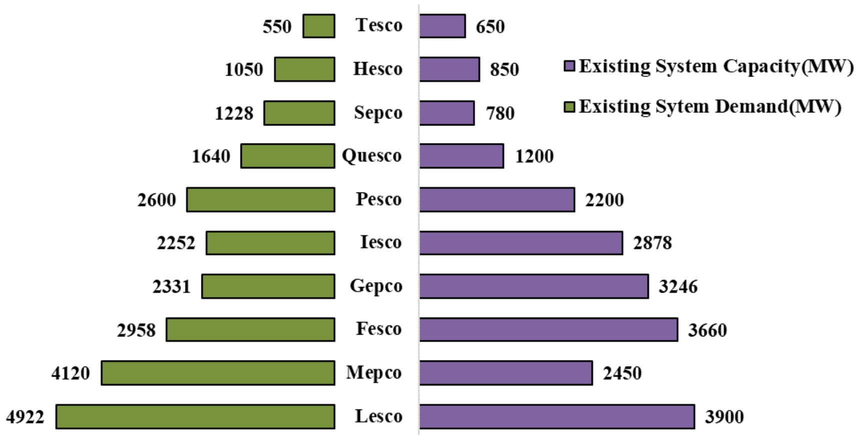

FIGURE 1. Comparison of system capacity and energy demand for different suppliers in Pakistan [11].

meters on these 12 feeders with modern static meters (SMs), which contributed to a 2% reduction in distribution losses. Eighty-four thousand SMs and 42,000 radio frequency-based automatic meter readers were installed by Peshawar Electric Supply Company (PESCO), which increased the revenue of the utility company by approximately 50% [12]. The Pakistan Engineering Council (PEC) is initiating a feed-in tariff (FIT) system in Pakistan that uses SG technology. The Government of Pakistan (GoP), in cooperation with PEC, has declared a FIT of 23.2934 US cents per kW·h of electricity [10]. Pakistan has a significant capacity for the incorporation of SGs along with RE technologies (RETs). To incorporate these technologies into production, Pakistan must formulate strong policies.

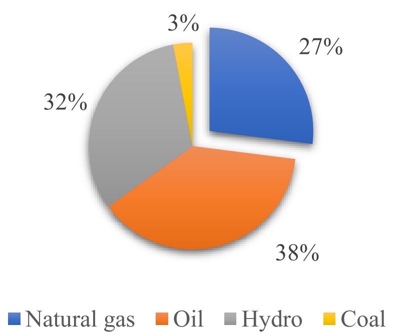

FIGURE 2. Various energy sources in Pakistan [7].

Although the studies mentioned above present the different prospects of SG and REs, such efforts were unable to highlight the SG system in Pakistan. In this study, the global RE trend, global investment in SG, the communication infrastructure of SG in Pakistan, and the energy market of Pakistan are analyzed. Selected works and tutorials regarding SGs in Pakistan are listed in Table 1. A tick (✓) indicates that the characteristic was explained in the quoted reference. In contrast, a cross (×) indicates that the cited attribute is absent in the referred paper.

The primary contributions of this work are as follows:

- The global SG trends, SG applications, global investments pertaining to SGs, worldwide SG policies, SG usage, and worldwide RE trends and usages are discussed. Moreover, the use of smart meters and appliances and the global trends in DRPs are analyzed.
- We critically investigate energy resources within Pakistan. The statistics of typical energy resources, comprising oil, coal, nuclear energy, and natural gas, and RE resources (RERs; i.e., solar, wind, biomass, geothermal, and waste heat resources) are also enlisted in various tables.
- Furthermore, the market trends of Pakistan, electricity structure, province-wise power distribution, a total installed power plants, including **(a)**RE plants, **(b)** nuclear plants, **(c)** coal power plant, **(d)** natural gas power plants, and **(e)** thermal power plants in Pakistan, are also described in detail.
- Finally, the availability of SG requirements is envisioned. Future energy forecast is also presented. The communication infrastructure, synchro-phasors, and satellite monitoring, independent power resources, smart meters, and distributed energy resources are also discussed. Future energy prospects are critically investigated with respect to the China–Pakistan Economic Corridor (CPEC).

The remaining paper is organized as follows. In Section II, the SG trends in different countries of the world are discussed. The energy demand statistics of Pakistan for RERs and conventional energy resources are discussed in Section III. The power market of Pakistan is analytically analyzed in Section IV. Basic requirements of SGs, future energy forecast, smart meters, and distributed energy resources about Pakistan, and the impact of CPEC on the SG system development within Pakistan are discussed in Section V. Section VI concludes the work with a concise summary and future work proposal.

II. GLOBAL TRENDS OF SMART GRID (SG)

The SG forms a distributed and automated energy delivery system and is capable of delivering quality power supply to consumers. The SG responds to a wide range of events that occur anywhere in the grid on the generation, transmission, or distribution side [1]. The growth of the SG is increasing day-by-day worldwide. Power systems are heading toward advanced, intelligent, and consumer-friendly modern electric grids termed as SGs, which are capable of resolving the alarming problems of the conventional power system. The SG is beneficial to society, the electrical power industry, consumers, and stakeholders. The issues relating to the SG must be addressed by the stakeholders of the electric power industry. Moreover, RE programs are implemented in the SG. The utilization of SG is rapidly increasing both in developed and underdeveloped countries owing to **(a)** reduced energy costs, **(b)** high efficiency and reliability, **(c)** high robustness, **(d)** DRPs, and **(e)** consumer empowerment [4]–[6].

A. GLOBAL APPLICATIONS OF SG

The application of SG technology assists **(a)** consumers, **(b)** utilities, and **(c)** policymakers [31]. The SG ensures reliability, efficiency, and flexibility of power generation, transmission, and distribution in a controlled and smart manner, thus lowering peak demand.

1) GLOBALLY USED SMART METERS AND SMART APPLIANCES

Smart meters perform an essential role in enabling the integration of new technologies [36]. Smart meters collect data by measuring and calculating daily consumptions; moreover, they help customers to reduce energy usage during peak hours to support the grid. Smart appliances perform a vital role in the SG [119]. The SG appliances that support the grid contribute to peak demands and store energy during critical peak periods. The electricity demand is increasing, and smart appliances assist in energy saving owing to their low power consumption. Peak periods vary from region to region, depending upon the weather conditions. In certain countries, the peak demand period is during summer, and in certain countries, the peak demand period is observed during winters [38]. Fig. 4 describes the SG projects in the USA and its neighborhood. Smart meters are installed in the USA, several European countries (Germany, France, Denmark, Austria, Italy, and Spain), the United Kingdom, China, Japan, Korea, New Zealand, and other developing countries. In the USA, approximately 46 million smart meters are installed [48].

2) GLOBAL TRENDS OF DEMAND RESPONSE PROGRAMS

One of the key aspects of the SG is a demand response (DR). The electricity consumption is controlled through DRPs [26], while the DR involves consumer participation and assists consumers to shift load at peak hours and emergencies. Load control devices and automatic metering infrastructure (AMI) are examples of DRs. Load management is an approach used by electric power and utility companies to reduce the load at peak hours when demand is high; thus, the load is shifted to low-peak periods. Consumers are offered incentives for saving energy at peak periods [40]. DR provides reliability by flattening the load profiles using an emergency resource, known as load rejection, that protects the grid [41]. Fig. 5 illustrates the applications of DR. DRP includes **(a)** dynamic pricing, **(b)** consumer utility, and **(c)** load management. DRP is an environment-friendly and cost-effective program. Canada, Australia, New Zealand, and the USA are contributing in terms of DRPs at both federal and state levels, and several regulations are organized to support DRPs [58]. European countries and China and other developing countries are also contributing to this field and have realized the requirement of these programs for avoiding blackouts and system failures.

B. GLOBAL APPLICATIONS OF SG (HEADING IS REPEATED AGAIN)

RE utilization in SGs is increasing owing to certain pertinent features, namely, **(a)** grid support, **(b)** power quality improvement, **(c)** reliability, and **(d)** cost reduction. Programs for RE are implemented in various regions of the world, in both developed and developing countries [42]. The distributed generation stabilizes a weak grid by accommodating the additional power into the grid and improves the power quality of the SG [31]. The renewable resources facilitate the massive generation, reduced CO_2 emissions, and an ecofriendly environment [46]. Renewable resources with advanced control systems can interact with SG control systems and provide supplementary services.

For example, the concept of distributed generation is used with capacitor banks for the management of power streams and to regulate active and reactive powers. If distributed renewable resources are grouped with the SG technology, it will contribute to transmission-level ancillary services, such as spinning reserves [31]. Table 2 lists the global investment in the RE sector for the previous years (2004–2015) measured in billion dollars ($bn). According to previous work, RE enhanced the global energy generation capacity and increased the investment in RETs, when compared to all other energy systems.

C. WORLDWIDE TOP RENEWABLE ENERGY INVESTORS

SG technology is improving consistently and poses positive impacts on society. These developments have revived the interest of researchers, which has aided in increasing grid efficiency [32]. According to Bloomberg New Energy Finance, a 12% increase in annual SG investment was observed in 2015. The installation and development of SG technologies depend on industrial drivers, policymakers, and investors. The USA played an important role in grid modernization and is known as a "world leader" in the development and installation of SGs as several US companies provide useful technological solutions, consequently increasing their SG exports [2]. However, in 2009, China surpassed the USA and

TABLE 1. Summary of certain state-of-the-art works.

Reference	PEDS	PRER	PAPP	GSMSA	DRP	REUGT	PMA	TIWSG	SGP	PPP	IPPS	REP	CISG	CPEC
[2]	×	×	×	×	×	×	×	✓	✓	×	×	×	×	×
[13]	×	✓	×	×	×	×	×	×	×	✓	✓	×	×	×
[14]	✓	✓	×	×	×	×	×	×	×	✓	×	×	×	×
[15]	×	×	×	×	✓	×	×	×	×	✓	×	×	✓	×
[17]	×	✓	×	✓	×	×	×	×	×	×	×	×	✓	×
[18]	×	×	×	×	×	×	×	✓	✓	×	×	×	×	×
[19]	✓	✓	×	×	×	×	×	×	×	✓	×	×	×	×
[20]	×	✓	✓	×	×	×	×	×	×	×	✓	×	✓	×
[21]	✓	×	×	×	×	×	×	×	×	✓	×	×	×	×
[22]	×	×	×	✓	×	×	×	×	×	×	×	×	✓	×
[23]	×	×	×	×	×	×	×	✓	×	×	×	×	×	×
[24]	×	×	×	✓	×	×	×	×	×	×	×	×	×	×
[25]	×	×	×	✓	×	×	×	×	×	×	×	×	✓	×
[26]	×	×	×	✓	✓	×	×	×	×	×	×	×	✓	×
[27]	×	×	×	✓	×	×	×	×	✓	×	×	×	✓	×
[28]	×	×	×	×	×	×	×	×	×	×	×	×	✓	×
Our Work	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Abbreviations: PEDS: Pakistan Energy Demand Statistics; PRER: Pakistan Renewable Energy Resources; PAPP: Pakistan Available Power Potential; GSMSA: Globally Used Smart Meters and Smart Appliances; DRP: Demand Response Programs; REUGT: Renewable Energy Usage and Global Trends; PMA: Power Market Analysis; TIWSG: Top Investors Worldwide in Smart Grids; SGP: Smart Grid Policies; PPP: Pakistan Power Production; IPPS: Independent Power Producers; REP: Renewable Energy Penetration; CISG: Communication Infrastructure in Smart Grids; CPEC: China–Pakistan Economic Corridor.

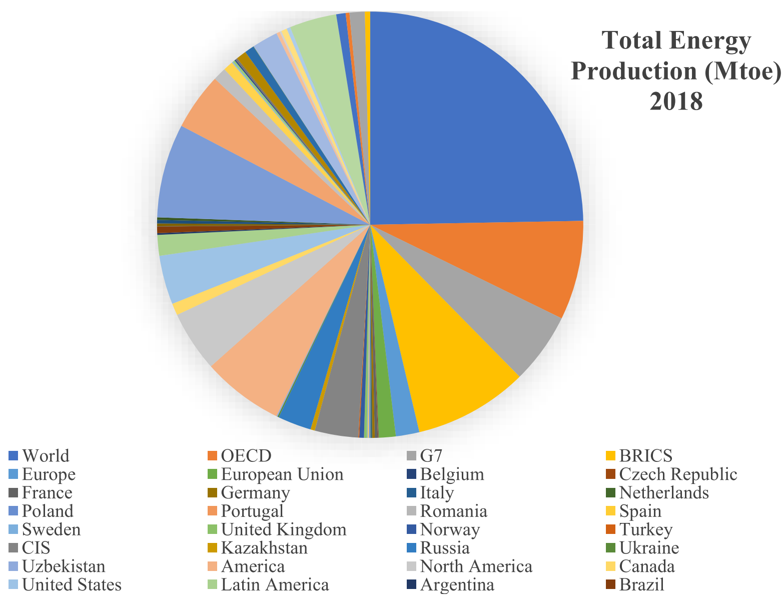

FIGURE 3. Total energy production (million tons of oil equivalent) [123].

became the largest market in the world in SG investment [47]. Table 3 lists the country-wise clean energy investments. Both developed and developing countries are focusing on SG development and installation after comprehending the requirement for SGs because of their efficiency, security, reliability, and reduced environmental impacts.

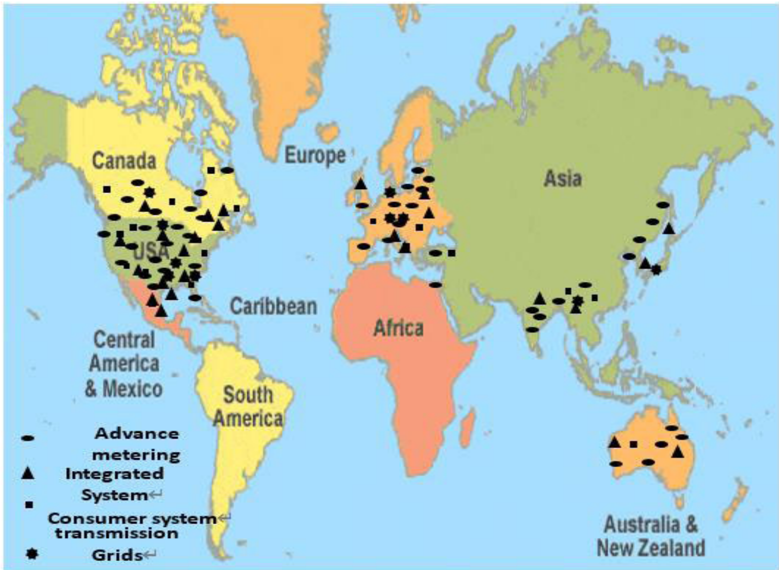

FIGURE 4. Smart grid projects around the globe [36].

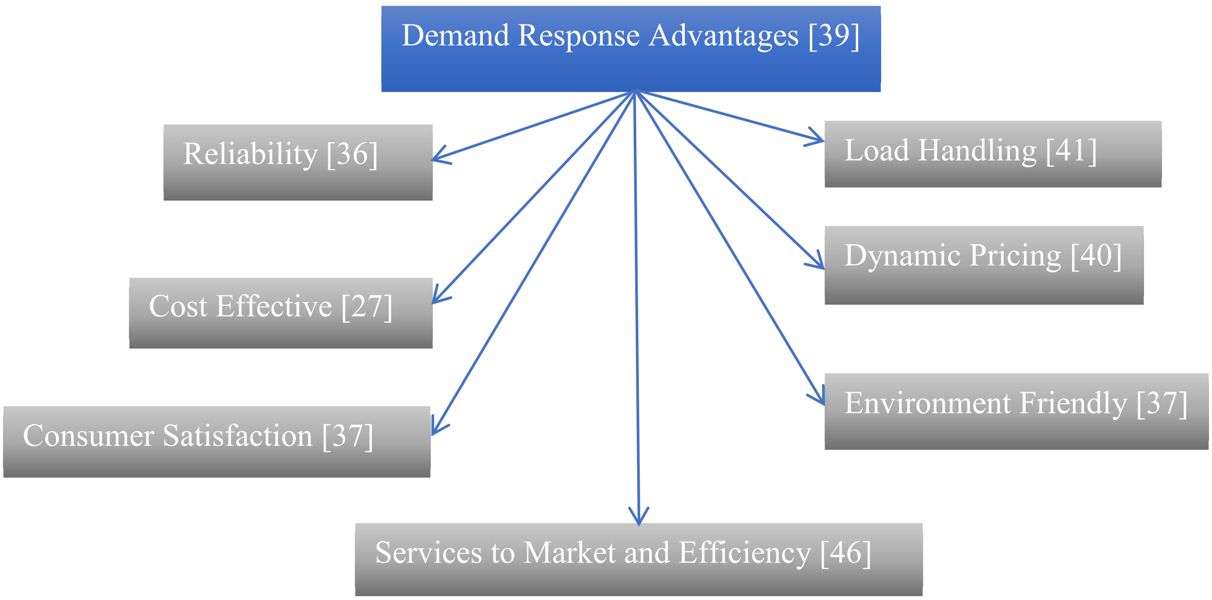

FIGURE 5. Demand response advantages and characteristics.

1) GLOBAL INVESTMENTS IN SG

From 2010 to 2013, the US electric industry spent approximately $18 billion for the deployment of SG technology. The analyst expected an increase in the expenditure from $1.2 billion in the year 2011 to $1.9 billion in the year 2017 and a decrease in AMI deployment expenditure from $3.6 billion in 2011 to $1.2 billion in 2017 [49]. Developing countries are also focusing on SG technology deployment. Electric Power Research Institute estimates that $338–476 billion will be expended to completely shift to SG technology in the next 20 years with initial expenditures of approximately $82–90 billion for transmission structures and substations, $232–339 billion for distribution structures, and $24–46 billion for consumer system employment [50]. The task is considerably exigent as grid-connected RE, and distributed energy applications have increased, resulting in the requirement for an efficient and intelligent grid system. However, interoperability and system integration challenges are expected to persist with changes in information management and control systems [48].

2) GLOBALLY IMPLEMENTED SG POLICES

Different SG policies are implemented worldwide for addressing several ongoing deployment problems. Countries

TABLE 2. Sector-wise Global Investment ($bn) in Renewable Energy (RE) Technology (2004–2015) [47].

Sources	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Wind	17.8	26.9	37.0	49.1	69.9	73.8	94.1	79.7	79.9	86.3	97.8	107.0
Solar	0.3	1.1	4.6	13.3	25.5	18.5	29.9	68.3	59.9	54.5	71.8	80.9
Biomass & w-t-e	7.3	8.9	11.1	14.1	16.3	13.2	14.5	16.5	12.3	9.6	9.6	5.2
Biofuels	3.2	7.9	22.9	24.9	15.9	6.9	7.2	7.0	4.1	2.0	2.0	0.7
Small hydro	2.4	7.1	7.3	6.5	7.1	5.8	4.6	6.9	5.9	5.1	4.7	3.5
Geothermal	0.9	0.8	0.7	1.5	1.0	1.8	2.5	2.9	1.2	0.5	2.4	1.8
Marine	0.005	0.03	0.8	0.5	0.04	0.1	0.03	0.1	0.1	0.1	0.1	0.002
Disclosed count	236	501	684	904	962	833	914	924	804	752	790	870
Total count	**1,125**	**1,621**	**1,991**	**2,213**	**2,410**	**2,329**	**2,851**	**3,077**	**2,935**	**3,325**	**3,444**	**2,424**

have set different targets for SG installation and are competing with other countries to overcome the current demands. The USA is focusing on low-carbon energy as the current energy system is not carbon-free and produces high emissions. Currently, only 11% of electricity is generated from renewable resources in the USA, whereas it is 19% and 27% in China and Italy, respectively [52]. For China, the development and installation of SGs in the energy sector is a national priority. China is creating policies to achieve a carbon-free environment and has set a goal to deliver clean energy and installation through SGs by 2020 [53]. The European Union ranks second in the world energy market, which accommodates 450 million customers [52]. Developing countries are planning to create new policies to improve their capabilities to be on par with developed countries. The government of the Philippines is planning an investment in the field of SGs in collaboration with the Asian Development Bank (ADB) and the World Bank by obtaining a loan of $250 million [31].

TABLE 3. Country-wise investment in clean energy (2004–2015) [47] and Top 16 countries for RE capacity investment from 2010 to 2019, in $BN [122].

