Arabian Journal of Geosciences (2020) 13: 77
https://doi.org/10.1007/s12517-019-5049-x

S. I. BIOCHAR

Biomass for renewable energy production in Pakistan: current state and prospects

Muhammad Yaseen[1] · Farhat Abbas[1,2] · Muhammad Bilal Shakoor[1] · Aitazaz A. Farooque[2] · Muhammad Rizwan[1]

Received: 10 January 2019 / Accepted: 19 December 2019 / Published online: 11 January 2020

Abstract
Energy security and environmental problems are important factors behind the increasing biomass consumption around the world including the lower-income countries such as Pakistan. To utilize local biomass reserves more efficiently in the context of future energy demand, the possession of knowledge about recent energy system in different sectors of the country has become interestingly important. A few initiatives and technologies are currently under process in order to move towards renewable resources from non-renewable resources and minimizing dependency on fossil fuels and reducing greenhouse gas emissions. In recent past, some ideas have been developed for sustainable biofuel production which will make sure a rapid shift from an unsustainable attitude towards a potentially sustainable approach. Hence, in this review, detailed data about the potential of biomass for the production of renewable energy in Pakistan have been presented, keeping in view the recent energy mix and future perspectives. The feasibility of local/indigenous biomass reserves and important conversion methods to transform such biomass reserves to bioenergy has also been discussed. Here, we also highlighted the drivers for consumption of local/indigenous biomass reserves in future energy system along with the challenges related to energy systems among various stakeholders. Finally, the suggestions/recommendations on the government policies and future directions for successful implementation of the energy production from local/indigenous biomass resources have been given which could be sufficient to meet increasing energy demands of Pakistan.

Keywords Biomass · Bioenergy · Energy resources · Residues

Introduction

Energy has been a fundamental need of the human beings since their birth on earth. Modernization and population explosion have enhanced the total energy requirements and the per capita energy usage. China is considered as the leading per capita energy-consuming country followed by India and Pakistan as shown in Table 1 (Mahmood et al. 2014; Ghafoor et al. 2016). The per capita consumption in the world elaborates that a huge quantity of energy is consumed in every sector (e.g., industry, domestic) of the countries. Economic progress of a country largely depends upon the extent of energy consumption and fast energy supply. The countries such as France, USA, and China have the greatest per capita energy consumption; consequently, these nations have the highest economic growth rate (Ozturk 2010; Ozturk et al. 2010).

Fossil fuels are used as a primary source of energy all over the world, but due to increasing population and diminishing resources, the global energy demand is increasing rapidly (Coyle and Simmons 2014). This escalating energy demand will surely cause some serious environmental issues such as global warming, future energy security, and depletion of fossil fuel resources. The amount of fossil fuel resources on the planet earth are diminishing rapidly day by day thus causing their prices to raise immensely which makes them economically expensive and limited. While fossil fuel consumption has some serious environmental impacts due to the massive emissions of toxic green house gases including CO_2, NO_x, and

This article is part of the Topical Collection on *Implications of Biochar Application to Soil Environment under Arid Conditions*

✉ Farhat Abbas
farhat@gcuf.edu.pk; fabbas@upei.ca

1 Department of Environmental Sciences and Engineering, Government College University Faisalabad, Faisalabad 38000, Pakistan

2 Faculty of Sustainable Design Engineering, University of Prince Edward Island, 550 University Ave, Charlottetown, PE C1A 4P3, Canada

Table 1 Comparison of electricity consumption in Pakistan with other countries of the world

Country	Per capita energy consumption (kW h)
Pakistan	457
India	644
China	2942
Sri Lanka	636.3
Afghanistan	119.8
Nepal	454.1
Bangladesh	278.1
France	7756
Turkey	2474
Germany	7217
USA	13,361

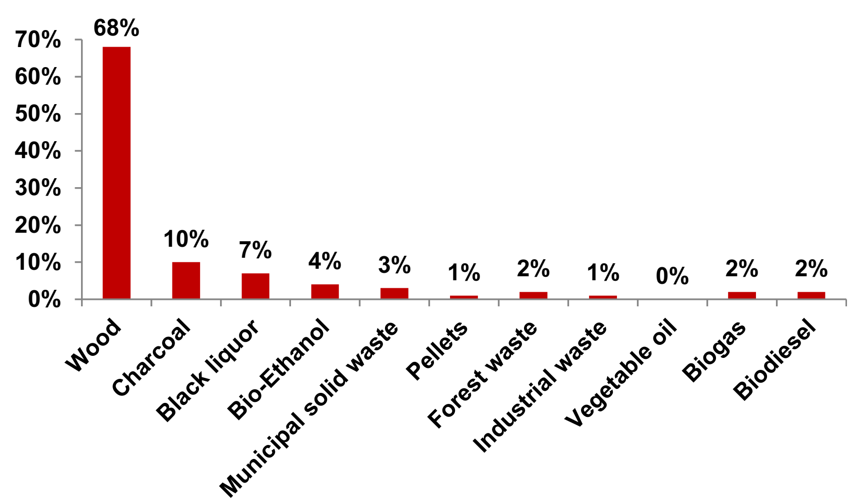
SO_x (Prairie et al. 2018; Sarkodie and Strezov 2019), China is the biggest producer of CO_2 having production of 8205.86 million tons (Mt) while India ranks third with1954.02 Mt emission (IEA 2014). The emission and subsequent accumulation of harmful greenhouse gases in the atmosphere has caused some crucial environmental problems for example rising environmental pollution and drastic changes in the climate of the earth. The United States Environmental Protection Agency (EPA) has reported that net greenhouse gas emission has been largely increased mainly owing to anthropogenic processes by ~42% during 1990–2012 (EPA 2015).

To reduce the damaging effects of greenhouse gases on the environment, the countries have been forced to set a potential task of lessening their emissions by at least 20% below the year 1990 under the agreement of European commission of climate action. To highlight the environmental and socioeconomic problems linked with fossil fuel consumption and to accomplish the aim of decreasing greenhouse gas, renewable energy sources are among the key solutions to fulfill the growing demands of energy around the world.

A number of methods/techniques are being developed for energy production which could replace non-renewable energy resources with renewable energy resources along with additional benefits of limited greenhouse gas emission and world's dependency on fossil fuels (Holdren 1991). Among various developing countries, Pakistan is also facing severe energy/electricity crisis, and in recent decades, the rate of energy consumption has increased greatly, but energy-producing systems have not been updated parallel to the growing demands of energy in the country as shown in Table 1 (Raza et al. 2015). Pakistan is still producing energy by conventional methods rather than using renewable energy sources. Among the major causes of energy crisis in Pakistan is the costly nature of the fossil fuel as the local industry and domestic users use furnace oil and natural gas for the production of electricity and heat (Ali et al. 2016). At present, the electricity fuel mix of Pakistan consists of hydroelectric power, oil, nuclear, coal, and natural gas as mentioned in Fig. 1 (World Energy Council 2016). About 38.5% of total energy is being generated from oil and 25.7% from natural gas (Pakistan Energy Yearbook 2014). Hydroelectric power contributes about 30.7% of total energy (Sheikh 2010).

As Pakistan is facing worst energy crisis, the country has imported fossil fuels for industrial and domestic use (Arshad et al. 2016), but still, energy requirements are not met. Thus, to overcome this issue, the government is now aiming to obtain energy from indigenous sources for instance solar, biomass, wind and hydro-power to meet increasing energy demands. The biomass from different sources could be a potential source for energy production due to its easy availability and inexpensive nature. Agriculture sector comprises over 60% of the economy in Pakistan and about 62% of rural population utilizes biomass for cooking and heating. Fossil fuel energy resources have limited supply for the people in rural areas and

Fig. 1 Distribution of biomass for the energy production in the world



energy is mostly obtained from animal dung, wood, and crop residues (Uddin et al. 2016). Renewable energy production especially from biomass can play a vital role to meet future energy demands of Pakistan (Ahmed et al. 2016).

