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Renewable Energy Technology Manufacturing Status in Pakistan and Future Road Map

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Chapter 1 INTRODUCTION

Pakistan being the sixth most populous country in the world with a population of more than 200 million people requires an efficient supply and management of energy resources to cater for its continuously increasing power demands. About two-thirds of the country's power demands are still being met by thermal sources like furnace oil and natural gas [1]. Pakistan's heavy dependence on fossil fuels to meet its power requirements occurred from political instability among a lot of factors. Till the 1980s more than 50% of the country's power requirements were being met by hydro energy [2]. Lack of political stability and foresight and focus on cosmetic measures led to a huge imbalance between energy supply and demand of the country. To make up for the rocketing energy demand, we started relying heavily on imported petroleum products. Apart from being unsustainable and harmful to the environment, the import of furnace oil, natural gas, and other petroleum products is crushing our economy. During the financial year 2015-16, almost 17.2% of total import bills were spent on petroleum products [3]. The power supply and demand gap have been intensified over the past two decades, creating a turmoil in society by impeding the economic and social growth. The gross domestic product or GDP; which is often considered as a measure of a country's economic well-being; shows a direct relationship between the consumption of electricity. To ensure a positive GDP growth, Pakistan must look upon affordable and sustainable energy resources for its ever-growing power demands.

World Energy Scenario

Globally, there is a lot of ongoing campaign and awareness movements to abolish fossil fuels. One of the major threats that fossil fuels pose is Greenhouse gas (GHG) emissions. Carbon dioxide, the most abundant GHG emission, is acting as a major source of global warming. The CO_2 emissions level reached an all-time high in 1950 at 300 parts per million and is still increasing [4]. Although the industrial revolution brought a lot of social and economic growth in the world, it escalated a never-ending phenomenon of increasing earth temperature levels and global warming through the burning of fossil fuels.

In 2015, parties under the banner of United Nations Framework Convention on Climate Change (UNFCCC) reached a historic agreement; also known as *The Paris Agreement*; to tackle global warming and boost the coordination needed for a sustainable future. To this date, 179 countries have ratified this agreement, to play their role in bringing earth's temperature down by 2 degrees Celsius. This agreement played a vital role to unite all nations for a common cause by enhancing financial and technical support to explore renewable energy resources that are not only clean but also sustainable. Because of this agreement, nations all over the world adopted the UNs "*2030 Agenda for Sustainable Development*", which ensures "Affordable and Clean Energy" for all, according to Sustainable Development Goal No. 07 [5]. Analysts predict that by 2040, the total share of renewables in electricity generation will reach 40% due to the rapid deployment of solar photovoltaic technology in China and India [6]. Encouraging policies regarding renewable energy sources in Europe will lead to about 80% share in total electricity generating capacity by 2030. Most of the renewable energy in Europe comes from wind energy, both onshore and offshore and this is magnified by thousands of households and businesses investing directly in solar photovoltaic panels. There is a bright future for renewables as they will capture more than two-thirds of the total investment in energy in the world by 2040 [6] (Figure 1).

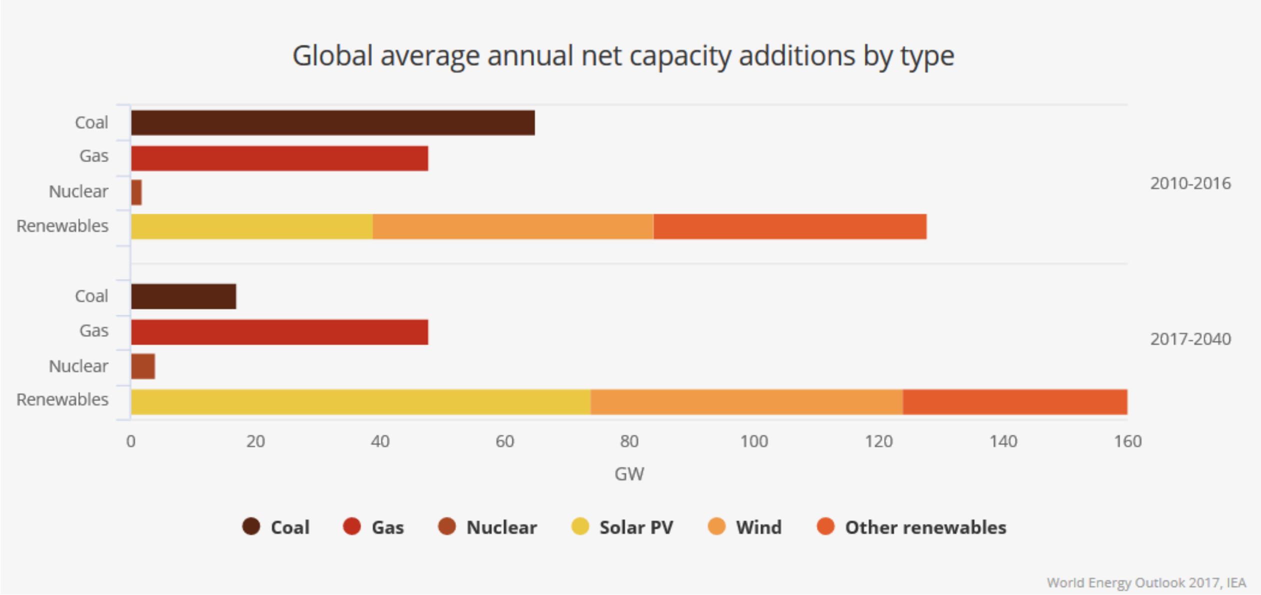

Figure 1-1 ***Global Average Annual Net Capacity Additions by Type***

Pakistan Energy Scenario

Since the mid-1980s, Pakistan has heavily relied on furnace oil and natural gas for electricity generation. Although oil and gas are explored and produced domestically in Pakistan as well, the local produce isn't enough to match the energy demand of a growing economy. The trend of Pakistan's dependence on different primary energy sources for electricity production from 1970 to 2015 is shown in Figure 2 [2].

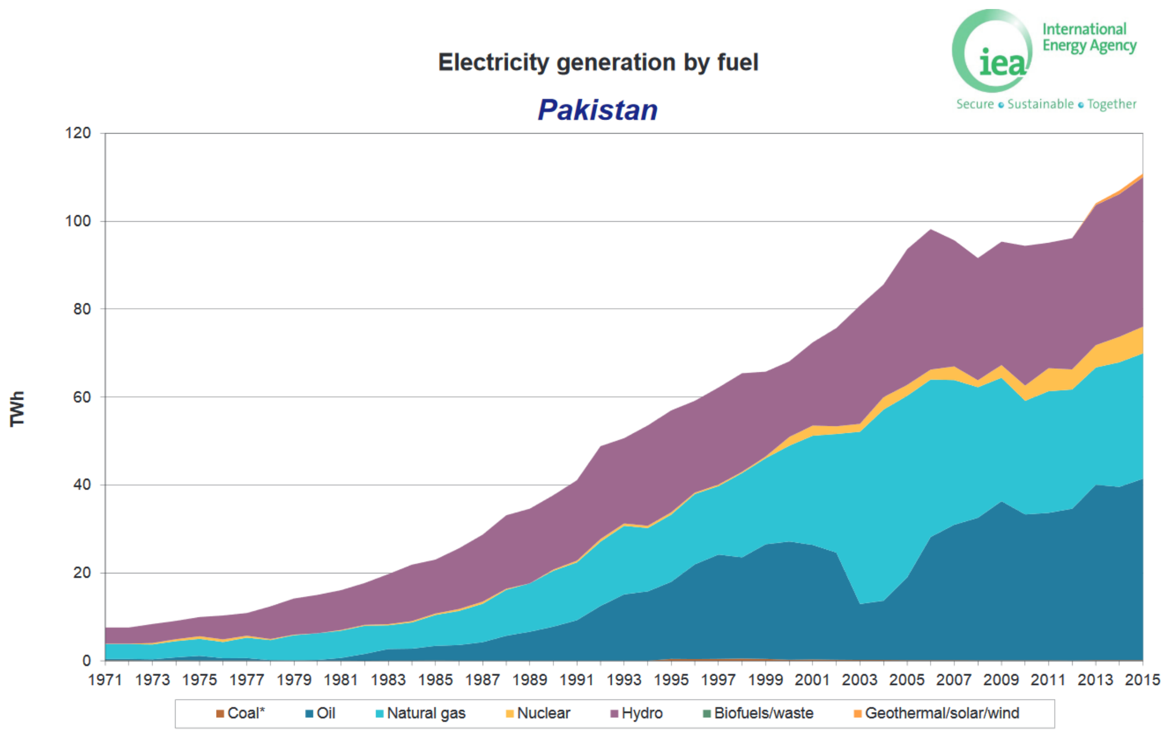

Figure 1-2 ***Electricity generation by fuel in Pakistan (1971-2015)***

As observed in Figure 2, major players in Pakistan electricity production scene have always been oil, natural gas, and hydro energy. Price of petroleum products is highly unstable and depends on a lot of geopolitical factors. During the global economic crisis of 2009, oil prices suddenly went up to an all-time high of US $140/barrel in the international market. The effect of this inflation was directly transferred to the consumer in the shape of power outages and high tariffs, thus disrupting the economic growth. As a result, Pakistan's GDP growth rate faced the lowest value of 0.4% in 2009 during the 21st century. Frequent load shedding and high tariffs of electricity caused local and international investors to shy away from industrial and infrastructure projects. Pakistan power generation capacity deficit went beyond 6000MW in the financial year 2011-2012 [7].

Renewable Energy Policy Development in Pakistan

In 1994, the Govt. of Pakistan put forward investment-oriented policy framework and package incentives to establish private power plants to meet the country's power demands. The policy gained positive response for thermal power plants. The government decided to extend this policy for hydropower resources in Pakistan through ***Hydel Power Policy 1995***. The policy included various incentives such as exemption from income tax, sales tax and stamp tax to attract private investors. The government also established the Privat Sector Energy Development Fund (PSEDF) with the assistance of World Bank to provide up to 30% of the funding at variable interest rates. The policy covered all the feasible hydropower plants having capacities up to 300MW.

Policy for Power Generation Projects 2002 focused on the exploitation of indigenous resources including renewable energy resources, human resources, and local manufacturing capacities. Many financial incentives were offered to the investors in this policy including concessionary rates for imported plant and machinery, exemptions from income tax (only for hydropower), turnover rate tax and withholding tax on imports.

Policy for Development of Renewable Energy for Power Generation 2006 was the first policy having a sole focus on the development of various renewable energy sources; small hydro, solar PV, solar thermal and wind; for power generation in Pakistan. The main goals of this policy are:

1. Increase share of renewable energy technology in power generation to at least 9,700 MW by 2030 according to Medium-term Development Framework (MTDF)
2. Attract private sector investment in the renewable energy sector with the help of financial incentives
3. Promote the productive use of renewable energy through the provision of social infrastructure in underdeveloped areas e.g. educational and medical facilities, sanitation, clean water supply, roads, and telecommunication.
4. Assist in institutional, technical and operational capacity building in the renewable energy sector
5. Promote the establishment of indigenous Renewable Energy Technologies (RET) manufacturing base to lower costs, improve service, create employment and enhance local technical skills.

Financing Power Plants using Renewable Energy was a financing scheme announced by State Bank of Pakistan in 2009 and in its revised form in 2016. According to this scheme, financing facilities will be provided through all commercial banks and Development Finance Institutions (DFI) to all prospective investors willing to establish renewable energy-based power plants with a capacity ranging from 1 MW to 50 MW. The scheme also included domestic consumers who need financing for renewable energy electricity generation ranging from 4 kW to 1 MW.

National Power Policy 2013 [8] was based on the principles of efficiency, competition and sustainability served as a founding stone to eradicate the imbalance of power supply and demand in the country. According to the medium-term goals in this power policy, the government focused on bringing less expensive fuels like coal, solar and hydro energy in Pakistan's energy mix. As a result, during the last five years, the share of renewable energy (excluding hydro energy) in Pakistan's energy mix went from mere nothing to about 2%. (Figure 3). Over the last five years, 1462MW of renewable energy capacity is added to the national grid with the coordination of Alternate Energy Development Board (AEDB) and investment of about US $ 2868 Million [1].

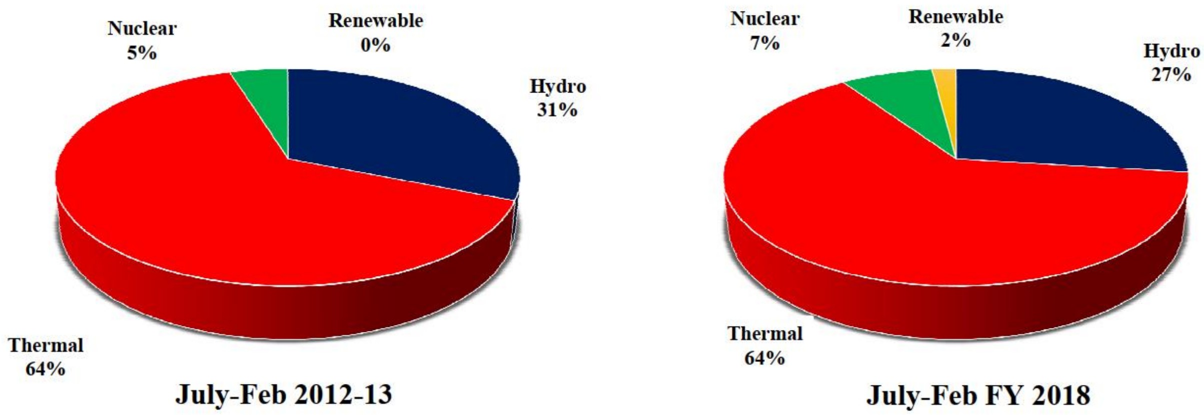

Figure 1-3 ***Comparison of energy sources for electricity generation between FY 2013 and FY 2018***

Many renewable energy projects have been established throughout Pakistan to gain sustainability and mitigate the hazardous effects of fossil fuels. During the last five years, 18 wind projects supplying a total power generation capacity of about 937 MW to the national grid have been established [1]. Most of these wind power projects are constructed in District Thatta of Sindh Province of Pakistan by coordination and support of AEDB. Six solar energy projects having a total capacity of 418 MW are also established throughout Pakistan. Most prominent of which is Quaid e Azam Solar Park in Bahawalpur, which is currently operating at a level of 100MW and will be expanded up to 1000MW in near future. The major hydro energy setup during the last 5 years is established in AJK, as Neelum Jhelum Hydro Power Project, which has a maximum capacity of 969MW. Many other small hydroelectric projects have also been constructed in Northern Areas of Pakistan with the assistance of Pakistan Council of Renewable Energy Technologies (PCRET), Pakhtunkhwa Energy Development Organization (PEDO) and AEDB. Most of these projects are off grid and have power generation range from 10kW to 2MW. These projects are fulfilling the power demands of communities and villages that cannot be electrified through the national grid.

The Scope of this Report

According to a survey conducted by the World Bank, 66.7% of the businesses in Pakistan identify the shortage of electricity as the major business obstacle ahead of corruption and crime/ terrorism which are 11.7% and 5.5%, respectively [9]. It is now imperative that Pakistan strengthen the technical and human resources required to explore further renewable energy sites for self-sufficiency in its energy requirements. The purpose of this report is to highlight the potential of manufacturing facilities available for Renewable Energy Technologies (RET) in Pakistan. Pakistan still depends on foreign technical and financial support for its energy projects instead of establishing local industries for this purpose. An example of this is China Pakistan Economic Corridor, under which China is investing US $35 Billion in the energy sector in Pakistan

(Economic survey of Pakistan FY18). This investment involves the establishment of power plants in different areas of Pakistan and improvement of National Transmission and Distribution Network. Our local manufacturing industry gets no or very minimum role in any of these energy projects. The following report discusses the RET products being manufactured in Pakistan, skilled workforce, availability of raw materials, social and economic issues related to RET, research and development, and protection of intellectual property in case of RET in Pakistan. The report has covered four main streams in RET that are: Solar (Photovoltaic and Thermal), Hydro, Biogas, and Wind.

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Chapter 2 SOLAR ENERGY

Solar energy is the fastest growing renewable energy source in the world, with an average annual growth rate of 49.7% during the period from 2006 to 2016 [1]. Due to rapid enhancements in technology and infrastructure, solar energy accounted for about 18% of total renewable energy capacity globally in 2017 [2]. There has been an exponential increase in the solar energy capacity of the world in the last decade, as seen in Figure 1, with solar energy capacity reaching 391 GW globally.

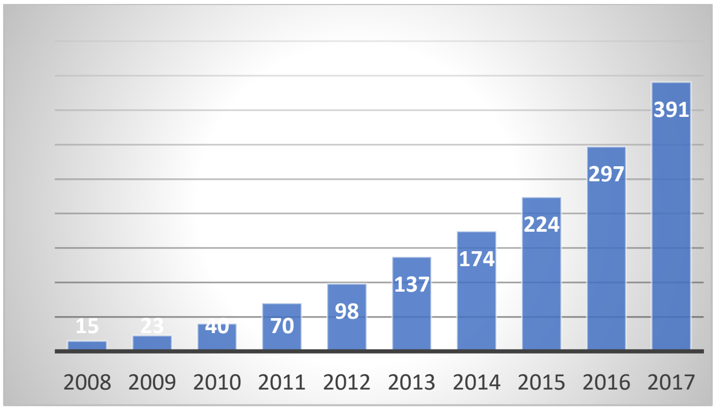

Figure 2-1 ***World Solar Capacity in GW***

Solar energy can be extracted in two ways mainly: Solar Photovoltaic (PV) and Solar Thermal Power Plants. Currently, solar PV holds about 98% of the total solar energy capacity in the world. In this chapter, we will discuss the manufacturing trends of both technologies in the world and Pakistan.

