Mehran University Research Journal of Engineering and Technology
Vol. 40, No. 3, 591 - 605, July 2021
p-ISSN: 0254-7821, e-ISSN: 2413-7219
DOI: https://doi.org/10.22581/muet1982.2103.13

Perspective of Bioenergy in Pakistan for Sustainable Eco-Friendly Energy Substitute: A Review

Ghulamullah Maitlo[1], Sikander Ali Abbasi[2], Rashid Mustafa Korai[3], Abdul Ghaffar Memon[4]

RECEIVED ON 25.09.2019, ACCEPTED ON 15.09.2020

ABSTRACT

Pakistan has remained an energy deficient country for the last few decades. The supply of electricity decreased in 2002-2007 against the exponentially increasing demand in Pakistan. In the meantime, severe load shedding was started across Pakistan that negatively affected the economic growth of the country. More than 63% of the population in rural areas live without electricity. The government cut down electricity supply eight to twelve hours per day in terms of load shedding that adversely affects the living standards and economic growth of the nation. In the world, Pakistan stands on 133 regarding ranking in energy consumption. Energy usage per capita in Pakistan is 482 kilograms of oil equivalent per year (kgoe/a) which is very low when compared with the industrialized countries. Besides that Pakistan strongly adheres with non-renewable energy options to mollify its energy demand. The import of fossil fuels to meet energy demand adversely affects the economy of Pakistan. This review helps in the identification of indigenous available biomass resources and their conversion processes for power production to improve power generation, living standards and economy of the country. The application of indigenous biomass resources for electricity generation will reduce the pressure caused by increased demand for energy.

Keywords: Biomass, Bioenergy, Potential, Sustainability, Pakistan.

1. INTRODUCTION

1.1 Current Scenario of Energy Shortage and Alternative Sources

Fossil energy dominates the supply of energy anywhere in the world and it is depleting, as every nation requires energy to fortify its development and prosperity and for enhancing the plight of common people [1]. Besides that consumption of fossil fuels results in greenhouse gas emissions that damage the environment while renewable energy is environmentally friendly. Therefore throughout the trend is developing to increase the contribution of renewable energy in the global energy mix [2]. Renewable energy can be used again and again due to their unending nature [3].
Certainly, one in four people on the earth lacks the right to use basic energy facilities, this is a major impediment to explore existing disorders in economic and social growth [4]. This is the reason that an uninterrupted supply of energy is an essential ingredient for virtually all accomplishments such as lighting, heating, cooking, transportation, food

[1] Department of Chemical Engineering, Dawood University of Engineering and Technology, Karachi, Sindh, Pakistan. Email: metlo2696@yahoo.com (Corresponding Author).
[2] Department of Energy and Environment Engineering, Dawood University of Engineering and Technology, Karachi, Sindh, Pakistan. Email: abbasisikandar12@gmail.com
[3] Department of Petroleum and Gas Engineering, Dawood University of Engineering and Technology, Karachi, Sindh, Pakistan. Email: engr_rashidmustafa@yahoo.com
[4] Department of Environmental Engineering, NED University of Engineering and Technology, Karachi, Sindh, Pakistan. Email: abdulghaffar@neduet.edu.pk

preservation, storage, educational activities and industrial operations. Throughout the world, the last two centuries have observed a rapid growth in the exploitation and development of energy resources. The energy intake per capita is considered one of the important indicators to access the development of any country. Therefore, energy-related concerns and strategies are generally focused on the increasing supply of energy. The supply of electricity decreased in 2002-2007 against the exponentially increasing demand in Pakistan. In the meantime, severe load shedding was started across Pakistan that negatively affected the economic growth of the country. It is expected that the demand will reach 35738MW in 2020 [5]. As per statistics of international energy association nearly 51 million people in Pakistan lack access to electricity. More than 63% of the population in rural areas live without electricity. The panacea is hidden in the application of renewable energy at a national level [6]. A wide variety of alternative energy options such as solar, biomass, wind, tidal and geothermal are not properly utilized for getting energy [7]. The energy released from the consumption of fossil fuels is generally categorized as non-renewable energy. These sources are very limited and expensive for energy production and will end up in the coming few decades. Similarly, energy which is collected from wind, solar, hydro, biomass sources are categorized as renewable energy. Renewable energy is cheap, available in abundant quantities and pollution-free. Among renewable energy sources, biomass in bulk quantity is produced and wasted in million tonnes per year. As global energy demand has increased tremendously as a geometric average of 5.6% from 1973 and onwards. Fossil fuel contribution in world primary energy consumption is more than 80% [8]. Worldwide proved fossil fuel reserves are 1688 billion barrels oil, 6558 trillion cubic feet of gas and 891 billion tons of coal respectively [9]. These energy resources are used up at the frequency of 0.092 billion barrels, 0.329 trillion cubic feet and 7.89 billion tons per day. Whereas the trend in the share of renewables is observed to be increased by around 3% and is expected to be increased by 8% up to the year 2035 [9]. Figure 1 shows our excessive adherence to fossil fuels for energy generation. As per OECD/IEA 2011 report, world fuels share in total primary energy are oil 32.5%, gas 21.46%, coal/peat 27.38%, biofuels and wastes10.03%, nuclear 5.42%, hydro 2.31% and others 0.9%.

Because of the mounting concern of environmental worsening and rising dependence on imported energy, advanced countries, and growing economies have been resorting to renewable and environmentally friendly energy substitutes in recent times. In this review, the availability of biomass and its potential for power generation is evaluated as it is largely an unexploited source of renewable energy in Pakistan. Biomass can be used as a feedstock for biomass conversion technologies.

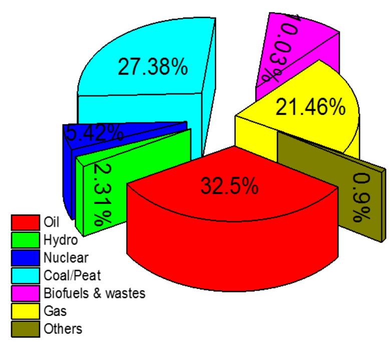

Fig.1: World fuels share in Total Primary Energy Supplies [10]

1.2 Energy Situation in Pakistan

Pakistan is experiencing the most awful energy quandary in its history. Lack of energy availability in the country is not only slowing down economic activities but also causes prolonged breakdowns in supply. The industrial production capability of production units has decreased to approximately fifty percent in recent years. Pakistan heavily relies upon fossil fuels to meet its energy demand. The non-renewable sources used for the production of energy for a few decades are expensive and less environmentally friendly. Fig. 2 shows that Pakistan's total energy primary supplies were nearly half of the developing Asia group.

