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REVIEW
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Renewable energy deployment to combat energy crisis in Pakistan

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Abstract

The huge deficiency of electricity due to heavy reliance on imported fuels has become a significant impediment to socio-economic development in Pakistan. This scenario creates an increase in local fuel prices and limits potentials in the establishment of new industrial zones. The current gap between the demand and production of electricity in Pakistan is approximately 5000–8000 MW with a constant increase of 6–8 % per annum. Hence, more sustainable and renewable energy sources are required to overcome the existing problem. Pakistan is endowed with potential renewable energy resources such as wind, solar, hydro, and biomass. These resources have the capacity to be major contributors to future energy production matrix, climate change reduction efforts, and the sustainable energy development of the country. This article reviews the availability of alternative energy resources in Pakistan and associated potentials for full-scale development of sustainable energy systems. It also discusses exploitation strategies to increase the distribution of indigenous energy resources.

Keywords: Energy crisis, Sustainability, Renewables, Biomass, Pakistan

Review

Background

Pakistan is one of the most populated countries in the southern Asia region, contributing approximately 2.56 % of the total global population. The country is expected to serve as an international trade and energy corridor in the near future due to its strategic location [1, 2]. Hence, among other social, economic, and political factors, Pakistan needs to ensure its energy supplies meet the direct and indirect demands of the country not only for maintaining economic growth but also for supporting regional and global economic initiatives. The vast deficit between demand and supply of electricity recorded in 2009–2010 was 26.82 %. This figure has increased up to 50 % during the summer of 2012 [1]. A routine problem is that electricity supply cannot be maintained during peak hours, resulting in frequent power shutdown (load shedding) of 13–14 h in urban areas, and 16–19 h in rural areas. As a result, many entrepreneurs and industrialists have invested and moved their businesses to neighboring countries [3]. Hence, short- and long-term measures are required to solve the existing energy problems. The present state of Pakistan's energy resources is summarized (Fig. 1). It can be seen that indigenous energy sources mainly consist of oil (38 %), hydro (32 %), natural gas (27 %), and coal (3 %) [1].

Sustainable supply of energy to meet the current and future domestic and industrial demands in Pakistan will rely on full-scale generation from the different energy sources in order to make significant contributions to the supply chain. Current energy generation has a huge financial burden on the country's economy due to the importation of oil to support existing mix, and the situation is heightened by the rapid declination of domestic gas assets. According to the Board of Investment Pakistan, the installed power capacity is 22,797 MW. However, current generation stands between 12,000 and 13,000 MW per day, against peak a demand of 17,000 to 21,000 MW [4]. Figure 2 shows the average annual demand of electricity, which is increasing at a constant rate of 8–10 % annually.

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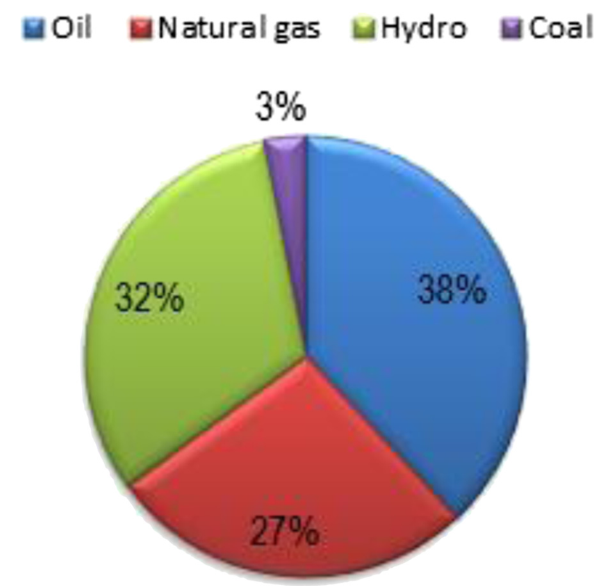

Fig. 1 Distribution of indigenous energy sources available in Pakistan [1]

The acute shortfall and burden imposed by oil importation creates a huge economic constraint for the country [5, 6]. Various efforts have been made by different governmental organizations and international bodies such as Asian Development Bank (ADB) and World Bank to stabilize the energy situation. They share similar objectives to enhance fossil fuel production for electricity generation. Unfortunately, governmental efforts to address concerns relating to energy security, climate change, and sustainable development have been minimal. Whilst little effort is put into increasing domestic fossil fuel (gas, coal, and oil) based electricity, the search for alternative fuel sources which are more sustainable and renewable should be a major national priority. Renewable energy in Pakistan was reported to be <1 % in 2010. However, Pakistani government has targeted to achieve 5 % of renewable energy by 2030 [7, 8]. The article reports on the potential and exploration of renewable energy as a major contributor to future sustainable energy pursuits in Pakistan.

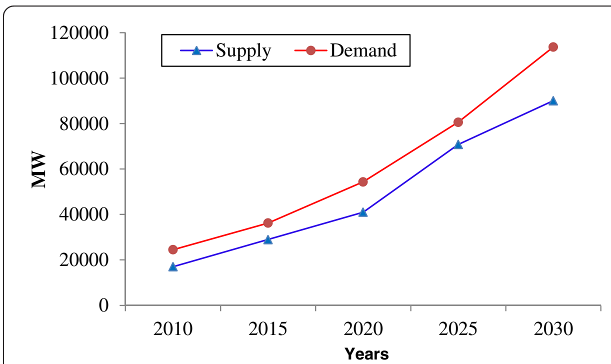

Fig. 2 Electricity demand and supply trends for Pakistan from 2010 to 2030 [5, 7]

Renewable energy potential in Pakistan

Pakistan has four main renewable energy sources. These are wind, solar, hydro, and biomass. These resources have a significant potential to provide solutions to the long-lasting energy crisis in Pakistan [8]. Hence, a steady development of these resources is a crucial step to overcome the existing energy challenges in an environmental friendly manner. Among the different renewable energy sources, solar energy has received the most research attention [9–16]. Sheikh [13], for instance, evaluated the potential of solar photovoltaic (PV) power generation capacity with 14 % efficient PV panels over area of 100 km^2, which is 0.01 % of total land area of the country. From the results, it was concluded that covering 100 km^2 area of land with PV panels can produce energy equivalent to 30 million tons of oil equivalent (MTOE) in Pakistan. Gondal and Sahir [15], considered 0.45 % of urban regions for PV installations to estimate the total energy generation capacity based on solar PV system. A survey conducted by Hasnain and Gibbs [16] showed that the interior part of the county consists of mainly agricultural land, which is appropriate for the development of biomass feedstock, whereas northern and southern corridors have a significant potential for hydro, wind, and solar. This finding is useful as it might possibly improve the diverse energy supply market and decrease the dependency on imported fuels and environmental pollution. Figure 3 shows the entire spectrum and end-uses of alternative sources which are the best options to meet basic requirements of energy needs, with various employment openings, local manufacturing.

It has been projected that Pakistan will contribute up to 10,000 MW to its energy mix through renewable energy resources by 2030 [17]. Therefore, timely and appropriate progress to exploit the potential of different natural energy resources will have a tremendously influence in meeting future projections.

Wind energy

The development and use of alternative energy resources have been a major endeavor since 2003. The Pakistani government has set up a recognized body [17], to coordinate efforts in this area. This organization plays an important role in narrowing the gap between demand and supply of electricity by promoting the utilization of renewable energy. Pakistan's Meteorological Department (PMD) has collaborated with the National Renewable Energy Laboratories (NREL), USA, to conduct a wind speed survey of 46 different locations in Sindh and Baluchistan provinces with height ranging from 10–30 m. The data from the feasibility studies were analyzed by Alternative

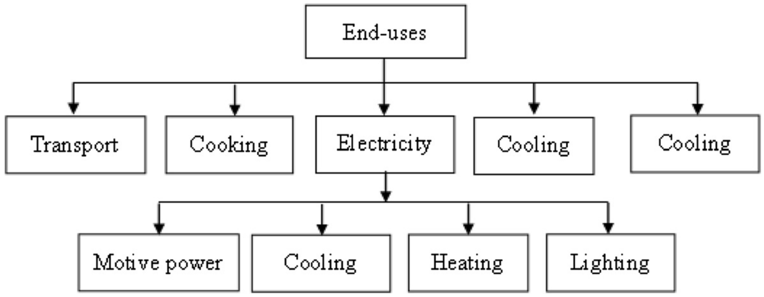

Fig. 3 End-uses of renewable energy resources

Energy Development Board Pakistan (AEDB) [12, 13], and it was found that a vast area of 9750 km^2 with a high wind speed was discovered and zoned as "Gharo-Corridor" as shown in Fig. 4. The area has a significant potential to produce around 50,000 MW of electricity. However, due to the occurrence of other economic activities, only 25 % of the area can be utilized with a production potential of 11,000 MW [12, 18].