Solar Photovoltaics (PV)

Solar PV technology uses a semiconductor material; mostly silicon (Si); to generate electricity from sunlight. Solar PV accounted for about 1.7 % of the total electricity generated in the world in 2017 [1]. China is currently the leading solar PV producer and is responsible for about 70% of the total solar PV manufacturing globally [3].

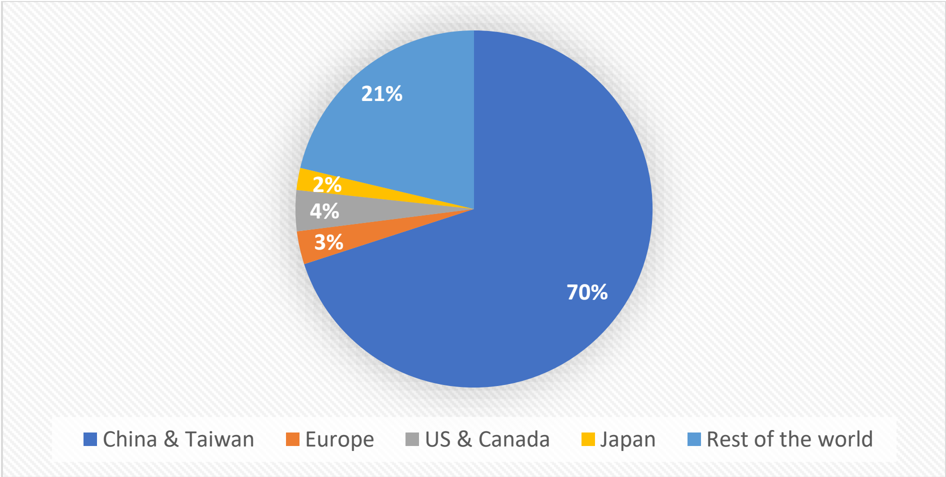

Figure 2-2 ***Total Solar PV production in 2017 = 94 GW***

The demand side picture is not different either; with China representing about half of the total solar PV demand in the world with a total installed capacity of 130 GW. Due to the high involvement of China in solar PV, any change in policy, and tariffs will have worldwide implications. International Energy Agency predicts that by 2022, total solar capacity in the world would reach 740MW; almost the double of what we have today. Figure 2 describes the share of different countries involved in solar PV production in 2017 [4].

Solar PV Technologies

Different materials have been used since the inception of solar PV to suit the needs of a wide range of consumer demands like efficiency, bandgap, cost and lifetime. Currently, the most used material for PV applications is crystalline Si and it holds about 95% of the total PV production in the world. In literature, solar PV materials are divided into three generations: first, second and third. The brief detail of each generation is given in Table 1.

Table 2-1 ***Three Generations of Solar PV Cells***

	First Generation (Crystalline Si)	**Second Generation (Thin Films)**	**Third Generation (Multi-Junction)**
Products	• Mono Crystalline Si • Poly Crystalline Si	• Amorphous Si • Copper Indium Gallium Di-selenide (CIS/CIGS) • Cadmium Telluride Cells (CdTe)	• Perovskites • GaAsP, GaInP • CIGS based materials
Efficiency	12% - 28%	10% -23%	22% - 46%
Commercial Status	Large-scale production (95% Market Share)	Small-scale production (5% Market Share)	In Research Phase
Advantages	• High Efficiency • Most mature technology	• Less expensive • Higher light absorptivity rate • High bandgap	• Highest efficiency • Absorbs a wide range of wavelengths
Disadvantages	• Low bandgap • Low absorptivity coefficient • Efficiency reduces with increasing temperature	• Lowest efficiency	• Technology is not mature • No commercial production

The record research cell efficiency of a concentrator monocrystalline Si cell has reached 27.6% in the lab, whereas polycrystalline Si cell efficiency has reached 22.3% in the lab [5]. The commercial efficiencies are much less than these due to losses and other uncontrollable factors.

Currently, first-generation PV i.e. mono and polycrystalline Si cells, dominate the PV production in the world [4].

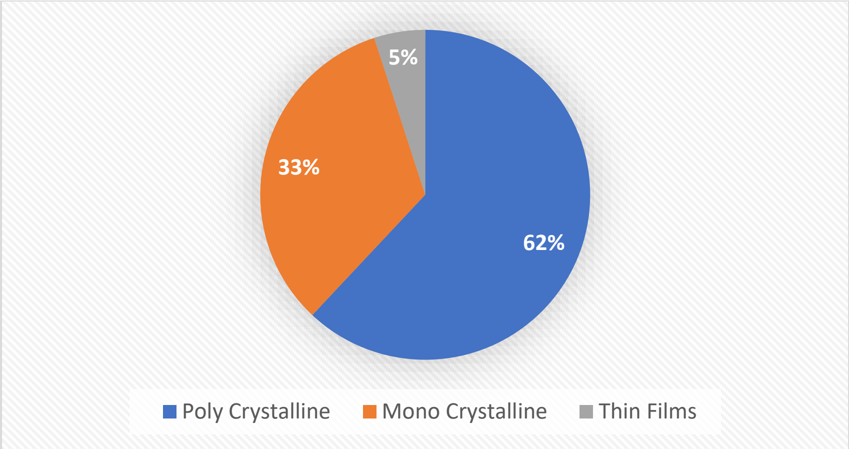

Figure 2-3 ***PV Production Share of different Technologies in 2017***

Crystalline Si PV cell Production Tiers

Globally, solar PV manufacturers can be divided into three tiers based on their experience in the field, the amount invested in research and development, manufacturing technologies and efficiencies exhibited by their products [6].

Table 2-2 ***Three Tiers of Solar PV Companies***

Tier 1	Tier 2	Tier 3
• Vertically Integrated • Fully automated production • Every process from cell manufacturing to lamination is done by the same company • Leaders in innovation	• Medium size manufacturers with 2-5 years of experience • Manufacture solar cells through well-established techniques • Less investment in R&D • Partially automated production	• Assemble PV modules only • No automated production • No R&D • Contributes to about 90% of PV market share

Solar PV Industry in Pakistan

Despite having tremendous potential for solar energy, Pakistan has installed cumulative solar capacity of about 730 MW only [2]. The country's southern regions boast Global Horizontal Irradiance (GHI) levels of about 1400-2400 kWh/m^2/year; highest among all South Asian countries [7]. After the implementation of *Renewable Energy Policy 2006* and *National Power Policy 2013*, government focus shifted towards less expensive renewable energy sources including solar energy. The start of China Pakistan Economic Corridor (CPEC) proved to be a game-changing moment for the energy sector in Pakistan, as around the US $35 billion investment was reserved for energy projects. The major project in this regard was the establishment of the grid-connected Quaid-e-Azam Solar Park (QASP) in Bahawalpur. The provincial government of Punjab has allocated 6500 acres of land for the solar park in Bahawalpur for a total 1000 MW capacity. The park became operational in 2014 with a pilot project of 100MW capacity by a Chinese company. Other than this, many other grid-connected projects are also launched in last five years in South Punjab and Baluchistan to harness solar energy.

In recent years, the demand for solar PV is rising rapidly in Pakistan, especially in those areas which are very far away from the national grid and there is no other source to obtain electricity. Baluchistan province of Pakistan possess the highest irradiance levels and is the most suitable place to set up solar power plants. A very important milestone achieved in this regard was the implementation of *NEPRA Distributed Generation and Net Metering Regulations 2015*, according to which "any customer of the national grid having three phase connection can avail net-metering facility for small-scale (1kW to 1MW) renewable energy installations". The idea to sell electricity back to the national grid and save utility costs served as a kickstart for many solar PV projects installed in the domestic, industrial and commercial sector. Figure 4 shows Pakistan's solar energy capacity rise in the last decade.

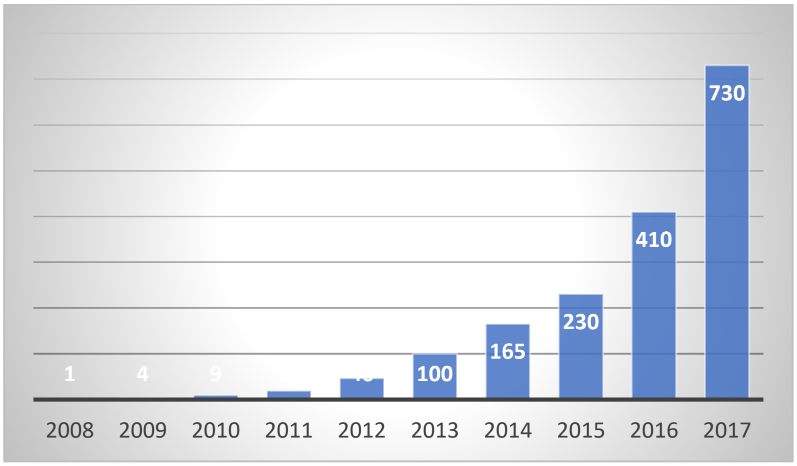

Figure 2-4 ***Pakistan Solar PV Installed Capacity in MW***

On the other hand, the supply side picture of the PV industry in Pakistan is quite dismal. Despite the increasing demand for solar PV, currently, there is not a single company producing crystalline Si solar cells on a commercial basis in Pakistan. Most of the solar PV industry in Pakistan only offer installation of imported PV panels according to client's requirements. We can classify the organizations or companies currently associated with Solar PV development into two fields: Public and Private Sector.

Public Sector Development in PV

Alternate Energy Development Board (AEDB)

AEDB was established in 2003 by Government of Pakistan to accelerate the promotion of RET through policymaking, renewable energy projects in coordination with the private sector and transferring the necessary technology for developing indigenous manufacturing facilities for RET. Not directly linked with solar PV manufacturing industry but AEDB is responsible for policy framing and implementation, promoting indigenous RET industry, technology transfer and coordinating with international organizations for assistance and support in RET.

Pakistan Council of Renewable Energy Technologies (PCRET)

In 2001, PCRET was established to support and finance research and development activities related to renewable energy in Pakistan. According to the classification of solar PV manufacturers into three different tiers, PCRET fall into Tier 2 category due to its cell manufacturing facility and investment on R&D activities. PCRET started a pilot project to locally manufacture monocrystalline Si cells in Pakistan. For this purpose, six labs were established:

- Crystal Growth Lab
- Wafer Lab
- Cell Process Lab
- Test and Measurement Lab
- Lamination Lab
- Solar Testing Lab
- Analysis Lab

Crystal growth lab contains a digital and an analog Czochralski Crystal Puller that produces monocrystalline Si ingots, from which Si wafers are obtained. A complete step guide of the process of obtaining monocrystalline Si cells from Si wafers is shown in Figure 5.

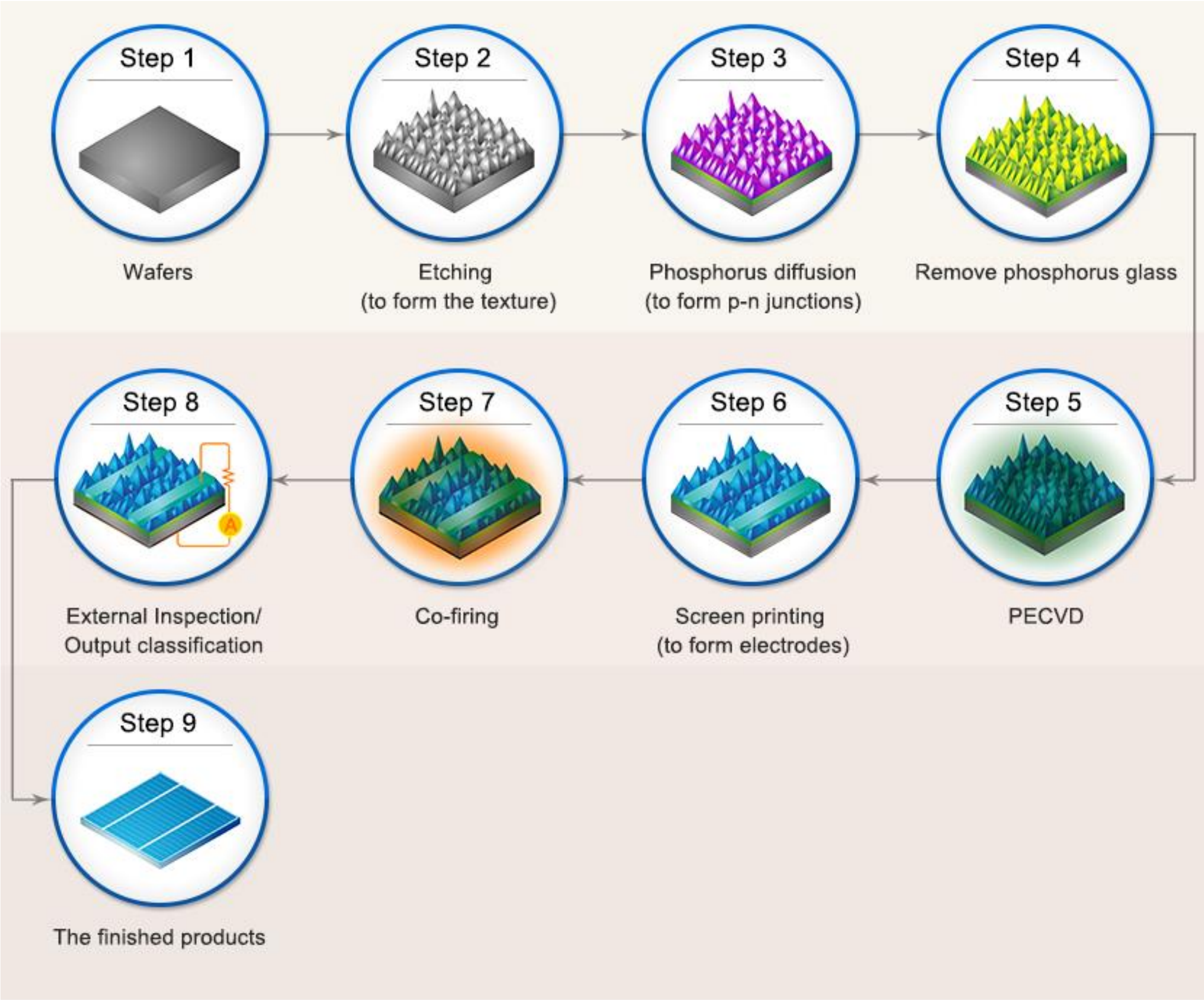

Figure 2-5 ***Solar Cell manufacturing from Si Wafers***

After testing the performance of manufactured solar cells, assembling of cells into PV module takes place in Lamination Lab. Three different lamination materials are used in this lab to produce PV panels of various specifications. For low power applications, Nd-YAG laser cutting facility is available to cut solar cells into smaller pieces. A complete step guide of assembling solar cells into modules is shown in Figure 6.

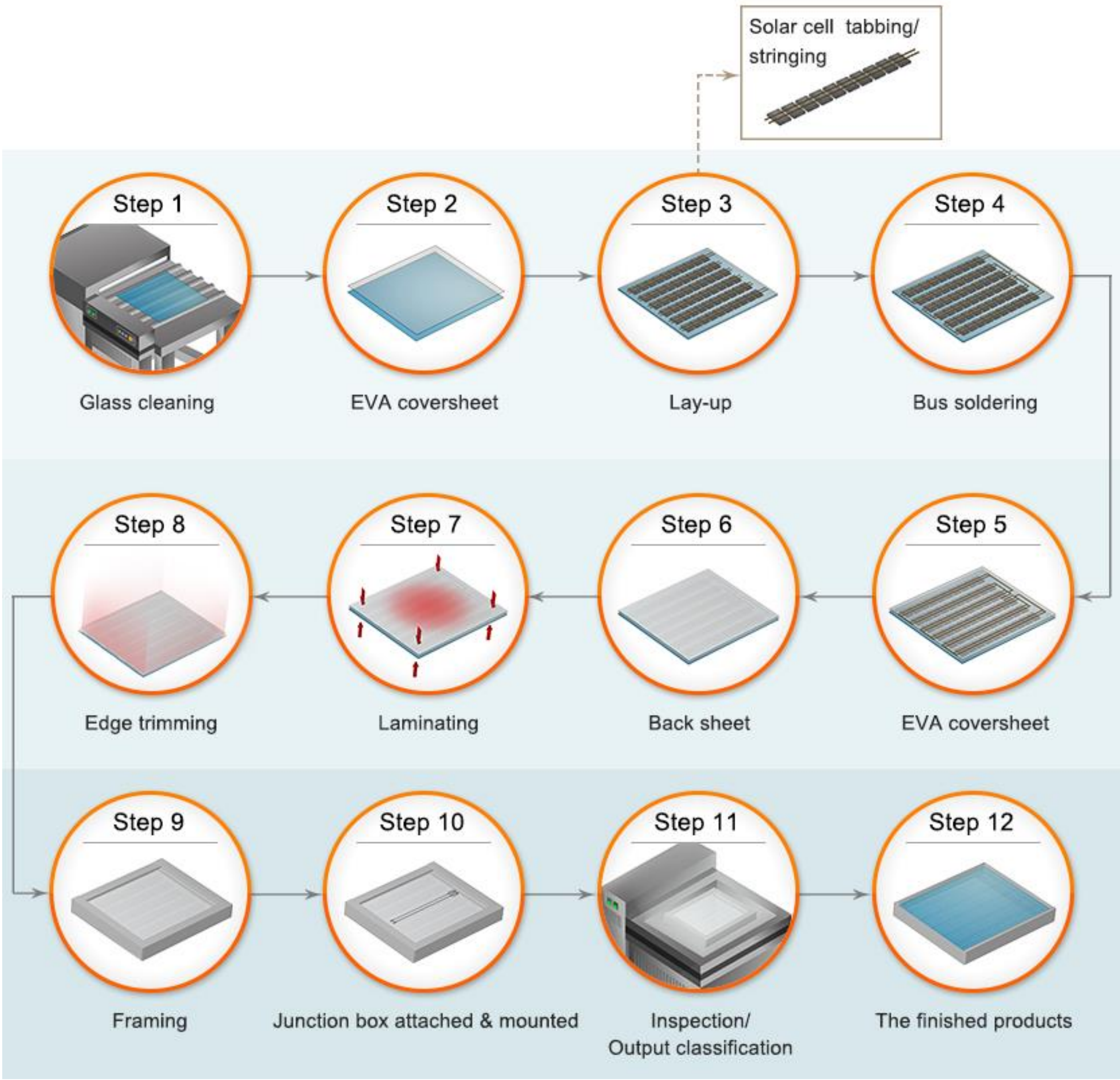

Figure 2-6 ***Solar Panel manufacturing from Solar Cells***

PCRET also ensured extensive testing to find material or production flaws in PV products. For this purpose, a Testing and Measurement lab was established. Following tests are being conducted in this lab:

- Solar Cell Testing
- Photovoltaic PV Panel Indoor Testing
- Photovoltaic PV Array Outdoor / Field Testing
- PV Panel Environmental Testing
- PV Panel Insulation Testing
- Solar Cell Contact Adhesion Testing
- Inverter Testing
- Battery Testing

Apart from these tests, the spectroscopic analysis of semiconductor materials to find any impurities is done in Analysis Lab. PCRET also perform following tests for private companies at a specified cost:

a. IV Curve PKR 15000/- per test
b. X-Ray test PKR 10000/- per test
c. Insulation test PKR 10000/- per test

Currently, the cell manufacturing plant of PCRET is not working due to human resource and financial constraints. Mono and polycrystalline cells are being imported through vendors and then assembled into PV modules in lamination lab according to client's demand.

