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Review

The Prospective Non-Conventional Alternate and Renewable Energy Sources in Pakistan—A Focus on Biomass Energy for Power Generation, Transportation, and Industrial Fuel

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Received: 19 August 2018; Accepted: 5 September 2018; Published: 13 September 2018

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Abstract: Pakistan is experiencing an undersupply of electricity, causing load shedding several hours per day due to the adherence to conventional energy resources having quantitative and environmental limitations. Fossil fuels generate more than half of the country's total electricity, but they will ultimately run out due to their limited supply. Their combustion emits greenhouse gases, posing environmental threats. Since the world is tending toward efficient and sustainable alternative methods for harvesting energy from nature, Pakistan has also been investigating an elevated deployment of renewable energy projects. This paper presents a critical analysis of the present energy sector of Pakistan along with global scenarios. Pakistan relies on mainly thermal, hydro, and nuclear energy for power generation. National solar, wind, geothermal, and biomass resources have not been extensively explored and implemented. This paper provides an insight into the potential of these resources in Pakistan to generate electricity for the national grid on a large scale. It focuses on biomass energy, which can be harnessed from bagasse, poultry waste, and municipal waste for power production, and biomass-based fuel for industries and transportation. It concludes that biomass is the most sustainable, available, implementable, and environment-friendly resource that can be utilized to lessen the energy demand and supply gap in Pakistan.

Keywords: electricity generation; energy crisis; renewable energy sources; transportation; biomass energy; biofuels

1. Introduction

A country's human and socioeconomic progress is broadly dependent on its energy potential, which can be expressed simply in terms of its energy contribution per capita [1]. There has been a significant growth in the global population and a rise in living standards that account for a raised demand of power and energy, especially in the developing countries [2]. As the energy demand is rising, the energy prices have also been increasing, which along with the recent geopolitical events, has drawn the world's attention toward the vital role played by affordable and sustainable energy in economic growth and human development [3].

Figure 1 shows an increase in the energy resources demand up to the year 2030. It can be observed that even though the energy demand using coal, oil, and gas has significantly increased, there will be a substantial rise in the use of renewable energy sources. In 2007, the world electrical energy production was 16,429 Terawatt-hour (TWh), and its projected consumption in 2030 is 28,930 TWh i.e., a 49% increase in the global energy demand and 87% rise in world electricity generation is expected [4,5].

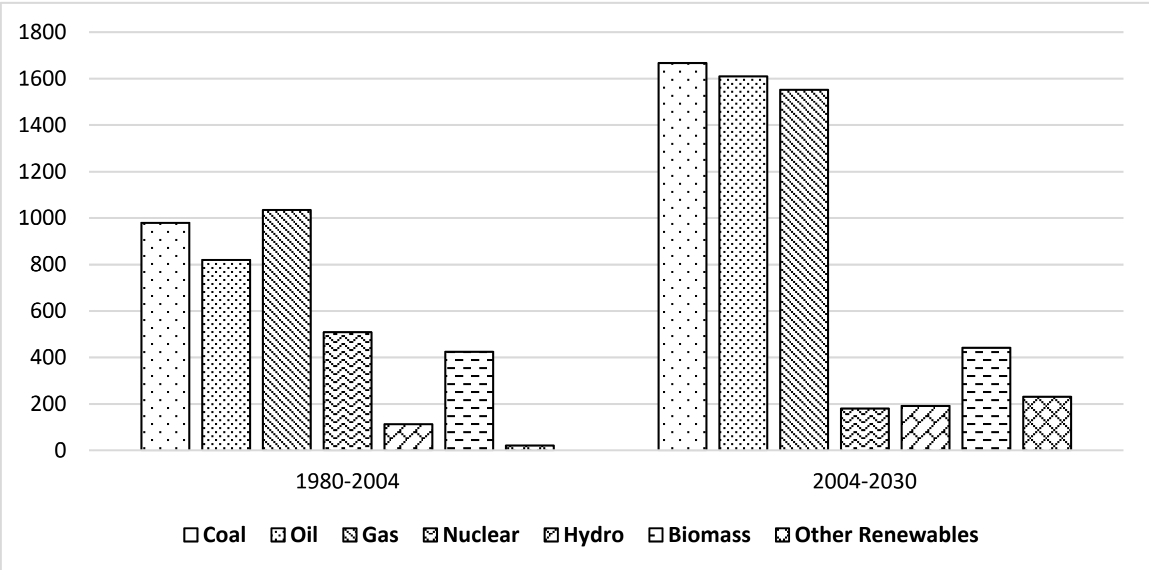


Figure 1. Increase in demand of energy resources.

The International Energy Agency (IEA) reports the improvement of the overall provision of energy from primary sources to 12,717 million tons of oil equivalent (mtoe) in 2010, which was up from 6107 MTOE in 1973, and includes oil, coal, natural gas, biofuels, nuclear, hydro, and various other resources with contributions of 32.4%, 27.3%, 21.4%, 10%, 5.7%, 2.3%, and 0.9%, respectively [6]. Group of Eight (G8) leaders met the heads of major developing countries and international organizations in 2005 and 2006, to work together with the IEA regarding clean and prosperous alternate scenarios of obtaining energy in future [3].

Figure 2 shows the projected electricity demand and supply from 2016 to 2020. It is expected that by 2020, the world will be able to bridge the energy and supply gap, and will also have a surplus power of 3491 megawatts (MW). Rapid decline in the worldwide fossil fuel resources and their impulsively instable costs have posed damage to the world's economy. The climate of the planet is affected by their abuse, causing an amplified degree of pollution, damage to the ozone layer, and extraordinary variations in the earth's climate. The inimitability of fossil fuels in the current energy scenario and their value to future generations is also certain [7]. Table 1 shows the energy situation using renewable resources by 2040. The European Renewable Energy Council (EREC) projected in 2006 that by 2040, 50% of the world's energy will come from renewables [8].

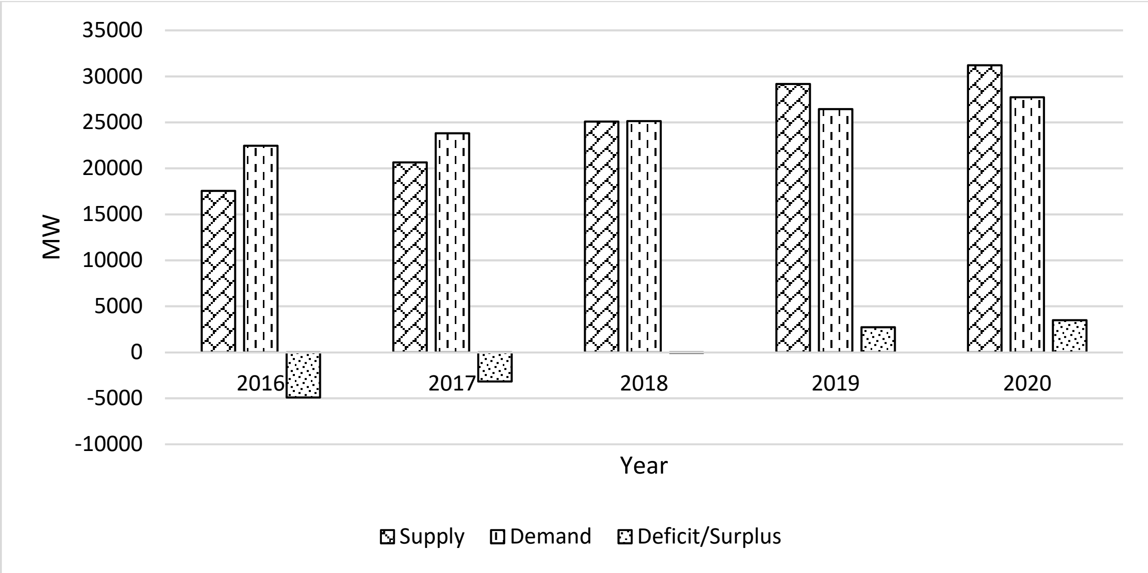


Figure 2. Projected electricity demand and supply for 2016–2020.

Pakistan ranks sixth in the world's most populous countries with 173.51 million people, and by 2050, it is predicted to be number four. At present, Pakistan has daunting problems regarding inadequate installed capacity, revenue shortage, and circular debt for energy production [9]. The energy sector majorly relies on conventional resources such as coal, oil, and natural gas. Due to increase in their demand, the country is facing a shortfall of these natural resources. Their use releases greenhouse gases, rendering them unfit for the environment. The deviations caused by man's actions in nature and the nature's response to these actions have greatly affected the environment of our planet in the last decades [10,11]. People around the globe are becoming aware of the finiteness of the natural resources and the threat to future generations due to their non-conservation [12]. The oil reserves of the world are located in regions of political and ethnic conflicts that are challenging to solve in a short time span [13]. Also, the fluctuation in furnace oil prices and the per-unit cost of electricity, along with the inflation rate, have adversely pressurized the national economy [14].

Table 1. Global renewable energy scenario for 2040.

Sources Category	2001	2010	2020	2030	2040
Total consumption (mtoe)	10,038	10,549	11,425	12,352	13,310
Biomass	1080	1313	1791	2483	3271
Large hydro	22.7	266	309	341	358
Geothermal	43.2	86	186	333	493
Small hydro	9.5	19	49	106	189
Wind	4.7	44	266	542	688
Solar thermal	4.1	15	66	244	480
Photovoltaic	0.2	2	24	221	784
Solar thermal electricity	0.1	0.4	3	16	68
Marine (tidal/wave/ocean)	0.05	0.1	0.4	3	20
Total renewable energy sources	1365.5	1745.5	2694.4	4289	6351
Renewable energy sources contribution (%)	13.6	16.6	23.6	34.7	47.7

The rift of 5201 MW (range 3000–6000 MW) in the demand and supply of power and energy, as of 2015, caused a daily power cut of 14–18 h. Even after some progress in the energy sector, the country still faces some deficit. The use of renewable energy resources will not only put an end to the deficit, but surplus energy will be available in coming years, as predicted in Figure 2 [15]. So, it is necessary to adopt renewable resources, considering their superabundance, sustainability, native availability, and environment safety [16]. Earth has a plentiful amount of the resources that are needed for the successful development of solar, hydraulic, wind, geothermal, and biomass-based projects, enabling a diversity in the country's energy mix [17]. Pakistan's current energy fuel mix based on installed capacity is shown in Figure 3. As of 2017, depending upon the sources, the fuel mix is divided into two categories, i.e., carbon-based and carbon-free, in which 65% of the current fuel mix is carbon-based, while 35% is carbon-free. Renewable energy has a share of only 3%. Natural gas has a share of 41% in the fuel mix and 10,332 MW capacity and oil has a share of 24% with 6137 MW capacity; these are the carbon-based fuels. Hydro energy has a share of 28% in the fuel mix and 7116 MW capacity, nuclear has a share of 3% with 787 MW capacity, and renewables have a share of 3% with 852 MW capacity; these are the carbon-free fuels. The vision by 2025 is to decrease the percentage of carbon-based fuels to 62%, so that the usage of clean energy sources may rise to 38% such that hydro, nuclear and renewable energy sources will have 27%, 7%, and 5% shares in the fuel mix and 13,142 MW, 3667 MW, and 2339 MW capacities, respectively [8,18].

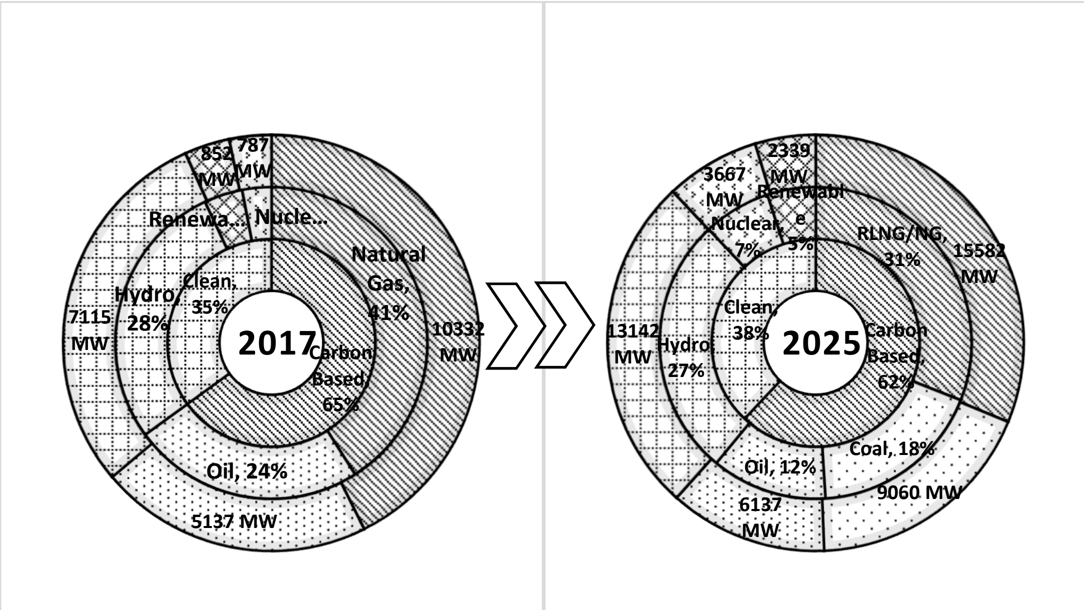


Figure 3. Pakistan's energy fuel mix (2017–2025).

Wind energy serves as a renewable clean energy source with a vast capacity of 346 gigawatts (GW). Pakistan has 120 GW viable, particularly in the coastal lines of Sindh and Balochistan provinces, the velocity of wind being 4–9 ms^{-1} and 12.5 ms^{-1} at 10 m and 50 m height, respectively [15].

Pakistan has 300 sun shining days because of its geolocation, creating a mean temperature per annum of 26–28 °C and 1900–2200 kWh/m^3 per annum global radiation, providing a solar potential of 2,900,000 MW. In total, 18 photovoltaic systems with 440 kW installed capacity are running in Pakistan. The solar energy share of the country is rising continuously. Yet, in order to decrease the power cut duration, incredible measures are still required. In northern areas, Pakistan can also use its geothermal resources, but unfortunately, no effort has been done to utilize them, due to a lack of investment and manpower [19].

Biomass can serve as another versatile renewable energy resource to bridge the energy supply and demand gap of the world in various energy applications such as electricity, transport, and buildings [20]. It has a 14% share in the total 18% of the world's renewable energy share. Raw material for biomass can be obtained from agricultural and forest leavings, industrial and municipal leftovers, and waste materials. Pakistan, as an agricultural country, holds a great capability to harvest energy from biomass comprising of waste that comes from crops such as wheat, rice, and sugarcane. Established poultry and livestock industries also leave behind excessive poultry and livestock ordure, which being organic in nature, can be processed to retrieve energy. A fresh study of the World Bank states a potential of 4000–6000 MW power generation using biomass. The Punjab government has projected a potential of

1500 MW of power generation through biomass that is used as fuel and 1000 MW of power through solid waste. It has been observed that the waste heat from the cement and chemical industries can be used to generate electricity that can be sold to the grid. Between 200–400 MW of electricity can be produced by waste heat recovery, according to recent estimates by the 2016 state of industry report [21].

The 2010–2035 global policies suggest an urgent imposition for bioenergy, excluding traditional biomass, with a required 3.3% annual increase i.e., 526 MTOE (2010) to 1200 MTOE (2035). However, by 2035, bioenergy will hold a greater share in the power sector, as mentioned in Figure 4 [22]. Biomass is an exclusive form of source of green and clean energy; it is also abundantly instituted in nature and can be produced easily both in urban and rural environs [23,24]. Biomass resources are segmented in three classes, as shown in Table 2 [25,26].

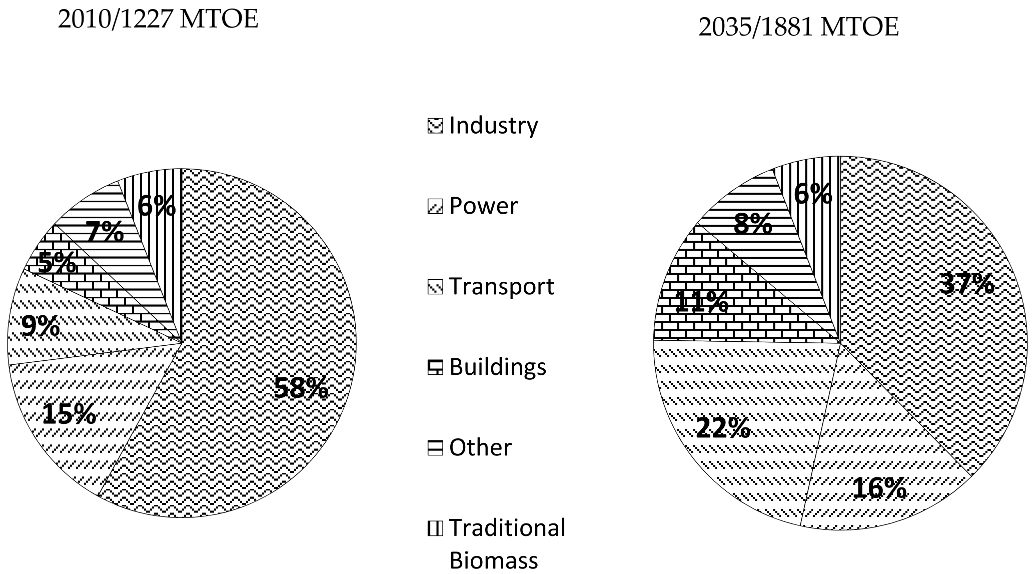


Figure 4. World bioenergy use by sector and use of traditional biomass in the new policy scenario (2010–2035).