The purpose of this review paper is to present an extensive literature review about renewable energy based on biomass, current energy scenario, and future perspective in Pakistan. This review article also includes future directions and promotional strategies of biomass consumption for energy production in Pakistan.

Indigenous energy resources

Conventional energy resources

The rate at which we are consuming oil and natural gas, the oil reserves will exhaust 2025, while natural gas reserves will exhaust by 2030 unless we explore more reserves (Imran and Amir 2015). An estimate reports that only 19% of gas reserves and less than 4% of oil reserves are remaining, whereas only 1% of coal reserves have been left (Kugelman 2015).

Natural gas

The use of compressed natural gas (CNG) in transport sector and natural gas for power production (Khan and Yasmin 2014) resulted in shortage of natural gas supply which also leads to load shedding of natural gas (Arslan et al. 2014). The first priority for the government is to supply natural gas to domestic and commercial sectors and then to the fertilizer industry (MPNR 2015). Natural gas at current rate of production of 1.49 trillion cubic feet (TCF) out of 23.64 TCF of total recoverable natural gas will exhaust by 2030 (Pakistan Energy Yearbook 2014). However, according to an estimate, Pakistan has six times more reserves compared to those described above (Sheikh 2010).

Oil

In 2014, the total production of oil in Pakistan was 86,500 barrels per day while total recoverable reserves were 371 million barrels but Pakistan spent 14.7 billion USD on oil import (State Bank of Pakistan 2015). Total shale oil reserves of Pakistan are 227 billion barrels out of which 9 billion barrels are recoverable shale oil reserves (Stevens et al. 2013).

With 48.8% consumption, the transport sector is the major consumer followed by power sector with 42.7% consumption of oil. Almost 92% share of oil consumption is consumed by these two sectors (Stevens et al. 2013). In early 1990s, the total oil consumption in the country was 50% for transport sector and 25% for power sector but due to increase in crude oil prices, there was a significant decline in oil consumption between 2001 and 2006 (HDIP 2014).

Coal

Total coal reserves of Pakistan are about 186 billion tones. Coal shares 5.4% of total primary energy consumption and it remained less than 1% in power sector in 2014. The underutilization of coal was due to inferior quality of coal extracted from Thar (Sindh, Pakistan) in particular (Stevens et al. 2013).

Nuclear energy

At present, about 5% of electricity in Pakistan is being generated by three nuclear power plants including Karachi Nuclear Power Plant (KANUPP) (unit 1), Karachi Nuclear Power Project (unit 2 and unit 3), and Chashma Nuclear Power Project. The KANUPP is operating on an extended lifetime after refurbishments and safety measurements, as its designed life of 30 years was completed in 2002 (Rauf et al. 2015; Raheem et al. 2016a, b). The government of Pakistan has directed Pakistan Atomic Energy Commission (PAEC) for the installation of 8800 MW electricity production nuclear power plants by 2030 (Kugelman 2015).

Sustainable energy resources

Hydroelectric power

According to an estimate, the total hydroelectric potential of Pakistan is about 41,700 MW, but only 17% of the potential, i.e., 7116 MW, is harnessed (Khan et al. 2012; Mirza et al. 2008a, b).

Wind energy

Wind is second highest renewable energy source for electricity production across the globe. Alternative Energy Development Board of Pakistan has estimated that Gharo-Keti Bandar Wind Corridor has a potential of 42,000 MW of gross resource and with a capacity factor of 25%, an exploitable potential of 11,000 MW. However, at present, wind capacity is about 106 MW only (NEPRA 2014).

Solar energy

Utilization of solar energy for power generation can be an alternative source to fossil fuels. With 1500 to 3000 sunshine hours, solar energy potential ranges from 2.0 to 8.5 kWh m^{-2} per day (NREL 2015).

Considering the high energy requirements, renewable energy sources must be adopted to overcome the energy crisis in environmental-friendly way (Ali et al. 2016; Gangadhara and Prasad 2016; Hiwot 2017; Nisar et al. 2017). Renewable energy sources are most favorable because they provide economically efficient solution for developing countries and have minimum impact on the environment. In Europe, approximately 71% of total electricity is produced using renewable energy sources (Cunado and Gracia 2005; Global Status Report 2012). In Pakistan during 2013, the electricity shortfall reached up to 6000 MW, and mostly, it remained between 4000 and 5000 MW throughout the year (GoP 2013).

In recent past, many studies have reported the use of biomass from agro-industry for energy production all around the world (Angeline et al. 2017; Ding et al. 2017; Gonzalez-Salazar et al. 2016). At present, the renewable energy resources contribute about 18% of global total energy of which 14% is obtained from renewable energy (Kumar et al. 2010).

Biomass resources and reserves in Pakistan

The organic matter primarily stores energy by the process of photosynthesis (Rehman et al. 2013; Shakeel et al. 2016)). Human uses biomass in the form of wood to cook food and heating the homes. In rural areas, biomass can easily replace conventional fossil fuels to fulfill the energy needs; however, a huge quantity of biomass is required to meet the energy requirements at large scale (commercial activities) (Mahmood et al. 2014). Biomass contributes about 10% of primary energy supplies worldwide which could be in the form of liquid, solid, or gas. The biomass which is used for producing energy consists of cellulose, lignin, and hemicellulose (Gondal et al. 2018). Instead of utilizing for energy production, a large amount of crop residues is openly burnt as the waste only due to lack of proper government policies and unawareness among the people.

Major sources of biomass for energy production in Pakistan include forest residues, agricultural crops, municipal solid wastes, and industrial wastes (McKendry 2002). Several types of biomass resources present in Pakistan are (Khan and Ahmed 2018)

- Food processing waste
- Forestry residues
- Sewage
- Animal livestock
- Agricultural residues
- Wood from woodlands and natural forests
- Industrial wastes
- Agro-industrial wastes
- Municipal solid waste

Here, we will discuss the most abundant resources available in Pakistan. Table 2 (Tan et al. 2015) shows the potential resources of biomass in Pakistan.

Forest wood residues

People use wood for heating their homes and cooking purposes. They collect wood and burn it in their stoves (Danish et al. 2015). The people living in the northern areas of Pakistan still utilize forest wood for heating and cooking purposes. Forest residues consist of trees, small branches, and unused wood. About 5.2% of the total available land area consists of forests in Pakistan, which is about 4.224 million hectares. The forest residue is considered an environment-friendly source of biomass and has a great potential to produce approximately 80% of the total energy consumption from biomass resources in Pakistan (Sheikh 2009).

Municipal solid waste

Pakistan is a country facing huge environmental problems related to health issues because of mishandling of municipal solid waste. Municipal solid waste consists of inorganic as well as organic matter which can be processed for energy generation. It has been estimated that municipal solid waste has calorific value of 6.89 MJ kg year^{-1} in Pakistan which could be treated through various methods for energy production of about 13,900 GWh annually (Akhtar and Amin 2012). The major cities of Pakistan like Multan, Islamabad, Karachi, and Lahore possessing industrial parks produce a large

Table 2 Potential of available biomass resources for energy production in Pakistan

Biomass resource	Current utilization	Conversion technology	Potential end use as energy product	Reference
Rice husk	Producing activated carbon, fuel, fiber, pet food etc	Gasification and combustion	Household energy, off grid energy generation	Sheikh (2010)
Wheat straw	Paper products and domestic heating etc	Gasification	Off grid energy generation	SBP (2015)
Animal dung	Biogas production, fertilizer etc	Composting and fermentation	Household fuel, biogas	Stevens et al. (2013)
Bagasse	Fuel, bioethanol production etc	Fermentation and hyydrolysis	Motor fuel	Stevens et al. (2013)
Municipal solid waste	Concrete strengthening, bottom ash production	Pyrolysis, combustion, sieving	Methane, methanol and ethanol production	HDIP (2015)
Forest residues	Fertilizer, fuel	Grinding, saw milling	Fuel wood	GOP (2015)

Table 3 Annual production of major crops and their residues in Pakistan

Name of the crop	Annual production (thousand MT)	Type of residue	Crop to residue ratio (residue/kg crop)	Total available residue (thousand MT)
Cotton	3000	Ball shell	1.1	3300
		Husk	1.1	3300
		Stalks	3.8	11,802.8
Rice	6883	Husk	0.2	1376.6
		Stalks	1.5	10,324.5
		Straw	1.5	10,324.5
Sugarcane	49,373	Bagasse	0.33	16,293
		Top and leaves	0.05	2715
Wheat	23,864	Pod	0.3	7159
		Stalks	1.5	35,796
Maize	296	Cobs	0.3	89
		stalks	2	592
Barley	82	Stalks	1.3	107
Dry chilly	188	Stalks	1.5	282
Bajra	470	Cobs	0.33	151
		Husks	0.3	141
		Stalks	2	940

quantity of municipal, which has a great capacity for energy production. Municipal solid waste comprises industrial, commercial, and household wastes, but due to lack of proper collection system, this potential power generation source is being wasted and has become a source of diseases.