Country-wise Clean Energy Investment				
Country	**2004-2014 (Billion Dollars)**	**Country**	**2014 (Billion Dollars)**	**Total Installed Capacity (MW)**
USA	447.642	**China**	89.491	121.660
China	427.617	**USA**	51.770	224.788
Germany	244.949	**Japan**	41.342	86.946
Japan	189.188	**Germany**	15.299	32.679
Italy	103.436	**UK**	15.229	8.774
UK	101.030	**Canada**	8.971	23.346
Spain	100.038	**India**	7.937	23.014
Brazil	78.943	**Brazil**	7.864	22.852
India	72.828	**France**	7.017	36.753
France	56.931	**Netherlands**	6.727	9.184

Top 16 Countries for RE Capacity Investment from 2010 to 2019, $BN [123]

Country	(Billion Dollars)
China	758
USA	356
Japan	202
Germany	179
UK	122
India	90
Italy	82
Brazil	55
Australia	47
France	45
Spain	35
Canada	33
Netherlands	25
Mexico	23
Belgium	22
Sweden	20

D. SMART TECHNOLOGY DEVELOPMENTS WORLDWIDE

The SG is an emerging technology used worldwide to overcome the problems of load shedding and power system failures. Manual meters are replaced with smart meters to overcome theft problems and high costs [54]. Several efficient, intelligent products have been designed to fulfill the current energy demands. Companies are providing solutions for air conditioning, ventilation, and heating through smart buildings. The grid stabilizes by incorporating energy storage devices, RE, AMI, and DRPs. All these features of the SG result in its resilience and suitability for existing energy demands and future requirements.

1) SG DEVELOPMENT IN THE USA

In the USA, the conventional electric grid is undergoing revolutionary changes by merging it with digital technologies. Policies are underway to encourage and boost investment by the business community in the field of growing renewable and distributed energy resources. The SG involves two primary processes: **(a)** introduction of digital technology and **(b)** information management; therefore, it enables the modernization of electric power delivery and distribution to consumers. However, the SG utilization and deployment processes across the world have witnessed a struggle with a set of new technical, regulatory, and financial trends, indicating the transformation and renovation in the field of energy [48].

- **Export Opportunities in the USA**

The investment in the SG field by the USA started in 2009, and currently, the country is one of the leading investors in SG. Various small and big investment companies in the USA are helping different countries of the world with their expertise in the deployment and development of the SG technology. From the beginning, the International Trade Association (ITA) has shown its interest in the SG field and is contributing to the research and analysis domain of the US government [45].

- **Leading International Markets of the USA**

The ITA ranks and grades "34" leading international markets of the USA for their export and determines the typical characteristics of top-ranking countries. Table 4 lists the ITA ranking and grading of the 34 leading global markets of the USA in terms of export growth. Owing to the development progress of the USA pertaining to SGs, the country is leading in the international energy market for SGs. A report based on various global market data and analyses reveals that the USA is competing globally in the field of services and products of various utilities. After China and Germany, the USA is the third-largest exporter of T&D equipment [45].

2) SG DEVELOPMENT IN EUROPE

Europe is facing specific challenges, and in response to the upcoming challenges, initiatives to benefit its consumers and increase grid efficiency are being considered. Therefore, Europe is investing on a large scale in SGs to fortify its power system [55]. There are several ongoing SG projects in Denmark, Austria, and France, whereas Germany is leading in multinational projects with approximately 105 projects. Currently, Spain, Italy, and France have 97, 89, and 76 transnational projects, respectively [57].

3) SG DEVELOPMENT IN CHINA

In the year 2004, the industrial sector in China witnessed a rapid growth in electricity consumption, resulting in an electricity shortage in the year 2005, which affected several companies. The generation capacity was improved by reducing line losses and installing high-efficiency transformers for load management. Owing to a rapid increase in electricity demand, China is focusing on SG deployment and is following in the footsteps of the USA and Europe. China is facing a severe challenge of maintaining the efficiency, sustainability, and reliability of the SGs. Furthermore, another problem is that the coal mines are at distant locations from major load centers in China [56].

4) SG DEVELOPMENT IN JAPAN

The SG transformation in Japan is a strategic energy planning process with the coordination of viable policies between different agencies and organizations. The Japanese SG community is divided into four major working groups, which include **(a)** development strategies, **(b)** global standardization, **(c)** a roadmap for future deployment, and **(d)** organization of smart house information. Japan is planning to manage energy consumption and integrate electric vehicles in systems with distributed generation in four major cities. A triple I (intelligent, interactive, and integrated) power system is also in the development stages, which aims to match the demand and supply for incorporating renewable distributed resources [31]. Historically, Japan is the first nation to invest in SG research and development in 2003. Moreover, Japan established the New Energy and Industrial Technology Development Organization, which has administered numerous SG-associated schemes.

5) SG DEVELOPMENT IN THE REPUBLIC OF KOREA

The Korean government is working on the vision of "Low Carbon, Green Growth" since 1968. This vision resulted in the formation of the foundation of the Korean SG Institute (KSGI). The institution is responsible for the exploitation of SG technology and the integration of renewable resources in addition to boosting economic growth. The KSGI, consisting of over 100 companies, is working on five megaprojects on infrastructure development, research, and analysis that link government and private sector investors [31].

6) SG DEVELOPMENT IN MEXICO

Mexico is planning the incorporation of various modes of SGs and the integration of RERs at the national level. The Mexican Federal Electricity Commission is formulating a tender for the implementation of a model project. The SG Development Model is planning and creating the roadmap for the transformation of SG technology [31].

7) SG DEVELOPMENT IN INDONESIA AND MALAYSIA

Indonesia is a country with several small, independent, distributed islands (over 17,000 small and large islands). It is showing significant interest in SG for addressing the requirements of its scattered public demand, particularly increasing the efficiency of existing grids and developing smaller-scale SG programs. Malaysia is investing in hydroelectric (hydel), solar, wind energy, and thermal electricity production. However, Malaysia is not perusing SG technology, considering the massive initial investment required for the project [31].

8) SG DEVELOPMENT IN NEW ZEALAND

The New Zealand government is planning to obtain 90% of its electricity from renewable resources, including hydrogenation, by 2025. The efficiency target of saving 55 PJ by the end of the year 2015 was possible through the employment of AMI systems. The Electricity Commission recommended the government to standardize the development of AMI comprehensively. However, the benefits of standardization do not outweigh the costs. The Electricity Commission recommended the formulation of regulations for interoperability, data security, and unplanned disconnection of consumers from the existing AMI systems [31].

9) SG DEVELOPMENT IN RUSSIA

The intellectual power system of Russia is a significant platform of the Russian Energy Agency and Federal Grid Company for the development of SG technology and its utilization. The objective of this platform is to formulate a comprehensive plan for employing SG technology with renewable resources

TABLE 4. Summary of certain state-of-the-art works.

	Export Market (Clusters)	**Common Characteristics**	**Examples** (Rank)
LONG-TERM	Increasing Grid Modernization	• Addressing essential problems in the broader electricity sector • High potential for longer-term export growth • Minor income markets • The present focus is on grid upgradation	South Africa (29) Indonesia (26) Thailand (28)
	Economic Laggards	• Mid- to large-size economies • The underprivileged economic health and/or business environment • SG investment growth with significant risks • Established current suppliers	Portugal (33) Russia (32) Poland (31) Italy (27)
MID-TERM	Rising SG Markets	• A small income, high growth, as well as in demand for electricity • Major infrastructure challenges • High potential for medium- to long-term export growth • More significant opportunities for equipment/services	India (8) Vietnam (9) Nigeria (21) Colombia (30) Brazil (32)
	Growth Competitors	• Competitive markets with growing SG investment • Extremely competitive local suppliers	Korea (13) Spain (15) Germany (18)
	Established Competitors	• Minor, high-income markets • Less favorable to US suppliers • Have already invested in SG infrastructure • More opportunities for SG information communications technology /services	Netherlands (16) New Zealand (19) Austria (22) Israel (23) Denmark (24) Sweden (25)
NEAR-TERM	SG Procurers	• Growing SG investment • Advanced metering infrastructure • Major procurements and deployments in progress	Japan (3) China (7) France (10)
	Toward Operation	• Rising and falling electricity demand • Procurements are beginning and helpful competitiveness for US firms • Primary investment growth in the electricity sector	Saudi Arabia (4) Turkey (12) Malaysia (14) Philippines (17) Singapore (20)
	Strong Economies	• Stable, healthy, mid- to large-size economies • Encouraging business environments • Investment in electricity infrastructure is the primary concern	Australia (5) Chile (11)
	Prime Trade Partners	• Top US export market • Geographic and/or cultural proximity • The account of achievement for US suppliers	Canada (1) Mexico (2) UK (6)

to shift the power system to SG. The primary demonstration of SG will be performed in the city of Belgorod in Russia, and the deployment, integration, and distribution will be triggered by this city [31].

10) SG DEVELOPMENT IN PAKISTAN

Pakistan is in the development phase, and the government is working on several projects. According to the Water and Power Development Authority (WAPDA), by 2016, "five" hydel power projects are expected to be completed. Several natural resources are available to overcome the current energy crises, and positive steps are required for stability in this area. Pakistan is facing several challenges in the field of energy and will require several years to gain the status of a developed country. The concept of SG has not yet been introduced in Pakistan, and the current grid is conventionally installed throughout the country. As some of the projects are in their completion phases under the CPEC and is expected to boost the economy, improve the current power crisis situation, and enhance the energy capacity of Pakistan.

E. CONCLUDING REMARKS

In the present era, scientists are inventing innovative techniques for the economical use of energy resources. The production, management, T&D of energy in existing conventional grids are in the process of transition and is being replaced by the SG technology in the developed countries of the world. The SG facilitates the consumers by provisioning of real-time energy tariffs to reschedule their load demands during peak-pricing hours. The SG technology is being extensively implemented by China, USA, Russia, Far East nations such as Japan, Korea, and in the south-east part of the world, especially Australia and New Zealand. Developing countries are also planning to adopt SG technology, considering the availability of resources and foreign investments. Underdeveloped countries are not familiar with the concept of SGs. Pakistan is investing in the SG technology to overcome the current energy crises and is utilizing its assets to boost the economy. It is perceived that in the next 15 years, most of the countries will strive for the deployment of SGs and the integration of RERs into SGs.

III. RENEWABLE AND NON-RENEWABLE ENERGY RESOURCES WITHIN PAKISTAN

Energy is a critical requirement in all aspects of human welfare. The development and sustainment of the economy of a country are dependent on electricity. In Pakistan, a large amount of energy is required for industrial as well as household requirements and to retain the country on the track of modernization. At present, the country is struggling to increase the sustained energy supply [59], [60]. In Pakistan, all forms of energy resources are abundantly available. The essential requirement is the effective utilization that will up improve the economy of the country [61].

The available energy resources within Pakistan are shown in Fig. 6. The energy potentials and resources are of two types, namely, **(a)** conventional energy resources and **(b)** RERs. Conventional resources indicate the sources of energy that are generally non-renewable. The primary conventional resources are thermal and nuclear energy resources. Thermal energy is generated from fossil fuels, coal, and natural gas. RE is produced from natural resources, such as geothermal, solar, wind, hydel, waste heat, and biomass energies. In an unindustrialized country, such as Pakistan, financial and cost-effective stability relies on the growth of the energy sector to motivate communal opulence and long-term development for the employment of domestic energy techniques. Since the last few years, Pakistan has been confronting an extraordinary energy catastrophe. Currently, the energy demand of Pakistan far exceeds its indigenous supplies, which has resulted in a dependency on imported oil, degrading the economy of Pakistan. Thus, to ensure the reliability of energy provisions, the GoP is implementing policies to increase its domestic supplies, attract foreign assets, increase the imports of coal, natural gas, and electricity, reassure economic inter-fuel replacement, endorse energy efficiency and the utilization of REs, and achieve provincial and interregional collaboration [8].

A. ENERGY DEMAND AND STATISTICS OF PAKISTAN

In the last few decades, there has been a significant increment in the demand for primary energy in Pakistan. The primary energy is a vast entity that includes all necessary forms of energy, such as gas and electricity, which are used for commercial and industrial applications [61]. In Pakistan, since 1991, the primary energy production and consumption have witnessed a steadily increasing gap that has a profound impact on energy resources. The difference between primary energy production and primary energy consumption was 0.9 million tons of oil equivalent (MTOE) (production was 28.5 MTOE, and consumption was 29.4 MTOE) in 1991, while the difference between primary energy production and consumption in 2013 was 7.31 MTOE (production was 64.59 MTOE, and consumption was 71.9 MTOE).

Statistics show that the increase in the growth rate of primary energy consumption from 1991 to 2013 was 136% [63]. Pakistan has several primary energy sources, of which gas provided 47% of commercial energy in 2013–2014. Other major resources such as oil, hydel power, coal, nuclear electricity, and liquefied petroleum gas (LPG) provided 33, 11, 6, 2, and 1%, respectively, as shown in Fig. 7(a). The commercial energy supply provided by REs was negligible. The proposed energy supply of Pakistan in 2024–2025 is shown in Fig. 7(b) [71]. The figure shows that gas is expected to provide 35% of commercial energy supply, followed by oil (20%), hydel (15%), coal and RE (each will provide 10%), nuclear (8%), and LPG (2%). The proposed energy mix of Pakistan shows that by the year 2024–2025, the energy supply from gas and oil will decrease, while the energy supply from hydel, coal, renewable, nuclear, and LPG will increase.

The primary consumers in Pakistan are commercial, agriculture, industrial, domestic, and transport sectors, as shown in Fig. 7(c). The primary energy consumption is divided as follows: industrial consumption was 35%, followed by transport consumption at 32%, domestic consumption at 25%, commercial consumption at 4%, agriculture consumption at 2%, and specific other sectors consumed 2% in 2013–2014. A study on energy consumption by sectors has built a forecast of the energy consumption of Pakistan in 2024–2025, as shown in Fig. 7(d). The forecast for energy consumption indicates an exponential trend, with a 0.3% built-in error [71]. The forecast of energy consumption according to sectors in Pakistan shows that the primary sector in energy consumption will be the transport sector, which is expected to consume 36%, followed by the domestic, industrial, commercial, other, and agricultural sectors, which are expected to consume 34, 22, 5, 2, and 1% of the total energy in 2024–2025, respectively. The forecast shows that the energy consumption by the industrial and agricultural sectors will decrease, while the energy consumption by transport, domestic, and commercial sectors will increase by the year 2024–2025 in Pakistan.

The energy supply and demand projections in Pakistan are illustrated in Fig. 8. Fig. 8 shows the gap between the supply and demand for primary energy in Pakistan. The increasing rate of primary energy demand in Pakistan is higher than the

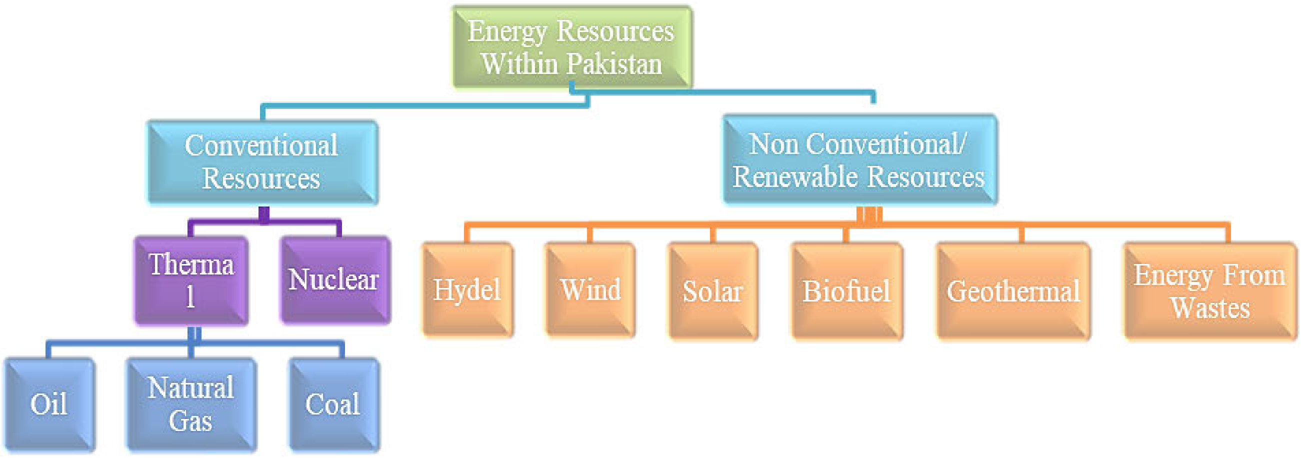

FIGURE 6. Energy resources within Pakistan [106].

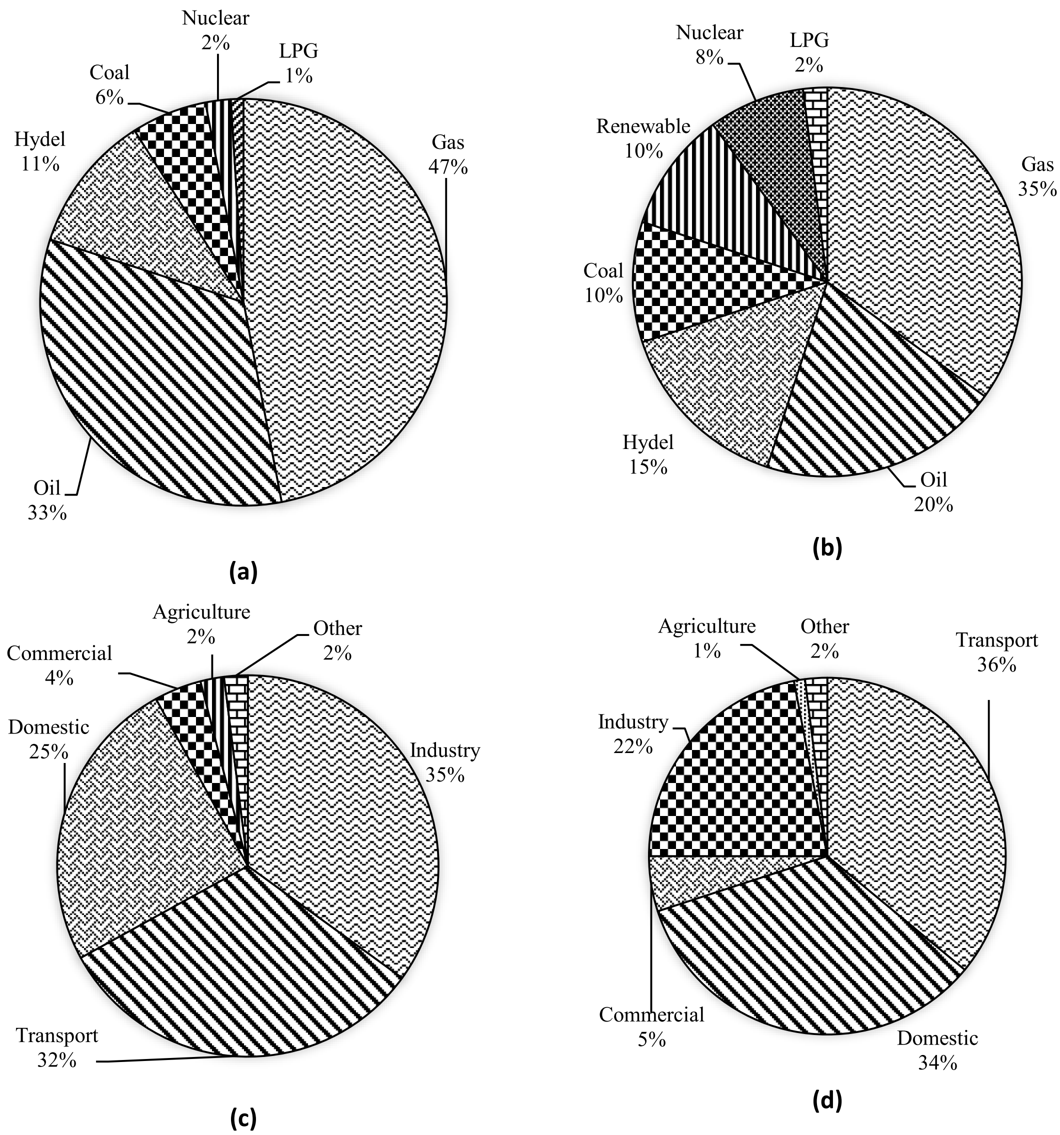

FIGURE 7. (a) Energy mix of Pakistan in 2013-2014 (b) Energy mix of Pakistan in 2025 (c) Energy consumption in 2013-2014 (d) Energy consumption in 2024-2025 [71].