Table 2. Biomass sources.

Biomass Source	Types
Wastes	Agricultural production wastes, crop residues, agricultural processing wastes, urban organic wastes, urban wood wastes, and mill wood wastes.
Forest products	Wood, trees, shrubs and wood residues, logging residues, sawdust and bark from forest clearing.
Energy crops	Starch crops (corn, wheat, and barley), sugar crops (cane and beet), oilseed crops (soybean, sunflower, and safflower), short rotation woody crops, herbaceous woody crops and grasses.

The advantage of obtaining energy from biomass resources is that the output is closed to the installed capacity, unlike other renewable resources [27], which can be witnessed in Figure 5. Furthermore, the production of thermal energy using biomass has less effects on the environment. Thus, energy harnessed from biomass resources is popular development in Pakistan as compared to other systems of renewable energies [28]. In early days, different biomass such as leaves, wood, and excrement have been used as energy resource in daily life. Despite the overriding of biomass by fossil fuels in both urban and rural regions since the industrial revolution, biomass is slowly becoming reaccepted as an energy supply at the industrial scale [29].

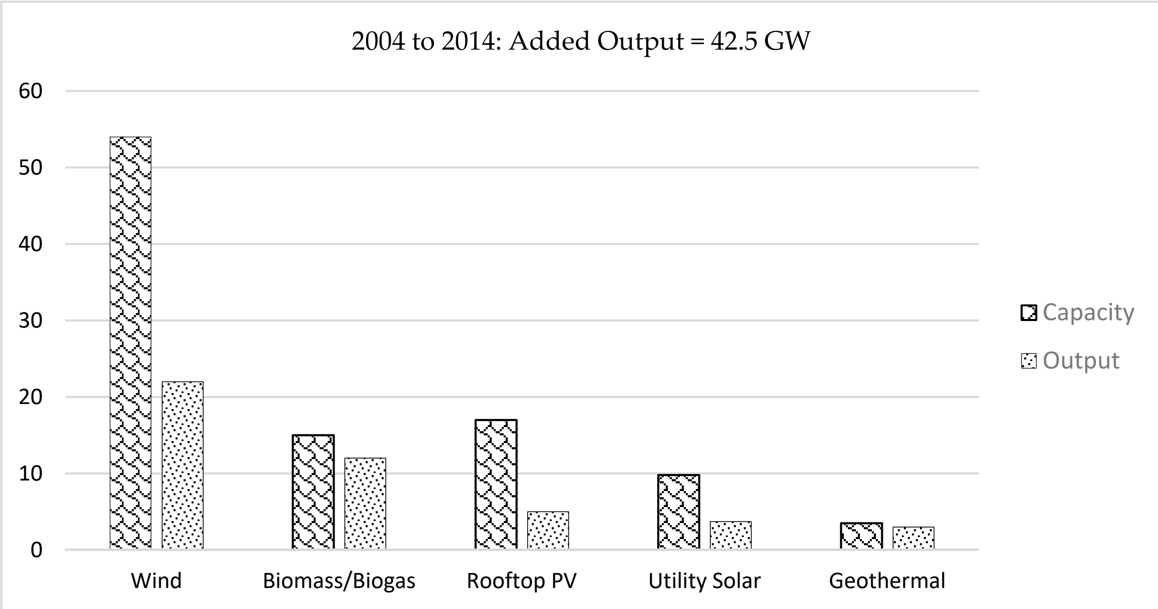


Figure 5. Output vs. installed capacity for various global renewable sources.

Research and development is being carried out for various technologies of producing biomass energy [30,31]. Electricity generation based on gasification technology has been practiced for more than a century. Anaerobic digestion and the combustion of biomass are developed and established technologies compared to gasification. In study [31], Bhattacharya demonstrate a biomass energy to co-firing with coal energy [32,33], and it is well developed in agro-industries. Additionally, biodiesel and bioethanol-based energy production are a few of the most striking biomass energy technologies in the current era [34].

This paper briefs the necessity of upgrading Pakistan's power sector by using the renewable resources. Some of the previous research studies in this domain only targeted one specific resource or two, while other research studies have targeted all of the resources. However, their analyses do not provide an insight as to which resource can quickly lessen the gap between energy demand and supply in the current situation in Pakistan. The first step toward the successful implementation of a renewable energy resource at a large scale is to study the various perspectives of all the available resources, and then opt for the most optimal and feasible one by properly analyzing all of the aspects of each resource. A comprehensive analysis has been done in this paper on the state, demand predictions, and existing sources of power generation in Pakistan using conventional, alternate, and renewable energy resources, along with global scenarios to comprehend where Pakistan stands in the world in terms of power and energy. This approach can help the government make decisions about the prioritization and utilization of resources, which will enable investors to wisely invest in high-priority resources based on facts and the potential advantages and disadvantages of individual resources. This study shows that the geolocation of Pakistan makes the place ideal for the implementation of any kind of alternate or renewable energy systems based on hydropower, thermal power, nuclear power, wind, solar, geothermal, and biomass power plants. It also discusses the biomass resources such as bagasse, municipal waste, and poultry waste to harvest biomass energy for power generation, transportation, and industrial fuel. Keeping in view the availability, sustainability, and lowest environmental impact of biomass energy, this paper concludes that the energy policies of Pakistan are in dire need of revision in order to bridge the demand and supply gap by bringing up projects based on renewable energies, especially biomass-based energy projects that hold enormous energy and fuel potential.

This paper has been structured in four main sections. Sections 2 and 3 critically review the existing demand and future sources of power generation predictions based on different power plants in Pakistan. The existing and future scenarios of biomass applications in electricity generation, transportation, and its use as an industrial fuel are the focus of Section 4. The discussion and recommendations have been presented in Section 5, in comparison to the existing energy situation of Pakistan. Finally, a conclusion is presented in Section 6. A graphical representation of the research methodology is also presented in Figure 6.

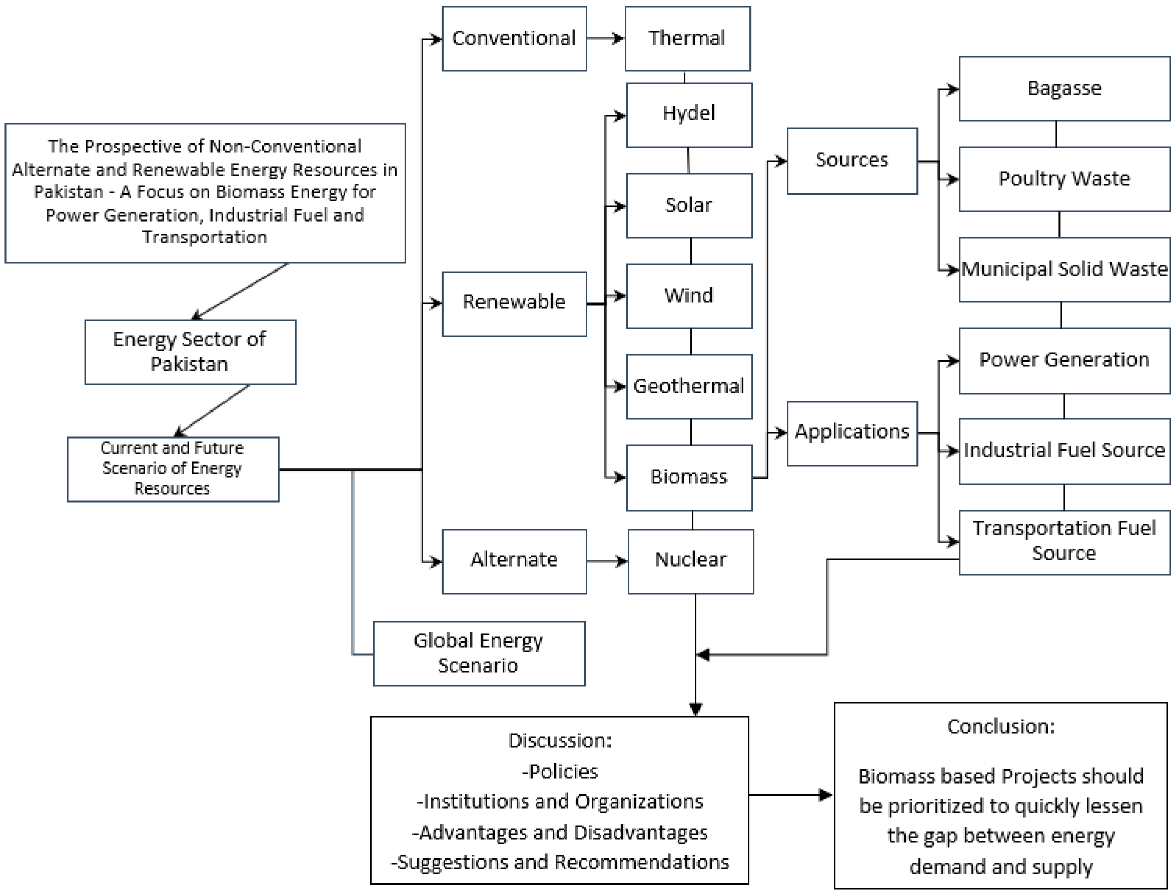


Figure 6. Graphical representation of the research methodology.

2. Energy Sector of Pakistan

A worldwide evaluation of energy policies has been carried out to meet the gap between supply and demand [35–38]. So, Pakistan's national power policy has the key objective of providing an efficient electricity supply system by transition of the country's electricity industry from the public sector toward potential efficiency improvements from private enterprise, because the public sector has been facing various constraints over the last two decades. Since 1994, the Government of Pakistan (GoP) has been following a policy of commissioning new generation capacity in the private sector via independent power producers (IPPs) [39,40]. Public and private sector (IPPs) contribute 53.64% and 46.36%, respectively, to the installed capacity of Pakistan. There has been an elevation in the overall installed capacity for power generation of Pakistan i.e., 24,961 MW in 2015 to 24,961 in 2016, representing an increase of 1.65%. The National Transmission and Dispatch Company (NTDC) and K-Electric's (K-EL) power plants generated 112,033 GWh as of 2016, relative to 108,916 GWh as of 2015 [21]. An overview of the power sector and discussion about its current generation capacity is given in the following sections.

2.1. Hydropower

Hydel power is a clean, cost-effective, and renewable energy source. Also, it shows a quick response with a fast varying load [41,42]. Keeping in view its advantages, more than 150 nations have established hydel power generation plants, which constitute about 16% of the world's power generation [43,44]. Results deduced by a comparison of electricity generation from hydropower and other renewable sources between 2010–2016, as shown in Figure 7, illustrate that hydropower electricity generation has three times greater efficiency than other sources [45]. The total renewable capacities of the top six countries are presented in Figure 8. As seen, China has the largest hydropower resource potential, with a capacity of 542 GW and 2470 TWh annual generation as of 2016 [45,46].

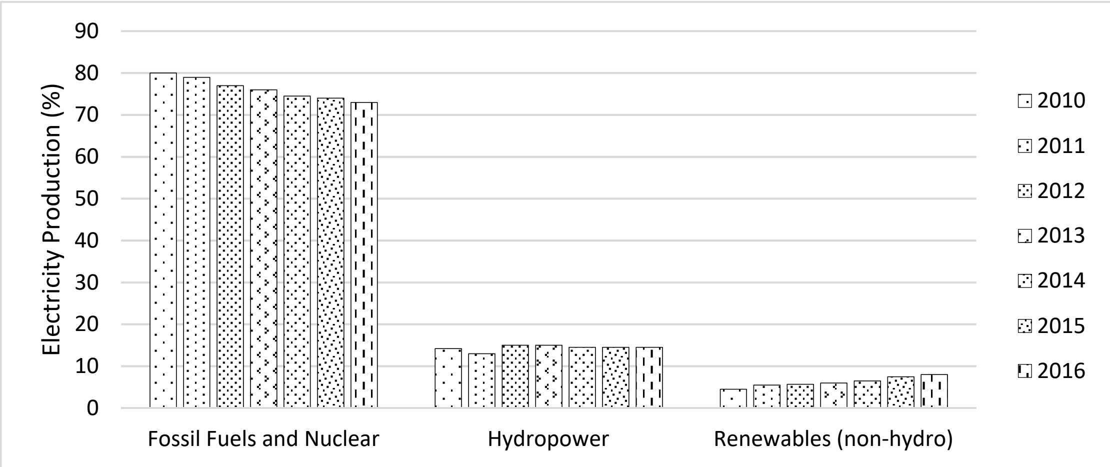


Figure 7. Worldwide electricity production for the period 2010–2016.

Hydro has remained a chief pillar of economical energy production in Pakistan. During 1960, this method generated 70% of the total electricity of the country, whereas by 2014, it had declined to only 30% (7000 MW). This constitutes 9% of the overall power produced from primary sources [47].

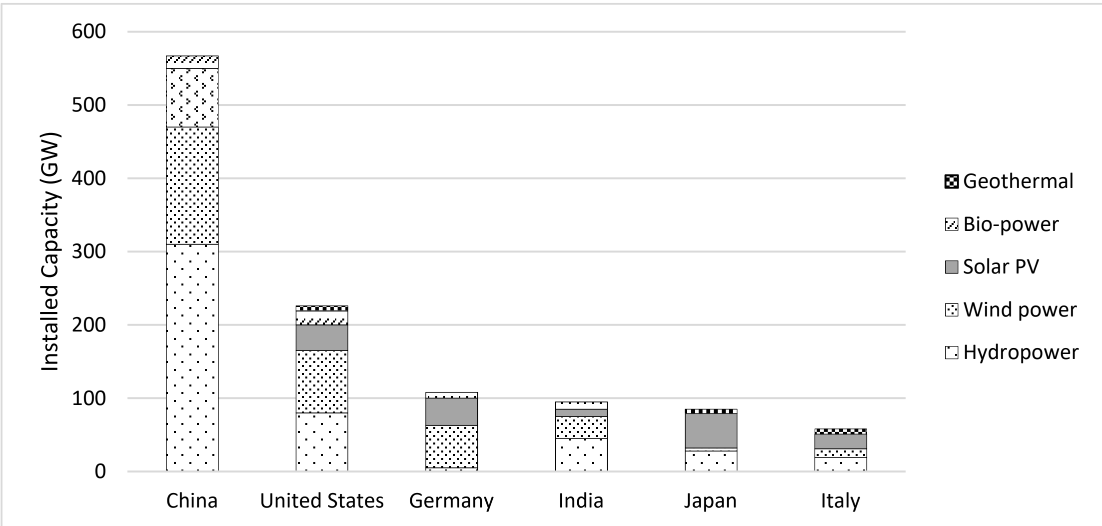


Figure 8. China has the world's largest total hydropower capacity.

Pakistan can tap its lakes, rivers, and waterfalls to generate hydro energy, which accounts for enormous potential of energy generation. For hydel-based electricity generation installations, several new locations have been chosen [48]. Pakistan's inability to sustain a hydropower share in the total electricity produced is one of the leading reasons for its energy crisis. In 2015, the overall share increased by an insignificant amount of 1%, making its share 31%. The loss of its share is due to the GoP's inability to establish new power production plants and trail the power requirement, as shown in Figure 9. Whereas, during this period, electricity production using thermal sources rose to 65% from

42% [49]. Owing to a decrease in the generation capacity, hydel power generation is prone to encounter limitations based on a deficit of water, mostly in winters. Limited reservoirs and dams further add to this problem [50].

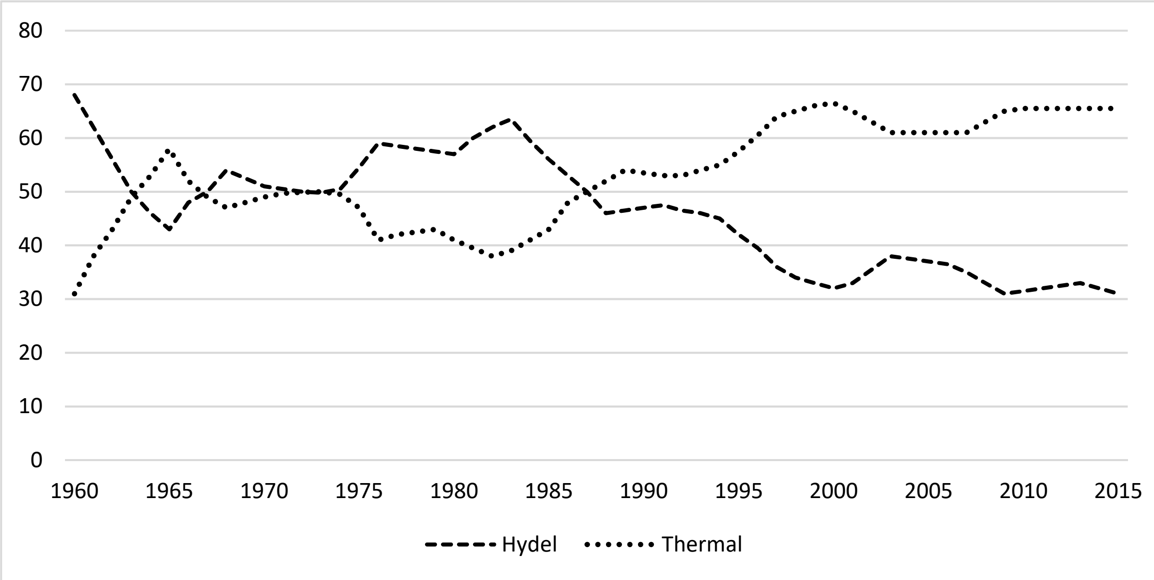


Figure 9. Decreased share of hydel in electricity generation from 1960–2015 in percentage.