Agricultural crop waste

Pakistan is an agricultural country and its livestock and agriculture sectors produce tons of biomass in the form of animal wastes (dung) and crop residues (bagasse, rice husk, wheat straw, rice straw) which can be utilized for energy generation (Table 3). Agricultural residue is produced during the harvesting and processing of crops like rice straws, wheat straws, cane trash, rice husk, cotton sticks, and bagasse (Kumar et al. 2014). According to World Bank, an area of about 26,280,000 ha is under cultivation (World Bank 2015) which supports 62% people of rural areas (GOP 2006).

Pakistan is on fourth number in producing sugar from sugarcane, and processing of sugarcane produces a huge amount of cane trash and bagasse (Iqbal and Iqbal 2014). In 2010–2011, about 63,920,000 metric tons of sugarcane was harvested that produced 5,752,800 metric tons of trash having a potential of energy generation of about 9475 GWh per year as bioenergy. Government of Pakistan allows sugar mills to produce up to 2000 MW from bagasse. Cotton sticks from cotton crop can also be used for energy generation and Pakistan nearly 11% of the total cultivable land area is specifically reserved for the cotton generation. In 2011, about 1,474,693 metric tons of cotton sticks residue was produced (Pakistan Economic forum 2015).

Conversion technologies for biomass

The biomass treatment methods such as chemical, biological, and physical methods produce solid, liquid, and gaseous fuels (Fig. 2) (Goyal et al. 2008; Valasai et al. 2017). The main purpose of this treatment is to foster carbonaceous, bulky low energy content to fuel. In growing season, biomass absorbs CO_2 and emits it during combustion. Hence, CO_2 is recycled but not added to greenhouse gas effect. Figure 2 shows the steps involved in the conversion of biomass into bioenergy.

Thermal conversion

In thermal conversion, gaseous, liquid, or solid fuels are produced by processing biomass feedstock. Thermal conversion can be done on small scale as well as at large scale.

Gasification

Gasification is the process in which biomass is converted to gaseous form. During this process, biomass is converted into combustible mixture of gases, which contains carbon monoxide, hydrogen, carbon dioxide, nitrogen, methane, and a small fraction of water vapors (Nunes et al. 2016). The produced low yield gas can be utilized in house fuel engines (Naqvi et al. 2017).

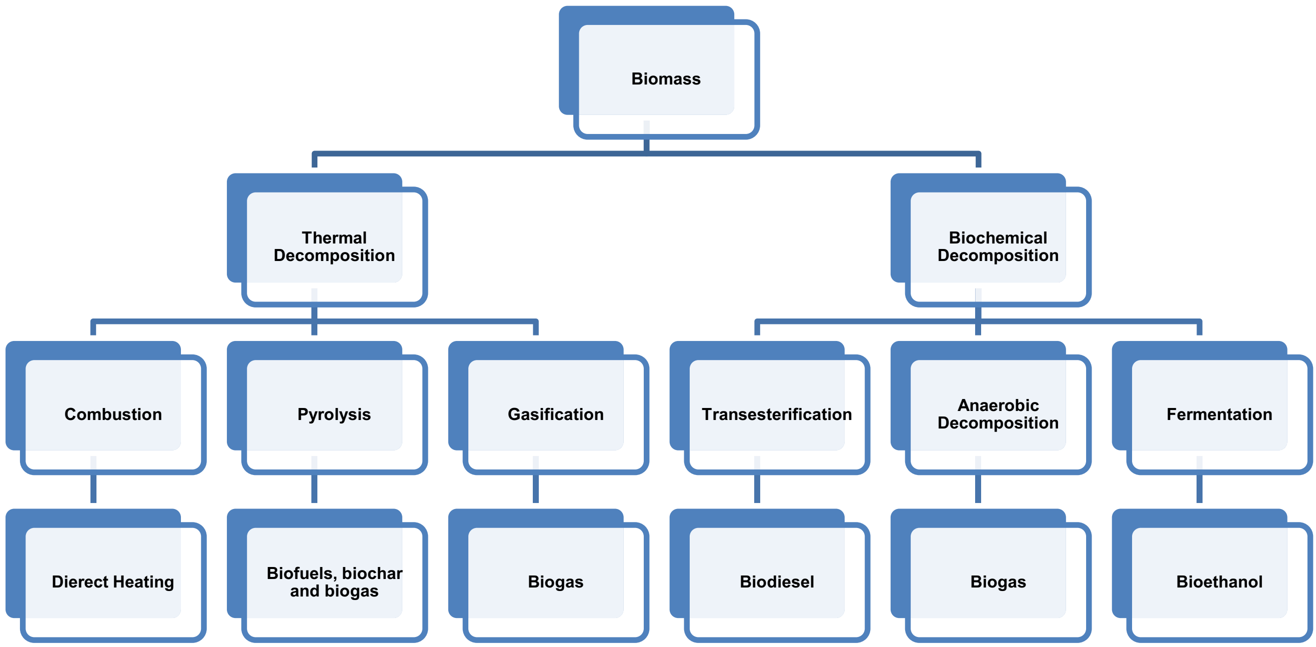


Fig. 2 Steps involved for the conversion of biomass to bioenergy

Pyrolysis

Thermal decomposition of the feedstock material in deficient or no oxygen/air environment is called pyrolysis. It is a basic chemical reaction which is considered as the precursor of gasification and combustion processes and mainly takes place in the first 2 s of the reaction in natural conditions. The biomass burning in pyrolysis process includes gases (carbon monoxide, carbon dioxide, methane) bio-oil and biochar. Char, carbon monoxide, carbon dioxide, water, and reduced molecular weight can be obtained, at less than 300 °C by the pyrolysis of cellulosic biomass. At temperature, 300–500 °C, the molecules depolymerize the anhydrous glucose forming tarry pyrozylate. In Asian countries, organic waste and agricultural wastes are the main sources of raw material for pyrolysis (Vladmimir et al. 2016; Kumaravel et al. 2016; Anke and Hawbodlt 2016; Yildiz et al. 2016; Tripathi et al. 2016).

On the basis of conditions provided, pyrolysis has three main categories such slow, fast, and flash while some researchers also report six categories including intermediate, vacuum pyrolysis, and hydropyrolysis (Table 4) (Iqbal et al. 2018).

Slow pyrolysis

Slow pyrolysis has long been used for charcoal production in the past. Typically, it is considered as a conventional pyrolysis process, characterized by long residence time and slow heating rate of feedstock. In this pyrolysis, the biomass/feedstock is decomposed at temperature of up to 400–500 °C, at a heating rate of ~ 0.1–1 °C s^{-1} and residence time period ranging from 5 to 30 min. Slow pyrolysis provides significant quantity of char while the gaseous components are produced only in a little amount (Ali et al. 2015).