Moreover, significant wind speeds were identified in the costal part of Baluchistan, particularly in Swat and some

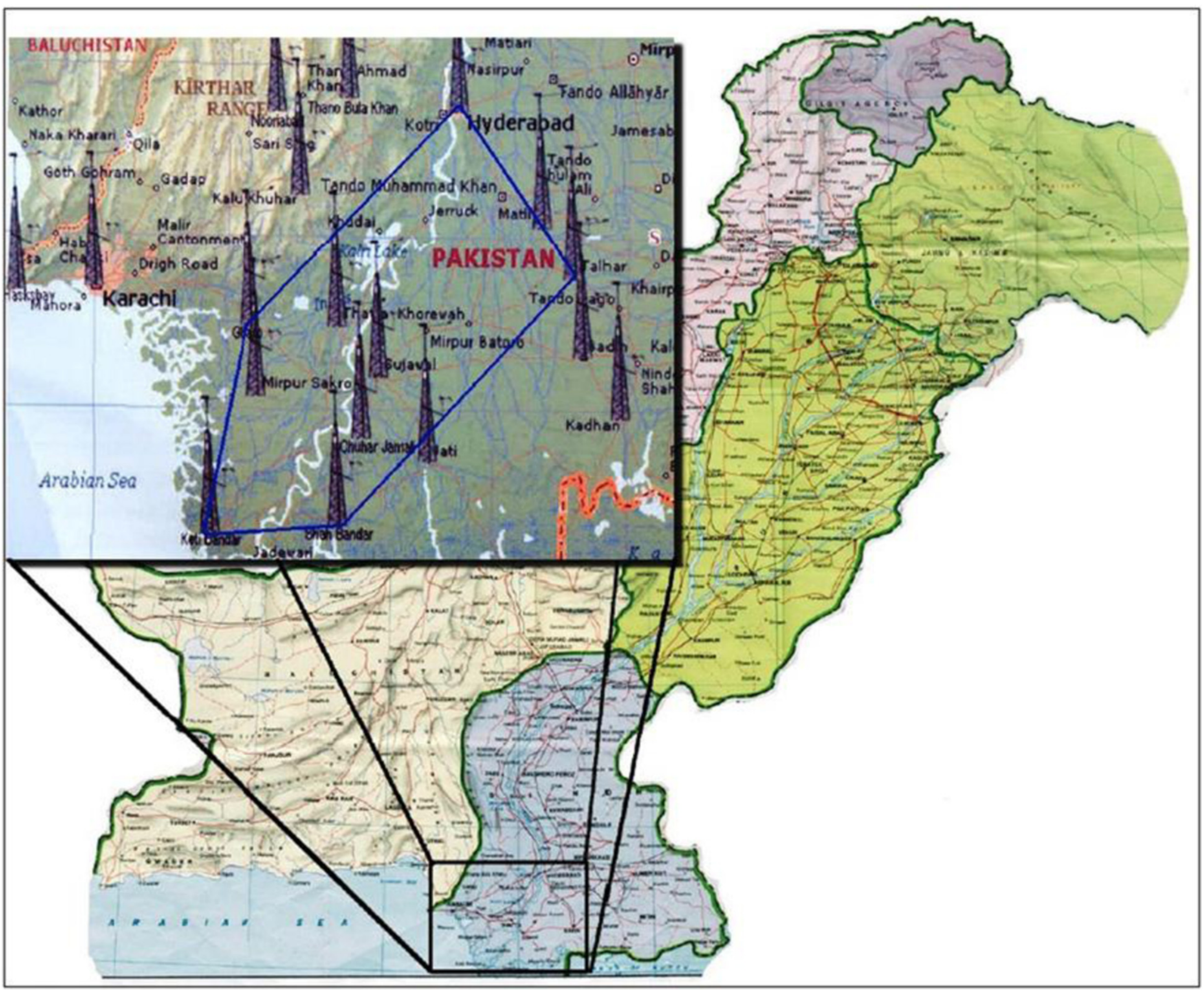

Fig. 4 Wind mapping stations in Sindh with a potential to produce 11,000 MW at a height of 50 m [12]

of the Northern areas. Out of 42 examined sites, seven have a capacity factor ranging from 10 to 18 % and are appropriate for Bonus wind turbines (Model 600/44 MK IV) [19]. However, the potential of these sites is still being explored although the capacity is not enough to contribute to the national grid. NREL, together with the United States Agency for International Development (USAID), has identified a total gross wind resource of 346,000 MW in Pakistan, where approximately 120,000 MW can be technically exploited to power the national gird [20]. Recently, a wind project with 500 MW capacities has been completed in 2013 [17]. In addition, more than 18 wind turbine companies are approaching AEDB to install 3000 MW wind project [21]. At the moment, the first phase of the Zorlu wind project generating 6 MW is in operation whilst a 56 MW plant is yet to be installed. Different wind power projects with a cumulative capacity of approximately 964 MW are at different phases of construction and would be completed in the near future. The Pakistan Council of Renewable Energy Technologies (PCRET) has installed nearly 150 small wind turbines ranging between 0.49 and 9 kW with a cumulative power output of 160 kW at the different areas of Sindh and Baluchistan, powering 1569 homes including 9 security check posts [22]. Also, thousands of small wind turbines with a capacity of 300–1000 W have been installed by different Non-Governmental Organizations (NGOs), electrifying rural areas of Sindh province. Most recently, three villages of Baluchistan have been powered using a wind/PV hybrid system [1]. With further investment and development, wind energy could become a major component of sustainable energy future in Pakistan.

Solar energy

Solar is believed to be one of the most endowed renewable energy sources. It is reliable and capable of producing substantial amount of energy without posing adverse impacts on the environment. Generally, PV cell and solar thermal conversion systems are used to capture sun energy for various applications in rural and urban areas. PV technology is capable of converting direct sun radiation into electricity (Fig. 5). Solar thermal technology uses thermal solar collectors to capture energy from the sun to heat up water to steam for electricity generation [23, 24].

Pakistan with a land area of 796,096 km^2 is located between longitudes 62° and 75° east and latitudes 24° and 37° north [25]. This unique geographical position and climate conditions is advantageous for the exploitation of solar energy. Almost every part of the country receives 8–10 h day^{-1} high solar radiations with more than 300 sunshine days in a year [14, 26]. Figure 6 illustrates the range of solar radiation levels per month in the major cities of Pakistan.

The prospects of solar energy in Pakistan have also been widely investigated by many researchers [27–33]. Adnan et al. [30] analyzed the magnitude of solar radiation data for 58 different PMD stations, and the data showed that over 95 % of the total area of Pakistan receives solar radiations of 5–7 kWh m^{-2} day^{-1}. Ahmed et al. [31] and Ahmed et al. [32] used different methods to estimate and characterize direct or diffused solar radiations in many parts of the country. Khalil and Zaidi [33] conducted the survey of wind speed and intensity of solar radiations at different locations of country. Furthermore, the data was then compared among wind turbine (1 kVA), solar PV (1 kVA), and gasoline generator (1 kVA) (Table 1). The comparison showed that the wind and solar energy are most appropriate alternative resources. The study also found that the 1 kW of solar PV can produce 0.23 kW of electricity, which can significantly contribute to reduce load shedding in Pakistan. Hasanain and Gibbs [16] detailed out the significance of solar energy in rural areas of the country.