As per the statistics of WAPDA, the energy requirement will surge to about 40,000 MW in 2020 [12]. The total power generated and consumed in the country for the financial year 2014-15 was 106,966 GWh, and the share of each source is given in Fig. 3. The electricity generation sources and their contribution to electricity production remained oil

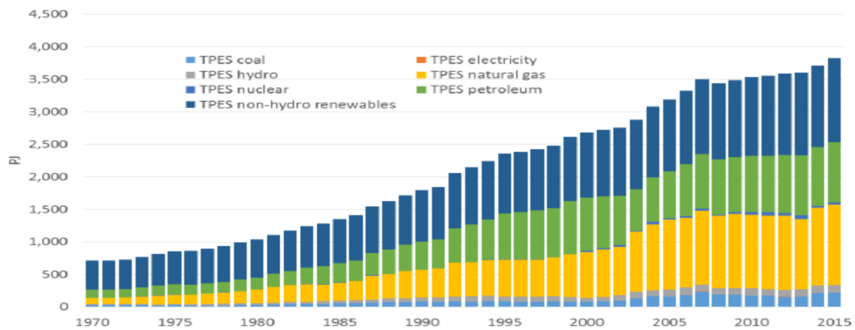

Fig. 2: Primary energy means by source [11]

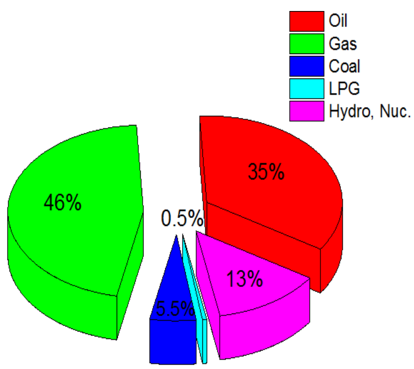

Fig. 3: The contribution of different fuels in electricity production [13].

35%, gas 46%, hydro nuclear 13%, coal 5.5% and LPG 0.5% respectively. It is obvious that the oil and gas sectors are key contributors to electricity generation. Thus the electricity generated using oil and gas is very expensive and is not within the reach of the common people. The Government of Pakistan has spent 1.52 trillion rupees for oil import since the last few years, most of which are used for electricity generation [13]. The contribution of renewable sources in power production in the year 2014-15 is less than 1% as represented in Fig. 3.

In year 2015-16 electricity consumption by various sectors are industrial 35.22%, domestic 24.45%, transport 32.34%, commercial 3.99%, agriculture 1.7%, other Govt. 2.2% [14]. The generation of electricity by different companies in Pakistan is given in Fig. 4.

The percent share in power generation by different companies in Pakistan, WAPDA is providing the maximum share of energy 41.5%, followed by IPPs, 19.8%, KESC, 8.7%, KAPCO, 6.6%, HUBCO, 6.3%,

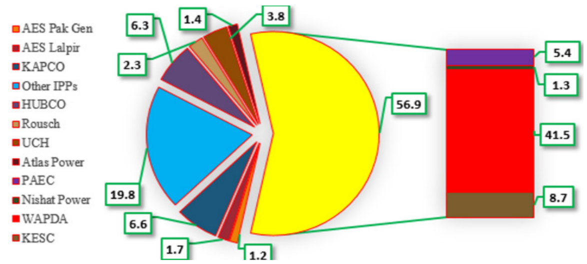

Fig. 4: Percentage share in electricity generation by companies 2014-15 [15].

AES Pak Gen 1.2%, Nishat Power 1.3%, Rousch 2.3%, UCH 3.8%, Atlas Power 1.4%, AES Lalpir 1.7% and Pakistan Atomic Energy Commission (PAEC) 5.4% respectively. Energy requirements are swiftly growing in Pakistan. In the last fifteen years, demand for energy is amplified by 80% from 34MTOE in 1994-95 to 70.3MTOE in 2014-15. Pakistan is deeply reliant on non-renewable energy supplies to mollify its energy requirements [16]. The energy consumption per capita oil equivalent per annual is represented in Fig. 5.

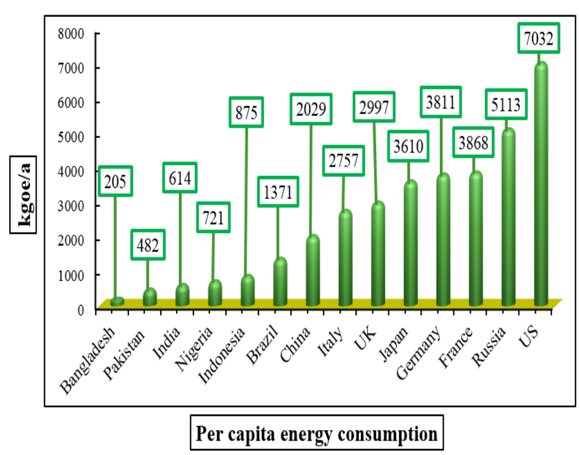

Fig. 5: Energy use per capita in different countries [17]

Conferring to the Government of Pakistan, the per capita energy intake of Pakistan is very low as compared to the U.S., Russia, France, Germany, Japan, UK, Italy, China, Brazil, India, and even from Indonesia. Pakistan's ranking regarding per capita energy consumption lies in 133 positions in the world. The energy inaccessibility for the country has continued core obstruction to the economic well-being of the nation. The government of Pakistan is determined to take major decisions to ensure the persistent supply of energy by pursuing strategies of increasing sustainable energy resources within the country and attracting foreign investment in the energy sector. Attracting foreign investment in the energy sector will enhance interregional co-operation. Pakistan is rich in alternative energy resources if these resources are sighted appropriately and used efficiently will not only minimize over-dependence on foreign aid for fossil fuel imports but also will increase energy intake. The accessible renewable energy resources in Pakistan have the greatest perspective to meet domestic energy needs, unluckily these means have not been sighted appropriately. According to the 2017 census of Pakistan, its population is 199.1 million and has approximately 1.86% of an annual growth rate. The rural population of the country is approximately 62 percent of the total population. Owing to speedy growth in population and energy demand has put massive pressure on the federal government to capitalize and go through its energy portfolio. Consequently, it is foreseen that out of all the renewable energy resources, biomass is a potential source that can assist vastly to the current energy predicaments encountered by the country. The classification of biomass sources is shown in Fig. 6.

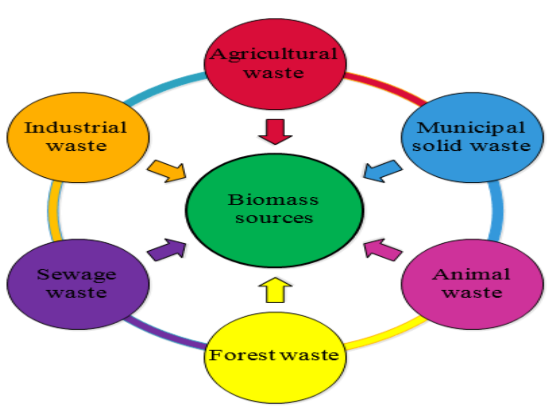

Fig. 6: Classification of Biomass Sources

More than 40% of the households in the country are deprived of electricity, a load shedding approximately of 8 to 12 hours per day causes a financial loss of 272.5 billion rupees per annum and a loss of 400,000 jobs [18]. Considering the assessed indigenous energy sources and their effective application for power generation will minimize the load shedding effects faced by Pakistan and will help in boosting the economy of Pakistan.

2. BIOMASS USES AND IMPACTS

Energy from the sun is stored in plants and animals. It is the most valuable resource of energy on the earth, energy from the sun is harnessed by the plants through the photosynthesis process in the form of chemical energy. Besides providing food biomass is a major source of energy, building materials, chemicals, medicines, papers, and fabrics. The importance of biomass is felt ever since man discovered fire. Biomass is utilized for energy production throughout the world. Biomass resources comprise bagasse, wheat straw, wheat husk, rice straw, rice husk, cotton stalk, sawdust, wood, pellets, fruit pruning, poplars, switchgrass, willows, cattle manure, and municipal wastes. Biomass is considered a major renewable energy resource for the future. Considering only woody biomass, which provides energy on a global level was nearly 3.8Gm^3/year (30 EJ/year) contributing to 9% of the total primary energy consumed in the world in 2010. Today world is thinking to increase the biomass contribution in the global primary energy mix because of sustainable, eco-friendly behavior of biomass. It is estimated that biomass contributes about 10 to 20% of world energy supply [19]. Biomass has approximately 14% contribution in developed countries, while 38% of developing countries. According to the statistics, Kenya consumes 68%, Brazil 25%, India 47%, and China 13% respectively. In Pakistan, the major resources of biomass include livestock, crop, forest, and municipal solid wastes [20].