For Pakistan, as a developing country, the ultimate preference could be hydropower, since it is inexpensive, plentiful, and a native source for renewable energy production. The expense for hydro energy production is approximately PKR 2–3/kWh, while using natural gas costs PKR 4–6/kWh. Likewise, the utilization of high-speed diesel (HSD) and residual furnace oil (RFO) for electricity production is five times more expensive than hydel i.e., PKR 15–18/kWh [43,51].

In the late 1970s, even with the worthwhile advantages offered by hydel, no remarkable accommodations were made after the establishment of the Tarbela and Mangla dams. Ghazi Brotha was the last significant venture; it was made in 2002, bringing 1450 MW capacity to the grid. Since then, no noteworthy investment has been made. From 2004 to 2012, the demand has increased by 27.5%, and overall capacity has increased by only 16%. Talks about the Kalabagh Dam and Diamer Bhasa Dam with 3600 MW and 4500 MW capacity, respectively, have been ongoing, but due to a lack of finance [52] and political problems [53], they have not been realized [54].

Table 3 shows an empirical analysis of the hydel portfolio in Pakistan. It is observable that while the 0.15–50 MW range covers the three classes, all of the projects having greater than 50 MW are taken as large hydrosystems. It has been suggested that adding more categories to the 450 MW section would render easier planning and estimation. The proposed categories are medium hydro, large hydro, and mega hydro, with capacities of 50–499 MW, 500–1000 MW, and 41,000 MW, respectively. Large and mega projects can expectedly have disparate scales of ecological and socioeconomic influence across notably different geographical locations and time scales [55].

Table 3. Pakistan's hydropower portfolio. MW: megawatt.

Category	Cumulative Capacity (MW)	Total Projects	Functional		Under Development	
			MW	Number of Projects	MW	Number of Projects
Micro hydro: <0.15 MW	6.62	79	1.93	20	0	0
Mini hydro: 0.15–5 MW	607.6	518	89.44	97	158.5	66
Small hydro: 5–50 MW	2020	123	196	13	719	42
Large Hydro: >50 MW	57,160	82	6433	6	29,162	43

The thought of micro hydel is not new for Pakistan; the still functional power station established in 1925 at the Bambawali Ravi Bedian (BRB) Canal in Renala generates 1.1 MW of power. The cumulative micro hydel potential at a total of 815 natural waterfalls and run-of-river sites is 3100 MW in the country. Major hydel projects under development under the Water and Power Development Authority (WAPDA) are shown in Table 4 [15].

Table 4. Hydropower projects under development in Pakistan. COD: commercial operation dates.

Sr. No.	Dam	Capacity (MW)	Expected COD
1	Neelum Jehlum	969	December 2017
2	Dasu	2 × 2160	2025
3	Diamir Bhasha	4500	2019–2020
4	Keyal Khwar	128	January 2020

There was an addition of 1908 GWh to the total hydropower energy generation in 2015–2016 as compared to 2014–2015, making up a total of 33,433 GWh energy production, while WAPDA's hydropower installed capacity persisted on 6902 MW from 2014–2016. Likewise, in 2015–2016, the hydel-based IPPs made a contribution of 52 GWh, and the installed capacity remained the same as that of 2014–2015. Throughout the year, the electricity production trend from hydropower has been consistent with the historical trends. For 2015–2016, operation and readiness was observed to be acceptable [21]. To inspire the installment of hydel-based projects, the GoP has permitted a 17% internal rate of return for such projects [54].

2.2. Thermal Power Source

The use of thermal energy has been greatly expanded in every sector of life, such as the residential industrial and commercial sectors e.g., for cooling and heating purposes. The IEA predicted that the need for thermal energy will persist in the near future. For thermal energy generation, primary sources are fossil fuels such as coal, oil, and natural gas. Nuclear reactors are also used in this regard [56].

Pakistan has a mixture of thermal, hydro, nuclear, and renewable energy power plants for electricity generation. In 1985, the ratio of installed capacity of hydel to thermal was 67% to 33%, but later, more power started to be generated thermally, lessening the electricity generation from hydel. As of 2016, the hydel-to-thermal ratio became 30:65, thus indicating a dilemma that Pakistan's power sector mainly relies upon thermal power plants that feed on oil and gas [57–59].

As of 30 June 2016, Pakistan had a total of 25,374 MW power generation capacity, out of which 16,619 MW i.e., 65.5% was harnessed from thermal power plants. Table 5 shows the various fuels utilized and percentage share of overall fuel consumed for electricity generation using thermal resources from 2010 to 2015 [21]. Pakistan is working on the three Regasified Liquefied Natural Gas (RLNG)-based power plants, which are expected to be functional as per the dates mentioned in Table 6. It has been observed that the public thermal power plants of Pakistan have been lacking in all of the key performance indicators (KPIs) for many years, and are functioning at below the rated capacities and efficiencies, contributing toward an overall higher cost of generation, since demand is increasing and the production has been lowered [60].

Table 5. Fuel consumption for thermal power production in tons of oil equivalent (TOE).

Fiscal Year	Unit	Gas	Furnace Oil	Diesel Oil	Coal	Total	Annual Growth Rate (%)
2010–2011	TOE % share	6,493,766 44.88	7,827,500 54.10	105,160 0.73	43,169 0.3	14,469,595 100	−8.22
2011–2012	TOE % share	6,732,876 47.45	7,206,839 50.79	203,072 1.43	46,800 0.33	14,189,587 100	−1.94
2012–2013	TOE % share	7,084,177 48.28	7,342,755 50.04	218,584 1.49	28.204 0.19	14,673,720 100	3.41
2013–2014	TOE % share	6,602,422 42.69	8,486,744 54.87	304,994 1.97	71,902 0.46	15,466,062 100	5.40
2014–2015	TOE % share	6,847,894 43.57	8,234,479 52.40	565,953 3.6	67.638 0.43	15,715,964 100	1.62

Table 6. New Regasified Liquefied Natural Gas (RLNG)-based projects under development in Pakistan.

Name of Project	Capacity (Gross)	Progress	Expected COD
Quaid-e-Azam Thermal Power Project, Bhikki	1180	52.30	20 December 2017
Haveli Bahadur Shah Power Project	1230.5	35.78	9 January 2018
Balloki Power Project	1223	38.1	30 January 2018

The projects under the supervision of the public sector mostly face delays of various natures, extending from the need for enormous funds to ecological problems as well as technical limitations such as geological reservations [48]. Such delays are not tolerable for thermal projects, but still due to procedural formalities, projects such as 747 MW gas-based Guddu Power Plant, Nandipur Power Plant, and coal-based Jamshoro units 5 and 6 have been delayed [58,61]. Table 7 provides additional details, for the years 2015 and 2016, of power plants integrated with NTDCs and K-EL systems along with their installed capacity and electricity generation. Table 8 shows a list of thermal power plants along with their capacities [21].

Table 7. Thermal installed capacity and electricity generation for 2015 and 2016. CPP: captive power producers, IPP: independent power producers, GWh: gigawatt hours, K-EL: K-Electric.

As of 30 June 2016		Installed Capacity (MW)		Electricity Generation (GWh)			
		2015	2016	2014–2015	2015–2016	Variation	%
GENCOs with PEPCO		5762	5762	13,300	14,490	1190	8.95
	K-EL Own	1874	1874	9319	10,323	1004	10.77
IPPs	Connected with PEPCO	8696	8696	44,369	44,591	222	0.5
	Connected with K-EL	252	252	1525	1421	104	6.82
CPPs/SPPs connected with K-EL		35	35	191	139	52	27.23

GENCO stands for power generation company, PEPCO stands for Pakistan Electric Power Company, CPP stands for captive power producers, SPP stands for small power producers, and K-E stands for K Electric.

Table 8. List of thermal power plants along with their capacities.

Sr. No.	Plant	Capacity (MW)	Net Capacity (MW)
1	Jamshoro Power Company Limited (GENCO-I):	2344	1974.56
2	Central Power Generation Company Limited (GENCO-II)	2431.7	2140.61
3	Northern Power Generation Company Limited (GENCO-III)	2291.65	2001.19
4	Lakhra Power Generation Company Limited (GENCO-IV)	150	93

2.3. Nuclear Power Source

Energy sustainability and environmental challenges have gained global attention in the transition to alternate energy sources from fossil fuel utilization. Nuclear energy, as part of the alternate resources for energy production, is deemed capable for the prevention of ecological deterioration and maintenance of energy security, so there have been worldwide investments in many nations in this domain. A total of 447 nuclear power plants are operational around the globe, while another 287 are going to be functional by 2035. Figure 10 shows the global expansion of the usage of nuclear energy continuously [62]. Nuclear power plants do not emit greenhouse gases, ensuring a carbon-free base load electrical energy. Also, they require a relatively smaller footprint on land, which can be observed from Table 9 [63].

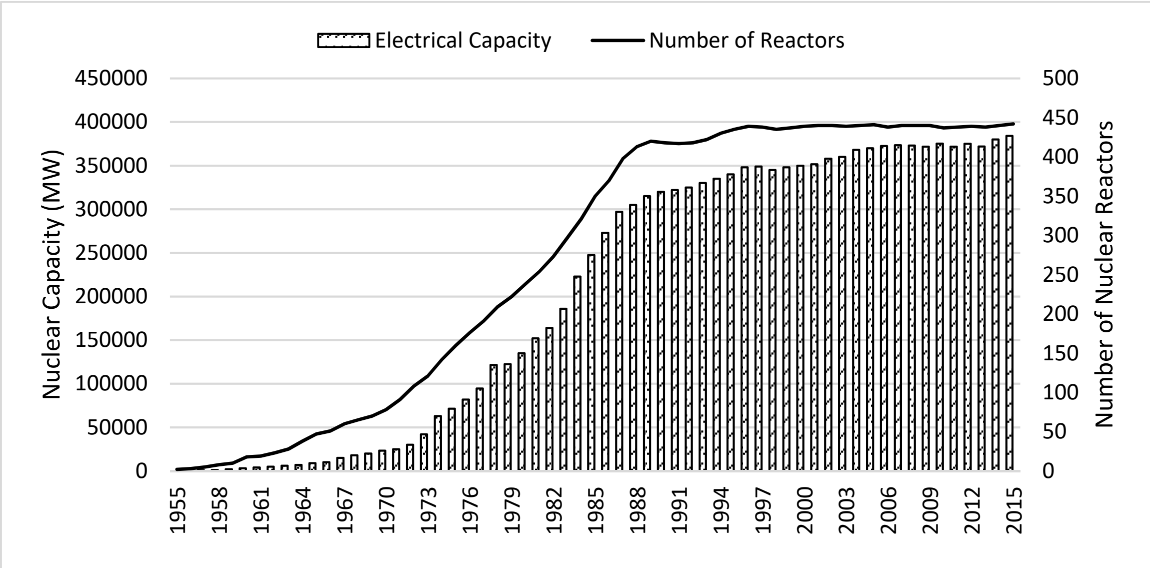


Figure 10. Global variation of functional nuclear plants with their total capacity (MW) between 1955–2015.

Table 9. Data and ranks of power generation sources based on sustenance, economy, and environmental effects. GHG: greenhouse gas, PV: photovoltaic.

Indicator (per TWh)	Coal		Natural Gas		Nuclear		Biomass		Hydro		Wind (Onshore)		Solar PV	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	value	Rank	Value	Rank
GHG emissions (t CO_2)	1,001,000	7	469,000	6	16,000	3	18,000	4	4000	1	12,000	2	46,000	5
Electricity cost ($ US)	100.1	4	65.6	1	108.4	5	111	6	90.3	3	86.6	2	144.3	7
Dispatchability	A	1	A	1	A	1	B	4	B	4	C	6	C	6
Land use (km^2)	2.1	3	1.1	2	0.1	1	95	7	50	6	46	5	5.7	4
Safety (fatalities)	161	7	4	5	0.04	1	12	6	1.4	4	0.15	2	0.44	3
Solid waste (t)	58,600	7	NA	1	NA	1	9170	6	NA	1	NA	1	NA	1
Radiotoxic waste	Mid	6	Low	3	High	7	Low	3	Trace	1	Trace	1	Trace	1
Weighted rank	-	6.0	-	2.0	-	1.3	-	6.7	-	3.3	-	2.3	-	5.3

The capacity of nuclear power of the world is expected to rise to 416 GW (2030) from 368 GW (2005) [64]. Globally, 6% of energy and 16% of electricity is harnessed from nuclear energy. The Organization for Economic Co-operation and Development OECD nations account for 55% of global uranium production. There was a rapid increase in global nuclear power consumption from 0.1% in 1970 to 7.4% in 1998, of which the major increase was observed in the 1980s [65].

Pakistan's electricity supply from nuclear resource is only 4.94% of the total supply; its provision takes place from Chashma Nuclear Power Plants I and II (CHASHNUPP I and II) and the Karachi Nuclear Power Plant (KANUPP) [66]. Two new units named Chashma-III and Chashma-IV have recently been constructed at the Chashma power plant site, each having a capacity of 350 MW. Two more units are also being constructed at the KANUPP site, which are expected to add 1100 MW to the national grid by 2020. The Pakistan Atomic Energy Commission (PAEC), in collaboration with the GoP, intends the establishment of power plants based on nuclear reactors by 2030, with a capacity of 8800 MW. Figure 11 shows the nuclear scenario of installed capacities by PAEC from 2012 to 2030 [66,67].

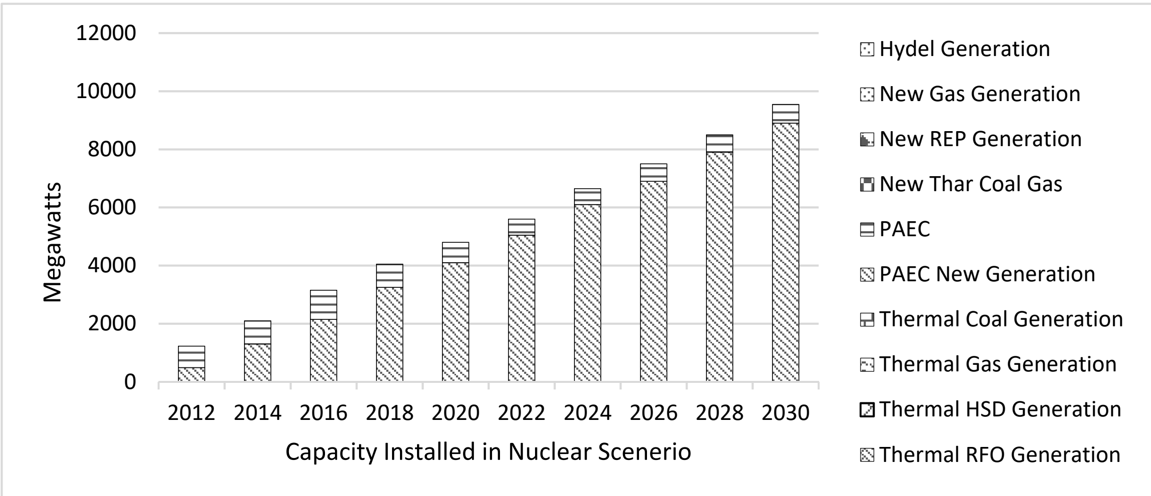
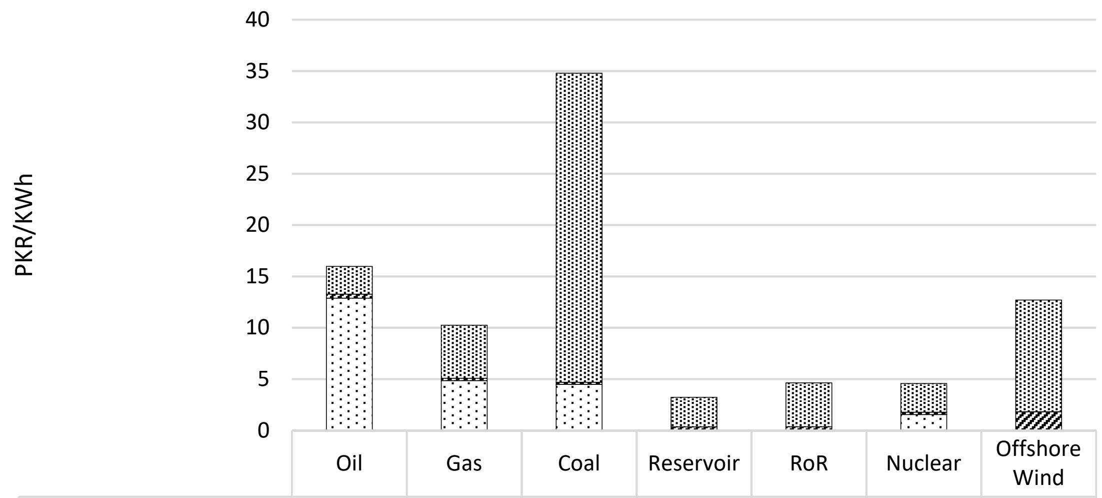


Figure 11. Nuclear scenario of installed capacities.

