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Review Article

Solar Energy Potential in Pakistan: A Review

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Abstract: This review paper focuses on the potential of solar energy and its applications in addressing the energy crisis in Pakistan. Currently heavily reliant on non-renewable sources, Pakistan faces severe power shortages and lacks access to electricity in many rural areas. The paper highlighting its geographical position and the availability of solar radiation. The review emphasizes the need to harness the vast solar energy resources available in the country. It was discovered that over 100,000 MW of electricity from sunlight could be generated, particularly in regions within the Sunny Belt. The annual average daily global radiation of Pakistan is: horizontal (GHI) - 16 MJ/m^2, oblique (GTI) - 13 MJ/m^2. The minimum annual average daily GHI in Pakistan is higher than the world average annual average daily GHI. At the same time, in Pakistan, thermal power generation accounts for most of the energy production (61% in 2020, 63% in 2021, and 61% in 2022), while renewable energy sources account for the least (3% in 2020, 2% in 2021, and 3% in 2022). It emphasizes the need for research and development, as well as policy support, to promote the adoption of solar energy technologies. In conclusion, this review paper sheds light on the significance of solar thermal energy as a renewable and sustainable solution for Pakistan's energy dilemma. It underscores the need for increased investments, technological advancements, and policy interventions to harness the immense solar energy potential and pave the way for a greener and more energy-secure future in Pakistan.

Keywords: Solar Energy, Solar Resources, Renewable Energy, Solar Reflector, Pakistan.

1. INTRODUCTION

Oil, gasoline, and coal are the main energy sources and are very commonly used [1, 2] and extremely negatively affect the ecological situation [3]. Oil is used extensively in industry, but the "oil-age" is coming to an end [4, 5]. Oil reserves will only endure for 35 years if current industrial and household use trends continue. There are still 37 years of natural gas' age and 107 years of coal's age left, respectively. Therefore, the only fossil fuel that will still be available after 2042 is coal reserves [6]. In terms of fossil fuels, they help meet 85% of the global energy demand. This causes an increase in CO_2 emissions, which contributes to global warming [7]. Pakistan's entire reliance on hydal power generation has made the energy crisis there critical. Three significant hydal power plants Terbela, Mangla, and Ghazi Brotha are currently producing energy, but their output is far less than the nation's rising need for it. Given the current energy problem, renewable energy sources need to receive more attention [8, 9]. So far as non-renewable energy sources are less ecological and and will run out sooner or later, technologies for sustainable development will become more and more important. This is pushing society to start developing renewable energy technologies now in order to prevent potential problems from arising [10, 11].

Moving toward renewable energy is the greatest way to tackle the energy dilemma. The application of renewable energy technologies can meet