Fast pyrolysis

This is a type of pyrolysis process in which the feedstock is pyrolyzed at temperatures up to 850–1250 °C, 10–200 °C heating rate for a little time span fluctuating between 1 and 10 s. Fast pyrolysis is specifically adopted for the generation of liquid bio-oil as the yield of bio-oil in the fastpyrolysis process dominates to the solid (char) and gaseous products. Generally, a typical fast pyrolysis process yields 60–75%, 15–

Table 4 Typical operating parameters and products of pyrolysis process

Type of pyrolysis	Heating rate (K/s)	Solid residence time (s)	Temperature (K)	Particle size (mm)	Product yield (%)		
					Char	Oil	Gas
Slow	0.1–1	450–550	550–950	5–50	35	30	35
Fast	10–200	0.5–10	850–1250	< 1	20	50	30
Flash	> 1000	< 0.5	1050–1300	< 0.2	12	75	13

25%, and 10–20% of liquid, solid biochar, and gaseous (non-condensable) products, respectively (Bridgwater 2003).

Biomass in the fast pyrolysis process is successfully converted to liquid product due to the high heating rate thus minimizing the reactions which could favor the formation of undesired solid char.

Flash pyrolysis

This is much improved and modified form of fast pyrolysis process. As discussed above, the decomposition of biomass material in fast pyrolysis is achieved by burning the material at very high temperature up to 1000 °C s^{-1} or in some cases above 1000 °C s^{-1}. In flash pyrolysis, the temperature ranges between 900 and 1200 °C and the time for the heat exposure to the biomass persists for a little period approximately about 0.1–1 s (Demirbas and Arin 2002). The main challenge in the application of flash pyrolysis process at industrial level is to optimize a system in which the biomass could last for a little time period at exceptionally increased heating rate. The important problem in flash pyrolysis system is the quality and stability of the bio-oil produced which is greatly influenced by ash/char contents in flash pyrolysis system. Moreover, the ash/char contents in liquid (bio-oil) product may catalyze the polymerization process occurring within bio-oil resulting in bio-oil with high viscosity (Canabarro et al. 2013).

Vacuum pyrolysis

In this type of pyrolysis, biomass is decomposed at reduced pressure under anaerobic conditions. The pressure and temperature during vacuum pyrolysis usually span between 0.05 and 0.20 and 450–600 °C, respectively (Carrier et al. 2011). The rate at which biomass is heated in the vacuum pyrolysis process is similar to the slow pyrolysis process. Although some working conditions in vacuum pyrolysis process are comparable to the conditions present in slow pyrolysis process, the vapor removal method from the reaction area makes a huge difference between these two processes.

The specific feature of vacuum pyrolysis is the use of reduced pressure to eliminate vapors generated during the process rather than the purge gas such as nitrogen (N) which is supplied in conventional pyrolysis methods (Korai et al. 2016). Fast vapor removal rate from organic materials under the vacuum pyrolysis process significantly minimizes the residence time of vapors thereby decreasing the secondary processes and yields high liquid product (Naqvi et al. 2016).

Intermediate pyrolysis

Intermediate pyrolysis is normally operated to create a balance between the solid-liquid products. As the name suggests, the operating conditions of different parameters in intermediate pyrolysis process are in-between the fast and slow pyrolysis. Usually, the system pressure is kept around 0.1 MPa in intermediate pyrolysis (Hornung et al. 2011). The temperature in intermediate pyrolysis process ranges 500–650 °C while heating rate and residence time spans between 0.1–10 °C min^{-1} and 300–1000 s, respectively. The typical products obtained during the intermediate pyrolysis include 15–25% biochar, 20–30% vapors (non-condensable gases), and 40–60% liquid (Kebelmann et al. 2013). An important benefit of intermediate pyrolysis process compared to fast pyrolysis process is that contrary to the fast pyrolysis process, the liquid produce of intermediate pyrolysis lacks reactive tar thus can be used in engines and boilers without any further treatment (Mahmood et al. 2013).

Hydropyrolysis

Hydropyrolysis process is comparatively a new method for the conversion of organic materials into superior quality bio-oil. This type of pyrolysis process operates at the conditions where hydrogen-based materials are introduced to the system together with feedstock at a pressure ranging 5–20 MPa which is greater than the atmospheric pressure. The temperature, heating rate, and residence time are almost similar to that of fast pyrolysis process; therefore, hydropyrolysis may be referred to as a fastpyrolysis method in which hydrogen-based organic compounds are introduced under high pressure. It is a well-known fact that hydrogen is considered as a reducing agent; thus, the occurrence of hydrogen at high temperature and pressure decreases the amount of oxygen in liquid bio-oil product and also prevents the char production (Mirza et al. 2017).

Advantages of pyrolysis

Use of pyrolysis is a fast growing process achieving an immense adaptability worldwide. One of the important benefits of this process is its flexibility as pyrolysis can be optimized as per the results required. For instance, for the production of higher contents of biochar, slow pyrolysis is adopted while in contrast, fast pyrolysis process is suitable for higher bio-oil production. Vacuum pyrolysis process has the potential to give more equally distributed yields and this process is currently being employed as a very important step for reduction of wastes and transformation of waste materials into value added things such as char, bio-syngas, and bio-oil (Carrier et al. 2012). Another benefit of using the pyrolysis is that a variety of biomass (wet, dry, soft, hard) and waste materials from industrial sectors and sewage sludge can be treated directly without any major problem; however, in some cases, biomass pretreatment before pyrolysis causes the process to be more efficient (Wang et al. 2012). The cost of the pyrolysis process may be a little concern but big unit of pyrolysis makes it in-expensive. The products of pyrolysis emits only a little amount of NOx and SOx gases which makes this process environmental friendly. Moreover, pyrolysis decreases greenhouse gas emission and assists in maintaining an unpolluted atmosphere along with reduction in global warming (Hornung et al. 2011).

Combustion

In combustion, complete oxidation of biomass occurs and is converted into energy. Biomass is combusted directly at elevated temperature ranging between 800 and 1000 °C (Naqvi et al. 2016). The flue gases produced are used to generate electricity from steam turbines (Singh and Shukla 2014). Combustion of biomass is one of the oldest forms of combustion. However, this method is only 10% efficient and causes substantial pollution (Pei-dong et al. 2007; Thornley et al. 2009).

Biochemical conversion

Micro-organisms decompose organic matter in the biomass anaerobically to produce biogas. They convert organic matter into biogas by simple chemical conversion.

Transesterification

Catalytic transesterification of bio-oils produces biodiesel. On industrial scale, different vegetable oils including soya bean, rapeseed, sunflower, mustard, palm, and hemp oils are utilized to produce biodiesel (Raheem et al. 2016a, b).

Fermentation

In fermentation, sugars are hydrolyzed biochemically by the activity of microorganisms into ethanol. A lot of countries are producing bioethanol on industrial scale by fermentation. Major raw materials for this process are sugar and starch (Tan and Lagerkvist 2011).

Anaerobic digestion

Microbial activities in the absence of oxygen produce biogas from biomass. Biogas is a mixture of methane, carbon dioxide, hydrogen, and traces of other gases. Biogas can be utilized for cooking purposes at domestic scale as well as at industrial scale to run gas engines (Jones and Ogden 1984).

Significance of biofuels

Pakistan is seriously facing a huge energy crisis owing to increasing energy demands and depleting energy reservoirs. Bioenergy production from the use of biomass has become an important step in many countries worldwide due to its characteristics (Singh et al. 2014; IEA 2016) like

•Reduction in emission of greenhouse gas
•Diversification of rural economy
•less land degradation
•Flexibility and wide availability
•Easily accessible source of energy

Energy from biomass provides sufficient energy to fulfill the energy requirements as well as also helps to handle municipal, commercial, and industrial waste in proper way. To cop the environmental issues and the spread of diseases, it is essential to manage the waste effectively (Rashid et al. 2013). Using biomass for bioenergy will also give strength to agricultural economy (Rauf et al. 2015).