Other than manufacturing PV products, PCRET also provides services like designing, sizing, and installation of a PV system. Training courses are also provided to solar industry aspirants and entrepreneurs related to solar PV cells manufacturing and lamination process. Private industry can also participate in the training provided by PCRET to increase their capacity building.

Private Sector Development in PV

Unlike PCRET; the leading public sector organization for RET research and production; most of the private sector solar PV companies in Pakistan are Tier 3 companies i.e. they only assemble solar panels from imported cells and don't invest in any research or development. 231 solar PV companies are registered by Pakistan Engineering Council (PEC) of which only 58 companies are involved in manufacturing PV products [8]. Rest of the companies offer services like designing, installation of imported panels, consultancy, operation and maintenance, and education and training.

Solar PV companies in Pakistan manufacture PV modules by importing solar cells from different countries. China is the leading exporter of solar cells and panels to Pakistan. According to a news report published in 2014 [9], two leading solar PV manufacturers in Pakistan; Akhter Solar and Tesla PV; meet about 5% of the total PV panels demand in Pakistan, while rest is being met by imported panels. The trend mentioned here is still the same even after four years: about 90% of PV panels installed in the country are imported from other countries; mainly from China.

Most of the companies involved in solar PV panel manufacturing in Pakistan have complete equipment available for cells segregation, soldering, assembly, connection, EL testing, lamination, framing and Flash testing of PV Modules. Figure 6 shows the detailed process of assembling solar cells to make a solar PV panel. The private sector companies usually try to save operational costs by employing low or unskilled personnel for soldering and lamination process, which negatively affects their products performance.

Recommendations to Increase Indigenous Production of Solar PV

Public-Private Partnership:

Public organizations like universities and technical institutes can play a leading role in bolstering the solar PV industry by incorporating special educational courses on PV panels production where students can learn using high-tech equipment to produce solar cells, cell assembly, and panel design. Such a step would not only provide trained experts for the solar PV industry in Pakistan but will also enhance entrepreneurship opportunities in Pakistan.

Industry-Academia linkage: Research groups for a common goal:

Although crystalline Si solar cells are currently dominating the PV cells production in the world; 95% of total PV cells produced in 2017 were crystalline Si cells, but their efficiency curve has reached the maximum point and there is very little room of improvement left there. Other PV technologies like Thin films and Multi-junction cells have shown a lot of prospect because of their low cost and high efficiency respectively. In this regard, the PV industry in Pakistan should collaborate with science and technology universities to explore various research areas to increase the efficiency-cost ratio of solar PV cells.

Policy framing:

Policymaking institutes like AEDB, Ministry of Finance, and NEPRA should collaborate with all the stakeholders when framing policies related to taxes, tariffs and distribution systems of solar PV. The government should encourage local industry to play their role in policy formulation of alternate energy resources.

Tax exemptions:

A tax-friendly environment can assist small industry owners and entrepreneurs to land their feet in solar PV industry. Tax concessions on utilities, raw materials, and equipment needed for solar cells production can pave a very bright path for the development of solar energy industry in Pakistan.

Startup financing:

Solar energy has the highest growth rate in the past decade because of applied research all over the world to improve the efficiency-cost ratio of solar panels. Startup incubators like *Plan9* and *NUST Technology Incubation Centre* should invest in solar energy startups to promote clean energy and sustainability in Pakistan.

Technology transfer:

The biggest rival of solar PV manufacturer industry in Pakistan is the influx of imported solar PV panels in the country. The local industry cannot match the cost and quality of imported panels because of the absence of high-tech equipment and skilled staff. Lack of automation does not only affect the manufacturing rate, but it also deteriorates the quality of manufactured panels. Defects like scratches on glass, excessive glue mark, poor sealing, soldering defects are common in locally manufactured PV panels. To match the efficiency and performance of internationally manufactured PV panels it is essential to transfer the required technology and skills in Pakistan.

Solar Thermal Energy

Solar thermal energy generation captures direct sunlight; Direct Normal Irradiance (DNI); to heat up a fluid (air or water) for domestic or industrial use or generate electricity from it through a steam turbine. Although the share of solar thermal energy in the world is far less as compared to solar PV, the benefits of this technology like less complicated systems and ability to store energy for nighttime cannot be denied. Solar thermal power systems are best suitable for regions which gets DNI of at least 2000 kWh/m^2/ year. Solar thermal systems can be further divided into two categories: Non-concentrating and concentrating collectors. The non-concentrator systems contain the same collector area as the absorber area; examples include flat plate collectors and evacuated glass tube collectors; while in the concentrator solar systems, the area collecting the solar radiation (collector area) is many times greater than absorber area; examples are a solar dish, parabolic trough collector.

Solar Thermal Industry in Pakistan

After the implementation of *Renewable Energy Policy (2006)*, practical measures have been taken to harness the profusely present solar energy in Pakistan. Both public and private sector industry is contributing in the field of research and development for solar thermal energy. PCRET being the leading public sector organization for R&D on solar thermal has spearheaded many projects for solar water heating, solar desalination plants, and solar dryer in different areas of Pakistan, where natural gas supply is not available. Although solar thermal technology is mature and tested throughout the world, its applications in Pakistan are quite limited due to low natural gas prices and the inability to penetrate the local market. Some common applications of solar thermal energy are given in Table 3 [10].

Table 2-3 ***Solar Thermal Energy Applications***

Applications		Temperatures ºC
Low-temperature Applications	Domestic Solar Air Heating	20-24
	Domestic Solar Water Heating	30-50
Medium Temperature Applications	Solar Drying	50-70
	Solar Desalination	65-75
	Food Pasteurization	70-80
	Solar Cooking	82-150
	Industrial Solar Water Heating	50-80
High-Temperature Applications	Process Steam Generation	150-250
	Solar Power Generation	300-650

Non-Concentrating Solar Devices

Most of the low and medium temperature applications of solar thermal energy utilize non-concentrating collectors; the collector area is same as the absorber area.

Solar Water Heaters:

Mainly there are two types of solar water heater that are being used most commonly in Pakistan: Flat plate solar thermal collector and Evacuated tube solar thermal collectors. A Flat plate solar collector consists of copper tubes in which usually water is heated for domestic applications. As far as production is concerned flat plate collectors are manufactured locally. The quality of these collectors is yet to be ascertained.

On the other hand, evacuated tube solar thermal collectors are made of glass (Borosilicate) tubes that are imported mainly from China because of their low cost. The process of manufacturing these glass tubes is capital-intensive as well as requires skillful labor. Although there has been an effort to manufacture these tubes locally, a single glass tube fabricated locally will cost about PKR 2000 to 2500. While the same tube if imported from China will cost PKR 500 per tube and from Germany, its import will cost PKR 1000 per tube approximately. The other components of an evacuated tube solar thermal collector like storage tank and supporting stand are locally manufactured. The tank is usually made up of stainless steel, aluminum or copper. Tubes are usually coated through a process called magnetron sputtering. Different diameter tubes (58mm and 72mm) with lengths (1.5m and 2.5m) are imported. Usually, 15 tubes are assembled in one collector with a heating capacity of about 15 liters of water/day. A testing facility is present in PCRET for measuring the efficiency of both flat plate and evacuated tube solar thermal collectors.

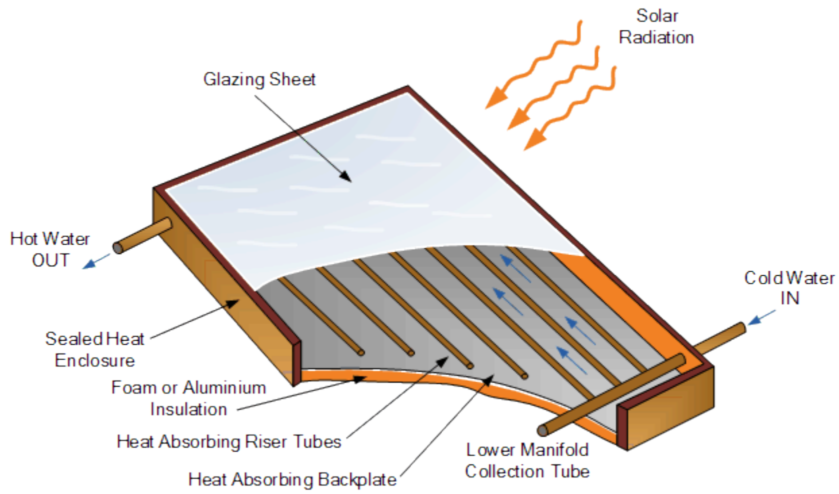

Figure 2-7 ***Design of a Flat Plate Solar Thermal Collector [11]***

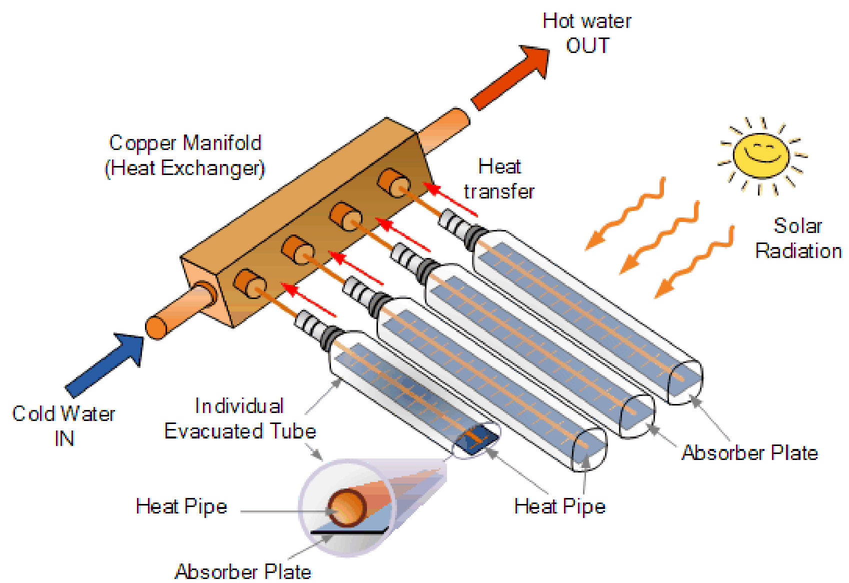

Figure 2-8 ***Design of an Evacuated Tube Collector [12]***

Solar Dryers:

Agriculture serves as the backbone of Pakistan's economy, thus in a country where a lot of remote regions still suffer from the unavailability of natural gas and electricity, solar drying is the best available option to preserve different fruits and vegetables for longer periods. Though natural sun drying of fruits is very common in northern areas of Pakistan, high-quality products cannot be obtained through open atmosphere drying due to the intervention of dust, contaminants and other unwanted particles. A high quality and even drying can be obtained through solar dryers. A typical solar dryer is a flat box covered with glass or plastic on top to trap sun radiations and have a black painted metal sheet on the back side to absorb the sunrays. Atmospheric cool air enters from one side, reaches a temperature of 40-50 ^{o}C, then rises into a drying chamber. The dryer's angle is usually kept at 35^{o}-45^{o} with respect to the horizontal surface in Pakistan. A chimney can be added to improve air circulation. Solar dryers do not involve any high-tech manufacturing process and can be easily manufactured throughout Pakistan.

Figure 2-9 ***Solar Natural Dryer (Glazed Collector) 10-kilogram loading capacity PCRET***

Solar Desalination:

Due to a shortage of fresh water, solar desalination plants have been established by different public and private sector organizations in Pakistan. Solar still, one of the simplest technologies to obtain fresh water can be easily manufactured for domestic purposes. It utilizes the sun's radiations to form water vapors which then sticks to the glass ceiling and the condensate then flows into a collecting channel. (Figure 10) [4]. Although the setup employed in a solar still is less expensive and readily available, it is very inefficient and only produces 2-4 liters/m^2/day of desalinated water. To achieve high productivity and gain efficiency, hybrid RO plants have been established by Govt. of Sindh in Mithi and Misri Shah. These plants utilize solar energy along with other conventional energy sources to produce about 2 million gallons of water a day [13].

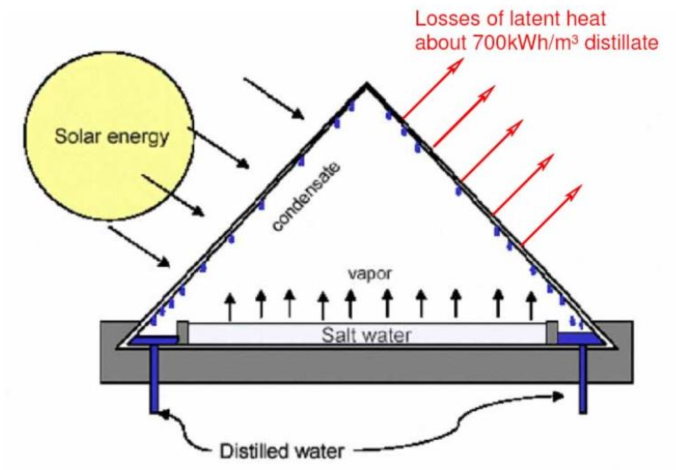

Figure 2-10 ***A Simple Solar Still***

Concentrating Solar Devices

High temperature solar thermal applications involve a group of mirrors or lenses collecting sunlight and then reflecting it on a single absorber. Temperatures higher than 250^{o}C can be achieved through such systems. Most common concentrated solar power (CSP) devices include Solar Power Tower, Parabolic Trough collectors, Fresnel Reflectors and Stirling Dish. Although research work has been carried out at PCRET on parabolic trough collectors, none of the four CSP technologies are employed or produced commercially anywhere in Pakistan. Some private firms like ZED Solar and AE Design are establishing concentrated solar Stirling engine dishes for various purposes like power generation, desalination plants, process steam, and enhanced oil recovery, but this technology is still amateur in Pakistan and most of the equipment is imported from Germany.

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Chapter 3 HYDRO ENERGY

Hydropower holds the largest share of the total renewable energy capacity installed in the world and is rapidly increasing with the installation of new hydel plants all over the world. More than one-fourth of the total capacity is installed in China alone. With the ever-growing energy demands all over the world due to an exponential increase in population and undue stress on fossil fuels, it is the need of the hour to focus on sustainable and clean energy resources. Hydropower is one of the cleanest energy sources available to mankind for centuries. Earlier, human beings harnessed the energy in the water to for various purposes like wheat milling, ore pressing, and papermaking. Electricity generation from hydro energy started in the first half of the 19th century with the development of hydro turbine by French engineer Benoit Fourneyron which had a capacity of generating around 4.5 kW. In the 20th century, the technological advancement and innovation caused massive growth in hydropower with the installation of new hydropower plants, having a capacity of thousands of MW, all over the world. Over the last few decades, China, USA, and Brazil have been leading the world in hydropower installation capacity with almost 43% of the total capacity installed in these three countries only. Figure 1 shows the progress in installed capacity of hydropower over the last decade [1].

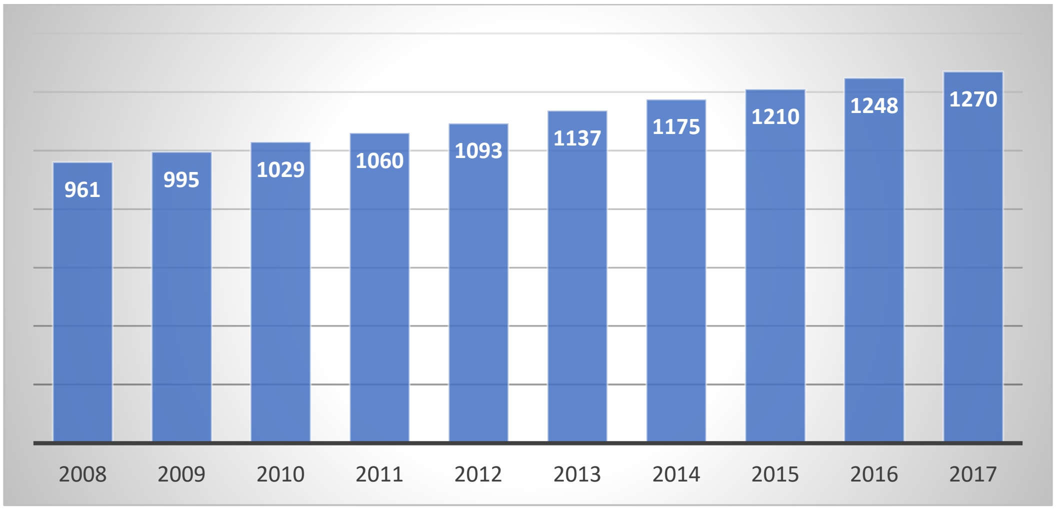

Figure 3-1 ***World Installed Capacity of Hydropower (GW)***

Installation of mega hydro projects in different countries around the world not only produced a source of clean and sustainable energy but also enhanced the energy independence of these countries. One such example is Brazil, which has installed capacity of more than 100 GW of hydropower. Brazil's investment in hydropower reduced its dependence on imported energy sources and caused a very swift economic growth during the last two decades. Brazil is currently satisfying more than 70% of its electricity demand through hydropower which has resulted in an increase in sharp GDP growth and prosperity over the last few decades.