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approximately 14% of the world's needs [12]. The supply of renewable energy sources is abundant, sustainable, and unrestricted [13]. Renewable resources persist over time. The supplies of clean energy include biomass, wind, solar, tidal, and hydroelectric power [14, 15]. Among the primary sources, solar energy shines as the most abundant and environmentally friendly option. The sun radiates on our globe with an estimated output of 175,000 TW [16] and it is four times as much energy as our peak energy consumption [17]. Renewable power resources such as biomass, hydro, solar, and wind are abundant in Pakistan [18]. Pakistan's vast landmass, plentiful sunshine, wind, and water resources provide ideal circumstances for the development of renewable energy. The province of Baluchistan and the deserts in Punjab, Sindh, and Cholistan have been highlighted as areas with high potential for the production of solar energy. The country receives an average of 15.5×10^{14} kW/h of solar radiation each year. However, the development of solar energy is still in its infancy [19]. Particularly in rural areas with a sizable population engaged in agriculture, biomass, which is obtained from organic and renewable sources, offers enormous potential for energy generation. Although there is currently inefficiency in the use of biomass resources, attempts are being made to create biomass energy technology [20]. Pakistan has abundant wind energy resources, especially in areas like Sindh, Baluchistan, and Punjab. Despite its potential, wind power currently makes up a small portion of the energy mix; nonetheless, by 2030, the government wants to produce 30 GW of wind power [21]. With a total capacity of 100 GW and 59 GW of recognised sites, hydroelectricity is the most major renewable energy source in the world and has tremendous potential in Pakistan. In order to achieve its goal of producing 16,000 MW of electricity from hydro sources, the government intends to construct small-scale hydropower projects. Beside this Pakistan boasts significant reserves of natural gas, amounting to approximately 282 trillion cubic feet (Tcf), of which 24 Tcf is considered recoverable. The country also possesses noteworthy hydroelectric potential, with multiple locations earmarked for the establishment of hydel-based power generation facilities. Furthermore, Pakistan possesses considerable coal reserves estimated at 185 billion tons, including proven reserves of 2.07 billion tons, primarily concentrated in the Thar region of Sindh province [22]. The most significant and plentiful sort of revolving resource in Pakistan is solar power. Installing solar power projects demonstrates to be an effective, quick fix for the electricity shortage [18]. Soon, solar applications might be pursued to address the energy dilemma [23]. Solar energy has a wide range of future applications, including rooftop and wall integration in buildings for self-sufficient electricity generation, revolutionizing agriculture through solar-powered irrigation systems, enhancing heating and cooling in commercial and residential sectors, improving agricultural storage with solar thermal refrigerators, optimizing drying processes with photovoltaic technology, supporting plant growth in solar greenhouses, enabling remote electricity supply and electronic device charging, facilitating wastewater treatment and salinity removal, and even powering space technology through solar arrays. With ongoing research and development, solar energy has the potential to address energy needs sustainably and drive advancements in various industries [24]. In 2010, the world's first smelted salt concentrating solar energy facility, known as "Archimede", was constructed on 8 hectares of land in Sicily, Italy. Owned by ENEL, this solar power facility takes the form of a parabolic trough and generates an impressive 9200 MWh of electricity each year during the summer season [25]. The 1600-acre Crescent Dunes Solar Project is situated near Tonopah, Nevada, in the United States. With a 110 MW generation capacity, it is presently active, furthermore uses solar power tower technics. Tonopah Solar Energy, LLC of Solar Reserve is the owner [26, 27]. China is building the Dacheng Dunhuang Molten Salt Fresnel project. It has a 50 MW generation capacity and employs linear fresnel reflector technology. Lanzhou Dacheng Technology Co. Ltd. is the owner [22, 23]. In Utah on 17 acreages The United States' Tooele Army Depot is situated. With a 1.5 MW generation capacity, it is not in use right now. This project, which belongs to Tooele Army Depot, uses Dish/Engine Solar Technology [28].

This research is novel since it examines CEPEC's involvement in renewable energy in Pakistan. Although there has been a lot of research done on solar energy, CEPEC's true capabilities in terms of renewable energy have not yet been examined.

2. PAKISTAN'S SOLAR POWER PROFILE

The geographical position of Pakistan corresponds to 24°-27° north latitude; 61°-76° E [25], which means there is a lot of potential for Pakistan [26]. Over 95% of the sovereign state, Pakistan has a global average solar radiation of 5-7 kWh/m^2/day. The sun shines for above 2300-2700 hours a year in the south-western province of Balochistan and the north-eastern region of Sindh. A few rural regions maked use of primarily photovoltaic (PV) devices with with power generation of 100–500 W/unit to produce electricity. It should be noted that more than 40,000 Pakistani communities lack access to power [29].

Alternative Energy Development Board (AEDB) served all four provinces of Pakistan by supplying energy to about 3000 homes. In the districts of Rawalpindi, Kohat, Turbat/Kalat, D.G. Khan, Tharparkar, 200 kW of PV power generating was made available. Each residence received an 80 W panel with illumination system. More than 500 mosques, schools, and homes received electricity from PCRET using PV power (capable of 80 kW generation). In Pakistan, the private sector has installed around 500 kW of solar power [30].

In the near future, more tiny independent projects are planned rather than any major initiatives. Just like the implementation of the 10,000 solar thermal unit system will be accomplished, the total PV installation appears to be significantly less than 1000 kW [30]. With a minimal number of solar panels, Akhat Solar Limited generated about 2 MW of electric light. Additionally, PCRET produces 26.5 KW through the aid of 13 solar panels that are erected and placed to various rural homes and small size schools [31].

3. THE ENERGY PROBLEM IN PAKISTAN AND ITS DOMESTIC ENERGY SOURCES

Energy problem of Pakistan has a few different primary causes. A significant shortage of electricity usually occurs due to an increase in the needs of the population for electricity, which is associated with its excessive consumption. In Pakistan, there is a severe power outage that can last for about 18 hours daily in countryside and 8 to 12 hours daily in city districts. This is a result of the 5-7 GW power supply deficit [32]. The electricity production system is very old and inefficient when compared to the needs for energy. In Pakistan, renewable resources are not used effectively.