For 2015–2016, the NTDC-based nuclear plants had a steady installed capacity of 650 MW, which was the same as for the years 2014–2015, but the energy generation declined by 1142 GWh relative to 2014–2015 and stood at 3854 GWh for 2015–2016. No major power outage in the NTDC-based nuclear plants occurred, so they showed satisfactory performance during 2015–2016, except for one major issue i.e., the instability of the national electricity grid [21]. KANUPP has repeatedly faced shutdowns caused by fluctuations in the grid. Considering this menace, PAEC has worked on technical infrastructure improvement to support current and future nuclear power plants. Additionally, the facilities of in-house instructional and training centers covering all of the aspects of nuclear science and technology have been provided [16].

The cost of electricity from nuclear resources is greater than other sources, since the reactor fuel is expensive, and most of it is imported. Figure 12 shows the comparison of electricity costs from various sources. Among alternate energy sources, nuclear is the costliest, with a price of PKR 4.58/kWh [68]. With the intent to raise the share of nuclear power to 8.8 GW by 2030, Pakistan would require 1600 tons of uranium. For that, the exploration, mining, and reprocessing of uranium in the country has been promised by the concerned authorities [69]. Also, by taking care of safety and health-related dangers, the encouraging impacts on the environment and national economic sustainability will increase nuclear-based electricity production.



	Oil	Gas	Coal	Reservoir	RoR	Nuclear	Offshore Wind
Annualized Capital Costs	2.7	5.17	30.09	2.88	4.27	2.79	10.88
O&M Costs	0.39	0.24	0.2	0.35	0.36	0.24	1.83
Fuel Costs	12.89	4.85	4.5	0	0	1.55	0

Figure 12. Comparison of electricity costs from different sources.

2.4. Wind Power Source

The GWEC (Global Wind Energy Council) reported that over 75 countries across the globe are generating electricity from wind energy, out of which 21 are producing more than 1000 MW. The total global installed capacity has increased to nearly 238 GW due to an additional 40 GW of capacity in 2011. Table 10 shows the top 10 countries that have the most capacities for wind power [70].

Table 10. Countries with top 10 wind power capacities.

Country	Installed Capacities
China	62,634 MW
United States (USA)	46,919 MW
Germany	29,060 MW
Spain	21,674 MW
India	16,084 MW
France	6800 MW
Italy	6737 MW
United Kingdom (UK)	6540 MW
Canada	5265 MW
Portugal	4083 MW
World Total	237.7 GW

Harnessing energy from wind is one of the best choices amongst other sources of renewable energy due to its inexpensiveness, endlessness, and environmental friendliness [71]. Figure 13 shows the overall installed wind energy capacity from 1997 to 2014 [1]. The vision of 2030 is to increase the wind energy production up to 920 TWh with an increase rate of 3% [72], as compared to the 2.0% rate in 2007 [73]. The rate of increase was 20% and 6% in Germany and Denmark, respectively [74–76].

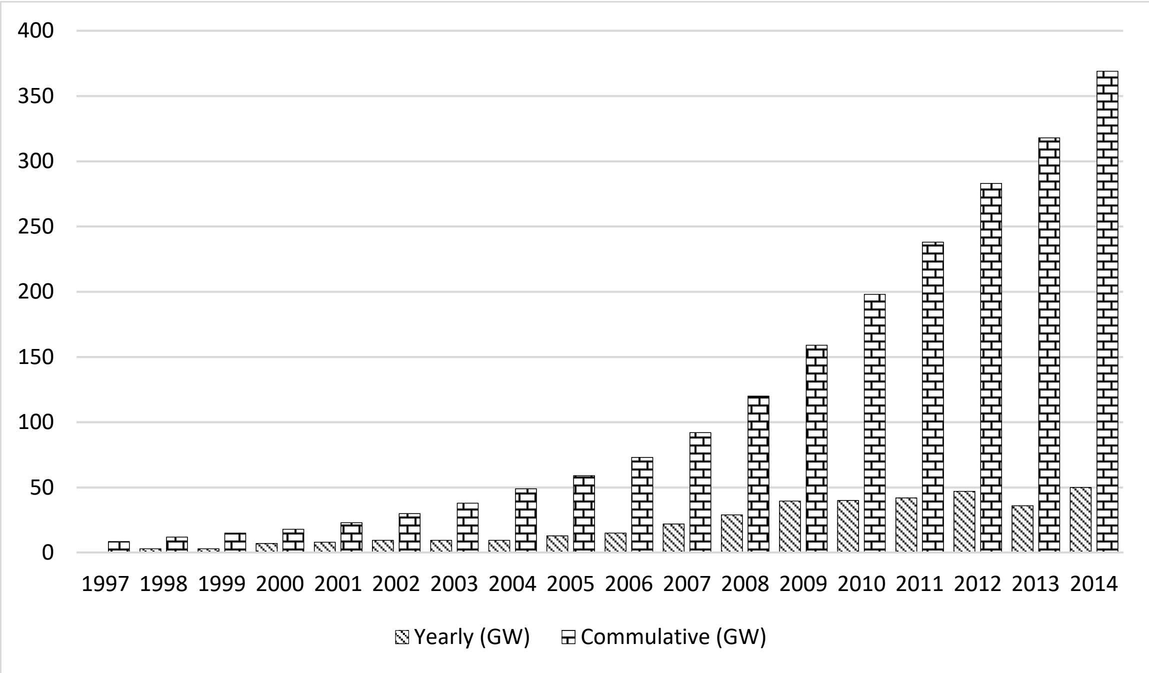


Figure 13. Overall installed wind energy capacity from 1997 to 2014.

Pakistan has enormous wind power resource potential. With the cooperation of the United States Agency for International Development (USAID), the Pakistan Meteorological Department, and the National Renewable Energy Laboratory (NREL); Pakistan's Alternative Energy Development Board (AEDB) established the very first wind map of the country, which provides a promising wind power potential of 346 GW in different regions of Pakistan [59]. Figure 14 shows that according to the survey report of the NREL, Pakistan is capable of overall 346 GW of power production from wind especially on the coastal areas of Sindh, where the velocity of wind is about 5–12 m/s, suggesting a potential of 20 GW from such wind sites [77]. A study was carried out for the wind potential of Pakistan for non-offshore areas, considering the assumption that 5 MW/km^2 is the installed capacity where the total land area of Pakistan is 877,525 km^2, and it was found out to be 132,000 MW. It has been summarized in Table 11 [78].

A number of sites for the installation of wind energy production, with the aid of private sector producers, are under consideration by the AEDB. Ghoro-Keti Bandar has a 25% capacity factor, and a mean wind velocity of 7 ms^{-1} at a height of 50 m; it is one of such sites with a power density of 400 W/m^2. Such sites can be utilized for commercially feasible wind farm projects. The evaluated capability for the power capacity of this site is more than 60 GW [79]. Nevertheless, the contribution of this site is insignificant, regardless of its considerable potential. From wind energy, the highest input of 106 MW was observed in 2014, producing only 0.2% of the total national electricity consumption [80]. Licenses have been granted to various companies by the AEDB. Several local and international companies have set up new projects. By 2030, the government is expecting a minimum of 30 GW capacity from wind resources [81].

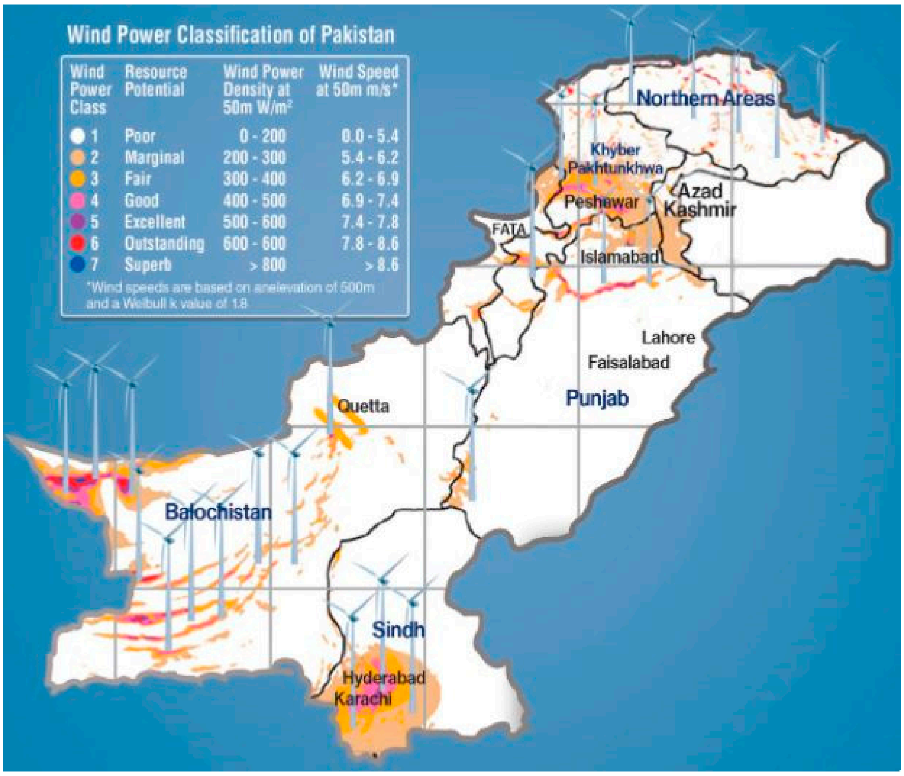


Figure 14. Wind power classification of Pakistan. (1.96", 1.96).

During the financial year 2015–2016, an addition of 50 MW of wind power has been done in the system of the NTDC, for a total wind-based power of about 306 MW in the system. The energy generated by wind-based power plants during the period 2015–2016 has been noted as 732 GWh [21].

Table 11. Wind resource in Pakistan at 50 m from good to excellent.

Wind Resource Quality Scale	Wind Class	Power (kW/m^2)	Speed (m/s)	Area (km^2)	Capacity (GW)
Good	4	0.4–0.5	6.9–7.4	18,106	90.53
Very Good	5	0.5–0.6	7.4–7.8	5218	26.09
Excellent	6	0.6–0.8	7.8–8.6	2495	12.48
Excellent	7	>0.8	>8.6	543	2.72
Total				26,362	131.8

2.5. Solar Power Source

At the conclusion of 2015, the global installed capacity of solar-powered electricity approached 227 GW, producing 1% of global electricity. The regions with relatively less solar resources i.e., Europe and China, have major solar installations, whereas those with more solar potential i.e., Middle East and Africa, are unexploited.

In the last 10 years, Germany has been leading solar photovoltaic (PV) installed capacity, and it is trailed by China, Italy, Japan, and the United States. Current electricity infrastructure can hinder the development of solar capacity, especially in novel solar markets. The renewable technologies of solar PV greatly depend on rare earth elements that may also have a supply interruption risk along with unsustainable mining procedures. Figure 15 shows the top solar PV capacity countries in 2014 and additions in 2015, where China has the highest capacity of 44 GW. After the addition of capacity in 2015, the total capacity became 59.2 GW [20].

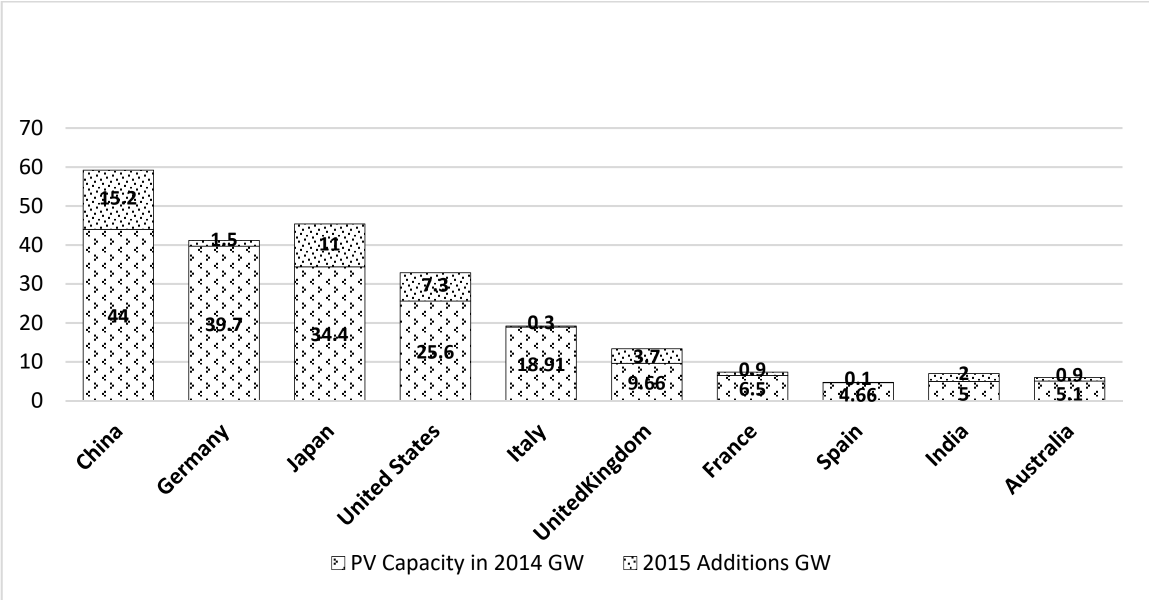


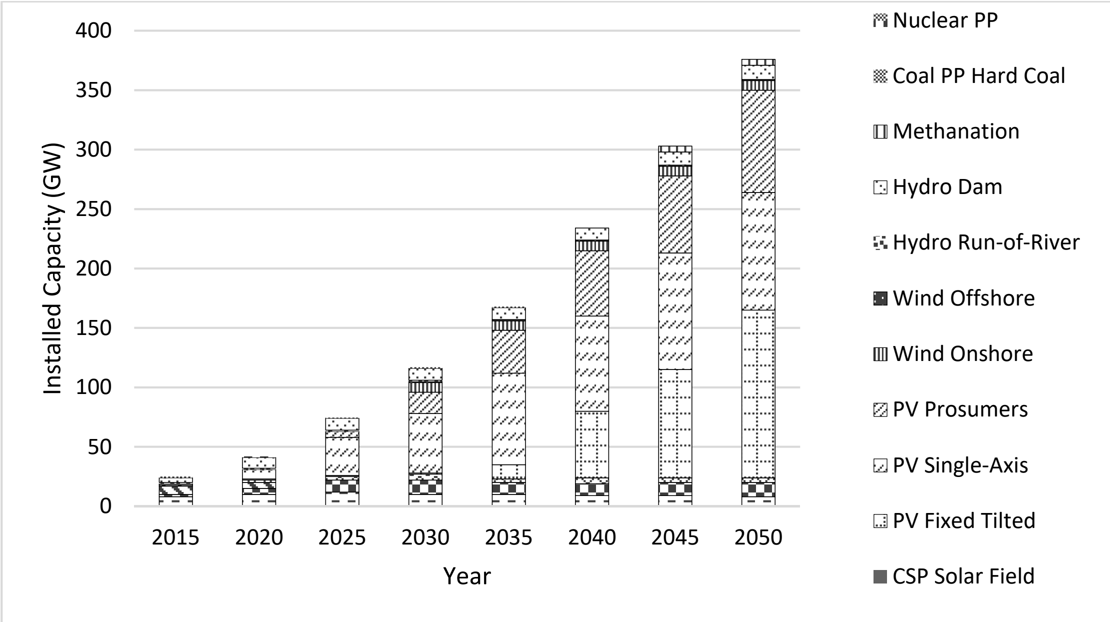
Figure 15. Top solar photovoltaic (PV) capacity in 2014 and additions in 2015.

On average, 5–7 kWh/m^2 irradiance per day is received on 95% of the land of Pakistan. The expansive deserts in Sindh, Punjab, and Balochistan can provide sites for solar PV-based power plants installation where the sunlight strikes 2300–2700 h/year [14,48]. In a recent 2018 study regarding Pakistan's energy transition toward 100% renewable energy by 2050, the domination of solar PV in the installed capacities of a completely renewable system by 2050 has been predicted, considering its lower costs and the tremendous state of solar resources. Figure 16 shows the collective installed capacity from all of the renewable resources by 2050, where the above-mentioned prediction can be observed [82]. The cost of off-grid solar PV has been calculated in a study for electrifying a household, which was calculated to be PKR 14.8/kWh less than the traditional supply [83].

