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Review

Present Status and Potential of Biomass Energy in Pakistan Based on Existing and Future Renewable Resources

Wajahat Ullah Khan Tareen [1,2,3,4,*], Muhammad Tariq Dilbar [1], Muhammad Farhan [1], Muhammad Ali Nawaz [1], Ali Waqar Durrani [1], Kamran Ali Memon [5], Saad Mekhilef [3,6], Mehdi Seyedmahmoudian [6], Ben Horan [7], Muhammad Amir [1] and Muhammad Aamir [4]

[1] Department of Electrical Engineering, International Islamic University, Islamabad 44000, Pakistan; muhammadtariqdilbar@gmail.com (M.T.D.); engineerfarhan1122@gmail.com (M.F.); ali.nawaz92@gmail.com (M.A.N.); alidurrani57@gmail.com (A.W.D.); m.amir@iiu.edu.pk (M.A.)
[2] Department of Electrical and Electronic Engineering, College of Engineering, University of Jeddah, Jeddah 21589, Saudi Arabia
[3] Power Electronics and Renewable Energy Research Laboratory (PEARL), Department of Electrical Engineering, University of Malaya, Kuala Lumpur 50603, Malaysia; saad@um.edu.my
[4] Department of Electrical Engineering, Bahria University, Islamabad 44000, Pakistan; muhammadaamir.buic@bahria.edu.pk
[5] School of Electronic Engineering, Beijing University of Posts and Telecommunications (BUPT), Beijing 100876, China; ali.kamran77@gmail.com
[6] School of Software and Electrical Engineering, Swinburne University of Technology, Hawthorn, Melbourne, VIC 3122, Australia; mseyedmahmoudian@swin.edu.au
[7] School of Engineering, Deakin University, Waurn Ponds, VIC 3216, Australia; ben.horan@deakin.edu.au
* Correspondence: wajahat.tareen@iiu.edu.pk

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Abstract: Pakistan is a developing country that is experiencing a shortage of electricity generation due to its rapidly growing demand. The existing and upcoming energy requirements for power generation and future transportation can be met by efficient utilisation of homegrown biomass resources. Determining the present energy mix resources in various sectors of the country is important. This article analyses the biomass resources and their potential and bioenergy utilisation in Pakistan. An overview of the global renewable energy scenario is presented. This article accentuates the importance and challenges of new technologies and estimates the current and future share of power generation from renewable sources, focusing on the technical potential of biomass energy, which is obtained from agricultural residues, animal manure and municipal solid wastes in Pakistan. This paper highlights the developing technologies that are primarily used to convert biomass waste into energy and presents a critical consideration on future directions in drafting the bioenergy framework policy in Pakistan. For effective implementation of biomass-based renewable energy production in the country, this paper presents an extensive literature review on current and future perspectives and suggestions on future directions and policies to overcome the deficit in electricity supply and environmental concerns. Furthermore, this paper discusses the utilisation of biomass resources in the rapidly growing transportation sector and presents a solution for upcoming mass transit projects in two major cities in Pakistan. The conclusion is that biomass energy is the most sustainable, eco-friendly and efficient renewable energy and is an emerging renewable energy resource that can meet the growing energy demand in Pakistan.

Keywords: transportation; future energy mix; cattle waste; agriculture residues; municipal solid waste; renewable energy sources

1. Introduction

Increasing energy requirements have led to daily energy crises caused by the high energy demand throughout the world. The need for energy is rapidly increasing to ensure that services can fulfil the needs of society and support economic enhancement and welfare development. Utilising renewable resources is a good approach to mitigate the effects of climate change and helps meet energy demand for future uses [1].

Energy is an integral part of any society and plays a key role in its socio-economic progress. With the expansion over time, energy consumption is increasing tremendously due to the rapidly growing world population and higher standard of living; meeting the energy demand to fulfil the needs of society and economic growth is becoming highly challenging [2]. The availability of electricity is now considered an essential necessity. Uninterrupted electricity supply is required to keep world development on track, to support ecosystems and to ensure a reasonable standard of living [3].

The world's energy demands are primarily met by fossil fuel resources. These conventional energy sources are important in economic growth but have negative effects on the environment and human health. The estimated electricity generation with respect to different energy sources from 2015 to 2050 worldwide is shown in Figure 1. Coal, oil and natural gases are considered vital fuel for electricity production. The oil market share is gradually decreasing and is projected to grow at considerably lower rates of 0.6% per annum due to upward cost fluctuations. However, as predicted, the primary energy demand of oil will increase to 372 million barrels per day. In other words, the average need for oil will rise by approximately 35% by the year 2040 with an average annual growth rate of 1.2%. Oil, coal and natural gas combined will continue to have the largest share of the global energy mix [4]. Therefore, addressing the current energy crisis due to the extensive utilisation of fossil fuels is essential [5].

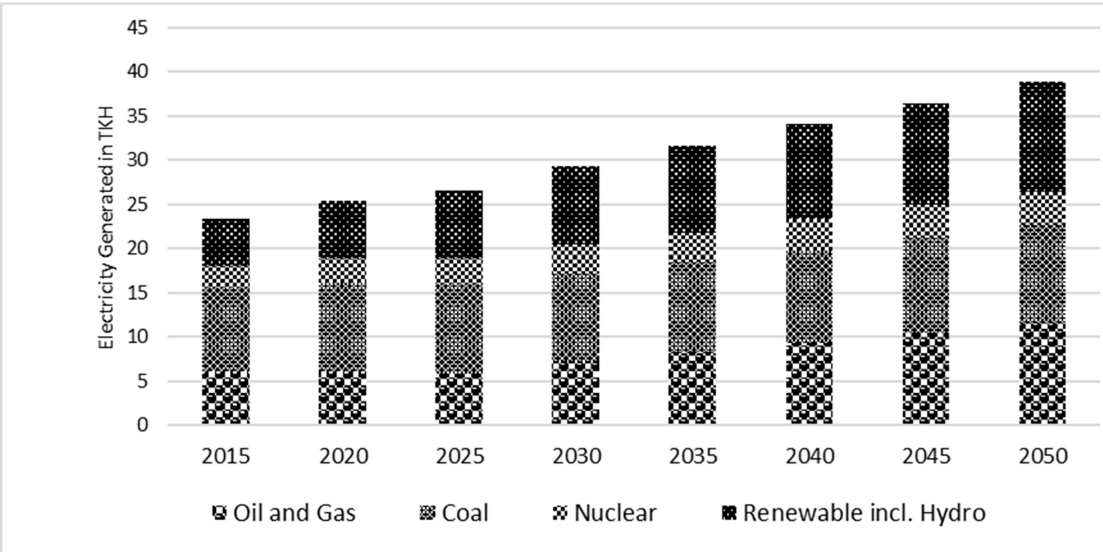

Figure 1. Estimated global electricity productions with respect to energy sources [5].

Electricity generation is increasing worldwide, as shown in Figure 2. The global economy is continuously growing at an average rate of 3.4% per annum corresponding to the increasing population, which is expected to reach over 9 billion by the year 2040 [6,7]. In the meantime, the global energy needs will likely expand by 30%.

Electricity can be produced through many methods, including the rotation of turbines, chemical reactions and solar energy cells. The energy gained from fuel combustion, nuclear fission system and hydroelectric power is used to rotate turbines. In 2018, power generated by fuel combustion accounted for 67.3% of global electricity generation [5,8,9]. Table 1 presents different energy fuel mixes with combustible fuels, including coal, oil, natural gas and biofuels. Ongoing development in many countries aims to make electricity generation cheaper and more reliable than before to mitigate the effects of climate change, provide renewal techniques and digitalise existing facilities.

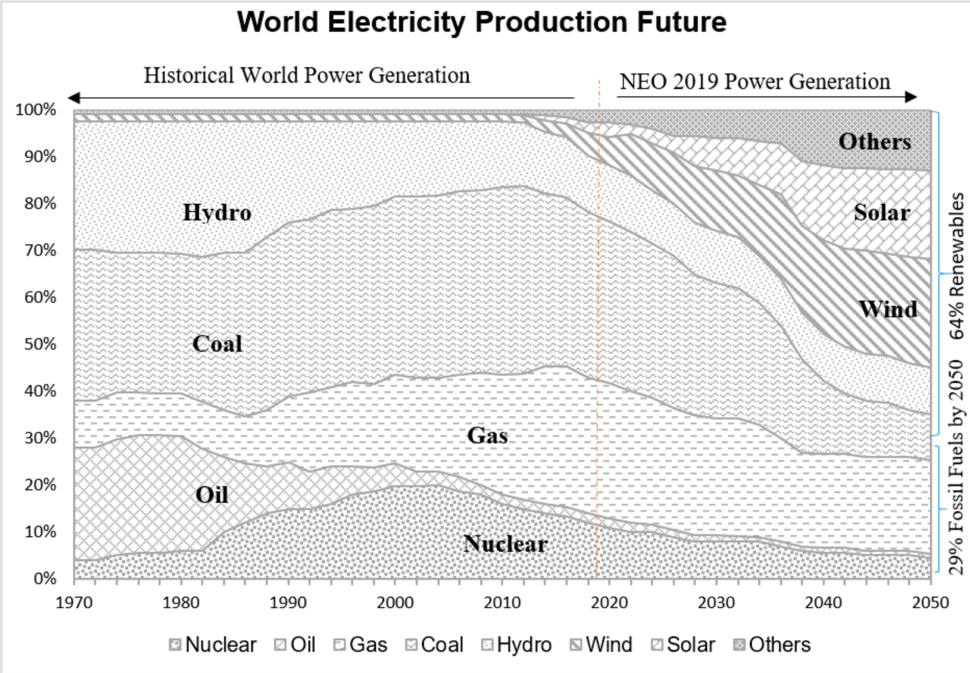

Figure 2. Future trend of worldwide electricity production [4].

Table 1. Electricity generation with fuel in GWh [5].

Country	Coal	Oil	Gas	Biofuels	Nuclear	Hydro	Solar	Wind	Other *	Total
World	9,594,341	931,351	5,793,896	462,167	2,605,985	4,170,035	328,038	957,694	201,561	24,843,507
Pakistan	156	37,392	33,327	588	4869	36,621	219	831	nil	114,003
Malaysia	69,153	1184	65,234	760	nil	20,019	310	nil	nil	156,660
Turkey	92,273	1926	89,227	1635	nil	67,231	1043	15,517	4819	268,852
India	1,104,828	23,426	71,239	41,972	37,916	137,533	14,130	44,856	1664	1,475,900
USA	1,354,034	34,759	1,418,100	60,493	839,918	292,113	46,633	229,471	18,584	4,275,521
Germany	273,196	5846	82,294	44,994	84,634	26,135	38,098	78,598	13,436	633,795
UK	31,481	1839	143,362	27,303	71,726	8354	10,421	37,367	7548	331,853
Saudi	nil	140,151	204,657	nil	nil	nil	1	nil	nil	344,809
Iran	488	32,035	233,252	nil	6620	16,421	4	250	24	289,070
China	4,241,786	10,367	170,488	64,700	213,287	1,193,374	44,782	184,766	64,833	6,123,550
France	10,520	2537	34,864	4971	403,195	64,889	8160	21,400	5476	550,536

In the current global scenario, in which we are searching for sustainable energy production, we should consider the opportunities in the usage of renewable energy resources [10]. Renewable resources that ensure the replenishment of ecological processes within a relatively short period of time are desirable. They are environmentally friendly in nature and can serve as substitutes to meet fossil fuel demands. Renewable resources are linked with sustainable evolution and poised to play a major role in social and economic progress, and they are proven to be effective drivers in improving environmental quality by reducing pollution and greenhouse gas (GHG) emissions [11]. A brief comparison of renewable sources and conventional energy sources is provided in Table 2 [12].

The use of renewable energy sources in electric power generation to meet the growing energy demand is characterised by socio-economic violability and environmental preference in terms of their low environmental costs. Renewable energy includes the electricity generated from wind turbines, solar panels, geothermal, biomass and hydropower plants (HPPs). The energy obtained from renewable resources can potentially generate meet to 10 to 100 times the present global energy demand. Renewable energy has been increasing by only over 17% per annum in recent years. Solar and wind technologies have experienced double-digit growth rates annually [13,14].

Table 2. Comparison of renewable and conventional energy sources.

Source	Benefits	Limitations
Conventional	• Energy supply security • Easy to energy access • No geographical limitations • Efficient synchronization • Reliable energy sources	• GHG emissions • Global warming • High generation cost • Dependences on fossils fuels • Unable to replenished
Renewable	• Inexhaustible sources of energy • Low generation cost • Reduce pollution eco-friendly • Boosts public health • Social-economic development	• Geographical limitations • Low generation efficiency • Fluctuations in energy output • Synchronization limitations • High installation cost

The global renewable energy market is classified based on the type of renewable source, end user or customer and geographical location. In 2016, the Asia-Pacific region dominated, having a 41.1% share in the global renewable energy market. The global renewable energy market is growing at a compound annual growth rate of more than 4.9% [15]. The International Energy Agency (IEA)'s 2018 World Energy Investment report indicated that recent annual investment in renewable resources is estimated to be more than US $298 billion. The total investment in the energy sector reached up to US $750 billion, as shown in Figure 3 [7,16].