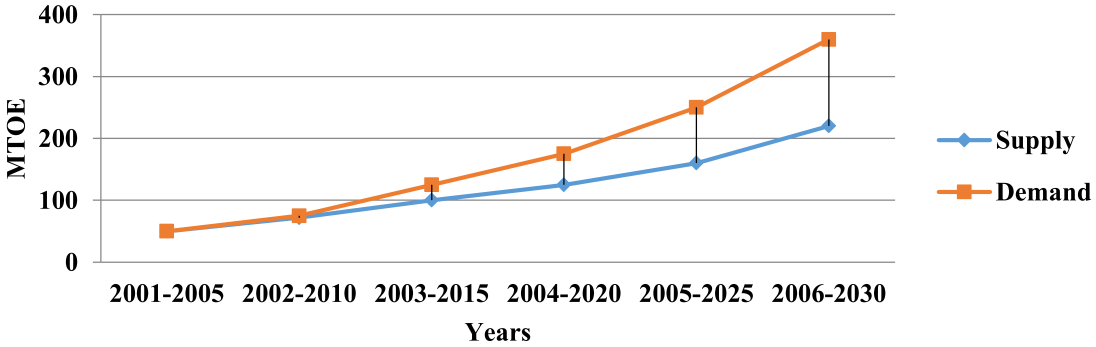

FIGURE 8. Energy supply and demand projections [4].

growth rate of primary energy supply. With such a trend in the primary energy demand, Pakistan will be facing an extreme shortage of energy in the future.

According to the National Energy Supply Program, the expected increment in the primary energy consumption in Pakistan is from 40.18 MTOE in 2005 to 360 MTOE in 2030, which shows a growth rate of 796%. Thus, in the future, Pakistan is expected to face more than a 31% shortage of energy. According to the ADB, the expected increment in the primary energy demand of Pakistan indicates growth from 84.6 MTOE in 2010 to 145.8 MTOE in 2035, which shows a 2.2% annual growth rate. With such a yearly growth rate, the energy demand in Pakistan will be 0.59 tons of oil equivalent (TOE) per person in 2035, which was 0.49 TOE per person in 2010 [63].

B. CONVENTIONAL ENERGY RESOURCES

At present, several countries in the world are excessively dependent on conventional energy resources to satisfy their requirements for power [64]. The primary sources of conventional energy are fossil fuels, such as coal, oil, and natural gas. Along with fossil fuels, nuclear energy is also a resource of conventional energy. Energy production in Pakistan is primarily dependent on conventional energy resources [60]. According to the National Transmission and Dispatch Company (NTDC), the average share of conventional resources from 2010–2015 in overall power generation was 66.1% in Pakistan. The average percentage of thermal power (oil, natural gas, and coal) was 62.05%, followed by hydropower (33.4%), and nuclear power (4.05%); also, the energy import was 0.36% in 2010–2015, as listed in Table 5. The aforementioned conventional energy resources are described below.

1) FOSSIL FUELS

The deposits of organisms that previously lived in the world contain hydrogen and carbon bonds and are known as fossil fuels. Owing to the advent of modern industry, fossil fuels are the leading energy sources. Fossil fuels include the following: **(a)** oil, **(b)** coal, and **(c)** natural gas [66].

Oil is a more efficient source of energy when compared to coal. Different organic compounds are obtained from crude oil and are transformed through a refining process into a wide range of products. Oil is extracted through a drilling process from the earth [66]. Since 1915, Pakistan has been producing crude oil. According to an estimate, the currently available assets of crude oil are 371 million barrels, primarily existing in the provinces of Punjab, Sindh, and Khyber Pakhtun Khwa (KPK). In 2013, the average production of oil was 76,200 barrels/day. Despite this, the domestic production of oil satisfies only 20% of the demand in Pakistan. Thus, to overcome the demand-supply gap, petrol/gasoline, furnace oil, diesel oil, and crude oil are imported from the Middle East countries to Pakistan [42]. The insufficiency of oil is the foremost limitation in Pakistan as it results in regular imports, both in the forms of crude oil and finished petroleum products. Pakistan imported $11.7 billion worth of petroleum in 2014–2015, which accounted for approximately a quarter of the total trade bill of the country [43]. In Pakistan, the energy supply from oil was 33%, and the consumption of oil energy was 30% in 2013–2014 [67].

Coal is used for heat and energy purposes. The industrial revolution was equipped with coal, transforming human civilization. Generally, coal is extracted in three primary forms from mines, namely, anthracite, bituminous, and lignite [66]. Favorably, Pakistan has a significantly economical and low-priced source for energy in the form of coal. To match the electric supply and demand in Pakistan, the utilization of coal is a feasible and durable solution, as the country has the fifth-largest amount of coal credits in the world. Estimations made in 2011 show that Pakistan has approximately 185 billion tons of coal reserves. The Thar desert in Pakistan, covering an area of approximately 10,000 km^2, contains nearly 850 trillion cubic feet of deposits, which is comparatively higher than the oil assets of Saudi Arabia, which is about 375 billion barrels. Presently 40.6% of the electricity in the world is being generated from coal. However, in Pakistan, only 2.27% of the total electricity is made from coal. The available coal deposits in the Thar region can only produce 20,000 MW of electricity in Pakistan for the next 40 years, excluding load shedding and at a cost less than Pakistan rupees (PKR) 4, when compared to the present price of electricity production [99].

Natural Gas is composed of methane and is the most recent gaseous form of fossil fuels. Natural gas is generally found at varying depths in the crust of the earth and is extracted

TABLE 5. Energy generation based on different sources in Pakistan [65].

Fiscal Year Ending 30th June	Hydro		Thermal		Nuclear		Imports		Total
	GWh	%age	GWh	%age	GWh	%age	GWh	%age	
2010	28,492	32.0	52,084	65.3	2,095.0	2.4	249.0	0.3	88,921
2011	31,990	35.3	55,386	61.1	2,930.0	3.2	269.0	0.3	90,575
2012	28,642	31.9	56,369	62.8	4,413.0	4.9	296.0	0.3	89,721
2013	30,033	34.0	54,212	61.4	3,640.5	4.1	375.1	0.4	88,264
2014	32,239	33.9	57,959	60.9	4,401.6	4.6	418.6	0.4	95,019
2015	32,563	33.4	59,320	60.8	4,996.0	5.1	442.6	0.5	97,321

TABLE 6. Comparison of fossil fuels [66].

Fuel	Specific CO_2 Emission	Specific Energy Content
Coal	0.37	6.7
Crude Oil	0.26	12.7
Natural Gas	0.19	15.3

through drilling processes from the earth. Coal and oil are less attractive than natural gas because of their lower calorific value and high carbon dioxide emissions, as listed in Table 6 [66]. In 1952, the first fundamental discovery of natural gas in Pakistan was made at a distant, and less-known location in Baluchistan called Sui. It is claimed that Pakistan still owns one of the most wide-ranging inland natural gas source substructures in the world with an unconceivable total length of approximately 140,000 km, which is sufficient to circle the whole world at least three times. Subsequent significant discoveries occurred in Mari and Kandhkot; however, these were not exploited in the preceding years because of a lack of requirements. The revolutionary sequence of significant discoveries happened in the last era of the 20th century at Qadirpur, Zamzama, and Sawan [101].

Consequently, the consumption of natural gas accelerated from 1,742 million cubic feet per day (MMCFD) in 1998–1999 to 3,181 MMCFD in 2004–2005; similarly, the rate of depletion of national gas assets was also observed. Presently, the average gas assembly is appraised to be approximately 4,000 MMCFD. At the same time, the supply-demand gap has reached 1,000-1,500 MMCFD and is predicted to widen up to 4,000 MMCFD by 2020 unless substantial new production is possible [43]. In Pakistan, the energy supply from natural gas was 47%, and the consumption of natural gas energy was 44% in 2013–2014 [67].

2) NUCLEAR ENERGY

A form of conventional energy, nuclear energy is primarily generated through controlled nuclear reactions such as nuclear fusion and nuclear fission. Atomic fission involves the breaking of a heavy atom into segments generating massive energy. In nuclear fusion, a larger nucleus is created from the combination of several small nuclei, which releases a large amount of energy. Concerning energy yield, all nuclear power comes from the nuclear fusion process, which is considered to be more productive than the nuclear fission process. To minimize the dependency of the world on oil for electricity production, a vital portion of power is obtained from nuclear energy. In the global primary sources of energy supply, approximately 7% is contributed by nuclear energy [66].

In Pakistan, all the nuclear energy initiatives, explorations, and research in the field are headed by the Pakistan Atomic Energy Commission (PAEC). The Karachi Nuclear Power Plant, the first nuclear power generator of PAEC of 137 MW, was started in 1971, approximately 25 km west of Karachi. Chashma 1, also known as Chashma Nuclear Power Plant 1, situated at the north of the Punjab province, is a second unit, which is a 325 MW pressurized water reactor (PWR), which was started in the year 2000 with 40 years of estimated life. In December 2005, the construction of Chashma 2 was started, and in March 2011, it was connected to the grid. Since then, expansions have added 5 MW of power (330 MW gross). The construction of Chashma 3, a 315 MW reactor, was started in May 2011, and the grid connection occurred in October 2016 [124]. Table 7 lists those mentioned above operational nuclear plants in Pakistan.

According to a report published in August 2011, Pakistan had proposed a long-term plan for the construction of nuclear reactors having a total potential of 8,000 MW at ten different locations by 2030. On the recommendations of the International Atomic Energy Agency and Pakistan Nuclear Regulatory Authority, the PAEC had selected six new sites for the construction of nuclear plants, which included the Pat Feeder canal near Guddu, Qadirabad-Balloki link canal bordering Qadirabad Headworks, Taunsa-Panjnad canal bordering Multan, Dera Ghazi Khan canal bordering Taunsa Barrage, Nara canal bordering Sukkur, and Kabul River. The reports of

TABLE 7. Operational plants in Pakistan [124].

Reactor	Province	Type	MW Net Generation
Karachi 1	Sindh	PHWR	125
Chashma 1	Punjab	PWR	300
Chashma 2	Punjab	PWR	300
Chashma 3	Punjab	PWR	315
Total (4)			1,040

the PAEC published in the year 2012 declared the plan for four reactors in the Taunsa-Panjnad link canal near Multan. According to a report published in January 2014, the PAEC planned to construct five additional nuclear reactors (1,100 MW) to overcome the increasing demands of electricity [40]. In Pakistan, the energy supply from nuclear energy was 2% of the overall energy supply in 2013–2014 [67].

C. AVAILABILITY OF RENEWABLE ENERGY RESOURCES

RE is generally generated from natural resources, such as geothermal, solar, wind, biomass energies, and energy from wastes. RERs have also played an essential role in human welfare since the beginning of civilization; for example, biomass has been used for cooking, heating, and steam production; the wind has been used for moving ships; both wind and hydropower have been used for powering grinding mills. RE that is obtained from domestic resources has the potential of providing energy services with almost zero emission of greenhouse and air pollutant gases. RERs are plentiful and are acknowledged to be robust and sufficiently abundant to satisfy the energy demands of the world multiple times [6].

In Pakistan, the potential exists for almost all types of REs [11]. RERs are available in various provinces of Pakistan, such as Sindh, Punjab, and KPK, where the average speed of wind at a specific location is approximately 5–7 m/s. Similarly, in Pakistan, 1,600 GW of the annual generation of electricity is possible from only solar energy. The share of electricity generated from geothermal energy is approximately 2% of the total green energy generated [70]. Pakistan has abundant availability of RERs; however, the major challenge is that these resources are not efficiently utilized. The first RE policy of Pakistan was published in 2006, which established mid- and long-term projects that included 9,700 MW of electricity generation from RERs by the year 2030 and the electrification of 7,874 off-grid villages. However, despite these ambitious projects, there has not been much advancement in the exploitation of emerging RETs in Pakistan. The share of emerging RETs in electricity generation was approximately 0.2% (excluding large hydro projects), with only 40 MW of installed capacity in 2008 [71].

The Pakistan Council of RETs (PCRET) has performed an essential function in the improvement and promotion of RE in Pakistan since 2001. The primary activities of PCRET include the installation and development of RE sources at the community level. Table 8 lists the notable achievements of the PCRET with regards to the RE-based products disseminated to the community till 2009. In 2010–11, there were no significant achievements by the public or private sector toward the development and installation of RE-based generation plants [72].

TABLE 8. Salient achievements of Pakistan council of RE technologies till June 2009 [72].

RE Technology	Units Installed	Capacity	Household Electrified/Benefited
Microhydel Power	404	5,537 KW	50,000
Wind Turbine (off-grid)	153	153 KW	1,500
Water Heater	61	400 Lit/Day	6,100
Solar Desalination Plant	3	15 Lit/Day	3
Solar Dehydrator	21	5,230 KG	21
Kaplan Turbine	1	50 KW	1
Solar Cookers Box Type	896	-	906
Solar Cell Fabrications	10,069	10.06 KW	-
Solar Module Fabrications	1,137	1.12 KW	-
Photovoltaic System	78	78 KW	730 Mosques/Schools
Biogas Cooking Stoves	70,100	-	70,100
Biogas	3,824	13,425 CM3/	3,824

The GoP has also started specific developmental projects using RETs that showed significantly promising results. However, these RETs have not been installed on a large scale and consequently are unable to contribute significantly to the electricity share of the country [71]. The available energy resources within Pakistan are discussed below.

1) SOLAR ENERGY RESOURCES

One of the green energy resources that do not pollute the environment or contribute to global warming is solar energy. Solar energy radiated in one second is more than the energy used by the people since the beginning of time. Solar energy is ecologically advantageous when compared to other green energy resources. Solar energy does not result in the depletion of natural resources, emission of CO_2 or other gases into the atmosphere, or production of solid or liquid waste products [73].

Pakistan is situated on the sunny belt and has a significant potential for solar energy. The Alternative Energy

TABLE 9. Annual averages of solar radiations [75].

Provincial Capitals	Annual Average Solar Radiations ($MJ/m^2/day$)
Quetta	21.65
Karachi	19.25
Peshawar	18.36
Lahore	17.0

TABLE 10. Monthly averages [75].

Provincial Capitals	Monthly Average Solar Radiation ($kW{\cdot}h/m^2$)	
	Minimum	Maximum
Lahore	2.8	6.27
Quetta	3.6	7.65
Karachi	3.39	6.31
Peshawar	2.4	6.35

Development Board (AEDB), in collaboration with the National RE Laboratory (NREL) of the USA, evaluated to measure the solar potential in Pakistan. The report states that Pakistan is located in a region where most of the days are long and sunny with high solar insulation and radiations, which is practically perfect for solar development projects. The average solar radiation in Pakistan is $15.5 \times 1{,}014$ kW h per year, with 8-10 h sunlight a day in most of the areas. The evaluated potential in Pakistan is approximately 1,600 GW annually, which is 40 times more than the existing power generation capacity [59].

The Pakistan Meteorological Department collected and measured solar radiation data for a long duration (27 years), which shows that Quetta receives a yearly average of 21.65 $MJ/m^2/day$ of solar radiation energy, with a maximum of 29.68 $MJ/m^2/day$ in June. This corresponds to an annual percentage of 6 $kW{\cdot}h/m^2/day$ and a maximum value of 8.25 $kW{\cdot}h/m^2/day$ pertaining to the solar resource. The yearly averages are 19.25, 18.36, and 17.0 $MJ/m^2/day$ at Karachi, Peshawar, and Lahore, respectively, as listed in Table 9 [75].

The measured monthly average of solar radiation in the four provincial capitals of Pakistan is listed in Table 10. The monthly average of solar radiation received by the capital of the Baluchistan province (Quetta) is at a minimum value of 3.6 $kW{\cdot}h/m^2$ and a maximum amount of 7.65 $kW{\cdot}h/m^2$. The capital of the Sindh province (Karachi) receives a monthly average of solar radiation at a minimum value of 3.39 $kW{\cdot}h/m^2$ and a maximum amount of 6.31 $kW{\cdot}h/m^2$. The minimum and maximum values of monthly average solar radiation received by the capital of the KPK province (Peshawar) are 2.4 and 6.35 $kW{\cdot}h/m^2$, respectively. The minimum and maximum values of monthly average solar radiation received by the capital of the Punjab province (Lahore) are 2.8 and 6.27 $kW{\cdot}h/m^2$.Pakistan has a significantly large prospective for harnessing energy from the sun. The only demerit of solar energy generation is the high prices of photovoltaic (PV) panels, which results in its suitability only for areas away from grids. However, Pakistan can maximize potential savings and minimize the consumption of fossil fuels by increasing the domestic utilization of solar thermal technologies in the form of water heaters and cookers. This will eventually improve the living standards of the masses and will also be more environmentally friendly. Also, it will minimize the dependency on fuel fuels domestically and will ultimately lead to a substantial decrease in the oil expenditure of the national treasury. Proper policy-making and organized goal-oriented efforts are required on behalf of the government to increase awareness and to assist and mobilize the people regarding the utilization of solar technology [103].

2) WIND ENERGY RESOURCES

Since the early 20th century, energy from wind has been utilized to add mechanical power for grinding grains and pumping water. The first wind turbine was developed to generate electricity. Wind power was considered as one of the promising RE sources in the 1990s. Toward the end of the 20th century, the capacity for wind energy was approximately doubling every three years worldwide. At present, windmills, wind pumps, and wind power plants are effectively working in several countries across the globe. Since the early 1980s, the costs of electricity generated from wind energy have decreased by approximately one-sixth, and the trend appears to continue. The use of wind energy does not cause toxic emissions; moreover, unsurprisingly, the global wind power is one of the rapidly growing RE sources [76].

In Pakistan, wind energy is an appealing RER, whose availability must be studied. For this reason, wind statistics in coastal regions of Pakistan are collected by the Pakistan Meteorological Department [77]. Mountains and coastal areas that have a high possibility of wind are most suited for wind energy usage. The approximately 1,120 km long coast of Pakistan has a population of roughly 10 million people [78]. Near the coastline of Baluchistan and Sindh, the monthly average wind speed reaches up to 7–8 m/s. In Pakistan, the number of operational wind farms is currently negligible. There are plans for producing 700 MW of electricity from wind energy in Gharo (Sindh). The long-term plans are to develop wind power plants of 9.7 GW capacities by 2030 [79].

Several studies were conducted by the Pakistan Meteorological Department to estimate the potential of wind energy

TABLE 11. Wind energy generation goals in Pakistan [79].

Year	Power from Wind Energy (MW)
2010	100
2015	800
2020	2,000
2025	3,500
2030	6,000

across the country. In southern Pakistan, particularly the area near the coasts of Baluchistan and Sindh, commercially utilizable wind energy potential was identified. The analysis of data from 20 sites shows that a 9,700 km^2 area can produce electricity of 43,000 MW by harnessing the wind power potential. The net power density estimated per square kilometer is 4 MW. However, this potential is restricted to 11,000 MW owing to land utilization constraints. Therefore, a suitable area for this potential was calculated to be 2,481 km^2, resulting in only 26% of the total area based on power density. Reports have summarized that the northern and eastern regions of Pakistan, such as KPK along with Pakistan-administered Kashmir and Punjab, are not favorable for electricity production from wind energy [79].

In 2005, the GoP planned to generate approximately 10% of its electricity from RERs by the end of 2012. However, from 2005 to 2008, owing to economic reasons, no new installed grids of RE were added to the main pool of the power sector. Considering this, in 2008, the government increased the expenditure for RE by up to 5% of the total spending on the power sector until 2030 [79]. The planning details pertaining to wind energy share in the power sector of Pakistan until 2030 are listed in Table 11.

According to the previous discussion, the capacity of global wind energy has been approximately doubled every three years. There is a requirement to have additional speculation and research for the positioning of wind energy projects in Pakistan to overcome the current power shortage. The numerous steps that must be performed include selecting a suitable site, mapping of winds, selecting and manufacturing of wind turbines for a specific site, evaluating the environmental and economic influence of wind turbine installation at a particular location along with the lifecycle charge of a particular position, and using computer software for choosing a specific type of obtainable wind turbine [66].

3) BIOMASS ENERGY RESOURCES

Biomass energy is another RER that does not cause CO_2 or other toxic emissions in the air. Biomass energy can perform a significant role in obtaining a sustainable and distinct energy mix. The organic matter derived from biological organisms (plants and animals) is called biomass. Ever since humans started burning wood for warmth or for cooking food, biomass has been used as an energy source. An estimate shows that with a conversion efficiency of 1% every year, 220 billion dry tons of biomass are produced by photosynthesis globally [5].

