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Renewable Energy; Identifying Potential and Development of Solar Energy to Contribute to Sustainable Energy Delivery in Pakistan

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Abstract: Pakistan, a developing country of South Asia, is an energy deficient country. The power sector of the country is suffering due to inadequate capacity and insufficient fuel supply to its power plants, resulting in load shedding. Pakistan despite being greatly blessed with Renewable Energy resources depends on fossil fuels for electricity generation. The reliance on fossil fuels is not only effecting foreign currency reserves of the country but also increasing Green House Gas emission. According to estimates, share of renewable energy in total energy mix is around 1%. This paper highlights the potential of renewable energy development in Pakistan with particular focus on the potential and development of solar energy in the country. The estimated potential of solar energy is 2.9 Million MW in Pakistan. The exploitation of solar energy resource can contribute to sustainable development and also offers socioeconomic benefits. This paper also illustrates the potential applications and benefits of solar energy, and the sustainability of this technology. In addition, the barriers to solar energy development despite its enormous potential have also been discussed.

Keywords: Energy crisis, Renewable energy, Solar energy, Sustainable energy delivery

I. INTRODUCTION

Energy plays an important role in socio economic development of any country. Pakistan, a developing country of South Asia, is highly energy deficient country. Energy situation in the country has turned into a crisis. The power capacity of the country has moved to a shortage of 7236 MW as of June 2017 [1] from a surplus of 1230 MW at the end of 2005 [2]. The computed demand in 2017 was 25,717 MW in comparison to system generation of 18,481 MW. The power sector is currently suffering due to inadequate capacity and insufficient fuel supply to its power plants, thus, resulting in load shedding [1],[3]. The energy sector of Pakistan greatly depends on fossil fuels for power generation (Fig. 1). The primary sources of energy include oil, gas, LPG, coal, hydro and nuclear with gas and oil being the dominant sources of energy in the country [3]. According to estimates, share of Renewable Energy (RE) in total energy supply is around 1% [4]. The present deteriorated energy scenario of Pakistan has been marked by uncontrolled load shedding and colossal circular debt. It is so that energy supply mainly depends on hydro and fossil fuel power generation. Approximately, 60% of total foreign exchange is spent for import of fossil fuels. High oil prices are forcing to curtail the quantum of import which unbalances the supply demand equilibrium.

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The reliance on fossil fuels is not only effecting foreign currency reserves of the country but also increasing Green House Gas (GHG) emissions [3], [5]. Besides being environmentally harmful, fossil fuels reserves are limited and also depleting rapidly. Therefore, developed countries are utilizing various sources of renewable energy to reduce their dependence on fossil fuels and to minimize GHG emissions [4]. Pakistan is greatly blessed with renewable energy (RE) resources. RE sources (solar, small hydro, wind, biomass and geothermal) being virtually inexhaustible sources of energy or regenerative have the potential to provide enough energy to solve the energy crisis in the country. However, very little work has been done in the past to exploit existing renewable energy sources. Pakistan is geographically located in a region of one of highest solar insolation the world and can produce a considerable amount of power from Solar Energy (SE). Unfortunately, due to negligence of concerned authorities, the generation of electricity from SE is still in its beginnings despite these favorable conditions [4], [6], [7].

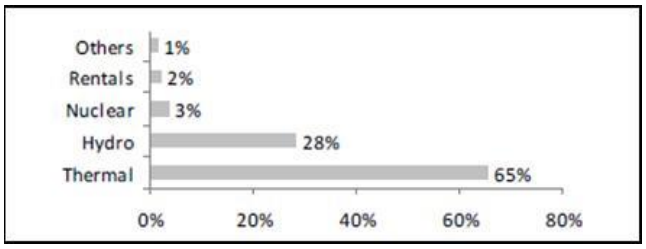

Fig. 1. Different Sources of Electricity Generation in Pakistan. Source [8], [9]

II. RENEWABLE ENERGY IN PAKISTAN

The current electricity shortfall in the country is a sign of an unsustainable energy scenario. It is vital for Pakistan to adopt and explore indigenous, sustainable and secure energy resources. It is obvious from the Fig.1 that contribution of RE technologies (excluding large hydro) in total energy mix is negligible [10], [11]. Recognizing the immense potential for utilizing RE, Government of Pakistan (GoP) has identified the RE sector as an important area for development, and so Pakistan's first RE policy was developed in 2006 with a target to generate 5% (9700MW) from RE resources (mainly solar and wind) and the electrification of 7874 remote and off grid villages by 2030 [6], [10], [12], [13]. The growing interest to increase RE proportion in total energy mix is that almost all RE sources are abundant, Environmentally friendly, sustainable and widely distributed beside being eligible to earn carbon credits under Clean Development Mechanism (CDM) [5], [7].

