Solar Thermal Opportunities and Challenges in Pakistan

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Abstract. In June 2018, the power deficit in Pakistan hit a record high of 9000 MW. Although alarming, it is not unprecedented due to past trends of exponential population growth, inadequacy of conventional energy sources to meet demand and lack of technological advancements. This represents an urgent and unavoidable need to turn to alternate renewable energy sources such as solar, wind and hydroelectric power. This paper aims to explore the possibilities presented by solar energy to solve the power crisis. This technology can be used to generate electricity which can then be used in different thermal applications. This paper presents a detailed discussion regarding these technologies, the institutions working in this field and scheme of solar thermal plants as per energy needs of Pakistan.

Index Terms: Solar energy, conventional energy, solar collector, solar energy potential.

1. Introduction

In recent times, frequent increase of population has been observed worldwide, particularly in developing countries with weak economies. This increase in population is inextricably linked with an increasing energy deficit. Since the economy and energy demand of a country are closely linked, as the economy of these developing countries grow, so does their energy demand. In the span of 2006 to 2030, marketed energy consumption of the whole world has been projected to be increased by 44% which is quite a brisk increase in the demand of energy globally [1]. This increased demand for energy can be catered only by introducing renewable resources of energy. These renewable sources of energy are cost effective and sustainable solution to energy crisis faced by developing nations.

The sun is considered to be one of the best alternative sources of energy. Due to its high surface temperature, it emits rays which are received by earth as form of solar energy. Being a natural emitter, the sun provides continuous yet varying amounts of energy to the earth, subject to the orientation of each area
towards sun. Surfaces which directly face the sun receive more solar radiation and vice versa. As solar energy is renewable, it does not produce harmful effects to the environment.

Past studies show that fossil fuels provide 88% of the total energy which is consumed for all purposes across the globe. Fossil fuels are harmful for the nature and affect environment in several ways [2]. Greenhouse gases emitted by burning fossil fuels significantly contribute to global warming. 1.6 billion tons of carbon was emitted in 1950 alone due to the burning of fossil fuels across the globe [3]. Burning of fossil fuels negatively impacts the environment as well as human lives. Every year, almost 160,000 people expire due to adverse effects of climatic changes which may increase twofold by 2020 [4]. Incorporation of solar energy for the production of electricity limits the use of fossil fuels, thereby contributing to control global warming. Solar energy is also renewable and sustainable, unlike fossil fuels which are depleting rapidly. This characteristic makes solar energy more appealing as a solution to combat the energy crisis.

Sun provides 100,000 TW energy to the surface of earth, which when extracted for an hour, is considered to be sufficient to fulfill energy needs of all humans for a year [5]. Proper harnessing of such a phenomenal amount of energy can be the answer to the current, and oncoming energy deficit.

Pakistan is an energy deficit country with a shortfall of several thousand megawatts. In 2008, the shortfall of the country stood at 4500 MW [6]. There are many remote areas throughout the country which are still not connected to national electricity grid. This is mainly due to the exponentially increasing population of the country, the unstable economy and government as well as poor infrastructure. Another key factor is the constantly fluctuating oil prices which make oil import for electricity generation more expensive. However, Pakistan has got abundant solar energy potential which can be harnessed in multiple ways to generate electricity for the country.

Solar energy can be harnessed in many ways. One way of extracting solar energy is to capture it through solar collectors. Solar collectors have the capacity to capture maximum possible solar energy and transfer it to a working fluid. This heated working fluid can be used for domestic heating purposes directly or stored for future use [7]. Solar collectors are also used to produce steam by concentrating sun rays on a particular structure containing water. Once this water is heated, it is converted to steam which is used to drive the rotor of a steam turbine. This is practiced worldwide to get extract maximum energy. These systems are especially useful in regions where there is a large number of sunshine hours.

Considering the entire situation, solar thermal generation seems to be a suitable and feasible mechanism to cope with the increasing energy demand in Pakistan. This clean technology ensures electricity generation with almost no adverse environmental effects. It is currently one of the best choices to mitigate the power crisis in the country. This paper aims to highlight the various advantages, hurdles and possibilities regarding solar thermal generation in Pakistan.

2. Solar Energy Potential of Pakistan

The latitude of Pakistan is between 620 and 750 East while its longitude falls under the range of 240 and 370 North [8]. Being in the sunny belt, it has been found to have tremendous solar energy potential standing at 2.9 TW [9].

The geography of the country is such that sunlight is evenly and plentifully distributed throughout the country. Average irradiation received by a flat surface in Pakistan has been estimated to be 200 to 250 watts per m², which is sufficient to make the country self-dependent in terms of power demand [10]. Sun shines in the country for almost 300 days annually. The topography of the country allows it to harness 1.9 MJ to 2.2 MJ solar energy. Many regions across the country have got enormous solar energy potential, Baluchistan being at the top. Baluchistan has such great potential that it is counted as one of the richest regions regarding solar energy potential. This claim is supported by the fact that on a particular sunny day, which comprises of 8 to 8.5 hours on average, Baluchistan receives irradiation of 19 to 20 MJ/m² [2].
3. Solar Thermal Technologies

The working principle of this technology is to harness solar energy to heat a working fluid, which is then utilized for various purposes. Normally two types of thermal power systems exist: Non-Concentrating Solar Systems and Concentrating Solar Power Systems (CSPs).