2.1 Traditional Uses of Biomass

In developing and developed countries biomass is a major source of energy to meet energy demand for cooking and heating purposes. People in rural and suburban areas of various countries spend enough time and energy on collecting everyday fuelwood. The average consumption of biomass in households in Pakistan is 2325 kg of firewood, 1160 kg of agricultural residues, and 1480 kg of animal dung per annum [21]. As per world health organization, the yearly deaths in Pakistan due to improper combustion of solid fuels are 70,700, while diseases attributed to solid fuel use is 4.6%, as compared to less than one percent observed in developed countries. The trade of outdated biomass technologies for energy production is also prevailing in villages and suburban areas of the country. The major drawback of these technologies is its very low efficiency, because of improper design and unrestrained burning. More than 62% of the rural population of Pakistan relies on biomass for domestic fuel needs because of the unavailability of commercial energy resources. Rural areas of Pakistan significantly rely on wood. Its contribution is 68.71%, followed by oil and natural gas 7.41%, electricity 0.05%. In urban areas of the country, wood consumption in cooking is 19.55%, whereas oil and natural gas are 77.84%. Traditional cookstoves used for cooking and heating increase concentrations of indoor air pollution. It includes, small particles having a diameter of less than 10mm commonly known as PM_{10}. Moreover, indoor air pollution also includes, carbon monoxide produced due to the incomplete combustion of biomass resources. The polluted air inhaled by the people causes severe respiratory, chronic lung diseases, lung cancer, an increase in birth defects and eye problems [22]. These health and environmental issues may be addressed by the application of improved wood-burning stoves having higher efficiency.

2.2 Modern Uses of Biomass

When compared with traditional uses, modern uses have greater impetus due to modern biomass conversion technologies. Modern conversion processes offer a controlled environment for biomass energy productions used for transportation and cooking purposes. A meaningful potential of biomass is available for modern conversion technologies in rural areas of Pakistan, particularly in transportation, cooking, and lighting sectors [23]. Amongst numerous approaches of adapting biomass feedstock for bio-based fuels, gasification is the utmost advanced thermochemical conversion technology. Gasification of biomass is a technologically more attractive, economically viable and more environmentally friendly. The most common method generally used for the assortment of biomass feedstock for gasification is its abundance, lower cost and easy availability [24]. Considering adopting the above-mentioned approach, it becomes easy to find out the right biomass material for gasification purposes more easily and accurately before gasification [25].

3. BIOMASS AVAILABILITY IN PAKISTAN

Biomass has always remained a major contributor to energy in Pakistan. People living in villages use less efficient traditional cookstoves, with an efficiency of approximately 9 to 13% [26]. Pakistan is working very hard to increase the contribution of biomass to attain 10% share of nearly 2700 MW in the country up to 2015 [27], and more than 10,000MW of its energy mix in 2030, the actual potential of the renewable energy is much higher. Renewable energy options like wind, hydro, nuclear power are now mature technologies and are widely used throughout the world. A study carried out in various countries, such as Bangladesh, Malaysia, India, Ghana, Nigeria, Nepal, and Slovenia, have evaluated the potential of the renewable source of energy and found unanimity that renewable resources are sustainable and secure energy alternatives for managing energy catastrophe and environmental problems. Pakistan is correspondingly blessed with renewable energy options.

3.1 Livestock in Pakistan

Livestock is a significant means of earning and job providing sources for the people of Pakistan. The population of livestock in millions from the year 2010 up to 2016 is shown in Table 1. More than 25 million people are employed and get 35% of their income from livestock [28]. Pakistan's census report 2017 - 2018 shows that the population of cattle reached to 38.8 million. Livestock contributed 58% to agriculture and 11.1% of the gross domestic product of the country in the year 2017. This ratio was 55.4% and 12.1% in 2011 respectively. In the subsequent year 2012 to 2013, 172.2 million animals were producing 652 million kg of dung per day that can be utilized for methane generation in the country. Livestock is a major source of biofertilizer used in farmlands [21].

Table 1: Population of Livestock in the Country from 2010 to 2016 (Millions)

Species	2010-11	2011-12	2012-13	Avg. growth rate (%)	2015-16
Cattles	35.6	36.9	38.3	0.036	41.1
Buffalo	31.7	32.7	33.7	0.030	35.8
Sheep	28.1	28.4	28.8	0.012	29.5
Goat	61.5	63.1	64.9	0.027	68.4
Camels	1	1	1	0.000	1.0
Horses	0.4	0.4	0.4	0.000	0.4
Asses	4.7	4.8	4.9	0.021	5.1
Mules	0.2	0.2	0.2	0.000	0.2

There are many sources available in the country including wastage of paper manufacturing industries, MSW, banana, poultry, food wastes, which can be used for biogas generation.

3.2 Contribution of Biogas in Power Generation in Pakistan

There is a great potential in rural areas of a country for biogas production, the assessed potential of biogas production is greater than 12 to 16-million-meter cube per day, the dung produced per day is adequate to encounter energy need of 28 million populations [29]. Several biogas plants were established in Pakistan from 2002 to 2012 is shown in Fig. 7. The Pakistan Council of Renewable Energy Technologies (PCRET) established 92 biogas producing units that produce 5 kW to 100 kW electricity. The gas generated from these plants is used for commercial and domestic purposes such as for the operation of tube wells and for cooking food. Over the last six years, Rural Support Programmes Network (RSPN) under its Punjab Power Development Board (PPDB) with support from the kingdom of the Netherlands has successfully built over 5,360 biogas plants which have benefited nearly 50,000 household members and generated employment for 1400 locals in 12 districts in central Punjab. In addition to this, PDBP has contributed to the sustainability of the biogas sector in Pakistan by establishing 50 local biogas construction companies and provided training to 450 masons according to international standards. Alternative Energy Development Board (AEDB) is working on the construction of the biogas project with the aid provided by New Zealand in Karachi, waste generated from 40,000 cattle available in the plant vicinity will be utilized for the production of biogas. The pilot plant will generate 250 kW of electricity using biogas. Furthermore, the plant capacity will be enhanced to 30 MW of electricity and 1500 tons of biofertilizer per day. Currently, 85 sugar mills in the country generate 700MW of electric power with the application of biogas as a fuel. According to the PCRET estimation, 35.625 million KWh/day energy can be produced with the help of utilizing the total potential of dung. PCRET aims to install a mega project of 25,000 biogas based power generation units throughout the country to reduce power shortages. So far PCRET established 3911 biogas producing units in the country from 2002 to 2007. From 2007 to 2012 total biogas plants installed were 2315, Islamabad, Punjab, KPK, Sindh, Baluchistan, AJK, 30, 1700, 155, 300, 80, 50 respectively [30].