At present, different public and private sector organizations are working for the promotion and development of RE in the country but unfortunately, these have weak technical and financial resources. Pakistan Council of Renewable Energy Technologies (PCRET) and Alternate Energy Development Board (AEDB) are the most renowned organization working on renewable energy in Pakistan. In addition, there are also some NGOs working for the promotion of SE in the country [7], [14].

A. Resource Potential in Pakistan

Potential for almost all type of RE exists in Pakistan. Resource potential of various RE technologies is given in Table I.

Table I. Resource Potential of RE in Pakistan

Resource	Potential
Solar	A solar energy potential of around 2.9 Million MW exist in Pakistan according to study conducted by National Renewable Energy Laboratory (NREL), USA in collaboration with USAID [15], [4].
Wind	Total estimated wind power potential in Pakistan is around 346,000 MW out of which 120, 000 MW is technically exploitable [4], [6], [16]. However, in Pakistan the installed capacity is only 106 MW [6]. Some areas of Baluchistan, Sindh and KPK are the most favorable regions for wind turbines exploitation [15].
Small hydro	Pakistan is among the countries that are blessed with huge hydro power potential. It has been estimated that large hydropower has the potential to produce more than 42 GW but only 6.5 GW has been tapped so far [12]. Besides large hydro, there are distinct prospects of development of small-mini-micro hydro power. Small Hydro is a valuable option for generation of electricity especially for remote communities. Presently, 128 MW is operational in the country, 877 MW is under implementation and around 1500 MW is available for development [15], [17]. Estimated potential for small hydro is 4500 MW as per available data [18].
Biomass Bagasse, straw, dung, rice husk, municipal solid waste, etc.	Agricultural and live stock sector of Pakistan produces large amount of biomass in the form of crop residues and animal waste [18]. The available crop residue in the country is estimated to generate 45,870 million kWh of electricity per year [4]. According to live stock census, there are around 51 million animals (cows, buffalos) in Pakistan able to produce 19.125 million m3 biogas per day. It is estimated that cooking and heating needs for 44% of the rural population could be met from this single source of energy [15]. In addition, municipal solid waste generated by urban areas could be disposed of in proper landfills to produce useable methane gas or alternatively incinerated to produce electricity. The estimated potential of this sector is 4000 MW [18].
Geothermal	Several sites in the country have been identified with geothermal potential of around 2000 MW power generation. However, the exact potential of geothermal heat and power is still to be exploited [18].

III. SOLAR ENERGY AND ITS POTENTIAL IN PAKISTAN

Solar energy (SE) is one of the most promising renewable energy and its resource exploitation yield greater outcome than the entire global energy demand [19]. Pakistan is geologically located in a region of highest solar insolation in the world. The average solar insolation level is 5 to 7 kWh/m^2/day exists in more than 95% of its area and is available for 88% of the year (Fig. 2) [6], [20]. According to the Alternative Energy Development Board (AEDB), the average global irradiation falling on the horizontal surface is 200 to 250 w/m^2/day which is approximately 6840-8280 MJ/m^2 in a year [4], [14]. The sun shines for 7 to 8 hours daily in many parts of the country with about 2400-3000 sunshine hours per annum and SE is available for more than 300 days in a year [10], [21]. Provinces of Balochistan, Punjab and Sindh are rich in solar energy. Balochistan is particularly excellent for harnessing solar energy with annual mean sunshine duration of 8 to 8.5 hours daily and daily global insolation of 19 to 20 MJ/m^2 which is estimated to be enough to electrify 40,000 villages [7]. According to a report by Solar Energy Research Centre (SERC), in Pakistan more than 70 percent of population lives in 50,000 villages which are far away from the national grid and could be electrified through solar energy [22]. As mentioned earlier, potential of 2.9 Million MW for solar energy exists in Pakistan [4], [15].

The impact of use of SE technologies will definitely reduce the GHG emissions and is a key component of sustainable development. However, beside this enormous potential, the contribution of solar energy for generating electricity is negligible [7], [13].

IV. POTENTIAL APPLICATIONS AND DEVELOPMENT OF SOLAR ENERGY IN PAKISTAN

SE can be developed through solar photovoltaic (PV) and solar thermal applications [11], [23]. Following sections give an overview of potential applications of SE and their development in Pakistan so far.