AEDB has estimated that Pakistan has about 2,900,000 MW (2900 GW) of solar power potential [18]. The main obstacles to full-scale exploitation include (1) high cost, (2) lack of technology, (3) socio-political behaviors, and (4) governmental policy conflicts.

In 2003, the chief minister of Punjab launched the “UJAALA” program, where 30 W PV panels were distributed among university students throughout the country. This program aimed at encouraging people to utilize alternative energy and cut-down their dependency

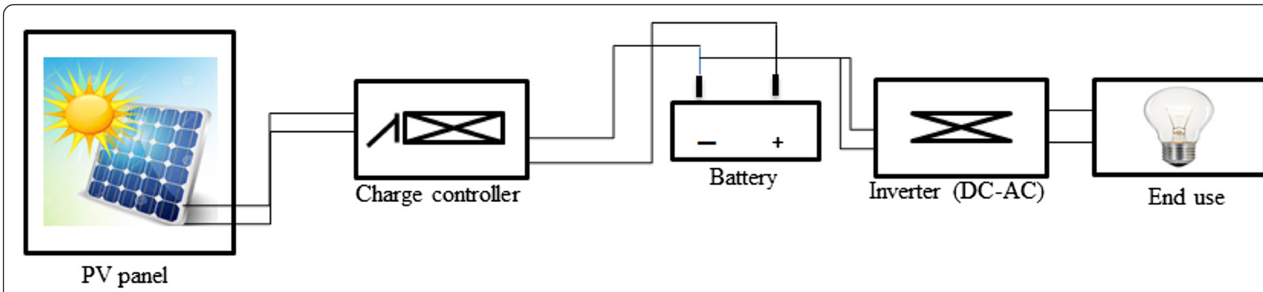

Fig. 5 A schematic drawing of the mechanism of operation of solar photovoltaic systems

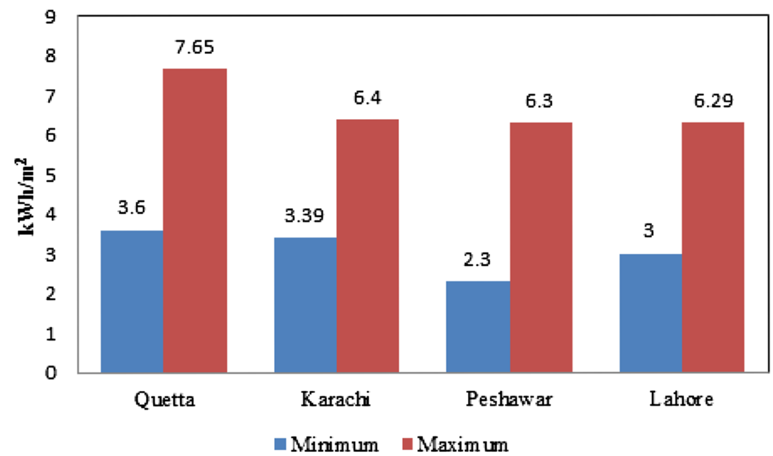

Fig. 6 Minimum and maximum range of solar radiations in Pakistan [27]

on the national gird. Another project introduced by the government was the "Quaid-e-Azam solar park." This solar park is built to produce 2000 MW of electricity by 2015 [23]. It is projected that the largest solar photovoltaic electricity production will be established after 2020 [1]. PCRET has set up approximately 300 solar PV units of 100 kW capacities to power 500 homes, colleges and mosques, including street lighting [34]. AEDB has powered 3000 families by installing 200 kW PV system together with 80 W solar charged lighting systems [28]. Many NGOs are effectively working to install PV units in several parts of the country. The solar street lamps and solar charging lights for households are particularly of major interest. Pakistan has a target of electrifying approximately 40,000 villages via solar PV by 2015 [28].

Solar water heating

The solar water heating technology has been extensively applied in Pakistan with an annual growth rate of 245 % during the last four years [35, 36]. AEDB has started a Consumer Confidence Building Program (CCBP) to promote solar water heating system in Pakistan. The main objective of this program is to create awareness and build-up consumer confidence thorough various incentives. At present, there are 55 companies importing solar geysers, including 25 local manufactures [37]. The main factors contributing to growth pattern are heftiness, affordability, technological reliability and increasing scarcity of natural gas. It is estimated that approximately 9500 of solar water heating units will be operated in the country by 2015, and projected to be 24,000 units by 2020 without any governmental subsidies [38]. According to Han et al. [39], utilizing solar water heating technology instead of natural gas or conventional sources has significant advantages on economic, environmental, and social sustainability.

Solar water desalination

Solar desalination is a new and cost-effective technology to remove salt and other minerals from water for daily life applications. The technology desalinates brackish water or seawater either using solar distillation or an indirect method whilst converting the solar energy into heat or electricity [39–41]. It is an environmentally advantageous and cost-effective technology; hence, it is much patronized by communities in rural regions [41]. Arjunan et al. [42] described the design layout and functioning principles of an installed solar water desalination unit in Awania, India. They reported that the distillation of brackish water using solar energy is an effective way to provide potable water for rural communities in arid and semi-arid zones. This makes it a potential technology to be employed in different areas of Pakistan where fresh water availability is limited such as Thar deserts and Cholistan regions. Most of the regions in the country have brackish subsoil water which is not appropriate for human and other living inhabitants [33]; hence, desalination by means of solar energy will be beneficial and sustainable in providing portable water for the rural areas of Sindh, Baluchistan, and Punjab [41]

Table 1 Running cost evaluation for different energy sources [23]

	Price (USD)	Fuel cons: (USD/h)	Maint: cost (USD/h)	Life (years)	CO_2 (g/l)	NO_2 (g/l)
Solar panel (1 kVA)	632	0	0	25	0	0
Gas generator (1 kVA)	1067.50	1.08	0.06	3–5	6.4	58
Wind turbine (1 kVA)	1165.44	0	0.03	12–15	0	0

The government of Balochistan has installed two solar plants in Gawadar, comprising 240 stills and each plant has the capacity to treat up to 6000 g day^{-1} of sea water. Projects to develop the same solar plant system have been initiated in different areas of Balochistan and other province of Pakistan [41]. The Pakistan Institute of Engineering and Applied Sciences (PIEAS) has fabricated a single basin solar still with an optimized efficiency of 30.62 %, being comparable to stills used globally.

Industrial solar water heating

Apart from domestic use, solar water heating system is also used in various commercial and industrial applications including laundries, hotels, food preparation and storage, and general processing and manufacturing. In the textile industry for example, water heating for dyeing, finishing, drying, and curing consumes approximately 65 % of the total energy [14]. Processing and manufacturing industries also require water heating for various operations such as sterilization, distillation, evaporation, and polymerization. Solar thermal technology is one of the most effective solutions to achieve the desired temperature and productivity for the aforementioned applications [42]. Pakistan is the fourth largest producer of cotton in the world; hence, this technology will contribute significantly to meet the water heating requirements of the cotton industry sustainably. As a major contributor to the economy of Pakistan, the textile industry is facing serious challenges in maintaining the global environmental standards. The industry is energy intensive; thus, high energy costs and persistent shortages in demand and supply impact negatively on the production and competitiveness of the industry. Full-scale operation of industrial solar water heating systems would contribute significantly to resolved energy problems faced by the industry. Energy is a crucial commodity on the international market, and its production and competitiveness are the functioning indicators [43, 44]. Water heating is an energy-intensive process and conventionally relies on the use of fossil fuels energy. Solar water heating technology can benefit textile industries in Pakistan by providing an economical choice and a potential alternative to conventional fossil-based routes. Mass implementation of solar water heating systems will also reduce the environmental impacts associated with fossil fuels significantly. Muneer et al. [45] reported a payback period of 6 years for solar water heating systems incorporated into Pakistan textiles industries. Muneer et al. [46] also examined the prospect of solar water heating system on Turkish textile industry and estimated a payback period of ~5 years.

In view of the existing enormous potential, solar energy offers a promising and useful option for Pakistan in various commercial applications. The government needs to consider this technology as an important source of energy and promote massive and rapid investments to meet the supply of power in rural regions such as Balochistan, Thar Desert, and Cholistan, where grid connectivity is not accessible.