Biomass can typically be classified as woody, non-woody, and animal wastes. Woody biomass consists of urban trees, forests, bush trees, agro-industrial plantations, and farm trees. Non-woody biomass constitutes crop wastes such as plant stems, domestic wastes (food, rubbish, and sewage), leaves and straw, and processing residues such as husk, nutshells, sawdust, and bagasse. Animal waste comprises waste from animal husbandry [81]. Pakistan is an agricultural country having a cultivating region of 22.2 million hectares, annually generating million tons of biomass. Crop waste of approximately 81 million tons per year is available in the country, which can produce 45,870 million kW·h of electricity per year. The estimated data shows that in Pakistan, cotton, wheat, sugarcane, rice, maize, sunflower, canola, and mustard crops have the potential of producing 40.78, 35.27, 29.0, 9.24, 8.5, 0.35, 0.13, and 0.20 million tons of biomass per annum, as shown in Fig. 9. The available crop residue in Punjab has a surplus of approximately 27.86 million tons for the generation of 15,777 million kW·h of electricity per year [83].

The overall power generating potential from different resources of biomass is listed in Table 12. From the table, it can be observed that Pakistan has significant potential for power generation from several biomass resources. The GoP must establish a comprehensive program to capitalize on the availability of biomass potential in the power sector [83]. In 2011–2012, the production of sugarcane was approximately 57 million tons in Pakistan. Pakistan has the potential for almost 3,000 MW of power generation from the sugar industry; however, the current generation is only 700 MW [83].

As per a recent livestock census, the animal (buffaloes, cows, bullocks) count in Pakistan is approximately 51 million [66]. On average, the moderate-sized dung dropping per animal is approximated at 10 kg/day, which can result in 510 million kg of dung per day. While considering only 50% of the dung collection, 255 million kilograms of manure can be collected per day and utilized for biogas production. Therefore, 12.75 million cubic meters of biogas can be generated per day, based on the assumption that 1 m^3 of biogas can be made from 20 kg of dung. Pakistan has the potential for generating 4,761-5,554 MW of power only from manure if all of the biogas produced is utilized in electricity generation. With the potential of generating approximately 5,000 MW from livestock and 3,000 MW from bagasse, biomass can achieve an enormous improvement in the energy mix of the country [83]. Apart from animal dung, the biogas potential can also be explored from poultry wastes, wastage of slaughterhouses, banana stem wastes, paper industry, and street wastes. The residues from the poultry sector are also contemplated as an

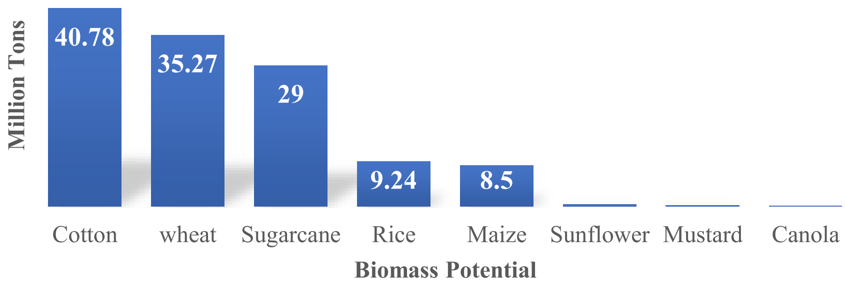

FIGURE 9. Accumulative biomass capacity of various crops [83].

ideal substrate for biogas generation. In Pakistan, the poultry zone has a prosperous growth rate of 7–8% per year [13].

4) GEOTHERMAL RESERVOIRS

Geothermal energy can be obtained from rocks and water within the earth at a temperature between 8 °C (close to the surface) and above 400 °C (at depths of several kilometers). Most geothermal areas consist of water at moderate temperatures (below 200 °C) that can be used for electricity generation [85]. Geothermal energy produces zero carbon and is emission-free. Geothermal energy is almost a great source of energy, and if used properly, a geothermal power plant can continue to work for more than a century [86]. Specific apparent sources of geothermal energy are hot springs, geysers, volcanoes, and fumaroles. These resources are deep underground and cannot be seen. Different methods are used by geologists to identify geothermal reservoirs [88].

In Pakistan, geothermal manifestations are explored as mud volcanoes, geysers, and hot springs. The promising capabilities of mud volcanoes and hot springs are explored in the country. Many geothermal manifestations are available in Chagai, Karachi, Hyderabad, and northern areas of Pakistan. Northwestern Balochistan has hot springs with high-temperature brines. Hot springs of modest temperature are available in South Balochistan. Hot springs of modest to low temperatures are present in the Indus Basin and Western Sindh zone. Similarly, low-brine-temperature hot springs are present in Southwestern and Northern Punjab. The reservoirs mentioned above are concentrated along the Main Karakoram Thrust (MKT), Main Mantle Thrust (MMT), and Main Boundary Thrust, which were created after the collision of the Eurasian and Indian plates [70].

Several hot springs are present along with the MMT at Burmodin, Tatta Pani, and Sassi, and along with the MKT at Chu Tran, Murtazabad, and Budelas, and other areas. Of these, the temperatures of the Murtazabad and Budelas reservoirs are estimated to range from 172-212 °C. The thermal springs at Murtazabad include the Hakuchar manifestation. Budelas has three geothermal manifestations, of which the one located nearest to the Karakoram granodiorite has the maximum potential. The estimated temperature range of this reservoir is 172–189 °C. The water from this hot spring is nearly at boiling temperature (91 °C) [31]. Two hot springs exist in Karachi, at Mangopir and Karsaz, with temperature ranges of 72–98 °C and 138–170 °C, respectively. The Chicken Dik hot spring is located in the southeastern part of Mashki Chah, at an altitude of 830 m [90]. The temperature of the Chiken Dik hot spring is 29.9 °C. The hot springs in the Chitral area were created owing to the fault system of Hindukush.

In contrast, the hot springs of Murtazabad, Dassu, Budelas, and Sassi in the Gilgit-Hunza region are located along with MKT, while the hot springs of Tatta Pani and Mashkin are situated along with MMT. The water temperature at Mashkin is approximately 57 °C, and the estimated temperature of the reservoir is in the range of 86–169 °C. At a distance of roughly 50 km northwest of Chitral, in the Garam Chashma valley, hot springs are located within the Ayun and Reshun fault domains [91]. The temperature of the Garam Chashma hot springs is estimated to be in the range of 85–252 °C. The springs in Koh-e-Sultan are settled in the vicinity of the Miri crater. The hot springs of Koh-e-Sultan that seep from the riverbed consist of lava and agglomerate. The water temperature of Koh-e-Sultan springs is in the range of 25–32 °C. The volcanic cones in the Chagai area and the volcano in Koh-e-Sultan were formed owing to the descent of the Arabian plate under the Eurasian plate. The water temperature in the thermal springs of Koh-e-Sultan is in the range of 150–170 °C [90]. The characteristics of the abovementioned geothermal resources of Pakistan are listed in Table 13.

All over Pakistan, minor geothermal energy sources are accessible, which can be functionalized for hot water supply along with air conditioning of houses and buildings. For demonstration, the Energy Foundation of Pakistan had installed geothermal heat pumps in three distinct regions, i.e., Peshawar, Islamabad, and Lahore. According to an estimation of the Energy Foundation, the shallow geothermal energy resources available in the entire country can generate more than 60,000 MW. The northern areas of Pakistan, in particular Pakistan-administered Kashmir and Gilgit-Baltistan along with Chitral, have an abundance of low-temperature hot water springs that can be directly used for various applications. Additionally, low-temperature hot water springs are available in other provinces of Pakistan, which can be

TABLE 12. Overall power generating potential from different biomass sources [83].

Year	Cotton Sticks (GWh)	Sugarcane Trash (GWh)	Paddy Straw (GWh)	MSW at 2% Increase Per Year (GWh)	Biogas (GWh)	Maize Stalk (GWh)	All biomass Sources (GWh)
2006-07	8,200	19,160	13,293	13,594	11,486	3,345	69,078
2007-08	7,434	22,372	13,598	13,859	11,879	3,905	73,047
2008-09	7,539	17,516	16,114	14,129	12,286	3,892	71,476
2009-10	8,237	17,281	16,825	14,405	12,439	3,533	72,720
2010-11	7,373	19,358	11,790	14,686	13,141	4,016	70,364
2011-12	8,671	20,313	15,058	14,972	13,670	4,627	77,311

utilized directly in many industrial processes. However, the Energy Foundation anticipated that the direct use of geothermal energy resources at a temperature of less than 90 °C could generate electricity exceeding 30,000 MW. According to an initial estimate by the Energy Foundation, Pakistan can produce electricity of more than 100,000 MW from the total available geothermal resources. However, a comprehensive and thorough study regarding the geothermal energy resources of Pakistan is essential for achieving baseload electricity production [100].

5) WASTE HEAT GENERATION

Waste heat energy is produced in various industrial procedures; however, it is not utilized for any beneficial purpose. Waste heat is generated from hot substances that exit industrial processes, heat transfer from surfaces of heated equipment, and heated gases that are discharged into the atmosphere. The exact quantity of industrial waste heat cannot be adequately determined; however, the estimated results of several works show that approximately 20–50% of the consumption of industrial energy is released in the form of waste heat [92]. The waste heat in the liquid form includes blow-down water, cooling water, heated wash water. Specific other nonapparent waste heat sources are boiler blow-down water, hot surfaces, and steam leaks [93]. Table 14 lists the information regarding the temperature range and characteristics of waste heat sources.

The waste heat recovery power generation (WHRPG) technology was initially implemented in Europe and the USA in the late 60s. WHRPG technology was feasible in the mid-70s and reached peak implementation in the early 80s [94]. The power from waste heat recovery adds no emission to the environment and is considered as clean energy. Waste heat energy is often viewed as more of an improvement in energy efficiency rather than as a source of RE [95]. WHRPG technology generates electricity through a specially designed steam turbine. Industrial waste heat with a low-temperature range of 120–400 °C is used to run the specified generator. The steam is generated by creating mechanical energy for electricity generation [94].

The primary WHRPG technologies, such as steam-based Rankine, Kalina, and organic Rankine cycles, are used worldwide. The waste heat recovery power plant (WHRPP) can use steam-based Rankine cycles, such as a dual pressure system; moreover, the single flash system is used in South Asia and Asia, where water is used as a medium for working, as it is abundant, inexpensive, safe, and environment friendly. At low temperatures, the organic Rankine cycle is a suitable scheme for waste heat recovery and is simple in the configuration. The amalgamation of ammonia and water is used in the Kalina cycle. The power generation process based on the Kalina cycle depends upon the applied pressure and temperature of the mixture [96].

In Pakistan, two cement plants, namely, Fauji Cement Ltd. and Askari Cement Ltd., can generate their electricity by installing WHRPP, as listed in Table 15. The waste heat recovered in Fauji Cement Ltd., as can be observed from the table, can be used to generate electric power of up to 10 MW by installing a WHRPP. Similarly, Askari Cement Ltd. can make electric power of up to 7 MW by installing a WHRPP to reprocess its waste heat. The primary barriers in the installation of WHRPPs in Pakistan are financial, technological, and other obstacles including the capacity of WHRPP for generating significant power [93], [95], [96].

In 2011, Bestway Cement, is the largest cement manufacturer in Pakistan, set up its first power plant for waste heat recovery with a capacity of 15 MW at Chakwal. The company has initiated two eco-friendly waste heat recovery plants of 13.5 MW at a rate of PKR 1.7 billion. Two power plants of 6.0 and 7.5 MW capacity for waste heat recovery were set up by Bestway Cement Limited at Farooqia and Hattar (Haripur district), respectively, in July 2015. Bestway Cement plans to invest approximately $30 million in Pakcem Limited for the operation of a 9.8 MW power plant for waste heat recovery at Kallar Kahar.

D. CONCLUDING REMARKS

Pakistan, an unindustrialized and developing country, is confronting severe resource constraints about energy and immediately requires new sources of energy for its development.

TABLE 13. Characteristics of geothermal energy resources of Pakistan [70].

Location	ST (°C)	GR	DP	PPT	IP	TC	PPG	CPG
Budelas	172–212	Hot Spring	✓	BCP	✓	Moderate	✓	☒
Karakoram granodiorite	172–189	Hot Spring	✓	BCP	✓	Moderate	✓	☒
Chiken Dik	29.9	Hot Spring	✓	☒	×	Low	☒	☒
Murtazabad	172–212	Hot Spring	✓	BCP	✓	Moderate	✓	☒
Mangopir	72–98	Hot Spring	✓	BCP	×	Low	✓	☒
Gilgit Region	24–71	Hot Spring	✓	RCP	×	Low	✓	☒
Karsaz	138–170	Hot Spring	✓	BCP	✓	Moderate	✓	☒
Hunza Region	50–91	Hot Spring	✓	RCP	×	Low	✓	☒
Mashkin	86–169	Hot Spring	✓	BCP	✓	Moderate	☒	☒
Salt Range Mianwali	30	Hot Spring	✓	☒	×	Low	☒	☒
Dadu District	41	Hot Spring	✓	RCP	×	Low	☒	☒
Garam Chashma	85–252	Hot Spring	✓	BCP	✓	Moderate	☒	☒
Hakuchar	49–50	Hot Spring	✓	RCP	×	Low	✓	☒
Tatta Pani	85	Hot Spring	✓	RCP	×	Low	✓	☒
Murtazabad Balai	91	Hot Spring	✓	RCP/BCP	✓	Moderate	☒	☒
Koh-e-Sultan	25–32	Thermal Springs	✓	☒	×	Low	☒	☒
Murtazabad Zareen	89	Hot Spring	✓	RCP/BCP	✓	Moderate	☒	☒
Koh-e-Sultan	150–170	Mud Volcano	✓	BCP	✓	Moderate	☒	☒
Darkut Pass	62	Hot Spring	✓	RCP	×	Low	✓	☒

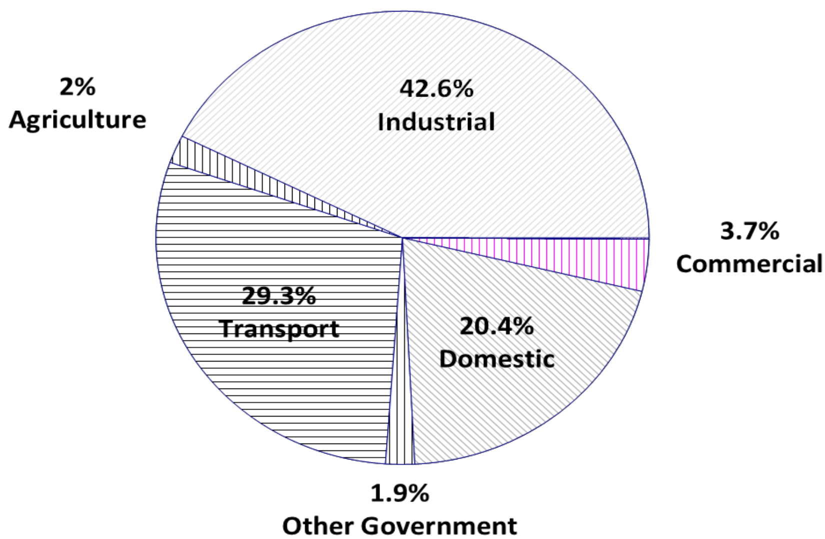

FIGURE 10. Sector-wise energy consumption [11].

The inference derived from the above deliberation is that although RERs cannot entirely replace conventional energy resources, they may serve to complement the long-term energy requirements of Pakistan to a substantial level. Pak-

TABLE 14. Temperature range and characteristics of industrial waste heat [93].

Waste Heat Sources	Cleanliness	Temperature Range
Gas combustion (Turbine) exhaust gases	Clean	900–1,100
Furnace or heating system exhaust gases	Varies	600–2,000
Jacket cooling water	Clean	190–200
Exhaust gases (for gas fuels)	Mostly Clean	900–1,100
Hot surfaces	Clean	150–600
Intercooler water used in compressors	Clean	100–180
Hot products	Mostly Clean	200–2,500
Condensate	Clean	150–500
Steam vents or leaks	Mostly Clean	250–600
Emission control devices	Mostly Clean	150–1,500

TABLE 15. Capacities of waste heat recovery power plants in the cement industry of Pakistan [92].

Cement Plant	Capacity	Gas from Preheater	Gas from Cooler Outlet	Demands for Drying (at Mill Inlet)
Fauji Cement Ltd.	Line 2 7,200 t/d	4,44,000 Nm^3/h at 320 °C	4,07,000 Nm^3/h at 300 °C	RM: 200–220 °C CM: 200–220 °C
Askari Cement Ltd.	3,700 t/d	1,67,400 Nm^3/h at 370 °C	1,92,500 Nm^3/h at 300 °C	RM: 180–190 °C CM: 180–190 °C

istan must concentrate on the generation of a considerable amount of energy through renewable sources, as significant amounts of resources exist in the country. However, so far, the total RE influence in the energy mix of the country is less than 1%. If RE equipment were industrialized and RE goods were more cost-effective through economic benefits or subsidies, the RE influence in the energy generation share can be increased by up to 30% when compared to the total energy requirement of the country. After analyzing and examining the published articles, periodicals, apprenticeships, and available data, it can be concluded and recommended that to ensure the sustainable growth of energy production for the future. There is a dire requirement for the expansion of the energy mix in Pakistan. Moreover, the literature review concludes that the power sector in Pakistan is predominantly dependent on conventional energy resources; the average share of conventional resources from 2010 to 2015 in overall generated power was 66.1%. Restricted domestic accessibility and the increase in the prices of fossil fuels will eventually lead to a limited energy supply, which in turn will increase the gap between supply and demand. With these underlying conditions, the country must search for alternative domestic energy sources. The long-term topographical and methodological potential of RERs was projected and reported.

Solar energy is the most abundantly available RE in Pakistan, having an irradiance of 15.5 × 1,014 kW h per year with 8–10 h of sunlight a day in most regions of the country. This significant level of solar potential can be efficiently used for solar thermal and solar electric projects. Moreover, wind energy can also overcome the energy deficit of the country by utilizing a suitable area near the coastal lines (an area of 9,700 km^2 has the potential of producing 43,000 MW of power). Also, energy production from biofuels could help minimize the dependency on conventional energy sources in Pakistan. Approximately 81 million tons per year of crop wastes are available in Pakistan, which can be used to generate 45,870 million kW·h of electricity per year. In the sugar industry, Pakistan has the potential for generating almost 3,000 MW of power, whereas only 700 MW is currently generated. Pakistan can generate 4,761–5,554 MW of power using only manure. Geothermal energy resources are abundant in Pakistan. To overcome the long-term energy crisis, the country should consider the practical employment of the abovementioned energy resources. The waste-heat-to-power industry continues to have pronounced potential for producing substantial amounts of clean energy in Pakistan. Regardless of its potential, the progress in this industry has been slow, and the growth is almost stagnant. RERs are directly proportional to the economic upheaval and can promote and maintain the future sustainable energy growth of the country. In the future, RETs can be utilized as a feasible and low-cost method to overcome the energy deficits of Pakistan.

IV. POWER MARKET ANALYSIS

Power market analysis expresses the total power generated by various renewable resources, for example, the hydro, wind, and solar energy resources; thus, the total power consumption (demand) per capita of the country is the power rate [63]. The increase in population and modernization have increased the overall power demand and annual power utilization, respectively. Modernization and per person power consumption have a direct effect on each other; for example, the increment in one demand results in thrust to the other demand. The consumption per person in Pakistan is approximately 457 kW·h [59]. The people of Pakistan are suffering from the energy gap between supply and demand. Energy is an essential element in the financial establishment of Pakistan [4]. Pakistan is one of the developing countries in Asia, and its large population has resulted in an energy shortfall.

Fig. 10 illustrates the sector-wise energy utilization of consumers within Pakistan. The consumers are divided into different categories based on their power utilization. The primary categories include the following: **(a)** industrial, **(b)** commercial, **(c)** domestic, **(d)** transport, and **(e)** agriculture. The industrial sector consumes most of the energy in the country, which is 42.6% of the total generated energy. The energy consumptions in the agricultural, transport, commercial, and other government sectors are 2, 29.3, 3.7, and 1.9%, respectively [11].