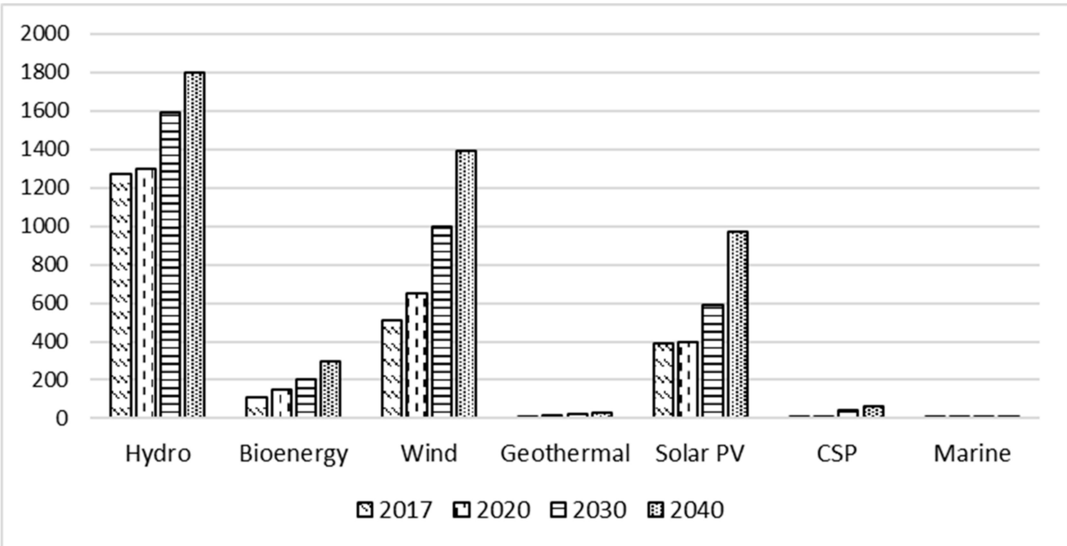

Figure 3. Global power sectors installed capacity in GW.

Power generated from renewable sources, including hydropower, accounts for a 30% share in the total global installed power capacity and a 23% share in total global electricity generation. In the last decade, wind and solar photovoltaic (PV) technologies have witnessed a rapid annual growth in installed generation capacity of 23% and 51%, respectively, although their collective contribution to overall electricity generation is only about 4% [17]. Renewable energy resources contribute 86% of the total electricity of the European Union [18]. As previously discussed, renewable resources account for about one-third of the global power-generating capacity; heat leads with a 51% share in net power generated from renewable resources (36%), and transport fuels have a 13% share. The estimated global renewable power consumption until 2030 is depicted in Figure 4.

The renewable industry is continuously striving towards modernisation to improve the reliability of currently available facilities. Table 3 briefly discusses the principle characteristics, advantages and limitations of renewable sources that account for current power generation.

Table 3. Renewable technologies [20–22].

Technology	Characteristics	Advantages	Limitations
Hydropower	• The potential energy of water flowing from a certain height is used to rotate the mechanical turbines, located at the lower end. • Total global hydropower capacity was 1114 GW, in 2017. • In China, 40% of new hydropower capacity installation, in 2017. • Hydro — Power = hadraulic head pgh ∗ flow rate Q ∗ efficiency η	• Irrigation • Flood control • Fishing • Recreation	• Depends on geographical location • High construction cost • Relocate local residence • Barrier in fish migration • Accumulation of sediments
Geothermal Power	• Geothermal energy originates from the earth's crust. • In 1911, first geothermal plant was successfully run in Italy. • In 2017, nearly 0.7 GW of geothermal capacity was installed • Net global capacity is estimated to be 12.8 GW.	• Low running cost • Heating purposes • Lower Impact on ecosystem	• Geographical resource risk • Constrains in technology development • High initial installation cost
Photo-Voltaic	• Convert solar radiation energy into DC electricity using PV modules. • Generating capacity modules are available in small to large scale • In recent past years, solar PV has surpassed the average total installation of fossil fuels and nuclear combined. • China leads in installation of new solar PV plants. • In 2017, the global capacity of solar PV raised around one-third, bringing net capacity to 402 GW DC. • Peak normal solar irradiance is 1kW/m2 • 25 square miles produces about 100–200 MW on average	• Produces no wastes/residue • Low running cost • No carbon emission	• Fluctuating energy resource • Geographical dependences
Concentrating Solar Thermal	• Solar thermal collects the solar radiation and heats the water into steam. • In 2017, CSP net global capacity reached 4.9 GW. • South Africa operates a 100 MW CSP power plant. • China is constructing a new 300 MW CSP power plant and a 350 MW CSP power plant is particularly active in Morocco. • Moreover, there is an ongoing research to overcome challenges of CSP development particularly in its technology cost reductions	• Heating water • Available simple small household systems • Growing technology market	• Suitable for low temperature heating • Required strong solar radiation • More expensive Installation • Higher maintenance cost • Small market share • Modular Durability against necessary hot water, heating resistance and strong solar radiation

Table 3. *Cont.*

Technology	Characteristics	Advantages	Limitations
Wind Power	• Conversion of wind energy into electricity from wind turbines. • Classified in onshore and offshore wind power plants • In recent past years, cost of wind power fell rapidly • In 2017, net power of 52 GW wind energy has added globally making a total of 539 GW. • The capacity of turbines and projects size is continuously increasing. • First commercial floating project was commissioned in Scotland. • By the year 2017, the total onshore wind power capacity has been doubled over the year 2011.	• No wastes or residues • Suitable for remote areas	• Risk of turbine damage during storms and bad weather • Huge Investment • High maintenances costs. • Low power density 2 W/m2
Biofuel	• Terms as waste-to-energy conversion technology. • Bioenergy is the major renewable contributor to provide total global energy demand, contributing 13% of the shares. • Traditionally in developing countries, biomass is mostly used in heating and cooking which accounts for about 8%. • Moreover, it contributes 4% in buildings and 6% in industry heat demand, as well as 2% and 3% in global electricity generation and transportation respectively. • USA and Brazil are the largest producers of biodiesel and ethanol.	• Suitable for fulfilling energy requirements • Low running cost • Used in transportation fuel generation i.e. bio-diesel.	• Carbon emissions from burning wastes • Resource availability risk

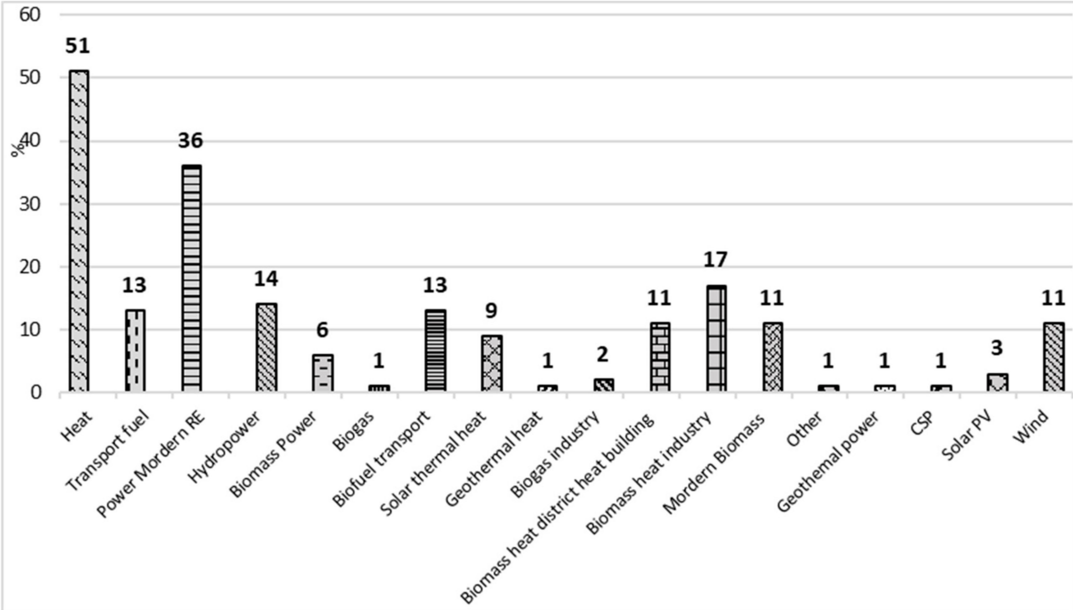

Figure 4. Global renewable consumption 2017 [19].

The energy sector of Pakistan, which is a developing country, is recently facing a severe energy crisis in fulfilling consumers' demand. The price of non-renewable energy fuel, such as natural gas and boiler oil, is a major concern for local industries during energy crises [23]. One-third of the country's economy depends on the agriculture sector to fulfil the national gross domestic product requirement. Therefore, the agriculture sector requires large biomass energy resources all year round and is a potential source of the present energy crisis. In rural areas of Pakistan, traditional cooking stoves utilise 80% of the current bioenergy, thereby resulting in 64% of biomass cooking and 86% of total biomass energy in the household sector [24]. In [25] discussed the availability of biomass energy resources in Pakistan and its potential that could support to improve the electricity generation. To stabilize the supply and demand many primary energy sources like coal 11.3%, natural gas 48.3%, oil 32.1%, and hydropower 11.3%, nuclear 7.6 % and liquefied petroleum gas (LPG) 0.6% contribute from 1980-2012 in the energy sector. Furthermore, several methodologies are mentioned to produce biomass energy as energy solution from renewable energy resources. In study [26] discussed a Pakistan energy policy regarding biomass energy conversion as renewable energy as a primary source to produce electricity. It showed that Pakistan possesses the potential to run 15 million biogas plant and increase the production rate from 1% to 5% by 2030. The limitation in this review is energy policy is not discussed in detail with respect to its implementation, utilization, government initiatives and necessary amendment in renewable energy policy. The data provided regarding the petroleum sales, Compressed Natural Gas (CNG) prices and electricity supply and demand is mentioned for a limited time span. The projected future demand and supply is dependent on CPEC not motivated by overall energy mix. In study [27] explored the potential of two major resources of biomass energy in Pakistan, such as bagasse and livestock increasing speedily to 42% in year 2013. The energy policy is discussed and economic comparative analysis has been described. The energy in Pakistan is produced from the fossil fuels and the energy policy need to be revised and an initiative should be taken in term of the environmental methane emission impact into the power grid. As a limitation, this paper analyses a limited time span data of unemployment, livestock population and renewable energy of 2008 till 2013.

The installed capacity is expected to reach 48,000 MW in 2024. The largest addition is likely from renewable energy, reaching nearly 35%. The expected demand and planned generation from the next five years are given in Table 4 [28].

Table 4. Expected generation of Pakistan until 2020.

Year	2017–2018	2018–2019	2019–2020
Planned Generation (MW)	28,751	33,545	35,590

This study focuses on an overview of the generation of electric power by utilising biomass as a fuel in Pakistan whilst considering assessments of biomass over conventional fossil fuels. This paper analyses the need to redesign Pakistan's power division, potential and bioenergy by utilising sustainable biomass resources. The primary focus is on the technical potential of biomass energy that can be generated from different resources in Pakistan. The study analyses previously published papers and suggests effective utilisation of all renewable resources available in the country. Biomass resources, such as municipal waste and bagasse, provide biomass energy for transportation, industrial fuel and power generation. A detailed analysis is presented regarding policy framework for biomass as a renewable resource and the challenges of developing technologies for energy conversion to meet upcoming energy issues. A comprehensive analysis of the state, demand predictions and existing sources for power generation in Pakistan using conventional, alternate and renewable energy resources and global scenarios is conducted to determine where Pakistan stands in the world in terms of power and energy. Pakistan's energy policies need to be amended to meet the electricity supply and demand. Future massive energy projects on biomass-based bioenergy need to be implemented in Pakistan.

This paper is structured as follows. Section 1 provides a general overview of the existing and future demand for electricity generation worldwide, especially in Pakistan's energy mix perspective. Section 2 briefly describes the biomass potential as fuel energy, biomass conversion techniques and its resource potential in Pakistan. Section 3 presents different types of bioenergy resources, such as agricultural, forestry residue, animal manure and municipal solid waste (MSW). Sections 4 and 5 discuss the installed capacity of biomass and the use of biomass as fuel for transportation in Pakistan. Section 6 presents the analysis and recommendations, and Section 7 provides the conclusion.

2. Biomass: An Energy Fuel

Bioenergy is the most abundant energy resource on Earth and has been used as an energy source for centuries by mankind. Biomass energy sources and new technologies have a great potential to solve the energy problems faced in particular by developing countries. Biomass technologies are an efficient way to dispose of public waste that is collected in large quantities daily from the urban and rural sectors. Future energy supply and environmental concerns are the key driving factors for the increased biomass. The availability of field residues depends on the collected yield crop ratio. The efficiency of residue collection is estimated to be 38% of the overall crop residue production, and MSW collection is about 60% of the total production of waste. As shown in Figure 5, crop residues and treated MSW are used to produce biofuels and renewable electricity, which correspondingly help fill the energy demand–supply gap. Biofuels are also used for heating and cooking purposes in the rural sector [29].

Biomass is a promising renewable source to supply local electricity. The global use of biomass for power generation is rapidly increasing, but biomass still has a large untapped potential. Biomass is a versatile renewable energy source in which energy is harnessed from organic matter, such as firewood, dung, crop residue and solid waste. The use of biomass as an energy fuel is viable because of its future availability and low estimated cost in the world's energy market. Using biomass energy to solve the major problems in power generation, such as climate change, global warming and environment pollution, yields many benefits. Biomass is used as an energy source either directly by combustion or gasification or by creating a biofuel, such as ethanol. Combustion of biomass sources like wood and garbage are used to generate electricity or local heating for homes and offices. Moreover ethanol and biofuel are consumed in transportation sector [30].