Mixed power scenario for the production of electricity in the pecuniary years 2021–2022 is depicted in Figure 1, Figure 2. Figures 1 and 2 display the contributions of various energy sectors to Pakistan's electricity production in GWh and percentages (%) for the fiscal years 2020, 2021,

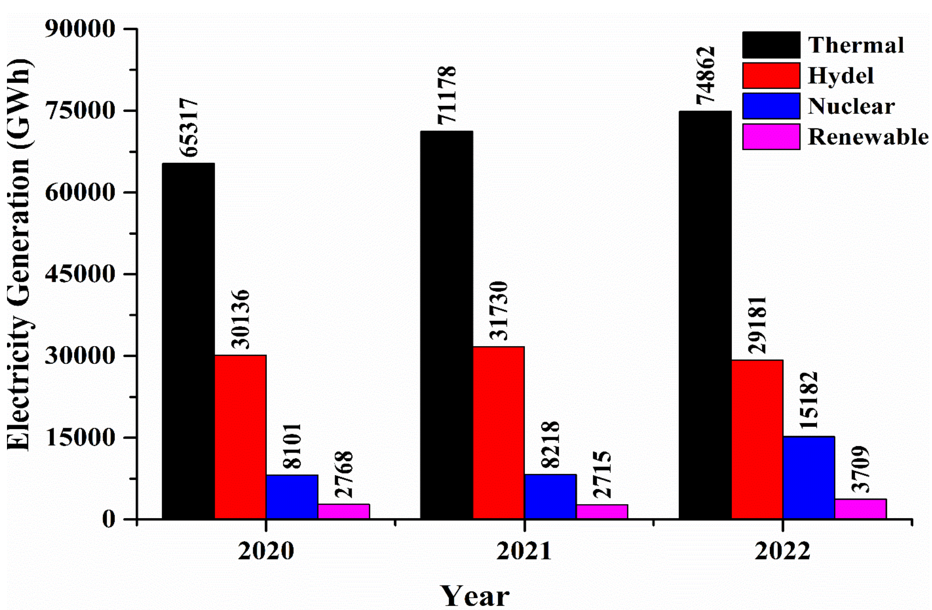

Fig. 1. Shares in electricity generation in GWh (Pakistan Economic Survey, 2021-22).

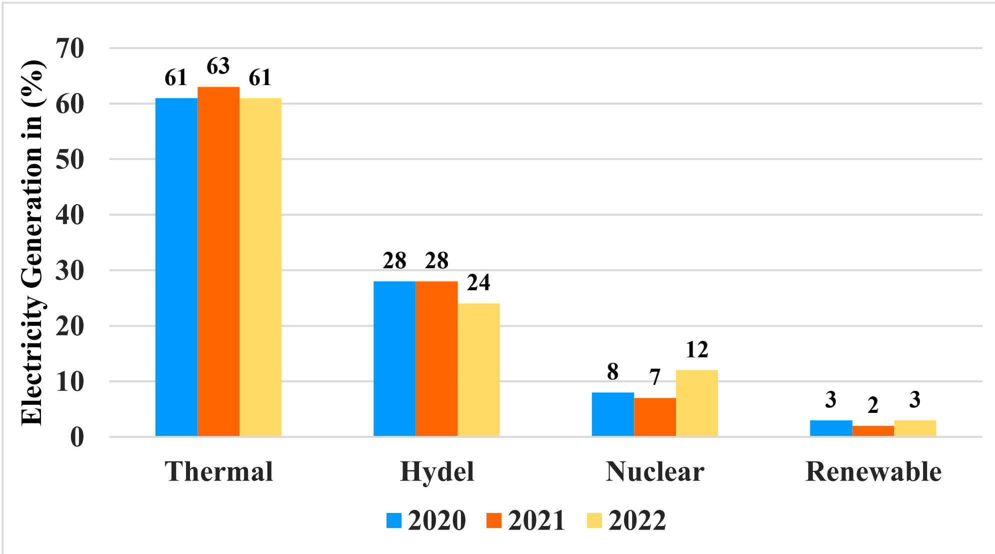

Fig. 2. Shares in electricity generation in percentage (Pakistan Economic Survey, 2021-22).