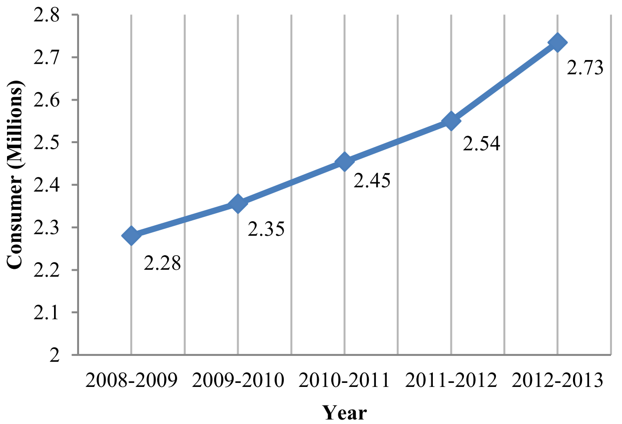

FIGURE 11. **Number of consumers per year [30], [116].**

Fig. 11 illustrates the historical record of the number of consumers per year. The consumer data in Fig. 11 is recorded from the data available with Gujranwala Electric Supply Company (GEPCO), which shows an annual increase in the number of consumers. The number of consumers in Pakistan in 2008–2009 was 2,280,691; in 2009-2010, the consumer ratio increased to 2,355,893; then, in 2012–2013, the consumer ratio increased to 2,734,552, which indicates an annual increase in demand. In 2012–2013, the energy ratio increased by 184,822, which shows the increasing demand in Pakistan [84]. IPPs with public generation companies contribute approximately 42% of the total power generated in Pakistan [30], [116].

A. CONCLUDING REMARKS

The power sector of Pakistan from 1980 to 1998 was limited in terms of power generation, which was produced by PEPCO. The Karachi Electric Supply Company (KESC) purchased power from NTDC through the Central Power Purchasing Agency. Another company that supplied power to the rest of the country was WAPDA. Afterward, WAPDA was further classified into specific corporations consisting of **(a)** four generation companies (GENCOs), **(b)**10 distribution companies (DISCOs), and **(c)** NTDC. Ten DISCOs are responsible for the distribution of power to Peshawar, Islamabad, Lahore, Quetta, Hyderabad, Gujranwala, and Sarhad. The electric supply companies are shown in Fig. 12 [84], [116].

WAPDA consists of 14 power generating units, followed by GENCOs, which are divided into four power generating units, and IPPs, which have 28 units that make 6,365 MW and transmit power to NTDC, which is connected to the DISCOs. In 1990, a sudden increase in energy consumption occurred owing to the rapid growth in consumers in Karachi. Owing to this reason, KESC granted permits for the generation, transmission, and supply of electricity in its permitted areas. In 2000, the per capita consumption of electricity increased in

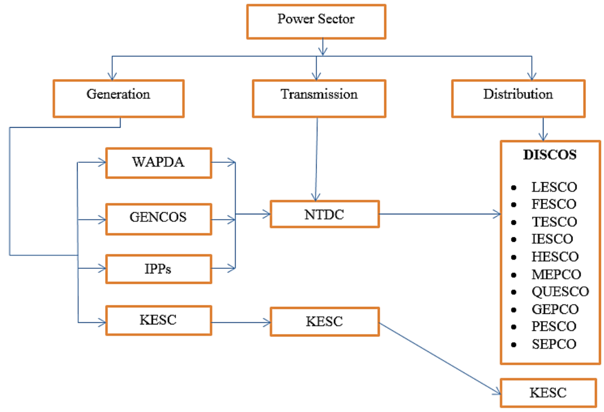

FIGURE 12. **Electricity sector structure in Pakistan [84].**

the residential sector, while in the industrial sector, the annual use reached a peak value, widening the gap between supply and demand. In 2006, the ADB announced that 45% of the total population of the country was suffering from an energy crisis [84]. NTDC established twelve 500 kV and twenty-nine 220 kV power grids with 5,077 km of 500 kV transmission lines and 7,359 km of 220 kV transmission lines in the country [116].

1) PROVINCE-WISE POWER DISTRIBUTION STATISTICS IN PAKISTAN

The power sector in Pakistan is governed by public GENCOs, transmission companies, and DISCOs, which supply approximately 42% of the total power generated by the incorporation of IPPs. Power is delivered to 10 DISCOs, namely, **(a)**PESCO, KPK; **(b)** Tribal Electric Supply Company (TESCO), Federally Administered Tribal Areas (FATA); **(c)** Islamabad Electric Supply Company (IESCO); **(d)** GEPCO, Punjab; **(e)** LESCO, Punjab; **(f)** Faisalabad Electric Supply Company (FESCO), Punjab; **(g)** Multan Electric Power Company (MEPCO), Punjab; **(h)** Quetta Electric Supply Company (QESCO), Baluchistan; **(i)** Hyderabad Electric Supply Company (HESCO), Sindh; and **(j)** Sukkur Electric Power Company (SEPCO), Sindh, as shown in Fig. 11.

- **Punjab**

The power DISCOs in the Punjab province are **(a)** MEPCO, **(b)** LESCO, **(c)** GEPCO, and **(d)** FESCO. Table 16 lists the historical record of the generation capacity in gigawatt hours. The total generation in 2014–2015 was 68,428 GW·h, followed by a whole generation of 71,094 GW·h in 2015–2016. It can be observed that the production is increasing annually; the total capacity in 2016–2017 was 75,437 GW·h. The overall forecast for generation in the year 2022–2023 is 104,578 GW·h in Punjab [84].

LESCO supplies power to five districts, namely, Nankana, Lahore, Kasur, Sheikhupura, and Okara. The consumption of the power provided by LESCO has increased annually, which

TABLE 16. Company-wise Generation in Gigawatt Hours [68], [80], [84], [113].

Name	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22	2022–23
LESCO	24,512	25,626	27,117	28,567	30,003	31,518	33,107	34,711	36,344
GEPCO	9,930	10,455	11,002	11,576	12,176	12,800	13,450	14,105	14,807
FESCO	14,345	15,131	16,185	17,293	18,448	19,677	21,176	22,827	24,543
MEPCO	18,641	19,882	21,133	22,395	23,395	24,953	26,251	27,561	28,884
Total	68,428	71,094	75,437	79,831	84,022	88,948	93,984	99,204	104,578

was obtained from the records of LESCO. The annual use is shown in Fig. 13 [84].

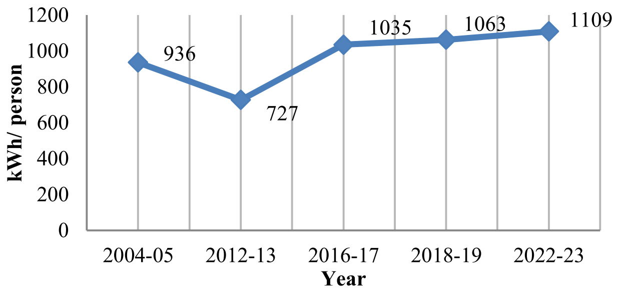

FIGURE 13. **Annual consumption of Lahore Electric Supply Company [84].**

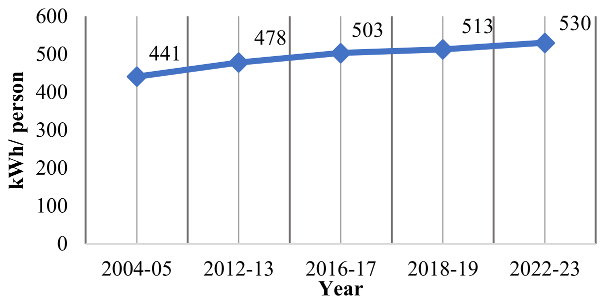

FIGURE 14. **Annual consumption of Gujranwala Electric Supply Company [84], [113].**

GEPCO distributes power to the Gujranwala region in Punjab. The areas to which GEPCO supplies power include the following: **(a)** Narowal, **(b)** Sialkot, **(c)** Gujrat, **(d)** Gujranwala, and **(e)** Mandi Bahauddin districts. In Fig. 14, the annual consumption of GEPCO is illustrated, which can be compared to that of LESCO [84], [113].

FESCO regulates the generation, transmission, and distribution of power under the National Electric Power Regulatory Authority (NEPRA) act of 1997. NEPRA issued a license to FESCO for power distribution for approximately 3.62 million people out of a population of 22 million. The area of operation of FESCO consists of eight districts, which include the following: **(a)** Faisalabad, **(b)** Mianwali, **(c)** Sargodha, **(d)** Khushab, **(e)** Toba Tek Singh, **(f)** Bhakker, **(g)** Chiniot, and **(h)** Jhang. Owing to the superior operational performance (as its distribution losses are shallow and collection of bill rates is high), FESCO is one of the developed power supplying organizations in Pakistan. FESCO primarily supplies electricity to Faisalabad, known as the "Manchester of Pakistan," owing to the presence of a large number of textile industries. The annual consumption of FESCO is shown in Fig. 15 [68].

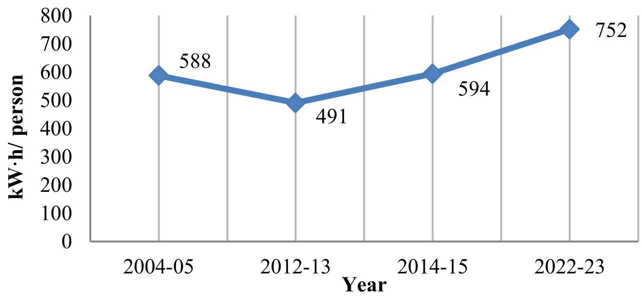

FIGURE 15. **Annual consumption of Faisalabad Electric Supply Company [68].**

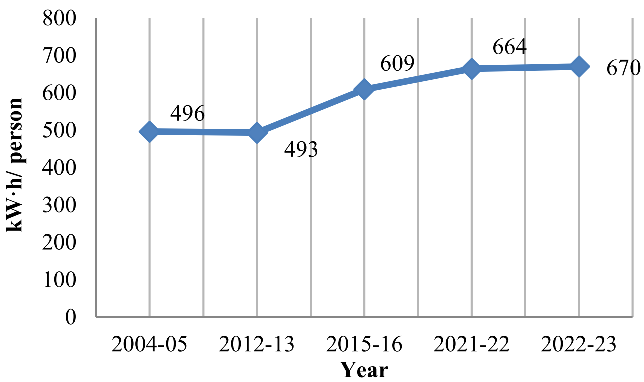

FIGURE 16. **Annual consumption of Multan Electric Power Company [80].**

MEPCO supplies power to the 13 districts of south Punjab with PEPCO, which provides the maximum electricity. MEPCO is a unique electricity supplying company as it is linked with five power supplying organizations from three other provinces of Pakistan, namely, QESCO (Balochistan) at Fort Manro, PESCO (KPK) at Vahova, HESCO (Sindh) at Sadiqabad, LESCO at Sahiwal, and FESCO at Bhakkar. The outer edge of Minchinabad, Bahawalnagar district (India),

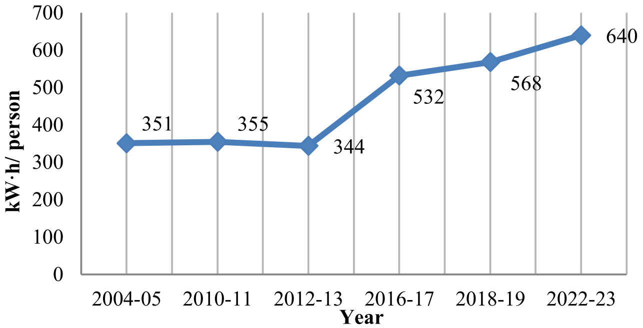

FIGURE 17. Annual consumption of Peshawar Electric Supply Company [84], [115].

is also linked with MEPCO. MEPCO supervises eight working circles, comprising the following districts: **(a)** Vehari, **(b)** Bahawalpur, **(c)** Sahiwal, **(d)** Rahim Yar Khan, **(e)** Dera Ghazi Khan, **(f)** Muzaffargarh, **(g)** Bahawalnagar, and **(h)** Multan. The annual incremental consumption of MEPCO is shown in Fig. 16 [80].

- **Khyber PakhtunKhwa**

The power DISCOs of KPK are **(a)** PESCO and **(b)** TESCO. PESCO is situated in Peshawar and distributes power to approximately 2.6 million users in all the local districts of KPK. At the PESCO distribution channel, PESCO supplies and sustains the power distribution at KPK using sub-transmission lines (of 66, 132, and 33 kV), substations, and 11 kV depressed transmission lines with transformers that supply power to the end-user. The service regions of PESCO consist of seven civil supervisory divisions: **(a)** Hazara, **(b)** Kohat, **(c)** Dera Ismail Khan (D. I. Khan), **(d)** Peshawar, **(e)** Bannu, **(f)** Malakand, and **(g)** Mardan districts. The KPK forecast of energy demand is listed in Table 17.

PESCO provides electricity to more than 2.6 million users of the districts of KPK. At PESCO systems, the KPK power supplying framework is sustained through 66, 132, and 33 kV sub-transmission lines and substations with 11 kV minor strain lines. The regions supervised by PESCO include seven civil legislative divisions: **(a)** Mardan, **(b)** Bannu, **(c)** Kohat, **(d)** Hazara, **(e)** Malakand, **(f)** D. I. Khan, and **(g)** Peshawar. The Peshawar division is comprised of three districts, namely, **(a)** Charsadda, **(b)** Nowshehra, and **(c)** Peshawar. The Mardan division consists of two districts: **(a)** Swabi and **(b)** Mardan. The annual per capita consumption forecast is shown in Fig. 17. [84], [115].

TESCO supplies power to seven agencies that are located across the border in Afghanistan. The seven agencies under the jurisdiction of TESCO are **(a)** Orakzai Agency, **(b)** North Waziristan Agency, **(c)** Kurram Agency, **(d)** Khyber Agency, **(e)** Bajur Agency, **(f)** South Waziristan Agency, and **(g)** Mohmand Agency. The Frontier Regions (FR) are **(a)** FR Tank, **(b)** FR Peshawar, **(c)** FR Dera, **(d)** FR Kohat, **(e)** Ismail Khan, **(f)** FR Bannu, and **(g)** FR Lakki. The annual consumption of TESCO is significantly higher than that of PESCO in KPK. The annual consumption of TESCO is shown in Fig. 18 [16].

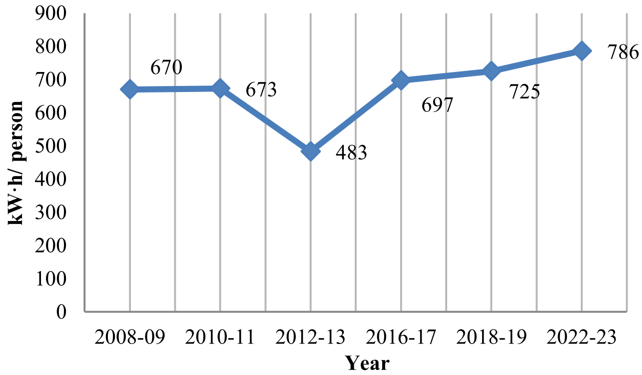

FIGURE 18. Annual consumption of Tribal Electric Supply Company [16].

- **Sindh**

The power DISCOs of Sindh are **(a)** HESCO, **(b)** SEPCO, and **(c)** KESC. Table 18 lists the forecasted demand summary calculated from the historical records of HESCO and SEPCO. The annual demand for HESCO and SEPCO was 2,473 MW in 2015–2016, which increased in 2016–2017 to reach to 2,586 MW.

SEPCO provides distribution services in two civil legislation divisions: (a) Larkana Sukkur and (b) Sukkur Division. The area supplied by SEPCO comprises five districts: **(a)** Sukkur, **(b)** Khairpur, **(c)** Ghotki, **(d)** Nawabshah, and **(e)** Noshehro Feroz. Fig. 19 shows the annual consumption per capita of SEPCO [96].

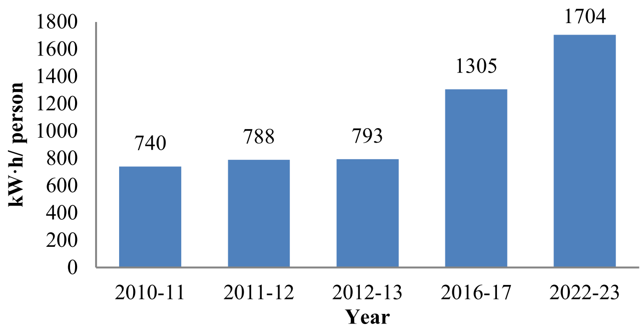

FIGURE 19. Annual consumption of Sukkur Electric Power Company [96].

HESCO is isolated into 12 districts of the Sindh territory and operates in four operation circles, namely, **(a)** Hyderabad, **(b)** Laar, **(c)** Nawabshah, and **(d)** Mirpurkhas. The annual consumption of HESCO is shown in Fig. 20 [87].

- **Baluchistan**

The power distribution company in Baluchistan is QESCO. WAPDA controls QESCO and, additionally, all the power establishments in Baluchistan. In 2011–2012, the total number of consumers was 515,850, which increased to 530,520 in the year 2012–2013. The annual consumption (kW·h/person) of QESCO per year is shown in Fig. 21 [104]. In 2016–17,

TABLE 17. Demand forecast summary of Khyber Pakhtun Khwa [84], [115].

Name	2015–16	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22	2022–23
PESCO	3,305	3,441	3,578	3,716	3,856	3,997	4,140	4,284
TESCO	861	887	914	941	970	1,000	1,030	1,062
Total	4,166	4,328	4,492	4,657	4,826	4,997	5,170	5,346

TABLE 18. Company-wise Generation in Gigawatt Hours [87], [96].

Name	2015–16	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22	2022–23
HESCO	1,343	1,398	1,454	1,512	1,571	1,633	1,696	1,761
SEPCO	1,130	1,188	1,249	1,312	1,378	1,446	1,517	1,590
Total	2,473	2,586	2,703	2,824	2,949	3,079	3,213	3,351

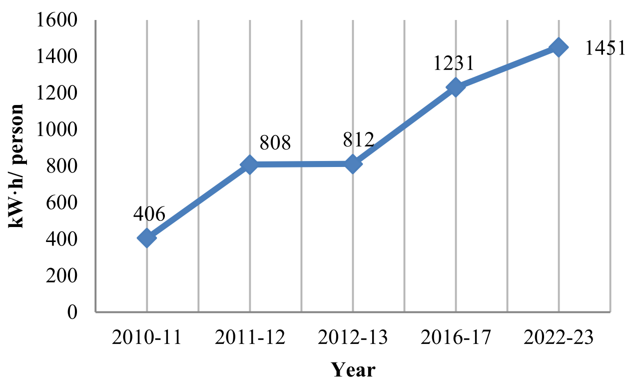

FIGURE 20. Annual consumption of Hyderabad Electric Supply Company [87].

the annual consumption was 574 kW·h/person, and it was projected to be 600 kW·h/person in 2022–23.

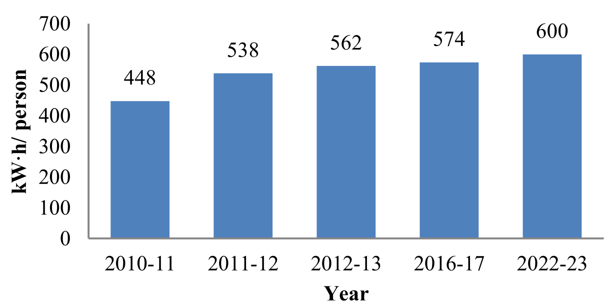

FIGURE 21. Annual consumption of Quetta Electric Supply Company [104].

V. CHINA–PAKISTAN ECONOMIC CORRIDOR (CPEC): ANALYSIS OF CPEC IMPACTS ON SG SYSTEM DEVELOPMENT WITHIN PAKISTAN

A. INTRODUCTION

Owing to energy shortfall, Pakistan faces the problem of disparity between the supply and the demand. Currently, Pakistan is unable to satisfy the needs of its consumers. There is a critical requirement for strict measurements by the GoP to enhance and improve energy production by redefining and reconstructing their policies. Recently, the CPEC agreement between China and Pakistan for the development of various sectors was signed, which will perform a pivotal role in enhancing the economy of Pakistan. From an energy perspective, CPEC incorporates various energy projects to satisfy the energy demands of Pakistan. This section highlights the impacts of CPEC on the energy sector of Pakistan. Furthermore, the geographical areas covered by CPEC, strengths, weaknesses, opportunities, and threats (SWOT) analysis of CPEC, future of SGs under CPEC, priority energy projects under CPEC, and potential energy sites in the CPEC route is discussed in this section.