Conventionally, fossil fuels, including coal, gas and petroleum, are the primary energy resources used throughout the world, as shown in Table 5 [31]. Their consumption will swiftly increase due to the accelerated growth of populations and industries. This situation is causing a devastating effect on the assets of fossil fuels, global warming and future energy security. Basic services and industrial economy are directly affected by the deficit of electricity and gas. Experts and enterprises are working to partially exchange non-renewable energy resources with renewable energy resources to decrease our dependence on fossil fuels [32]. Bioenergy may not be the primary alternative to energy captured through fossil fuels, such as petroleum products, but it can contribute a relatively good share to total energy production.

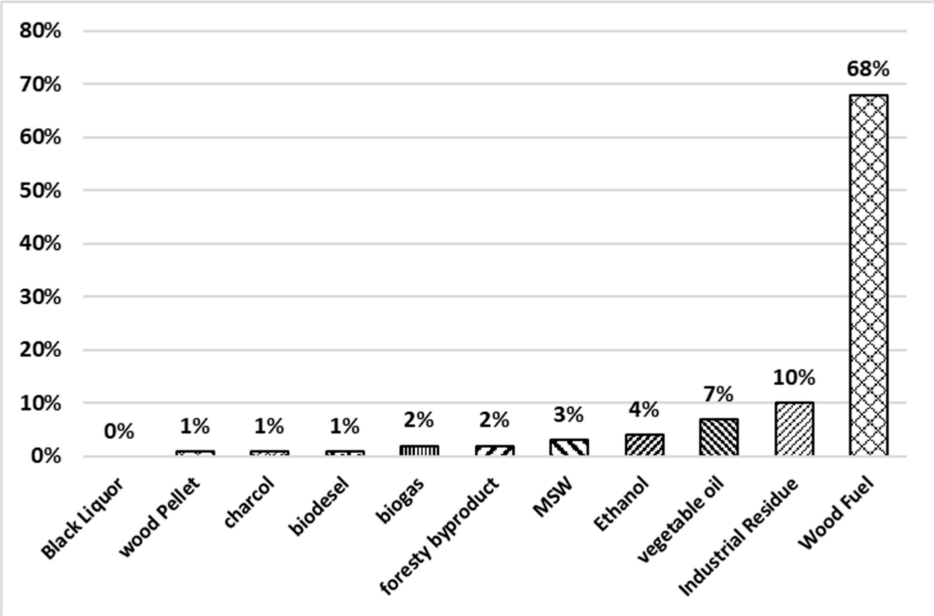

Figure 5. Global biomass distribution as primary resources [30].

Table 5. Global biomass distribution as primary resource.

Source	Percentage %	Source	Percentage %
Biodiesel	1	Wood Pellet	1
Charcoal	1	Ethanol	4
Wood Fuel	69	Municipal solid waste	3
Industrial Residue	10	Forestry Residue	2
Vegetable Oil	7	Biogas	2

2.1. Biomass in Electricity Generation

The emerging trend of biomass power generation has gained much attention in the power market in recent years. Biomass consists of organic components, which are raw materials in energy generation. Advanced technologies are installed to transform thermochemical and biochemical energy into practical biofuels and gases [33] for boosting the potential of renewable energy obtained from biomass, as illustrated in Figure 6 [34].

The cost of moving feedstock to energy generation plants is the key component for estimating the net cost of energy recovery from biomass. The current capacity of biomass and waste fuels is approximately 9.8 GW of electricity, with wood waste having a capacity of about 6.1 GW and MSW having a capacity of about 2.2 GW. The installed capacity of the bioenergy of different countries is shown in Table 6. The potential of electricity generation from biomass in the United States was estimated to be from 22,000 MW to 70,000 MW by the year 2010 [35]. The potential for power generation using biomass in India is almost 18 GW. However, approximately 32% of total energy comes from bioenergy sources. The Indian Ministry of Renewable Energy aims to achieve 10 GW power generation from biomass power by the year 2022 [36].

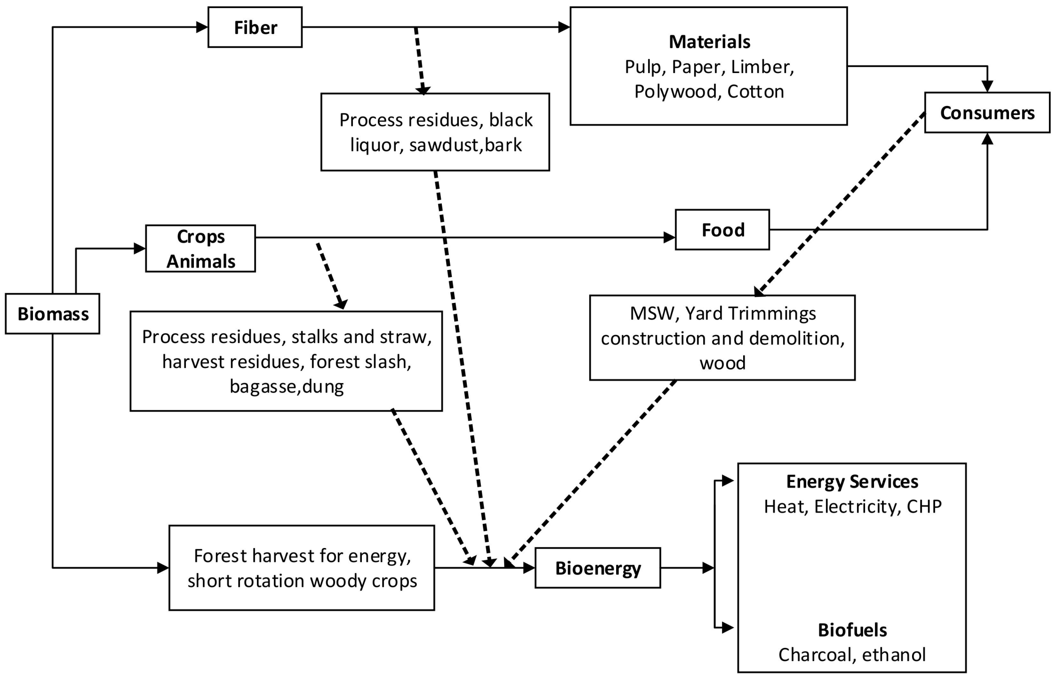

Figure 6. Biomass flow chart.

Table 6. Bioenergy installed capacity [33,34].

Country	Installed Capacity MW	Country	Installed Capacity MW
China	11365	Thailand	3824
India	9533	Germany	8993
Malaysia	940	Brazil	14,583
Indonesia	1746	Japan	2131
America	2459	Europe	36,438
Pakistan	323	World Total	109,213

In Asian countries, valuable residue yield ratios for numerous agricultural crop residue yields are used for electricity generation. Only 35% of residues are removed from field crops without affecting the yields, whereas the recovery factor of crop-processing residues is 100% [37]. In 2017, urban and rural households used 7.6% and 37% of crop residues, respectively. These numbers declined to 0.4% and 6% in 2018. This rapid decline in the conventional use of biomass source implies that crop residues can be utilised to generate sustainable electricity [38].

Modern bioenergy was responsible for 50% of all renewable energy consumed in 2017, contributing four times more than solar PV and wind combined. Modern bioenergy is used in final energy consumption to deliver heat in buildings and for industries. Bioenergy is the largest source of growth in renewable energy consumption over the period 2018 to 2023 and will account for 30% of the growth in renewable consumption in this period, as shown in Figure 7. This situation is a result of the considerable use of bioenergy in heat and transport. Other renewables have minimal penetration in the two sectors, which account for 80% of total final energy consumption [39]. In 2023, bioenergy will remain the major source of renewable energy, although its share will decline from 50% in 2017 to 46% with the expansion of solar PV and wind increases in the electricity sector.

The potential of sustainable and renewable energy obtained from biomass can be delivered throughout the year. Major factors that describe the energy potential of a given source include overall theoretical, technical, economical and practical potential [40]. Advanced biomass gasification technology has been utilised to convert biomass into efficiently synthesised fuel. Major types of bioenergy plants include direct-fired, cofired, gasification, pyrolysis and anaerobic digestion, as explained in Table 7.

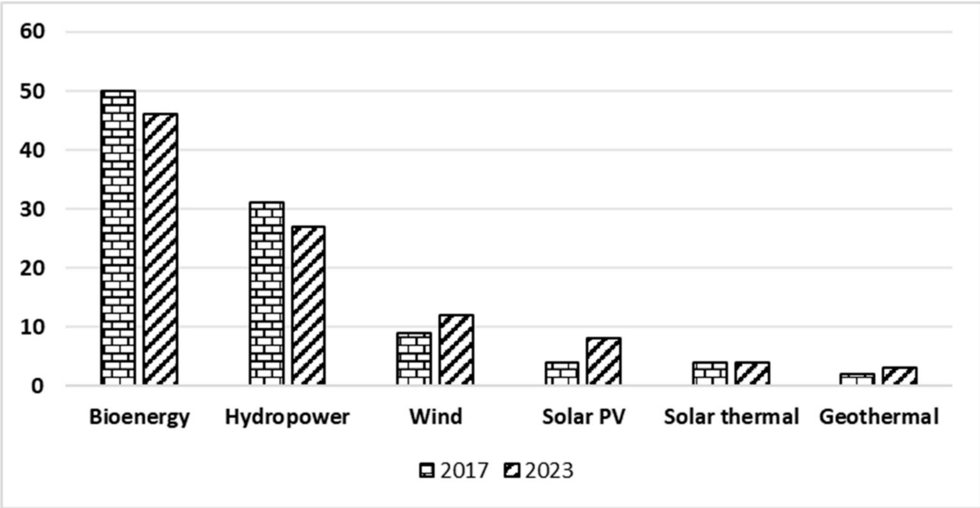

Figure 7. Renewable energy consumption 2017–2023.

Table 7. World electricity productions in biomass.

Country	Biomass TPES (EJ)	TPES (GJ)	GDP (MJ/s)	PES (%)	References
Pakistan	1.27	6.97	8.92	5.58	[41]
Brazil	4.07	16.89	2.99	28.30	[18]
USA	4.12	12.40	0.28	35.51	[42]
India	8.41	6.79	5.88	23.50	[43]
China	9.39	6.81	5.05	17.99	[19]

Several emerging technologies have been investigated to transform waste into energy. Therefore, a number of industries are practising new trends of competitive technologies in waste transformation into power generation for a beneficial impact on social and economic development. Figure 8 shows different types of technologies implemented in biomass conversions, in which biomass is transformed into another practical energy form.

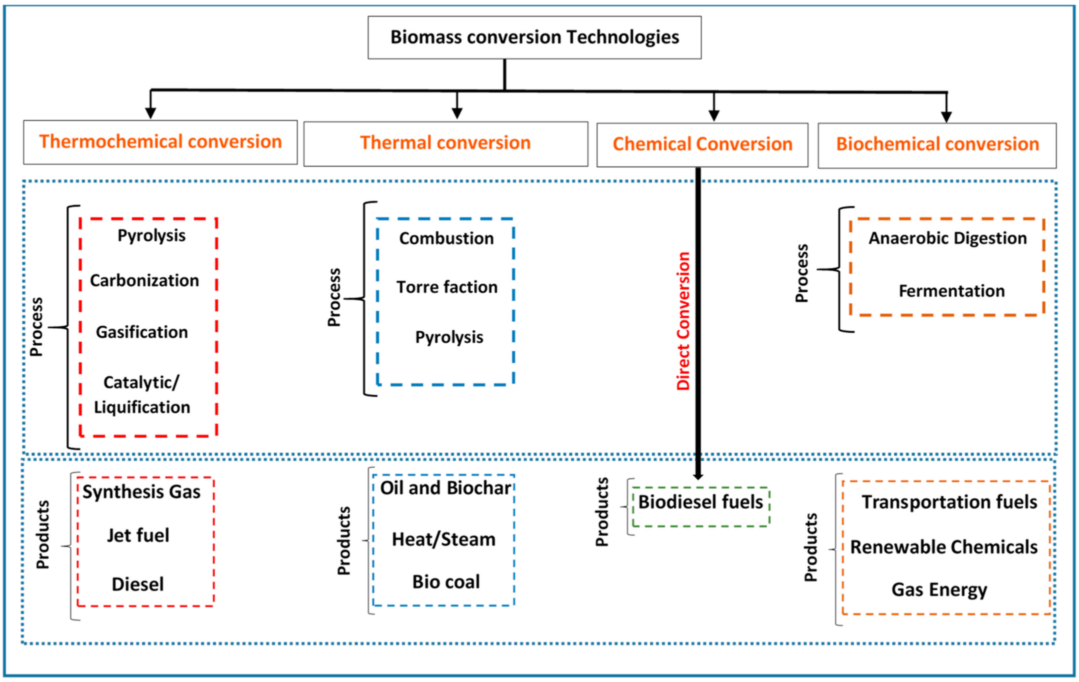

Figure 8. Biomass conversion technologies [44–46].

Microbes have long been used to produce alcohol. Several biochemical factories have recently been working on biochemical conversion treatment techniques on microorganisms, enhancing fermentation technologies and promoting the innovation of fertiliser and fuel in the agriculture sector. These innovations involve evaluating the quality of food and energy [47]. Various new technologies have been implemented in thermochemical conversion of biomass into biofuel and gases in recent years, as shown in Tables 8 and 9. This procedure includes the conversion of solid biomass into biogases in a heating chamber [48,49]. These biogases are then converted into biofuels, which are then condensed into fully concentrated and synthesised forms. This technique is used to produce lubricants, ammonia and biodiesel [50]. The complete cycle of biomass energy conversion process is shown in Figure 9.