Biomass

Biomass is typically derived from plants, animals, and agricultural wastes. It has been in used for various applications such as cooking, heat, fuel, and electricity in rural areas. Broadly, biomass is classified into four major groups: (i) agricultural waste, (ii) municipal solid waste, (iii) animal residue, and (iv) forest residue [47]. However, plants and animals are the main sources of biomass production. Almost 220 billion tons of biomass is produced globally each year from these sources, which is capable of producing substantial amount of energy without releasing high concentrations of carbon dioxide (CO_2) and other greenhouse gasses compared to fossil fuels [48, 49]. Technically, they can be converted into different products either using thermochemical or biochemical methods. However, each of the conversion methods has its own pros and cons and process conditions such as characteristics of biomass feedstock and the desired end product [50]. Biomass could be appropriate and effective for commercial exploitation to generate electricity throughout world, due to its characteristics for high value fuel products [50].

Pakistan is an agricultural country where most of its population (around 70 %) lives in remote areas [2, 51]. Hence, the availability of biomass is very extensive particularly from agriculture and livestock sources, including crop residues and waste from animals. These wastes amount to 50,000 tons day^{-1} of solid waste, 225,000 tons day^{-1} of agricultural residue, and approximately 1 million tons day^{-1} of manure [26, 52, 53]. Due to limited access to grid electricity and advanced technologies in these remote areas, most people are powered using traditional practices to fulfill their energy needs [1, 2]. The sugar cane production industries produces bagasse as residue and this can be used to produce electricity to power sugar mills. Pakistan is the fifth largest country worldwide with sugarcane producing capacity of over 87,240,100 million tons. AEDB and NREL, USA, have estimated 1800 MW of power generation from sugarcane bagasse [17, 54, 55]. In the view of present energy scenario, the government has authorized sugar mill owners to sell their surplus power to the national grid station under the limits of 700 MW [50]. Moreover, urban areas produce large quantities of municipal waste which could possibly be digested to produce biogas, a renewable fuel further used to produce green electricity, heat, or as vehicle fuel and the digested substrate, commonly named digestate, and used as fertilizer in agriculture [13, 52, 56]. Figure 7 is added to explain working principles of biogas plant and applications of the produced products from the process.

Biogas technology is highly advanced in China and India. More than 6 million domestic plants and nearly 950 small and medium units were installed in China by 2007, with an estimated production of 2 million m^3 of clean burning fuel to meet 5 % of its total gas energy needs [57]. A domestic biogas plant was launched in Tibet, China to explore the potential of cattle manure as feedstock, and this has been successfully implemented to improve the social and economic conditions of the region [58]. Efforts have been made to implement biogas technology in Pakistan. The first biogas plant was constructed in 1959 to process farmyard manure (FYM) in Sindh [59]. However, only in 1974 did the government of Pakistan start putting efforts into the implementation of residential biogas technology as an alternative source of energy. Plants with fixed dome, portable gas digesters, and small tanks/bags are the three most frequently used designs for biogas operating plants in Pakistan [60]. Currently, Pakistan has more than 5000 installed biogas plants to meet its domestic fuel needs. These plants are efficiently producing up to 2.5 million m^3 of biogas annually together with 4 million kg $year^{-1}$ of bio-fertilizer [1, 61]. The total estimated nationwide biogas potential is about 13–15 million m^3 day^{-1} [48, 62]. There are opportunities to utilize biomass to produce biogas in the country's remote regions through community biogas plant networks. Almost 57 million animals exist in Pakistan with an annual growth rate of 10 % [60, 61]. The number is capable of producing enough biomass to generate over 12 million m^3 day^{-1} of biogas, which is sufficient to meet the energy needs of more than 28 million peoples in the rural areas, along with approximately 21 million tons day^{-1} of bio-fertilizer [47, 63]. The collaboration between the Ministry of Petroleum and Natural Resources and the Directorate General of New and Renewable Resources (DGNRER) enabled the installation of more than 4000 biogas plants by 1974 to 1987. The plants were intended to produce about 3000 to 5000 ft^3 day^{-1} of biogas for lighting and cooking applications [63]. The scheme was divided into three stages. In stage 1, around 100 Chinese fixed-doom type plants were installed by DGNRER for demonstration purposes on grant-basis. In stage 2, the budget expenses for sponsorship was shared between the recipients and government, and in stage 3, all the economic sponsorships were withdrawn by the government though free technical supports continued but not reliable. However, the scheme failed due to the following reasons: (i) withdrawal of financial sponsorship by the government, (ii) technology was expensive to invest in and maintain, (iii) less technical awareness/training offered to the locals, (iv) lack of incentives, (v) low patronage or participation by the peoples, and (vi) ineffective demonstration [63]. Pakistan Council of Appropriate Technology (PCAT) also collaborated with GDNRER to develop a renewable energy technology strategy under the Ministry of Science and

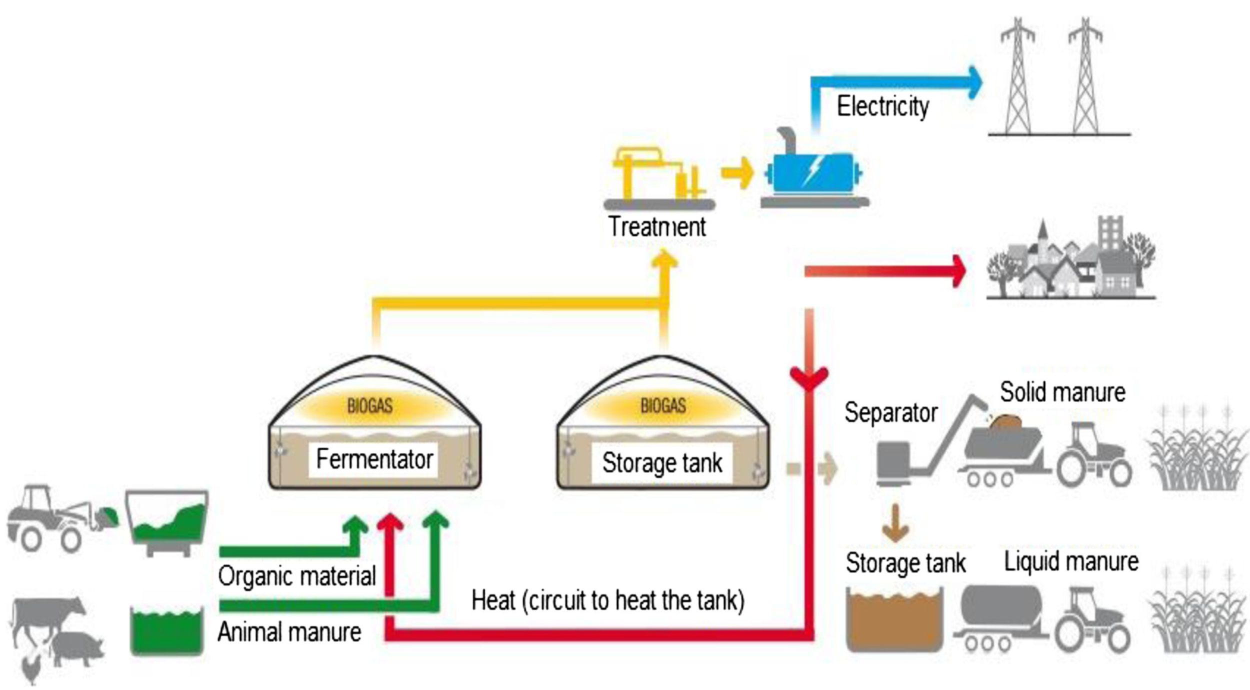

Fig. 7 Working principles of biogas plant and products application [56]