3.1 Non-Concentrating Solar Systems

These differ mostly because non-concentrating solar systems produce less temperature since solar energy is not focused on a particular point. These systems have higher efficiencies, moderate costs and are normally suitable for intense climates. These properties make them suitable for domestic purposes. As of 2010, this technology has benefited above 70 million residential areas globally [1]. Two forms of this technology are widely used these days: Flat Plate Solar Collectors and Vacuum Tube Solar Collectors.

3.1.1 Flat Plate Solar Collectors

Flat plate collectors are made up of multiple parts which are described as follows.

3.1.1.1 Absorber Plate

Absorber plates are made up of such materials which enable them to capture maximum amount of solar radiation. Sometimes, selective coating is also applied over the surface of the absorber plate to enhance its absorbing capacity.

Figure 1. Solar insolation map of Pakistan
3.1.1.2 Transparent Glass Sheet
A Transparent Glass Sheet is provided on top of the absorber plate to reduce heat loss from absorber surface.

![Figure 2. Flat plate solar collector [10]](image)

3.1.1.3 Metal Pipes
Metal pipes are directly attached to the absorber plate to enable maximum heat exchange with the working fluid present within the metal tubes.

Further, an insulated support is installed to minimize heat loss from the surface of the absorber plate. All parts are then protected by an external shell [11]. Since Flat Plate Collectors absorb solar radiation from any direction, the need for a complicated tracking system (required to appropriately position the collector) is eliminated.

3.1.2 Evacuated Tube Solar Collectors
Evacuated tube solar collectors are generally better in performance because they produce higher temperatures than their flat plate counterparts. It consists of following parts.

3.1.2.1 Vacuum Glass Tubes
Vacuum filled glass tubes reduce convective and radiation heat loss.

3.1.2.2 Copper Tubes
These are used to transfer solar energy to the working fluid in the form of heat.

An outer casing made of aluminum protects the collector from the influence of the external environment, thus enabling it to be used in harsh environments. However, this type of collector requires a high capital cost [11].
3.2 Concentrating Solar Power Systems (CSPs)

CSPs are more common and used globally for power generation. Its working principle is similar to that of steam turbines. Solar radiation is directed to solar collectors or mirrors to concentrate it on a particular structure. This structure contains a working fluid which is heated to produce steam which is used to run the rotor of a steam turbine to generate power [13]. There are two types of CSPs [14]; Line focusing CSPs and Point focusing CSPs.

3.2.1 Line focusing CSPs

Line focusing solar thermal collectors and power systems focus sun rays on a line where working fluid is heated. In these power systems, sun rays are reflected from a surface in such a manner that they are focused in the shape of a line on a structure where working fluid gets heated to carry out the desired function. Line focusing solar collectors can achieve temperatures in the range of 350 °C to 550 °C [15].

3.2.2 Point focusing CSPs

Points focusing solar collectors are those which, when exposed to direct solar radiations, focus all radiations on a single point to heat a working fluid. This heated fluid then performs a specific function, usually power generation.

There are different forms of CSPs through which higher temperature of particular fluids can be achieved for various purposes. Past studies show that multiple CSPs have been made to achieve the best possible conversion of solar energy to heat energy. Today, many choices are available to collect solar energy and convert it into heat energy with best possible efficiency. As technology advances, many changes are observed on a regular basis to modify the structure of different collectors to absorb maximum solar energy.

Pakistan has not yet moved to produce power using CSPs [16]. The following four collectors [15] are very important and can produce sufficient power for Pakistan to mitigate its blackouts: Parabolic Troughs, Parabolic Dishes, Solar Tower and Linear Fresnel Reflectors.
3.3 Parabolic Troughs
Parabolic troughs are widely used to generate power in energy deficient areas. They are a type of line focusing CSPs. This technology uses a parabolic trough which has the distinctive property of concentrating sun rays over a receiver containing the working fluid. The receiver is a tube, coated with a specific material, receives concentrated solar rays reflecting from parabolic trough. Sometimes, the receiver tube is fitted in evacuated glass to minimize heat loss. It is strategically placed in the optical focal line of the parabolic trough for maximum efficiency. To further improve efficiency, one dimensional tracking systems are also installed to enable them to capture maximum direct radiations. Without tracking, solar rays may not always be directed perpendicular to the surface of the trough, which reduces the intensity and the temperature in the receiver.

In parabolic troughs, the fluid inside receiver can be heated up to 400 °C, which is then used to produce steam. This steam then runs the rotor of turbine to produce the required power [17].

![Parabolic trough collector](image)

**Figure 4.** Parabolic trough collector [18]

3.4 Parabolic Dishes
Parabolic dishes are point focusing solar collectors which capture solar rays and direct them to a point to convert this solar energy to heat energy. These solar collectors can achieve a very high temperature of 1500 °C [19].

Parabolic dishes are in the shape of a paraboloid, which is made by revolving a parabola about its own axis. The surface of the dish, which directly faces sun, is made up of highly reflective material to reflect and concentrate maximum solar radiation. The receiver, which again contains the working fluid, is installed at the focal point of the parabolic dish. It is generally made up of a metal for maximum heat transfer to the working fluid. It is tightly attached to a support which mounts it in a fixed position. The working fluid is heated up to the desired temperature and then utilized either in Stirling engines or steam power plants to produce power.