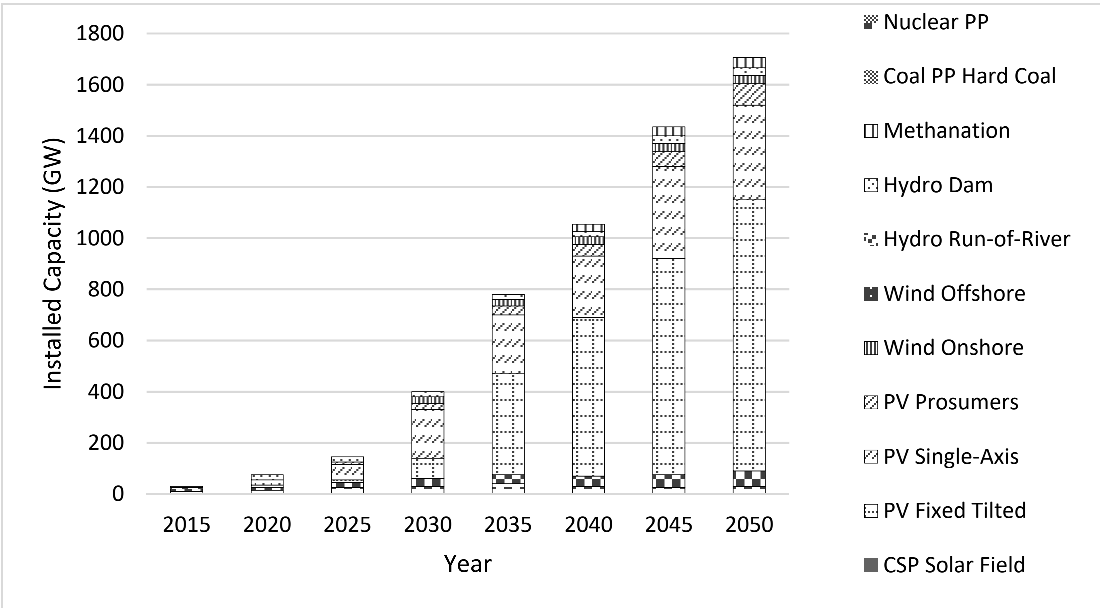
In 2012, with funds from Japan under a project in Islamabad that aimed to introduce solar-based clean energy, the first solar-based electricity generation plant was established. Due to this project, two 178-kW capacity solar PV power plants were established in the vicinity of the Planning Commission of Pakistan and Pakistan Engineering Council. Pakistan's first solar park, which was called Quaid-e-Azam Solar park, has been constructed in Bahawalpur, which has a capacity of 1000 MW. Similarly, with the cooperation of private energy sector companies and China's aid, solar-based power generation plants are being installed in Kashmir, Punjab, Sindh, and Balochistan provinces [84]. Table 12 shows the solar PV projects that are under development along with their capacity and estimated Commercial Operation Dates (COD) [15].

Of the total primary energy supply, approximately 10% is utilized for water heating; thus, 100–500 W/unit solar PV capacity systems have been planted [19]. Considering this, the number of imported solar water heaters rose to 16,715 from 260 between 2007–2013 phases. Renewable energy development organizations such as the AEDB, Pakistan Council Renewable Energy Technologies (PCRET), and private energy sectors have solar PV-based generation capacities of 200 kW, 80 kW, and 500 kW, respectively [85].

Solar PV systems are becoming more and more resourceful due to the research and development of PV technology, which is helping PV materials and PV inverters become exquisitely efficient, rendering the PV systems economical. However, time and huge investments are necessary for such commercial end products [86]. To make the public acquainted with solar technology, the provision of several energy-extraction technologies to 100 homes per province has been made for applications such as water portability, lighting, heating, and cooking. Keeping these advancements in view, the yearly power generation using solar technology is expected to be 1600 GW, and it has an ability to be a main power generation source in the impending future [87,88].



(**a**)



(**b**)

Figure 16. Collective installed capacity from all of the renewable resources by 2050 for (**a**) the power and (**b**) integrated scenarios.

During 2015–2016, 300 MW of solar energy projects has been added to the NTDC's network. For a rise of 204 GWh for the energy generated through solar through this period, the total energy through solar has been recorded to be 230 GWh [21].

Table 12. Solar PV projects under development with their capacities and estimated COD.

Sr. No.	Company	Project Capacity	Location	Expected COD
1	Access Solar Pvt. Ltd.	11.52	Pind Dadan Khan, Punjab	March-2018
2	Bukhsh Solar (Pvt.) Ltd.	10	Pind Dadan Khan, Punjab	December-2017
3	Integrated Power Solution	50	Nooriabad, Sindh	June-2018
4	Jafri & Associates	50	Nooriabad, Sindh	June-2018
5	Solar Blue Pvt. Ltd.	50	Nooriabad, Sindh	June-2018
6	Safe Solar Power Pvt. Ltd.	10	Bahawalnager, Punjab	December-2017
7	Access Electric Pvt. Ltd.	10	Pind Dadan Khan, Punjab	March-2018
8	R.E. Solar I Pvt. Ltd.	20	Dadu, Sindh	March-2018
9	R.E. Solar II Pvt. Ltd.	20	Dadu, Sindh	March-2018
10	Jan Solar (Pvt.) Ltd.	10	Sultanabad, RYK, Punjab	March-2018
11	Janpur Energy Limited	10	Mehmood Kot, Muzafargarh, Punjab	March-2018
12	Blue Star Hydel Pvt. Ltd.	1	Pind Dadan Khan, District Jehlum, Punjab	December-2017
13	Blue Star Electric Pvt. Ltd.	1	Pind Dadan Khan, District Jehlum, Punjab	December-2017
14	Siddiqsons Energy Karachi	50	Chakwal, Punjab	March-2018
15	Harappa Solar (Pvt.) Ltd.	18	Harappa, District Sahiwal, Punjab	December-2017
16	AJ Power (Pvt.) Ltd.	12	Adhi Kot, District Khushab, Punjab	December-2017
17	Adamjee Power Generation Pvt. Ltd.	10	Norsar, Bahawalnager, Punjab	December-2018
18	Forshine (Pakistan)	50	Gharo, Thatta, Sindh	June-2019
19	ET Solar (Pvt.) Ltd.	50	Fateh Jhang Road, District Attock, Punjab	December-2018
20	ET Solar (Pvt.) Ltd.	25	Gharo, Thatta, Sindh	December-2018
21	Act Solar (Pvt.) Ltd.	50	Sindh Province	December-2018
22	Crystal Energy (Pvt.) Ltd.	2	Sambrayal, District Sialkot, Punjab	May-2019
23	Asia Petroleum Ltd.	30	Punjab Province	December-2018
24	First Solar (Pvt.) Ltd.	2	Makhayal, Kalarkahar, District Chakwal, Punjab	December-2018

2.6. Geothermal Power Source

In the world's primary energy consumption, only a small portion is contributed by geothermal energy i.e., less than 1%. In 2015, the total geothermal capacity of the world rose to 13.2 GW due to an additional 315 MW of capacity installed in 2018. The geographical locations of geothermal-based power plants, which produce 72% of the total global geothermal capacity, are along Pacific Rim hot spot features or the tectonic plate borders. An unbalanced percentage of 43% for installed capacity is located on regions or island nations, and is suitable for applications such as heating, power production, and the storage of heat in ambient situations [20]. Figure 17 shows the geothermal installed capacity around the world [89].

Geological studies suggest that since Pakistan is located at a junction of tectonic plates, it has plentiful resources of geothermal energy with a tendency to be utilized to keep the energy supply on par with the demand of the country. This opinion is based on the proper buildout of alteration zones and fumaroles across the country, the presence of hot springs, and the signs of quaternary volcanism [90]. Unfortunately, there is no installed geothermal power plant in the country, making this sector the least exploited among all of the other energy resources.

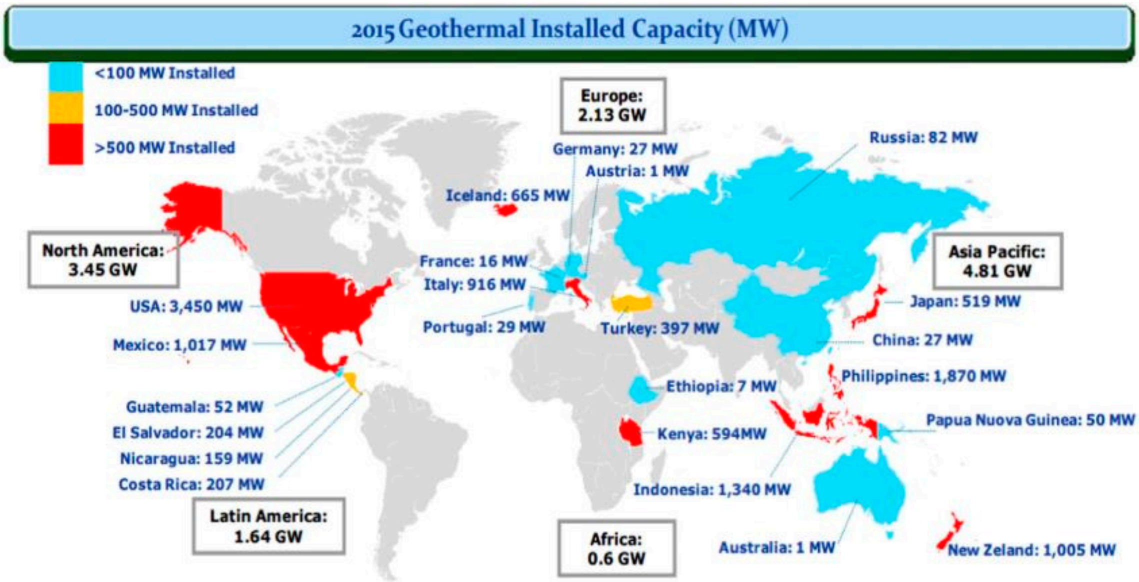


Figure 17. Geothermal installed capacity around the world. (1.96", 1.96).

In Pakistan, geothermal areas are classified into three main zones: the Chaghi volcanic arc, Himalayan collision zone, and Indus basin margin zone, as seen in Figure 18 [91]. The surface hot water of the Himalayan collision zone has a temperature of 90 °C. In the southernmost area of foredeep, the gas and Giandari oil reservoir have a peculiarly elevated thermal gradient i.e., 4.1 °C/100 m. Similarly, high gradients of about 3.0–3.49/100 m have been recorded at the gas and oil wells of Mart and Sui. Thermal springs are present in Uch and GarmAb, which are located at the base of Bakkur, Taunsa, Mari Hills, and ZindaPir, and can serve as geothermal energy. Talking about the Indus basin zone, the gas and oil fields of Lakhra in the south Kirthar zone also shows a high thermal gradient of 3.3 °C/100 m, while those of Sari and Karachi have a geothermal gradient of 3 °C/100 m. A cluster of hot springs is present in ManghoPir and the Karsaaz area of Karachi, presenting a potential of geothermal energy. The volcanic arc in the Chaghi zone has less thermal springs than the other two zones, which are linked with the Sinjrani volcanics of Koh-i-Sultan [91,92]. Depending upon the temperature ranges, geothermal resources can be divided into categories for application, which are shown in Table 13 [93].

As mentioned earlier, Pakistan has not exploited much of its geothermal potential. Less than 10% of hot springs waters are utilized for residential and commercial purposes on a very small scale. All of the remaining spring water becomes a part of rivers and the sewer system without being used [94]. The apparent reason for not capitalizing on the geothermal resources in Pakistan is lack of data [92], which can be countered with detailed geological analysis by the use of new technologies. Currently, research is being done in the domain of Hard Dry Rock (HDR) geothermal energy, which has shown promising results, but still more detailed geoscientific information is required in order to implement it [95].

Figure 18. Map showing areas of geothermal activity and some important geological and tectonic features of Pakistan. (1.96", 1.96).

Table 13. Applications for the geothermal resources of Pakistan.

Location	Resource Type	Temperature	Applications
Chaghi	Hydro Geothermal	200–300 °C	• Flash and dry steam power plant • Hydrogen production
Mutazabad	Hydro Geothermal	185–230 °C	• Binary power plant • Ethanol, biofuels production
Tatta Pani, Tato, Kotli	Hydro Geothermal	100–200 °C	• Binary power plant • Fabric drying • Refrigeration and ice making • Lumber drying • Cement and aggregate drying • Heating, ventilation and air conditioning HVAC • Pulp drying
Karachi	Hydro Geothermal	70–145 °C	• Pulp and paper processing • Fruit and vegetable drying • Soft drink carbonation • Green housing • Food processing • Concrete block curing
Chakwal	Hydro Geothermal	60–90 °C	• Aqua culture • Mushroom culture • Biogas production • Heat pump HVAC

2.7. Biomass Power Source

Biomass, being the fourth biggest global energy resource, offers 10% of the world's primary energy, and can be gaseous, liquid, or solid phase. It comprises various crop remains from agriculture, forest residues, ordure, and industrial and municipal waste. In 2011, the total installed capacity of biomass-based energy rose to 72 GW due to a 9% increase in electricity generation [96].

Pakistan can take advantage of being a large producer of many crops such as sugarcane, wheat, rice, cotton, oilseeds, grains, and pulses, by extracting biomass and biofuels from their leftovers, while in parallel providing for the food demand without any extra cost. Also, Pakistan has an immense capability of bagasse utilization for power production, since the country is the fifth largest sugarcane producer [97]. Unfortunately, this beneficial and existing renewable resource has not yet been optimally used in Pakistan. According to statistics performed by the United Nations in 2015, bagasse production per annum was 19,886 metric tons in Pakistan [84].

During 2015–2016, there was an increase of about 63 MW in the generation of power from bagasse-based power plants, for a total of about 146 MW in the NTDC's system. The energy generated by bagasse-based power plants during the FY 2015–2016 has been noted as 547 GWh [21].

3. Biomass Resources Potential in Pakistan

Biomass potential has been endorsed worldwide such that many countries have implemented and used biomass for energy production. Table 14 shows biomass resources, their possible utilization, and technologies for conversions. A comparison between the biomass potential of various countries and production has been made in Table 15.

Table 14. Biomass resources, their possible utilization, and technologies for conversions.

Biomass Resource	Present Utilization	Potential Conversion Technology	Potential End-Use as an Energy Product	Reference
Wheat straw	Paper products, domestic heating	Gasification	Off-grid electricity generation, Synthetic Natural Gas SNG	[98]
Rice husk	Pet food fiber, making of activated carbon, fuel	Gasification and combustion	substitute household energy, off-grid energy generation	[99]
Bagasse	fuel and bioethanol production	Fermentation and hydrolysis	Renewable motor fuel	[100]
Poultry/cow manure	Biogas and fertilizer production	Composting, fermentation	Biogas, household fuel, methane	[97]
Forestry residues and wood	Fuel, biomass production, fertilizer	Grinding and saw-milling	Fuel wood	[101]
Municipal solid waste	Strengthening concrete, Bottom ash production	Pyrolysis, sieving, combustion	Methanol, methane and syn gas production	[15]

Table 15. Biomass production and energy potential in various countries.

Sr. No	Countries	Biomass Production Mt Yr^{-1}	Biomass Energy Potential	References
1	Nigeria	145.62	1958.94 *PJ	[102]
2	Turkey	526 (2010)	16,920 ktoe	[22,103]
3	Malaysia	160	16,920	[22]
4	China	57.4 *TWh	14,888	[104,105]
5	Bangladesh	80.4	3447 estimated value	[106]
6	Pakistan	95.3 KWh billion	91,772 *ktoe	[101,107]
7	Jordan	5.83	313.14 *MCM	[108]
8	World	493 *TWh	573 *EJ	[29,107,109]

*PJ: Petajoule, *TWh: terawatt-hour, *Ktoe: kilotonne of oil equivalent, *MCM: Million cubic meters, *EJ: Exajoule.

Pakistan has an abundant amount of waste produced in the form of bagasse, poultry waste, and municipal waste. This paper will highlight the importance of the potential usage of these wastes as biomass energy sources [110–112].

3.1. Bagasse

The industrial refinement process of sugarcane produces by-products along with sugar that include molasses, press cake, and bagasse, which make up 40% of the weight out of the total crushed sugarcane. It has been observed that each ton of processed sugarcane produces 200–300 kg of bagasse [113,114]. Therefore, to cope with the energy requirements and produce surplus electricity, a continuous refinement process is desirable, thereby contributing as a renewable resource [110,111,115]. Generally, 0.173 tons of oil (about \$80/ton) and 0.263 tons of coal (about \$55/ton) are comparable to one ton (about \$15/ton) of bagasse [116]. The cogeneration plant is often located near the sugar industry to save the environment from dust pollution that could otherwise be caused during transportation. Relative to the combustion of fossil fuels, cogeneration effectively lowers the production of greenhouse gases. It is advisable that bagasse is used for the cogeneration because if it is not used, it starts decaying by itself and producing methane gas, which is 27 degrees more hazardous for the ozone layer than CO_2 [117].

Pakistan is a large sugarcane producer, with several mills of sugar located in Punjab and Sindh. Pakistan has a potential of about 3000 MW or even more power production from sugar mills, as shown in Figure 19 [83]. Unfortunately, the available bagasse resource has not been optimally employed due to technological constraints such as the low-pressure boilers and low-efficiency steam turbines that bound the sufficient amount of electricity production, so it can only meet the mill's own demand [118].

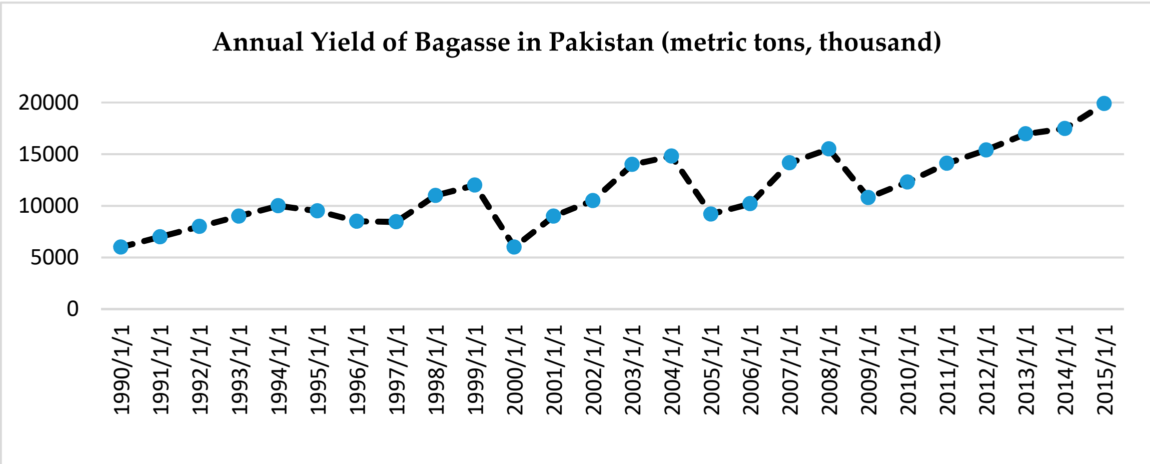


Figure 19. Bagasse yield per annum in Pakistan from 1990–2015.