Technology. In 2001, PCAT merged with the National Institute of Silicon Technology to form Pakistan Council of Renewable Energy Technologies (PCRET). The council develops and disseminates biogas plants and other suitable options of renewable energy generation into communities in the remote areas [63]. Currently, approximately 1250 biogas plants have been installed with 50 % of the cost shared between the recipient and PCRET [64]. On top of that, three community based plants were installed in the remote parts of Islamabad, supplying energy to about 20 homes. Sahir and Qureshi [2] suggested that by installing pilot size plants, the available biomass can be used to operate high level biogas plants based on crops and dungs in the remote regions and street wastes in the urban areas. A biogas plant of 1000 m^3 capacity has recently been set up in the area of Cattle Colony, Karachi [64], and the trials and preliminary operations of the project were sponsored by New Zealand Aid (NZAID). There are 400,000 cattle in the area, producing wastes as the feedstock for the biogas plant. The initial generation capacity is ∿250 kW of power, and this will be increased to 30 MW with 1450 tons day^{-1} of fertilizer. Another biogas plant at Shakarganj Mill, with the capacity to produce up to 8.25 MW, is still under construction through the help of AEDB [65]. In addition, PCRET aims to provide alternate renewable energy system in rural households/villages by installing 50,000 medium-scale biogas plants at various locations in the country by 2015, with total annual biogas generation capacity of 110 m^3 [1, 48]. Biogas productivity and quality is greatly influenced by the waste type, waste composition, and operational parameters such as temperature, feeding rate, retention time, particle size, water/solid ratio, and C/N ratio [66]. A temperature range between 30 and 40 °C is found to be optimal for high biogas production rate [67]. Feedstock available and batch loading are also important parameters for efficient biogas plant operation and help to maximize biogas yield. However, over or under loading of feedstock and water affects the overall efficiency of the process. It has been observed that carbon is consumed 25 times faster than nitrogen during anaerobic fermentation by microorganisms. Therefore, to meet this requirement, microbes require 25–30:1 carbon to nitrogen ratio with most of the carbon degraded within the minimum retention time [68, 69]. Retention time refers to the digestion period for which the waste remains inside the digester. It is estimated to be average 10 days to few weeks depending on the waste composition, process parameters location of plant and atmospheric conditions [70]. The digestibility of waste is essential to promote its decomposition into simple organics and biogas products. The digestibility is usually enhanced by treatments using calcium hydroxide, ammonia, and sodium hydroxide. Water and urea can also improve waste digestibility [71].

Bioethanol and biodiesel

Pakistan has a considerable potential to produce biofuels such as bioethanol and biodiesel. The establishment of these biofuels will help reduce the oil demands of the country of which 82 % is sourced by importation. Various initiatives have been commenced by the government to increase biofuel production. Pakistan Sugar Mills Association (PSMA) is the agency responsible to develop bioethanol production in the country. Sugar millers offer incentives and materials such as fertilizers and pesticides to sugarcane growers to enhance crop production and maximize bioethanol production [14]. In 2007, only 6 out of 80 sugar mills in the country had the facilities to convert raw molasses [14]. With the existing production rate of sugarcane, Pakistan has the potential to produce more than 400,000 tons $year^{-1}$ of ethanol. However, only about a third (120,000 tons) is produced currently [55]. Though several small projects have been carried out to evaluate the commercial applications of bioethanol, significant efforts to develop and promote bioethanol are still lacking due to ineffective government policies and lack of infrastructure for large-scale manufacturing. Also, a major portion of the limited bioethanol produced is traded in different forms such as alcohol and molasses.

A significant potential to produce biodiesel also exists in Pakistan through the use of castor bean, a self-grown crop found in different parts of the country. It is estimated to produce more than 1180 kg oil ha^{-1}, which is significantly higher than other biomass such as corn (140 kg oil ha^{-1}), soybean (375 kg oil ha^{-1}) and sunflower (800 kg oil ha^{-1}) [14]. Due to its high oil content, castor bean can be a promising alternative feedstock for biodiesel production. Castor oil has the advantage of being soluble in alcohol under ambient temperature conditions, and this is beneficial to biodiesel production. It is an untapped resource in the country; thus, utilization for biodiesel production will not only contribute to meeting the energy demands of the country but also emerge as a value-adding process that can promote economic, social, and environmental sustainability of the country.

Hydropower in Pakistan

Water is one of the most vital constituents that support all form of life on earth and offers various other services such as power generation [72]. Hydropower relates to the generation of power from dropping water [73]. The kinetic energy present in water dropping from elevated levels can be transferred into mechanical power via hydropower turbine and then to electricity using an electric generator (Fig. 8). The output of electricity is directly proportional to the elevation of moving water (pressure) and flow rate [74].

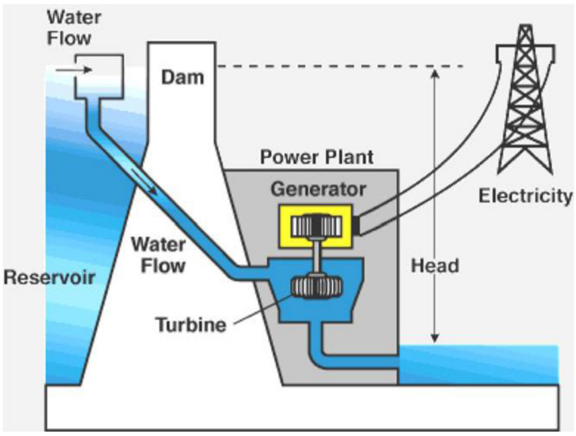

Fig. 8 Design and operating mechanism of a hydropower plant [74]

Based on the flow of water, hydropower power plants are classified into small and large. Large hydro power plants require large dams together with water flow control mechanism [75, 76], whereas small hydro power plants (SHPPs) are used to extract energy from low volumes of water flow such as canals, rivers, and streams [74]. SHPPs are run-of-river systems, and thus do not require any extensive structures such as dam to store water, leading to significantly low environmental impacts [77, 78]. Hence, SHPPs are considered ideal renewable energy generation. Hydropower is one of the most established and reliable renewable energy, contributing approximately 20 % to worldwide energy market [14]. Hydropower plays a leading role in the total energy mix of several countries in the world. Norway accounts for more than 95 % of its power generation from hydropower and Brazil is almost 88 %. Similarly, Canada produces 70 % and Austria produces 65 % of hydropower to meet their energy needs [14]. India incorporated domestic fluvial systems by integrating its main rivers to improve hydrological control and to increase their hydropower production to 54,000 MW in 2012 [78, 79]. Hydropower is also a major energy source in China, and it is projected to contribute 27,000 MW of the total energy by 2020 [79]. The technology is ongoing in 27 countries in Asia, and countries such as India, Iran, Bhutan, Japan, Kyrgyzstan, Tajikistan, Turkey, Vietnam, and Pakistan [79, 80].

Hydropower is a major source of renewable energy in Pakistan with a great potential for SHPPs especially in locations between the Arabian Sea and mountainous areas such as Hindu Kush, Himalayas, and Karakorum. These features offer enough potential energy to the falling water to develop a maximum pressure [81]. Moreover, major rivers such as Sutlej, Ravi, Chenab, and Jhelum, falling into Indus River can be explored for power generation [5, 82]. The power generation capacity of SHPPs for the above sites is 2250 MW [78]. Pakistan has 18,502,227,829.8 m^3 capacity to store 13 % of its annual river flow whilst the rest of the water directly flows down to the Arabian Sea [5]. Therefore, additional water storage capacity (such as dams) will be obligatory for future sustainable irrigation and electric power generation. In Pakistan, the total estimated hydropower generation is over 42,000 MW, but unfortunately, only 16 %, amounting to around 6758 MW, has been technically exploited so far. Ninety percent of this comes from hydropower resources in the northern parts of Pakistan [1, 14]. Figure 9 shows current operational hydropower projects in Pakistan also shows the respective projects that will be completed by 2015 to bring the installed capacity to over 8000 MW.