B. GEOGRAPHY OF CPEC

CPEC covers a significant area of Pakistan, ranging from Gwadar (Baluchistan) to Kashgar (Western China). This corridor will go through the various parts of Baluchistan, Punjab, Sindh, and KPK. It will reach up to the Khunjarab Pass of Gilgit-Baltistan in the northern part of Pakistan and end in the Xinyang Province of China.

Pakistan has agreed with the Chinese officials to build ‘‘three’’ corridors after dynamic consultations. These routes are as follows:

1) Western route
2) Eastern route
3) Central route
4) **Western Route:**

The western route starts from Gwadar and will continue to cover the southern and eastern parts of Baluchistan (separately through Dera Bugti and Khuzdar) as shown in Fig. 22. This route will also pass by certain localities of south Punjab [89]. From Gwadar, this route will pass through Turbat, Panjgur, Khuzdar, Kalat, and will end at Quetta (the capital city of Baluchistan province). From Quetta, the western route

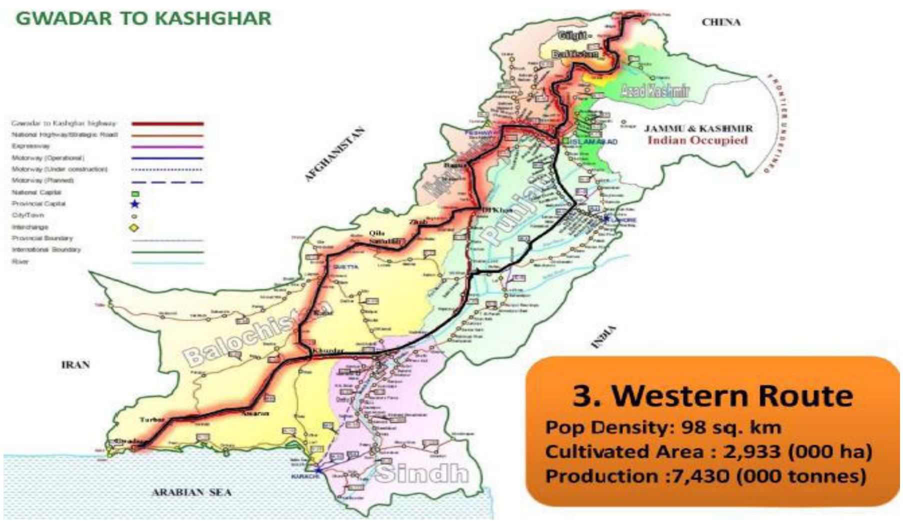

FIGURE 22. Western route [89].

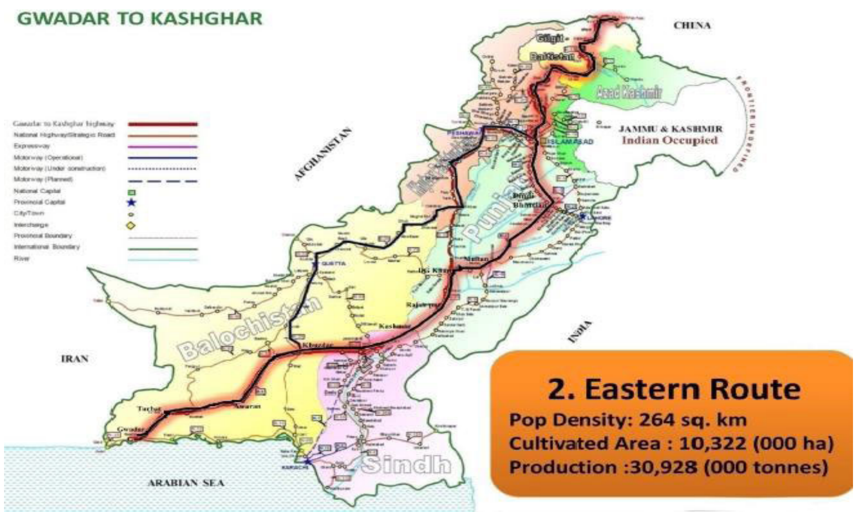

FIGURE 23. Eastern route [89].

will expand to Zhob, D. I. Khan, Bannu, Kohat, and then to Peshawar. The passage will continue to expand to Hassan Abdal, Haripur, Abbottabad, and Mansehra (the principal cities of Hazara Division, KPK). Furthermore, the route will cross the capital of Azad Jammu and Kashmir (AJK; Muzaffarabad) and reach the northern parts of Gilgit-Baltistan, i.e., Hunza, Attabad, and finally it terminates at Khunjrab. The western route will link Iran with Afghanistan through Quetta, Kho-e-Taftan, and Chaman (Baluchistan).

a: EASTERN ROUTE

The eastern route will initiate from Gwadar and will connect Turbat, Panjgur, Khuzdar, Ratodero, and Kashmore as depicted in Figure 23 [89]. It will pass through the southern part of the Punjab province and will join Rajanpur, Dera Ghazi Khan, Multan, Faisalabad, Pindi, and Bhatian. From central Punjab, the passage will connect to Islamabad (the capital of Pakistan) and ultimately will follow the same route as the western route of Hassan Abdal, Haripur, Abbottabad, and Mansehra, up to Khunjerab Pass. The eastern route has significant importance as it connects Taxila through Peshawar and Torkham, ultimately connecting to Jalalabad in Afghanistan. Pakistan is planning to connect India through the eastern route through Hyderabad, Mirpurkhas, Khokhrapar, Zero Point, and the periphery of Wagah (Lahore).

b: CENTRAL ROUTE

The central route passes through Gwadar, Turbat, Panjgur, Khuzdar, Ratodero, Kashmore, Rajanpur, Dera Ghazi Khan, D. I. Khan, Bannu, Kohat, Peshawar, Hassan Abdal, and onwards as shown in Fig. 24 [89].

C. SIGNIFICANCE OF CPEC FOR PAKISTAN

Pakistan possesses unusual terrestrial focal points. The borders of Pakistan link South Asia, the Arab world, China, the Indian Ocean, and the Persian Gulf. The various alarming

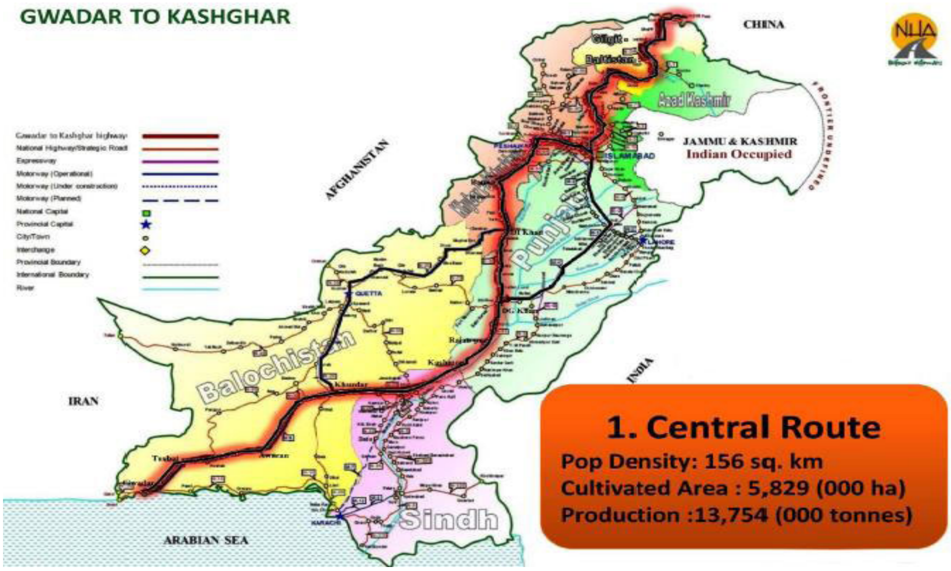

FIGURE 24. Central route [89].

problems that persist in Pakistan are **(a)** unstable geopolitical situation, **(b)** lack of transportation frameworks, and **(c)** energy deficiency. The economy of Pakistan has been unable to achieve its maximum capacity. According to Pakistan Economic Work (2013–2014), the amount of trade between China and Pakistan increased from US$ 4.1 billion in 2006–2007 to US$ 9.2 billion in 2012–2013, which shows an economic growth of 124%. The Chinese exports to Pakistan expanded by 1% in this period; the exports by Pakistan grew by 400%, from approximately $600 million in 2006–2007 to $2.6 billion in 2012–2013 [69].

Under the CPEC, a $46 billion agreement was signed by China and Pakistan for industrialization activities, which is equivalent to approximately 20% of the overall GDP of Pakistan. In total, the CPEC will incorporate the production of 17,000 MW at the cost of roughly $34 billion [112]. The development of transportation infrastructure, including the reformation of railway tracks between Karachi and Peshawar, is also being considered under the CPEC. The CPEC will incorporate various benefits and remunerations to Pakistan, such as follows:

- Highway infrastructure development (3,000 km).
- Crude oil refinery set up at Gwadar.
- Construction of the Gwadar port and international airport.
- Opening doors for the Pakistani market to enter Europe, Middle East, Gulf countries, Russia, and Africa.
- Telecommunication (installing optical fiber cable from the border of China to Rawalpindi).
- Railway track structuring (1,100 km; Kashgar to Islamabad).
- Rehabilitation of existing rail structure in Pakistan.
- Energy infrastructure development.
- Research activities (joint research of cotton biotechnology).

The execution of CPEC will enhance the economic, corporate, and geostrategic atmosphere of Pakistan. Moreover, the prominent challenges in Pakistan, such as (a) unemployment, (b) poverty, and (c) the encroachments between the undeveloped areas of Pakistan [51] will be overcome upon successful completion of CPEC projects. The CPEC is a turning point for the economy of Pakistan owing to the introduction of significant trade and financial activities; consequently, this will open a new landscape of development and prosperity for the people of Pakistan and China.

Based on the statistical analysis, CPEC will result in more harmony and will strengthen the strategic relationship between Pakistan and China. The CPEC schemes will upgrade the $274 billion GDP of Pakistan by more than 15%. The CPEC funding to various sectors will assist in removing the existing tags and labels that are associated with Pakistan, such as the ‘‘center of terrorism,’’ ‘‘most insecure nation,’’ and ‘‘a deteriorating country’’ [111].

Currently, Pakistan is a modest, less-expensive, developing country. The financial and military aid from China will assist Pakistan in reducing the continually expanding gap between its economic, atomic, and military sectors and that of India. It will also help in enhancing and improving its defense capabilities. The various development projects included in CPEC, such as **(a)** implementation of energy projects, **(b)** transportation framework, and **(c)** infrastructure development will provide benefits to the people of both countries. Further, the CPEC will incorporate the construction of motorways and highways to interconnect both nations easily. The infrastructure developments, such as **(a)** Gwadar port, **(b)** the reshaping and redesigning project of Karakoram Highway in the second phase, **(c)** motorway extension between Karachi and Lahore, **(d)** Thakot-Havelian motorway, **(e)** Gwadar port road, **(f)** Gwadar international airport, and **(g)** Karachi-Sukkur motorway will enhance and induce cooperation in the joint efforts pertaining to the sectors of energy, business, finance, education, industry, and banking [110].

D. ANALYSIS OF STRENGTHS, WEAKNESSES, OPPORTUNITIES, AND THREATS OF CPEC

A SWOT analysis aids in identifying the strengths and weaknesses, as well as the opportunities and threats to an organization. Developing a complete awareness of the various conditions will benefit an organization in terms of both tactical planning and decision making. The SWOT technique was initially created for corporates and businesses; however, it is also beneficial in the tasks of analyzing public health, progress, education, and personal development. During the implementation of large corporate verdicts, one of the smartest processes to be performed in the development stage is the execution of a SWOT analysis.

In this subsection, the SWOT analysis of CPEC is conducted as follows:

- **Strengths**
  a) The geographical location of Pakistan and its potential.
  b) Potential energy resources in Pakistan.
  c) Job opportunities for residents in the energy sector.
  d) Significant development of energy infrastructure in the country.
- **Weaknesses**
  a) Lack of long-term and non-interruptive internal (local) and external (foreign) policies.
  b) Political perspectives.
  c) Lack of seriousness on project implementation.
  d) Lack of transparency in fund usage.
- **Opportunities**
  a) Significant opportunities for local and foreign investors to invest in the energy sector.
  b) Iran–Pakistan–China gas pipeline for energy production.
- **Threats**
  a) Targeting of ongoing energy projects in the region by spies supported by the Indian Research and
  b) Analysis Wing, Central Intelligence Agency of the US, and Mossad of Israel. Tax and power tariff problems.

E. FUTURE OF SG UNDER CPEC

Pakistan was facing an annual shortage of 5,000 MW owing to chronic energy deficiency in 2015. Considering the early harvest schemes of the CPEC, China and Pakistan have agreed to generate over 10,000 MW of electricity from 2018 to 2020. Moreover, other power projects are parallelly executed, as follows: **(a)** the Karot Hydropower Project is under construction in the Punjab province of Pakistan with an installed capacity of 720 MW, which is a run-of-river, concrete-core, rockfill gravity dam; **(b)** Port Qasim Coal-fired power plant of 1,320 MW, **(c)** Bhikki Power Plant with a capacity of 1,180 MW; **(d)** Solar Park in Bahawalpur of 900 MW; **(e)** wind farm of 260 MW at Jhimpir; **(f)** Thar coal projects for $1.2 billion; and **(g)** hydel projects in KPK province.

After the completion of all the CPEC energy projects, Pakistan is expected to be self-sufficient, and the chronic energy shortfall will be terminated. The completion of the CPEC energy projects will ensure a new era of prosperity and progress in Pakistan. Furthermore, Pakistan will enjoy uninterrupted power supply, affordable electricity, access to electricity for remote areas, reduction in foreign dependence, and fewer emissions from thermal power plants [62]. After the completion of the CPEC project, Pakistan will enjoy the following pertinent remunerations:

- Infrastructure advancement of high-voltage transmission lines.
- Implementation of AMI by incorporating smart metering and monitoring.
- Provision of low electric tariff per unit.
- Ensuring a match between demand and supply.
- Implementation of solar and wind parks for a clean and sustainable environment.
- Substation automation and control.
- Implementation of high-voltage direct current links through DC/AC substations.
- Research and development centers to accommodate pertinent features of SG in CPEC projects.
- Involvement of prosumer activity.

Owing to CPEC, Pakistan will be able to modify and invest in the power sector to achieve the new goals in advanced power technology. CPEC will cover all deficiencies that exist in the power sector of Pakistan and will aid in the implementation of the SG system in Pakistan. The implementation of SG will be a more feasible task for the energy sector. The SG will revolutionize the different aspects of energy infrastructure. Further, SGs will manage and eradicate the problem of energy theft with the help of smart meters that will communicate with the central control room. This will require an AMI so that the electric company can determine how the load produced is being consumed and can reduce the line losses due to electricity theft. Owing to this setup, every consumer will have to pay his bills regularly. The primary advantages of the SG are that load prediction, and scheduling is possible for optimizing and improving the power generation and consumption. Another vital feature of SG is that it provides a platform to integrate the RE sources with the existing power grid. This will encourage prosumer activities by motivating the users to install solar panels at homes to produce energy of their own; moreover, the surplus energy can be exported back to the electric company.

The implementation of SG is a considerably captivating and challenging task, particularly when Pakistan is facing "12–18" hours of load shedding, circular debt, trampling economy, electricity theft, corruption, and derated power sources. However, upgrading the power grid infrastructure under the umbrella of CPEC will be a challenging task.

TABLE 19. China–Pakistan economic corridor (CPEC) priority energy projects [62].

Project Name	MW	Estimated Cost (US$ M)	Current Status
The coal-fired power plant in Sahiwal, Punjab	1,320	1,912	Connected to main grid
Thar surface mine of Coalfield, Block-II, Thar, Sindh	-	630	In progress
HUBCO Coal Power Plant	1320	1,912	Connected to main grid
Gwadar coal /liquified natural gas/oil power project	300	542	In progress
SSRL Mine-Mouth Power Plant	1,320	2,000	In progress
Engro Thar Coal-fired Project	660	995	Connected to main grid
Quaid-e-Azam Solar Park, Bahawalpur	1,000	1,301	In progress
UEP wind Farm, Jhimpir	100	150	Connected to main grid
Sachal Wind Farm, Jhimpir	49.5	134	Connected to main grid
Karot Hydropower Station	720	1,698	In progress
Suki Kinari Hydro Power Station	870	1,707	In progress
The transmission line from Matiari to Lahore	2000	1,658	In progress
Port Qasim Electric Company Coal-Fired	1,320	1,980	Connected to main grid l

It will require a significant amount of investment and cautious planning to streamline and modernize the existing power grid, which has persisted untouched for decades.

F. CPEC PRIORITY ENERGY PROJECTS

The energy projects under CPEC will assist in matching the energy supply with demand. In this regard, priority energy projects are included in the CPEC execution timeline. The priority projects are listed in Table 19. The completion of the priority energy projects will boost the energy sector of Pakistan and will make Pakistan an energy sufficient country. Moreover, the completion of these projects will provide cheap and clean energy for the residents of Pakistan. The power quality will be enhanced, and the prominent problem of load shedding will be reduced. Further, the details of the priority energy projects under CPEC are provided in this subsection.

1) COAL-FIRED POWER PLANT IN SAHIWAL, PUNJAB

An IPP will finance the Sahiwal Coal project located in Sahiwal (Punjab) under the supervision of the Punjab Power Development Board (PPDB). Coal (imported) will be the primary source of energy. Two plants will be installed with a total capacity of 1,320 MW (660 MW each). Huaneng Shandong Rui Group from China is the financing company for this project. The estimated cost for this project is US$ 1,600 million [62].

2) THAR SURFACE MINE OF COAL FIELD, BLOCK-II IN THAR, SINDH

Surface mining is a wide-ranging category of mining in which overlying soil and rocks that cover the mineral deposits are removed. This project is located in Thar Block-II (Sindh), and the open-pit mining technique will be adopted under the supervision of the Thar Coal Energy Board (TCEB). The estimated cost is US$ 1,470 million and will be sponsored by the China Machinery Engineering Corporation (CMEC) and Sindh Engro Coal Mining Company [62].

3) HUBCO COAL POWER PLANT

A 660 MW, coal power plant, will be installed in the Hub region of the province of Baluchistan. Imported coal is the primary energy input, and the required cost for the project is US$ 970 million. HUBCO coal power plant will generate 660 MW of electricity. An IPP will finance the entire scheme under the supervision of the Private Power and Infrastructure Board (PPIB). The core sponsors are Hub Power Company with the Ministry of Water and Power as a coordinating sponsor [62].

4) GWADAR COAL/LIQUIFIED NATURAL GAS/OIL POWER PROJECT

The estimated cost of this project is US$ 600 million, and it is supervised by the Gwadar Port Authority and Gwadar Developmental Authority. The site is located in Gwadar (Baluchistan). This project started its operations before March 31, 2017. Coal, liquified natural gas, and oil are the primary sources of energy for the plant, and the total generating capacity is 300 MW [62].

5) SINO-SINDH RESOURCE LIMITED (SSRL) MINE-MOUTH POWER PLANT

PPIB is the administrator for the 1,320 MW Sino-Sindh Resource Limited (SSRL) mine-mouth power plant at Thar Block-I in Sindh. The expected cost is US$ 2,000 million and will be financed by IPPs [62].

6) ENGRO COAL-FIRED PROJECT

Thar is well renowned globally for its coal reservoirs. The primary source of energy for this project will be coal, which will be provided from the existing reserves in Thar. The Engro Thar coal-fired power plant is located at Thar Block-II in the province of Sindh. Four power plants will be installed, each of 330 MW capacity (total capacity of 1,320 MW). This project will cost approximately US$ 2,000 million and will be financed by IPPs under the supervision of PPIB. The project will be sponsored by CMEC and Engro Power Generation with the Ministry of Water and Power as a coordinating ministry [62].

7) QUAID-E-AZAM SOLAR PARK, BAHAWALPUR

Quaid-e-Azam (QA) Solar Park is located in Bahawalpur, Punjab. PV solar technology is used for power generation. The total capacity of this project is 1,000 MW, with an estimated cost of US$ 1,350 million, which is financed by IPPs. The executive agency is Hanergy/QA Solar Power (Pvt.) Ltd., Pakistan, and PPDB supervises it. This project is divided into three phases. The commercial operation date (COD) of the first phase (100 MW) is being achieved, and the second and third phases are under test [62].