Parabolic dishes also need proper two-dimensional tracking systems to face the sun directly to receive maximum solar radiation. Since the parabolic dish is rotated in two dimensions, it requires extra strength. Hence, a foundation along with supporting frames are also installed in the system [20].
3.5 Solar Tower
Solar tower is one of the best options to harness solar energy for power generation. This technology consists of a central receiver system (CRS) and widely distributed mirrors. These mirrors are called heliostats. Each heliostat tracks sunlight to focus it on a receiver mounted at the top of the tower. Working fluid is present inside a heat exchanger which is heated up to a certain temperature to serve a desired function [15]. The working fluid inside the receiver may be water, air or molten salt [20]. Generally, a cylindrical receiver is mounted to receive maximum reflected rays from the heliostats. When solar rays are concentrated on a particular CRS, the working fluid is heated, which in turn, is stored in a thermal energy storage tank or used directly in power generation systems. Thermal energy stored in a tank may be used to generate power during the night or on cloudy days. Solar towers can achieve extremely high temperature up to 1500 °C [22].
3.6 Linear Fresnel Reflector
Linear Fresnel reflectors also contain mirrors which are used to focus solar rays on the receiver. In 1993, the first Fresnel Reflector was developed in the University of Sydney, and later patented in 1995. When sun rays fall on the surface of the mirrors, they are focused on a linear metal receiver. Since this utilizes the line focusing technique, a single axis tracker is required to directly face the sun. The receiver tube contains the working fluid, which is heated by concentrated solar radiations. This highly heated working fluid can be used either directly used for power generation or passed through heat exchangers for steam production, which is then used to operate steam power plant [22].

![Figure 7. Linear Fresnel Reflector [24]](image)

4. Comparison of Different Concentrating Technologies
There are various concentrating technologies available worldwide for power production. Some are point focusing while others are line focusing. Each technology produces different temperature ranges depending upon the collector’s surface. Those surfaces which concentrate more light rays, produce greater temperature and vice versa. Table 1 compares various features of these concentrating technologies.

| Technology      | Parabolic Troughs | Parabolic Dishes | Solar Tower | Linear Fresnel Reflector |
|-----------------|-------------------|------------------|-------------|--------------------------|
| Temperature     | 400 °C            | 750 °C           | 1000 °C     | 270 °C                   |
| Efficiency      | 10-15%            | 18-25%           | 14-17%      | 9-15%                    |
| Concentration   | Line              | Point            | Point       | Line                     |
| Cost ($/KW)     | 4200              | 6000             | 4500        | 2200                     |
5. Working of a Typical Solar Power Plant
Solar thermal power plants operate on the basis of the Rankine cycle. The Rankine cycle incorporates various components of the power plant. A solar thermal collector functions as an evaporator where water is heated to produce steam. This high pressure steam is used to turn the rotor of the turbine. A condenser then condenses water under low pressure. Water is then pumped to the evaporator and the cycle is repeated[25].

![Figure 8. Working of a typical solar thermal power plant][26]

6. Solar Thermal Applications in Pakistan
As established before, Pakistan has high solar energy potential due to its advantageous geographical position. While this energy can be utilized to generate power, it can also be used for other purposes. Some of these alternative applications are discussed below.

6.1 Solar Water Heating
Solar water heating (SWH) is an efficient, globally used technique to heat water with the help of solar energy. Solar energy, collected by a solar collector, is converted to heat energy and transferred to water thereby increasing its temperature. This is a rapidly emerging and growing technology, currently implemented in multiple countries, due to its efficient results. Solar water heating can be used for several domestic purposes, commercial activities and industrial processes. They can also be used for air conditioning through dedicated absorption chillers [27].

This technology is especially relevant because water heating consumes a great amount of energy globally. It has been found that 15 to 20% of the total domestic energy consumption is used to heat water. The United Kingdom and the United States of America have been found to be using 23% and 18% of their total domestic energy to heat water respectively. As in domestic applications, water heating is also of prime importance in the industrial sector. Heated water is used for various processes carried out in different industries. The textile industry consumes 65% of its energy to heat water for different purposes. Past studies
show that Pakistan uses 10% of its domestic energy to heat water [6]. SWHs are also preferable because they do not emit carbon unlike fossil fuels. Although, these systems are costly [27], their payback period seldom exceeds three years [6]. Solar water heating technology is gaining popularity in northern part of the country because of the cold environment and lack of availability of natural gas [28].

As the population of Pakistan increases, the energy demand for domestic and industrial purposes is increasing as well. A large portion of this energy is used to heat water. The textile industry of Pakistan provides 60% of the total income earned due to export. At the same time, it needs water heated up to 80 °C for various purposes [28]. This makes solar water heating a viable option for domestic and industrial needs in Pakistan.

6.2 Solar Cookers

Cooking is one of the most vital phenomena occurring worldwide. Often, it consumes a lot of heat energy since the food being cooked contains a lot of water. South Asian countries are considered to be among prime users when it comes to energy consumption for cooking purposes. They consume a great portion of primary energy for cooking which amounts to one third of the consumption of primary energy [16]. Water has a boiling point of 100 0C. In order to completely remove water from the food, temperatures between 90 and 100 0C must be supplied. When food is cooked, more energy is required for sensible heating. Thus, while cooking food, 20% of the heat is used to boil it, 35% is used to remove water and the remaining 45% is lost to the external environment in the form of heat losses [29].

Solar cookers are one of the feasible options for cooking in the countries like Pakistan. Solar cookers are relatively cheaper than wood or other fossil fuels which makes them an attractive option for people with limited financial resources. These cookers also reduce the wood utilized for cooking, thus decreasing deforestation.