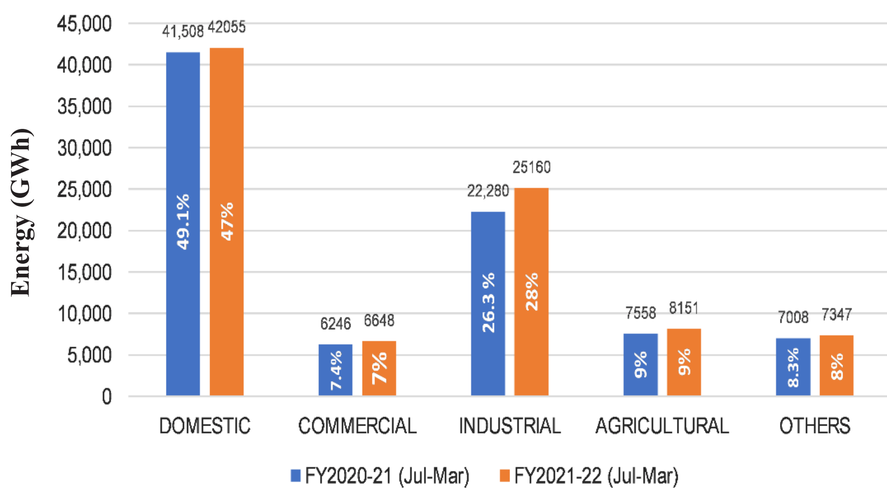

Fig. 3. Energy consumption by sectors (Pakistan Economic Survey, 2021-2022).

and 2022. In Pakistan, thermal power generation accounts for most of the energy production (61% in 2020, 63% in 2021, and 61% in 2022), while renewable energy sources account for the least (3% in 2020, 2% in 2021, and 3% in 2022) (Pakistan Economic Survey, 2021-22). Figure 3 represents the domestic energy use is the largest energy consumption sector in Pakistan for the financial years 2021 and 2022, with a percentage of 49.1% in 2021 and 47% in 2022. The industrial sector is on the second place with a percentage of 26.3% in 2021 and 28% in 2022, and the agricultural sector is on the third place with a percentage of 9% in both financial years 2021 and 2022 (Pakistan Economic Survey, 2021-2022).

Solar power is an abundant revolving resource that can be used for electricity generation. Over 100,000 MW of electricity from sunlight could be generated, particularly in regions within the Sunny Belt [33]. Approximate radiation dose in the Pakistan' provinces like Punjab and Khyber Pakhtunkhwa (KPK) is 400-440 cal/cm^2 daily, while Sindh and Balochistan obtain more than 440 cal/cm^2 daily. The northern regions and Kashmir only receive fewer than 400 cal/cm^2 daily of radiation. Finally, accumulating about 6840-8280 MJ/m^2 daily, provides an average daily exposure of about 00 to 250 W/m^2 [2014]. The annual average daily global radiation of Pakistan is: horizontal (GHI) - 16 MJ/m^2, oblique (GTI) - 13 MJ/m^2. The minimum annual average daily GHI in Pakistan is higher than the world average annual average daily GHI. This demonstrates the brilliant potential of Pakistan in the field of solar energy [34].

In order to increase the efficiency of the use of sunlight, solar reflectors are placed on the side of the solar panels. Solar Collectors Performance and Gain are also increased by using solar reflectors. The incident sun energy is concentrated onto the receiver via solar reflectors [35]. Since the energy is dispersed, nothing heats up quickly. However, employing solar reflectors to focus the sun's energy can have amazing benefits. Of the actually existing known solar reflectors, the most stable material is a silver/glass thick mirror, which has a reflectance close to 94% [36]. A thin, highly reflective film with self-cleaning capabilities. For the solar front reflectors, this thin film of TiO_2-SiO_2-Ag was successfully created by magnetron sputtering. After a 1200-hour ageing test, this layer still has a high reflectivity of 0.9578.

However, applications for silver polymer solar reflectors tend to use dish concentrators. As a result, there are less solar losses and more solar energy is stored [37]. Reflector material can indeed be made using recycled or locally sourced materials, specifically when utilizing glass. The production of solar reflectors can successfully utilize recycled glass. In the construction of Fresnel mirror reflectors, glass is employed to effectively reflect light. These reflectors utilize flat mirror strips that are adept at reflecting incoming light and can be conveniently adjusted to track the sun's movement [38].