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A. Solar Photovoltaic (PV)

PV systems convert SE directly into electricity and this

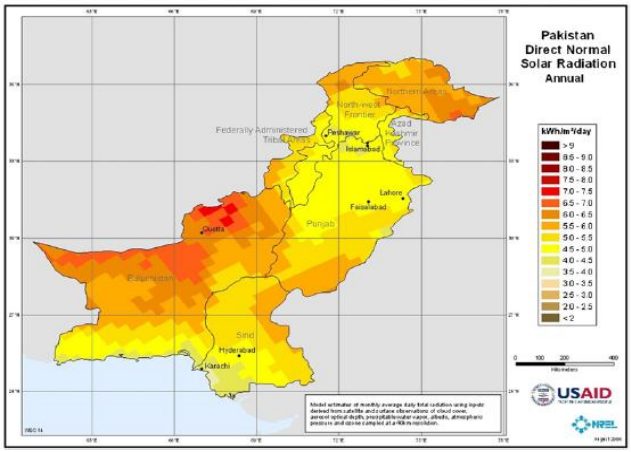

Fig.2. Direct Normal Solar Radiation Map of Pakistan Developed by NREL. Source [14]

technology is most appropriate for small power requirements and remote areas applications. For example, remote village of Balochistan, Cholistan and Thar deserts are particularly suitable for utilizing solar energy through PV. Balochistan having highest solar insolation is the largest province of Pakistan area wise, with 77% population living in rural areas. 90% of the villages do not have electricity due to remoteness of location and difficult terrain whereas electricity requirement for each house is 50 to 100 W. It is nearly impossible to extend high-tension transmission lines to such remote areas and the only feasible option to provide clean electricity to these areas is off grid PV [14], [20], [24]. It is estimated that enough electricity could be generated to meet the demand of Pakistan if only 0.25% of Baluchistan was covered with solar panels with an efficiency of 20% [22], [25].

The utilization of solar energy date back to 1980s, when eighteen PV stations with total installed capacity of 440 KW were set up by GoP for village electrification but these systems were no longer in operation in 1990s due to lack of technical know-how about operations and maintenance [7],[13], [14]. Under such circumstances, PCRET took the responsibility for ensuring development and sustainability of solar and other renewable energy projects in the country. AEDB also joined such efforts in 2003. There are also more than 20 manufacturers and suppliers active in solar energy business in the country in private sector. AEDB have electrified around 3000 households with total PV power generation of 200 KW in different areas of Punjab, Sindh and Balochistan and similarly, PCRET electrified more than 500 mosques, schools, houses and 265 streets and garden lights in different cities through PV with the total capacity of 100KW (Fig.3). The PV installations in the private sector are around 500 KW. To overcome the energy crisis of the country, PV stand alone micro projects are being planned in the country in future [7], [13], [23] such as rural telephone exchanges, highway emergency telephones and refrigeration for vaccine and medicines in hospitals etc [24]. AEDB has also supplied PV lights and fans of 80 to 120 W each in 5000 houses in Sindh [7].

GoP and different NGOs are working to electrify off grid/remote areas. For example, few villages near Muzzaffargarh (Punjab) are being run on SE as a primary source of electricity, which were without electricity since decades. Households generally had to use kerosene lamps and immediate benefits of SE were clean, bright and safe electricity [26]. Ten other villages in Punjab in district Sahiwal have also been electrified through off grid solar power [27]. Government of KPK also plans to connect at least 10% of the 40% of the off-grid province area by 2018 with solar power and small-scale hydroelectric plants. They also planned to supply solar power to 5800 off grid households in 200 villages [28]. Different NGOs in Pakistan are trying to bridge the electricity gap through solar technology and are providing solar lanterns to villagers around the country [29].

Underground water is also being lifted up by using PVs for use in irrigation [14]. GoP has also installed about 20 solar water pumps in the country for providing drinking water [21], [24]. Globally, the vast majority of installed PV capacity is grid connected and off grid is only 2% of global total PV capacity, while developing country markets (such as India, Pakistan, Bangladesh) favor off grid PV systems due to their large rural population [19], [30]. PV standalone projects are in progress in Pakistan instead of mega PV projects. With the grant assistance from JICA, Pakistan's first solar power grid station of 356 KW had been installed in Islamabad in 2012 [16]. However, Quaid-e-Azam solar park (QASP) located in Punjab, is the first large scale solar power generation project in Pakistan with capacity to generate 100MW in first phase and additional 900MW in next two phases. First 100 MW were commissioned in May 2015 [31], [32]. At present, 28 projects of 956.8 MW capacity are at various stages of development within the framework of AEDB policies and procedures [33].