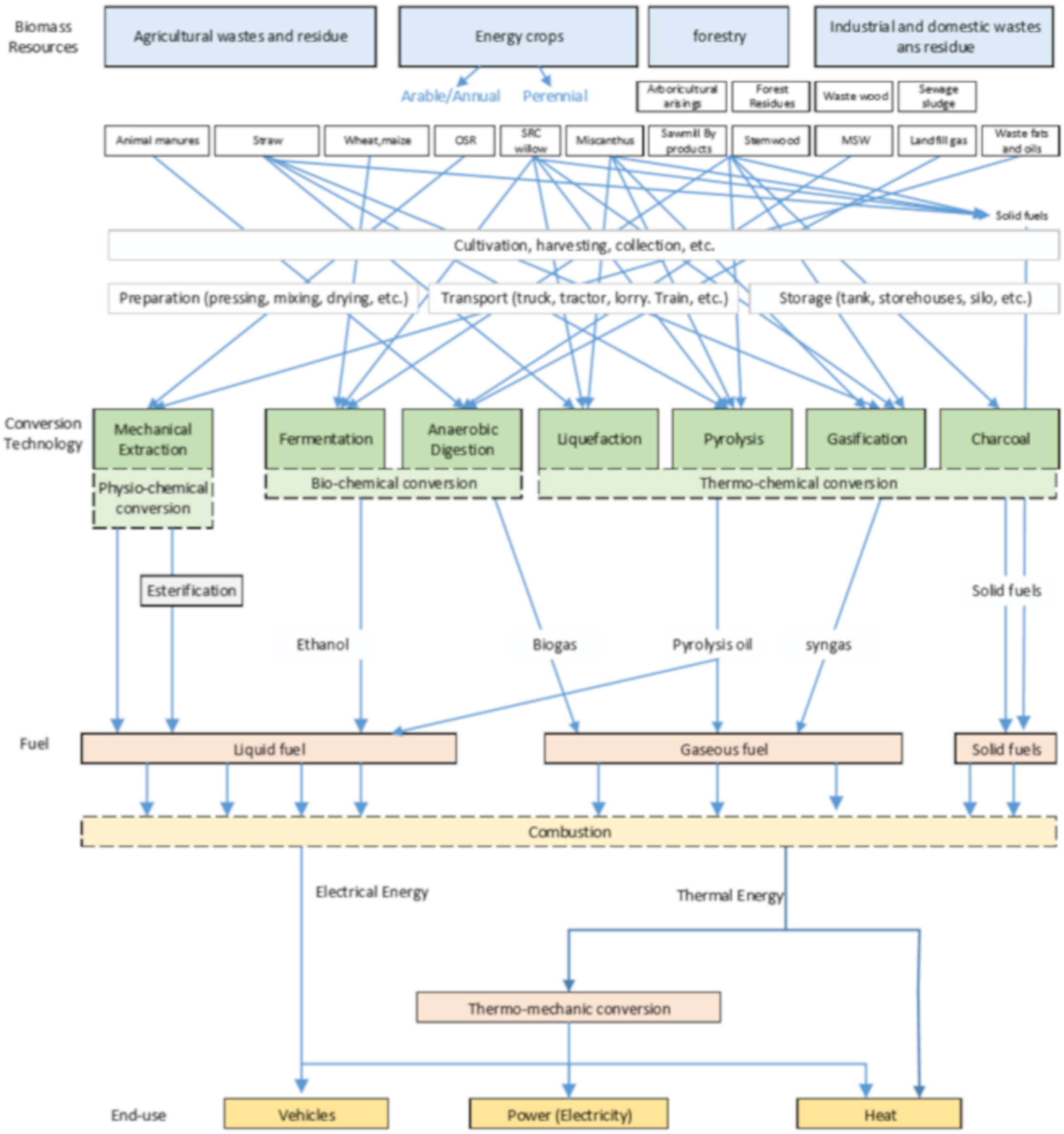

Figure 9. Biomass energy conversion process [51].

Table 8. Biomass conversion techniques.

Conversion Type	Technique	Description
Biochemical conversion	I. Anaerobic Digestion	• Organic materials are used extensively in the production of carbon-rich biogas and methane by anaerobic digestion of food scraps, crop residues and manure of animal and human, in which processing is done in oxygen-free environments. • Syngas and methane are the byproduct of anaerobic digestion which can be used in energy requirements. • Anaerobic digestion normally used to minimizing the secretion from landfills and in handling of wastewater [52,53]. • Anaerobic digestion is a series of multi-stage process. in the hydrolysis process, bacteria dissolve the biomass and then transformation of amino-acids and sugar into hydrogen, carbon dioxide and ammonia which finally outcomes into synthesis gases. • In optimal conditions, anaerobic digestion converts the feedstock into syngas of about 91% which contains roughly 55% methane depending upon the organic content present in biomass [54].
	II. Fermentation	• Fermentation is the process in which yeasts converts the carbohydrates into ethanol most notably alcohol. • The overall process involves different multi-stages [55]. Crop biomass is mixed with water and grounded to produce a slurry. Enzymes and sufficient heat are applied to the ground materials for dissolving and converted to a fine slurry. Glucose slurry is draw into the chamber for fermentation to which mixing of yeast. Ethanol is then extracted from the mixture of fermentation approximately after 48 hours [56].
	III. Trans Esterification	• Trans esterification is a chemical procedure which reduces the viscosity of fatty acids and convert it into combustible fuels, most notable biodiesel.
Thermo-chemical conversion	I. Combustion	• Fifty percent of the world population fulfill its heat and energy requirements through combustion of charcoal, fuel wood, and non-conventional biofuels. • Domestic use of biomass energy is cooking and heating; notably in the developing countries like Pakistan, conventional fuel is more expensive.
	II. Gasification	• Gasification is a much viable procedure in which the solid wastes are transforms into combustible gases which can be used as an energy fuel [57]. • In 1980, a significant awareness about the gasification procedure came about [58].
	III. Pyrolysis	• Pyrolysis is an irreversible chemical procedure in which there is thermal decomposition of the organic residue into liquid, tar and char fractions and gaseous bio fuels. • Utilization of pyrolysis process in solid biomasses or organic waste have become more captivating [59,60].

Table 9. Biomass Conversion Technologies, Process, Products, Advantages and disadvantages [45,46,61].

Technologies	Process	Products	Advantages	Disadvantages
Thermo-chemical conversion	I. Pyrolysis II. Carbonization III. Gasification IV. Catalytic Liquefaction	I. Synthesis Gas II. Jet fuel III. Diesel	I. Cheap, Easy to transport & easy to store. II. Large quantity of charcoal and associated by products can be produced. III. Control of the reaction condition is crude. IV. Less Processing required to produce marketable products. V. High quality products of greater energy density can be produced.	I. Heat is required to produce a synthesis gas. II. High Investment cost is required III. Technical problems are so far limited
Thermal conversion	I. Combustion II. Pyrolysis III. Torre faction	I. Heat/Steam II. Oil and bio-char III. Bio-coal	I. Biomass can be co-fired with existing fossil fuel power stations. II. Use to operate the steam turbine to produce electricity. III. Can be operated at nominal temperature range.	I. Specific temperature and control system is required. II. Emissions of hazardous gases are expected.
Chemical conversion	I. Direct Conversion	I. Biodiesel fuels	I. Advance Biofuel can be obtained	I. Energy input for Agriculture and feed stock production reduced. II. Large-scale conversion operations required.
Biochemical conversion	I. Anaerobic II. Digestion III. Fermentation	I. Transport fuels II. Gas Energy III. Renewable chemicals	I. Applicable in microbial engineering. II. Less potent to greenhouse gas in the atmosphere. III. Make use of the energy in the gas. IV. Reduce the volume of sludge to be disposed for facilitating proper disposal. V. Economically competitive in the medium term.	I. Health threat to people and livestock

2.2. Pakistan Energy Perspective

Pakistan, which is an underdeveloped and populous country, is confronting a drastic electric power crisis, the results of which are challenging for long-term social and economic growth. Currently, the demand–supply gap is met through blackouts. Industries, commercial activities and everyday life are seriously affected by the shortage and high cost of electricity [62]. The current population of Pakistan is about 200 million and is growing at an annual rate of 3.64%. A United Nations report showed that the population of Pakistan is approximately 2.63% of the global population and that it is the sixth most populous country in the world [63,64]. The population of Pakistan increased rapidly from 138.5 million in the year 2000 to 170.5 million in the year 2010 to 200.8 million in the year 2018. The energy consumption and economic growth of any nation are closely related and have a great impact on theoretical and empirical levels. The current average demand is 22,000 MW, and the average shortfall during peak demand is 5000 MW. Electricity demand is increasing at an average annual rate of 8% in Pakistan [65]. The situation has become difficult to manage, especially during peak demand times due to low generation capability. The estimated monthly electric generation is illustrated in Figure 10.

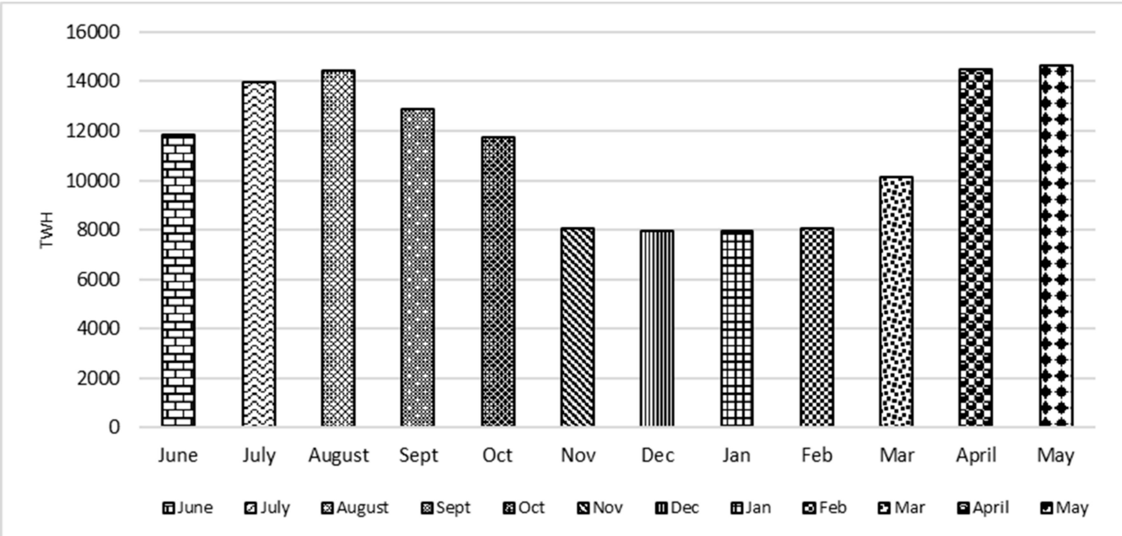

Figure 10. Electricity generation in 2018 (GWh) [19].

Fossil fuels play a key role in Pakistan's power generation sector. Thermal plants generate approximately 62% of power, with 31.5% and 30.5% coming from natural gas and furnace oil, respectively. Hydropower is second to fossil fuel with an overall generation capacity of 33.5%. Major HPPs that contribute to electricity generation are Tarbela Power Plant, Mangla Power Plant and Ghazi Barotha. Moreover, 3% of electricity comes from nuclear power plants, such as Chashma and Karachi nuclear power plants, whilst another 3% comes from renewable resources, including the Jhimpir/Gharo wind and solar projects located in Punjab and Sindh. The total installed energy fuel mix of Pakistan in the years 2017 and 2025 is provided in Table 10.

Table 10. Pakistan installed capacity energy fuel mix [23].

Year	2017		2025	
	Generation MW	**Percentage %**	**Generation MW**	**Percentage %**
Oil	6137	24	6,137	12
Gas/Coal	10,332	41	24,642	49
Hydro	7,116	28	13,142	27
Renewable	852	3	2339	5
Nuclear	787	3	3667	7

Pakistan had a mounted installed power generation capacity of more than 30,000 MW in March 2018. However, the total power generation was only approximately 19,000 MW due to a number of circumstances, including low efficiency of installed power plants and large line losses in transmission and distribution networks. Other major factors in the energy crises of Pakistan are economic inflation and the growing circular debt. In the forthcoming years, the electricity demand of the country is expected to increase by 4% to 5%. The government of Pakistan is focusing on installing additional power plants to overcome the power shortage crisis. The generation of electricity from renewable sources should be considered, and the dependence on fossil fuel sources should be decreased [66]. Domestic, agriculture, industry and commercial are the major electricity consumers. The local customers and the industry are utilising natural gas and furnace oil to meet their energy requirements [67]. The major power plants in Pakistan are listed in Table 11 [37,67–69].

Table 11. Major power plants in Pakistan [37,67–69].