Biogas

The waste organic matter is decomposed by bacteria anaerobically to produce biogas. Biogas is a mixture of carbon dioxide, methane, and some other gases in traces. Biogas is a respiratory product of decomposers produced during anaerobic digestion, but due to its high combustibility, it can serve as source of energy. Animal manure in wet condition can produce biogas. Rural areas of Pakistan have potential to produce biogas, where a large amount of animal waste and crop residues are available (Bhattacharya and Abdulsalam 2002).

Bioethanol

Bioethanol is a precious substitute to the gasoline to run internal combustion engines and is produced by the fermentation of waste by using yeast or bacteria (Niven 2005; Limayem and Ricke 2012). Municipal solid waste and crop residues have significant potential for the production of bioethanol (Mussatto et al. 2010). Nowadays, sugarcane and starch-based crops are being used to produce bioethanol (Oscar and Carlos 2008).

Biodiesel

Biodiesel is a liquid fuel, produced by processing waste oil from oil-producing plants and household waste oil. Many plants like canola, corn, peanut, soya bean, sunflower, avocado, and mustard seeds contribute for the biodiesel production. Biodiesel can also be produced by animal fats and recycling of cooking oil.

In the presence of catalyst and alcohol esterifictaion of animal fats and plants, oil also yields biodiesel which is used in transportation as a replacement of petro-fuels (Ma and Hanna 1999; Pramanik 2003; Schuchardt et al. 1998; Freedman et al. 1984). Use of biodiesel in transportation has following advantages (Tan and Lagerkvist 2011):

•direct use in any diesel engine without upgrading

•eco-friendly
•comprises no petroleum, but can be mixed with conventional engines
•degradable, non-toxic, and lead free
•clean burning alternative fuel

Transport fuel

Transportation is highly dependent on petro-fuels for energy needs and the main user of fossil fuels is transportation sector in Pakistan (NREL 2006). Biofuels are in liquid form produced from crop residues and oils extracted from plants. The biofuels which are produced across the world include bioethanol, biodiesel, butanol, and gasoline etc. Bioethanol and biodiesel can be used as fossil fuels alternative in Pakistan.

Potential impact of bioenergy

Household impacts of bioenergy

Around 62% population of Pakistan lives in rural areas and they utilize animal dung, crop residues, and firewood to meet their energy demands for cooking and heating purposes (GOP 2006). Biogas and animal dung have a potential to fulfill the energy demands of an average of about 28 million people in rural areas (Mirza et al. 2008a, b). Due to unavailability of other energy alternative sources, nearly 76% household depends on biomass resources in Pakistan (GOP 2006). The use of fuelwood in Pakistan at household level is expected to increase in recent years owing to poor economic condition of the country. This has resulted in the significant rise in the deforestation rate as Pakistan ranked second among the highest deforestation rate around the globe [IUCN 2002]. On average, 420 km^2 or 1.66% of the area is lost per year. Pakistan lost 33.2% or nearly 8400 km^2 of its forest cover between the years 1990 and 2010. Although Pakistan was expected to improve its forest cover from 4.8% to around 5.7% in year 2011 and then 6% in 2015 but this goal has not been achieved (Ouerghi and Heaps 1993).

Industrial impacts of bioenergy

Fossil fuels are primary source for running the industries, where biomass is being focused as an energy alternative. The energy share reserved for industrial sector is about 23% of the total energy consumption in Pakistan. Bagasse from sugarcane is primary source of biomass for industries and can be used directly or indirectly by many industries. Sugar industry itself uses 70% of total bagasse to run condensation-extraction steam turbines. The rest of bagasse is used by different industries to run combined heat and power systems (Larson and Kartha 2000). Agricultural residues such as wheat corn, rice husk and cotton sticks are also used for energy generation in industries. Mostly, the crop residues are directly burnt in brick kilns (Rauf et al. 2015). Being an agricultural country, the potential of potential of producing crop residues in Pakistan is enormous which could act as a significant source of energy in Pakistan. The term crops or agricultural residue is usually assigned to organic waste materials produced as a by-product during the crop harvesting or processing. There are two types of crop residues such as primary and secondary residues. The agriculture/crop residues produced during the harvesting of crops in the field are termed as primary residues for example sugarcane tops and rice straw, while crop residues produced simultaneously during the processing are defined as secondary residues such as sugar cane bagasse. The main and important crops of Pakistan are cotton lint and Pakistan ranks 4th in the cotton production, 5th in sugarcane production, and 11th in paddy rice production in the world (Butt et al. 2013). Thus, there is a great advantage to use these crop residues in order to produce energy for industrial sector.

Commercial sector

Limited data is available on the use of biomass for energy production in commercial sector like bakeries, restaurants etc. Only the fuelwood is reported to use in the commercial sector which contributes nearly 10 PJ of energy, thus only contributing 1% of the total biomass consumption (Butt et al. 2013).

Advantages of energy from biomass over fossil fuels

The products obtained from petroleum act as primary fuel in transport sector and are major source of energy in each industry. The emission of dangerous greenhouse gases, from the volatile organic compounds (VOC) present in petroleum products, contributes towards serious environmental issues (Dincer 2000). The effective and efficient solution to these environmental issues is renewable energy which can play a vital role (Edenhofer et al. 2012). In recent years, bioenergy is getting more attention. Bioenergy has a number of advantages for environment (Gopalakrishnan et al. 2011) such as
•biodegradable or renewable energy
•reduces emissions of greenhouse gases
•supports agriculture and food processing industries
•provides economic development
•provides employment opportunities
•reduces landfills
•abundantly available and cost saving
•reduces dependence on fossil fuels
•energy security and reliability
•can be used to produce different products such as enthanol

Promotional strategies for bioenergy

It is needed to find some new resources besides conventional bioenergy resources to cope with demand and energy issues of the country. Pakistan is a country which is rich with biomass resources easily available for energy generation. Here, we explored some alternative biomass resources easily available in Pakistan for energy production;

City wastes

Urban areas of Pakistan are generating approximately 55,000 t of solid wastes per day and if this waste is collected and treated appropriately can serve as a potential source for energy generation. A massive quantity of waste is openly burnt in some areas causing the emission of greenhouse gases and produces pollution in different parts of the environment along with lethal diseases outbreak. If city waste is burnt in an organized manner, then its heating power can be used for electricity production in Pakistan. By designing and maintaining proper landfill sites and utilizing wastes properly, an appropriate quantity of electricity and heat could be produced.

Poultry litter

Poultry-based farms are widely available in Pakistan and a massive quantity of poultry litter (chicken litter) originated both from broiler-chicken and layer-chicken is produced daily. This type of biomass source can be used significantly for energy production in Pakistan with special attention of the government. According to an estimate, 528 million broiler chicken and 15 million layer-chicken were produced during 2003–2004 including share of 3.5, 6.5, 22, and 68% of Baluchistan, KPK, Sindh, and Punjab, respectively. The reports suggest that in Pakistan, 15 t of chicken-litter is produced per annum from a poultry farm of 3000 chickens. If government process and handle this waste-litter technically, it may provide sufficient energy needed for the production of 40 MW of electricity daily.

Animal slurry

In 2000, livestock census and Pakistan Federal Bureau of Statistics (FBS) estimated that there are about 46.69 million of animals such as cows, bullocks, and buffaloes generating 700 million kg dung on daily basis (FBS 2002). Hassan (2002) reported that in addition to 50 million kg of biofertilizer production, 17.5 million m^3 of biogas can be generated by biomethanation process from the animal dung on daily basis. So far, animal dung is being used to produce biogas only at a small scale and this could be used on commercial basis if authorities take interest and develop a proper policy.