Once the industry is established, both virgin and recycled glass can be employed effectively side by side to lower the whole manufacturing process' capital cost. Aluminium can also be recycled from garbage. Instead of importing such structures from other countries, it will be much more lucrative to produce them with domestic resources. If this industry is able to run smoothly, it will eventually bring in money for the government and employ the harmed workers [38].

4. APPLICATIONS OF SOLAR THERMAL ENERGY

By utilising its thermal qualities, solar power may be applied directly across a wide range of use cases. These technologies are relatively straightforward, inexpensive, and simple to use [39]. In Pakistan, these use cases include cooling and heating buildings, heating and cooking, harvesting agricultural products by drying them, heating water for industrial and domestic purposes [40].

4.1. Sun-Powered Water Heaters

Solar water preheating use in Pakistan has been somewhat restricted despite the fact that the technology is highly developed. This is mostly due to the larger initial investment required for water heaters that run on solar energy in comparison with conventional models that use natural gas. Due to the cold climate and the scarce and challenging natural gas supply in these areas, some government organizations are beginning to actively create low-cost solar water heaters, which are now gaining popularity, mainly in the northern mountainous regions. Solar water heaters will no doubt be adopted due to the ever-increasing cost of electricity and natural gas. Such heaters are already being produced and commercialised in the individual households [40].

4.2. The Solar Panel

Numerous society sector organisations have worked on the manufacturing of affordable and effective designs for both drawers and type of hub solar panels in the past and are actively working on it today. The Pakistan Council for Renewable Energy Technologies (PCRET) regularly organizes educational lectures and seminars on the application and maintenance of such high-tech devices [41].

4.3. Sun Dryers

Agricultural products may be of better quality when dried and at a lower cost if solar dryers are used thanks for the cost savings from not utilising electricity or other heating fuels for the same reason. For example, fruits such as apricots were thrown out by the ton every year in the northern highlands of Gilgit and Sakardu, etc., due to a lack of logistics and fundamental infrastructure. Large amounts of this fruit are now dried using solar dryers before being transported and sold later in the urban market, which has a good impact on the local economy [42].

NGOs are making a concerted effort to increase the use of these dryers. In the provinces of Punjab and Sindh, solar dryers could be utilised equally efficiently for the process of drying agricultural crops for a higher market value and to create local jobs [43]. Drying processes in developing countries contribute significantly to their overall energy consumption, with fossil fuels like coal and natural gas being the primary sources for meeting these energy needs. For instance, India annually consumes approximately 157 million tonnes of coal, 89 million tonnes of petroleum products, and 233 million tonnes of other conventional energy sources to fulfill industrial, agricultural, and domestic requirements. However, there exists a considerable potential for solar dryers in the agricultural sector, offering an alternative to open sun drying and industrial drying while conserving substantial energy quantities. Solar drying presents advantages such as lower operating costs and the production of higher-quality food. Despite its potential, solar drying faces challenges such as intermittent sunshine, higher initial costs, and the availability of space compared to fossil fuel alternatives, impacting its widespread adoption [44].

5. PAKISTAN'S DEVELOPMENT IN SOLAR ENERGY

Punjab's Bahawalpur is home to the magnificent Quaid-e-Azam Solar Power Park (QASP) project. It is a 1000 MW project that would aid in reducing Pakistan's energy shortage [45, 46]. Solar energy is a requirement for QASP's main energy input. In this Solar Park, conventional PV silicon-based solar panels have been erected. The silicon that makes up the PV module transforms sunlight immediately into direct current electricity. Is used to power electrical appliances after being remaded into AC power by an inverter. This massive plan is installed by organizing three stages. Start-up of Phase-I plant with a capacity of 100 MW is completed, and more than 200 hectares of flat wilderness in Bahawalpur, about 400,000 solar panels were put in place. Phase-II and Phase-III of the QASP each have an installation capacity of 300 MW. The end of Phase-II was in August 2016. As soon as 1000 MW plan is finished and operational, 1530 GWh per year of output is anticipated [47-49].