SOURCE	SPONSOR/PROJECT NAME	CAPACITY MW	LOCATION	EXPECTED COD/REMARKS
COAL	• Huaneng Shandong Energy Pvt Ltd.	1320	Sahiwal	Operational
	• Engro Power gen Thar Limited (EPL)	2 × 330	Thar Coal	2019
	• HUBCO	1320	HUB Baluchistan	2019
	• Port Qasim coal-fired power	2 × 660	Karachi	Operational
OIL	• Thermal Power Station	1350	Muzaffargarh	Operational
	• Nishat Group/Lalpir Limited	362	Muzaffargarh	Operational
	• Rosch Power Limited	450	Khanewal	Operational
	• Hub Power Project	1292	HUB Baluchistan	Operational
GAS/COMBINED FUEL (GAS, HSD, RFO)	• Uch 1-2 Power Limited	586 + 426	Baluchistan	Operational
	• Guddu Thermal Station	1750	Sindh	Operational
	• KAPCO	1638	Kot Addu	Operational
	• Bin Qasim Power Plant II	560	Karachi	Operational
	• KAPCO	1638	Kot Addu	Operational
NUCLEAR	• CHASNUPP Unit-1-4	1325	Chasma	Operational
	• KANUPP	137	Karachi	Operational
SOLAR	• Quaid-e-Azam Solar Park	100	Bahawalpur	Operational
	• Harappa Solar Pvt Ltd.	18	Sahiwal, Punjab	Operational
	• Integrated Power Solution	50	Noori Abad	Operational
	• ET Solar (Pvt.) Ltd.	50	Attack, Punjab	Dec-18
	• ACT Solar (Pvt.) Ltd.	50	Sindh	Dec-18
HYDRO	• Tarbela	3478	KPK	Operational
	• Warsak	240	KPK	Operational
	• Mangla	1000	AJK	Operational
	• Ghazi brotha	1450	Punjab	Operational
	• Chashma	184	Punjab	Operational
WIND	• FFC Energy Limited	49.50	Jhimpir	Operational
	• Zorlu Energy Pakistan Pvt ltd	56.40	Jhimpir	Operational
	• Three Gorges Pakistan Wind Pvt ltd	49.5	Jhimpir	Operational
	• Foundation Wind Energy –I Ltd.	50	Gharo	Operational

In Pakistan, fossil fuels account for 65% of the total energy mix, whereas the share of renewables is less than 4%. This situation calls for a comprehensive analysis and review of Pakistan's electric power dynamics and an exploration of the potential of renewable energy resources. Biomass energy is a favourable renewable energy resource and is abundantly available in Pakistan [68]. Biomass resources are found in various forms, from firewood to crop residues to MSW; about 50% of domestic energy necessities are fulfilled by fuel wood and 34% by animal and crop residues. However, fuel wood has become less accessible because the growth rate of forests has shrunk to 8.8% [23,69]. The biomass potential of Pakistan is indicated in Table 12.

Table 12. Biomass resources in Pakistan [70].

Category	Types of Biomass	2015–2016	2017–2018
	Sugarcane	65,482	81,102
	Cotton bales	7717	8235
	Wheat	25,633	26,792
Crops in tones	Rice	6801	7542
	Maize	5271	5702
	Gram	330	340
	Bajra	300	335
	Barley	58	57.9
Animal Live stock in million	Cattle	42.8	46.1
	Buffalo	36.6	38.8
	Sheep	29.8	30.5
	Camel	1	1.1

3. Potential of Biomass Resources in Pakistan

Biomass is a potential energy resource in developing countries. Bioenergy has been used in Pakistan for a long time. Pakistan has a promising bioenergy potential, particularly in rural areas where a considerable amount of available biomass resources exists in the form of indigenous agricultural wastes. Solid wastes from high-density urban areas are the other main raw materials for biomass fuel. The presently available country biomass agriculture sources are shown in Figure 11 [71].

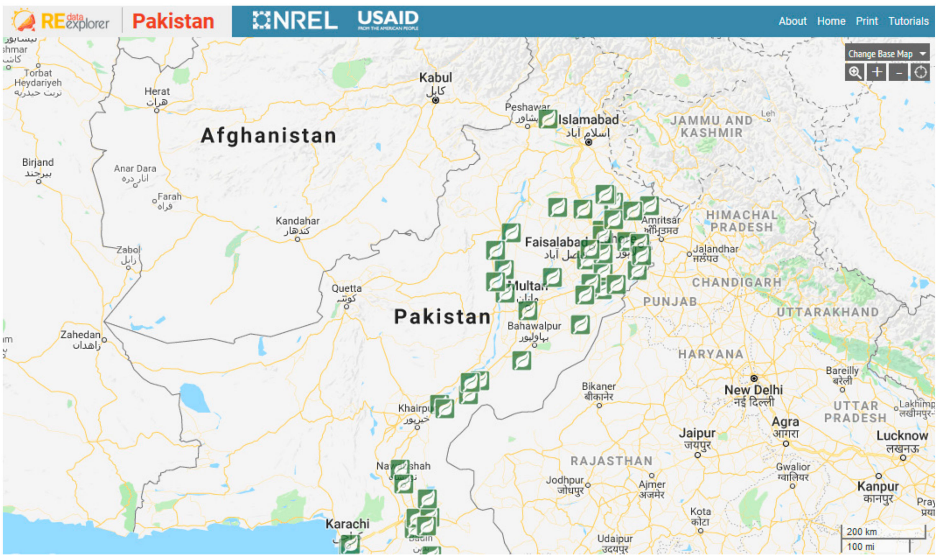

Figure 11. Available country biomass agriculture sources [71].

Biomass energy can help increase the segment of renewables in total energy production from 1% to 5% by the year 2030. Pakistan has over 3000 installed biogas plants to meet its local energy needs [72]. The three major sources of biomass in Pakistan can be categorised into the following:

1. Agricultural/forestry residue
2. Animal manure
3. MSW

The potential biomass resources in the country are crop residues, MSW and animal manure. The total potential of energy from biomass from the years 2010 to 2030 is provided in Table 13 [73]. Table 14 presents the updated summary of the six major crops produced in the years 2017, 2018 and 2019 across the world [74].

Table 13. Geographical biomass potential (TWh).

Type of Residue	2010	2020	2030	References
MSW	8	16	25	[75]
Animal waste	219	280	355	[41]
Field residue	33	38	44	[76]

Table 14. Summary of world's major crop productions in the last three years [74].

Commodity	World	Total Foreign	United State	Asia (WAP)			South America	Selected Other	All Others
				China	India	Pakistan	Argentina	Turkey	
-------Million Metric Tons-------									
Wheat									
2017	756.5	693.7	62.8	133.3	87.0	25.6	18.4	17.3	236.3
2018	763.1	715.7	47.3	134.3	98.5	26.7	18.5	21.0	244.1
2019 Projected	733.4	682.2	51.3	132.5	99.7	25.5	19.5	19.0	232.5
Coarse Grains									
2017	1413.7	1011.1	402.6	270.9	43.5	6.6	48.6	10.8	337.7
2018	1357.3	973	384.3	266.6	47.0	6.2	39.3	13.0	338.5
2019 Projected	1373.6	988.5	385.1	263.8	42.3	6.8	50.4	13.5	337.4
Rice									
2017	490.8	483.7	7.1	147.8	109.7	6.8	0.9	0.5	152.1
2018	495.1	489.4	5.7	148.9	112.9	7.5	0.9	0.5	151.9
2019 Projected	491.1	484.2	6.9	143.6	111.0	7.4	0.8	0.5	153.7
Total Grains									
2017	2661.0	2188.5	472.6	552.0	240.2	39.1	67.8	28.5	726.2
2018	2615.4	2178.2	437.3	549.8	258.4	40.3	58.7	34.5	734.5
2019 Projected	2597.5	2154.2	443.3	539.9	253.0	26.4	70.6	33.0	721.9
Cotton									
2017	106.7	89.5	17.2	22.8	27.0	7.7	0.8	3.2	14.9
2018	123.7	102.8	20.9	27.5	29.0	8.2	0.8	4.0	16.0
2019 Projected	118.7	100.2	18.6	27.0	27.5	7.4	1.2	4.3	15.8
Oil Seeds									
2017	572.8	445.9	126.9	54.9	37.1	3.7	60.2	2.8	85.0
2018	575.4	443.9	131.5	59.5	34.8	4.0	42.5	3.2	87.6
2019 Projected	600.5	465.0	135.5	59.7	35.2	3.9	60.4	3.6	87.0

3.1. Agricultural/Forestry Residues

Agricultural residues are abundantly available biomass sources that can be considered a principal source for power generation. Pakistan, which has an agriculture-based economy where over 60% of the population are involved in agriculture-related activities, has a promising potential to utilise agricultural wastes, as explained in Table 15. The statistics report of the World Bank showed that 47% of the land area is used to grow crops [77–79]. Pakistan has vast agriculture resources and vacant land to support the cultivation of several crops. Major agricultural residues include rice husk, wheat straw, bagasse, rice straw, cane trash and cotton sticks. Traditionally, crop residues are burnt in fields. The major crops in Pakistan include sugar cane, cotton and wheat, which are harvested on a large scale [80,81]. The growth percentage is as follows: cotton (11.4%), sugarcane (7.4%), rice (8.7%), maize (7.0%) and wheat (4.4%) [71].

Table 15. Agricultural residues [82–84].

Sr. No	Sources	Potential
1	BAGASSE/CANE TRASH	• Bagasse is the residue waste obtained from sugarcane fields after juice is taken out from it. • It is usually dumped by sugar mills, but it can be made beneficial in power generation. • Currently bagasse is widely used as an alternative for conventional fuel in a power plant to produce fire for heating the boilers. Electricity generation using bagasse is the profitable method of electricity production in Pakistan.
2	WHEAT STRAW	• Wheat straw is the primary ingredient of food for livestock due to which the use of wheat straw as a fuel source is limited.
3	RICE HUSK	• At the present time, the fuel of brick kilns is mostly dependent upon rice husk and other use of it is as food for animals. So, the use of rice husk as biomass fuel cannot be under considered.

The consumption rate of timber and firewood plays an important role in wood stock and forest area in Pakistan. With the rising population of the country, the consumption of these products is increasing due to the growing energy demand, and no alternatives are available to replace wood consumption. This research is based on time-series macroeconomic data and projections to the year 2040 of wood supply, forest area, population growth and different uses of wood in the country. Wood accessibility in Pakistan is highly reliant on forest wood stock and forest area. Table 16 gives a summary of forest areas in Pakistan with percentage contribution to the total national forests [85].

Table 16. Forest area (hectares) in Pakistan.

Region	KPK	Sindh	Punjab	FATA	Baluchistan	AJK	Gilgit/Baltistan	Islamabad	Total
Forest Area (m ha.)	1.51	0.661	0.554	0.534	0.499	0.435	0.337	0.0203	4.5
National Forest Area (%)	33	14.5	12	11.75	10.8	10	7.5	0.45	100
Total Land Area in Forest (%)	20.3	4.6	2.7	19.5	1.4	36.9	4.8	22.6	5.1

Timber supply from state forests has decreased from 18% to less than 10%, whereas farmland share has increased from about 41% to 84%. Wood yield extraction per hectare will increase from 7.4 m^3 to 10.9 m^3 in 2040. Figure 12 shows that wood stock availability will decline over time. Wood extraction from domestic forests is projected to exceed the annual national wood yield growth (40.112 million m^3) in 2018, and this phenomenon will change the future of Pakistan, as shown in Table 17. The Khyber Pakhtunkhwa (KPK) government pledged to reforest 348,400 hectares for the Bonn Challenge. The aim is to restore 150 million hectares of deforested land worldwide by 2020 and 350 million hectares by 2030 [86].

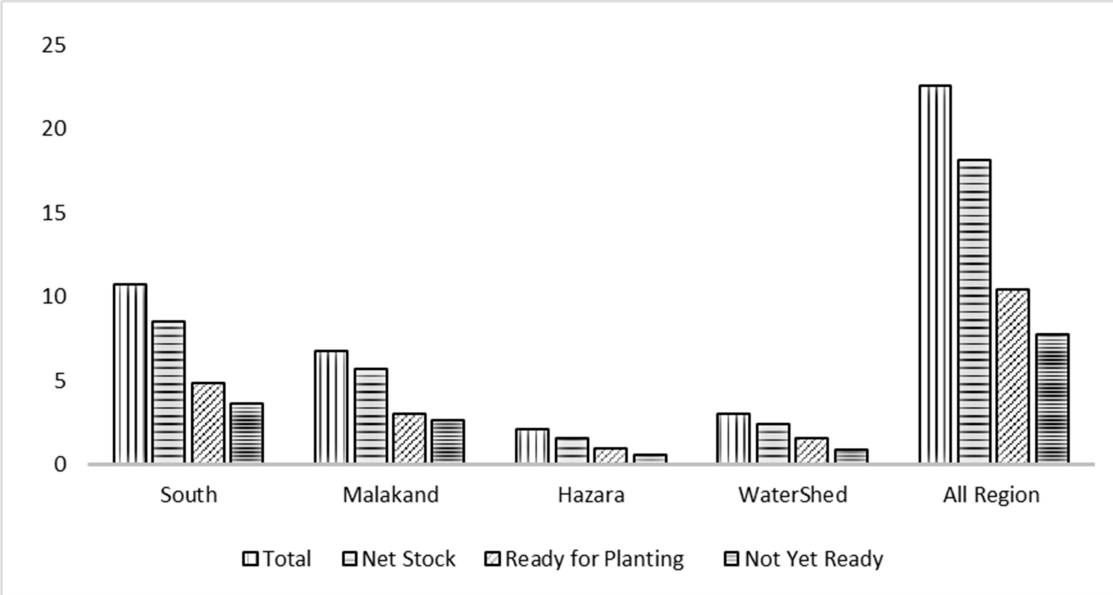

Figure 12. Region-wise status of planting stock.