Fig.3. Examples of Installation of solar PV for Households (A,D) School (B) and Mosque (C) in Remote Areas of Pakistan. Source [13], [14].

B. Solar Thermal Technologies

Solar thermal is another technology to convert sunlight into electricity. These technologies are comparatively low cost, simple and easy to adopt. Generally the locations with annual solar radiations more than 1800 KWh/m^2 (such as Pakistan) are best recommended for installation of solar thermal systems [14], [15].

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In solar thermal side, a number of public and private organizations are working for development and commercialization of solar thermal units in Pakistan but their contribution in energy provision is negligible. Solar thermal units such as solar cooker, solar desalination and solar dryers are mostly being used in rural areas. Solar water heaters have application both in rural and urban areas [14], [15], [24]. The aggregate installed capacity of solar thermal units appears to be 10,000 KW in the country [13], [23]. A brief description of these applications in Pakistan is given below.

C. Solar Water Heaters

Solar water heaters utilize sun's energy to heat water. These systems are gaining popularity in Pakistan, especially in northern areas due to increasing shortage of natural gas. According to Munir and Asif, this technology is one of the fastest growing renewable technologies in the world and has great potential in Pakistan too with a payback period of less than 3 years. It is expected that 25,000 units will be operational by 2020 even in absence of any government subsidy [15], [16]. Beside domestic use, they have large applications in commercial and the industrial sector. In textile industry, solar water heating can be utilized to save up to 65% of conventional energy for dying, finishing and curing processes [15].

D. Solar Cooker

At the moment, nearly 5000 solar cookers are in use in Pakistan but this figure is very low when compared to India (14,500) and China (60,000). Pakistan needs to increase the use of solar cookers in order to reduce the consumption of forest resources (e.g. wood) as fuel. GoP is planning to distribute 10,000 solar cookers in remote areas of Sindh province. Cooker can be used for cooking from 9:00 am to 3:00 p.m. on all sunny days of the year. However, slow cooking processes, the limited availability of space in urban areas, a high initial cost, the intermittent nature of sunshine, and a resistance to the adoption of new technology are the main hurdles in increasing their use [14], [15], [16].

E. Solar Dryers

Effective drying of agricultural products is possible through solar dryers and good quality can be achieved at very low cost. In Pakistan, significant amount of agricultural products are wasted due to lack of basic infrastructure (mostly in northern regions of Sakardu and Gilgit). Solar dryers are now being used to dry fruits in these remote areas which could be transported later to urban areas resulting in positive impacts on the economy of these areas. These solar dryers could also be effectively used for drying agricultural products in Sindh and Punjab province for higher market value and to generate local employment [14], [15]. Over hundred solar dryers of the capacity 500 kg each have been developed and distributed by PCRET in rural areas of Pakistan [16].

F. Solar Desalination

Solar desalination utilizes sun's energy to convert brackish and saline water into potable water. Scarcity of fresh water is a major issue in deserts of Cholistan and Thar. People are forced to consume saline or brackish water. Moreover, sea water is abundant along the coastline in Baluchistan but drinkable water is not available. Solar desalination has wider application for people living in such areas. Two plants with the capacity to clean 6000 gallons/day have been installed at Gawadar in Baluchistan and remained very successful. A number of schemes are also under consideration in Baluchistan and Thar desert areas of Punjab and Sindh [14], [15]. PCRET has also developed and distributed hundreds of solar water desalinaters of capacity up to 250 gallons/day in rural areas of Pakistan [16]. Solar desalination technology being low tech technology can be easily adopted by local people in such areas [14], [15].

V. COMPARISON WITH OTHER COUNTRIES

In Pakistan, the contribution of renewable energy is only fraction (less than 1%) of the percentage in total energy mix [4], [13], [15]. Pakistan despite being blessed with abundance of sun light still has negligible contribution of solar energy for generating electricity. Although, most of the countries in Europe are not very sunny but the installed capacity of solar thermal technology is expected to reach 83 GW by 2030 and 342 GW by 2050 in Europe [15]. Germany, being the world leader of PV technology had installed capacity of 41 GW at the end of 2016 [34]. While, Germany on average has 1600-1800 sunny hours per year in sunniest regions of the country [35]. A comparison with the other countries of the same region (India, China) shows that Pakistan being blessed with highest solar irradiation is far behind in terms of installed solar power capacity [15]. India (neighboring country of Pakistan) is also actively extending its current solar installation and has planned to install solar energy systems of about 20 GW by 2022. A solar thermal power station is being constructed as part of this project in Banaskantha district in North Gujarat which would be world's largest solar power station once completed [36]. China also being neighboring country of Pakistan has reached up to 43 GW solar PV installed capacity in 2016 and is also world's biggest supplier of solar panels. China has shown keen interest to invest for 660 MW and 300 MW power sector projects in Pakistan plus the remaining 900 MW capacity of QASP is to be installed under the China-Pakistan economic corridor [31], [37].