8) UNITED ENERGY PAKISTAN WIND FARM, JHIMPIR

HydroChina (for engineering, procurement, and construction) Goldwind, China (is the supplier), and United Energy Pakistan (Pvt.) Ltd. is going to sponsor the Jhimpir 100 MW wind farm. AEDB will supervise the US$ 250 million project with the Ministry of Water and Power as a coordinating ministry [62].

9) SACHAL WIND FARM, JHIMPIR

HydroChina and Arif Habib Corporation Limited, as the administrative company, will invest US$ 134 million for the production of a 50 MW wind farm in Jhimpir, Sindh [62].

10) KAROT HYDROPOWER STATION

The 720 MW Karot Hydropower station will be installed on River Jhelum, situated near the AJK/Punjab province. SMEC Holdings Limited (Australia) / China Three Gorges Corporation (CTGC) and Associated Technologies (Pvt) Ltd will invest approximately US$ 1,420 million under the supervision of PPIB [62].

11) SUKI KINARI HYDROPOWER STATION

This hydro project is located at River Kunhar, a tributary of River Jhelum in the district of Mansehra, KPK. The assessed cost is US$ 1,802 million and will be executed by the Mott McDonald of UK, Coney Blair of France / Al Jomaih Holding company (LLC), Riyadh, Saudi Arabia, and Eden Inc. Berhad, Malaysia, under the supervision of PPIB [62].

12) TRANSMISSION LINE FROM MATIARI TO LAHORE

The China Electric Power Equipment and Technology Co. Ltd. (CET), a subsidiary of State Grid Corporation of China, will invest approximately US$ 1,500 million for the Matiari to Lahore transmission line. The project will install ±660 kW bipole high-capacity digital communications with converter and grounding electrode stations, and it will be supervised by NTDC [62].

13) PORT QASIM ELECTRIC COMPANY COAL-FIRED POWER PROJECT

This project is located in Sindh at Port Qasim. The primary energy source is coal, which will be imported from neighboring countries; further, the existing coal reserves of Pakistan can also be used. Two plants will be installed (each of 660 MW capacity), with a total capacity of 1,320 MW. The estimated cost is US$ 1,980 million. PPIB has been allocated the task of supervising the project with Sinhydro Resource Ltd. and Al Mirqab as the executing companies [62].

G. ENERGY PROJECTS ACTIVELY ENDORSED BY CPEC

This subsection highlights the actively promoted energy projects under CPEC. Upon completion of priority/early harvest energy projects, the energy supply is expected to match the energy demand, and Pakistan will become an energy self-sustained country. Moreover, the energy projects under future consideration are expected to enable Pakistan to export electric energy to neighboring countries. Table 20 lists the actively promoted projects under CPEC.

The actively promoted projects include **(a)** HUBCO coal power plant (Hub, Balochistan), **(b)** Pakistan Wind Farm II at Jhimpir and Thatta **, (c)** Gaddani Power Park project **, (d)** Kohala hydel project (AJK)**, (e)** Thar Mine Mouth Oracle, and **(f)** Muzaffargarh Coal Power Project. The HUBCO coal power plant generates 660 MW, and the cost was US$ 970 million. The power plant is operational in 2018/2019, and it was sponsored by the China Power Hub Generation Company (Private) Limited. The Pakistan Wind Farm II is established at Jhimpir and Thatta in Sindh. The total wind generation is 100 MW, with the estimated cost is US$ 150 million. Gaddani power park project will have an installed capacity of 1,320 MW and will cost US$ 3,960 million. The project is still under study. The Kohala hydel project will be sited at Jhelum River near Muzaffarabad, AJK. The estimated cost of the project is US$ 2,300 million, and CTGC sponsors it. The feasibility study is at the first stage, and NEPRA will announce the tariff. The land acquisition process has started, and the projected COD was 2013. Thar M Mouth Oracle will be situated at Thar, Sindh, with an estimated generation capacity of 1,320 MW. The project will cost approximately US$ 1,300 million. For the Muzaffargarh Coal Power Project, the coal will be imported for power generation. The PPDB will supervise the project; however, the sponsors have not yet been confirmed. The total production will be 1,320 MW, and the estimated cost is US$ 1,600 million [62].

H. POTENTIAL ENERGY SITES ON CPEC ROUTE

The CPEC routes include various cities with potential energy sources, namely, **(a)** Islamabad, **(b)** Quetta, **(c)** Bahawalpur, **(d)** Karachi, **(e)** Lahore, and **(f)** Peshawar. These cities possess RE potential that can enhance energy production and perform a vital role in overcoming the chronic energy shortage

TABLE 20. Projects actively endorsed by CPEC [62].

Project Name	Estimated Cost (US$ M)	MW	Current Status
HUBCO Coal Power Plant, Hub Balochistan	970	660	Connected to main grid
Pakistan Wind Farm II, Jhampir & Thatta	150	100	Connected to main grid
Gaddani Power Park Project	3,960	1,320	In progress
Kohala Hydel Project, AJK	2,300	1,164	To be completed in 2026
Thar Mine Mouth Oracle, Thar	1,300	1,320	In progress
Muzaffargarh Coal Power Project	1,600	1,320	In progress

of Pakistan. The energy potential of these sites has been investigated using the hybrid optimization model for multiple energy resources (HOMER) software [109] and the NREL database [125]. This work emphasizes the solar and wind potentials of these cities along with the clearance index of the sites and temperature curve to present the climatic changes throughout the year. The solar energy profile, wind energy profile, temperature curve, and clearance index graph of each of the cities mentioned above are provided to illustrate the energy potential of these cities. Finally, the overall solar potential, wind potential, and climatic behavior of Pakistan are incorporated.

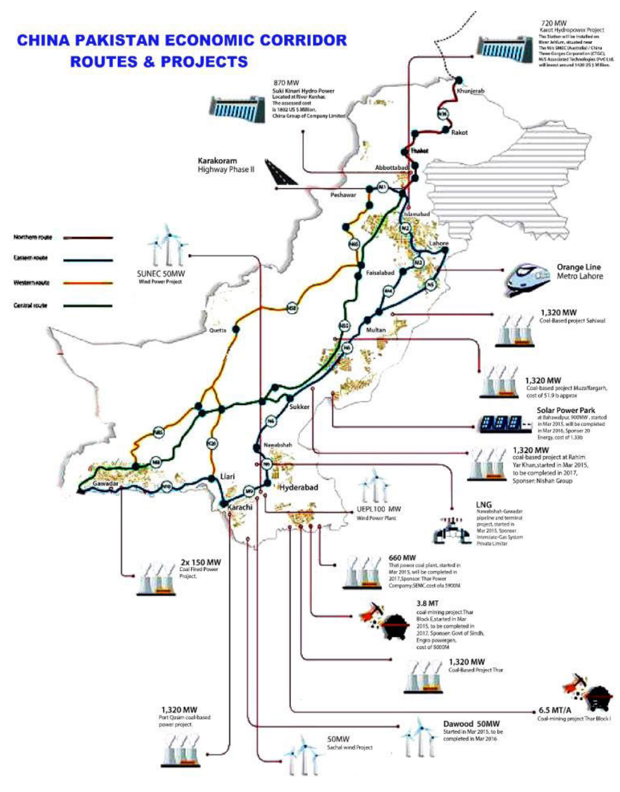

FIGURE 25. China–Pakistan economic corridor: routes and projects [35].

1) ISLAMABAD

Islamabad, the capital city of Pakistan, performs a vital role in the CPEC projects from the perspective of energy. For the future investigation of solar- and wind-based productions, the solar clearance index and annual solar radiance are determined, as illustrated in Fig. 26. To consider the wind potential in Islamabad for future deployment of wind energy in CPEC, this subsection shows the wind potential with average wind speed and the annual temperature curve. Islamabad receives a moderate amount of solar radiation. The average daily radiation is 5.243 kW·h/m^2/day in April, May, June, and July; the total daily radiation at its maximum value is 6.31, 7.27, 7.54, and 6.44 kW·h/m^2/day, respectively. The data of Islamabad was obtained from the HOMER software. The data illustrates that a considerable amount of solar energy potential is present in the locality and is utilized in a couple of sites, namely, **(a)** PEC [102] and **(b)** Pakistan Parliament. The solar setup of the solar energy system at PEC generates 356.16 kW of electricity. This setup incorporates an on-grid solar project that possesses an arrangement of net metering, which allows the beneficiaries to export surplus electricity to IESCO. Therefore, other projects such as solar and wind parks can be installed to utilize the never-ending energy sources under the CPEC energy schemes in Islamabad. The economic and environment-friendly wind energy must be exploited and utilized to overcome the long-lasting energy shortfall in Pakistan. Islamabad can be considered as a potential site for installing the wind energy parks owing to the developed infrastructure. Islamabad possesses a significant amount of wind energy potential, which can be exploited for energy production to eliminate the energy shortfall. This zone has a moderate wind speed that can efficiently operate the wind park. According to new research, different wind turbines have been designed that can run at a wind speed of 3–4 m/s for electricity generation [3], [122]. From Fig. 26, it can be observed that the minimum amount of wind speed is 5.44 m/s in August, which can be exploited for energy production. The daily average temperature curve of Islamabad is also illustrated, describing the climatic behavior of the region. The climate has direct and indirect effects and is a crucial parameter for the solar clearance index, solar radiation, and wind speed.

2) QUETTA

Quetta is in northwestern Baluchistan near the Pakistan-Afghanistan border and is a major trade hub between the

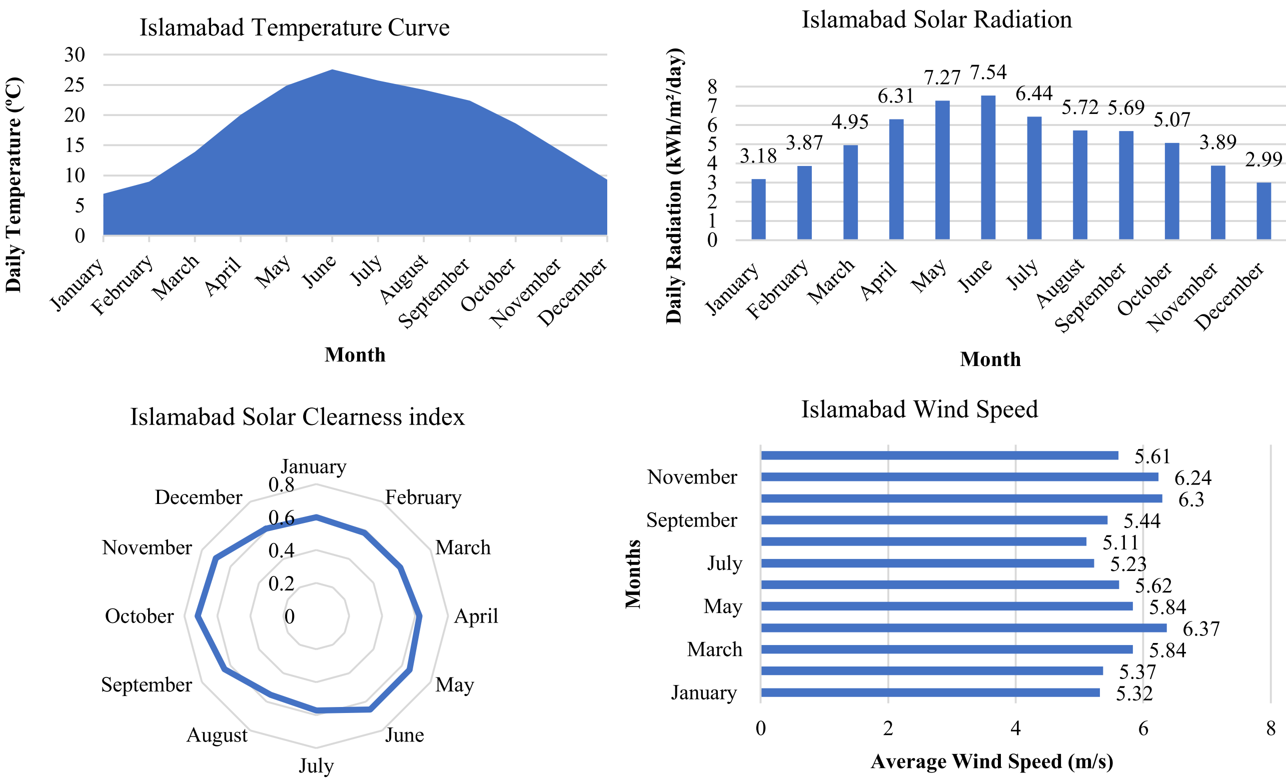

FIGURE 26. Solar clearness index, solar radiation (kW·h/m^2/day), wind speed (m/s), and temperature curve (°C) measured at Islamabad [125].

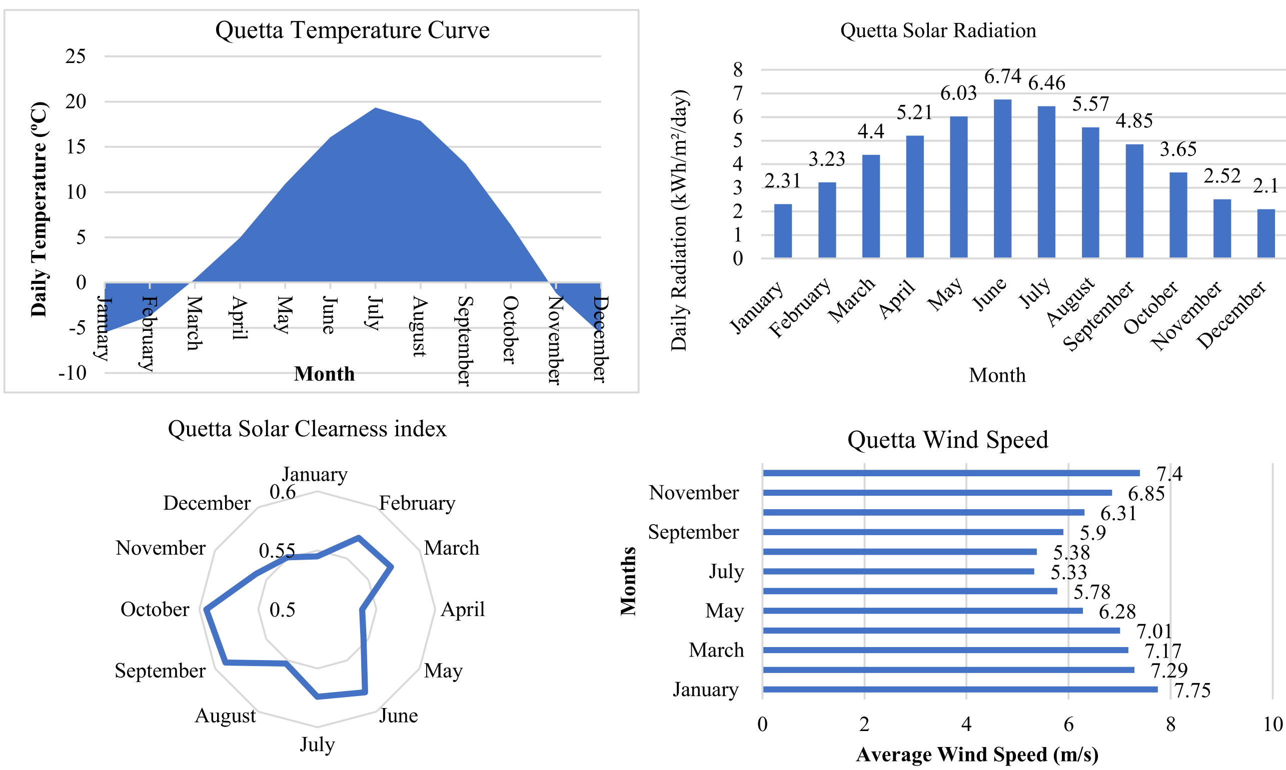

FIGURE 27. Solar clearness index, solar radiation (kW·h/m^2/day), wind speed (m/s), and temperature curve (°C) measured at Quetta [125].

two nations. Quetta is situated near Bolan Pass, also known as a gateway from Central Asia to South Asia [120]. The average solar clearance index of Quetta is approximately 55–60% annually, and its variation depends on climatic drifts. The solar clearance index is illustrated in Fig. 27 and depicts the average solar radiation of Quetta. This region receives daily solar radiation of 5.21, 6.03, 6.74, 6.46, and 5.57 kW·h/m^2/day in April, May, June, July, and August, respectively. The solar radiation in Quetta is illustrated in Fig. 27 for the entire year; additionally, the wind energy potential was examined and can be utilized to overcome the energy crisis. The temperature curve demonstrates the climatic conditions of the zone and provides an insight into the terrain.

3) BAHAWALPUR

Bahawalpur is located in the Punjab province of Pakistan. Bahawalpur is the 12th largest city in Pakistan, with an estimated population of 798,509. The city is also located near the ancient Derawar Fort in the desert near the Indian border and serves as a gateway to the Lal Suhanra National Park in Pakistan. QA Solar Park is located in Bahawalpur, Punjab. The region possesses significant solar and wind energy potentials, as illustrated in Fig. 28. Under the CPEC project, 100 MW was generated in the first phase of the project [62]. PV solar technology is used for power generation. The total capacity of this project is 1,000 MW. Similarly, the wind potential should be utilized for power generation, as illustrated in Fig. 28, which demonstrates a viable potential in the region of Bahawalpur.

4) LAHORE

After Karachi, Lahore is the second most populous city of Pakistan. Lahore is situated in the northeastern part of the Punjab province. According to the statistics of 2014, Lahore contributes significantly to the GDP of Pakistan, i.e., approximately \$58.14 billion [121]. In comparison with other cities, Lahore has considerable solar potential, which can be incorporated into the existing grid to assist in reducing the load shedding hours. The solar clearance index, solar potential, wind speed, and temperature curve are illustrated in Fig. 30. The solar energy at this site has significant potential for energy generation, reaching up to 6–7.34 kW·h/m^2/day in the hot summer season, which can be exploited for RE production.

5) PESHAWAR

Peshawar, the capital of KPK, serves as an economic hub and administrative center to FATA. The historic Khyber Pass, a gateway to Afghanistan, is also located near Peshawar. This region receives a daily average solar radiation of 7.07, 7.68, and 6.96 kW·h/m^2/day in May, June, and July, respectively. The Peshawar region also receives a high wind speed; therefore, a hybrid system of wind turbines and solar panels can result in a considerable difference in the energy-deficient country. The energy potential of locality is illustrated in Fig. 31 with other parameters.

6) OVERALL PAKISTAN

This subsection presents the solar clearness index, solar potential, wind potential, and temperature curve for the entire country of Pakistan (Fig. 32) to provide an insight into the overall averaged potential of the country. Pakistan receives solar radiation of 6.46, 6.57, and 6.1 kW·h/m^2/day in May, June, and July, respectively. The southern region of Pakistan has a significant potential for wind and solar powers, notably the 1,050 km coastal line near the Arabian sea. The average wind speed of Pakistan is above 4.5 m/s, making the locality favorable for wind energy production along with the solar power generation system.

I. BENEFITS ANALYSIS OF CPEC ENERGY PROJECTS FOR PAKISTAN

The energy projects mentioned in Table 19 and Table 20 are of great importance to Pakistan that will connect 10,000 MW into the national grid [62]. Pakistan was facing a severe shortfall of 7000 MW in 2011 that incurred severe mismatched between demand and supply, higher energy tariff per unit, extra loading on power equipment, and interrupted power supply with some areas facing 10 to 12 hours load shedding per day [125]. The CPEC focused energy sector of Pakistan and started various energy projects with an overall capacity of 10,000 MW [62]. Some of the energy projects completed during the last three years (2017-2020) that resulted in the connection of approximately 3555 MW in the national grid listed in Table 19 and 20 [62]. The timely completion of these projects resulted in zero shortfalls in 2019 and exceeded the supply versus demand by 1392 MW in 2020 [126]. As a result, Pakistan is enjoying low electric tariff per unit, clean energy, and abundant energy to easily overcome the increasing demand for industrial and residential energy requirements. The CPEC projects will provide the potential for industrial expansion to earn GDP growth and attract potential investors for establishing and expending the industrial sector within Pakistan. Further, the energy requirements increased during and after Covid-19 as most of the jobs relies on working at home. The software industry is also flourishing within Pakistan that has its requirement of energy and which will play a major role in an economic revolution in Pakistan. The CPEC energy projects will provide some pertinent benefits, such as (a) supply and demand match, (b) zero electricity theft as a result of deploying smart metering infrastructure, (c) clean energy like solar and wind farms, (d) prosumers activity, (e) low electric tariff per unit, and (f) reduced line losses.