There are two types of solar cookers available today: Box type solar cookers and Concentrator type solar cookers. Box type solar cookers use direct solar radiations for cooking purposes whereas concentrator type solar cookers have a solar collector, which concentrate solar radiations to heat a working fluid, which is then used for cooking.

Pakistan is quickly adopting solar cooker technology. Many public, private and non-governmental organizations are engaged to develop this efficient and low cost technology. South Asian countries like China and India have already adopted this technology and are getting great advantage through it. China is quite familiar with this technology. 60,000 and 14,500 solar cookers are used across China and India respectively. Pakistan, when compared to these countries, is quite far behind adopting this technology because only 5000 of these cookers are present in the country. Food cooked in solar cookers is healthy because solar energy does not impact the amount of vitamins in the food. Moreover, solar energy does not alter taste and flavour of the food [28].

There are certain barriers which prevent the widespread use of this technology throughout the country. One of the main causes is slow cooking. Food cooked in solar cookers takes more time compared to conventional cookers. Solar radiations are not always directed perpendicular, thus solar tracking is required to achieve greater efficiency. Another issue faced by this technology is that it produces lower temperatures compared to conventional cooking temperatures. Sunshine hours also play a critical role. Solar radiations are unavailable for more than 60% of the day which makes solar cooking impossible for a greater part of the day [16]. Furthermore, people are still not mentally prepared to accept this technology as an alternative to conventional cooking. Public awareness through various campaigns and promotional ventures are required to educate people about this technology. Since the population in cities has increased exponentially, there is limited space available in urban areas which further poses a hindrance to the implementation of this technology. Initial cost of solar cookers is also quite high which does not allow poor people to take advantage of this technology [30].
6.3 Solar Dryers

Pakistan is an agricultural country which produces a lot of products including vegetables and fruits. Fruits are a vital part of the country’s economy. Fruits are either consumed while fresh or dried for future use in off seasons. Solar energy is crucial in this aspect because it is considered to be the best choice for drying these fruits. Two methods are commonly used to dry these fruits in Pakistan: direct solar drying and convective solar drying. Direct solar drying is not a preferable technique because fruits are directly exposed to solar radiations in open atmosphere which makes them vulnerable to dust, grimes, insects, birds, animals and harsh environmental conditions. Moreover, this type of drying leads to degradation of the fruit [28].

Crops and fruits demand intensive care regarding drying. They need to be properly handled during this period to retain their natural taste and flavour. Solar drying, unlike conventional drying, has proved to be a better choice for drying agricultural products, like fruits, because it does not deteriorate their quality and retains their natural composition. Food products being dried are highly sensitive to high temperatures. They need to be provided with suitable temperature ranges. While open atmosphere solar drying is highly recommended for fruits, it is less preferable for vegetables, which usually get rotten due to high temperature of solar radiations [31].

Convective solar drying has proved to be a better choice compared to open atmosphere drying because it is smoother, faster and more efficient. The low manufacturing and operating costs of solar dryers also make them a feasible option for drying different products [1].

Solar dryers are gaining popularity in the mountainous regions of Pakistan e.g. Gilgit Baltistan, which produces a vast variety of fruits. Apricots are abundantly found in this region. However, this region lacks basic infrastructure due to which a huge amount of fruit is spoiled and wasted every season, leading to a major economic loss. Thus, solar dryers are a suitable option for drying and preserving apricots. Although people are familiar with solar drying technology, many non-governmental organizations are working hard to create public awareness [32]. Punjab and Sindh can also utilize their solar energy potential for solar drying thereby creating opportunities for local residents [33].

The energy required for solar drying of a product depends on the moisture content of the product before and after drying. Different products require different temperatures for drying. Maximum energy consumption occurs when water evaporates since this process requires a large amount of energy. Relative humidity and air velocity also play very important role in solar drying [34].

Solar dryers are being used across the world to preserve different sort of fruits, vegetables and other agricultural products. These dryers have produced good results and are economically viable. They are also attractive since their functioning does not harm environment. Drying fruits and crops through this technology improves the standard of the product and increases their shelf life. It also reduces the consumption of fossil fuels.

Currently, different sorts of solar dryers are available in market depending on the shape, size and design. The needs of a customer determine the appropriate solar dryer required. This technology can also act as a viable option for food industries to preserve high quality food. By using this technology, solar energy and hence renewable energy will be familiarized, leading to reduction in the usage of conventional fuels and thereby decreasing environmental pollution [33].

Pakistan is a country which produces large amount of fruits, crops, vegetables and other agricultural products. A large amount of these products is wasted every year due to low demand and lack of storage capacity. People who grow these products cannot get maximum benefit due to wastage and hence receive less return on investment. In Pakistan, open air drying is more common compared to solar convectional drying which results in lower quality product and larger wastage. Open air drying is also less favourable because products are open to dust, insects, wind and rain. When dust gets stuck to the products, it can cause diseases in consumers. Thus, solar drying is preferable since it is reliable, does not depend on conventional energy resources, reduces electricity bills and is environment friendly.
6.4 Solar Desalination
Desalination is the process of removal of salt from brackish or seawater to make it fit for different purposes. Solar desalination uses solar energy for desalination of brackish water [28]. Water beneath the earth’s surface contains dissolved salt which makes it unfit for drinking and laundry purposes. Usage of this water is also dangerous for health [32]. Many areas of Baluchistan, Sindh and southern Punjab suffer from lack of availability of sweet water. Solar desalination technology can be an option for these far flung areas because it is operationally simple and economical. It also reduces the number of germs present in water. So far two plants have been brought into operation. These purify 6000 gallons of water each day in Gwadar, Baluchistan. This project has facilitated many people in the area who are now taking advantage to purify their drinking water through this project [8].