Ventures for biomass visions in Pakistan have been promised by PCRET [14]. The significance and necessity of bagasse-based fuels in the country have also been emphasized by the AEDB [119]. Some crucial steps have been taken by the National Electric Power Regulatory Authority (NEPRA) to determine the tariff for future power projects based on bagasse-based cogeneration to intrigue customers and investors [120].

3.2. Poultry Waste

Pakistan has a well-established industry of poultry [112]. The GoP renounced sales and income tax import amenities, making the poultry business successfully operational in the market. As of now, the poultry industry shares 1.26% and 5.76% of the complete gross domestic product (GDP) and total production from agriculture, respectively [121].

To date, Pakistan has more than 25,000 poultry farms striving to fulfil the country's protein demand in the forms of eggs, meat, and for the further reproduction of poultry animals, and this number is continuously rising. Consequently, a tremendous volume of poultry waste is left over [121,122]. Organic matter from poultry waste is not consumed in any productive way, and is usually pronounced as waste [123], but in reality, it is an advantageous source of energy with vast applications [124–127]. Biogas generation can be carried out with organic matter such as feathers, blood, manure, and spilled feed, which can be utilized for electricity generation [128,129]. The anaerobic digestion process of poultry waste produces biogas [123,130]. Anaerobic digestion also produces a nutrient rich by-product called biodigestate, which can be consumed as a fertilizer [131].

Pakistan can make use of the factory's process flow diagram to generate power using poultry waste, as shown in Figure 20. From 2011 to 2015, the amount of poultry waste produced has been reported in Figure 21. A huge amount of manure, feathers, feet, blood, spilled feed, and other inedible organs are disposed of. Proper poultry waste management using biomass energy conversion technologies could guarantee approximately 10,335 m^3 of biogas, which in turn would be capable of generating about 300 MWh per day. The conversion process from poultry waste to biogas also leaves biodigestate as a by-product, which could serve as a biofertilizer [132].

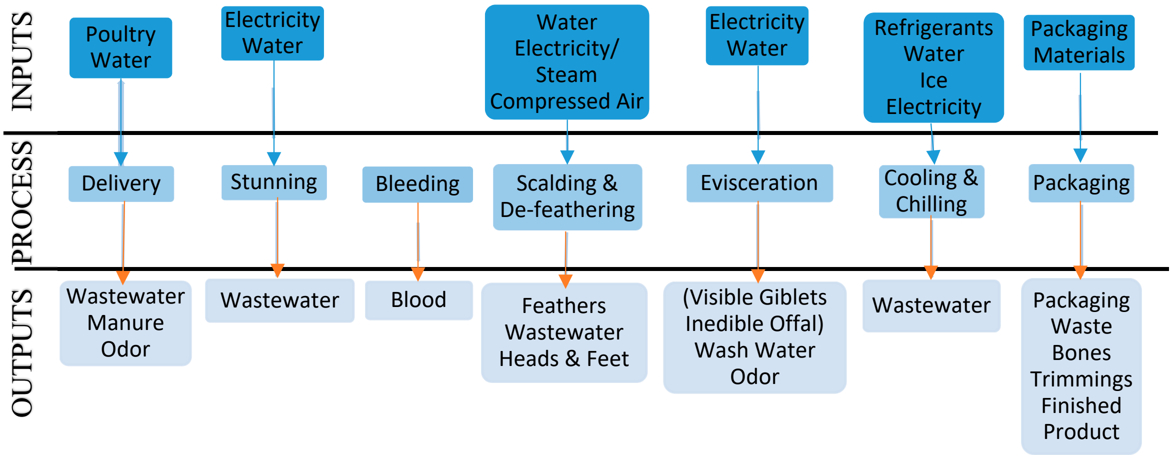


Figure 20. Factory's process flow diagram to generate power using poultry waste.

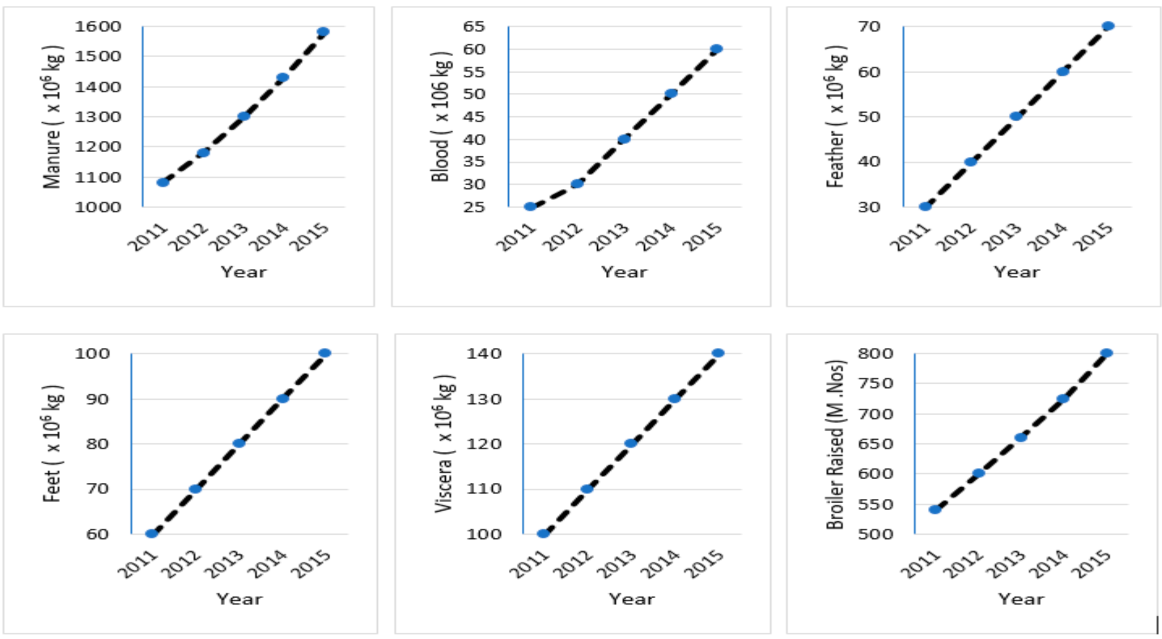


Figure 21. Waste produced in the poultry farms from 2011 to 2015.

3.3. Municipal Waste

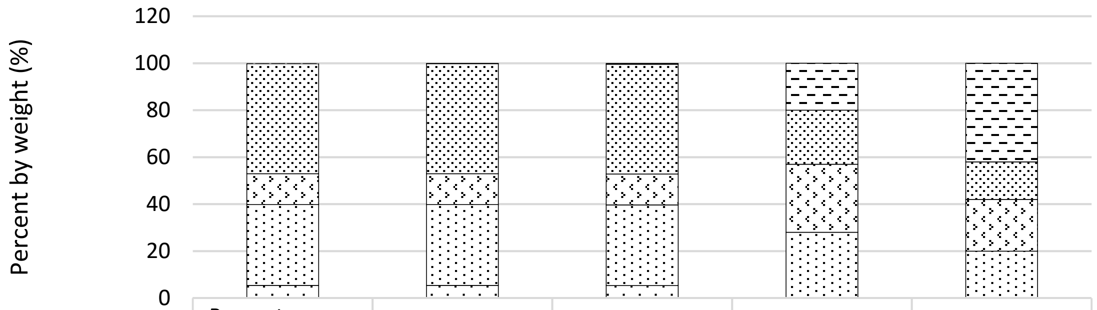
Anything that is regarded as useless, worthless, or in excess is called waste. All of the waste gathered from domestic, commercial, and industrial sources by private and public authorities is called municipal solid waste (MSW) [133]. A waste-management process and the relevant systems are organized programs that are established for the disposal of waste, recycling, reuse, composting, and incineration. They are also an important way to conserve resources and protect the environment [134]. In underdeveloped and developing countries, MSW is an extremely ignored factor [135]. Environmental pollution and health hazards are a result of the poor management of waste [136]. The burden of emissions and resources depletion that is placed on the environment can be highly reduced by appropriate waste management strategies [137,138]. Biogenic MSW is considered a source for renewable energy by the United States (US) Environmental Protection Agency because it would otherwise be dumped into landfills [139].

In Pakistan, millions of tons of diverse kinds of wastes are produced annually that pose health and other environmental hazards. Even though the private and public sectors have been long conscious of the waste disposal crisis, they are unacquainted with the possible use of MSW for electricity production to reduce the country's power crisis. In Pakistan, a significant barrier to the promotion of such renewable energy projects is the deprivation of the suitable recognition of the management of diverse waste types and associated power production technologies [140]. For 2014 and 2016, the amount of waste produced in Pakistan's foremost cities are shown in Table 16, demonstrating that a gross total of 32.3 megatons (MT) per year is generated [141].

Table 16. Quantity of municipal solid waste (MSW) generated in the major cities of Pakistan in 2014 and 2016.

City Corporation	2014			2016		
	Population (Million)	Generation Rate (kg/Capita/Day)	Total Quantity (MT/Year)	Population (Million)	Generation Rate (kg/Capita/Day)	Total Quantity (MT/Year)
Karachi	14	0.572	2.92	22.825	0.572	4.765
Lahore	0	0.151	0.507	10.335	0.75	2.835
Faisalabad	2.7	0.53	0.522	3.675	0.45	0.604
Hyderabad	9.2	0	0	2.99	0.8	0.873
Peshawar	0	0	0	1.785	0.38	0.248
Gujranwala	1.85	1.08	0.73	2.195	1.08	0.865
Quetta	0	0	0	1.14	0.378	0.157
Multan	2.06	0.53	0.402	1.95	1.53	0.377
Sialkot	0	0	0	0.58	0.313	0.067
Islamabad	0	0	0	0.74	0.53	0.143
Rawalpindi	2.5	0.21	0.192	1.77	0.21	0.136
Kharian	0.035	2.57	0.033	0	0	0
Lala Musa	1	0.027	0.01	0	0	0
Sukkur	0	0	0	0.585	0.45	0.096
Total	33.345	5.67	5.316	50.59	6.443	11.166
Remaining urban area	0	0	0	23.11	0.84	7.086
Rural area	0	0	0	114.32	0.30	12.518
Subtotal	33.345	5.67	5.316	188.02	7.583	30.764
Hazardous waste		0	0	0	0	1.538
Gross total			5.316			32.3

Figure 22 shows that the use of biochemical processes of MSW will cause a reduction from 0.1% to 0.03% in the share of imported electricity [50]. The energy attained by the biochemical processing of MSW may contribute up to 0.07%. The thermal chemical processing of MSW contributes 0.34%, whereas the contribution of gas, oil, nuclear and hydro, and coal are 46.74%, 34.34%, 13.14%, and 5.34%, respectively, as shown in Figure 22. The share of supply from gas, nuclear and hydro, oil, and coal can be reduced to 0.13%, 0.17%, 0.45%, and 1.11%, respectively, with the treatment of MSW with thermal chemical processing. The dependency on imported energy will be reduced by using energy from treated MSW [141,142]. Hence, an improved environment and development of the economy also rely on waste to energy conversion, along with other factors.



	Present energy consumption of Pakistan	Present study (Bio-Ch.P)	Present study (Th-Ch.P)	2015	2013
MSW	0	0.07	0.34	0	0
Biomass	0	0	0	20	42
Imported elec.	0.1	0.03	0	0	0
Gas	46.8	46.8	46.74	23	16
Hydro/Nuclear	13.2	13.2	13.14	29	22
Oil	34.4	34.4	34.34	28	20
Coal	5.4	5.4	5.34	0	

Figure 22. Biomass/MSW contribution in total energy supply.

4. Current and Future Scenarios of Biomass Applications in Pakistan

This section discusses the current and future elements involved in the biomass applications in Pakistan. Different energy consumption sectors have been discussed in terms of biomass power source applications.

4.1. Power Production

Biomass is considered to have great capabilities as an important and available renewable energy source for developed, developing, and underdeveloped cTuntries. Pakistan is still in the experimental stage for using biomass for power production. In the NTDC's system, an increase in power generation of about 63 MW for a total of about 146 MW from bagasse-based power plants has been observed during 2015–2016, having 547 GWh of energy. Three companies with an aggregate capacity of 99.0 MW applied during this span for the complete approval of an upfront tariff for bagasse-based power production schemes, as mentioned in Table 17 [21].

Pakistan lacked any biomass/bagasse-based power plants until 2014. Power stations, namely Jamal Din Wali-II, Jamal Wali-III, and Rahim Yar Khan Mills, which are located in Rahim Yar Khan (Punjab), started their operation from 2015, and Chiniot Power, which is located in Chiniot (Punjab), started its operation from 2016. The installed capacity in MW and electricity generation in gigawatt hours GWh, as recorded on 30 June 2016, have been listed in Table 18 [21].

According to the NEPRA 2016 state of industry report, the estimated costs and commercial operation dates (COD) of in-operation and under construction biomass energy projects are shown in Table 19, whereas those for future biomass/bagasse projects are shown in Table 20, in which most of the projects are in the Letter of Intent stage, and will probably be completed by the end of 2018 [21]. According to the Renewable Energy Policy of 2006, various electricity generation projects involving biomass/bagasse were given licenses for generation, keeping in view their fuel type and technology. Table 21 shows a list of generation licensees for bagasse/biomass. These projects are majorly based on bagasse fuel, and their technologies make use of steam turbines. In Pakistan, the companies that are captive power producers (CPPs) using biomass/bagasse are 35 in number. Shakarganj Energy (Pvt.) Limited is the only Isolated Generation Company (IGC) for energy production using biomass [21].

Table 17. Upfront tariff for new bagasse-based cogeneration projects in Pakistan.

Sr. No.	Company	Installed Capacity (MW)
1	Chanar Energy Limited	22
2	Al-Moiz Industries Limited	36
3	Thal Industries Corporation Limited	41
	Total	**99**

Table 18. Installed capacity (MW) and electricity generation in gigawatt hours (GWh) of bagasse/biomass power stations as of 30 June 2016.

Power Station	Fuel		Installed Capacity (MW)					Electricity Generation (GWh)				
	Primary	Alternate	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Jamal Din Wali-II	Bagasse + Biomass		0	0	0	26	26	0	0	9	163	159
Jamal Din Wali-III	Bagasse + Biomass		0	0	0	27	27	0	0	0	132	151
Rahim Yar Khan Mill	Bagasse	Bagasse	0	0	0	30	30	0	0	0	32	77
Chiniot Power	Bagasse	Bagasse	0	0	0	0	63	0	0	0	0	169

Table 19. Status of existing projects (in operation and under construction).

Sr. No.	Name of Project	Capacity (MW)	COD/Expected COD	Estimated Cost (US $ Million)	Status
1.	JDW Sugar Mills Limited (Unit-II)	26.35	June 2014	26.26	Operational
2.	JDW Sugar Mills Limited (Unit-III)	26.35	October 2014	26.26	Operational
3.	Chiniot Power Limited	62.40	November 2014	62.19	Operational
4.	RYK Mills Limited	30	March 2015	29.90	Operational
5.	Hamza Sugar Mills Limited	15	—	14.95	Under Construction

Table 20. Future biomass/bagasse-based projects.

Sr. No.	Name of Project	Capacity (MW)	COD/Expected COD	Estimated Cost (US $ Million)	Status
1.	Layyah Sugar Mills Limited	41	2017	40.86	EPA/IA Signed
2.	Alliance Sugar Mills Limited	30	2017	29.90	LOI Stage
3.	Safina Sugar Mills Limited	20	2017	19.93	LOI Stage
4.	Almoiz Industries Limited	36	2017	35.88	LOI Stage
5.	Etihad Power Generation Limited	76.40	2017	76.13	LOI Stage
6.	Shahtai Sugar Mills Limited	32	2017	31.89	LOI Stage
7.	Chinar Energy Limited	22	2017	21.93	LOI Stage
8.	RYK Energy Limited	25	2018	24.92	LOI Stage
9.	Sheikhoo Power Limited	30	2018	29.90	LOI Stage
10.	Indus Energy Limited	31	2018	30.89	LOI Stage
11.	Hamza Sugar Mills Limited (Unit-II)	30	2018	29.90	LOI Stage
12.	Hunza Power (Pvt.) Limited	49.80	2018	49.63	LOI Stage
13.	Bahawalpur Energy Limited	31.20	2018	31.09	LOI Stage
14.	Mirpur Khas Energy Limited	26	2018	25.91	LOI Stage
15.	Faran Power (Pvt.) Limited	26.50	2018	26.45	LOI Stage
16.	Ittefaq Power (Pvt.) Limited	31.20	2018	31.09	LOI Stage
17.	Mehran Energy Limited	26.50	2018	26.41	LOI Stage
18.	Lumen Energia	12	2018	22.62	LOI Stage

Table 21. List of generation licensees bagasse/biomass power projects under the renewable energy policy of 2006.