In addition, WAPDA have completed a feasibility study of run-of-river hydro projects with combined installed capacity of approximately 21,000 MW at various locations in the country. This includes Bunji (7100 MW), Tarbela fourth extension (1399 MW), Kohala (1095 MW), Lower Palas Valley (660 MW), Mahl (599 MW), and Lower spat Gah (495 MW) [14, 81]. Apart from these run-of-river projects, there is also a high potential for large-scale reservoir projects (dams) including Diamer Basha (4400 MW), Dasu (4250 MW), Munda (735 MW), Kurram-Tangi (80 MW), and Kalabagh dam (KB) (3600 MW). Apart from electricity generation purposes, dams are also used to control flood in Pakistan. One of the dams used for that purpose is Kala-bagh (KB). At the provincial level, there are some objections for its construction; however, the perception has changed when the dam was used to control flood and saved lives during 2010's flood [83]. On that incident, over 2000 people were killed; $ 9.7 billion loss of economy and more than 20 million people were highly affected in terms of their lives, homes, and crops [84, 85]. Sindh and Khyber Pakhtunkhwa provinces were the worst affected, those suffered immense losses [86]. This massive destruction resulted long-lasting impacts not only on social human life and economy but it has also resulted in destruction of natural environment posing land erosion, killing of wildlife and other natural resources [87].

The feasibility study of the KB dam showed the construction of a 260-ft high rock-fill dam that would be able to store approximately 7,400,891,131.92 m^3 of water [83]. The dam consists of two spillways for effective distribution of flood water for instant and appropriate water disposal. During probable floods, these spillways are able to discharge more than 2 million cusecs of water [83]. The mean annual river flow at KB is high, approximately 111,013,366,978.8 m^3 due to the additional nullahs and other tributaries that join the Indus River between KB dam and Diamer Bhasha dam. So, the approximate volume of flood to be managed at KB dam

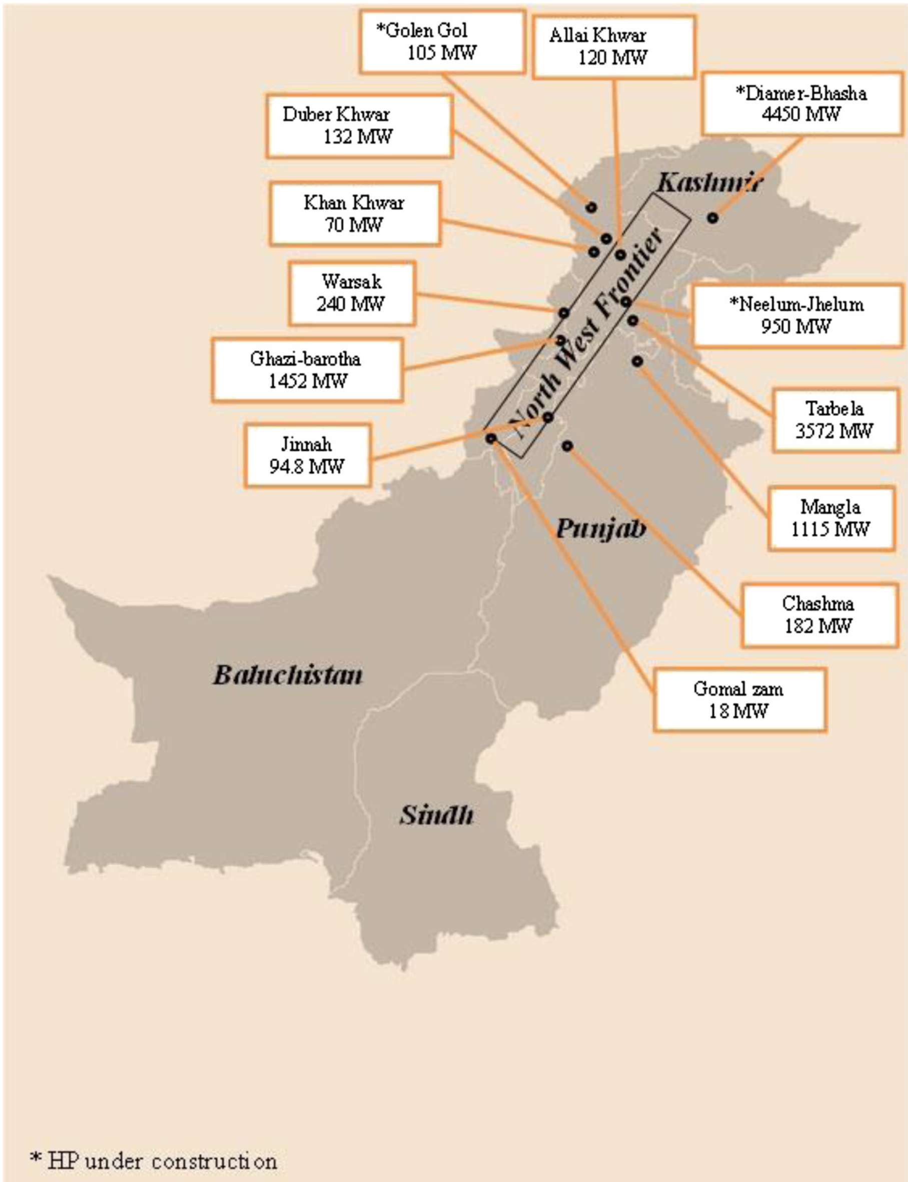

Fig. 9 The major hydropower (HP) projects in service with installed capacity and under construction with proposed capacity in Pakistan [5, 88]

is around 2,200,000 cusecs [88]. Therefore, the development of KB dam is important to the government for flood management which capable in preventing future flood risks and combat energy crisis. To realize the full benefits of hydropower generation systems in Pakistan, crucial policy reforms are obligatory to develop hydropower by enhancing sustainable generation capacity.

Conclusions

Energy is crucial to the socio-economic development of all countries. A steady transformation is being observed throughout world from primary energy supplies based on conventional sources to renewable resources. Pakistan continues to formulate efforts towards renewable energy endeavors. However, with the current gap between the demand and production of power in Pakistan, which is approximately 5000–8000 MW with a constant increase of 8–10 % per annum, and the heavy dependence on limited fossil fuel resources, renewable alternatives which are able to commercially support conventional energy options must soon be in full-scale operation. Wind, solar, hydro, and biomass are the resources that are abundantly present in Pakistan. In Table 2, the energy generation capacities of these resources stand at 120,000 MW for wind, 2,900,000 MW for solar, 5500 MW for biomass, and 42,000 MW for hydropower [1, 14, 18, 20]. This creates a

Table 2 Summary of all renewable energy resources and their current status

Status	Completion date	Capacity (MW)	Reference
Wind			
Technically exploitable potential		120,000	[20]
Installed projects	2013	500	[17]
5 commissioned projects	2014	255.4	[89]
9 projects under construction	2016	479	[89]
Projects under feasibility study	Not known	964	[89]
Solar			
Technically exploitable potential		2,900,000	[18]
Quaid-e-Azam solar park (commissioned)	2015	2000	[23]
6 projects under development	2016	46	[89]
3 projects under development	2017	150	[89]
22 projects under development	2018	513.6	[89]
Biomass			
Technically exploitable potential in 2010		5500	[25]
Sugar Mills Ltd (Unit-II) at Rahim Yar Khan (Operational)	2013	26.35	[89]
Sugar Mills Ltd (Unit-III) at Ghotiki (Operational)	2013	26.35	[89]
13 projects under development (at different locations in country)	Not known	301	[89]
Hydropower			
Technically exploitable potential		42,000	[1, 14]
Current production	2013	128	[89]
7 projects under development	2017	877	[89]
9 projects under feasibility study	Not known	1500	[89]