Non-availability of sweet water is one of the main challenges in Cholistan and Thar deserts. Inhabitants of these deserts do not have access to fresh water due to its scarcity which compels them to use brackish water. Very few areas in these deserts contain suitable drinking water whereas the rest contain brackish water [35]. Salinity is also one of the major problems across the coastline of Baluchistan where the presence of dissolved salts renders the water used for multiple domestic purposes [36].

As discussed above, solar desalination uses solar energy to remove salts from the water. Two methods can be used to desalinate water with the help of solar energy. First method of solar desalination is called solar distillation. In solar distillation, water is heated with the help of solar energy and converted into vapours. These vapours, which are free from salts, are collected and condensed. Another method of solar desalination converts solar energy to thermal or electrical energy, which in turn is used to power conventional desalination methods. This is termed solar driven desalination. Research studies carried out at Awania village of India show that solar distillation is a more viable option for off-grid remote areas with fewer communities [37].

An easy method used for desalination of water uses the water still. The water still is comprised of a tray and a glass cover. Saline water is poured in a shallow tray. This tray is kept inside a glass cover with an inclined surface. When solar radiations fall on saline water, it is heated. Due to this heat, water evaporates. These vapours condense when they touch the relatively cooler glass surface. This fresh liquid water is collected at the bottom and can be used for various purposes. Through this mechanism, that 4 kg/m² of desalinized water can be produced daily, given that there are enough solar radiations [9].

Water stills are used worldwide to desalinate water. Pakistan is also a country which is quickly adopting this technology with different organizations working on making efficient solar stills. The Pakistan Institute of Engineering and Applied Sciences (PIEAS) is one such organization which has worked on the fabrication of solar stills. It has fabricated an optimized glass cover single basin solar still which showed an efficiency of 30.56%, which can compete with the efficiency of solar stills produced globally. This solar still is also economically competitive and can benefit poor people who live in remote areas [9].

6.5 Solar Water Pump
Pakistan has many areas where water is scarce. Water scarcity occurs due scarce and unpredictable rainfalls throughout the country. The Cholistan desert is one such area where water is scarce, relative humidity is low and evaporation and wind velocities are high. However, the solar intensity is also high in this particular desert. Other regions of the country, mainly many parts of Punjab and some part of Sindh also suffer from a similar problem. People store rain water and use it for different purposes. On hot summer days, when there is no rainfall, existing water evaporates leaving dry areas. When there is a severe water crisis, people migrate to other regions of the country, along with their domestic. These people live a very low standard of life due to lack of facilities. This is a serious injustice, which prevents them from taking part in activities which help the country grow. This makes it necessary to provide these people with opportunities to make their lives easier [9].
Solar water pumps can be used to pump water in these areas. Water can be pumped from beneath the surface of earth towards its surface by using a 1 or 2 hp engine, which is quite effective. Many organizations, like Pakistan Atomic Energy Commission (PAEC), are working to develop solar pump technology in the country. PAEC has developed a solar water pump which runs through a 2 hp steam engine. Steam is produced through a boiler with the help of 21 feet diameter paraboloid which contains flat mirrors [35]. The steam produced operates a steam engine, which in turn is used to run a solar water pump. Solar pumps can also be operated through PV modules. People related to farming have used these PV pumps in different regions of the country. The Agricultural Development Bank of Pakistan (ADBP) distributed these pumps among users [9].

Solar pumps can be a revolutionary technology, but at the moment, its initial capital cost prevents it from being implemented throughout the country. China, a technologically advanced country, required 261 MW in 2010 for solar water pumping [38]. Baluchistan can prove to be a huge beneficiary of the solar pump technology, if Pakistan learns from China.

6.6 Solar Ponds
Solar ponds are specifically built for collecting and storing solar energy. These ponds work on the principle of not allowing convective heat transfer by maintaining high temperatures at the bottom of the pond. To prevent convection, salt also is mixed in water. Such ponds are called salt gradient solar ponds. This technology is gaining fame and multiple solar ponds have been constructed across different countries over the last few years. The hot water can be used for different purposes e.g. generating power and desalination. Moreover, it can also be used for agricultural purposes and in dairy farms [39]. Like other countries, solar ponds technology can be a useful option for different applications in Pakistan.

7. Possibility of installation of Solar Power Plants in Pakistan
In Pakistan, cheap and sustainable sources of power generation are the need of the hour. Federal and provincial governments agree that new power plants are required to cope with the increasing energy demand. Power plants, particularly solar power plants, can fulfill this need on a national level. The Sindh government has signed a Memorandum of Understanding (MoU) with one of the leading companies in Germany, Azur solar. According to this MoU, a 50 MW solar power plant will be constructed in a village called Dhabeji in Thatta. The company will start with building a 60 kW power station. This power station will benefit the residents of the undeveloped villages, educational institutions like schools and other fundamental health care centres in the area of Badin [40].