J. CONCLUDING REMARKS

CPEC is expected to emerge as a revolutionary project for the energy sector of Pakistan. The development of RE systems is planned across the eastern, western, and central routes. These distributed energy systems will provide ancillary services to

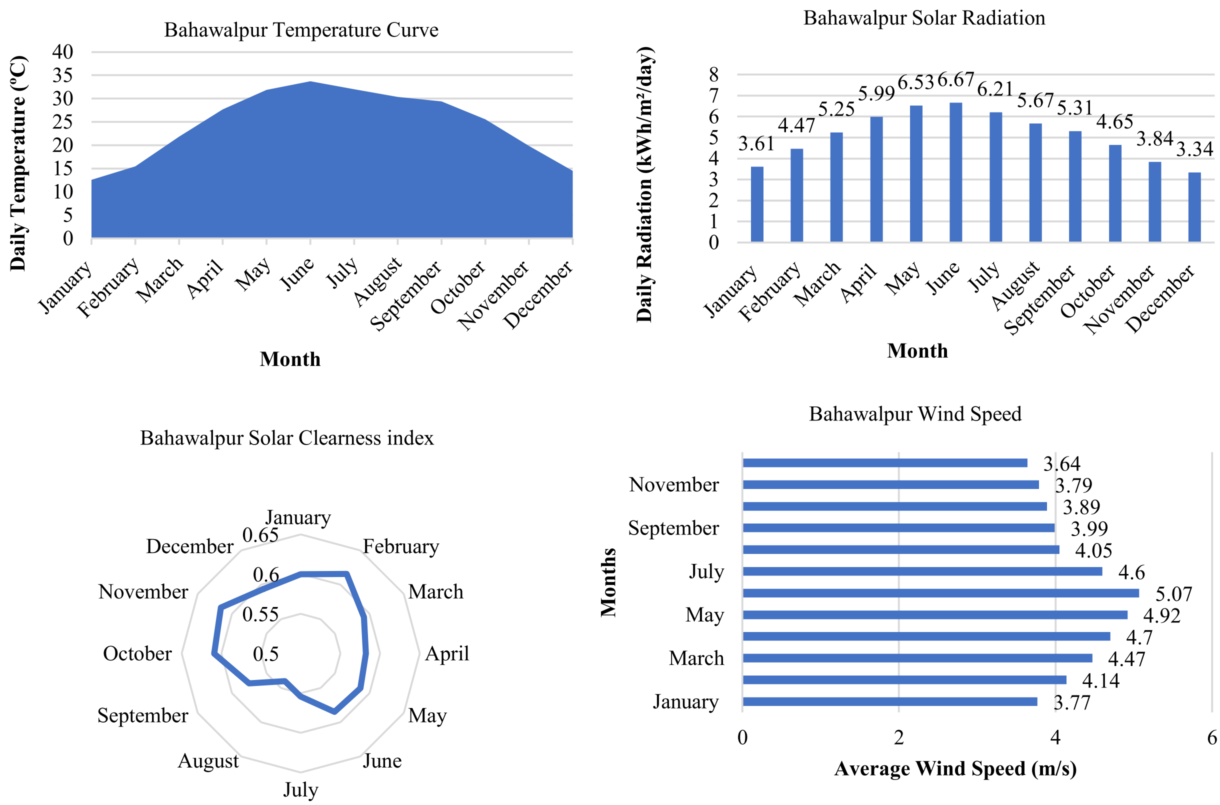

FIGURE 28. Solar clearness index, solar radiation (kW·h/m²/day), wind speed (m/s), and temperature curve (°C) measured at Bahawalpur [125].

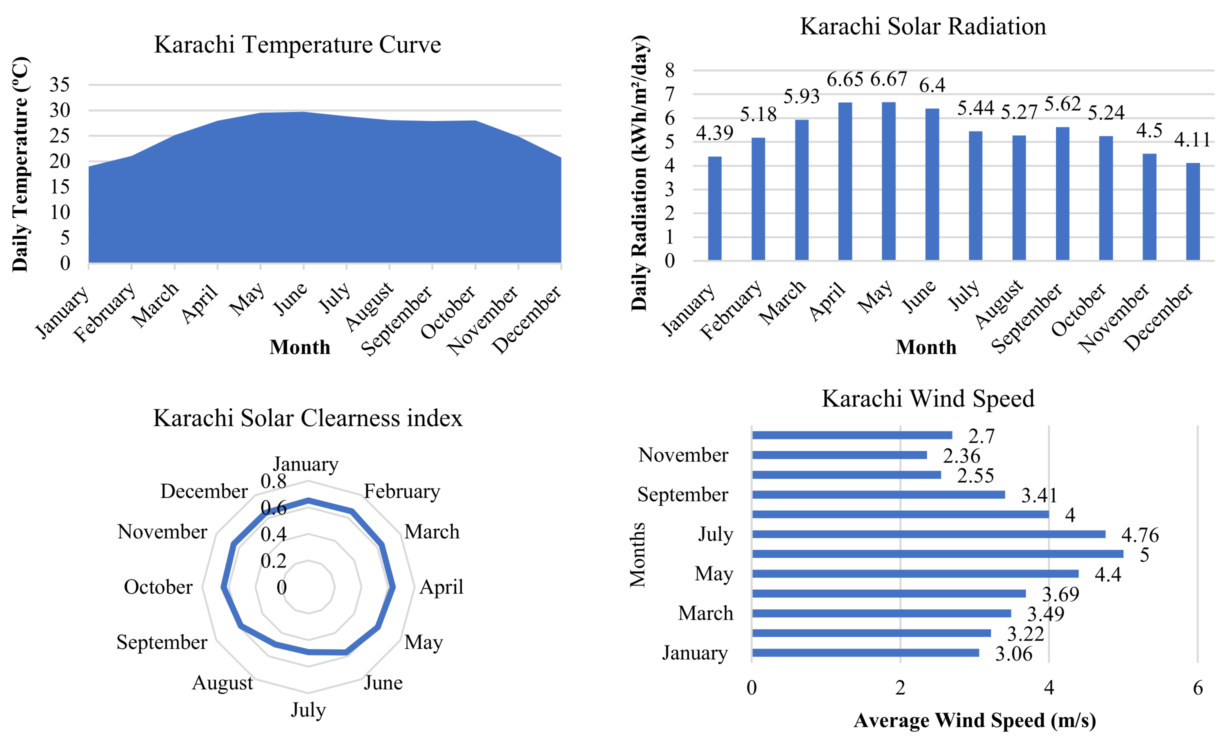

FIGURE 29. Solar clearness index, solar radiation (kW·h/m²/day), wind speed (m/s), and temperature curve (°C) measured at Karachi [125].

the local grids, such as power support, voltage support, and load sharing, and management. The various energy projects listed above will be completed soon; thus, the energy generation system of Pakistan will be strengthened. Moreover, the existing virtual power plants, IPPs, WAPDA, and power-producing agencies (KEPCO, GENCOs, PESCO, and others)

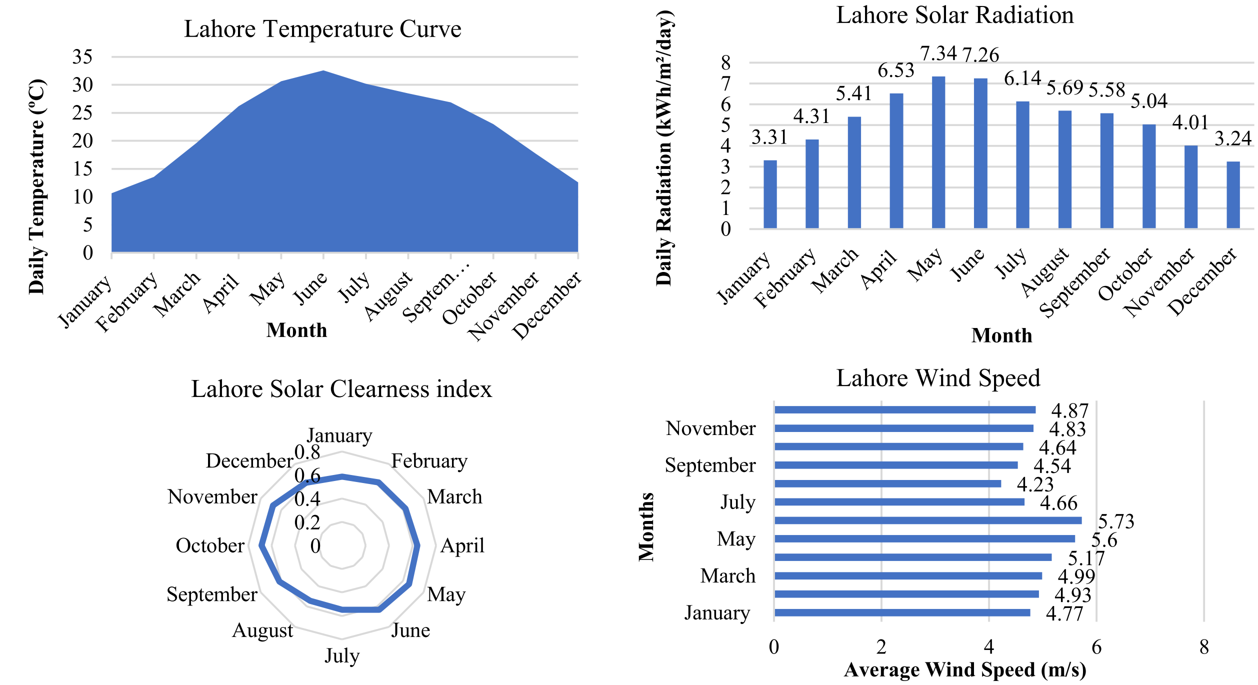

FIGURE 30. Solar clearness index, solar radiation (kW·h/m^2/day), wind speed (m/s), and temperature curve (°C) measured at Lahore [125].

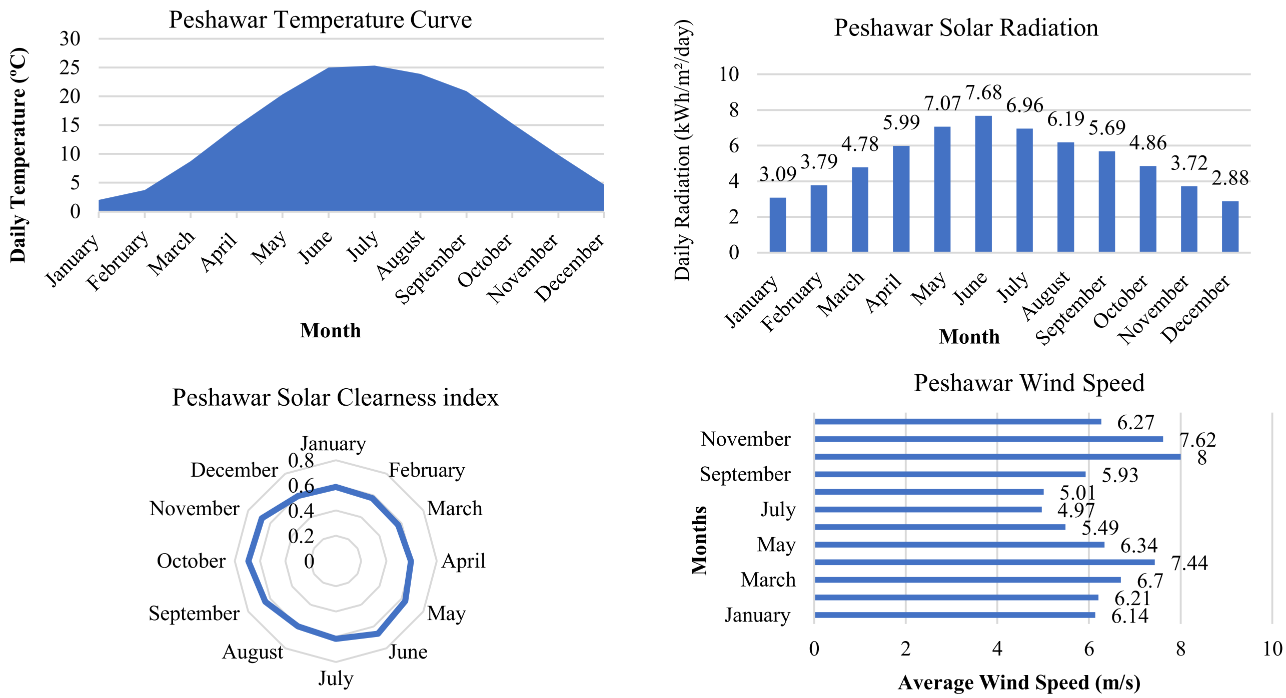

FIGURE 31. Solar clearness index, solar radiation (kW·h/m^2/day), wind speed (m/s), and temperature curve (°C) measured at Peshawar [125].

will reduce the burden on the economy of Pakistan with the implementation of green system technology. Furthermore, local energy demand will be satisfied, and the surplus can be exported to neighboring countries. Thus, the economy of the country will grow and flourish.

Some of the energy projects mentioned in Table 19 and Table 20 are operational and resulted in some pertinent benefits mentioned in the aforementioned subsection [62]. The timely completion of all CPEC energy projects will fulfill the requirements of SG implementation that includes the upgradation of the conventional grid, devise policies for SG implementation including energy market, independent energy providers, prosumers, and developing the government policies to recognize energy sector as a sector and provides the physical base for SG implementation. Smart meters are already implemented in Pakistan that provides

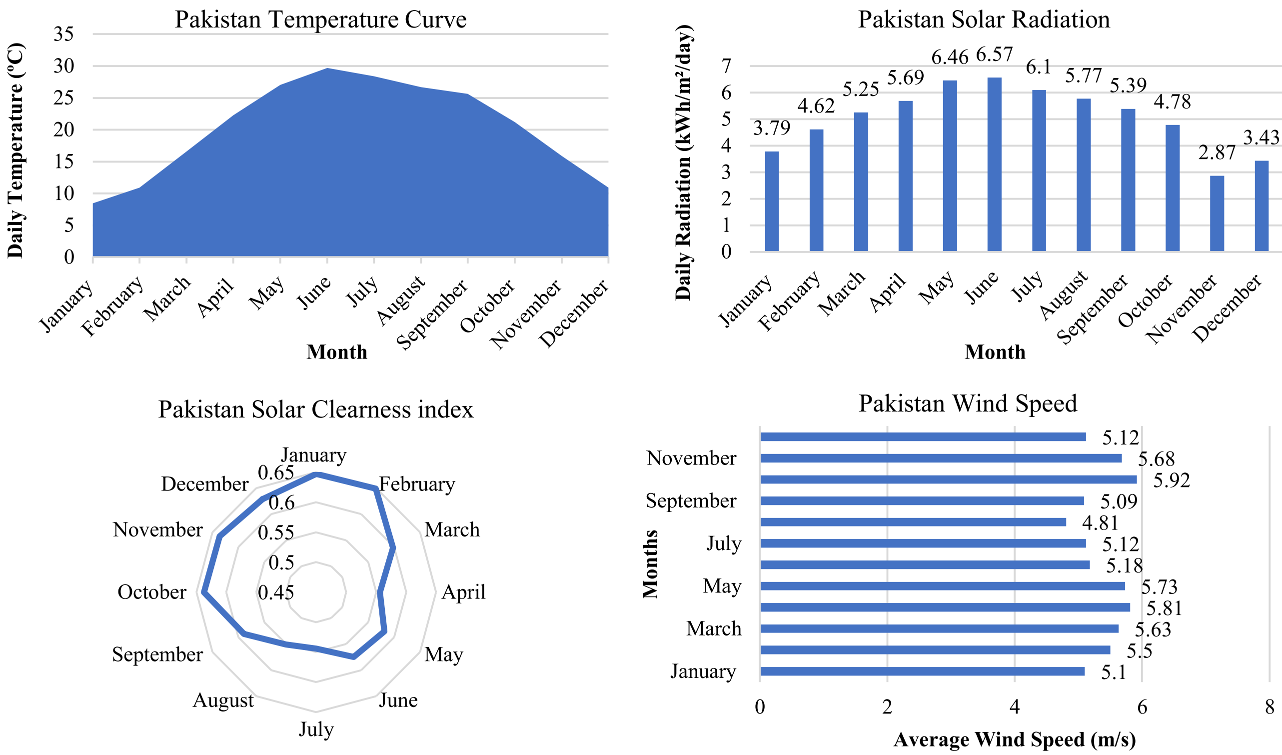

FIGURE 32. Overall solar clearness index, solar radiation (kW·h/m^2/day), wind speed (m/s), and temperature curve (°C) for Pakistan [125].

the opportunity to prosumer to export extra energy to the main grid and earn an incentive in terms of load adjustment. However, there are still different level policies required to implement and provide fully functional SG infrastructure and the possible developments must be noticed after the completion of all CPEC energy projects that will boost the industrial sector and will provide access to the global economy. The expected time of completion of projects mentioned in Table 19 and 20 is 2026 [26] and implementation of SG infrastructure will be ensured a few years after the completion of these projects.

VI. CONCLUSIONS AND FUTURE WORK

The conventional power grid infrastructure in Pakistan has resulted in various alarming issues, such as **(a)** supply and demand mismatch, **(b)** energy deficiency, **(c)** unprotected power system, **(d)** inferior power quality, and **(e)** power T&D challenges. These problems can be solved through reduced losses in the distribution network and improvement in DSM technology for commercial, domestic, and industrial sectors. The existing power generation capacity of Pakistan is insufficient to satisfy the demands of the country. These challenges and inefficiencies have motivated the GoP to shift from the conventional power system to SGs. The transition from the existing power system to SGs will improve the pertinent features of the power sector of Pakistan. Presently, there is a critical requirement for the implementation of energy projects to enhance the power generation capacity and thus match the supply with the demand, which is a prerequisite for the installation of SGs, which is beneficial for Pakistan. The supply and demand must be balanced before moving toward SGs. The study signifies the advents and the advantages of SG for the developing countries like Pakistan, highlighting the global trends, applications, and technology development in the field of smart grid in different countries.

A detailed review of the global market, investment by various countries, and SG implementation all over the world was presented initially. After global statistical analysis, the power market of Pakistan was discussed, and various renewable energy market statistics were presented. The structure of electricity sector in Pakistan is also overviewed, in which the generation and consumptions were highlighted. The energy demand statistics and available potential of conventional energy and RE were analyzed. It was concluded that there is a shortage of electrical energy in Pakistan and conventional resources are unable to fulfil the requirements. Analysis of the CPEC project were presented in this paper, which concluded that the energy projects will satisfy the demands of the country and will also assist in the implementation of SGs in Pakistan. SWOT analysis was performed for evaluation of the present conditions of the power system in Pakistan, and SGs were considered. The analysis showed that an efficient planning and considerable investments in the power sector are required to exploit the energy resources of Pakistan. CPEC can perform a significant role in overcoming the energy crisis in Pakistan.

The analysis proved that. the end product of the energy projects completion under CPEC will ensure the implementation of SG features, such as **(a)** AMI, **(b)** low power tariffs, **(c)** prosumers activities, **(d)** penetration of RERs into the national grid, and **(e)** DSM. Further, the distributed energy and essential SG requirement, including smart meters and other appliances, were discussed to facilitate SG implementation. The role of CPEC was elaborated to highlight the future implementation of SGs in Pakistan. In summary, it was concluded that the advent of the SG will lead to a more proficient and environmentally reliable future for Pakistan with well-enhanced power services. However, before the vision of a bright future becomes factual, Pakistan still has a long way to go. Pakistan requires improvements in the field of SG for a promising future. Soon, after the completion of CPEC energy projects, we plan to investigate and analyze the impact of CPEC projects on the SG system. We will also incorporate the design and modeling of a wide-area SG system with respect to Pakistan with a focus on barriers and limitations to SG implementation. The implementation of advanced linear control schemes and cloud data centers for SGs will increase the energy potential of Pakistan, and we will analyze these advance control schemes and cloud computing for distributed data centers in the wide-area SG system.

In near future, several case studies will be performed on the different renewable energy potential sites of Pakistan to analyze the sustainability of the standalone or grid connected systems. The study will help the authorities or investors to identify the promising sites for the installation of renewable energy systems and assist the deficiency of energy sector of Pakistan and pave a reliable road for the incorporation of SG.

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