significant potential to overcome existing fuel needs in the country. This potential capacity is fairly distributed among the different provinces. Sindh is endowed with wind potential in the South, Baluchistan is rich with solar potential in the West, and Khyber Pakhtunkhwa is rich with hydro in the northeast area. Therefore, existing potential of renewables can be explored in four distant regions for power generation, water/space heating, engine fuel, and stand-alone power systems (SAPS). Though different efforts have been made to address the roadblocks which renewable energy technologies (RETs) face, the development has not been completely viable due to social, technological, economical, and informational hindrances. These concerns are the prime deterrents in the development of renewables. The country's future energy should come from a balanced mixture of all these resources to steadily decrease its reliance on imported oil. The importance should be given to more rapid and targeted advancement of hydropower as large potential exists in country and most of feasibility studies have been concluded [14, 81]. The supply of electricity from wind to grid has already started in 2014. However, it is still a challenge due to some impediments such as absence of infrastructure (e.g., large cranes, road network) and inadequate grid integration ability. Therefore, it is necessary to address these challenges by prioritizing the provision of these facilities. The economical and user friendly solar cookers, solar water heaters, and solar dryers should be progressed, as instantaneous integration approach can have insightful influence on the overall energy demand in Pakistan. The frequent public demonstrations and official campaigns must be carried out to educate the general public regarding environmental and commercial benefits of green energy, which will boost up the acceptability of those facilities. Besides, the specific feasibility studies should be conducted for the installation of large-scale gird connected to solar thermal power stations. The renewable energy syllabus must be introduced from the primary to the university levels in the institutions to develop consensus in support of accepting renewables as energy sources in Pakistan. The graduate students should be sent to foreign institutions to acquire more knowledge on emerging renewable energy technologies. Policies for buying small scale renewable energy systems using a payable loan scheme for public should be framed. Security, law, and order situations in country must be addressed at priority basis to encourage the attention of the local and foreign investors to invest in renewable energy. The power demand of Pakistan is projected to increase up to 11,000 MW by the year 2030 [1]. Therefore, a more holistic approach by addressing all above mentioned issues are important to fully utilize the renewable energy potential to achieve a sustainable energy future of the country. A determined political will is the key to energy independence.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
AR, SRS, AM, and YHT-Y developed the methodology and analyzed and interpreted the data collected. MKD, SAA, and RH studied the conception and design and contributed to the critical revision and inputs into the manuscript. All authors read and approved the final manuscript.

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References
1. Farooqui SZ (2014) Prospects of renewables penetration in the energy mix of Pakistan. Renew Sust Energy Rev 29:693–700
2. Sahir MH, Qureshi AH (2008) Assessment of new and renewable energy resources potential and identification of barriers to their significant utilization in Pakistan. Renew Sust Energy Rev 12:290–298
3. Sakran H, Butt TT, Hassan M, Hameed S, Amin I (2012) Implementation of load shedding apparatus for energy management in Pakistan. Commun Comput Info Sci 281:421–431
4. Board of Investment Pakistan (BOI) (2014) Power and energy. Available online at http://boi.gov.pk/Sector/SectorDetail.aspx?sid=2
5. Tajwar MI (2011) A report of hydro potential in Pakistan. Available online at http://www.wapda.gov.pk/pdf/BroHydpwrPotialApril2011.pdf. pp 1-2.
6. Aziz MF, Abdulaziz N (2010) Prospects and challenges of renewable energy in Pakistan. In Energy Conference and Exhibition (EnergyCon), 2010 IEEE International (pp. 161-165). IEEE
7. Khan HA, Pervaiz S (2013) Technological review on solar PV in Pakistan: scope, practices and recommendations for optimized system design. Renew Sust Energy Rev 23:147–154
8. Shahbaz M, Zeshan M, Afza T (2012) Is energy consumption effective to spur economic growth in Pakistan? New evidence from bounds test to level relationships and Granger causality tests. Economic Modeling 29:2310–2319
9. Ullah I, Chaudhry Q-u-Z, Chipperfield AJ (2010) An evaluation of wind energy potential at Kati Bandar Pakistan. Renew Sust Energy Rev 14:856–861
10. Raja I, Dougar MG, Abro RS (1996) Solar energy applications in Pakistan. Renew Energy 9:1128–31
11. Mirza UK, Maroto-Valer MM, Ahmed N (2003) Status and outlook of solar energy use in Pakistan. Renew Sust Energy Rev 7:501–14
12. Pakistan Meteorological Department (PMD) (2004) Feasibility report of the establishment of commercial Wind Power Plant of 18 MW at Gharo, Pakistan.
13. Sheikh MA (2009) Renewable energy resource potential in Pakistan. Renew Sust Energy Rev 13:2696–702
14. Asif M (2009) Sustainable energy options for Pakistan. Renew Sust Energy Rev 13:903–9
15. Gondal IA, Sahir M (2008) The potential of renewable hydrogen production in Pakistan. Sci Technol Vision 6:68–81
16. Hasnain SM, Gibbs BM (1990) Prospects for harnessing renewable energy sources in Pakistan. Solar and Wind Technology 7(321):325
17. Jatoi LA (2006) Policy for development of renewable energy for power generation: government of Pakistan. pp. 5-15. Available online at http://www.aedb.org/Documents/Policy/REpolicy.pdf.
18. Alauddin A (2012) 500 MW will be added to national grid soon: Alternative Energy Development Board (AEDB) Pakistan. (The Nation Pakistan), Lahore Pakistan
19. Pakistan Meteorological Department (PMD) (2008) Wind mapping project phase-II: northern areas of Pakistan results. Availabe online at http://www.pmd.gov.pk/wind/wind_project_files/page483.html.
20. Harijan K, Uqaili MA, Memon M, Mirza UK (2011) Forecasting the diffusion of wind power in Pakistan. Energy 36:6068–73
21. Cheema U (2011) Alternative Energy Development Board (AEDB) receives 17 offers for 3000 MW wind projects. The Nation newspaper 10th December. Available online athttp://nation.com.pk/business/10-Dec-2011/AEDB-receives-17-offers-for-3000MW-wind-projects
22. Siddique S, Wazir R (2016) A review of the wind power developments in Pakistan. Renew Sust Energy Rev 57:351–361
23. Khalil HB, Zaidi JH (2014) Energy crisis and potential of solar energy in Pakistan. Renew Sust Energy Rev 31:194–201
24. Bradford T (2006) Solar revolution: the economic transformation of the global energy industry. The MIT Press, Cambridge
25. Farooq MK, Kumar S (2013) An assessment of renewable energy potential for electricity generation in Pakistan. Renew Sust Energy Rev 20:240–54
26. Chaudhry AM, Raza R, Hayat SA (2009) Renewable energy technologies in Pakistan: prospects and challenges. Renew Sust Energy Rev 13:1657–62
27. Nasir SM, Raza SM (1993) Wind and solar energy in Pakistan. Energy 18:397–9
28. Sheikh MA (2010) Energy and renewable energy scenario of Pakistan. Renew Sust Energy Rev 14:354–63
29. Harijan K, Uqaili MA, Memon M (2008) Renewable energy for managing energy crisis in Pakistan. Commu Comput Inform Sci 20:449–55
30. Adnan S, Khan AH, Haider S, Mahmood R (2012) Solar energy potential in Pakistan. J Renew Sust Energy 032701:1–7
31. Ahmed MA, Ahmed F, Akhtar AW (2009) Estimation of global and diffuse solar radiation for Hyderabad, Sindh, Pakistan. J Basic Appl Sci 2:73–7
32. Ahmed MA, Ahmed F, Akhtar AW (2010) Distribution of total and diffuse solar radiation at Lahore, Pakistan. J Sci Res 40:37–43
33. Khalil MS, Khan NA, Mirza IA (2005) Renewable energy in Pakistan: status and trends. Pakistan Alternative Energy Development Board
34. Pakistan Renewable Energy Society (PRES) (2012) Available online at http://www.pres.org.pk/tag/solar-water-heaters/page/188/
35. Sukhera MB (1984) Utilization of solar energy—a programme for the development of Cholistan desert. Solar Energy 33:233–35
36. Muneer T, Maubleu S, Asif M (2006) Prospects of solar water heating for textile industry in Pakistan. Renew Sust Energy Rev 10:1–23
37. ENGERCON (2013) Manufacturers of solar geysers in Pakistan: the national energy conservation center. Available online at http://www.enercon.gov.pk/index.php?option=com_content&view=article&id=36&Itemid=16
38. Government of Pakistan (GoP) (2010) Pakistan economic survey: Economic Advisers Wing, Ministry of Finance (June, 2010). Availabe online at http://www.finance.gov.pk/survey/chapter_11/15-Energy.pdf
39. Han J, Mol APJ, Lu YL (2010) Solar water heaters in China: a new day dawning. Energy Policy 38:383–91
40. Delyannis E, Belessiotis V (2004) Solar water desalination. Encyclopedia Energy 5:685–94
41. Samee MA, Mirza UK, Majeed T, Ahmad N (2007) Design and performance of a simple single basin solar still. Renew Sust Energy Rev 11:543–9
42. Arjunan TV, Aybar HS, Nedunchezhian N (2009) Status of solar desalination in India. Renew Sust Energy Rev 13:2408–18
43. Karagiorgas M, Botzios A, Tsoutsos T (2001) Industrial solar thermal applications in Greece: economic evaluation, quality requirements and case studies. Renew Sust Energy Rev 5:157–73
44. Bhutto AW, Bazmi AA, Zahedi G (2012) Greener energy: issues and challenges for Pakistan-Solar energy prospective. Renew Sust Energy Rev 16:2762–80
45. Muneer T, Maubleu S, Asif M (2006) Prospects of solar water heating for textile industry in Pakistan. Renew Sust Energy Rev 10:1–23
46. Muneer T, Asif M, Cizmecioglu Z, Ozturk HK (2008) Prospects for solar water heating within Turkish textile industry. Renew Sust Energy Rev 12:807–23