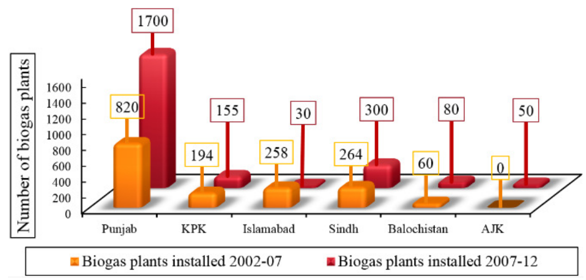

Fig. 7: Biogas plants installed by Pcret from 2002- 12 in different regions

The first biogas unit was developed in 1959 in Sindh; later on, 21 biogas units were developed in the country by Pakistan Council of Appropriate Technology (PCAT). Biogas Support Program (BSP) was introduced in the year 2000 aiming to install 1200 biogas units in the country and a total of 10000 biogas units were anticipated to be installed till 2006. Pakistan Diary Development Company (PDDC) decided to install biogas plants in the country under their umbrella 556 plants were commissioned by 2009. PCRET is taking endeavors to overcome energy shortages and has installed 4016 biogas plants, PCRET installed units produce 20,545m^3/day biogas. These plants were installed in two phases, in the first phase, 1596 units were commissioned in all four provinces, including the capital city Islamabad, whereas in the second phase, 2513 plants were installed including, Azad Jammu Kashmir and Islamabad. The majority of these plants are working in rural areas for cooking purposes. PCRET under the project of Installation of biogas plants has installed around 10,100 plants in the country in the year 2014-15 [31].

3.3 Municipal Solid Waste in Pakistan

In developed as well as in developing countries appropriate handling and management of municipal waste has become a serious concern [32]. As the expenditure level of countries rise it causes the rise in waste generation. In South Asia, Pakistan is one of the rapidly urbanizing countries. Therefore the generation of municipal solid waste in Pakistan is increasing rapidly. Furthermore, the timely surveys are important to deal with the problems attached to waste produced. In developed countries different decision support tools are used to study the impact of solid waste generated in the environment and health of people. The most common decision support tools used for the study include, life cycle analysis, and some comprehensive indicator systems are used. However most of the studies focused on the large cities to investigate the waste generation and handling such as Beijing, Shanghai, Mumbai, and Lahore [31]. All these investigations revealed that major cities face proper management of municipal solid waste collection and handling issues [33]. The energy potential from municipal solid waste is maximum in Karachi followed by other cities as given in Table. 2.

3.4 Electricity Generation Potential of Crop Residues

Agriculture sector plays a significant role in the Gross Domestic Product (GDP) of Pakistan and is the main contributor to socioeconomic development. In Pakistan, nearly 80% of the cultivated area is irrigated through the public irrigation system. The percentage of crop area under different crops in the country is given in Fig. 8. Three main terms used for the statistical analysis of agricultural growth are (a) the area under agriculture (b) the production from the area (c) the crop yield. While for the calculation of crop production, crop area harvested is multiplied by the average yield per unit area. The Amount of a crop that was harvested per unit of the land area is crop yield. Fig. 9 represents the crop residue availability for energy production in Pakistan. Furthermore, the energy estimation from crop residues was done by the researcher [35].

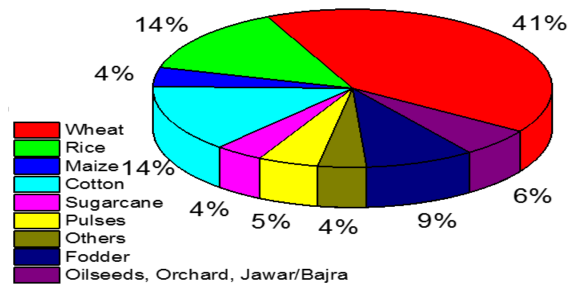

Fig. 8: Percentage of crop area under different crops [34]

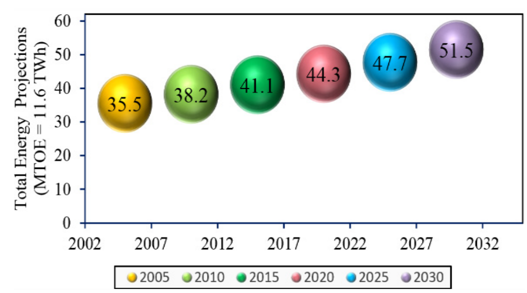

Fig. 9: Year-wise energy Potential from crop residues [35]

Table 2: MSW in major cities of Pakistan [33]

Cities	Residue collected (1000 tons)	R/P ratio (kg/capita/day)	Population (Millions)	Collection Efficiency (%)	Organic waste (1000 tons)	Energy potential (million m^3)
Karachi	1378	0.61	11.62	53	216	22
Lahore	953	0.61	6.29	68	639	64
Faisalabad	296	0.39	2.5	65	136	14
Rawalpindi	320	0.58	1.77	86	144	14
Multan	325	0.45	1.45	60	211	21
Gujranwala	128	0.47	1.44	52	51	5
Hyderabad	374	0.56	1.39	72	206	21
Peshawar	149	0.49	1.24	67	67	7
Islamabad	225	0.53	0.74	91	216	22
Quetta	100	0.38	0.73	75	37	4
Total	4247		29.18	---	2423	242

In Pakistan, major crops cultivated are wheat, sugarcane, rice, cotton, maize, pulses, most of the crop residues are produced from these crops as wheat produces wheat straw and chaff. The cotton crop generates stalks, the rice crop generates straw and husk and sugarcane produce bagasse and maize generate corn stalks and corn cobs. The residue collection efficiency is 40% for primary residues and 100% for secondary residues [33]. Besides wheat production, Pakistan produces rice in considerable amounts. Pakistan is 13thlargest rice producing country in the world. Currently, rice residues are used to generate electricity at a small scale in the rice mills. After wheat and rice, cotton is the main industrial crop cultivated in the country occupying 14% of the cultivatable land. The cotton crop is cultivated in the Sindh and Punjab provinces of the country. Residues collected from the cotton crop are used for cooking food throughout the country. Consumption of different crop residues and their energy production potential are summarized in Table 3.

Table 3: Crop residues and energy potential [36].

Feedstock	Consumption [Mt]	Energy [PJ]
Bagasse	14.5	125.604
Cotton Stalks	3.86	68.7
Dung	43.800	226.924
Fuelwood	21.144	312.544
Rice Husk	1.25	4.186
Shrubs	1.678	23.906
Others	35.254	192.7
Total	121.486	954.564

Pakistan produces sugarcane in substantial quantities. The low-value commercial by-products of sugarcane are sugarcane tops, green leaves, and bagasse. Bagasse is a fibrous material left over after the extraction of juice. Bagasse is used for manufacturing of particleboard, cattle feed, partition walls, tabletops, cupboards, racks, etc. Bagasse is traditionally burned in boilers for producing the steam required for the generation of power. As per the Food and Agricultural Organization (FAO), Pakistan produces about 69 million tons of field residues every year. Energy production from field-based crop residues is an attractive option, especially for agricultural countries. Bio-based energy generated from crop residues is playing a leading role in various developed and developing countries i.e. Germany, Denmark, Spain, China, and Zimbabwe. In Zimbabwe, more than 47% of gross energy consumption comes from crop residues, forestry residues, and fruit waste. China presently has established nineteen waste material based units that transform five million tons of straw and other agricultural related waste into energy. Most of the facilities installed are having a power generation capacity of 25 to 30 MW and each plant requires around 250,000 tons of straw, cotton stalks every year. China is aiming to install 40 more plants fueled by about 10 million tons of agricultural waste [37]. Pakistan's agricultural sector has the substantial potential of bioenergy, proper management of agricultural residues can meet the energy supplies of the country at a substantial level [38]. Rice producing countries are taking deep importance to introduce rice husk based energy projects in forthcoming days. Rice husk in India, Cambodia, Indonesia, Philippines, and Thailand is used for the generating of electricity from rice husk gasification-based power plants. In Cambodia alone currently, 55 gasification plants are in operation, having power generation capacity from 200 to 600KW. These biomass power generation plants can be operated in dual fuel mode on producer gas and diesel and have replaced 75% of diesel usage in Cambodia [39].