Hydropower in Pakistan

Up till the 1980s, hydropower was the biggest source of electricity generation in Pakistan due to the establishment of mega hydro projects soon after the country gained independence. The most significant progress was observed in the 1960s during the tenure of General Ayub Khan who laid the foundations of three mega hydro projects that are: Tarbela, Mangla and Warsak Dam. The last two decades of the 20th

century saw no progress in hydropower sector of Pakistan due to inconsistent governments and completely ignoring the establishment of new mega hydro projects in Pakistan. As a result, our dependence on imported furnace oil and natural gas for electricity generation increased and now Pakistan is obtaining about 68% of its electricity generation from thermal energy resources [2]. Pakistan has about 60 GW of hydropower potential and much of this potential is in northern areas of Pakistan. The total installed hydropower capacity in Pakistan is around 7129 MW [2]. The four major hydropower plants currently working in Pakistan are:

Hydropower Plant	Capacity (MW)
Tarbela	3478
Ghazi Barotha	1450
Mangla	1000
Neelum Jhelum	969

Classification of Hydropower Projects

Hydropower projects all over the world can be classified into two main types: Reservoir and Run of river projects. Following is the brief detail of each of these.

Reservoir Hydropower Projects involve a great amount of civil work in the form of dam construction to make a reservoir. The dam controls the amount of water that can be flowed downstream and provides the necessary head for power generation. The reservoir hydropower projects are multifunctional and in addition to generating electricity through turbines, these dams also serve as a water reservoir for water supply, agricultural purposes, flood control, fishing, and recreation. Tarbela and Mangla Dam are two notable reservoir type dam projects in Pakistan. Figure 2 shows a simple illustration of the reservoir type hydropower plant [3].

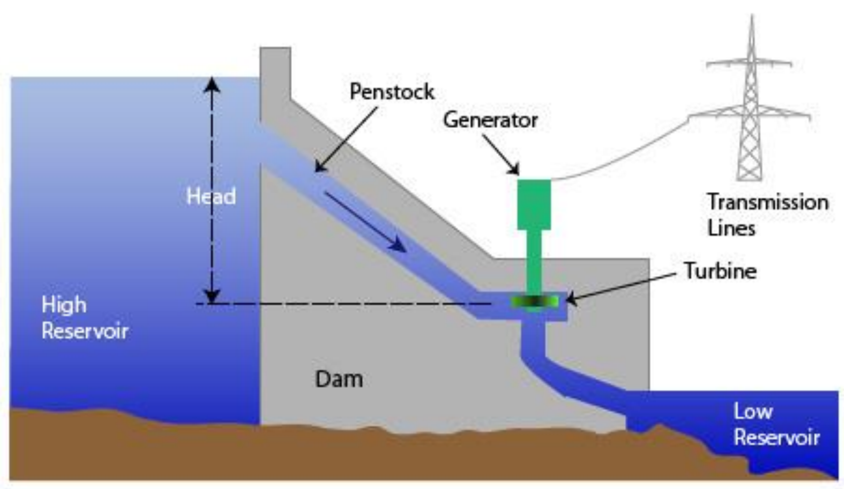

*Figure 3-2: **A Reservoir Hydropower Project***

Although there are many benefits associated to reservoir type hydropower for its multi-functionality; the reservations related to such projects cannot be ignored. Environmental concerns are often raised due to harmful effects of damming rivers on ecological system. The dam blocks the fish and other aquatic animals' migration downstream thus causing the extinction of many species. Due to the sediment entrapment by the dam, the life in and around the downstream river changes drastically including erosion of riverbanks, riverbed deepening and lowering of groundwater tables. Low downstream flows cause harmful effects on the environment in shape of decreased water flow for irrigation purposes and extinction of many varieties of fishes. Such example can be seen in Pakistan as the construction of dams on Indus river has deteriorated the once very fertile Indus delta. Over the last few decades, Sindh; the lower riparian region; has constantly opposed the construction of Kala Bagh Dam due to the above-mentioned reasons. The Government of Sindh maintains that huge dam projects on river Indus have adverse socio-environmental effects on Sindh's population. The depleting flow of river Indus in Sindh has caused huge harm to the livelihood of many people. Industries like forestry, fishery, livestock, and agriculture, which were once considered as the backbone of the local economy of Sindh, are now facing threats due to depleting flow of water in river Indus [4]. Another big concern related to large hydropower projects is the resettlement issues of the local human population. A lot of financing is required for buying land and resettlement of people affected by dam projects. However, these issues can be resolved with proper planning and execution of such projects.

Run-of-River Hydropower Projects harness the energy of flowing water to generate electricity and requires no reservoir or dam to store water, thus avoiding environmental problems related to the construction of the dam. The amount of power generated by these projects often fluctuates according to the river flow. A diversion is constructed to allow the required amount of flow to pass through a channel and then through a penstock to a power generating turbine. Most notable run-of-river hydropower project in Pakistan is Ghazi Barotha canal which has a maximum installed capacity of 1450 MW. Figure 3 illustrates one such kind of power plant.

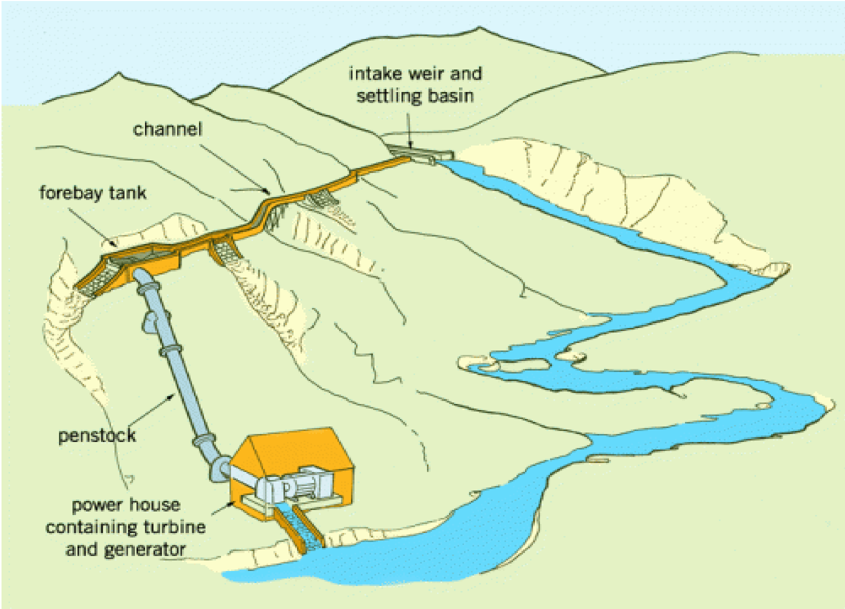

Figure 3-3: ***A Run-of-River Hydropower Project***

Small Scale Hydropower Development in Pakistan

The large hydropower projects are often not sustainable due to their huge adverse impacts on the environment, economics, and society. Internal funding for such projects is also difficult and often international donor agencies like the World Bank and Asian Development Bank are consulted to get loans of billions of dollars for such kind of projects. Apart from economics, these projects take a huge time to be completed and achieve their maximum generation capacity due to many social and political factors. An alternative to this is the establishment of small hydropower plants (SHP). There is no clear definition to determine the maximum capacity of SHP, but usually, hydropower plant with less than 10 MW capacity is referred to as an SHP. The cost of establishing an SHP is about $1 million per MW with a payback period of about 5-7 years [5]. Small hydropower plants are usually run-of-river type and their power generation depends on the flow rate of the water. SHP often serves the electricity needs of remote areas that have no access to the national grid. Often the term "distributed generation" is used for decentralized electricity generation technology like small hydropower plants where the power plant is situated close to the load it serves. Small hydropower plants can be further categorized as Mini hydropower (100-500 W), Micro hydropower (5-100 kW) (MHPs) and Pico hydropower (<5 kW).

Small hydropower plants are best suited to mountainous areas with many canals and waterfalls that provide the necessary head and flow rate for power generation. Pakistan's northern areas boast many prime locations to employ such projects. With the feature of distributed generation, many micro hydropower plants have been established in KPK and Gilgit Baltistan through the support of different government and private organizations. Over 3000 MW of MHP potential is identified in northern areas of Pakistan and about 860 MHP projects are established to provide electricity to nearby communities. More than 600 such projects are in pipeline [6]. Most of these projects employ locally manufactured turbines, which not only give a boost to local industry but also provide job opportunities to many people. Following is the list of different organizations working for the development of MHPs in Pakistan.

Organization	Achievements
Pakhtunkhwa Energy Development Organization (PEDO)	• Establishment of 356 MHPs (15kW to 500 kW) in 12 hilly districts of KPK through NGOs with a total capacity of 35 MW • PC-1 for the construction of an additional 672 MHPs (20kW to 1500 kW) with the assistance of ADB
Sarhad Rural Support Program (SRSP)	• 332 MHPs installed in KPK with the assistance of EU • Total 28 MW installed capacity
Agha Khan Rural Support Program (AKRSP)	• 2 MHPs in Yarkhun (800 kW) and Laspur (500 kW) • 2 local power utility companies founded • 55 projects registered as Clean Development Mechanism (CDM) projects with UNFCCC • 147 MHPs constructed in Gilgit Baltistan and Chitral with total generating capacity of 13.5 MW • Construction of 57 MHPs in the off-grid area of Chitral in progress, with a total generation capacity of 8.2 MW
German Development Bank (KfW) and Pakistan Poverty Alleviation Fund (PPAF)	• Establishment of 5 MHPs (36 kW to 306 kW) with a total capacity of 803 kW in Chitral, Upper Dir and Buner districts of KPK
Pakistan Council of Renewable Energy Technologies (PCRET)	• Installation of 538 MHPs for distributed generation and total installed capacity of 8 MW.

*Table 3-1: **Small-scale Hydropower Development in Pakistan***

MHPs Manufacturing Status in Pakistan

Most of the MHPs up to 300 kW generation capacity are locally manufactured and assembled. The process of installing an MHP involves many different processes from designing to commissioning. For projects less than 300 kW, every step is being done by local engineers. Higher capacity projects are usually outsourced to foreign companies to achieve greater accuracy and efficiency. Setting up a Micro-Hydropower Plant requires surveying, designing, planning, civil work, machinery manufacturing, assembly, installation, operation and maintenance of installed power plant. Figure 4 shows all the components of an MHP plant [7].

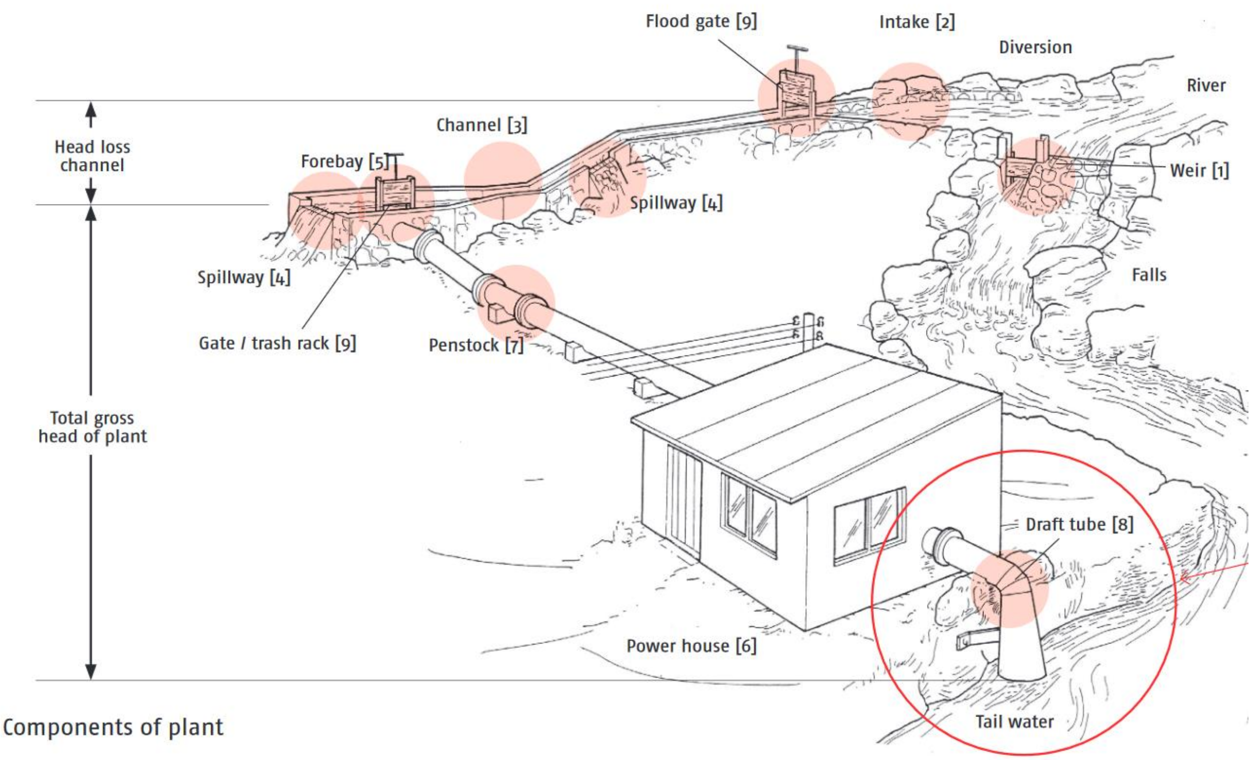

*Figure 3-4: **Different elements of an MHP plant***

The survey is necessary to find the best available place in a certain area to establish a hydropower plant. Through the survey, engineers find the location to divert water, determine the length of the channel and obtain the available head for the power plant. Water flow rate and available head determine the power capacity of the power plant. All the civil works including the construction of the weir, channel, forebay, and powerhouse building are outsourced to the laborers belonging to the area where the project is being installed. Other components like turbines, penstock, and dummy load are manufactured by companies specializing in hydropower. Currently there is no company present in Pakistan manufacturing generators, electronic load controllers (ELC) and other electrical components required for stable electricity generation, so usually imported components are utilized.

Turbine Manufacturing

The major component of an MHP plant is the turbine and its selection depend on the available head and water flow rate. As previously mentioned, turbines up to 300 kW capacity are being manufactured locally, but for higher power demands turbines are imported (mostly from China) to achieve greater efficiency. Table 2 lists various types of turbines installed in MHP projects in Pakistan and their selection criteria [8].

No.	Turbine Type	Suitable Head Range (m)	Comments
1	Pelton	80-1000	• Suitable for high head and small flowrate

			• A wide range of high efficiency • Pure impulse turbine
2	Turgo	20-300	• Simple structure • Suitable for high head and small flowrate
3	Francis	10-150	• Medium head and medium flowrate • High efficiency • Wide application range
4	Crossflow	5-80	• Suitable for low head and low flow rate • For low power applications • Simple construction, Medium efficiency • Most widely used in MHPs
5	Kaplan	1-16	• Suitable for low head and high flow rate • High efficiency • Cost-effective • Pure reaction turbine

Table 3-2: ***Turbine Selection Criteria***

T-15 Crossflow Turbine

Crossflow turbine is being widely used for MHP purposes in Pakistan. The most commonly used model is the T-15 Crossflow turbine, which is the property of Entec Consulting and Engineering, and manufactured here with license rights. In this type of turbine, water flows through the cylindrical runner, hitting the curved blades of runner twice. A guide vane regulates the amount of water flow through the turbine. Figure 5 shows the main components of a T-15 crossflow turbine [7].

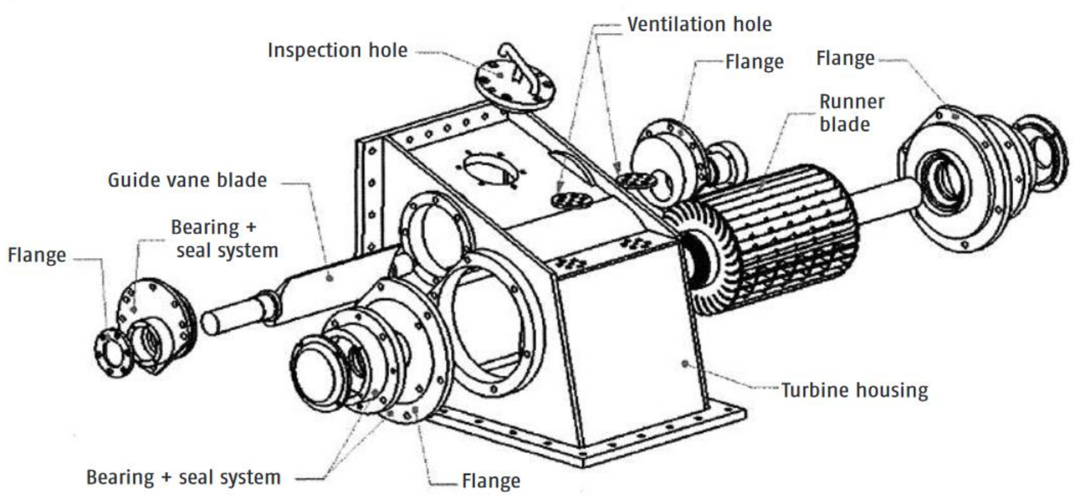

Figure 3-5: ***Assembly Drawing of a T-15 Crossflow Turbine***

Three models of this turbine are currently in practice: a standard 300mm diameter runner, and runner diameters of 400mm and 500mm for larger flow rates. Most of the turbine's parts are manufactured from mild steel in Pakistan. For high durability and strength, runner blade is sometimes manufactured from stainless steel, but that increases the cost of the turbine. Figure 6 shows a crossflow turbine runner.