Table 17. Project detail (Forest Ontario) [85].

Category	Quantity
Central Model Nurseries (Seedling)	50 Million
Private Nurseries (Number)	2700
Fast growing trees(ha)	6000
Along Roads (ha)	500

3.2. Animal Waste

Livestock wastes have been used in burning fire and as soil fertiliser for centuries. Livestock wastes can be utilised to obtain biogases to resolve the current energy crisis. Bangladesh has 6000 small biogas plants. Every year, about 20,000 small biogas plants are being constructed in Nepal. The number of small biogas plants in Vietnam grows by about 18,000 per year [87]. The biogas plant generation capability depends on the contents of organic compounds present in the feedstock. The contents of organic compounds in the manure of cattle and buffalo are about 12% on average. The national herd population, according to 2017–2018 assessments, crosses 196 million with 37% goats, 23.47% cattle and 15% sheep [33,88].

The average total manure produced over one full day is estimated to be about 2.5 million tonnes from 196 million livestock. A 100-cubic-feet biogas plant is required to process 50 kg of animal manure; this 100-cubic-feet biogas plant will be sufficient for households and can generate approximately 3 KWh of electricity. Livestock has an important value in Pakistan and has been receiving increasing interest because of increasing demand [78]. The cattle colony of Landhi in Karachi is the most feasible site in Pakistan for a biogas plant project [89,90]. This cattle colony covers about 3 km^2 and has a population of about 400,000 animals, making it one of the world's largest cattle associations. The animals produce about 4200 tonnes of manure each day and thus have an electricity generating capacity of around 20 MW to 22 MW. The Karachi Electric Supply Company set a target of 500 MW by 2020, which will increase to 1500 MW in 2030. Electricity generated from this plant will be fed into the national grid to meet the growing energy demands of the country [91].

3.3. MSW

The population is also increasing with the expansion of cities and industrial areas. The local municipal committees of Pakistan and other developing countries face a challenge when addressing the growing amount of waste. The increasing population in urban areas is responsible for this upsurge in the amount of waste, thus forming a direct relationship between population and solid waste. Estimations show that the net generated MSW is up to 48 million tonnes per annum, which is growing at an annual rate of 2% in Pakistan. Nevertheless, major cities of Pakistan lack a proper waste management system. About 65% of MSW of cities is collected, and the remaining MSW is either openly burnt or dumped [92].

Open dumping of MSW has hazardous impacts on soil and vegetation growth. Pakistan is facing rapid environmental deterioration due to the prevailing conventional system of collection and dumping of solid wastes. Therefore, waste management has become a major concern in the country [93]. The MSW potential for energy production using biochemical and thermochemical conversion is around 216 and 552 kWh/t, respectively. Pakistan has a great potential in operating biogas plants [94]. Table 18 shows the MSW capability in the major cities of Pakistan [23,74,95–99].

Table 18. Major cities of Pakistan generating MSW [23,74,95–99].

City	Population (Million)	MSW Generation tons/day	MSW Generation (kg/C/day)
Lahore	11.13	6510	0.61
Karachi	14.91	9440	0.61
Quetta	1	326	0.38
Islamabad	1	1000	0.53
Peshawar	1.97	1888	0.49
Hyderabad	1.39	3581	0.56
Faisalabad	3.204	4883	0.39
Gujranwala	2	3125	0.47
Total	36.604	30,753	4.04

The average waste production in Pakistan is around 0.5 kg/day per capital. MSW has the third greatest potential to be a main source of biomass-based energy production in the country. Considering only the urban areas of the country, about 9.8 million tons of MSW were generated in the year 2005. Table 19 shows the estimated physical composition of MSW collected in Pakistan.

Table 19. Composition of MSW [100].

MSW Component	Percent%	MSW Component	Percent%
Ash, Bricks and Dirt	18	Paper	6
Glass	6	Plastic	9
Textile	2	Rubber	1
Cardboard	7	Metal	4
Food Wastes	30	Wood	2
Leather	1	Yard Wastes	14

Adequate and appropriate methods of collecting and utilising solid waste are not yet adopted in the country. As a result, sanitation issues have become severe, thus negatively affecting society. Concerns regarding solid waste management are widespread and require direct or indirect attention [101]. The net collection rate of MSW is 57%, and the collected MSW is about 5.3 million tons. Amongst the collected waste, 50% consists of organic materials that can be used effectively to produce energy. Applying subsequent conventions in the power generation from collected MSW can help address the energy shortfall in Pakistan.

The assessment of power generation from wastes highly depends on the rate of net waste production and collection. An assessment of net MSW production and collection in large cities of the country should be considered to properly utilise MSW [102]. Waste production is evaluated on the basis of the number of residents and the waste collection rate per capita in each city. Pakistan produces 0.38 kg to 0.61 kg of waste per capita per day. In urban zones, the waste collection rate varies from 51% to 61%. REVGREEN Pakistan is a biogas company that has been recently working on different projects in Pakistan, and they use the organic part of MSW to generate biogas energy, as shown in Table 20.

Table 20. Summary of different biogas projects of REVGREEN Pakistan [71].

Location	Capacity	No. of Digester	Feedstock	Biogas per Day m^3/day	Utilization
Islamabad	1×200 M^3	1	Cow Dung farm waste	100	Heat and Power Generation
Kasur	2×100 M^3	2	Poultry	150	70 KVA Gas Generator
Manga Mandi	1×300 M^3	1	Cow Dung	150	50 KVA Gas Generator
Sheikhupura	1×700 M^3	1	Cow Dung Vegetable waste	100	75 KVA Gas Generator
Lahore	1×1200 M^3	1	Cow Dung Vegetable waste	800	150 KVA Gas Generator
Lahore	5×500 M^3	5	Cow Dung Vegetable waste	2000	Methane Production for Factories
Lahore	3×1000 M^3	3	Cow Dung Vegetable waste	1000	Gas

4. Installed Capacity of Biomass in Pakistan

Several projects related to electric power generation are currently in operation in Pakistan to achieve energy supply demand balance due to the high potential of biomass in power generation [103]. These power projects have profitable outcomes due to emerging biomass power generation technologies. Industries utilise crop residues in biofuels, biodiesel and ethanol by applying various biochemical and thermochemical conversion methods, which can effectively save and utilise green energy [104,105]. Biomass potential is high due to the high availability of crops in Pakistan, as shown in Table 21.

Table 21. Potential of harvesting residues of crop based on current usage [106].

Crop Type	Residues Type	Technical Potential Annual (1000 Tons)	Energy Potential TJ/Year	Residues GWh/Year	References
Cotton	Cotton stock	6013	90,195	25,054	[107]
Wheat	Wheat straw	6488	93,427	25,952	[108]
Rice	Rice straw	8314	103,925	28,868	[76]
Sugar Cane	Cane Trash	3516	44,302	12,306	[109]

The government of Pakistan has taken the initiative to install additional biomass energy plants and revise the renewable energy policies because of the large potential of biomass resources in the country. The National Electric Power Regulatory (NEPRA) is working to enhance the power capacity of the country by offering attractive incentives to independent power plants for building new cogeneration firing waste for power generation plants. Wastes from different industries, such as sugar, paper/pulp processing, vegetable storing and livestock, are utilised as bioenergy in electric power generation, as indicated in Table 22 [110]. Power plants operate on the basis of cogeneration and the combination of coal/bagasse as fuel, as shown in Table 23.

Table 22. Biomass energy power plants [110,111].

Location	Capacity	Agricultural Crops	Biomass Supply SOU
Jhang, Punjab	12 MW	Cotton stalk, rice husk, sugarcane trash, bagasse,	Al Abbass sugar Mills Ltd.
Mirpurkhas, Sindh.	12 MW	Bagasse, Rice husk Cotton Stalks, Wood Chips	Tharparkar, Digri, Mirpurkhas, Najma Sugar Mills
Faisalabad, Punjab	12 MW	Rice husk, corncob, cotton sticks	Nil
Matli, Sindh	9 MW	Biogas	Nil
Mardan	200 MW	Nil	TMA, Mardan

Table 23. Cogeneration project in Pakistan [106,110,112,113].

Project	Capacity	Feedstock	Location
JDW Cogeneration	93 MW	Coal/Bagasse	Rahim-Yar-Khan
Hamza Cogeneration	122MW	Coal/Bagasse	Rahim-Yar-Khan
Janpur Cogeneration	60 MW	Coal/Bagasse	Rahim-Yar-Khan
Fatima Cogeneration	120 MW	Coal/Bagasse	Kot Addu, Muzaffargarh
Chishtia Cogeneration	65 MW	Coal/Bagasse	Sillanwali Sargodha
Kamalia Cogeneration	35MW	Coal/Bagasse	Toba Tek Singh
Etihad Cogeneration	60 MW	Coal/Bagasse	Karamabad

Approximately 83 sugar mills are currently operating in Pakistan and produce an average of 33.5 M MT/annum sugar with an overall crushing capacity of 597,900 TCD. They generate approximately 3 GW of power during the sugar cane harvest season, and this power is mostly utilised in sugar mill operations. However, the harvest season lasts for only a few months. Sugar mills run on coal when sugar cane is unavailable to maintain the power supply to the national grid [114,115]. A list of biomass power projects is shown in Table 24. Power generation from sugar mills can be increased by taking steps to improve power utilisation and generation by giving more attention to biomass resources than depending on fossil fuels. Improving biomass techniques can help overcome the energy crises [116].

Table 24. List of generation licensee bagasse/biomass power projects under the renewable energy policy [41].

Sr.#	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 YarKhan, 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

Biomass Energy for Transport Sector

Global reliance on fossil fuels in transportation is currently inevitable because most petroleum fuel (about 80%) is used in the transportation sector. Oil combustion in the transportation sector contributes significantly to global CO_2 gas emissions [117]. Transportation accounts for the largest share of GHG emissions. Vehicular discharges, including nitrogen oxide, sulphur oxide and carbon monoxide, seriously impact the climate. In 2016, the transportation sector contributed nearly 28.5% of GHG. IEA formulated a renewable fuel standard programme to expand the nation's renewable fuels sector and reduce GHG [96].

Alternatives to fossil fuel in the transportation sector include biofuels and synthetic fuels. Their technologies are rapidly evolving and thus lead to substantial environmental benefits, such as electric vehicles, which have fewer CO_2 gas emissions. Advances in the public transportation sector can reduce the nation's carbon emissions by 37 million metric tons annually [97]. GHG emissions from the transportation sector are increasing by 5% annually. The CO_2 gas emissions in Pakistan from the transportation sector were 37.1 million tons CO_2 gas in 2008. If no GHG moderation measurements are taken, then GHG emissions from the transportation sector can reach as high as 66.6 million tons CO_2 by the year 2020 [118].

Pakistan has an enormous potential for biodiesel production due to the availability of multiple feedstock that can be considered for synthesis. Bioplants, such as jatropha and pongamia, can be utilised in biodiesel production. Vehicle efficiency and performance can also be improved using biomass fuels, such as bioethanol and biodiesel. Public and private sectors promote the cultivation of bioplants at various suitable sites. Recent initiatives taken by the Pakistan State Oil aimed to plant 6 million bioplants, which have an estimated 24 million kg of oil-bearing seed capacity, to produce 7.2 million litres of biodiesel worth Rs.345 million [68].

The Pakistan Sustainable Transport Project is a joint venture of the United Nations Development Programme and Global Environment Facility and is being implemented by the government of Pakistan to provide substantial technical support for moderating the increase in energy consumption and the related environmental concerns of the transportation sector in Pakistan. This project also enables investment in environment, drafts a supportive policy framework, improves fuel efficiency and provides awareness about sustainable transport market capacity in the urban transport sector of Pakistan. The estimated total budget was about $7.8 million [119]. Several of the ongoing mass-transit projects are listed in Table 25.

Table 25. Bus rapid mass transit projects in Pakistan.

Metro	Passing Year	Length km	Total Stations	Status
Trans Lahore	1980	160	112	Operational
Islamabad-Rawalpindi	06/2015	22.5	24	Operational
Lahore Metro bus	02/2013	27	27	Operational
Multan Metro bus	01/2017	18.2	21	Operational
Peshawar BRT	04/2018	37	32	Under Construction
Green Line Karachi	12/2017	109	90	Under Construction
Islamabad II	2017	25.6	10	Under Construction

5. Pakistan Metrobus System

The metro bus transport (MBT) project has substantial importance in Pakistan. The government of Pakistan paid a high subsidy and is working to advance the MBT system because a recent survey indicated that both men and women prefer travelling on the MBT to other public transport systems and that women feel comfortable on the MBT. The metro bus system, which is the largest transport network of the government, offers great benefits for the people of Pakistan.

Pakistan has established metro bus systems in different provinces, such as KPK and Punjab. The government designated the Punjab Mass transit Authority (PMTA) to oversee the initial work of the metro bus system to increase system performance. The PMTA operates the transport network in cities such as Lahore, Rawalpindi and Multan, ensuring that the public can travel comfortably on the metro bus system. The PMTA has been working on enhancing the performance, planning, operation and planning of the metro bus network, which includes the following:

- Rawalpindi–Islamabad (RWP–ISB) Metrobus
- Lahore Metrobus
- Multan Metrobus

The metro projects that were launched in Pakistan's cities are listed in Figure 13.

Figure 13. Current and projected cities of Pakistan that operate on the metro bus system.