3.5 Forest Residues

Food and agricultural organization has assessed the forest zones of Pakistan in 2010. As per FAO assessment report, the area under forest in Pakistan is 16870 km^2. The total land area of Pakistan is 770880 km^2 and which becomes 2.19% of the total land area of Pakistan [38]. Coniferous and non-coniferous forests are considered in forest area while shrub forests fall in the class of another wooded land. Farmland trees, miscellaneous plantations add up further 1% of the total land area. Forest residues have remained a major source of biomass energy [37], besides providing timber for construction activities, it has remained a vital source of heating, cooking, and fodder in many countries. It is expected that people of Pakistan will remain dependent on forest residues for their energy requirements in the coming years due to distressing economic conditions. Due to over-dependence on forest resources for daily energy supplies, the deforestation rate has increased. In Pakistan, 10% to 15% of total fuelwood comes from forests, whereas the rest is obtained from farmlands. The forest residues are collected from the nearest village forests, the residues gathered from forests are leaves, roots, barks, twigs. The generation of different residues in the country and their share to fulfill the energy appetite of people is given in Table 4.

Table 4: Fuelwood production from forests in Pakistan [36].

Fuelwood	Production [MT]	Energy in (PJ)
Agriculture areas	16.465	242.75
Natural forests	0.816	11.8
Plantations	0.645	9.838
Wood wastes	2.578	38.31
Other Wooded lands	0.640	9.838
Total	21.144	312.536

4. COMMON FEEDSTOCK CONVERSION METHODS

There are different conversion methods used for the conversion of biomass into valuable products. All methods are commonly employed in the country for energy generation. The feedstock conversion efficiency of biomass for each conversion process is different. The characteristics of feedstock and conversion methods are selected considering the type of biomass used [40].

4.1 Thermochemical Conversion

In thermochemical conversion processes, heat is applied with or without the presence of molecular oxygen to transfigure feedstock into other forms of usable energy including syngas, oils, and methanol. The energy produced through thermochemical processes can be used in automotive engines for power production. In the thermochemical conversion process of biomass combustion technologies, pyrolysis technologies and gasification technologies are employed [41]. The main advantages of thermochemical conversion processes are fewer emissions of greenhouse gases, the processing time is short, various feedstocks can be used and small footprints [42].

4.1.1 Combustion

In uncontrolled burning, biomass feedstock undergoes through the process of chemical transformation, which results in heat energy. Consequently, the heat produced by the combustion can be transformed into the mechanical energy and electrical energy through various processes and equipment including, boilers, cook stoves, furnaces, and steam tribunes. Large quantities of agricultural waste, municipal solid waste, forest waste are produced in Pakistan and wasted every year that can be burnt with fossil fuels feedstock for power production. Most of the power plants in the country use fossil fuels for power generation and emit many pollutants in terms of NOx, SOx, CO_2 and many other harmful pollutants. The use of existing power

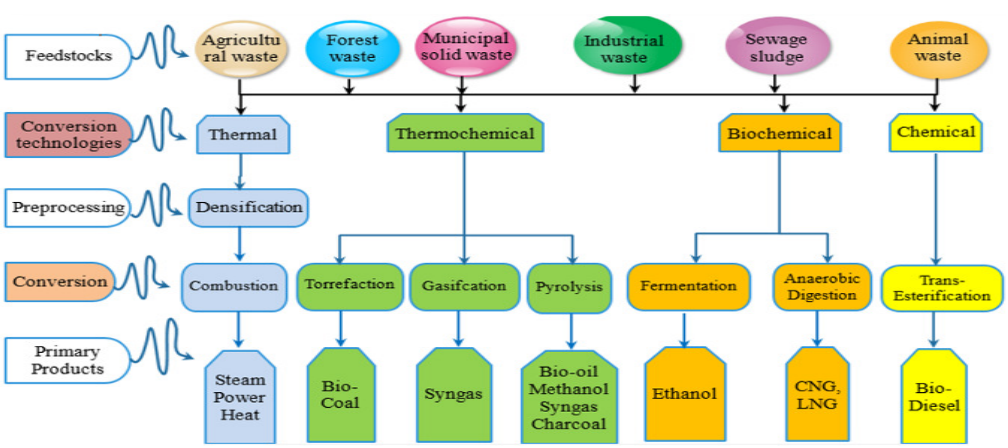

Fig. 10: Energy production routes from wastes and their output.

generation plants with some modifications, to co-fire biomass, is cost effective and a source of meeting hard emission targets. Biomass-based fuels possess low sulfur content and have the potential to offset the higher sulfur content of fossil fuels. For co-generation commonly known as combined heat and power (CHP) generation plants have the potential to produce heat and power over the same span of time. Uncontrolled combustion of biomass is a less efficient method of energy generation, efficiency lies in between 5 to 10% [43]. In addition to very low energy output, the traditional open combustion method has a number of weaknesses, e.g. indoor air pollution causing respiratory problems in various countries. Traditional fuels like forest waste, agricultural residues, animal dung, and firewood currently pay a major contribution in meeting daily energy necessities for low-earning families in Pakistan. In remote areas of the country, biomass is a major resource for cooking and heating purposes. Moreover biomass is normally called as a “poor women’s oil”. Meanwhile people of rural areas go for collecting daily fuelwood needs because the majority of households do not have access to better alternatives [44].

Combustion reactions:

$$C + \frac{1}{2}O_2 \rightarrow CO \quad (1)$$
$$C + CO_2 \rightarrow 2CO \quad (2)$$
$$CO + \frac{1}{2}O_2 \rightarrow CO_2 \quad (3)$$

4.1.2 Gasification

In biomass gasification method, conversion of feedstock including forest waste, crop waste and municipal solid waste (MSW) is done at elevated temperatures typically in the range of 800 to 900°C to obtain burnable syngas with a conversion efficiency greater than 85% [45]. Biomass combustion technologies are categorized as a fixed bed and fluidized bed combustion processes, during combustion hot gases are produced having a temperature from 800 to 1000°C [46]. Under restrained conditions, almost all of the biomass is converted into syngas. Gasification of biomass happens in two main stages, in the first stage of gasification partial combustion takes place to form syngas and charcoal followed by a chemical reduction in the second stage. A major role of biomass gasification is foreseen on large-scale gasifiers directly coupled to turbines for electricity generation. There is a meaningful potential of biomass available in Pakistan for gasification, unfortunately, no countable effort has been taken in promoting biomass gasification technology in Pakistan [47].