Figure 3-6: ***A Crossflow Turbine Runner***

The part load efficiency of T-15 crossflow turbine is quite impressive: with only 20% of flow, efficiency reached 50% during laboratory tests. The turbine is linked with generator either through a belt drive or direct coupling with the shaft. The choice of the connection depends on the power output of the turbine as shown in Figure 7 [9]. Two of the major manufacturers of T-15 crossflow turbine in Pakistan are *Hydrolink Engineering and Equipment Company (HEECO), Taxila* and *Mukhtiar Engineering, Mardan*. These two companies are responsible for the manufacturing and installation of more than 270 units of T-15 crossflow turbines with a cumulative generating capacity of about 17 MW [8].

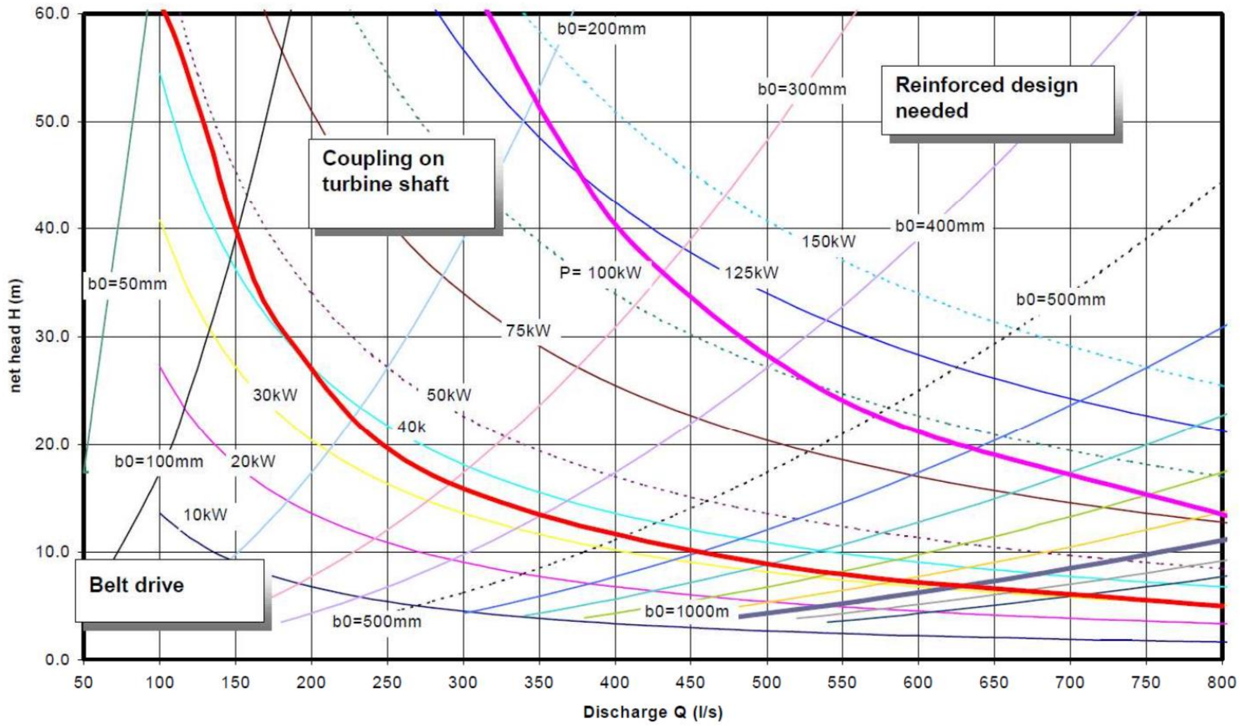

Figure 3-7: ***Application Range of T15-300mm***

T-34 Cross Pilot Reaction Turbine

Unlike T-15 turbine for which Pakistani companies have only license rights, T-34 Cross Pilot Reaction Turbine was the result of local ingenuity and innovation of Ch. Akhtar; owner of *Chitral Engineering Works (CEW) Taxila*. This turbine is a modified form of the Francis reaction turbine and patented by Intellectual Property Organization (IPO) of Pakistan in 2013. The unique point of this turbine is that it gives high efficiency and costs less to manufacture. Chitral Engineering Works installed first 130 kW T-34 Cross Pilot Reaction turbine in Nov 2016 with the funding of EU in District Swat. Four other orders of this turbine were also installed in Chitral district.

Figure 3-8: ***A T-34 Cross Pilot Reaction Turbine installed in District Swat by CWE***

TP 100 Cross Flow Turbine

Another turbine with complete manufacturing facilities available in Pakistan is TP 100 Cross Flow Turbine. *Hydrolink Engineering and Equipment Company*, *Taxila* holds its manufacturing license in Pakistan. This turbine costs less to manufacture; about PKR 40,000; and produces less power. This turbine falls in the category of Pico hydropower and produces power in the range of 500-2000 W. Some general specifications of this turbine are: [8]

Runner Diameter	100 mm
Turbine Size	275mm x 295mm
Turbine Width	30mm, 60mm, 100mm
Minimum Head	6m
Efficiency	70% (Laboratory Test)
Capacity	500W-2000W
Site Requirements	40m head with 5 liters/s flow or 8m head with 25 liters/s

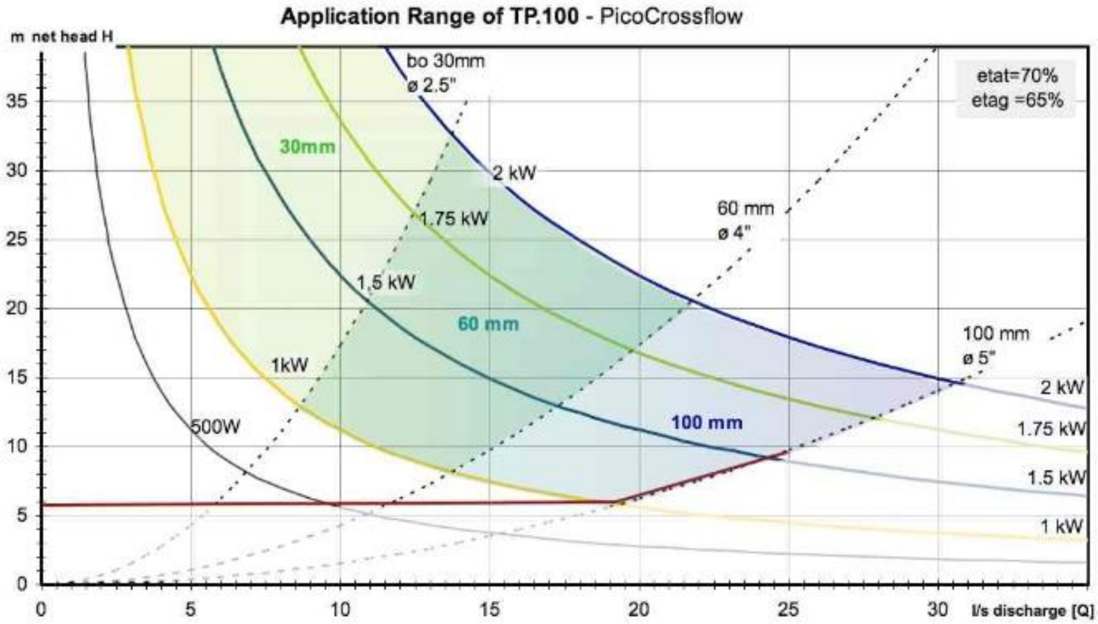

Figure 3-9: ***Application Range of TP 100 Crossflow Turbine [10]***

Other MHP Products

Other hydropower turbines that are locally manufactured in Pakistan are Pelton turbines for high head applications (5kw to 300kW) and Kaplan Turbines for high flow rate applications (10 kW to 100 kW). Although the turbines manufactured locally do not depict the higher efficiencies as compared to their imported counterparts, but still, these are the only feasible and economical option for installation in poor communities for electrification.

Apart from the turbines, local manufacturers like HEECO, Taxila and Mukhtiar Engineering, Mardan also specializes in the construction of penstock, storage tanks for hot water storage and assembly of dummy loads, transformer and Electronic Load Controller. CEW developed the first locally manufactured "Hydraulic Speed Governor" for the turbine in Pakistan and specializes in electrical synchronization of multiple turbines. CEW also developed two local patents which are registered under IPO-Pakistan. Those include "Development of T -34 cross pilot reaction turbine" under patent no 141818 and "Improved multi-chamber cross-flow turbine" under patent no 141820. Projects larger than 300 kW capacity, are mostly outsourced to foreign companies due to lack of state of art technology and machines necessary for achieving higher efficiency in Pakistan.

T-15 Crossflow Turbine manufacturing (HEECO)

Crossflow Turbine manufacturing (HEECO)

An imported Francis Turbine waiting to be installed (HEECO)

Team USPCAS-E NUST visited HEECO, Taxila on July 24, 2018

Team USPCAS-E NUST visited Mukhtiar Engineering, Mardan on September 4, 2018

Figure 3-10 **Visit Gallery**

Figure 3-11: ***T-15 Crossflow Turbine Fabrication (Mukhtiar Engineering)***

Figure 3-12: ***T-15 Crossflow Turbine Runner (Mukhtiar Engineering)***

Figure 3-14: ***Penstock Fabrication (Mukhtiar Engineering)***

Figure 3-13: ***Electronic Load Controller Assembly (Mukhtiar Engineering)***

Figure 3-15: ***Dummy Load: Water Heater***

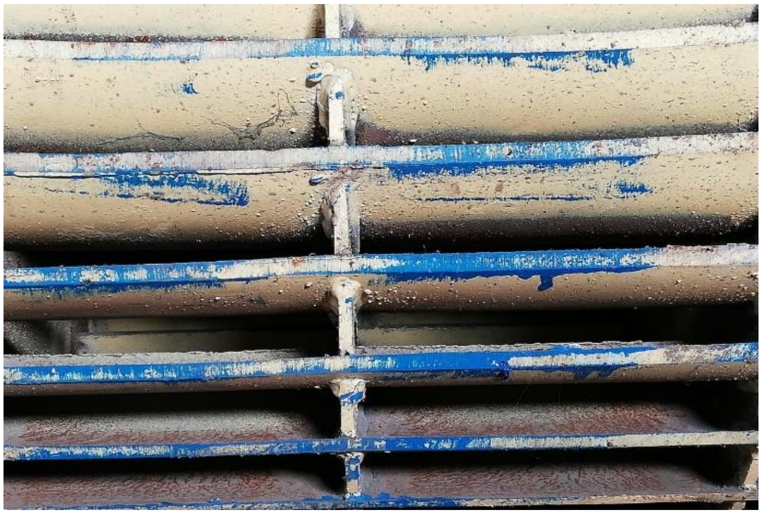

Figure 3-16: ***Defective Runner Blades (Rough Surface Finish)***

Challenges Faced by MHP Industry in Pakistan

Implementation of Testing and Commissioning Protocol

Currently, there is no authority to test the quality, efficiency, and durability of MHPs manufactured in Pakistan. The absence of third-party testing has caused severe degradation in the performance of these turbines. To enhance the quality and efficiency of MHPs manufactured in Pakistan, there should be a protocol established, according to which standard tests must be run on each turbine manufactured to check the material's quality, turbine's efficiency and power produced.

Workforce

Lack of skilled workforce; necessary for the intricate designing of the turbine's components; is causing a serious blow to the efficiency of products manufactured. Recently, KPK TEVTA has launched a four-tier training program which focuses on MHP with subjects ranging from management to design. Industry-academia linkage can alleviate this problem through specialized courses that aim at designing and fabrication of a hydropower turbine.

Research and Development (R&D)

R&D is vital to match the high efficiency and power produced by MHP turbines all over the world and to stay alive in a highly competitive industry. Unfortunately, our industry prefers quantity over quality, even in the case of MHPs. Science and Technology Universities can play a significant role in this scenario by providing design guides and doing productive research in the field of MHP. *Mukhtiar Engineering, Mardan* plans to establish an R&D unit to help them achieve higher efficiency design targets. If established, it will not only enhance their product's quality but also force other MHP manufacturers to do the same.

Inadequate High-tech Equipment

Old fashioned machines and construction methods to manufacture MHP turbines cause various defects and flaws in the final product. Due to the low-cost approach used by clients of these MHPs, manufacturers have not cared to go for high-tech equipment, because it will put an unnecessary economic burden on them. The absence of modern machines such as vertical lathe machine has hindered the ability to produce complex yet more efficient turbines; like Francis turbine that caters a wide range of head and flowrates; locally. It is also the reason that the local MHP industry still hasn't produced a single MHP turbine more efficient than crossflow turbine for low head and low flow rates.

Post Commissioning Issues

According to a survey conducted by *GIZ Pakistan*, inability to solve the issues that arise after the installation and commissioning of MHP turbines can affect the productive use of renewable energy. Some common issues observed during their assessment were: [8]

- Voltage and Frequency fluctuation
- Control system not working properly
- Belts and Pulley issues
- Alignment and vibration issues
- Civil structure issues
- Variation in the design parameters
- Insufficient installed capacity
- Transmission and Distribution system issues
- Not operational

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Chapter 4 BIOMASS ENERGY

With today's technological advancements, there are many new concerns which are surfacing and needed to be addressed on priority. The most serious of which is the Climate Change. The main contributor to this cause is CO_2 emissions which are coming from the combustion of fossil fuels for power generation, transportation, and other applications.

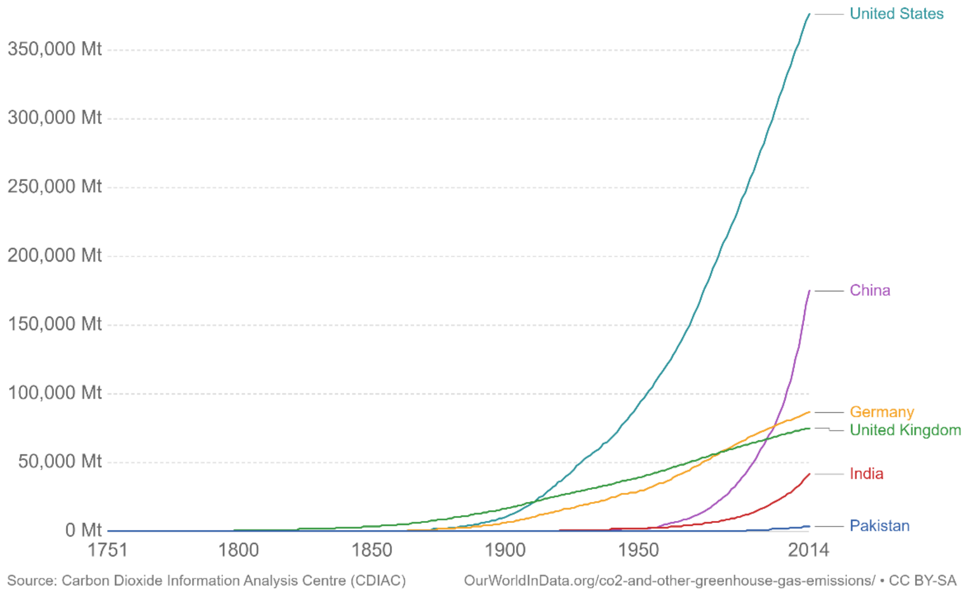

Figure 4-1 ***Cumulative CO_2 Emissions since 1751***

Figure 1 is showing a continuous increase in CO_2 emissions which is alarming [1]. Although in Pakistan the situation is not that worse as compared to the rest of the world, still it is a great concern to keep a tight check on the growth rate of CO_2 emissions in Pakistan. Figure 2 is depicting the increase in CO_2 emissions in Pakistan in the last few decades. [1]

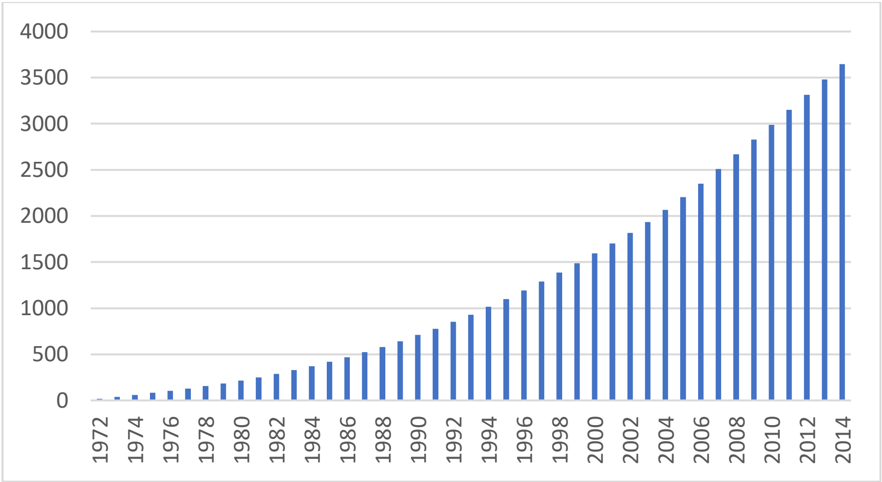

Figure 4-2 ***Yearly CO_2 Emissions in Pakistan (Million tons)***

A source of clean energy termed as Bio-Energy can be used as a replacement for conventional fuels that can reduce the CO_2 emissions. Term Bio-Energy includes all kind of Energy extracted from organic matter (biomass), materials of biological origin that is not characterized as fossils. The material (Biomass) can be used in its basic form or can be pre-treated and then used in some energy generation process. Generally, biomass fuels are classified into the following major categories:

- Solid
- Gas
- Liquid

The World Energy Council characterized the Bio-Energy raw materials into traditional biomass (forestry and agriculture waste) and modern biomass and biofuels (transformed from the biomass collected from natural surroundings or specifically gown for the purpose of energy production) These fuels can be used in many applications that include transportation, domestic, cooking, heating and electricity generation etc.