A 50 MW solar thermal power plant in Jacobabad can be used to assess the viability of solar thermal power plants in Pakistan. This power plant uses the Stirling dish technology to produce electricity. Prior to constructing a solar thermal power plant, reliable solar insolation data is required. In case of this power plant, data was provided by a well-established organization of the country, the Bureau of Meteorology (BoM). Solar insolation data indicates that Jacobabad is among those regions which show higher solar energy potential. Solar energy potential of this region is sufficient, with the minimum solar energy potential being 4.45 kwh/m²/day. This is quite high compared to the average solar energy potential of the world, which is 3.61 kwh/m²/day. This value of solar energy potential suggests that it can be harnessed even when there is diffused irradiation and low sun intensity [40].

Once solar data was available, the economic and technical feasibility of this project was checked. A 25 kW Stirling dish system was used for this analysis. Dish technology is considered a popular option because it can harness solar potentials as less as 2 kWh/m² and can be used on cloudy days as well. Jacobabad, situated in Sindh, experiences extreme temperatures and low rainfall. The temperature in this region ranges from 45 to 50 °C in summer and 10 to 25 °C in winter. The low temperature average is 19.95 °C and high temperature average is 34.15 °C with overall average temperature being 27.05 °C [9]. This makes it quite similar to a desert, where global irradiation is as high as 1735 kWh/m²/year [41]. The land required for
installation of solar power plant was available at a cost much lower than the cost required for acquisition of land in United States of America and Europe [42].

Solar thermal power plants can be a good move for the mitigation of the energy crises in Pakistan. The 25 kW dish technology can act as a suitable source of harnessing solar energy for electricity production. This technology can be appropriate for electricity production in multiple high solar potential regions of the country like Federally Administered Tribal Areas (FATA), Sindh and Baluchistan. In Sindh, Jacobabad is ideal for the installation of solar thermal power plants operated via dish technology because its solar energy potential is more than 1700 kWh/m²/year [40].

When it comes to economic considerations, the maintenance and operation costs of solar power plants ($0.001/kWh) are higher compared to conventional power plants. However, these costs are acceptable if the government is keen to invest in renewable energy. If subsidies given to conventional power plants are given to solar power plants, they can be quite beneficial for the future of the country. Other calculations show that electricity is generated at a cost of 3 to 12 US Cents/kW [9], which is quite high compared to electricity generated from other resources like hydel and fossil fuels. Thus, strong government initiatives are required to make solar power plants an attractive and viable option for electricity generation in the future.

8. Advantages of Solar Thermal in Pakistan
Solar thermal technology has got some remarkable advantages. This technology does not require resources other than solar energy. It is not dependent on resources which are going to deplete unlike conventional systems which generate electricity using non-renewable fossil fuels. These fossil fuels are rapidly depleting thus, there is an increasing need for alternate resources to generate power.

Environmental pollution has also become a major concern in recent times which requires regulation of greenhouse gases. Burning fossil fuels leads to emission of greenhouse gases (GHG). These gases are quite harmful for the environment and people [43]. The emission of gases due to burning of fossil fuels is one of the main causes for many diseases. These diseases include neurological problems, heart issues, cancer and diseases associated with breathing. GHG emissions are quite low in the case of solar energy when compared to coal and natural gas. CO₂ emission are in the range of 0.64 to 1.63 kg/kWh of energy generated from coal, 0.27 to 0.91 kg/kWh of energy generated from natural gas and 0.03 to 0.09 kg/kWh of energy generated from solar resources. These statistics show that the ratio of carbon emissions is 18:9.5:1. This clearly implies that solar energy is cleaner than coal and gas. Thus, power generation from solar resources can lessen the chances of these diseases. Some studies reveal that the use of renewable energy like solar energy instead of fossil fuels can decrease the number of wasted workdays, premature mortality rates and health related expenditures [44].

Solar technologies also require more labour. This suggests that they can provide greater job opportunities to the people living in nearby communities. According to some reports, the solar industry in USA has provided up to 208,859 jobs to different people in different capacities [44]. Similarly, the implementation of solar technologies in Pakistan will definitely provide greater job opportunities to the people living in the country.

9. Limitations of Solar Thermal Technologies in Pakistan
There are also many limitations which are currently associated with the implementation of solar energy technologies in Pakistan. Solar energy systems need high initial capital cost which makes them unaffordable for many people across the country. They are also more expensive compared to other conventional electricity production systems like fossil fuel and nuclear energy based generations. Other challenges include manufacturing techniques and waste materials. Pakistan is a country with low literacy rates, due to which proper guidance for consumers about the opportunities and usage of solar energy appliances proves to be a hard and costly task. False hopes given to rural communities about electrifying rural areas by
politicians also cause hurdles in the development of solar energy. It is also difficult to get proper data regarding environmental conditions, which is crucial for harnessing solar energy.

Besides other issues, the intermittent nature of the solar energy is also of prime concern. Solar energy is not considered to be a reliable source of energy because of its sporadic behaviour and thus is not a suitable choice for continuous power supply. Preferably, solar energy should be used in combination with another sort of power generation system to provide continuous power. If another power generation system is not used in combination with solar energy production, a proper storage system should be employed to ensure continuous power supply. Quality issues are also associated with solar energy.

Certain damages to environment are also possible due to poor handling of solar thermal power plants while in operation. Solar power tower technology can be dangerous for birds, insects and other animals flying in the course of concentrated solar rays. The high temperatures associated with the concentrated rays can kill these animals. The working fluids used in solar concentrators are sometimes harmful for humans and should be properly dealt with [1].