5.1. RWP–ISB Metrobus

The PMTA operates the metro bus system in Islamabad and Rawalpindi, the twin cities of Pakistan, which greatly impact the economy of Pakistan. Islamabad is a diplomatic area; therefore, the PMTA must ensure that the facilities are sufficient for safe and comfortable travelling. The PMTA completed the construction of two lanes for the mass transit system from Saddar (Rawalpindi) to secretariats (Islamabad) on 4 June 2015. The metro bus system has 24 stations, and its roads are covered by safety steel grilles. The PMTA ensures safety through closed-circuit television systems and trained guards. The PMTA offers convenient facilities for passengers, such as easy ticketing, elevators, bus scheduling and their location. The metro authority serves 151,000 passengers per day in the twin cities alone. As of 1 May 2017, the system has transported 76 million passengers.

The previous government of Pakistan decided to extend the metro bus service that connects Rawalpindi with Islamabad to serve passengers heading for the new Islamabad International Airport. The total estimated fund for this project was Rs16.43 billion, and it was started on April 2017 and was expected to be completed in 2018. The government had extended the metro bus system from Islamabad to Islamabad International Airport, Fateh Jang Road. The citizens of the twin cities can easily access Islamabad International Airport via the metro bus system. This extension work received an Rs16.43 billion grant. The PMTA stated that the project will be completed in 2018, but it has been delayed due to funding problems. The route is designed to have two lanes with a length of approximately 23.7 km.

The PMTA operates the metro bus system in Lahore, which was inaugurated in February 2013. Lahore City is the second largest city in Pakistan and is popular among tourists because of its history and heritage. The PMTA constructed two-lane systems, ensures passenger safety and offers convenience and assistance. The Lahore metro bus system consists of 27 stations, in which the first one is Gajjumata, and the last one is Shahdara. The route length is approximately 27 km.

Rawalpindi Integrated Transportation System Phase-I

The PMTA started the operation of integrated public transport system in Rawalpindi. In phase I of the project, the PMTA planned the addition of six feeder routes to the existing Pakistan Metrobus System. This system uses 78 minibuses (8 m long). In this transportation system, the passengers do not need to pay twice when transferring from one bus or route to other but will pay a discounted fare. The operation of the Rawalpindi feeder routes is shown in Table 26.

Table 26. New Project of PMTA RWP–ISB.

Route #	Route Alignment	Route Length (Km)	Number of Buses
1	Suwan Adda to Railway Station via GT Road, Flashman, Haider Rd, Railway Station	9	12
2	Islamabad Expressway to Railway Station via Airport Rd, Chaklala Railway Dtation, Dhok Kashmirian, Raheemabad Stop, Jinnah Park, Katcheri stop, Punjab Hours, Marrir Br and Railway station	12	16
3	Dhoke Kasmirian to Railway Workshop via Tipu Road, Liaqut Rd, Ghanj Mandi Rd	7	12
4	Dhoke Kasmiria to TB Hospital via Rawal Rd, Rescue 1122, Chandi Choke, TB Hospital	7	12
5	Pirwadai Mor to Murir Bridge via GT Road, Kashmir Road	8	11
6	Faizabad Interchange, IJP Rd, 6th Road, Rehmanabad stop, Sadiqabad chowk, Kahnna Rd, Khanna Pull	9	15
	Total Number of Buses	52	78

The RWP–ISB Metrobus RIMB project engaged an international firm to develop a master transportation plan [112]. RIMB was launched on 4 June 2015 and spans an area of 22 km from Islamabad Pak Secretariat to Rawalpindi Saddar. The project aims to interlink both cities and provide a comfortable transportation facility on this overcrowded route [85]. To fulfil its operational electricity demand, several generators are installed in the metro bus stations. The power capacity is considerably greater than the scheme's requirements, and the generator sets work under load; thus, the fuel and maintenance costs are high.

The fuel and maintenance costs are analysed in accordance with the S.M JAFAR Power Company's reports in 2016–2018. The yearly cost of fuel is about 52 million, and the maintenance cost is about 3 million, as shown in Figure 14. Each metro station has two installed generators; thus, about 48 generators are installed with different ratings, including 250, 230, 350 and 400 KVA with a 360 kW spare rating. The installed capacity of DG set is about 12.5 MVA. The required electricity for metro bus operation is about 60%–70% of the total installed capacity [120]. Twenty DG sets with a 5 MVA installed capacity are required for the ongoing Islamabad II metro bus project [21]. The total electricity requirement for both projects is approximately 17 MW.

This electricity demand can be partially fulfilled by installing nearby small biomass power plants that utilise MSW as fuel because they are abundant in the populous cities of Pakistan, including Islamabad, Rawalpindi, Karachi, Lahore and Peshawar, to generate a high average MSW, as discussed in Section 3.

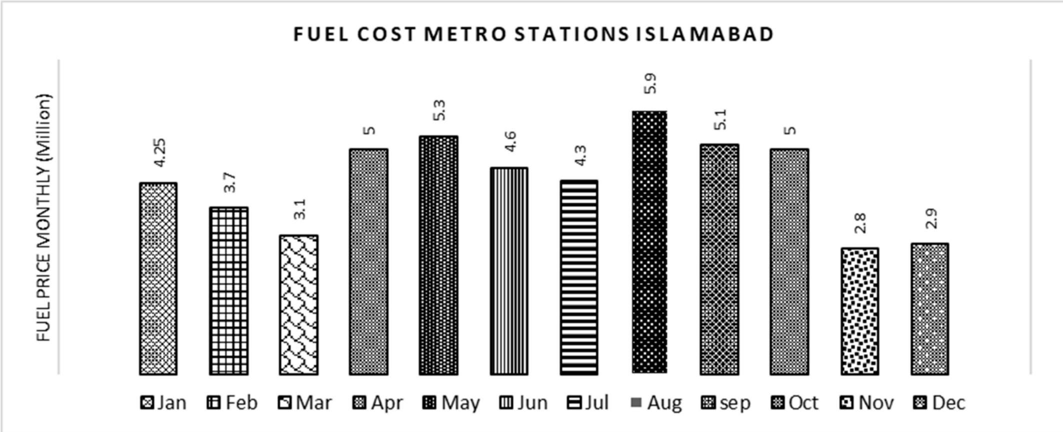

Figure 14. Fuel cost per annum (Metro).

6. Analysis and Recommendations

Pakistan needs to concentrate on renewable resources to achieve a cost-effective and reliable energy system. In the context of exploring available renewable energy options, biomass energy is an emerging renewable resource in Pakistan. Electricity is the backbone of the socio-economic progress of any country. The present energy demand is continuously growing and is a primary concern. Global energy primarily depends on fossil fuels. Concerns regarding climate change, fossil fuel depletion and increasing cost are gradually being acknowledged and have sparked interest in various forms of renewable energy. Energy sources need to be diversified to address energy availability. This study prescribes various measures to utilise indigenous biomass resources in the future energy mix. However, challenges include supply chain management; research and development in conversion technologies; a decentralised system; and provision of better infrastructure, monitored subsidies and public awareness. These issues must be addressed whilst developing an efficient renewable power generation market in Pakistan. Some of the technologies and initiatives have already been introduced to quickly achieve sustainable social, financial and environmental development. Renewable energy has great potential as an alternative to conventional energy to reduce the local electricity deficit, fossil fuel dependency and GHG emissions. Therefore, Pakistan has a strong potential to utilise biomass energy. Effectively evaluated and comprehensive policies should be crafted to systematically control and integrate them at the national level. Pakistan has no unified biomass energy strategy and follows the incremental evaluating policy approach. Suitable fundamental policies must be adopted to adjust development, investment and operation and maintenance costs. The participation of public and private power sectors should be encouraged to start commercial utilisation of bioenergy in combined heat and power production or converting them into vehicle fuels.

This study examines the utilisation of crop residues in biomass energy resources for electricity generation, as listed in Table 27 [74]. Wheat crop residues are traditionally used for cooking, bagasse is utilised in the sugar industry for power generation; and molasses is used to generate biodiesel for the transportation sector. The use of crop residues in the form of solid waste burning is unviable because it produces smoke. Industrial sewage contaminates water and soil. Open dumping of MSW has hazardous impacts on the environment. Pollutants mixed with water seep into the groundwater and cause serious health problems. The density and ash content of biomass are the key factors to determine valuable feedstock. Bioenergy has a highly variable cost range. Costs of transportation, pre-treatment and storage and conversion technologies impact the overall cost of energy generation from biomass. Thus, unlike other renewable resources, biomass power generation depends on the adequate availability of a long-term predictable, sustainable and low-cost bio-feedstock supply. Research on the energy effectiveness of biomass use in electricity generation is evolving. Biomass power plants are being installed at sites where most agricultural waste is available. Energy generation from biomass will increase at a high rate universally, as shown in Figure 15.

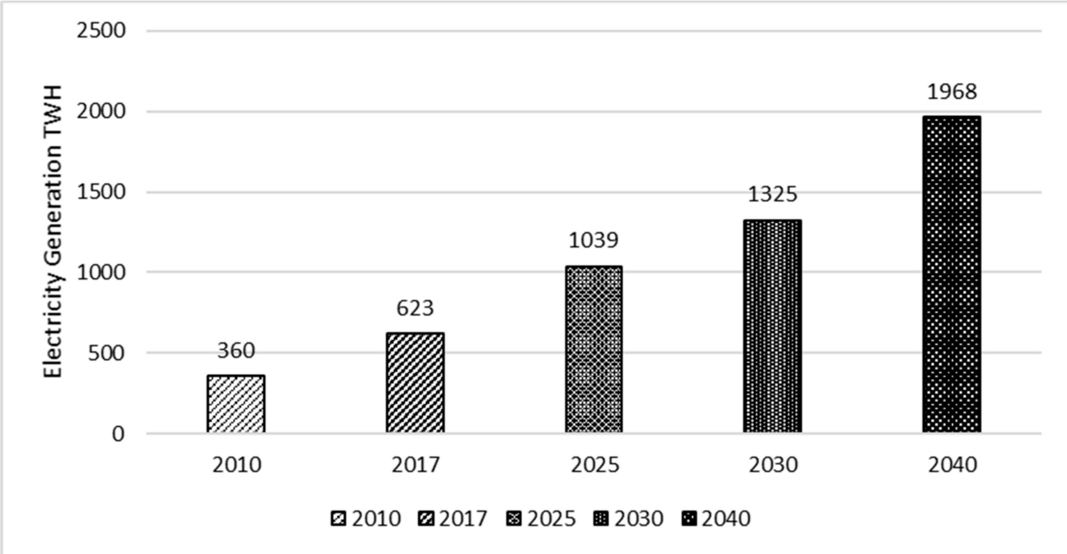

Figure 15. Bioenergy in electricity generation worldwide [23].

Table 27. Summary of major crop productions in different regions of the Earth [74].

Country/Region	Area (Million ha)		Yield (Metric Tons Per ha)		Production (Million Metric Tons)	
	2017–2018	2018–2019	2017–2018	2018–2019	2017–2018	2018–2019
Wheat Area, Yield and Production						
World	220.0	216.35	3.47	3.39	763.06	733.41
United State	15.19	16.03	3.12	3.20	47.35	51.29
Total Foreign	204.81	200.32	3.49	3.39	715.72	682.13
China	24.51	24.21	5.48	5.47	134.33	132.50
Middle East						
Turkey	7.80	7.62	2.69	2.50	21.00	19.00
Iran	6.70	6.70	2.09	2.16	14.50	14.50
Iraq	2.23	2.30	1.81	1.74	4.03	4.00
South Asia						
Pakistan	8.97	8.75	2.97	2.91	26.67	25.50
India	30.79	30.00	3.20	3.32	98.51	99.70
Afghanistan	2.55	2.50	1.96	1.60	5.00	4.00
Coarse Grain Area, Yield and Production						
World	326.49	325.47	4.16	4.22	1357.30	1373.61
United State	36.74	36.41	10.46	10.58	384.26	385.12
Total Foreign	289.75	288.82	3.36	3.42	973.05	988.50
China	44.58	43.76	5.98	6.03	266.57	263.81
South Asia						
India	23.81	23.15	1.97	1.83	46.97	42.25
Pakistan	-	-	-	-	-	-
Afghanistan	-	-	-	-	-	-
Middle East						
Turkey	4.22	4.34	3.08	3.10	12.97	13.45
Iran	1.75	1.79	2.24	2.41	3.92	4.32
Rice Area, Yield and Production						
World	162.62	162.75	4.54	4.51	495.07	491.14
United State	0.96	1.17	8.41	8.43	5.66	6.93
Total Foreign	161.66	161.58	4.52	4.48	489.41	484.21
China	30.75	30.06	6.92	6.82	148.87	143.58
Iran	0.63	0.63	4.03	4.12	1.66	1.70