VI. SUSTAINABILITY OF SOLAR TECHNOLOGY

Globally, solar power generation system being environmentally advantageous has been gaining significance as a method to solve the energy problems [38]. Solar energy technologies (PV and solar thermal) provide tremendous environmental benefits in comparison to conventional sources of energy contributing towards. Sustainable development of human activities. The major advantages of the use of SE technologies include reduction in GHG and air pollution emissions [38], [39]. In Pakistan, SE has a resource potential that could be utilized to deliver sustainable, clean and secure energy and also to combat energy crisis. The exploitation of this resource can contribute to sustainable development and also offer socioeconomic benefits such as job opportunities, diversification in energy supply, electrification of remote locations, and poverty alleviation of people living in remote areas.

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Another advantage of using solar energy is that it is readily, locally and easily available and minimizes the burden of extensive networking in order to utilize energy on individual or mass levels [7], [14].

Every energy generation and transmission method has adverse effects on the environment. Similarly, there are potential negative environmental impacts on land use, air, soil and water resources, and ecology associated with solar power. These environmental impacts vary greatly depending upon the technology e.g. PV and solar thermal, and also depends on the scale and nature of the project. The potential environmental burdens are often sites' specific and the possible concerns are emissions associated with manufacturing, transportation, installation, maintenance, and decommissioning of solar products (mostly PV). However, adverse effects of solar power are generally minor and can be eliminated or minimized through appropriate mitigation measures. Moreover, the life cycle emission rates from solar PV and solar thermal are far less than the emissions from conventional sources (coal and gas etc). In short, solar energy can be considered as an almost safe and clean energy source [38], [39], [40].

VII. BARRIERS TO SOLAR ENERGY DEVELOPMENT

Several barriers have been identified in the literature that prevents the penetration of renewable energy technologies. This includes policy and regulatory barriers, market barriers, financial and fiscal barriers, institutional barriers, technical and social barriers [21], [41], [42]. In Pakistan, the existing infrastructure remained ineffective to advance the status of SE, although a comparative analysis of the countries in the Indian subcontinent by Szweda [43] reflects a promising depiction for Pakistan. High initial cost, technical and institutional weaknesses and lacks of awareness of these technologies and their benefits by the people are the major barriers that are deterrent to solar energy development in Pakistan [20], [24]. Different studies have highlighted that increased pool of local finance and incentives, capacity building, technology transfer, public awareness and large scale research and development programmes are crucial for the development and promotion of solar energy [14], [20], [24].

Moreover, the main barriers to grid-connected RE have been identified by Schenck [44] for Bangladesh which are valid for Pakistan too. These barriers include the low power tariff levels compatible with costs of RE technologies and long-run marginal costs of expansion and, inadequate policies and institutional framework for sale of power into the main grid, insufficient capacity and knowledge in representative agencies, private sector and financial institutions for promoting RE and a lack of strong political support. GoP has set up sound institutional infrastructure to lever RE development including, AEDB, PPIB, PCRET and NEPRA. In order to overcome such barriers, based on lesson learnt, GoP is offering excellent incentives for solar power development in the country. Investors are being offered profitable fiscal and financial incentives that are attracting them to come to this market [33].

VIII. CONCLUSION

Pakistan, an energy deficient country is mainly relying on fossil fuels to meet its energy demands. Unfortunately, the contribution of RE in energy mix scenario of country is virtually negligible. Pakistan needs to diversify its energy supply mix to ensure a sustainable energy future. Pakistan has high potential for harnessing SE with estimated potential of 2.9 Million MW. SE can be utilized through solar PV and solar thermal. Solar PV technology could be an ideal solution to deliver electricity to remote or off grid communities while as the country as a whole can adopt solar thermal technologies such as solar cooker, solar heater etc.

The impact of use of SE could help in overcoming energy crisis of the country. Utilization of SE will help improve the living standards of thousands of people, improve rural economy, contribute to country's economic growth and ensure a more sustainable environment. Despite vast potential, the development of SE is still limited and demonstrates much lag with respect to neighboring countries. The suggested parameters to examine country's performance encompass institutions, economy, social capacity and equity, and environment. Accordingly, Pakistan inescapably needs to improve panorama to exploit best solar-irradiation in the world. Macro and micro assessments including comparison with similar countries are prerequisites to surmount objectives.

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