Conclusions and future directions

Biomass could be a potential source of bioenergy for Pakistan in near future, as country is facing terrible energy crisis. In order to cope with this energy crisis, scientists and researchers are focusing on biomass for energy generation due to its easy availability. Biomass is considered as an emerging source for production of bioenergy in developing countries to meet the energy demands. Pakistan is also a developing country, and to tackle its energy crisis, Pakistan should make efforts to utilize biomass for production of bioenergy. Some technological measures have been taken by the government considering the significance of energy produced from biomass. To reduce the energy shortage in the country, government and private sectors must work on urgent basis for increased production of bioenergy. It is very important to select the suitable biochemical or thermal conversion methods for biomass-producing fuels such as pyrolysis vapors, char, syn gas, or bio-oil which can further produce methane, methanol, dimethyl ether, hydrogen etc. These fuels may be used to run combined heat and power systems and as vehicle fuels. The future potential of biofuels, thermal energy, or electricity generation at small scale must also be considered. The government of Pakistan must make new projects and policies on bioenergy production from biomass in collaboration with different countries and companies.

Acknowledgments The authors are thankful to Government College University Faisalabad, Pakistan.

References

Ahmed S, Mahmood A, Hasan A, Sidhu GAS, Butt MFU (2016) A comparative review of China, India and Pakistan renewable energy sectors and sharing opportunities. Renew Sust Energ Rev 57:216–225

Akhtar J, Amin NS (2012) A review on operating parameters for optimum liquid oil yield in biomass pyrolysis. Renew Sust Energ Rev 16:5101–5109. https://doi.org/10.1016/j.rser.2012.05.033

Ali SH, Zuberi MJS, Tariq MA, Baker D, Mohiuddin A (2015) A study to incorporate renewable energy technologies into the power portfolio of Karachi, Pakistan. Renew Sust Energ Rev 47:14–22

Ali G, Bashir MK, Ali H, Bashir MH (2016) Utilization of rice husk and poultry wastes for renewable energy potential in Pakistan: an economic perspective. Renew Sust Energ Rev 61:25–29. https://doi.org/10.1016/j.rser.2016.03.014

Prairie YT, Alm J, Beaulieu J, Barros N, Battin T, Cole J, Harrison J (2018) Greenhouse gas emissions from freshwater reservoirs: what does the atmosphere see? Ecosystems 21(5):1058–1071

Anke K, Hawbodlt K (2016) Blends of Pyrolysis oil, Petroleum and other bio-based fuels: A review. Renew Sustain Energy Rev 59:406–419

Angeline AA, Jayakumar J, Asirvatham LG et al (2017) Power generation enhancement with hybrid thermoelectric generator using biomass waste heat energy. Exp Thermal Fluid Sci 85:1–12. https://doi.org/10.1016/j.expthermflusci.2017.02.015

Arshad A, Zakaria M, Junyang X (2016) Energy prices and economic growth in Pakistan: A macro-econometric analysis. Renew Sust Energ Rev 55:25–33. https://doi.org/10.1016/j.rser.2015.10.051

Arslan M, Zaman R, Malik RK (2014) Impact of CNG load shedding on daily routine: A study of Pakistan. SSRN Electron J. https://doi.org/10.2139/ssrn.2515042

Bhattacharya S, Abdulsalam P (2002) Low greenhouse gas biomass options for cooking in the developing countries. Biomass Bioenergy 22:305–317. https://doi.org/10.1016/s0961-9534(02)00008-9

Bridgwater A (2003) Renewable fuels and chemicals by thermal processing of biomass. Chem Eng J 91:87–102. https://doi.org/10.1016/s1385-8947(02)00142-0

Butt S, Hartmann I, Lenz V (2013) Bioenergy potential and consumption in Pakistan. Biomass Bioenergy 58:379–389

Canabarro N, Soares JF, Anchieta CG, Kelling CS, Mazutti MA (2013) Thermochemical processes for biofuels production from biomass. Sustain Chem Process 1:22–10. https://doi.org/10.1186/2043-7129-1-22

Carrier M, Hugo T, Gorgens J, Knoetze H (2011) Comparison of slow and vacuum pyrolysis of sugar cane bagasse. J Anal Appl Pyrolysis 90:18–26. https://doi.org/10.1016/j.jaap.2010.10.001

Carrier M, Hardie AG, Uras Ü et al (2012) Production of char from vacuum pyrolysis of south-African sugar cane bagasse and its characterization as activated carbon and biochar. J Anal Appl Pyrolysis 96:24–32. https://doi.org/10.1016/j.jaap.2012.02.016

Coyle ED, Simmons RA (2014) Understanding the Global Energy Crisis. Purdue University Press e-books 2014

Cunado J, Gracia FPD (2005) Oil prices, economic activity and inflation: evidence for some Asian countries. Q Rev Econ Finance 45:65–83. https://doi.org/10.1016/j.qref.2004.02.003

Danish M, Naqvi M, Farooq U, Naqvi S (2015) Characterization of South Asian Agricultural Residues for Potential Utilization in Future 'energy mix.'. Energy Procedia 75:2974–2980. https://doi.org/10.1016/j.egypro.2015.07.604

Demirbas A, Arin G (2002) An overview of biomass pyrolysis. Energy Sources 24:471–482. https://doi.org/10.1080/00908310252889979

Dincer I (2000) Renewable energy and sustainable development: a crucial review. Renew Sust Energ Rev 4:157–175. https://doi.org/10.1016/s1364-0321(99)00011-8

Ding LC, Meyerheinrich N, Tan L et al (2017) Thermoelectric power generation from waste heat of natural gas water heater. Energy Procedia 110:32–37. https://doi.org/10.1016/j.egypro.2017.03.101

EPA [Environmental Protection Agency] (2015) Inventory of U.S. Greenhouse Gas Emissions and Sinks. EPA 430-R-14-003. Accessed in January 2020 from https://www.epa.gov/sites/production/files/2015-12/documents/us-ghg-inventory-2014-main-text.pdf

Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Kadner S, Zwickel T, Eickemeier P, Hansen G, Schlömer S, von Stechow C, Matschoss P (2012) Renewable energy sources and climate change mitigation. Cambridge University Press, Cambridge

FBS (2002) Pakistan statistical year book-2002: federal Bureue of statistics (FBS). Pakistan: Government of Pakistan

Freedman B, Pryde EH, Mounts TL (1984) Variables affecting the yields of fatty esters from transesterified vegetable oils. J Am Oil Chem Soc 61:1638–1643. https://doi.org/10.1007/bf02541649

Gangadhara R, Prasad N (2016) Studies on optimization of transesterification of certainoils to produce biodiesel. Chem Int 2: 59–69

Ghafoor A, ur Rehman T, Munir A, Ahmad M, Iqbal M (2016) Current status and overview of renewable energy potential in Pakistan for continuous energy sustainability. Renew Sust Energ Rev 60:1332–1342

Global status report (2012) REN21 - Renewable Energy Policy Network for the 21st Century. Accessed in January 2020 from https://www.ren21.net/

Gondal IA, Masood SA, Khan R (2018) Green hydrogen production potential for developing a hydrogen economy in Pakistan. Int J Hydrog Energy 43(12):6011–6039

Gonzalez-Salazar MA, Venturini M, Poganietz W-R et al (2016) Development of a technology roadmap for bioenergy exploitation including biofuels, waste-to-energy and power generation & CHP. Appl Energy 180:338–352. https://doi.org/10.1016/j.apenergy.2016.07.120

GOP (2006) Pakistan economic survey 2005–06. Islamabad,Pakistan: Economic Advisers Wing, Ministry of Finance; 2006

GoP [Government of Pakistan] (2013) The Causes and Impacts of Power Sector Circular Debt in Pakistan, Planning Commission, Government of Pakistan, Islamabad. Accessed in January 2020 from http://climateinfo.pk/frontend/web/attachments/datatype/USAID%20(2013)%20The%20Causes%20and%20Impacts%20of%20Power%20Sector%20Circular%20Debt.pdf

GOP (2015) Economic survey of Pakistan 2014–15. Ministry of Finance, Government of Pakistan

Gopalakrishnan G, Cristina NM, Snyder SW (2011) A Novel Framework to Classify Marginal Land for Sustainable Biomass Feedstock Production. J Environ Qual 40(5):1593–1600