Table 27. *Cont.*

Country/Region	Area (Million ha)		Yield (Metric Tons Per ha)		Production (Million Metric Tons)	
	2017–2018	2018–2019	2017–2018	2018–2019	2017–2018	2018–2019
South Asia						
India	43.79	44.00	3.87	3.78	112.92	111.00
Pakistan	2.90	2.80	3.85	3.96	7.45	7.40
Bangladesh	11.27	11.68	4.35	4.43	32.65	34.50
Cotton-Seed Area, Yield and Production						
World	32.91	32.63	1.37	1.35	45.13	43.39
United State	4.49	4.20	1.30	1.25	5.83	5.31
Total Foreign	28.42	28.43	1.38	1.36	39.30	28.08
China	3.40	3.35	3.18	3.16	10.80	10.60
South Asia						
India	12.40	12.40	0.99	0.96	12.31	11.89
Pakistan	2.50	2.40	1.32	1.46	3.55	3.22
Middle East						
Turkey	0.40	0.52	2.63	2.88	1.05	1.50
Iran	0.10	0.09	0.98	1.06	0.10	0.09
Corn Area, Yield and Production						
World	190.61	188.46	5.65	5.84	1076.18	1099.91
United State	33.47	33.09	11.08	11.23	370.96	371.52
Total Foreign	157.14	155.37	4.49	4.69	705.22	728.40
China	44.18	41.50	6.11	6.17	259.07	256.00
South Asia						
India	9.22	9.20	3.12	2.82	28.72	26.00
Pakistan	1.23	1.32	4.63	4.77	5.70	6.30
Middle East						
Turkey	0.57	0.53	10.00	10.38	6.00	5.50
Iran	-	-	-	-	-	-
Barley Area, Yield and Production						
World	48.07	49.30	3.00	2.85	144.01	140.72
United State	0.79	0.80	3.91	4.17	3.09	3.33
Total Foreign	47.27	48.50	2.98	2.83	140.92	137.39
China	0.43	0.45	4.19	4.11	1.80	1.85
South Asia						
India	0.66	0.68	2.67	2.61	1.75	1.77
Pakistan	-	-	-	-	-	-
Middle East						
Turkey	3.40	3.60	1.88	2.06	6.40	7.40
Iran	1.60	1.60	1.94	1.94	3.10	3.10
Iraq	1.07	1.00	1.24	1.00	1.33	1.00
Oats Area, Yield and Production						
World	9.51	9.45	2.46	2.40	22.86	22.71
United State	0.32	0.35	2.21	2.33	0.72	0.82
Total Foreign	9.19	9.10	2.47	2.41	22.69	21.89
China	0.21	0.22	1.43	1.42	0.30	0.31
Middle East						
Turkey	0.10	0.11	2.21	2.30	025	0.23
Rye Area, Yield and Production						
World	4.02	3.82	3.06	2.75	12.29	10.51
United State	0.12	0.11	2.12	1.95	0.25	0.21
Total Foreign	3.91	3.71	3.08	2.77	12.05	10.30

Table 27. *Cont.*

Country/Region	Area (Million ha)		Yield (Metric Tons Per ha)		Production (Million Metric Tons)	
	2017–2018	2018–2019	2017–2018	2018–2019	2017–2018	2018–2019
Middle East						
Turkey	0.10	0.08	3.17	2.91	0.32	0.32
Oilseed Area, Yield and Production						
World	-	-	-	-	575.35	600.47
United State	42.79	41.78	3.07	3.24	131.50	135.50
Total Foreign	-	-	-	-	443.86	464.97
China	24.16	24.46	2.46	2.44	59.90	59.70
South Asia						
India	33.83	34.50	1.00	0.98	33.99	34.44
Pakistan	3.11	2.80	1.27	1.29	3.96	3.61
Middle East						
Turkey	1.11	1.36	2.53	2.60	3.17	3.55
Rapeseed Area, Yield and Production						
World	35.37	35.02	2.09	2.01	74.03	70.22
United State	0.81	0.79	1.75	2.09	1.42	1.65
Total Foreign	34.56	34.23	2.10	2.00	72.60	68.57
China	6.65	6.47	2.00	1.99	13.27	12.85
South Asia						
Pakistan	0.24	0.25	096	0.98	0.23	0.23
India	6.00	6.50	1.08	1.00	6.45	6.00
Bangladesh	0.25	0.25	0.92	0.92	0.23	0.23
Sunflower seed Area, Yield and Production						
World	25.98	26.46	1.83	1.91	47.41	50.47
United State	0.54	0.50	1.81	1.75	098	0.88
Total Foreign	25.44	25.96	1.83	1.91	46.43	49.59
China	1.25	1.25	2.50	2.60	3.12	3.25
South Asia						
Pakistan	0.08	0.07	1.13	1.07	0.09	0.08
India	0.33	0.40	0.70	0.81	0.23	0.32
Middle East						
Turkey	0.60	0.75	2.21	2.40	1.55	1.80
Iran	0.04	0.04	1.08	1.08	0.04	0.04
Peanut Area, Yield and Production						
World	25.90	25.26	1.73	1.66	44.91	41.95
United State	0.72	0.55	4.49	4.55	44.91	41.95
Total Foreign	25.18	24.71	1.66	1.60	41.68	39.47
China	4.45	4.56	3.71	3.73	17.09	17.00
South Asia						
Pakistan	0.09	0.10	094	0.95	0.09	0.09
India	4.93	4.70	1.35	1.00	6.65	4.70
Soybean Area, Yield and Production						
World	124.69	128.31	2.72	2.88	339.47	369.20
United State	36.23	35.75	3.31	3.50	120.04	125.18
Total Foreign	88.46	92.55	2.48	2.64	219.43	244.02
China	7.60	8.83	1.84	1.81	15.20	16.00
Middle East						
Turkey	0.03	0.03	3.75	3.81	0.09	0.10
Iran	0.07	0.07	2.29	2.29	0.16	0.16
South Asia						
Pakistan	-	-	-	-	-	-
India	10.40	11.00	0.80	1.00	8.35	11.00

This study evaluates the present situation of power, transportation, and energy in Pakistan. Furthermore, it argues the potential and transportation dependency on biomass energy renewable resource as a future choice. Different authorities, such as NEPRA and Alternative Energy Development Board (AEDB), in Pakistan are determined to fill any gaps in biomass energy by examining the generation policy framework and drafting a transparent process for tariff determination to boost its development. The NEPRA Act 1997 on power clearly authorises federal and local governments to impose tariffs and other terms and conditions for the supply of electric power facilities. However, a clear guideline for tariff regularisation has yet to be established. Feed-in tariff is regulated on small-scale solar PV and bagasse cogeneration power plants, whilst a minimum feed-in tariff is expected to promote innovations in biomass technology development. The NEPRA Act 1997 also provides a clear path to regulate the energy sector in a transparent manner. The AEDB Act 2010 further clarified the regulation processes for the development of renewable power generation. The absence of a formal policy and procedures will make determining the energy prices and obtaining permits difficult for investors. As a result, investing in biomass power generation is challenging. Even in the presence of all policy and regulatory aspects, a transparent financing policy is necessary to attract significant investment in biomass power generation. Some approvals have been presented to create an atmosphere for soft financing for biomass power projects. Site assessment of isolated vacant spaces is needed for renewable energy generation projects, primarily in Federally Administered Tribal Areas, Sindh Province, Baluchistan Province, KPK province, Azad Jammu and Kashmir and North Areas. This study examines the technological improvements, cost reductions and policy framework support, which are the key factors in improving biomass power ability. The major challenges and their solutions need to be addressed whilst forming future policy frameworks for biomass power generation, as listed in Table 28 [99,121–126]. In addition, the Table 29 concluded the important recommendations and suggestions for the utilization of biomass resources as a fuel source in transportation, industrial, energy and power sectors in Pakistan.

Table 28. Recommendations for biomass energy production.

CHALLENGES	RECOMMENDATION
BARRIERS AND CHALLENGES	• Inaccessibility to the located renewable resource • Resource availability and net cost • Low generation capacity of resource • Lack of modern technologies • Unapproved professional models • Uncertainty in supervisory policies • Lower scalability • Small project share • Higher cost of contract for loan dispensation • Less striking by bankers and venture funds
POLICY MAKING	• Ownership models • Operation and risk management • Cost analysis of resources • Resources delivered • Cash flow
PRODUCTION BASED INCENTIVES	• Resource risk is not shifted to sponsor • Protection against political risk • Attractive internal rate of return. • Reduce import duties on facility • Guaranteed purchase of all available renewable the energies • Grid connectivity and regulation is the responsibility of the purchaser

Table 28. *Cont.*

CHALLENGES	RECOMMENDATION
MARKETING	• Setup few small-scale power projects for demonstration • Provide substantial financial support for development • Support bidding of IPP under solicitated and unsolicited categories • Defining site allocation for power plants • Categories various zones the ensure the biomass availability • Promote new technologies for efficient output
ACCESS TO FINANCE	• Funding on research and development • Mandatory use of renewable projects in the public-sector • Monetary incentive • Trade effectiveness • Competitive tariffs • Minimum feed-in tariff • Decrease sales, income, upfront and withholding tax • Ease in currency conversion

Table 29. Biomass energy utilization in Pakistan in transportation, industrial and power generation.

Application	Potential	Key Observations	Discussion/Recommendation
Transportation	I. Biofuel is environment friendly. II. By utilizing the fuel based on biomass like biodiesel can increase the transportation vehicles efficiency. III. Free from emission of hazardous gases such as Sulphur, carbon monoxide.	I. It is observed that mode of transportation in Pakistan is based on liquid fuel. Now a day's hybrid vehicles are increasing to fulfill the fuel requirement. II. Developed countries like United states (US), uses biomass based fuel for transportation like by converting the biogas into bio-methane.	I. By proper utilization of biomass type fuel concept. II. Pakistan can produce fuel from biomass resources instead of importing fossil fuel like petroleum, gas, diesel and gasoline etc. III. Changing the vehicles technology by implementing the efficient hybrid/electric vehicles. IV. The EVs, are more efficient in energy (25–40%) as compare to old conventional vehicles (17–21%), converting fuel into energy. V. New vehicles/transportation policy is needed to use more electric and hybrid vehicles for limited CO_2 carbon emission per passenger mileage with advance infrastructure and EVs charging stations. VI. A tax policy is need to be investors friendly to promote the biofuel market. VII. To focus the market to keep the demanding biofuel products supply at the standard price. VIII. In upcoming days, a flex fuel engine is need to be installed for fuel powered vehicles. IX. In commercial transportation like buses, a methane type should be used for low carbon emissions.

Table 29. *Cont.*

Application	Potential	Key Observations	Discussion/Recommendation
Industrial Fuel	I. The emission of harmful gases and greenhouse effect can be controlled by recommending biofuel as a substitute. II. The reduction in greenhouse gases and security of fuel is guaranteed by using the biofuel.	I. Due to continuous utilization of fossil fuel, the atmosphere is disturbed and facing harmful smog and fog challenges in Pakistan.	I. Instead of importing fossil fuels from foreign countries, Pakistan has a lot of potential to run the industries by producing its own biomass-based fuel. II. In Pakistan, the wood fuel can be substituted by the cogeneration of boiler, furnace and cooling in a medium density. III. It will be atmosphere friendly as well. IV. Pakistan government needs to bring the private sector to invest in the installment of advanced bio-fuel plants.
Energy Generation	I. Exploitation of solar, wind, and biomass potential. - Wind: 132 GW. - Solar: 2.9 Million MW. - Biomass: 4000–6000 MW.	I. Due to being neglected and not amending the energy policy, Pakistan is unable to get benefit from the biogas fuel in energy sector.	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. V. More advanced and high efficient energy technologies is implemented in the country like LED bulbs. VI. The expansion of installing the biogas plants for power generation, the government is needed to encourage the subsidy price guideline as compare to carbon price to make the system more competitive.
Power production	I. In 2015–2016, the National Transmission and Dispatch Company (NTDC) in Pakistan, has produces the power generation of about 63 MW, producing a total of about 146 MW from bagasse-fuel built power plants, generating a total energy of 547 GWh.	I. It is observed that during 2018–2019 many power plants are in use for the generation of fuel from the biogas. II. In 2015 the major plants that are initiated are working on biogas steam turbines are utilized for future power generation	I. The year 2019 is significant due to the initiative of power generation policy implementation in term of hybrid and utilization of biomass resources. II. Micro-grid concept can also implemented in Pakistan for better control, and atmosphere friendly electricity production. III. Availability of water resources expansion. IV. Logistical management is needed for biomass supply to the generating power plants.

7. Conclusions

This article presents an extensive analysis of the biomass renewable energy potential in Pakistan based on the current energy scenario and future evaluation of biomass potential in electricity generation and in transportation fuel. It also highlights the availability of indigenous biomass resources and state-of-the-art biomass conversion technologies. The rapid development in the technology and the improving market strategy prospects serve as bases to explore the vast potential of biomass energy. This study analyses the conditions for increased and efficient use of biomass in Pakistan to meet electrical power generation requirements. Pakistan has a massive biomass potential for energy conversion. Multiple biomass power generation and biodiesel production projects have been started in Pakistan to fill the energy supply–demand gap. This study can be further enhanced by obtaining biomass energy data from the field, industries, organisations and private and government institutions. This study is expected to assist government authorities, such as NEPRA and AEDB, in modelling the biomass and biofuel transportation and energy projects.

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Abbreviations

AEDB	Alternative Energy Development Board
COD	Commercial operation dates
GEF	Global Environment Facility
CNG	Compressed natural gas
FY	Financial year
GENCO	Generation Companies
UNDP	United Nations Development Program
GHG	Greenhouse gas
IGC	Isolated Generation Company
IFC	International Finance Corporation
IESCO	Islamabad Electric Supply Corporation
KANUP	Karachi Nuclear Power Plant
MW	Megawatts
MT	Megatons
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
PEPCO	Power Company
PCRET	Pakistan Council Renewable Energy Technologies
PV	Photovoltaic
PAEC	Pakistan Atomic Energy Commission
PJ	Petajoule
RIMB	Rawalpindi-Islamabad metro bus
SNG	Substitute natural gas
TWh	Tera watt hour
TPES	Total Primary Energy Source
WAPDA	Water and Power Development Authority

WEC World Energy Council
WTO World Trade Organization

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