Power systems fed from the sun do not need special maintenance once it is installed. It anticipates reduced maintenance expenses, resulting in a reduction in staffing needs. Pakistan ranks among the top 15 solar PV countries and accounts for 1% of global PV usage [50]. In 2014, the Pakistani government approved the Quaid-e-Azam Solar Park, a solar photovoltaic project with a capacity of 1000 MW. The first phase of the project, consisting of 100 MW, was successfully completed by the end of 2014 and officially established as the Quaid-e-Azam Solar Power Pvt Ltd. (QASP) in Bahawalpur, Pakistan [51]. Figure 4 shows the electricity produced by the

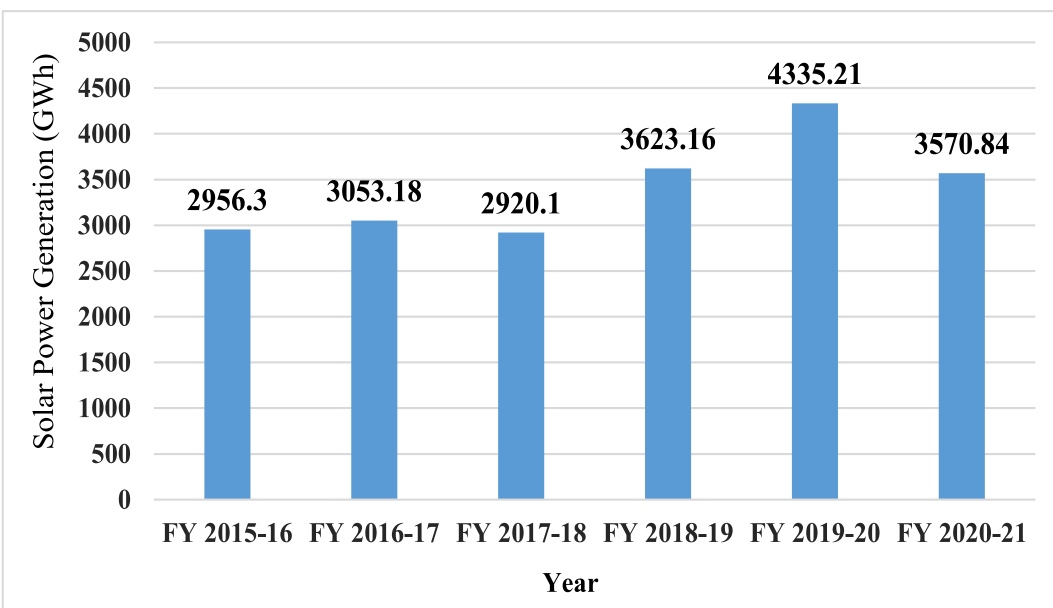

Fig. 4. Quaid-e-Azam Solar Power Generation (Solar Power Plant Bahawalpur, 2021-22).