Gasification reactions

$$C + H_2O \rightarrow CO + H_2 \quad (4)$$
$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O \quad (5)$$
$$CO + H_2O \rightarrow CO_2 + H_2) \quad (6)$$

4.1.3 Pyrolysis and Torrefaction

The pyrolysis is a process to change coal and biomass to gaseous, liquid and solid fuels. Pyrolysis of feedstock is done under oxygen-starved conditions. Furthermore, pyrolysis converts less energy-dense material into more energy dense material than the original biomass. It also reduces handling and transportation costs and possesses more suitable burning features [48]. The solid products obtained are called biochar, which is rich in carbon content. However, liquid fuels are produced due to the low temperature resulting in the production of oils, tars, methanol, and acetone. The process of torrefaction is also carried out in the absence of oxygen but at the lower temperatures used in the pyrolysis process. In torrefaction, the temperature ranges from 200°C to 320°C. The purpose of the torrefaction process is to remove water and to produce biochar by partial thermal decomposition of organic material.

4.1.4 Incineration

Among various waste treatment processes, incineration of waste in one of them, the combustion of waste at high temperature and is a thermal treatment process. Currently, the incineration of waste has got great attention due to the energy recovery from organic waste through incineration [49]. This is a high energy recovery process from the waste. Incineration reduces the volume of the waste and is environmentally friendly as compared with other treatment options available for organic waste treatment. The incineration of biomass is done in various countries for centuries for the production of steam that is used in turbines for the production of electricity. More modern electricity-producing units operated through incineration of waste are highly technical and meet stringent air and land pollution regulations. Furthermore, modern incineration plants are more environmentally friendly as compared to landfilling processes. Treatment of waste through incineration results in less greenhouse gas emissions [50].

4.1.5 Plasma gasification

Gasification of organic and hazardous waste through the plasma is an extreme thermal process that transforms waste into producer gas [51]. The main components of syngas produced using plasma method are H_2 and CO. In plasma gasification, high temperature above 5000C is managed for the conversion of organic waste into fuel gas. Positively and negatively charged particles. Plasma is sometimes called the fourth state of matter in which atoms and molecules are ionized by creating a vast quantity of positive and negative charged particles. The advantage of plasma gasification is that it destroys all the potentially toxic compounds in the waste. The extremely high voltage is passed through the gas in a special chamber to heat the waste material. The gas varies depending on the process conditions, most commonly used gases are oxygen, nitrogen, argon, and air. The high voltage inside the chamber ionizes the gas between the electrodes of the plasma torch. Under high temperatures, waste materials are rapidly broken into molecules and atoms. The main components released during plasma gasification are CO, H_2, and CH_4 [52].

4.2 Biochemical Conversion

As a thermochemical process occurs at higher temperatures with high reaction rates as compared to biochemical conversion processes. Fermentation and anaerobic digestion are the most common examples of the biochemical conversion process [53]. Ethanol production with the application of microorganisms is an ancient art, but nowadays such organisms are used for the production and treatment of biological materials at the industrial scale. Biochemical conversion processes are applied for the production of fuels, fertilizers, and many other products all over the world. Two main categories of biochemical conversion technologies are ethanol through fermentation and methane through anaerobic digestion.

4.2.1 Fermentation

A fermentation process is a biological conversion process of biomass by which the living cells obtain energy through converting sugar or starch into alcohol, acid and other valuable products [53]. Starch-based biomass for ethanol production is cheaper than sugar-based but requires expensive processing. The most common biochemical process is the production of ethanol from glucose and starch through the fermentation process [54]. The fermentation process takes place in various steps. At an initial stage pulverization of crop residues is carried out, then water is added to form a slurry. In the second stage of fermentation heat and enzymes are introduced to break down the pulverized material into glucose and sugar. Yeast is added to fermentation tanks to carry out the reaction, after completion of reaction mash is distilled to separate alcohol from the spent wash. Lignocellulose materials must first be broken down into sugars before being fermented into ethanol. In Pakistan, fermentation for ethanol production is done on a commercial scale by using sugarcane molasses. Currently, twenty-one distilleries produce different grades of ethanol in Pakistan [55].

$$C_6H_{12}O_6 \rightarrow 2C_2H_5O + 2CO_2 \tag{7}$$

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6 \tag{8}$$

4.2.2 Anaerobic Digestion

Innumerable kinds of feedstock are functional in anaerobic digestion for the making of methane and carbon-rich gas in the absence of oxygen. The most common biomass material used for anaerobic digestion include animal dung, spent wash, crop residues, food scraps, and forest wastes. Anaerobic digestion of biomass is a multistage process. In the first process, biomass is hydrolyzed to break down carbohydrate in the form that is digestible by the bacteria. After hydrolysis, the sugars and amino acids present in the substrate are converted into organic acids by acetogenesis microorganisms. Finally, these products are converted into methane by methanogens bacteria. The mixed type of culture works well at Optimum temperature and pH for better yield. Anaerobic digestion for biogas production is carried out for biomass materials containing high moisture such as cattle manure, crop waste. For animal dung, the appropriate retention time in the digester is in the range of 20 to 40 days and for organic waste other than animal dung, it is 60 to 90 days [56]. The biogas thus recovered contains methane 55 to 80%, which strongly depends on the type of waste utilized for biogas production.

Hydrolysis reaction:

$$\text{Biomass} + H_2O \rightarrow \text{monomers} + H_2 \quad (9)$$

Acetogenesis reactions:

$$C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3H_2COOH + 2H_2O \quad (10)$$

$$C_6H_{12}O_6 \rightarrow 2CH_3H_2OH + 2CO_2 \quad (11)$$

$$CH_3CH_2COO + 3H_2O \rightarrow CH_3COO + H + HCO_3 + 3H_2 \quad (12)$$

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2 \quad (13)$$

$$CH_3CH_2OH + 2H_2O \rightarrow CH_3COO + 2H_2 + H) \quad (14)$$

$$2HCO_3 + 4H_2 + H \rightarrow CH_3COO + 4H_2O \quad (15)$$

Methanogenesis reactions:

$$2CH_3CH_2OH + CO_2 \rightarrow 2CH_3COOH + CH_4 \quad (16)$$

$$CH_3COOH + CO_2 \rightarrow CH_4 + CO_2 \quad (17)$$

$$CH_3OH \rightarrow CH_4 + H_2O \quad (18)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (19)$$

$$CH_3COO + SO_4 + H \rightarrow 2HCO_3 + H_2S \quad (20)$$

$$CH_3COO + NO + H_2O + H \rightarrow 2HCO_3 + NH_4 \quad (21)$$

4.2.3 Chemical Conversion

Transesterification is the most common conversion process, carried out on the commercial scale for biofuels [57]. Transesterification is one of the reversible reaction and proceeds by mixing the reactants. Chemical conversion process occurs with the application of different chemical agents for the breakdown of biomass materials into biofuels. In this type of conversion process, various changes are performed to transform feedstock into new forms of usable energy. The most common chemical-based conversion of biomass is transesterification. In transesterification reaction, fats, oils, greases are bonded to alcohol through the chemical reaction. This process is used to lessen the viscosity of fats, oils, and greases to make them combustible. The transesterification process decreases the viscosity of any bio-oil such as soya bean oil, tallow, tree oil, or animal fat converting these oils into biodiesel.