Solar thermal systems require the coolant to be changed over a specific period of time which poses a real challenge because it can be harmful for the surroundings. Apart from this, solar thermal systems require a large amount of dedicated land. Another issue related with these systems is they require large amount of water for cycle cooling, which is only possible when surrounding areas have an abundance of water. It has also been seen that solar energy potential is often more in deserts where there is scarcity of water, thus making it difficult to harness solar energy for thermal generation because water is frequently needed for thermal cycles and to clean surfaces of reflectors [15].

The efficiencies of solar thermal systems are quite low as these systems have not yet been properly developed. Based on the different power systems used, their efficiencies can range from 10 to 17%. Their initial cost is also very high which makes them undesirable for end customers. These systems work only during the day when solar energy is available. However, in most cases, peak loads occur at night time. Hence, a storage system should be available to provide energy during peak hours. Expensive batteries, which need to be changed every 3-5 years, are used for this purpose. These batteries account for 30 to 40% of the total cost. Furthermore, solar energy is highly dependent upon geographical location and plants cannot be installed unless detailed feasibility studies are carried out [45].

As solar energy is a form of renewable energy, it faces a lot of challenges. There are certain issues involved in the switch from conventional energy resources to renewable energy resources. Public awareness is one of the toughest hurdles when discussing the implementation of a renewable energy program. To counter this, multiple organizations and agencies should be brought in to action to make familiarize the public with renewable energy. Training and guidance programs should be also arranged on timely basis to spread the importance of the need for sustainable energy. Besides general public awareness, research and development activities are necessary. Universities can play a very crucial role in the development of sustainable energy. Research is quite important yet challenging due to the lack facilities. Regardless, various subjects regarding sustainable energy should be included in the curriculum. As of now, Pakistan does not have the proper infrastructure for renewable energy. Thus, proper infrastructure needs to be developed to commercialize renewable energy in the market. Financial incentives, if properly given can change the current power scenario of the country. Strict monitoring for the implementation of this program is also lacking in the country [46].

10. Institutions working for Development of Solar Energy in Pakistan

Solar energy can act as an ideal resource for power generation in the country since it can mitigate the power crises in the country. Many institutions have been made to monitor all activity regarding solar energy. These institutions are busy in research and development to promote solar energy in the country. Some of them also provide technical and financial assistance to promote solar energy. Some of these institutes are discussed below.
10.1 Pakistan Council of Renewable Energy Technologies (PCRET)
PCRET was brought into existence in 2001 by merging the National Institute of Silicon Technology (NIST) and the Pakistan Council for Appropriate Technologies (PCAT). The merging of these two institutes was necessary to carry out research and development activities in a better manner and to avoid any sort of complications regarding duplication of research activities. PCRET has established its head office in Islamabad and four regional offices in Quetta, Karachi, Lahore and Peshawar.

Currently, PCRET is one of the most important institutions busy in promoting renewable energy in Pakistan. It is responsible for research and development of different renewable energy programs. PCRET is particularly active in promoting solar energy. Apart from conducting research activities related to PV modules, it has also done a remarkable job to promote solar thermal technology. PCRET has designed and fabricated many solar thermal based appliances. These appliances include solar water stills, solar cookers, solar dryers for drying of agricultural products, solar heaters for heating water and solar heating systems for space heating. These appliances are used for different domestic, commercial and industrial purposes across the country. Being a responsible organization, PCRET has worked and is currently working on different type of solar appliances to modify and improve them to achieve better results. Apricots are produced abundantly in the country and their preservation and dehydration is a major task. Other achievements of PCRET include design and fabrication of solar cookers and solar water stills. PCRET provided more than 500 solar cookers to non-government organizations (NGOs) for distribution among local communities to familiarize them with this technology. 50 solar water stills were also given to NGOs to provide them to residents of the country. This increases awareness regarding renewable energy which makes people less hesitant to switch to these systems in the future. Another prominent achievement of PCRET is the development and fabrication of a solar space heating system in the local market. This system provides heat to the PCRET building.

Solar dryer technology is used worldwide. Pakistan is also taking a keen interest to develop this technology. For this purpose, PCRET is playing a key role to develop and promote solar dryer technology across different regions of the country. A hybrid solar dryer has been designed and fabricated by PCRET to dehydrate apricots, which is a great achievement. Under another project, PCRET has fabricated and manufactured 10 solar dryers best suitable for communities in remote areas. These remote areas use these solar dryers for drying of dates. These dryers have capacity to store 500 kg of dates. Regions where these dryers have been installed include Jhang, Multan, Muzaffargarh and D.G. Khan districts of Punjab, Sukkur and Khairpur districts of Sindh, Turbat and Panjgoor districts of Baluchistan and Dera Ismail Khan district of KPK. Fabrication of these solar dryers has been done locally. This project was possible due to local community involvement. The cost of the project was also shared. The local community chose two persons who were fit for the job and they remained in touch with the project from starting till finishing to acquire the necessary training. These dryers dry an appreciable amount of 25 tons of dates each year. These dates are used to provide these communities with 3.5 million revenue. These dryers are operated by local communities. Routine maintenance is also done by the communities. The technical assistance team of PCRET closely monitors and checks performance of these dryers to resolve any complications [9].