Sr. No.	Company and Location	Installed Capacity (MW)	Fuel Type	Technology
1.	SSID Bioenergy Limited, Mirpur Khas, Sindh	12.00	Bagasse	Steam Turbine
2.	Lumen Energia (Pvt.) Limited, Jhang, Punjab	12.00	Biomass	Steam Turbine
3.	Shakarganj Mills Limited-II, Jhang, Punjab	12.00	Bagasse + Furnace Oil	Steam Turbine
4.	Pak-Ethanol (Pvt.) Limited, Tando Muhammad Khan, Sindh	9.132	Biogas	Gas Engine
5.	JDW Sugar Mills Limited, Rahim Yar Khan, Punjab	26.35	Bagasse + Biomass	Steam Turbine
6.	JDW Sugar Mills Limited, Ghotki, Sindh	26.35	Bagasse + Biomass	Steam Turbine
7.	Chiniot Power Limited, Chiniot, Punjab	62.40	Bagasse	Steam Turbine
8.	RYK Mills Limited, Rahim Yar Khan, Punjab	30.00	Bagasse	Steam Turbine
9.	Hamza Sugar Mills Limited, Rahim Yar Khan, Punjab	15.00	Bagasse	Steam Turbine
10.	Alliance Sugar Mills (Pvt.) Limited, Ghotki, Sindh	30.00	Bagasse	Steam Turbine
11.	Ansari Powergen Company (Pvt.) Limited, Tando Muhammad Khan, Sindh	30.00	Bagasse	Steam Turbine
12.	TAY Powergen Company (Pvt.) Limited, Tando Allayar, Sindh	30.00	Bagasse	Steam Turbine
13.	Bandhi Powergen Company (Pvt.) Limited, Shaheed Benazirabad, Sindh	30.00	Bagasse	Steam Turbine
14.	Etohad Power Generation Limited, RYK, Punjab	74.40	Bagasse	Steam Turbine
15.	The Thal Industries Corporation Limited, Chiniot, Punjab	20.00	Bagasse	Steam Turbine
16.	The Thal Industries Corporation Limited, Layyah, Punjab	41.00	Bagasse	Steam Turbine
17.	Almoiz Industries Limited, Mianwali, Punjab	36.00	Bagasse	Steam Turbine

4.2. Biomass as Industrial Fuel Source

Industries running on fossil fuels are one of the main sources of environmental pollution. Biofuels have been recommended as substitutes that can guarantee the security of fuel and reduce levels of greenhouse gas production. All of the regions in the world can obtain these benefits, which would result in a reduction of air pollution, as well as improvements in the quality and freshness of air, rendering the good health of the citizens. A country cannot prosper without a long-lasting power supply to its industries, since the economy depends upon the prosperity of its industries.

Pakistan, even though it is an energy-thirsty nation, still has a lot of potential to run its industries by producing its own biomass-based fuel, because its economy is mostly dependent on agriculture [143]. This fuel would provide an alternative to the huge expenditure of importing fossil fuels from foreign countries [40].

Ethanol and bagasse production from sugar are used as fuels to suffice the heat production requirements in industries. During the last 10 years, the viability of bagasse based-biofuel has been observed and adopted by many countries of the world. For example, in Australia and Brazil, cogeneration is done for heating furnaces and boilers, and it is also sufficient for electricity production [110]. In sugar mills, bagasse serves as energy fuel for firing boilers to heat the juice. In some industries, it is employed to yield medium-density fiberboard, which serves as an alternate for natural wood [144].

4.3. Biomass in Transportation as Fuel Source

Reliance of the world on fossil fuels for transportation is currently inevitable. Biofuels and bioethanol are undisputed issues in the World Trade Organization (WTO). A very small number of energy-producing countries that have membership in the WTO have never rightly investigated and considered energy concerns, because biofuels constitute a small percentage of the world's energy supply. Biodiesel is still considered an industrial product, but there is an ambiguity regarding bioethanol for its uses, and it is classified as an agricultural product by the WTO. There are two types of biofuels according to different classification methods, i.e., bioethanol and biodiesel, because they are manufactured from an extensive range of materials [145].

Sweden is the world's leader in the use of biomass resources for transportation by modifying biogas to biomethane. Several biogas-based light and heavy vehicles from cars to trains can be found running throughout the country [146]. Dramatic developments have been observed worldwide, e.g., in Europe, 30% of cars are now diesel-based, which consumes 2/3 times less fuel than petrol-based cars. The US and Brazil have massively increased the production of ethanol and biodiesel [117].

Transportation by road, being the spine of the transport system of Pakistan, has 90% and 96% of the passenger traffic and cargo movement of the country, respectively. In the period from 2010–2015, transport fuel consumption increased at 16.5% of the aggregate growth rate, whereas the increase in the cumulative growth rate for the rest of energy consumption of the country was 4.7%. The energy consumption for the transport sector in 2015 was 32.4% (13.6 MTOE) of the total country's consumption [147]. Pakistan produces just 18% of the total fuel using its own resources, while the rest of the 82% demand is fulfilled through imports [148].

Transportation utilizes about 50% of the country's oil ingestion, and in 2011–2012, a rise of 5.3% in this consumption was observed [120]. The transportation system of Pakistan has vehicles with engines that feed on liquefied petroleum gas, natural gas, jet fuel, high-speed diesel, and gasoline. The massive exploitation of natural gas reserves that were discovered in 1952, in the form of Compressed Natural Gas CNG, has outstretched concerns over its sustainable future [142].

Pakistan's situation cannot directly relate to the international biofuel developments, because Pakistan's biofuels have their own particular features that have only recently started to become understood. Vehicle efficiency and performance has been greatly increased by the use of bioethanol in recent years. It also reduces greenhouse gaseous emissions from vehicles [149]. Lower particulate emissions are also less harmful for health. Ongoing backing in research, development, and production is vital to identify the transition trails by which future biofuel systems will start their evolution with an excellent structure of technology and policy changes.

A crucial concern for the biofuel industry is sustainability. If biomass is used as a transport fuel, then it would create a big demand on biomass, which must be produced in a sustainable manner. In the future, biofuel could be a potential market advantage if Pakistan improves its capacity to produce fuel that can be qualified as 'sustainably produced'.

5. Discussion and Recommendations

The current scenario regarding the power deficit in Pakistan calls for some immediate steps to overcome this shortfall. The major and foremost problems that have been continuously hindering Pakistan's power sector growth have been listed in Table 22. Their probable and prime reasons, along with their direct consequences, have also been summarized as follows. The problem of the underutilization of the power plants' capacities is caused by their poor maintenance and the deliberate, reluctant behavior of the authorities in full capacity operation. Strict regulatory policies should be devised so that the power plants are compelled to be properly maintained and produce electricity to their full capacity. Pakistan does not have an adequate number of power plants, and the existing ones are less efficient than they should be. Consequently, the undersupply of electricity occurs, and to overcome this problem, investments in efficient-energy projects should be made. The financial problem persists in the energy sector. Hence, wise decisions should be incorporated in those resources that will benefit the energy sector. The new projects face large procedural delays, increasing the overall budget of the project and again causing financial instability. Thus, such delays should be eliminated completely by strict policies that are not affected by any political situation. Technical difficulty handling in power plants should be strengthened to avoid huge blackouts and equipment failure through the establishment of institutions that train the work force. High auxiliary power is used, which causes high heat rates and loss of energy. Hence, cogeneration based on renewable energies should also be implemented by exploring new resources. Pakistan suffers from an exploration problem due to a lack of awareness in the society about the potential of renewable energy resources. Also, research and development should be encouraged and done at larger scales to facilitate exploration by government funding. The quality of the power produced by power plants is not up to the mark due to inefficient transmission and distribution networks that have incorporated poor circuit designs and inefficient circuit components. Theft and leakages also play a role in the degradation of the quality of power in the grid, which ultimately leads to low-voltage issues. The low-frequency noise from such a setup also causes health issues. Smart grid systems should be deployed to track down the energy utilization, which will help eliminate power theft. The International Electrotechnical Commission rules—and other rules—must be followed in order to ensure power quality [150,151]. At the end of this study, suggestions have been given that can help overcome those issues.

Although the major energy contribution to date comes from conventional sources (i.e., 65% from thermal [49]) in Pakistan, the risk involved with these sources is compelling us to shift the energy paradigm toward renewable sources. The first and foremost step on this road is to develop plans and policies so that the utilization of renewable energy can be enhanced. Integrated energy policies should be formulated to find new ventures in the renewable regime and improve the capacity of existing plants, whose chief features should be as follows:

1. National Security of Energy

This feature has been elaborated in Table 23, which covers the potential expansion of the use of coal found in the Thar Desert, the exploitation of shale gas and oil, the exploitation of solar, wind, and biomass potential, and the encouragement of hydropower projects based on storage. It shows its importance for Pakistan in becoming self-sufficient regarding energy and minimizing problems regarding payment balancing.

2. Deep Rooted Sustainability of Environment

The share of the power sector in global emissions is 25%, while a 75% overall share comes from the agriculture, transportation, residential, commercial and industrial sectors. For deep-rooted environmental sustainability, the following measures should be taken:

- All of the sectors of Pakistan should strive to be on par with the international environmental standards.
- To guarantee the complete surveillance of all of the emission sources, the structure of regulations for environmental compliance needs to be revised.
- International Finance Corporation IFC standards for emissions and National Environment Quality Standards NEQS need to be employed in upcoming coal-based projects to control the impact on the environment by using standard technological interferences. Fortunately, it has been predicted that Pakistan will have a far lower level of emissions as compared to many other countries.

3. Conservation and Efficiency of Energy

Constant education and awareness are required to transform the outlook of the local populace regarding energy conservation. Energy-efficiency programs should be started, and grants need to be provided to establish a system that has efficient vehicles and efficient lighting. The buildings should implement mandatory disclosure codes/regulations and commercialized benchmark laws. Table 24 lists the areas where efficient energy and conservation measures can be taken. The energy-efficiency practices include efficient vehicles i.e., hybrid/electric vehicles, efficient lighting, and efficient building codes [152]. The efficient vehicles convert 25–40% of gasoline into energy, while conventional vehicles just convert 17–21% of the fuel into energy, which increases fuel efficiency. Hybrid vehicles do not emit harmful gases, so these should be paid attention to for implementation at a large scale economically.

Efficient lighting using Light Emitting Diode LED bulbs give 50–80% more efficiency than alternate bulbs. Efficient building codes can reduce energy footprints while at the same time benefiting the owners and residents economically.

4. Competitive Tariff Establishment

It has been predicted that the upcoming mix of fuel will help lower the fuel cost part of the power tariff. The focus should be to minimize transmission and distribution losses by replacing and/or upgrading the technology that is required for this purpose.

The GoP has planned to develop 5% of its total energy from the renewable sources by 2030 [9]. For that, the GoP introduced organizations and institutions that pursue the research and development of alternate and renewable energy resources. The Pakistan Council of Renewable Energy Technologies (PCRET), Center for Energy Research and Development (CERAD), and Alternative Energy Development Board (AEDB) are the three main organizations aiming to achieve country's energy mix with a greater share of renewable energy sources. In addition, the major universities of Pakistan are also participating and playing their part in research regarding the renewable energy potential in Pakistan. Table 25 summarizes the research being carried out in the different universities of Pakistan. Regardless of the efforts, there are certain barriers to the implementation of renewable energy systems in abundance that still need to be overcome. They are as follows:

1. Financial barriers
2. Information and technology barriers
3. Institutional barriers
4. Policy barriers
5. Regulatory barriers

While hydropower is contributing almost 31% of the country's total power production [49], other renewable sources currently have negligible involvement. It has been found that hydropower bears a great capability to help lift the energy supply up to the demand. Pakistan has the capacity for large, small, and mini/micro hydropower projects. Each category has its own advantages and disadvantages, which have been summarized in Table 26. A summary of Table 26 is as follows. Large-scale hydropower projects remain an unfeasible solution in a larger number for Pakistan's current situation, since it is costly in and of itself, even though it supplies many purposes such as irrigation, energy generation, recreation, control of flood, navigation, fishing and supply of water to the population. However, in most cases, its construction costs much more than that because of population displacements and other compensations. Small-scale hydropower projects that are often carried out in hilly areas are harder to scale, and are consequently higher in costs. Above all, their expansion to the national grid is greatly difficult, being susceptible to losses. Hence, the mountain specifications and feasibility analysis should be performed with great care. Mini/micro hydropower projects have an advantage in that they don't require expansion to the grid, and they come under the decentralized power system category. In this case, the costs can be reduced by using efficient components that are often locally available. They are also best suited for poor and rural areas, which leads to the conclusion that small hydropower projects, being the most feasible, should be started at various locations all over Pakistan with suitable terrain. The GoP has permitted a 17% internal rate of return to inspire the installment of hydel-based projects.

Pakistan is blessed with various landforms such as plains, plateaus, mountains, and coastal areas. Coastal areas act as a hub for wind energy. According to international standards, wind sources in Jamshoro are befitting for power generation due to their high speed [1]. Thus, more wind turbines should be installed there in order to achieve higher wind generation potential, because Pakistan has 132 GW of wind power potential, but is only utilizing only 1% of it. Due to firming up the infrastructure of institutions, three wind farms have been established that are interconnected with the national grid. They add over 150 MW to the national grid, and further wind projects are near the completion stages. For a quick implementation of wind-based projects, the following recommendations should be considered:

1. Maintenance and improvement in the strength of the infrastructure of institutions, as per the increase in the demand of energy, should be ensured.
2. There should be a fast processing of project proposals, eliminating procedural delays that ultimately cause cost overruns.
3. The usage of latest technologies, and by reducing tariffs, wind power generation can be more rewarding. However, the key challenges of frequency mismatch and lack of grid connectivity must be addressed on a higher priority.
4. International and private investors should be made aware of and educated regarding the striking renewable energy policy put forward in 2011, which holds great incentives for wind power project investors.
5. The wind power plants need to operate on a commercial level that can result in a wind power contribution of 2.6 GW, and thus, the goal of the GoP of attaining a 5% share of renewable energy can be met by 2030.

At present, power generation from solar energy is continuously growing in Pakistan. Although Pakistan has an estimated potential of 2.9 Million MW, only 1% is currently being utilized. Government of Pakistan can help encourage solar-based projects. Recommendations are as follows [9].

1. Provision of subsidies on PV cells should be ensured.
2. Solar cells can be made more feasible by locally producing them, which will eventually reduce the cost of electricity.
3. Awareness should be spread among local communities, and proper technical information should be available to guide them.
4. Peak demand of load can be managed by shifting toward PV-based solar cells. Street lights and parks can be illuminated by them to shed the load off the grid.
5. Since a large area is needed to install PV cells for solar farms, these can be aptly installed in remote areas of Baluchistan, Sindh, and Punjab to fulfil the energy requirements of the local communities. The mountainous regions of the country can be exploited as well, since they get a lot of solar radiation for long hours on a daily basis.

Geothermal resources are in abundance in Pakistan, but due to a lack of proper policies and the required database, they have never been capitalized on a large scale. Consistent and thorough research and development (R&D) is required to clear pathways for utilizing geothermal potential. It has been observed that since Pakistan is situated on tectonic plate junctions, they can offer high, medium, and low temperature reservoirs for electricity generation. Pakistan has no geothermal power plant yet, so this domain is a blue ocean for Pakistan that thoroughly needs to be brought to the fore.

Biomass-based energy is resourceful, sustainable, cost-effective, socially acceptable, and environment friendly alternative for power production [22]. Being a new field, it is in the early stages of development, and more research is required to get the most out of it. Three major sources for biomass in Pakistan are bagasse, poultry waste, and municipal waste. It has been proven that biogas-based plants have less of an environmental impact than PV and wind technologies. Table 27 summarizes the analysis of biomass potential in this study. The summary of Table 27 is given as follows. Bagasse can produce over 3000 MW of power by cogeneration techniques. The use of biomass sources for cogeneration is encouraged because of biomass degradation to environmentally harmful methane gas. Poultry waste, if processed and utilized for producing biogas, can generate 300 MWh of energy per day. Similarly, municipal solid waste is also left over in large quantities of 32.3 MT per year. The associated processing technologies and awareness needs to be raised in all three resources. This potential can be utilized for power production and as a fuel source in industries and transport vehicles, as summarized in Table 28. The summary of Table 28 is given as follows. Up until 2014, Pakistan did not have any biomass-based power generation capability. Afterwards, the potential for biomass-based power plants was explored, and during 2015–2016, 547 GWh of energy was harvested from such schemes. The capabilities that biomass holds in this regard have started to be acknowledged in Pakistan. Consequently, more such projects are being launched for power generation. Biomass-based fuel for transportation and industrial fuel has been known to be more efficient and beneficial for the vehicle performance and the environment as well. Pakistan needs to follow other countries such as Sweden that consume biomass-based fuel in their vehicles, so that Pakistan's expense on importing fuel gets lowered. Although some small biomass-based projects are running in the country, they are still not capable of producing any big impact. One basic hurdle in adopting biomass-based energy sources is a lack of financial and technological support [132], which can be easily overcome with the help of public–private partnership.

This study would have been further enhanced if the data related to bagasse, poultry waste, and municipal solid waste could be obtained from the major cities of Pakistan by direct survey from related organizations by arranging a field trip. Still, the data has been obtained from recent reliable sources, which suffice to fulfil the objectives of this study.