Availability of biomass resources across the world based on data from the World Bioenergy Association (2016) is shown in Figure 3 [2].

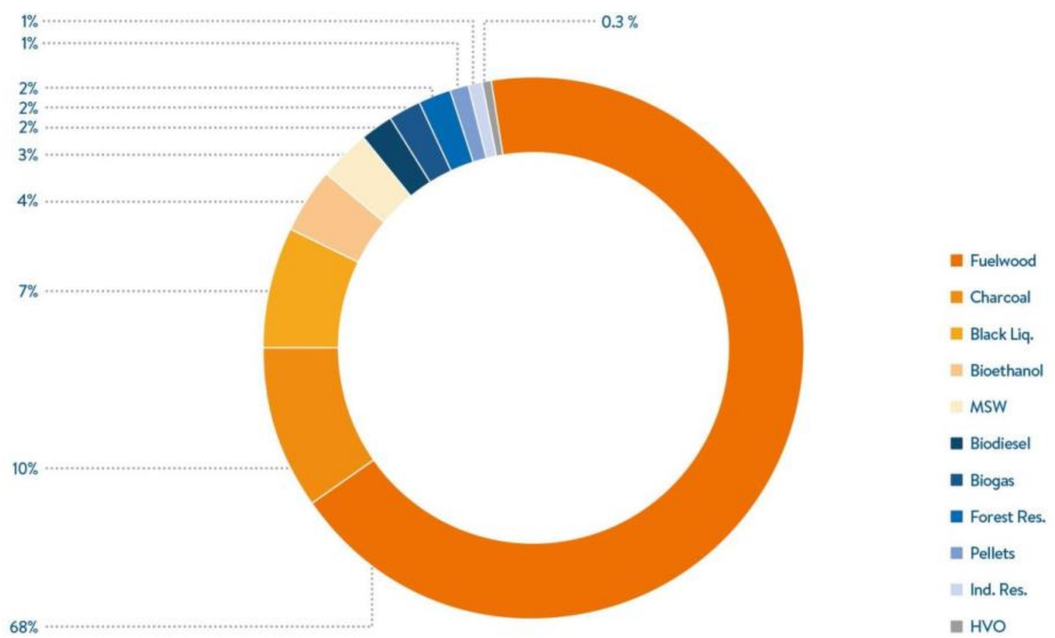

Figure 4-3 ***Availability of Biomass Resources across the World***

Bio-Energy Status in World

Feeling the heat of climate change, all developed countries are focusing to include a handsome amount of renewable in their energy mix that also includes the bio-energy. According to World Bio-Energy organization renewable share in the global energy mix is growing by 0.2% and currently, it is about 18.6% in which Bio-Energy is having the largest portion of 14% [3]. (Figure 4)

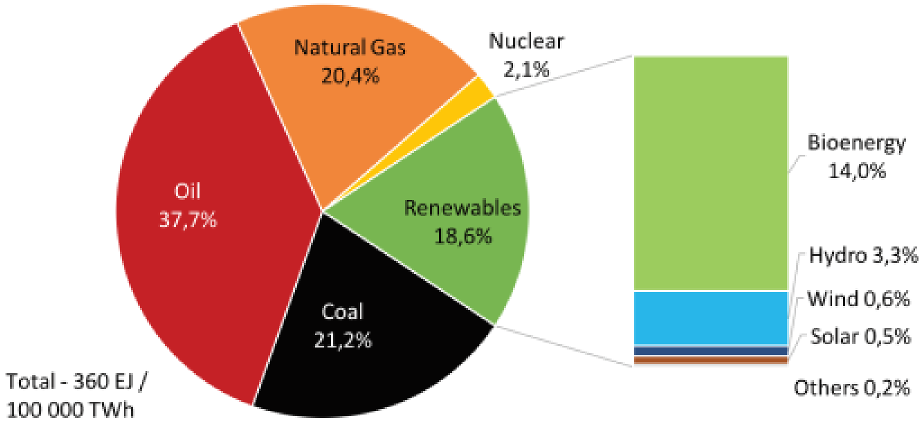

Figure 4-4 ***Renewables share in the Global Energy Mix***

The cleanest and efficient form of energy is electricity which is used mostly around the world. The share of renewables in electricity generation is 5469 TWh. Hydro is the largest portion, generating 3983 TWh. Biomass is the third largest renewable electricity generating source which generates around 493 TWh globally [3].

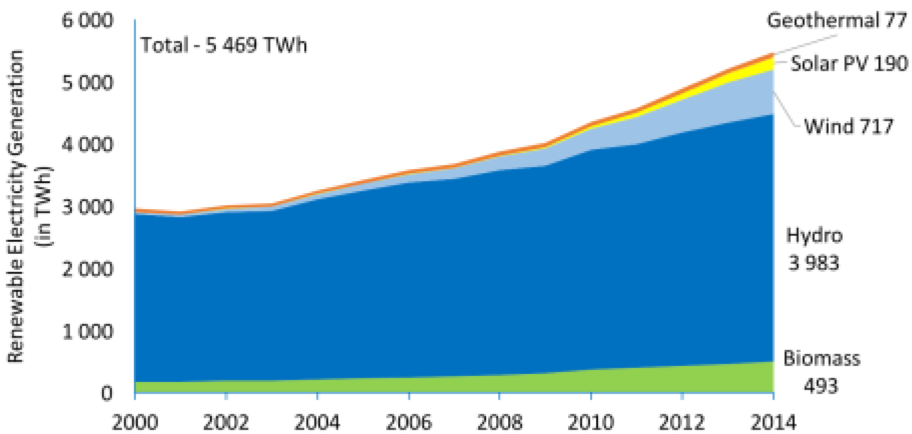

Figure 4-5 ***Renewables share in Global Electricity Generation***

There are many varieties of bio-energy which are available globally and can be obtained through different processes. An overview of conversion routes of different feedstocks to the end user product is described in Table 1 [4].

Table 4-1 ***Wide variety of Bio-energy Routes***

Feed Stock*	Conversion Routes**	End Product	
Oil crops (rape, sunflower etc.), waste oils, animal fats	(Biomass upgrading***) + Combustion	Heat and/ or Power	
	Transesterification or hydrogenation	Biodiesel	Liquid fuels
		Syndiesel/ Renewable diesel	
Sugar and Starch crops	(Hydrolysis) +Fermentation	Bioethanol	Liquid fuels
	AD****(+ biogas upgrading)	Heat and/or Power	
		Methanol, DME	Liquid Fuels
		Biomethane	Gaseous fuels
Lignocellulosic biomass (wood, straw, energy crop, MSW, etc.)	(Biomass upgrading***) + Combustion	Heat and/ or Power	
	(Hydrolysis) +Fermentation	Bioethanol	Liquid fuels
	Gasification (+ secondary process)	Heat and/ or Power	
		Bioethanol	Liquid fuels
		Syndiesel/ Renewable diesel	
		Methanol, DME	
		Other fuels and fuel additives	
		Biomethane	Gaseous fuels
		Hydrogen	
	Pyrolysis (+ secondary process)	Heat and/ or Power	
		Syndiesel/ Renewable diesel	Liquid fuels
		Other fuels and fuel additives	
	AD****(+ biogas upgrading)	Heat and/or Power	
		Methanol, DME	Liquid Fuels
		Biomethane	Gaseous fuels

	Other biological/ chemical routes	Other fuels and fuel additives	Liquid fuels
Biodegradable MSW, sewage, sludge, manure, wet wastes (farm and food wastes), macro-algae	(Hydrolysis) +Fermentation	Bioethanol	Liquid fuels
	Gasification (+ secondary process)	Heat and/ or Power	
		Bioethanol	Liquid fuels
		Syndiesel/ Renewable diesel	
		Methanol, DME	
		Other fuels and fuel additives	
		Biomethane	Gaseous fuels
		Hydrogen	
	Pyrolysis (+ secondary process)	Heat and/ or Power	
		Syndiesel/ Renewable diesel	Liquid fuels
		Other fuels and fuel additives	
	AD****(+ biogas upgrading)	Heat and/ or Power	
		Methanol, DME	Liquid Fuels
		Biomethane	Gaseous fuels
	Other biological/ chemical routes	Other fuels and fuel additives	Liquid fuels
Photosynthetic micro-organisms, e.g. microalgae and bacteria	Bio-photochemical routes	Biodiesel	Liquid fuels
		Syndiesel/ Renewable diesel	
		Hydrogen	Gaseous fuels

* Parts of each feedstock, e.g. crop residues, could also be used in other routes

** Each route also gives co-products

*** Biomass upgrading includes any one of the densification processes (Palletization, Pyrolysis, Torrefaction etc.)

**** AD = Anaerobic Digestion

For gaseous fuels (biomethane and hydrogen) feedstock consists of biodegradable municipal solid waste, manure, and food waste. These are easily available and there is no food to energy or deforestation clash in this kind of bioenergy which in other case is a burning issue amongst the researchers. In other words, there is a huge potential for this kind of bioenergy if processes involved (gasification and anaerobic digestion) are made efficient to extract maximum energy from the feedstock. At present, the global bioenergy fraction is shown in Figure 6.

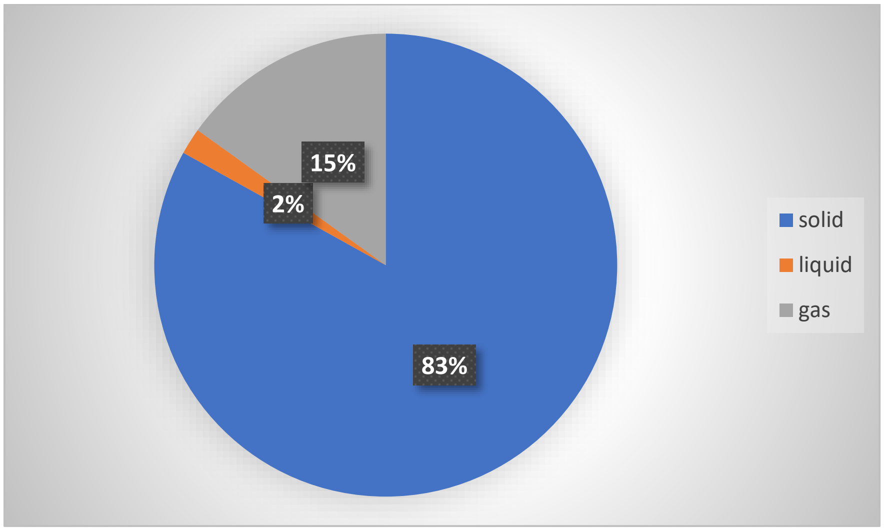

Figure 4-6 ***Global Fraction of Bioenergy***

From the Figure 6, we can extract that major portion of bioenergy consist of the solid fuel and only 15% is biogas which is quite low as compared with solid fuel and requires keen attention to improve. Although the overall trend of bioenergy across the globe is increasing as shown in Figure 7 [5].

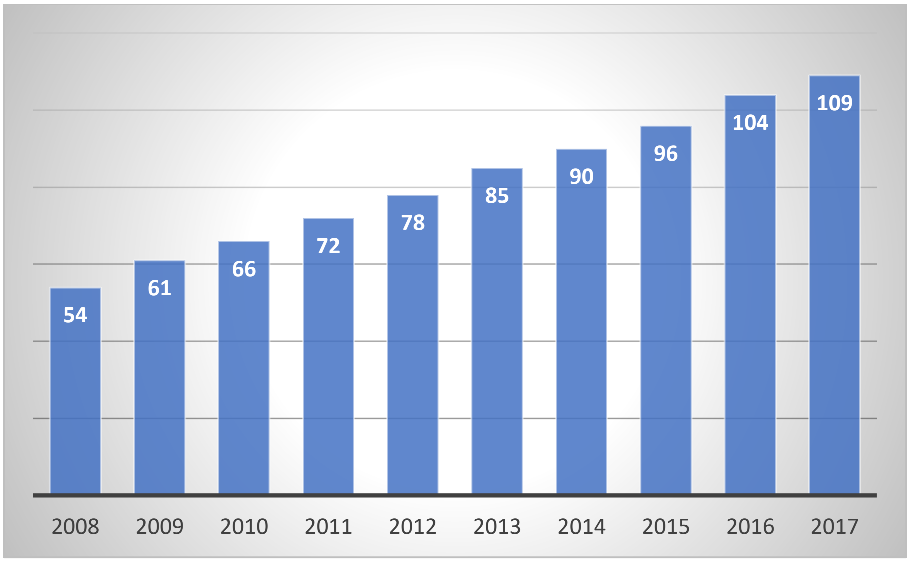

Figure 4-7 ***World Bioenergy Capacity (GW)***

Pakistan Bioenergy Potential

Figure 4-8 ***Available Resources of Biomass in Pakistan [6]***

Pakistan being a developing country requires to consume available energy resources for its economic growth. At present Pakistan is facing an energy crisis in many ways. In Pakistan, high pricing of fossil fuel can be considered the root cause of the energy crisis because the domestic and industrial sector uses the fossil fuel for electricity and heating purposes. To meet the peaking demands of energy, Pakistan has to focus on all sources of energy that can be utilized and they are also environmentally friendly. Pakistan being the agricultural country has a huge potential for bioenergy. Pakistan is having almost 159 million animals producing 652 million kg of manure daily; this excludes the manure from chickens, and only that can generate about 16.3 million m^3 biogas per day. The residue after gas generation can be used as fertilizer so it can produce 21 million tons of biofertilizer per year. Generation of biogas will save our conventional fuel reserves as estimated that a 10 m^3 size of biogas plant can save almost Rs 90,000 per year which will otherwise be spent on conventional fuels [7].

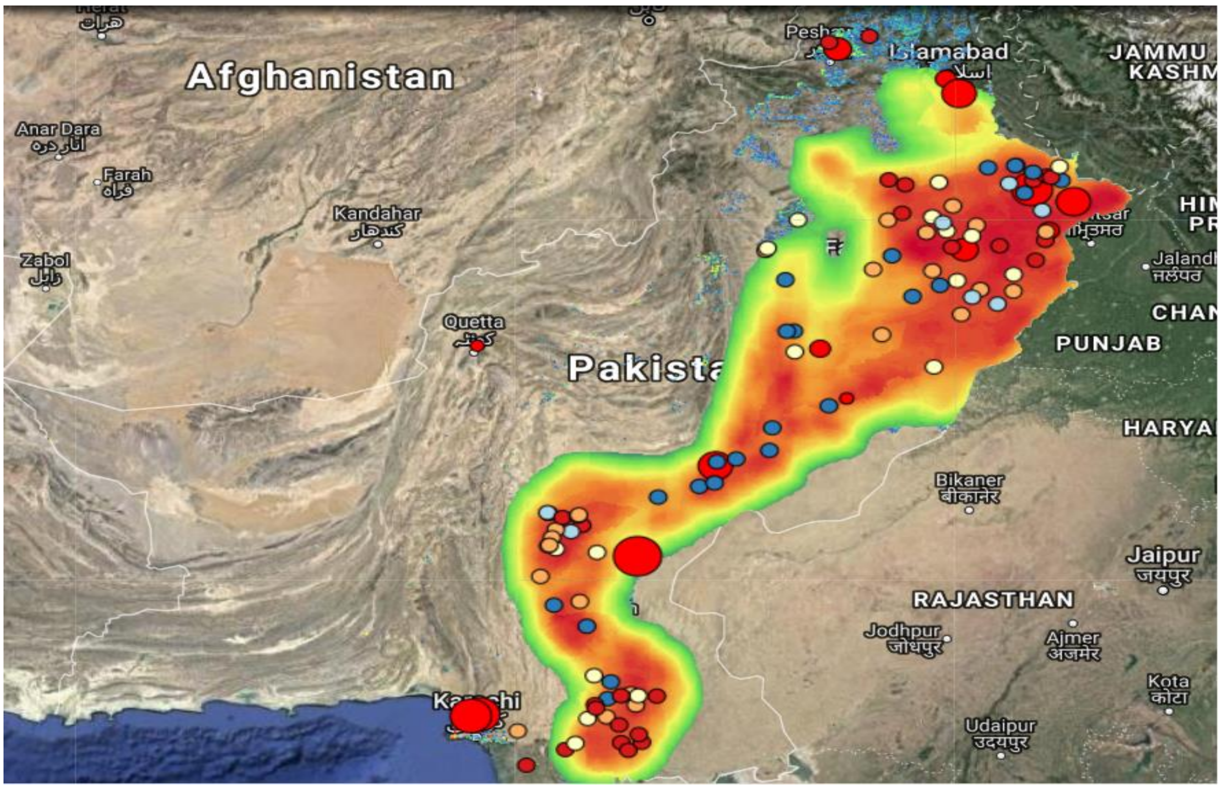

Figure 4-9 ***Bioenergy Potential in Pakistan***

Figure 9 shows the bioenergy potential in Pakistan. It almost covers half of the territory and with efficient technology handsome amount of biogas can be generated. Although at present there are many plants working which can generate partial power by using bioenergy resources. A survey by World Bank was carried across 44 districts of Punjab and Sindh and bioenergy potential was evaluated. Below is the list of 25 top potential sugar mills which can use bioenergy in their cogeneration plant [8]:

Table 4-2 ***Top 25 Potential Sugar Mills in Punjab for Cogeneration Plant***

Province	District	Sugar mill	Bagasse production (tons/yr.)	Additional feedstock sourced (tons/yr.)	Feedstock sourcing area (km^2/GWh)	Gross power capacity output	Electricity export (use of bagasse only) (GWh/yr.)	Electricity export (use of bagasse and additional feedstock) (GWh/yr)
Punjab	Rahim Yar Khan	Hamza Sugar Mills Ltd	1,127,487	1,287,559	0.19	122	327	711
		JDW Sugar Mills Ltd	859,989	887,492	0.19	93	249	542
	Toba Tek Singh	Kamalia Sugar Mills Ltd	495,000	419,163	0.26	53	143	312
Sindh	Ghotki	JDW Sugar Mills Ltd (Unit IV)-Dehrki	477,284	347,969	0.20	52	138	301
		JDW Sugar Mills Ltd (Unit III)-Ghotki	451,430	303,121	0.14	49	131	285
Punjab	Muzaffargarh	Shaikhoo Sugar Mills Ltd	442,446	368,632	0.37	48	128	279
	Rahim Yar Khan	Etihad Sugar Mills Ltd	420,302	352,526	0.30	45	122	265
Sindh	Shaheed Benazirabad	Al Noor Sugar Mills Ltd	387,978	293,258	0.24	42	112	245
Punjab	Rahim Yar Khan	RYK Sugar Mills Ltd	378,329	276,127	0.34	41	110	238
	Faisalabad	Tandlianwala Sugar Mills Ltd (II)	376,187	295,626	0.25	41	109	237
	Rahim Yar Khan	JDW Sugar Mills Ltd (Unit II)	355,881	243,689	0.26	38	103	224
	Layyah	Layyah Sugar Mills Ltd	345,863	303,420	0.48	37	100	218
	Bahawalpur	Ashraf Sugar Mills Ltd	345,000	276,544	0.27	37	100	217
Sindh	Tando Allah Yar	Mehran Sugar Mills Ltd	341,920	232,503	0.27	37	99	216
	Shaheed Benazirabad	Habib Sugar Mills Ltd	334,966	206,850	0.19	36	97	211
Punjab	Muzaffargarh	Fatima Sugar Mills Ltd	326,940	256,527	0.39	35	95	206
Sindh	Tando Muhammad Khan	Faran Sugar Mills Ltd	274,488	172,477	0.24	30	80	173
Punjab	Mandi Bahauddin	Colony Sugar Mills Ltd-I, Bahauddin	252,000	175,657	0.26	27	73	159
	Jhang	Shakarganj Mills Ltd-I, Jhang	249,225	198,425	0.51	27	72	157
	Nankana Sahib	Haseeb Waqas Sugar Mills Ltd	246,600	178,795	0.26	27	71	155
KPK	Dera Ismail Khan	Chashma Sugar Mills Ltd Unit-I	242,406	206,923	0.68	26	70	153
		Almoiz Sugar Mills Ltd	238,909	228,571	0.88	26	69	151
Punjab	Mandi Bahauddin	Shahtaj Sugar Mills Ltd	235,104	188,747	0.40	25	68	148
	Jhang	Kashmir Sugar Mills Ltd	231,747	186,024	0.55	25	67	146
	Kasur	Chaudhry Sugar Mills Ltd	230,511	161,473	0.28	25	67	145
Total			**9,667,992**	**8,048,098**		**1,044**	**2,800**	**6,094**

Table 4-3 ***List of 3 MW Rice Husk-based Power Plants with Lowest Sourcing Area for additional Feedstock [8]***

Province	District	Rice mill	Rice husk production (tons/yr.)	Additional feedstock sourced (tons/yr.)	Feedstock sourcing area (km^2/GWh)	Electricity export (GWh/yr.)
Punjab	Gujranwala	Al-Hameed Rice Mills	81	34,278	0.40	19
Sindh	Larkana	Abadghar Rice Mill Larkana	560	30,058	0.40	19
	Qambar Shahdadkot	Memon Rice Mill Kamber	760	31,591	0.41	19
		Muzamil Rice Mill Mirokhan	800	33,582	0.41	19
	Larkana	Dastagheer Rice Mill Badah	800	31,946	0.41	19
	Qambar Shahdadkot	Hamid Rice Mill Wagan	800	32,680	0.41	19
		Tunio Rice Mill Mirokhan	800	33,582	0.41	19
	Larkana	Kashtkar Rice Mill Larkana	800	29,569	0.41	19
	Qambar Shahdadkot	Mughari Rice Mill Kamber	800	32,103	0.41	19
	Larkana	Amaanullah Rice Mill Larkana	900	28,315	0.41	19
	Qambar Shahdadkot	Bismillah Rice Mill Nasirabad	960	32,886	0.41	19
Punjab	Nankana Sahib	Amin Ittefaq Rice Mills	1,000	33,340	0.41	19
Sindh	Qambar Shahdadkot	Faiz Masasn Rice Mill Nasirabad	1,120	32,734	0.41	19
		Mohammadi Rice Mill Nasirabad	1,120	32,732	0.41	19
	Larkana	Jawed Rice Mill Larkana	1,200	28,498	0.41	19
	Qambar Shahdadkot	Ubaidullah Rice Mill Kamber	1,200	31,092	0.41	19
		Aziz Rice Mill Wagan	1,200	32,211	0.41	19
		Abdullah Rice Mill Mirokhan	1,200	33,099	0.41	19
		Madina Rice Mill Mirokhan	1,200	33,099	0.41	19
	Larkana	Bismillah Rice Mill Ratodero	1,440	30,970	0.42	19
		Masha Allah Rice Mill Ratodero	1,600	29,097	0.42	19
	Qambar Shahdadkot	Aaquib Rice Mill Kamber	1,600	30,664	0.42	19
Punjab	Chiniot	Iqbal Rice Mills	2,008	31,978	0.42	19
	Gujranwala	Kashif Rice Mills	2,190	30,812	0.43	19
Sindh	Larkana	Husnain Rice Mill Ratodero	2,400	29,054	0.43	19
Total			**28,539**	**789,971**		**475**

Table 4-4 ***Potential Power Plants installed at the Landfills [8]***

Name of Landfill (Waste Management Company)	MSW dumped (tons/day on a wet basis)	Annual biogas production (Million m^3/yr.)	Gross electricity output (GWh/yr.)	Rated gross power capacity (MW)	Electricity export to the grid (GWh/yr.)
Gondpass (Sindh Solid Waste Management Board)	6,000	262.8	629	79.8	597.5
Jam Chakro (Sindh Solid Waste Management Board)	6,000	262.8	629	79.8	597.5
Bhakkay Wala (Gujranwala WMC)	6,000	262.8	629	79.8	597.5
Mehmood Booti (Lahore WMC)	3,500	153.3	366.9	46.5	348.6
Lossar (Rawalpindi WMC)	1,200	52.6	125.8	16	119.5
Makkuana Site I (Faisalabad WMC)	1,100	48.2	115.3	14.6	109.6
Ring Road (Water and Sanitation Services Peshawar)	850	37.2	89.1	11.3	84.7
Gondlanwala (Gujranwala WMC)	850	37.2	89.1	11.3	84.7
Sector I-12 (Capital Development Authority)	700	30.7	73.4	9.3	69.7
Eastern Pass (Quetta Municipality)	375	16.4	39.3	5	37.3
Tiba Badarshar (Bahawalpur WMC)	225	9.9	23.6	3	22.4
Ratta Village (Sialkot WMC)	185	8.1	19.4	2.5	18.4
Total	**26,985**	**1,182**	**2,829**	**359**	**2,687**

Table 4-5 ***Potential Power Plants installed at the Dairy Farms [8]***

Name of Dairy Farm	Manure collected (tons/day on as-received basis)	Annual biogas production (m^3/yr.)	Gross electricity output (GWh/yr.)	Rated gross power capacity (MW)	Electricity export to the grid (GWh/yr.)
Engro Dairy Farm Nara	64	747,520	1.79	0.23	1.70
JK Dairies Pvt Ltd	30	350,400	0.84	0.11	0.80
Sarsaabz Dairy Farm Nestle	6	70,080	0.17	0.02	0.16
Total	**100**	**1,168,000**	**2.80**	**0.36**	**2.66**

Table 4-6 ***Analyzed Combinations of Power Plants Technologies and Capacities [8]***

Technology	Power plant capacity (MW)
Horizontal gate combustion steam boiler + steam turbine	3, 8 and 15
Inclined gate combustion steam boiler + steam turbine	3, 8 and 15
Bubbling fluidized bed combustion steam boiler + steam turbine	8, 15, 25, 50 and 100
Circulating fluidized bed combustion steam boiler + steam turbine	15, 25, 50 and 100
Gasifier + syngas engine/ turbine	0.5 and 1.5
Anaerobic digester + biogas engine/ turbine	0.5, 1.5, 3 and 8

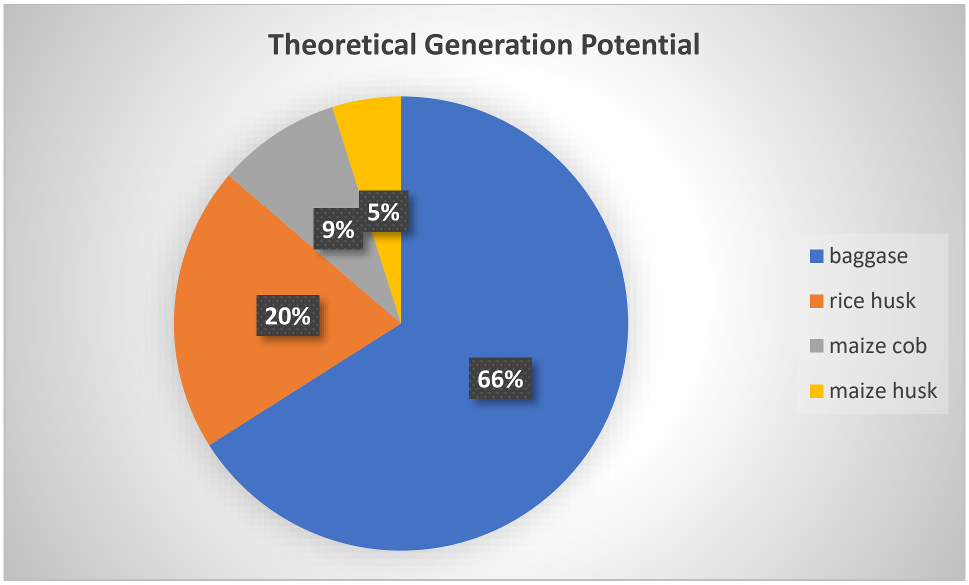

Figure 4-10 ***Theoretical Generation Potential of Crop Processing Residues [9]***

The study depicts the huge potential of bioenergy across the country. It should be noted that the data listed above comprises the survey of 44 districts only and most of them are from Punjab and Sindh. If other provinces are included then the value may rise further. Unfortunately, up till now bioenergy potential of Pakistan is not fully investigated. There should be a clear policy from the government and all measures should have been taken to implement that policy to take advantage of our bioenergy resources in fulfilling our energy needs. Figure 11 is showing the bioenergy capacity increase of Pakistan from 2008 to 2017 [5].

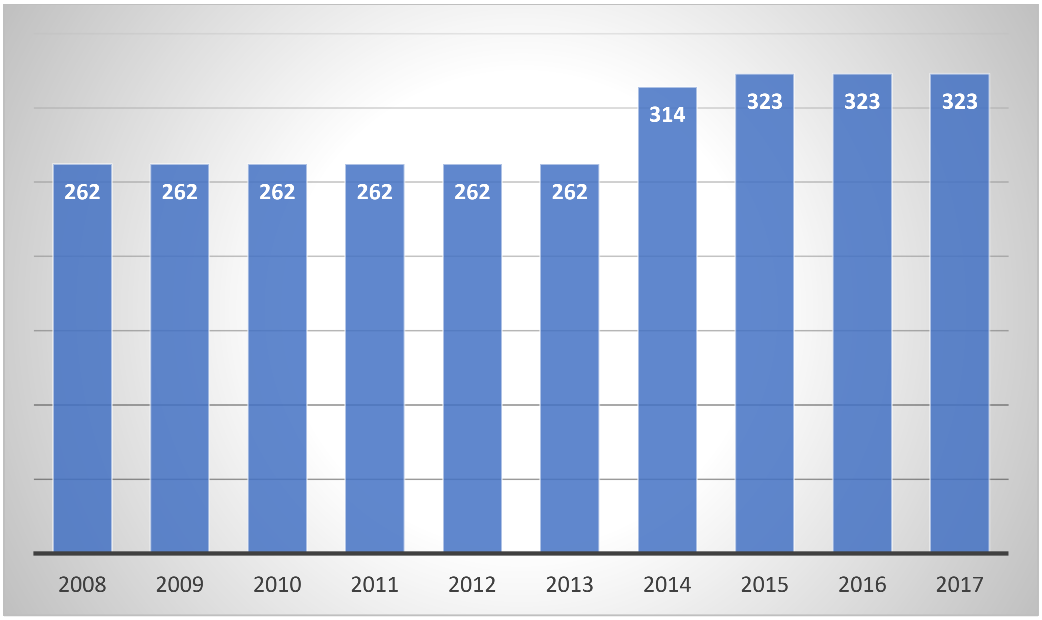

Figure 4-11 ***Pakistan Bioenergy Capacity (MW)***

Present Status of Bioenergy Technology in Pakistan

Literature shows that grid-connected biomass electricity generation plants are still nowhere to be seen in the country rather focus was given on establishing the domestic biogas plants to fulfill the needs of the communities not connected with the grid. Our survey team visited PCRET to acquire an up-to-date status on the plants. It was revealed to them that main work is done on setting up digestors because of its easy handling and fabrication and are deployed in the rural areas of Punjab and Sindh. Over 2500 biodigesters of different kinds and sizes were deployed under the Public Sector Development Program (PSDP), which are working on animal dung and kitchen waste feed (PCRET Website). For feeding a 5 m^3 digester, 1 trolley of animal waste or 1/4 trolley of kitchen waste is required.

Table 4-7 ***Typical Composition of Biogas [10]***

Compound	Formula	%
Methane	CH_4	50-75
Carbon dioxide	CO_2	25-50
Nitrogen	N_2	0-10
Hydrogen	H_2	0-1
Hydrogen sulfide	H_2S	0.1-0.5
Oxygen	O_2	0-0.5

Gas generated by digester can be used in multiple applications e.g. cooking, transportation and electricity generation. A 50 m^3 digester can run a Peter Engine for 5 hours to pump out the water from a tube well. The exhausted slurry from digester can be used as natural fertilizer for the crops. So, the waste is recycled in an efficient way. The working temperature of the plant is 25-30^o C. In winters it is necessary to maintain the required temperature to get the designed output.

PCRET has standardized two family models of biogas plants of 3 m^3 and 5 m^3 daily gas production capacity. The total cost of 5 m^3 fixed dome biogas plant including all appliances is PKR 35,000 and cost of 3 m^3 is PKR 14,666. The main reason to adopt this technology was less technical skills required for operation and maintenance [11].

Table 4-8 ***Comparison of Fixed and Moveable Dome Digesters***

	Advantages	Disadvantages
Moveable Gasholder	• Gas pressure is regulated by the weight of the gasholder. • Gasholder helps in stirring/ scum breaking. • Easy to construct (can be constructed in a week time) easy to repair. • Due to black painted metallic gasholder, the greenhouse cover works effectively to raise the temperature in the top layer of slurry in the winter season.	• Metallic gasholder is exposed to the atmosphere and causes heat losses. • As it dips in the slurry, anti-corrosion treatment is required. • Periodical painting of gasholder is required to avoid rusting.

	• Easy disposal of exhaust slurry due to gravity flow.	
Fixed dome Gasholder	• Since it is underground, the plant space can be utilized. • Fairly steady temperature can be maintained inside the digester. • Post-installation maintenance like painting, plastering is seldom needed.	• Construction needs special skills. • Stirring and scum breaking are generally difficult. • Gas pressure control is difficult. • Leakage of gas from hairline cracks developed in the dome. • Leakage of gas from sides of a manhole cover. • A good quality of gas produced in the slurry displacement chamber is not captured/ utilized and is emitted in the air. • Exhaust slurry is to be taken out manually.