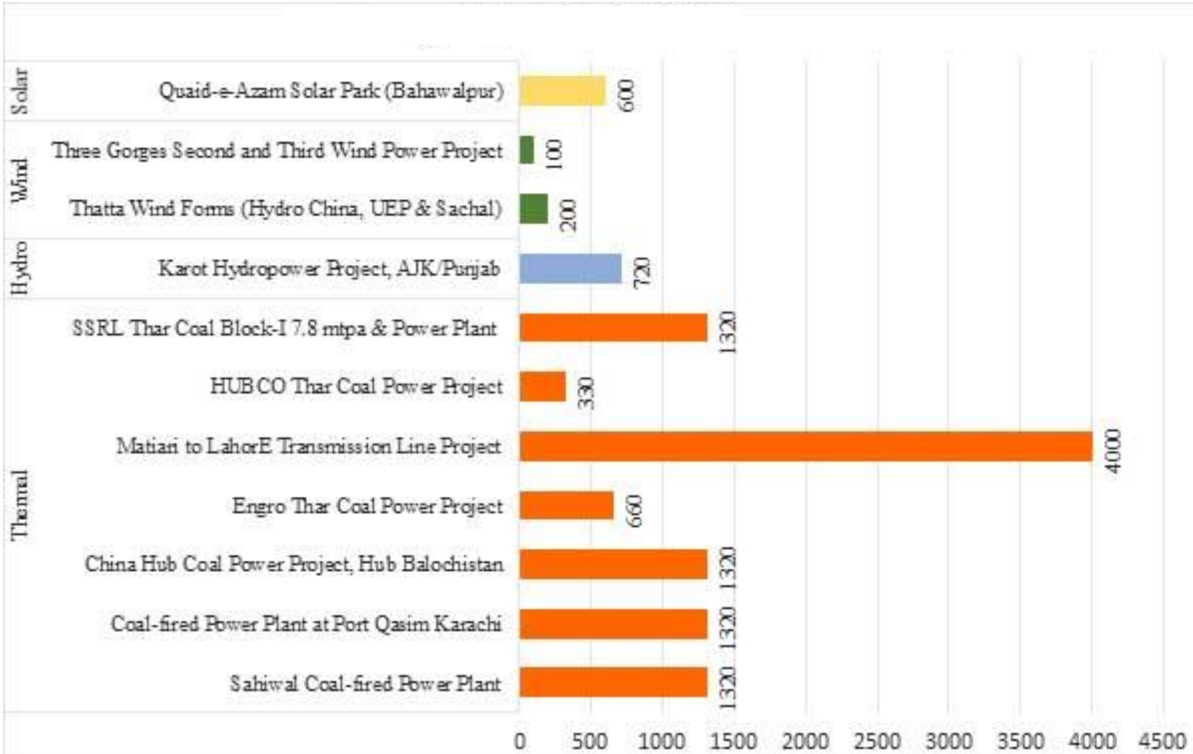

Fig. 5. Renewable energy projects under CPEC (CPEC).

Quaid-e-Azam Solar Plant from 2015 to 2021 (Solar Power Plant Bahawalpur, 2021-22).

Pakistan's Punjab and Sindh provinces are home to a number of active solar energy installations. The entire project of Quid e Azam solar plant is expected to cost US$1302 million. The Ministry of Water and Power organised it. Punjab Power Development Board and AEDB served as the overseeing organisation [52].

6. CONCLUSIONS

One of the best heavily irradiated nations in the world, Pakistan is located on the Sun Belt. Unfortunately, no action has been taken thus far to use such a package of energy for the advancement of the nation. Solar reflectors may turn out to be in concealment for efficiently collecting solar energy from the sun. Since sunshine is abundant in our country, developing indigenous energy technologies like solar reflectors is urgently needed to address this shortfall. The oil import cost, which is truly a big burden on Pakistan's economy, is expected to diminish with increased usage of solar energy technologies. The government must make well-planned and coordinated efforts to encourage solar energy use and inform the public about its advantages. Balochistan has abundant solar radiation, yet this resource is still untapped. It is the largest province in terms of area, but unemployment there is still at an all-time high. A reflector-solar PV industry must be concentrated on the enormous undeveloped region of Balochistan. In Pakistan, CPEC must be more than just a route; if the solar reflector business is established through cooperation, then it will be beneficial for both nations.

7. RECOMMENDATIONS

Against the background of the global energy crisis, associated simultaneously with several problems, such as a shortage of fossil fuels for energy [53, 54] and greenhouse gas emissions from the combustion of fossil fuels [53, 55], Pakistan has a significant advantage in the form of solar energy. As a result, many countries experiencing a lack of solar radiation are engaged in the search and development of other types of renewable energy [56 - 58].

However, there is a great potential for the use of solar energy in Pakistan. If this potential is used, the country will have enough energy by 2050. The government is currently very interested in utilising the solar energy potential and has begun to set up solar power producing plants in locations where this resource is more abundant. The work on CEPEC projects may move more quickly because CEPEC includes numerous renewable energy projects in Pakistan.

8. INTEREST OF PRIVATE ORGANIZATION IN RENEWABLE ENERGY

The development of the new industry is greatly aided by the privatisation of the new technologies. To establish an industry, solar projects must use solar reflectors. If private businesses and organisations adopt this, there will be a greater likelihood that technology will become affordable and widely accessible to the general people. For commercialize the practical implementation of solar technologies in the citizens homes and government agencies, a consultative and/or consulting council must be established to oversee the solar reflector business, as well as propose creative concepts.

9. EXPLORATION OF BALOCHISTAN SOLAR POWER AND CPEC RENEWABLE ENERGY PROJECTS

In the entire nation, Balochistan has the highest solar resource potential. How to transport the power generated by Balochistan's solar resources to load centres is a critical issue. Presenting plans for utilising the solar energy potential, the China-Pakistan Economic Corridor (CPEC), a significant infrastructural project between the two countries, might encourage R&D in Balochistan. It would mark an important turning point in Balochistan's development, spurring further growth [45, 59]. Figure 5 represents the various renewable energy projects under CPEC.

10. CONFLICT OF INTEREST

The Authors declare no conflict of interest.

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