This study enables examining the state of power and energy harnessed from all of the available and potential resources in Pakistan. Keeping in view all of the aspects mentioned in this section, it can be deduced because of this study that biomass is the most economical and readily available resource that can be used to harness energy to generate power and as transportation and industrial fuel. Other renewable resources such as solar, wind, and geothermal resources are too expensive to set up at a large scale for Pakistan's current economic situation, even though they have a lot of potential. They also require more complex technologies and large manpower for their setup, which in the case of biomass, is relatively less of a problem. Hence, this comprehensive study may enable the government and investors to make wise decisions about the most suitable resource that, if implemented in upcoming and future projects, will help reduce the supply and demand gap in a minimal time span. Hence, they may set priorities on the utilization of these resources based on this study for their future investments. In this study, biomass has been found to be that resource which is environmentally, sustainably, and economically the most feasible in solving the power and energy issues, and should be set up as the highest priority for its utilization in all possible aspects.

Table 22. Major problems of the power sector of Pakistan: reasons, consequences, and solutions.

Sr. No.	Major Problems of Power Sector of Pakistan	Reasons	Consequences	Suggestions for Solutions	References
1	Capacities of power plants are not fully utilized	1. Poor maintenance of power plants 2. Deliberate reluctance in fully fledged operation of power plants	1. Utilization factor per annum is lowered 2. Load shedding 3. Deficient performance of power plants 4. Availability of units is constantly declining 5. Higher heat rates are observed than National Electric Power Regulatory Authority (NEPRA)'s approved heat rate	1. Constant and strict performance monitoring by higher authorities. 2. Call for periodic reports from power plant authorities frequently. 3. Strict policies should be developed to force the power plant authorities to ensure full utilization of capacity.	[1,21,51]
2	Inadequate power supply relative to demand	1. Small number of power plants 2. Inefficiency of power plants	1. Many factories and industries have been shut down 2. Pakistan's economic growth has been negatively affected	1. Measures should be taken to imply international standards to improve the performance of the grid to minimize energy losses. 2. New plants with greater energy capacity and efficiency should be installed.	[9,18]
3	Financing issues	1. Control of the power sector is centralized 2. Wrong funding priorities 3. Circular debt	1. Lack of investments in new and novel projects 2. Aging and degradation of existing plants 3. Unworthy investments leading to expensive failure 4. Higher electricity costs	1. Proper rules and regulations should be incorporated for project financing schemes. 2. Feasibility surveys should be carried out before project execution. 3. Risk management should be employed according to risk register. 4. Encouragement of private power sector is necessary.	[4,21,39,51,54]
4	Procedural delays	1. Political situations 2. Poor project management skills 3. Deliberate suppression of approvals by authorities for organizational benefits	1. Delay in the start of operation of power plant 2. Lowering of annual factor of utilization	1. Policies should be such that no political situation can affect the welfare projects. 2. Project should be properly managed by experienced project managers who strictly follow the work breakdown structure of the project.	[12,21,54]
5	Lack of expertise in catering of technical difficulties	1. Lack of technical staff with expertise 2. Lack of availability of jobs in such areas	1. Switchyard equipment failure 2. Large system blackouts	1. Institutions should be developed for special training to cater for the technical faults in power systems. 2. Job vacancies for capable and intelligent people should be increased in the power sector.	[18,21,48]

Table 22. *Cont.*

Sr. No.	Major Problems of Power Sector of Pakistan	Reasons	Consequences	Suggestions for Solutions	References
6	High consumption of Auxiliary power	1. Poor efficiencies of power generation equipment 2. Actual power production capacity of the plant is lower than the requirement of auxiliary power.	1. Higher heat rates 2. Loss of energy e.g., in 2016, national exchequer faced financial deterioration due to overutilization of auxiliary power by TPS Guddu, leading to 121.089 GWh loss of energy.	1. Cogeneration schemes, such as bagasse-based cogeneration, should be employed to power the auxiliary generation equipment. 2. Energy storage-based projects should be installed. 3. Load-balancing schemes should be deployed.	[18,21,30]
7	Primitive methods utilized for electricity generation	1. Lack of funds for new power projects 2. Lack of research and knowledge of new methods of power generation 3. Lack of equipment and technologies for the establishment of new generation methods 4. Lack of policies for alternate energy power plants 5. Exploration problem	1. Primary energy resources such as oil, coal, and gas are being depleted 2. Greenhouse emission levels are increasing 3. Low energy efficiency being obtained from existing plants e.g., power plant in Uch produces only a few MW, even though it is capable of generating 800 MW.	1. Research and development of alternate and renewable energy resources should be pursued along with their implementation in new power plants. 2. Policies should be updated according to the requirements of alternate and renewable energy resources such as solar, wind, and biomass. 3. Awareness about the potentials of alternate and renewable resources should be spread nationwide.	[1,9,13,21]
8	Lower power Quality and low frequency noise	1. Instability of transmission and distribution grid 2. Power theft 3. Leakages 4. Technical faults in manufacturing conductors and their weakening 5. Poor design of circuitry	1. Low-voltage issue arises 2. Transmission circuit's efficiency is lowered 3. Affects human health and causes distress	1. Measures should be taken to improve the transmission and distribution circuits and equipment such as transformers, transmission lines, spacers, insulators, and dampers. 2. Employment of Smart Grid system that will also help monitor the overall power system to avoid theft issues as well along with other benefits. 3. International Electrotechnical Commission rules along with other standards should be followed to enhance the quality of power.	[1,4,18,21,39]

Table 23. Integrated energy policy regarding the national security of energy.

Sr. No.	Potential		Discussion/Recommendations
1	Expansion of use of coal found in Thar Desert	• Seventh largest reserves of coal are situated here • The grade of coal is lignite, and its quantity is 175 billion tons • This quantity has the potential to serve for more than 100 years with a power generation capacity of 100,000–200,000 MW	i. To intrigue the private sector to invest, incentives in tariffs and mining should be given ii. Water should be made available to convert to steam for power generation
2	Exploitation of shale gas and oil	• Shale gas: 105 trillion cubic feet • Shale Oil reserves: 9.1 billion barrels • Efficiency of combined cycle RLNG plants is 60–62% at 6–7 cents/kWh • Assurance of native gas obtainability to further reduce tariff via search of tight and shale gas should be done.	i. Policy should give incentives for quick potential growth of tight and shale gas/oil ii. New areas should be explored
3	Exploitation of solar, wind, and biomass potential	• Wind: 132 GW • Solar: 2.9 Million MW • Biomass: 4000–6000 MW	i. Revision of import policy for tariff of solar equipment to promote solar applications ii. Establish local industry for manufacturing of solar equipment iii. Net metering should be employed by utility authorities iv. Encouragement of off-grid applications to supply power to the deprived 27% population
4	Encouragement of hydropower projects based on storage	• Such projects have a capability of generating 60,000 MW. At present, 7116 MW are being generated • 4000 MW of hydel-based projects are at various steps of implementation • Water and Power Development Authority (WAPDA) is also dealing with projects that are at the feasibility stage with 25,000 MW	i. Feasibility analysis must be done prior to the beginning of the project ii. Allocation of budget should be done iii. Cogeneration schemes should be emphasized to strengthen current infrastructure

Table 24. Integrated energy policy regarding the conservation and efficiency of energy.

Sr. No.	Efficiency Practices	Advantages	Recommendations
1	Efficient vehicles: hybrid/electric Vehicles	• Electric vehicles, being more efficient, convert 25–40% of gasoline into energy, while conventional vehicles just convert 17–21% fuel into energy • Hybrid vehicles are fuel-efficient • Electric vehicles cause zero emissions	Pakistan should add electric and hybrid vehicles in its auto policy along with the deployment of stations for battery charging
2	Efficient lighting	50–80% more efficiency can be achieved by using LED bulbs instead of alternate bulbs	There should be no sales and import tax and duties on LED bulbs
3	Efficient building codes	• Reduction of energy footprints • Building owners and residents get economic benefits	Commercial centers should strictly follow the timings of business

Table 25. Ongoing research on renewable energy resources and technologies in universities of Pakistan.

Sr. No.	University	Research Directions
1	Ghulam Ishaq Khan Institute GIK, Toppi, Khyber Pakhtunkhwa KPK	Solar cells
2	Government College University, Lahore	Biofuel production from biomass
3	Mehran University of Engineering and Technology, Jamshoro	Bioenergy
4	National University of Science and Technology (NUST), Islamabad	• Biomass • Electric vehicles • Wind turbines • Solar thermal energy
5	Nadirshaw Eduljee Dinshaw NED University of Engineering & Technology Karachi.	• Solar collectors • Wind turbines
6	Quaid e Awam University of Science and Technology, Nawabshah	• Utilization of solar energy • Solar tracker
7	Quaid e Azam university Islamabad	Biofuel technology

Table 26. Analysis of hydropower potential in Pakistan's context.

Sr. No.	Hydropower Project Category	Factors Deciding the Category	Advantages	Disadvantages	Discussion and Recommendations
1	Large	Requirement of large dam size	Serves numerous purposes. For example i. Irrigation ii. Energy generation iii. Supply of water to population iv. Control of flood v. Navigation vi. Fishing vii. Recreation	i. The size of the dam causes the forced relocations of local settlements. Such objections have been raised on the Kalabagh dam project ii. Costly iii. Greater construction time iv. Buildup of sediments v. Barrier to fish migration vi. Decomposition of biomass releases CH_4 and CO_2. vii. Technical, social, and political issues are related to them	Considering sustainable development, this scheme is not reliable because of the following reasons: i. To compensate for population displacement and the degradation of the environment, there has been a demand that their costs have to be adjusted with upfront costs. Financing is already a problem in Pakistan, which renders this scheme as an unreliable option. ii. If, somehow, arrangements of funds are made by the government, the expenses of resettlements are huge, e.g., $33.2 billion will be spent on the resettlement associated with the Kalabagh dam through the construction of 20 model and 27 extended villages.
2	Small	Requirement in hilly areas with an abundance of controllable and natural waterfalls	i. Cost of equipment, civil work, and overall establishment depends upon the location only ii. Power profile permits immediate response to demand fluctuations; addressing both base and peak demands of load iii. Lower impact on ecosystem iv. No reservoir required	i. More expensive than large-scale hydropower projects. ii. Harder in terms of scaling than large-scale hydropower projects. iii. It is difficult to expand the grid in hilly areas, which are prone to losses	i. Mountain specifications and feasibility analysis should be done. ii. Since this category is less risky, and has profound advantages, it can be helpful in keeping pace with the increasing energy demand.
3	Mini/Micro	They are site-specific especially with no grid extension	i. No storage required ii. Can be made less expensive iii. Decentralized power system	i. Lower load factor ii. Slow demand buildup	i. Lower costs can be achieved by selecting components that boost efficiency. ii. Since this scheme is employed in mostly poor and rural communities, these projects act as a source of income for them, since it can be locally made. This type is also beneficial for Pakistan, after the small hydropower scheme.

Table 27. Analysis of major biomass resources.

Major Focus of This Study	Potential	Advantages	Disadvantages	Discussion/Recommendations
Bagasse	i. Each ton of processed sugarcane produces 200–300 kg of bagasse ii. Over 3000 MW can be produced by bagasse-based cogeneration facilities	i. Oil of 0.173 tons (about $80/ton) and coal of 0.263 tons (about $55/ton) is comparable to one ton (about $15/ton) of bagasse ii. Cogeneration plant is located near the sugar mill	i. Continuous refinement of raw materials is required ii. Low-pressure boilers and low-efficiency steam turbines bound sufficient electricity production	i. The cogeneration method effectively lowers greenhouse emission levels. ii. It is recommended that bagasse is used for the cogeneration, otherwise it starts decaying by itself and producing methane gas, which is 27 degrees more hazardous for the ozone layer than CO^2.
Poultry Waste	Poultry waste can guarantee approximately 10,335 m^3 of biogas, which in turn would be capable of generating about 300 MWh per day.	i. Pakistan's poultry industry is established i.e., 25,000 poultry farms across the country leave a tremendous volume of poultry waste ii. Anaerobic digestion process on poultry waste produces biogas.	i. Lack of established waste to energy conversion technologies ii. Lack of awareness about potential of poultry waste as a biomass energy resource	i. Waste-to-energy conversion technologies should be implied to convert waste into treasure of energy. ii. Anaerobic digestion produces a by-product called biodigestate, which should be used as fertilizer.
Municipal Solid Waste (MSW)	i. Gross total of 32.3 MT per year of MSW is produced ii. Use of MSW as a biomass resource for power production will cause a reduction from 0.1% to 0.03% in the share of imported electricity	Variety of MSW processing and treatment techniques are available	Lack of expertise and manpower in this domain in Pakistan	i. Waste is the most abundant and easily available entity. This regime should definitely be explored and acted upon, since it is beneficial in terms of the environment. ii. It can greatly help reduce the share of conventional resources of power generation in Pakistan's energy fuel mix.

Table 28. Biomass utilization in Pakistan for power production, transportation, and industrial fuel.

Sr. No.	Biomass Application	Potential	Key Observations	Discussion
1	**Power Production**	In the National Transmission and Dispatch Company (NTDC)'s system, an increase in power generation of about 63 MW for a total of about 146 MW from bagasse-based power plants has been observed during 2015–2016 having an energy of 547 GWh.	i. Pakistan lacked any biomass/bagasse-based power plants until 2014 ii. The projects started in 2015 are majorly based on bagasse fuel iii. Their technologies make use of steam turbines iv. 35 *captive power producers (CPPs)* are using biomass/bagasse for power production v. Shakarganj Energy (Pvt.) Limited is the only *Isolated Generation Company (IGC)* for energy production using biomass	The year 2015 has been beneficial in terms of the start of biomass-based power production. Many projects have been put forward for implementation, since companies have found it to be a convenient way to generate electricity.
2	**Transportation**	i. Vehicle efficiency and performance can be greatly increased using biomass-based fuels such as bioethanol and biodiesel ii. Environmentally-friendly fuel	i. The transportation system of Pakistan has vehicles with engines that feed on liquefied petroleum gas, natural gas, jet fuel, high-speed diesel, and gasoline. ii. Countries such as Sweden use biomass resources for transportation by modifying biogas to biomethane	Pakistan imports a huge amount of fossil fuels to fulfill its transportation needs. Pakistan also needs to follow the concept of using biomass-based fuels to feed the vehicular engines.
3	**Industrial Fuel**	Biofuels have been recommended as substitutes guaranteeing the security of fuel and reduced levels of greenhouse gas production.	Pakistan's industries are still using fossil fuels that produce harmful gases that are bad for the environment	i. Pakistan has a lot of potential to run the industries by producing its own biomass-based fuel, instead of importing fossil fuels from foreign countries. ii. Pakistan can start from using cogeneration for heating furnaces and boilers for juice heating and yield medium-density fiberboard, which is an alternate for natural wood. iii. This will help clean the environment, too.

6. Conclusions

Pakistan is in dire need of the diversification of its energy mix to lessen its reliance upon fossil fuels and its consequences on the environment. This review concludes that the government of Pakistan should prioritize biomass energy based-projects among other renewable energy resources, since it would prove to be the most economical and environment-friendly resource. This would lead to a quick bridging of the gap between the demand and supply of energy. In the future, this study can be further enhanced by obtaining data from organizations and institutions that will help the government model biomass-based projects.

Author Contributions: All the authors contributed in completing the Paper. The main idea of the paper was presented by W.U.K.T. while Z.A., N.Y., L.S., and I.F. helped in accumulating the research data in this review paper. M.A., M.S., B.H., and L.W.C. prepared the format of the paper. S.M., S.A.M., and M.D. are the head of research team.

Funding: The authors would like to acknowledge the financial support received from the University of Malaya, Malaysia, through Frontier Research Grant No. FG007-17AFR and Innovative Technology Grant No. RP043B-17AET.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

AEDB	Alternative Energy Development Board
BRB	Bambawali Ravi Bedian
COD	Commercial operation dates
CPP	Captive power producers
CNG	Compressed natural gas
CERAD	Center for Energy Research and Development
EJ	Exa joule
FY	Financial year
GENCOs	Generation Companies
GHG	Greenhouse gas
GWEC	Global Wind Energy Council
GW	Gigawatts
GWh	Gigawatt-hour
GDP	Gross domestic product
GoP	Government of Pakistan
HSD	High-speed diesel
HDR	Hard Dry Rock
HVAC	Heating, ventilation and air conditioning
IPPs	Independent power producers
IGC	Isolated Generation Company
IFC	International Finance Corporation
IEA	International Energy Agency
K-EL	K-Electric's
KPIs	Key performance indicators
KANUPP	Karachi Nuclear Power Plant
KTOE	Kilotonne of oil equivalent
MW	Megawatts
MT	Megatons
MCM	Million cubic meters
MSW	Municipal solid waste
NREL	National Renewable Energy Laboratory
NEPRA	National Electric Power Regulatory Authority
NEQS	National Environment Quality Standards

NTDC	National Transmission and Dispatch Company
OECD	Organization of Economic Cooperation and Development
PEPCO	Power Company
PCRET	Pakistan Council Renewable Energy Technologies
PV	Photovoltaic
PAEC	Pakistan Atomic Energy Commission
PJ	Petajoule
RFO	Residual furnace oil
RLNG	Regasified Liquefied Natural Gas
SPPs	Small Power Producers
SNG	Substitute natural gas
TWh	Tera watt hour
TOE	Tons of oil equivalent
WAPDA	Water and Power Development Authority
WTO	World Trade Organization

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