Goyal H, Seal D, Saxena R (2008) Bio-fuels from thermochemical conversion of renewable resources: A review. Renew Sust Energ Rev 12:504–517. https://doi.org/10.1016/j.rser.2006.07.014

Hassan MU (2002) Biogas technology to light up villages in Pakistan: Karachi Dawn science-dot-com magazine. 14: 6-7

HDIP (2014) Pakistan energy yearbook 2014. Hydrocarbon Development Institute of Pakistan (HDIP)

Hiwot T (2017) Determination of oil and biodiesel content, physicochemical properties of the oil extracted from avocado seed (Perseaamericana) grown in Wonago and Dilla (gedeo zone), southern Ethiopia. Chem Int 3:311–319

Holdren JP (1991) Population and the energy problem. Popul Environ 12: 231–255. https://doi.org/10.1007/bf01357916

Hornung A, Apfelbacher A, Sagi S (2011) Intermediate pyrolysis: a sustainable biomass-to-energy concept – biothermal valorisation of biomass (BtVB) process. J Sci Ind Res 70(August):664–667

IEA [International Energy Agency] (2016) World energy outlook 2016. International Energy Agency, Paris

IUCN [The World Conservation Union] (2002) Environmental Issues. Land, Fuel- wood. Available at http://www.edu.sdnpk.org/edu/land.htm;accessed on 03 January 2020

International Energy Agency (Iea) International Energy Agency (Iea) (2014) Sustainable Energy for All 2013–2014: Global Tracking Framework Report. doi: https://doi.org/10.1596/978-1-4648-0200-3

Imran M, Amir N (2015) A short-run solution to the power crisis of Pakistan. Energy Policy 87:382–391. https://doi.org/10.1016/j.enpol.2015.09.028

Iqbal MA, Iqbal A (2014) Sugarcane Production, Economics and Industry in Pakistan. American-Eurasian J. Agric. & Environ. Sci 14(12):1470–1477

Iqbal T, Dong CQ, Lu Q, Ali Z, Khan I, Hussain Z, Abbas A (2018) Sketching Pakistan's energy dynamics: prospects of biomass energy. J Renew Sustain Energy 10(2):023101

Jones HB, Ogden E (1984) Biomass energy potential from livestock and poultry wastes in the southern United States. Biomass 6:25–35. https://doi.org/10.1016/0144-4565(84)90005-2

Kebelmann K, Hornung A, Karsten U, Griffiths G (2013) Intermediate pyrolysis and product identification by TGA and Py-GC/MS of green microalgae and their extracted protein and lipid components. Biomass Bioenergy 49:38–48. https://doi.org/10.1016/j.biombioe.2012.12.006

Khan FB, Ahmed A (2018) Prioritization of various renewable energy resources for Pakistan using analytical hierarchy process. Science 37(4):184–194

Khan MI, Yasmin T (2014) Development of natural gas as a vehicular fuel in Pakistan: issues and prospects. J Nat Gas Sci Eng 17:99–109. https://doi.org/10.1016/j.jngse.2014.01.006

Khan AN, Begum T, Sher M (2012) Energy crisis in Pakistan: causes and consequences. Abas J Soc Sci 4(2):341–363

Korai MS, Mahar RB, Uqaili MA (2016) Optimization of waste to energy routes through biochemical and thermochemical treatment options of municipal solid waste in Hyderabad, Pakistan. Energy Convers Manag 124:333–343

Kugelman M (2015) Pakistan's Interminable Energy Crisis: Is there any way out? A publication with a collaborative effort between the Woodrow Wilson International Center for Scholars' Asia Program and the Fellowship Fund for Pakistan. pp 166. Accessed in January 2020 from https://www.wilsoncenter.org/program/asia-program.

Kumar A, Kumar K, Kaushik N et al (2010) Renewable energy in India: current status and future potentials. Renew Sust Energ Rev 14: 2434–2442. https://doi.org/10.1016/j.rser.2010.04.003

Kumar A, Negi YS, Choudhary V, Bhardwaj NK (2014) Characterization of cellulose nanocrystals produced by acid-hydrolysis from sugarcane bagasse as agro-waste. Mater. Chem. Phys. 2(1):1–8

Kumaravel S, Murugesan A, Kumaravel A (2016) Tyre pyrolysis oil as an alternative fuel for diesel engines – A review. Renew Sust Energ Rev 60:1678–1685. https://doi.org/10.1016/j.rser.2016.03.035

Larson ED, Kartha S (2000) Expanding roles for modernized biomass energy. Energy Sustain Dev 4:15–25. https://doi.org/10.1016/s0973-0826(08)60250-1

Limayem A, Ricke SC (2012) Lignocellulosic biomass for bioethanol production: current perspectives, potential issues and future prospects. Prog Energy Combust Sci 38:449–467. https://doi.org/10.1016/j.pecs.2012.03.002

MNPR [Ministry of Petroleum and Natural Resources] (2015) Monitoring and Evaluation Report – July to (2015) Accessed in January 2020 from http://www.mpnr.gov.pk/mpnr/userfiles1/file/3rdMEReport%20Revised.pdf

Ma F, Hanna MA (1999) Biodiesel production: a review1Journal series #12109, agricultural research division, Institute of Agriculture and Natural Resources, University of Nebraska–Lincoln.1. Bioresour Technol 70:1–15. https://doi.org/10.1016/s0960-8524(99)00025-5

Mahmood AS, Brammer JG, Hornung A et al (2013) The intermediate pyrolysis and catalytic steam reforming of brewers spent grain. J Anal Appl Pyrolysis 103:328–342. https://doi.org/10.1016/j.jaap.2012.09.009

Mahmood A, Javaid N, Zafar A et al (2014) Pakistans overall energy potential assessment, comparison of LNG, TAPI and IPI gas projects. Renew Sust Energ Rev 31:182–193. https://doi.org/10.1016/j.rser.2013.11.047

Mckendry P (2002) Energy production from biomass (part 1): overview of biomass. Bioresour Technol 83:37–46. https://doi.org/10.1016/s0960-8524(01)00118-3

Mirza UK, Ahmad N, Majeed T (2008a) An overview of biomass energy utilization in Pakistan. Renew Sust Energ Rev 12:1988–1996. https://doi.org/10.1016/j.rser.2007.04.001

Mirza UK, Ahmad N, Majeed T, Harijan K (2008b) Hydropower use in Pakistan: past, present and future. Renew Sust Energ Rev 12:1641–1651. https://doi.org/10.1016/j.rser.2007.01.028

Mirza S, ur Rehman H, Mahmood W, Qazi JI (2017) Potential of cellulosic ethanol to overcome energy crisis in Pakistan. In Frontiers in Bioenergy and Biofuels (Eds. Jacob-Lopes L and Leila Queiroz Zepka L), online book Published on January 25th 2017, pp. 207. https://doi.org/10.5772/63185

Mussatto SI, Dragone G, Guimarães PM, Silva JP, Carneiro LM, Roberto IC (2010) Technological trends, global market, and challenges of bio-ethanol production. Biotechnol Adv 28:817–830

Naqvi M, Dahlquist E, Yan J (2016) Complementing existing CHP plants using biomass for production of hydrogen and burning the residual gas in a CHP boiler. Biofuels 8:675–683. https://doi.org/10.1080/17597269.2016.1153362

Naqvi M, Yan J, Dahlquist E, Naqvi SR (2017) Off-grid electricity generation using mixed biomass compost: A scenario-based study with sensitivity analysis. Appl Energy 201:363–370. https://doi.org/10.1016/j.apenergy.2017.02.005

NEPRA (2014) National Electric Power Regulatory Authority [state of industry report 2014]. Government of Pakistan; 2014

Nisar J, Razaq R, Farooq M, Iqbal M, Khan RA, Sayed M, Shah A, Rahman IU (2017) Enhanced biodiesel production from Jatropha oil using calcined waste animal bones as catalyst. Renew Energy 101:111–119