4.2.4 Aerobic composting

It is the decomposition of organic waste with the application of microbes that work well under aerobic conditions [58]. The microorganisms naturally occur and sustain life in the moisture conditions and are commonly found near the organic matter. The surrounding oxygen near organic matter diffuses into the moisture and finally used by the microbes that are responsible for the decomposition of matter. The by-products of the aerobic process are water, heat and carbon dioxide. The carbon oxide produced during the decomposition is a greenhouse gas. The aerobic composting is the most widely used process throughout the world for the production of biofertilizer from organic waste. Compositing of organic waste requires low investment, while during compositing no energy is required and maintenance cost of the process is zero [59].

5. CONCLUSION

Pakistan is among one the developing countries in the world. Much of the financial assets are used for the purchasing of oil and gas that is used for the generation of electricity. The production of electricity through the application of oil and gas increases the generation cost of electricity. The oil and gas resources are nonrenewable and depleting at a faster rate. Fossil fuel consumption for energy production is costly and terrible for an environmental point of view. As Pakistan is an agricultural country and possesses livestock waste, agricultural waste, forest waste, municipal solid waste is underutilized and wasted in million tons every year that could be used for power production. Advanced biomass conversion technologies are highly efficient which can be employed for the utilization of biomass for energy production. The modern biomass conversion technologies are more efficient in power generation and will minimize the environmental problems caused by the open burning of biomass for energy purposes. It is evident that biomass resources are sustainable and have the potential to replace fossil fuel consumption in the future. Some of the developed and developing countries are already using this window of opportunity. It is the proper prospect for Pakistan to focus more on the alternative energy sector, rather than investing considerable capital on the import of crude oil from foreign countries. Although strenuous efforts have been taken on in Pakistan to increase bioenergy contribution, its application rests very low because of the embryonic stage regarding bioenergy research and development in Pakistan.

ACKNOWLEDGMENTS

No funding was received for the completion of this research work. However, authors are highly thankful to Dawood University of Engineering & Technology, Karachi, and Mehran University of Engineering & Technology, Jamshoro, Pakistan for providing a research environment during the research period.

REFERENCES

1. Havas L., Ballweg J. C., Penna., Race D., “Power to change Analysis of household participation in a renewableenergy efficiency programme in central Australia”, *Energy Policy*, Vol. 87, pp. 325-333, 2015.
2. Maitlo G., Mahar R. B., Unar I.N., Brohi K. M., “Kinetic Study of Cotton Stalk and Rice Husk Samples under an Inert and Oxy Combustion Atmospheres”, *Mehran University Research Journal of Engineering and Technology*, Vol. 37, pp. 327-336, April 2018.
3. Shah A.S., Memon Z.A., Shafaq S., Shah A., Sethar W., “Renewable Energy Technologies Diffusion in Sindh: An Overview”, *Mehran University Research Journal of Engineering and Technology*, Vol. 36, pp. 673-680, July 2017.
4. Lillo P., Marti F. L., Baldor F. A., Ramirez B., “A new integral management model and evaluation method to enhance the sustainability of renewable energy projects for energy and sanitation services”, *Energy for Sustainable Development*, Vol. 29, pp. 1-12, 2015.
5. Narejo G. B., Azeem F., Zardari S., “An Energy Policy Analysis and Proposed Remedial Actions to Reduce Energy Crises in Pakistan”, *Mehran University Research Journal of Engineering and Technology*, Vol. 36, pp. 401- 406, April 2017.
6. Nawaz M. A., Raheem A., Shakoor R., Anwar A., “Feasibility and Optimization of Standalone PV-Biogas Hybrid Distributed Renewable System for Rural Electrification: A Case Study of a Cholistan Community”, *Mehran University Research Journal of Engineering and Technology*, Vol. 38, pp. 453-462, April 2019.
7. Maitlo G., Mahar R. B., Bhatti Z. A., Unar I. N., “A Comprehensive Literature Review of Thermochemical Conversion of Biomass for Syngas Production and Associated Challenges”, *Mehran University Research Journal of Engineering and Technology*, Vol. 38, pp. 495-512.
8. Mohr S. H., Wang J., Ellem G., Ward J., Giurco D., “Projection of world fossil fuels by country”, *Fuel*, Vol. 141, pp. 120-135, 2015.
9. Kalair N.A., Kalair A., Khan N., “Review of Fossil Fuels and Future Energy Technologies”, *Futures*, Vol. 69, pp.31-49, 2015.
10. “*Pakistan Energy Yearbook*”, Hydrocarbon Development Institute of Pakistan, Islamabad, April 2015.
11. West J., Schandl H., Hosking K., “Green Asia country report: Pakistan”, *Technical Report*, Commonwealth Scientific and Industrial Research Organization, Canberra, Australia, 2016.
12. Shakeel S. R., Takala J., Shakeel., “Renewable energy sources in power generation in Pakistan”, *Renewable and Sustainable Energy Reviews*, Vol. 64, pp. 421-434, 2016.
13. Kazmi S. H., “*Pakistan's Energy Crisis*”, *The Diplomat*, August 31, 2013.
14. Shoaib M., “*Pakistan Economic Survey 2013-14, Chapter 14: Energy”*, pp. 217-230, Government of Pakistan, Ministry of Finance, 2014.
15. Sheikh M. A., “Energy and renewable energy scenario of Pakistan”, *Renewable and Sustainable Energy Reviews*, Vol. 14, pp. 354-363, 2010.
16. “*Pakistan Energy Yearbook 2015*”, Hydrocarbon Development Institute of Pakistan, Ministry of Petroleum and Natural Resources, Government of Pakistan, April 2015.
17. “*World Bank Energy use per capita report in Kilograms of oil equivalent*”, World Bank, 2011.
18. Makhdoom T.R., Nawaz M., Narejo N.B., “*Effects of Loadshedding on Retail Business: A*

Glimpse From Hyderabad, Pakistan", *Journal of Grossroot*, Vol. 51, No.1, pp. 166-177, 2017.