47. Easterly JL, Burnham M (1996) Overview of biomass and waste fuel for power production. Biomass and Bioenergy 10:79–92
48. Mirza UK, Ahmad N, Majeed T (2008) An overview of biomass energy utilization in Pakistan. Renew Sust Energy Rev 12:1988–1996
49. Ramachandra TV, Kamakshi G, Shruthi BV (2004) Bioresource status in Karnataka. Renew Sust Energy Rev 8:1–47
50. Chang J, Leung DYC, Wu CZ, Yuan ZH (2003) A review on the energy production, consumption, and prospect of renewable energy in China. Renew Sust Energy Rev 7:453–68
51. Elliott P (1993) Biomass energy overview in the context of Brazilian biomass-power demonstration. Bioresour Technol 46:13–22
52. Khan MA, Latif N (2010) Environmental friendly solar energy in Pakistan's scenario. Renew Sust Energy Rev 14:2179–81
53. Hussain ST (2013) "Barriers in renewable energy deployment in Pakistan," Paper # 268, pp. 107-122. Available online at http://pecongress.org.pk/images/upload/books/268.pdf.
54. Aziz N (2015) Biomass energy potential in Pakistan: bio-energy consultant, 2015. Available online at http://www.bioenergyconsult.com/biomass-pakistan/
55. Kiani K (2006) Plan to blend petrol with ethanol approved. Available online at http://www.dawn.com. 28th July, 2006.
56. Holm-Nielsen JB, Al Seadi T, Oleskowicz-Popiel P (2009) The future of anaerobic digestion and biogas utilization. Bioresour Technol 100:5478–84
57. Jingjing L, Xing Z, DeLaquil P, Larson ED (2001) Biomass energy in China and its potential. Energy for Sust Dev 5:66–80
58. Feng T, Cheng S, Min Q, Li W (2009) Productive use of bioenergy for rural household in ecological fragile area, Panam County Tibet in China: the case of the residential biogas model. Renew Sust Energy Rev 13:2070–78
59. Imran S (2012) Evaluating the effectiveness of biogas technology and its impact on the environment, human health and socioeconomic conditions: a case study in Sialkot and Narowal District. Thesis, Lahore School of Economic. pp 33–34
60. Ali S, Zahra N, Nasreen Z, Usman S (2013) Impact of Biogas Technology in the Development of Rural Population. Pak J Anal Environ Chem 14:65-74
61. Hussain S, Habib u-R (2013) Biogas plants. Available online at http://pcret.netau.net/about%20us.html
62. Farouqe N, Hameed S (2012) Effective Use of Technology to Convert Waste into Renewable Energy Source. J Life Sci, 9:654–61
63. Amjid SS, Bilal MQ, Nazir MS, Hussain A (2011) Biogas, renewable energy resource for Pakistan. Renew Sust Energy Rev 15:2833-37
64. Ahmad S (2010) Energy and Bio-fertilizers for Rural Pakistan: Opportunities, Integrated Technology Applications, Vision and Future Strategy
65. Bhutto AW, Bazmi AA, Zahedi G (2011) Greener energy: issues and challenges for Pakistan—biomass energy prospective. Renew Sust Energy Rev 15:3207–3219
66. Santosh Y, Sreekrishnan TR, Kohli S, Rana V (2004) Enhancement of biogas production from solid substrates using different techniques––a review. Bioresource Technol 95:1–10
67. Ali S, Zahra N, Nasreen Z, Usman S (2013) Impact of biogas technology in the development of rural population. Pak J Anal Environ Chem 14:65–74
68. Bardiya N, Gaur AC (1997) Effects of carbon and nitrogen ratio on rice straw bio methanation. J Rural Energy 4:1–16
69. Malik RK, Singh R, Tauro P (1987) Effect of inorganic nitrogen supplementation on biogas production. Biol Wastes 21:139–142
70. Demirbas MF, Balat M (2006) Recent advances on the production and utilization trends of bio-fuels: a global perspective. Energy Convers Manage 47:2371–81
71. Niazi AHK, Ali S, Kausar T, Nazir MM (1993) Chemical treatment of biogas plant waste to improve its feeding quality. Sci Int Lahore 5:275–275
72. Yuksel I (2010) Hydropower for sustainable water and energy development. Renew Sust Energy Rev 14:462–469
73. Twidell J, Weir AD (2006) Renewable energy resources, 2nd edn. Taylor and Francis, New York, pp 204–10
74. Paish O (2002) Small hydro power: technology and current status. Renew Sust Energy Rev 6:537–56
75. Bhutto AW, Bazmi AA, Zahedi G (2012) Greener energy: issues and challenges for Pakistan-hydel power prospective. Renew Sust Energy Rev 16(5):2732–2746
76. Freris L, Infield D (2008) Renewable energy in power systems, 1st edn. John Wiley and Sons Ltd, UK, pp 23–25
77. Purohit P (2008) Small hydro power projects under clean development mechanism in India: a preliminary assessment. Energy Policy 36:2000–15
78. Kaldellis JK (2007) The contribution of small hydro power stations to the electricity generation in Greece: technical and economic considerations. Energy Policy 35:2187–96
79. Sternberg R (2010) Hydropower's future, the environment, and global electricity systems. Renew Sust Energy Rev 14:713–23
80. Bartle A (2002) Hydropower potential and development activities. Energy Policy 30:1231–9
81. Mirza UK, Ahmad N, Majeed T, Harijan K (2008) Hydropower use in Pakistan: past, present and future. Renew Sust Energy Rev 12:1641–1651
82. Yaqoob A (2011) Indus waters across 50 years: A comparative study of the management methodologies of India and Pakistan. Institute of Regional Studies
83. Butt A, Khan A, Ahmad SS (2015) Evaluation of increasing susceptibility of areas surrounding Kala Bagh Dam, Pakistan to flood risk: a review. Middle East J Business 10:2
84. Straatsma M, Ettema J, Krol B (2011) Flooding and Pakistan: causes, impact and risk assessment. http://www.itc.nl/flooding-and-pakistan.
85. Akhtar S (2011) The south asiatic monsoon and flood hazards in the Indus river basin, Pakistan. J Basic and Appl Sci 7:20–34
86. World Bank News and broadcast (WBNB) (2012). Asian Development Bank (ADB)-World Bank (WB) assesses Pakistan flood damage at $9.7 billion. Press Release No: 2011/134/SAR. http://web.worldbank.org/WBSITE/.
87. Khan A, Khan MA, Said A, Ali Z, Khan H, Ahmad N, Garstang R (2010) Rapid Assessment of Flood Impact on the Environment in Selected Affected Areas of Pakistan. Pakistan Wetlands Programme and UNDP Pakistan. p 35 Available online at http://www.pakistanwetlands.org/reports/REIA%20of%20floods%20in%20selected%20areas%20-%20final.pdf
88. Luna BA, Jabbar M (2011) Kalabagh—a superior dam designers' view point. In: 71st Annual Session Proceedings. Engineering Congress, Pakistan, p 288-302.
89. Alternative Energy Development Board (AEDB) Pakistan. [http://www.aedb.org/index.php].