10.2 Solar Energy Research Center
Solar Energy Research Center is working under the Ministry of Science and Technology. It is situated in Hyderabad city. This center is mainly concerned with research activities in the field of solar energy. The research of this center is particularly focused on solar thermal applications. These solar thermal applications include solar desalination systems, solar heating and air conditioning and power generation from solar thermal technologies [8].
10.3 Alternate Energy Development Board (AEDB)
AEDB was established in 2003 under the supervision of the federal government. The prime objective of the AEDB was to enhance the development of renewable energy in the country. Another goal of the AEDB is to switch 5% power generation of the country to renewable and alternate energy by 2030. It was also responsible for electricity supply to 80,000 remote villages of the country through renewable and alternate resources of energy [32].

10.4 Renewable and Alternative Energy Association of Pakistan (REAP)
REAP is an institution currently working in different areas to improve and develop renewable and alternate energy in the country. It is specifically responsible for promoting renewable and alternate energies to decrease reliance on conventional fossil fuels for power generation [32].

10.5 EME College, NUST Islamabad
EME College is a part of NUST (National University of Sciences and Technology), located in the capital of the country, Islamabad. EME College is engaged in research and development activities regarding solar energy. This college has worked to install a solar water heater with a capacity of 40 tons/day for a local industry at Lahore. This college is also busy in activities regarding solar pumps. It is also working to electrify houses through solar energy. FATA has benefited from this facility. Work has been started to electrify 450 houses in FATA since May 2009. Other activities of this college include wind/solar hybrid water pumping systems. It also intends to install 50 such units in Kharan which is a district situated in Baluchistan. It also works to promote solar cookers and solar dryers. For this purpose, it has provided Bagh, Azad Kashmir with twelve solar cookers and two dryers, each with a 50 kg capacity [9].

10.6 Academic Institutions
Research activities are not focused on in a majority of the universities in Pakistan because research environment in Pakistan is still not developed. Same applies to research activities in the field of renewable energy, particularly solar energy. Regardless, some universities are busy in conducting research and development activities in the broad field of solar thermal energy. Some institutions are worth mentioning regarding research in solar thermal applications. Institute of Environmental Studies at Ghulam Ishaq Khan (GIK) Institute of Engineering Sciences and Technology in Topi, Swabi is currently engaged in the testing of solar thermal devices. Department of Mechanical engineering at University of engineering and technology (UET) Lahore is also conducting various research activities in the field of solar thermal technologies [8].

10.7 U.S.-Pakistan Center for Advanced Studies in Energy (USPCAS-E), NUST Islamabad
This center has been established at NUST Islamabad. It is a joint venture by NUST and USAID. This center is focused on the development of research and development activities in the country, with the help of USAID, to make country secure in terms of energy. The primary focus areas of research in this center are renewable and emerging technologies [32].

10.8 U.S.-Pakistan Center for Advanced Studies in Energy (USPCAS-E), University of Engineering and Technology (UET), Peshawar
UET Peshawar has established this center in collaboration with USAID to conduct research and development activities in the field of energy. Despite being rich in natural resources, the country is experiencing a power deficit. This center is busy in conducting different research activities in the field of energy. For this purpose, it has started several projects in different areas of the country. It has also initiated several projects with local communities. Local communities are involved in sharing responsibilities which familiarizes them with renewable energy. This center is also busy in educating students through different
postgraduate studies programs. Renewable Energy Engineering is one of these programs which is purely based and focused on renewable energy.

11. Conclusion
Pakistan is facing a severe energy crisis at the moment. There are many regions across the country where load shedding has become a routine matter. Due to routine power cutoffs, the residents of the country, especially those residing in rural areas, are severely affected since electricity dependent domestic chores cannot be executed properly. Businesses and commercial activities are also disturbed due to uninformed load shedding schedule.

In these circumstances, the country is in a dire need for power generation. Currently, the country relies on expensive, non-renewable fossil fuels for power generation, which are depleting rapidly. Moreover, they are quite hazardous for the environment since they produce greenhouse gases upon burning. These greenhouse gases pollute the environment and cause multiple diseases. Considering these circumstances, power generation in the country should shift to renewable energy resources.

Solar energy is one of the main sources which can be used to mitigate the power crises in the country. Pakistan is blessed with a tremendous amount of solar energy potential which needs to be harnessed. Solar energy is clean and does not pollute the atmosphere upon usage. Pakistan has got multiple regions with sufficient solar intensity for power generation through solar thermal power plants. Furthermore, the country has a large area available for the installation of these plants. These will not only produce power, but will also help in controlling greenhouses gases emissions. At the moment, the cost of solar thermal power plants is higher compared to conventional power plants. However, solar thermal power plants can provide affordable electricity, if the government provides sufficient subsidies similar to those provided to conventional power plants.

Most of the people living in remote areas of the country are poor. Solar thermal appliances can prove to be most beneficial to these groups of people. Solar cooking will help these people, not only economically, but also by ridding them of the need to collect fuels like wood, which will improve the standard of living in these rural communities. The solar pump can be a vital technology for remote areas which are not connected to the electrical grid and lack water. This technology will provide ease of access to water, leading to social improvement. Solar drying is also a useful technique which can help people in remote areas in the preservation fruits and vegetables, which in turn can act as great source of income for these communities. Besides that, agricultural products will not be wasted due to rotting, which will help in reducing the scarcity of food in the country. The advantages of this technology can be availed only if the residents of the country are properly trained and familiarized with them. Solar thermal technologies can be amongst the best options for the country in the near future, if proper attention is given.

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