19. Colantoni A., Delfanti L., Recanatesi F., Tolli M., Lord R., "Land use planning for utilizing biomass residues in Tuscia Romana Preliminary results of a multi-criteria analysis to create an agro-energy district", *Land Use Policy*, Vol. 50, pp. 125-133, 2016.
20. Easterly J. L., Burnham M., "Overview of biomass and waste fuel resources for power production", *Biomass and Bioenergy*, Vol. 10, pp. 79-92, 1996.
21. Mirza U. K., Ahmad N., Majeed T., "An overview of biomass energy utilization in Pakistan", *Renewable and Sustainable Energy Reviews*, Vol. 12, pp. 1988-1996, 2008.
22. Smith K., "*Health effects in developing countries bioenergy and the environment Colorado Westview*", 1990.
23. Amjid S. S., Bilal M. Q., Nazir M. S., Hussain A., "Biogas, renewable energy resource for Pakistan", *Renewable and Sustainable Energy Reviews*, Vol. 15, pp. 2833-2837, 2011.
24. Haryanto A., Fernando S. D., Pordesimo L. O., Adhikari S., "Upgrading of syngas derived from biomass gasification a thermodynamic analysis", *Biomass and Bioenergy*, Vol. 33, pp. 882-889, 2009.
25. Vaezi M., Fard P. M., Moghiman M., Charmchi, M., "On a methodology for selecting biomass materials for gasification purposes", *Fuel Processing Technology*, Vol. 98, pp. 74-81, 2012.
26. Harijan K. Uqaili M. A., "Potential of Biomass Conservation Through Dissemination of Efficient Cook Stoves in Pakistan", *APCBEE Procedia*, Vol. 5, pp. 358-362, 2013.
27. Malik I. A., Siyal G.A., Abdullah B. A., Alam A., Zaman K., Kyophilavong P., "Turn on the lights: Macroeconomic factors affecting renewable energy in Pakistan", *Renewable and Sustainable Energy Reviews*, Vol. 38, pp. 277-284, 2014.
28. "*Pakistan Economic Survey 2004-05*", Economic Advisor Wing, Ministry of Finance", Governemnt of Pakistan, 2005.
29. Lv P. M., Xiong Z. H., Chang J., Wu C. Z., Chen Y., Zhu J. X., "An experimental study on biomass air-steam gasification in a fluidized bed", *Bioresource Technology*, Vol. 95, pp. 95-101, 2004.
30. Uddin W., Khan B., Shaukat N., Majid M., Mujtaba B., Mehmood C., "Biogas potential for electric power generation in Pakistan: A survey", *Renewable and Sustainable Energy Reviews*, Vol. 54, pp. 25-33, 2016.
31. Khan W., Ali B., Shaukat N., Aslam M., Mujtaba, G., Mehmood A., "Methane production for power generation in Pakistan A survey", *Renewable and Sustainable Energy Reviews*, Vol. 54, pp. 210-233, 2017.
32. Ali M., Geng Y., Robins D., Cooper D., Roberts W., Vogtländer J., "Improvement of waste management practices in a fast expanding sub-megacity in Pakistan, on the basis of qualitative and quantitative indicators", *Waste Management*, Vol. 85, pp. 253-263, 2019.
33. Farooq M. K., Kumar S., "An assessment of renewable energy potential for electricity generation in Pakistan", *Renewable and Sustainable Energy Reviews*, Vol. 20, pp. 240-254, 2013.
34. Saeed M., Irshad A., Sattar H., Andrews G., Phylaktou R., Gibbs M., "Agricultural Waste Biomass Energy Potential in Pakistan", *Proceedings of the International Conference, International Bioenergy Exhibition and Asian Bioenergy Conference,* 21-23 Oct 2015, Shanghai, P.R. China, 2015.
35. Memon M. D., Uqaili M. A., Mirza U. K., "Potential of Crop Residues as Energy Source in Pakistan", *Proceedings of the World Renewable Energy Congress-IX*, Florence, Italy, 19-25 August 2006.
36. Butt I., Hartmann., Lenz V., "Bioenergy potential and consumption in Pakistan", *Biomass and Bioenergy*, Vol. 58, pp. 379-389, 2013.
37. Xinhua, "*China's First Straw-burning Power Project Switches on*", China Radio International (CRI English), 2006.
38. Marquez A. L., Banos R., Gil C., Montoya M. G., Agugliaro M. F., Montoya F. G., "Multi-objective crop planning using Pareto-based evolutionary algorithms", *Agricultural Economics*, Vol. 42, pp. 649-656, 2011.
39. Pode R., "Potential applications of rice husk ash waste from rice husk biomass power plant", *Renewable and Sustainable Energy Reviews*, Vol.

53, pp. 1468-1485, 2016.

40. Kumar A., Kumar N., Baredar P., Shukla A., "A review on biomass energy resources, potential, conversion and policy in India", *Renewable and Sustainable Energy Reviews*, Vol. 45, pp. 530-539, 2015.
41. Katyal S., "Effect of carbonization temperature on combustion reactivity of bagasse char", *Energy Sources, Part A: Recovery, Utilization and Environmental Effects,* Vol. 29, No.16, pp. 1477–1485, 2007.
42. McKendry, P., "Energy production from biomass gasification technologies", *Bioresource Technology*, Vol. 83, pp. 55-63, 2002.
43. Karekezi W. D. S., "*Household stoves in Zimbabwe*", Nairobi African Centre for Technology Studies,1990.
44. Bhutto A. W., Bazmi A. A., Zahedi G., "Greener energy: Issues and challenges for Pakistan-Biomass energy prospective", *Renewable and Sustainable Energy Reviews*, Vol. 15, pp. 3207-3219, 2011.
45. Mande S., Kishore V.V.N., "*Towards Cleaner Technologies: a Process Story on Biomass Gasifiers for Heat Applications in Small and Micro Enterprises*", The Energy and Resources Institute, 2007.
46. Mirza U. K., Ahmad N., Harijan K., Majeed T., "Identifying and addressing barriers to renewable energy development in Pakistan*", Renewable and Sustainable Energy Reviews*, Vol. 13, pp. 927-931, 2009.
47. Naqvi M., Yan J., Dahlquist E., Naqvi S. R., "Waste Biomass Gasification Based off-grid Electricity Generation: A Case Study in Pakistan", *Energy Procedia*, Vol. 103, pp.406-412, 2016.
48. Demirbas D. A., Demirbas A. H., "Briquetting properties of biomass waste materials", *Energy Sources*, Vol. 26, pp. 83–91, 2004.
49. Malinauskaite J., Jouhara H., Czajczyńska D., Stanchev P., Katsou E., Rostkowski P., "Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe", *Energy*, Vol. 141, pp. 2013-2044, 2017.
50. Jeswani H., Smith R., Azapagic A., "Energy from waste: Carbon footprint of incineration and landfill biogas in the UK", *The International Journal of Life Cycle Assessment*, Vol. 18, 2012.
51. Byun Y., Cho M., Hwang M., Chung J., "Thermal plasma gasification of municipal solid waste", *Energy*, Vol. 234, pp. 183-210, 2012.
52. Salah A., Hanel L., Beirow M., Scheffknecht G., "Modelling SER Biomass Gasification Using Dynamic Neural Networks", *Computer Aided Chemical Engineering*, Vol. 38, pp.19-25, 2016.
53. Arshad M., Hussain T., Iqbal M., Abbas M., "Enhanced ethanol production at commercial scale from molasses using high gravity technology by mutant S. cerevisiae", *Brazilian Journal of Microbiology*, Vol. 48, pp. 403-409, 2017.
54. Cherubini F., "The biorefinery concept: Using biomass instead of oil for producing energy and chemicals", *Energy Conversion and Management*, Vol. 51, pp. 1412-1421, 2010.
55. Hamelinck C. N., Hooijdonk G., Faaij P. C., "Ethanol from lignocellulosic biomass: techno-economic performance in short, middle and long term", *Biomass and Bioenergy*, Vol. 28, pp. 384-410, 2005.
56. Gebrezgabher S. A., Meuwissen M. P., Prins B. A., Lansink M. O., "Economic analysis of an anaerobic digestion-A case of a Green power biogas plant in The Netherlands", *NJAS - Wageningen Journal of Life Sciences*, Volume. 57, pp. 109-115, 2010.
57. Demirbas, A., "Biodiesel fuels from vegetable oils via catalytic and non-catalytic supercritical alcohol transesterifications and other methods a survey", *Energy Conversion and Management*, Vol. 44, pp. 2093-2109, 2003.
58. Medina V.F., Guerra E. M., Cosper S. C., "Military Solid and Hazardous Wastes: The Army Corps of Engineers Disaster Debris Management Mission", *Waste*, pp. 553-565, 2019.
59. Shafy H. I., Mansour M. S., "Solid waste issue: Sources, composition, disposal, recycling, and valorization", *Egyptian Journal of Petroleum*, Vol. 27, pp. 1275-1290, 2018.