Niven RK (2005) Ethanol in gasoline: environmental impacts and sustainability review article. Renew Sust Energ Rev 9:535–555. https://doi.org/10.1016/j.rser.2004.06.003

NREL (2006) National Renewable Energy Laboratory. Innovation for our energy future; 2006. Available at: ⟨www.nrel.gov⟩

NREL (2015) GeoSpatial toolkit. National Renewable Energy Laboratory; 2015

Nunes L, Matias J, Catalão J (2016) Biomass combustion systems: A review on the physical and chemical properties of the ashes. Renew Sust Energ Rev 53:235–242. https://doi.org/10.1016/j.rser.2015.08.053

Oscar JS, Carlos AC (2008) Trends in biotechnological production of fuel ethanol from different feedstock. Bioresour Technol 99:5270–5295

Ouerghi A, Heaps C (1993) Pakistan household energy strategy study (HESS)In Household energy demand: consumption patterns. Stockholm, Sweden: Stockholm Environment Institute (SEI)

Ozturk I (2010) A literature survey on energy–growth nexus. Energy Policy 38:340–349. https://doi.org/10.1016/j.enpol.2009.09.024

Ozturk I, Aslan A, Kalyoncu H (2010) Energy consumption and economic growth relationship: evidence from panel data for low and middle income countries. Energy Policy 38:4422–4428. https://doi.org/10.1016/j.enpol.2010.03.071

Pakistan Economic forum III (2015) Draft report. The Pakistan Business Council; 2015.Available at ⟨http://www.pbc.org.pk⟩

Pakistan Energy Yearbook (2014) Primary Energy Supplies by Source. Accessed in January 2020 from https://hdip.com.pk/docs/important-tables-14-03-2012.pdf

Pei-Dong Z, Guomei J, Gang W (2007) Contribution to emission reduction of CO2 and SO2 by household biogas construction in rural China. Renew Sust Energ Rev 11:1903–1912. https://doi.org/10.1016/j.rser.2005.11.009

Jacob Jørgensen Peter (2009) Biogas–green energy, 2nd ed.. Digisource Danmark A/S

Greg Phal (2008) Biodiesel: grouping a new energy economy, 2nd ed. White River

Pramanik K (2003) Properties and use of jatropha curcas oil and diesel fuel blends in compression ignition engine. Renew Energy 28:239–248. https://doi.org/10.1016/s0960-1481(02)00027-7

Raheem A, Hassan MY, Shakoor R (2016a) Bioenergy from anaerobic digestion in Pakistan: potential, development and prospects. Renew Sust Energ Rev 59:264–275. https://doi.org/10.1016/j.rser.2016.01.010

Raheem A, Abbasi SA, Memon A, Samo SR, Taufiq-Yap YH, Danquah MK, Harun R (2016b) Renewable energy deployment to combat energy crisis in Pakistan. Energy Sustain Soc *6*(1):16

Rashid N, Rehman MSU, Han J-I (2013) Recycling and reuse of spent microalgal biomass for sustainable biofuels. Biochem Eng J 75:101–107. https://doi.org/10.1016/j.bej.2013.04.001

Rauf O, Wang S, Yuan P, Tan J (2015) An overview of energy status and development in Pakistan. Renew Sust Energ Rev 48:892–931. https://doi.org/10.1016/j.rser.2015.04.012

Raza W, Hammad S, Shams U, Maryam A, Mahmood S, Nadeem R (2015) Renewable energy resources current status and barriers in their adaptation for Pakistan. Bioprocess Chem Eng 3:1–9

Rehman MSU, Rashid N, Saif A et al (2013) Potential of bioenergy production from industrial hemp (Cannabis sativa): Pakistan perspective. Renew Sust Energ Rev 18:154–164. https://doi.org/10.1016/j.rser.2012.10.019

Sarkodie SA, Strezov V (2019) Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Sci Total Environ 646:862–871

SBP (2015) Import payments by commodity. State Bank of Pakistan - Statistics and Data Warehouse Department, Government of Pakistan

Schuchardt U, Sercheli R, Vargas RM (1998) Transesterification of vegetable oils: a review. J Braz Chem Soc. https://doi.org/10.1590/s0103-50531998000300002

Shakeel SR, Takala J, Shakeel W (2016) Renewable energy sources in power generation in Pakistan. Renew Sust Energ Rev 64:421–434

Sheikh MA (2009) Renewable energy resource potential in Pakistan. Renew Sust Energ Rev 13:2696–2702. https://doi.org/10.1016/j.rser.2009.06.029

Sheikh MA (2010) Energy and renewable energy scenario of Pakistan. Renew Sust Energ Rev 14:354–363. https://doi.org/10.1016/j.rser.2009.07.037

Singh R, Shukla A (2014) A review on methods of flue gas cleaning from combustion of biomass. Renew Sust Energ Rev 29:854–864. https://doi.org/10.1016/j.rser.2013.09.005

Singh N, Kumar A, Rai S (2014) Potential production of bioenergy from biomass in an Indian perspective. Renew Sust Energ Rev 39:65–78. https://doi.org/10.1016/j.rser.2014.07.110

State Bank of Pakistan (2015) Balance of payment. Accessed in January 2020 from http://www.sbp.org.pk/reports/annual/arFY14/BoP.pdf

Stevens SH, Moodhe KD, Kuuskraa VA (2013) China shale gas and shale oil resource evaluation and technical challenges. SPE Asia Pacific Oil and Gas Conference and Exhibition

Tan Z, Lagerkvist A (2011) Phosphorus recovery from the biomass ash: A review. Renew Sust Energ Rev 15:3588–3602. https://doi.org/10.1016/j.rser.2011.05.016

Tan Z, Chen K, Liu P (2015) Possibilities and challenges of China′s forestry biomass resource utilization. Renew Sust Energ Rev 41:368–378. https://doi.org/10.1016/j.rser.2014.08.059

Thornley P, Upham P, Huang Y, Rezvani S, Brammer J, Rogers J (2009) Integrated assessment of bioelectricity technology options. Energy Policy 37:890–903

Tripathi M, Sahu J, Ganesan P (2016) Effect of process parameters on production of biochar from biomass waste through pyrolysis: A review. Renew Sust Energ Rev 55:467–481. https://doi.org/10.1016/j.rser.2015.10.122

Uddin W, Khan B, Shaukat N, Majid M, Mujtaba G, Mehmood A et al (2016) Biogas potential for electric power generation in Pakistan: A survey. Renew Sust Energ Rev 54:25–33

Valasai GD, Uqaili MA, Memon HR, Samoo SR, Mirjat NH, Harijan K (2017) Overcoming electricity crisis in Pakistan: A review of sustainable electricity options. Renew Sust Energ Rev 72:734–745

Vladmimir FK, Lavrenov VA, Larina OM, Zaichenko VM (2016) Use of Two-stage pyrolysis for Bio-waste Recycling. Chem Eng Transact 50:151–156

Wang Y, He T, Liu K, Wu J, Fang Y (2012) From biomass to advanced bio-fuel by catalytic pyrolysis/hydro-processing: Hydrodeoxygenation of bio-oil derived from biomass catalytic pyrolysis. Bioresour Technol 108:280–284. https://doi.org/10.1016/j.biortech.2011.12.132

World Bank (2015) Pakistan development update Washington, DC. ©World Bank. ⟨https://openknowledge.worldbank.org/handle/10986/22926 License: CC BY3.0IGO; 2015

World Energy Council (2016) World Energy Resources | 2016. Accessed in January 2020 from https://www.worldenergy.org/assets/images/imported/2016/10/World-Energy-Resources-Full-report-2016.10.03.pdf

Yildiz G, Ronsse F, Duren RV, Prins W (2016) Challenges in the design and operation of processes for catalytic fast pyrolysis of woody biomass. Renew Sust Energ Rev 57:1596–1610. https://doi.org/10.1016/j.rser.2015.12.202