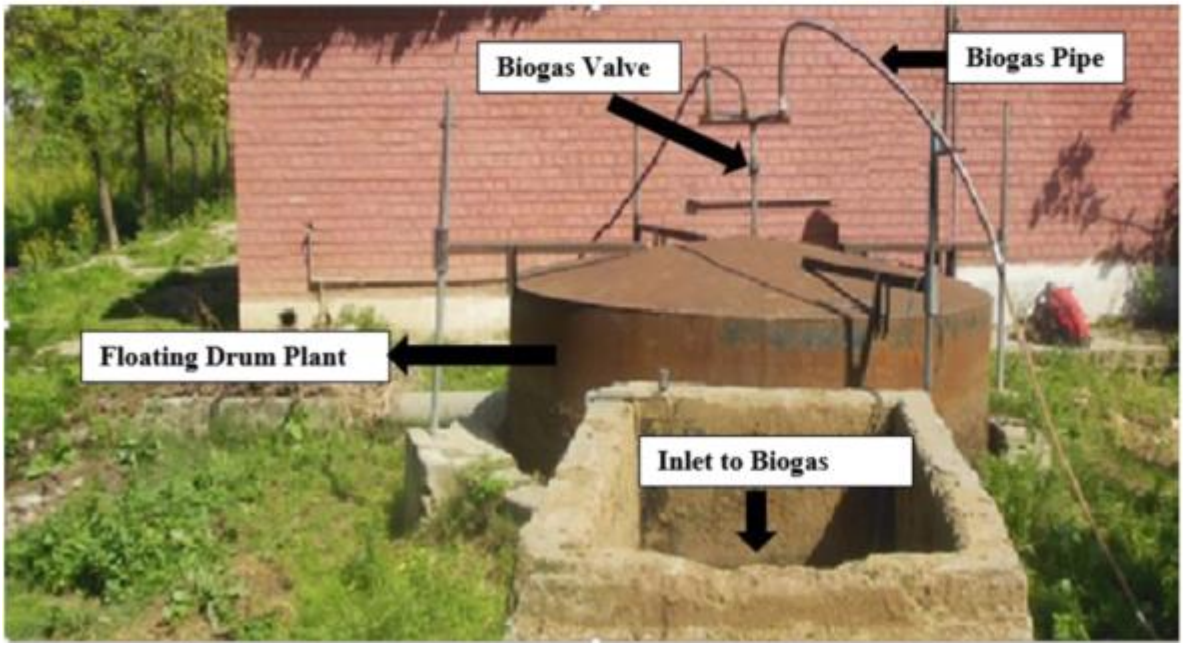

Figure 4-12 ***Floating Dome Biogas Digester [12]***

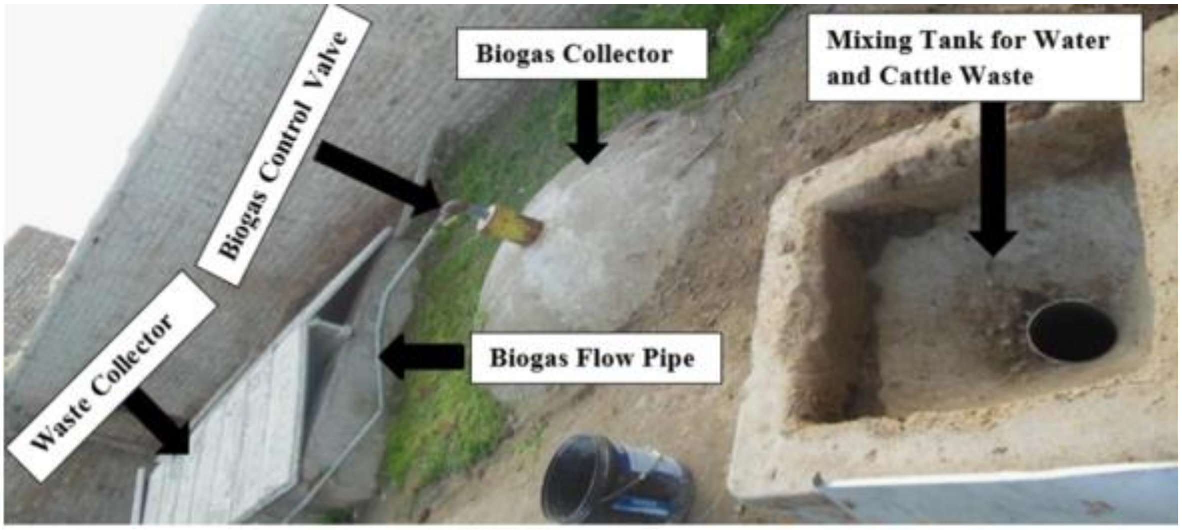

Figure 4-13 ***Fixed Dome Biogas Digester [12]***

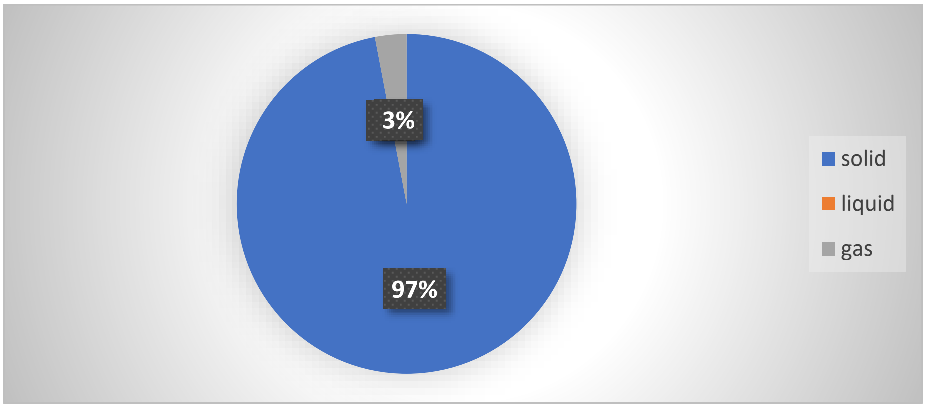

Figure 4-14 ***Fraction of Bioenergy in Pakistan***

The fraction of biogas as compared to whole bioenergy available is quite low. Instead of restricting ourselves only to biogas, will not suffice our energy needs. It is the sole responsibility of the policymakers to develop and afterward enforce the policies which should cater to all available technologies to extract energy from biomass which is abundant around us.

At present Descon Engineering Pvt Ltd is manufacturing a boiler for sugar industries that utilize bagasse as fuel for steam generation. It is the need of the hour to put some serious efforts into developing the indigenous technologies to extract bioenergy from biomass. It will not only make up our energy needs but also will have a great impact on our carbon emissions.

Biogas made at the commercial level can also be used in the transport sector as Pakistan has the third largest setup of gas utilization in the transport sector. A continuous supply of biomass is to be ensured for commercial plants which can be done by streamlining by establishing the plants in those areas where biomass is in abundance.

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Chapter 5 WIND ENERGY

Wind is a clean, readily available and free source of energy. In the present world of technology, wind turbines are capturing the power from wind and converting it into the electricity to fulfill the needs of energy across the world. As the world is focusing more towards cleaner energy resources to overcome many problems associated with the conventional fuel combustions, they are searching for reliable and abundant sources of clean energy. Wind is amongst the one that is why wind turbine installations continue to grow throughout the world.

The terms "Wind Power" or "Wind Energy" can explain the process of generating mechanical power or electricity from the wind. The tool or machine used to convert wind energy is called wind turbine which converts the kinetic energy of the wind into rotary motion and then this rotary motion can be used for multiple tasks like generating electricity, pumping out the water, grinding etc.

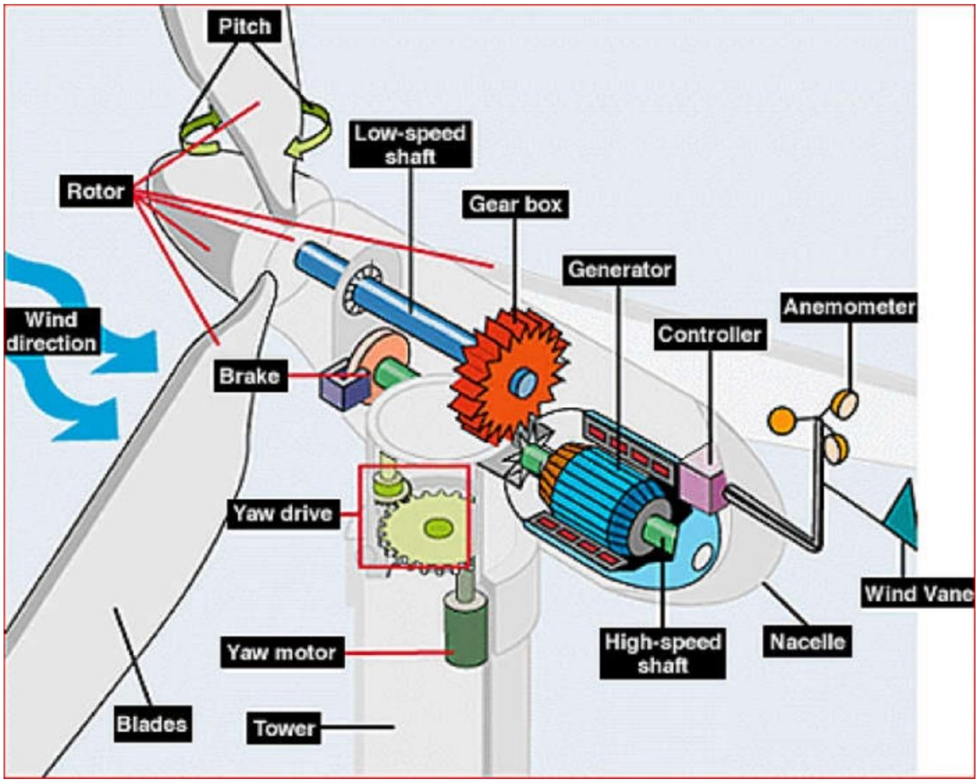

Figure 5-1 ***Use of Wind Turbine for Electricity Generation***

A wind turbine works quite opposite to fan. The wind rotates the blade and this rotating motion is transferred to the generator to generate electricity. There are normally two types of wind turbines classified on the basis of the axis of rotation as "horizontal-axis" and "vertical-axis". The technology of horizontal axis wind turbine is matured and is used commercially across the globe for electricity generation. The main components of a horizontal axis wind turbine include a blade or rotor that converts the wind energy into rotary motion of the shaft. Then a drive train transfer that energy to the generator, a tower on which all this is mounted. Other equipment includes controllers, electrical cables, ground support structure [1].

Wind turbines are usually grouped together into a single wind power plant which is known as a wind farm. These farms are of two types;

a. Onshore farms
b. Offshore farms

Wind farms situated on the land are termed “Onshore wind farms”. Wind farms established in the oceans along the coastline are called “Offshore wind farms”.

Figure 5-2 ***Off Shore and On Shore Wind farms***

There are certain factors that are to be considered before establishing a wind farm, those are listed below [2]:

a. Understanding wind resources
b. Evaluation of distance from existing transmission line
c. Determination of benefits and barriers of land development
d. Establishing access to capital investment
e. Identification of reliable power purchaser or market
f. Addressing siting and project feasibility considerations
g. Understanding the wind energy’s economics
h. Obtaining zoning and permitting expertise
i. Establishing dialog between turbine manufacturers and project developers
j. Making a secure agreement to meet O&M needs

Global Wind Energy Scenario

There is a great potential for wind energy across the world. According to the survey of the Global Wind Energy Council, there was over 360,000 MW of installed capacity of wind energy across the globe at the end of 2014 which is now increased to 539,123 MW. China, the United States, and Germany are the leading countries.

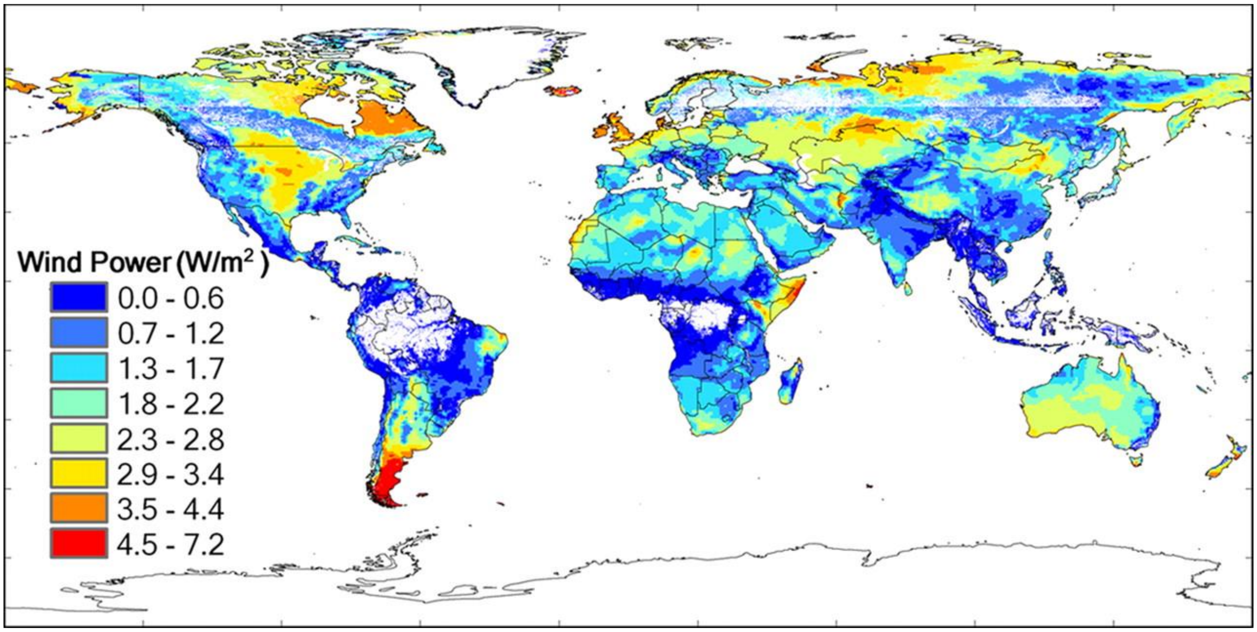

Figure 5-3 ***Wind Power Intensity Map***

Figure 4 is showing the installed capacity of wind energy on yearly basis from 2001 till 2017. From the graph the increasing trend is obvious.

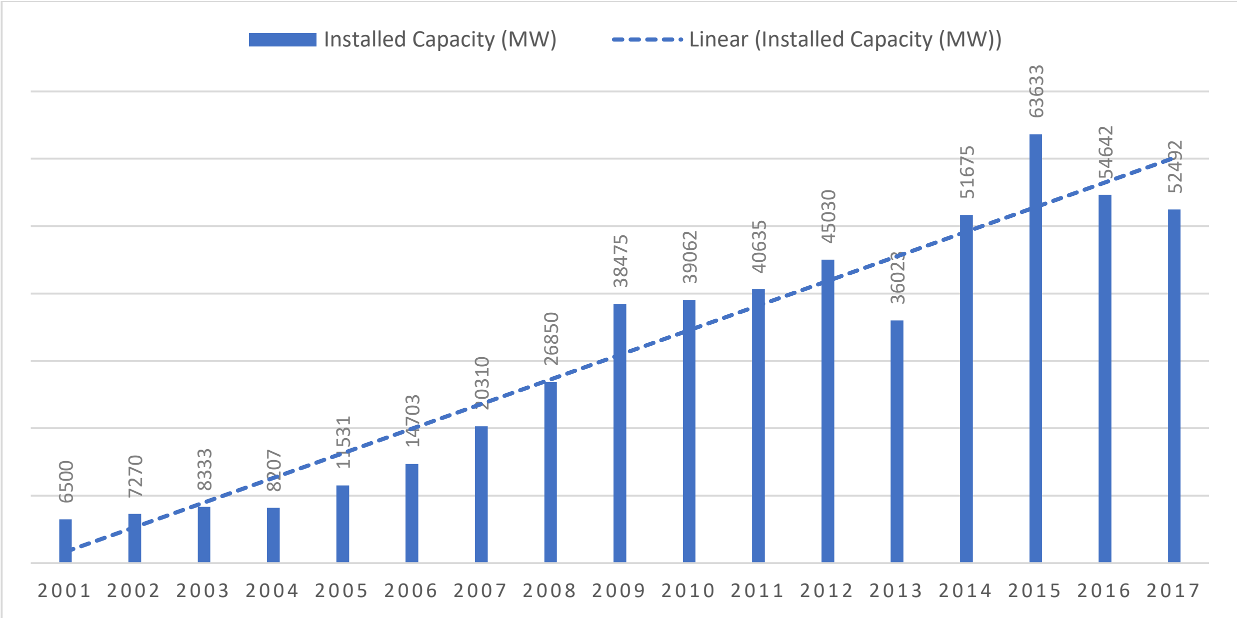

Figure 5-4 ***Global Installed Capacity OF Wind Energy (MW)***

The overall insight of the global wind energy capacity can be observed by the Figure 5.

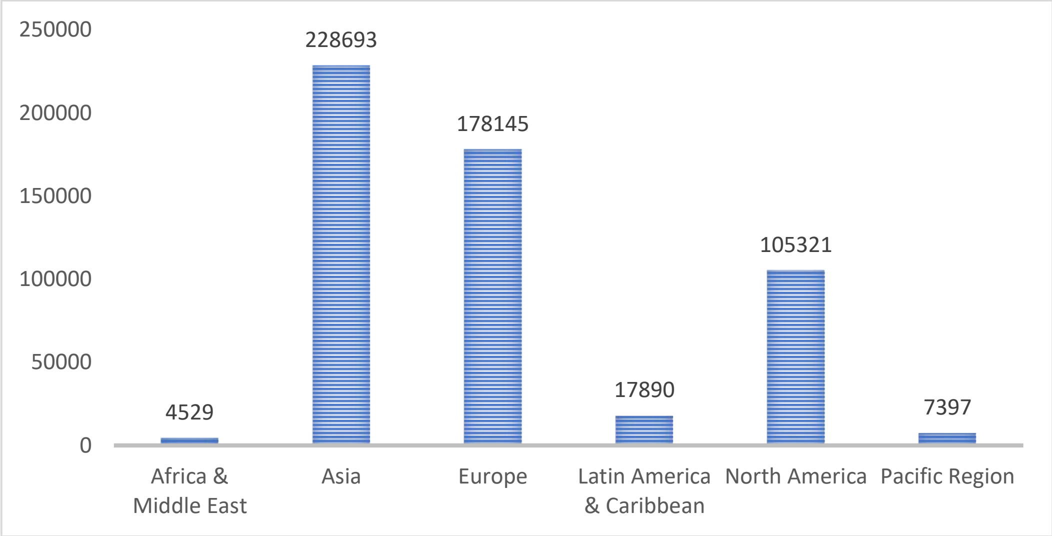

Figure 5-5 ***Global Installed Wind Power Capacity (MW), 2017***

Most of the world share of wind energy is generated in Asia, China being top in production. Europe is the second biggest continent to produce wind energy and Germany being the top European country on the continent [3].

Wind energy farms acquire quite a large area on the ground. So, the researchers came up with the idea to utilize the shallow water line along the cost for installation of the wind turbine. The idea was picked up and positive results were obtained which ultimately urged the engineers to install wind turbines off-shore. It is a tough job to undertake, it comes with good results in terms of power generated. According to survey an increase from 12 mph wind speed to 15 mph wind speed, the wind turbine can produce double power. The other benefit of off-shore wind farms is the steady speed of air because of no obstructions so the power generated is also steady and reliable. During 2017, a total of 4,334 MW off-shore wind capacity is installed increasing the cumulative off-shore capacity to 18,814 MW [3].

Pakistan Wind Energy Potential

To establish a wind farm, it is necessary to have a complete feasibility of the site is required. It should contain the required climate information and more importantly the wind speed and direction information. Pakistan Meteorological Department (PMD) was not having a satisfactory wind data of the country because of lack of infrastructure and technical issues. In 2007 National Renewable Energy Laboratory (NREL), a US-based organization made the significant effort under US Agency of International Development (USAID) assistance program to develop a mesoscale (wind) map of Pakistan. Figure 6 is showing the wind speed potential available at 50m height [4].

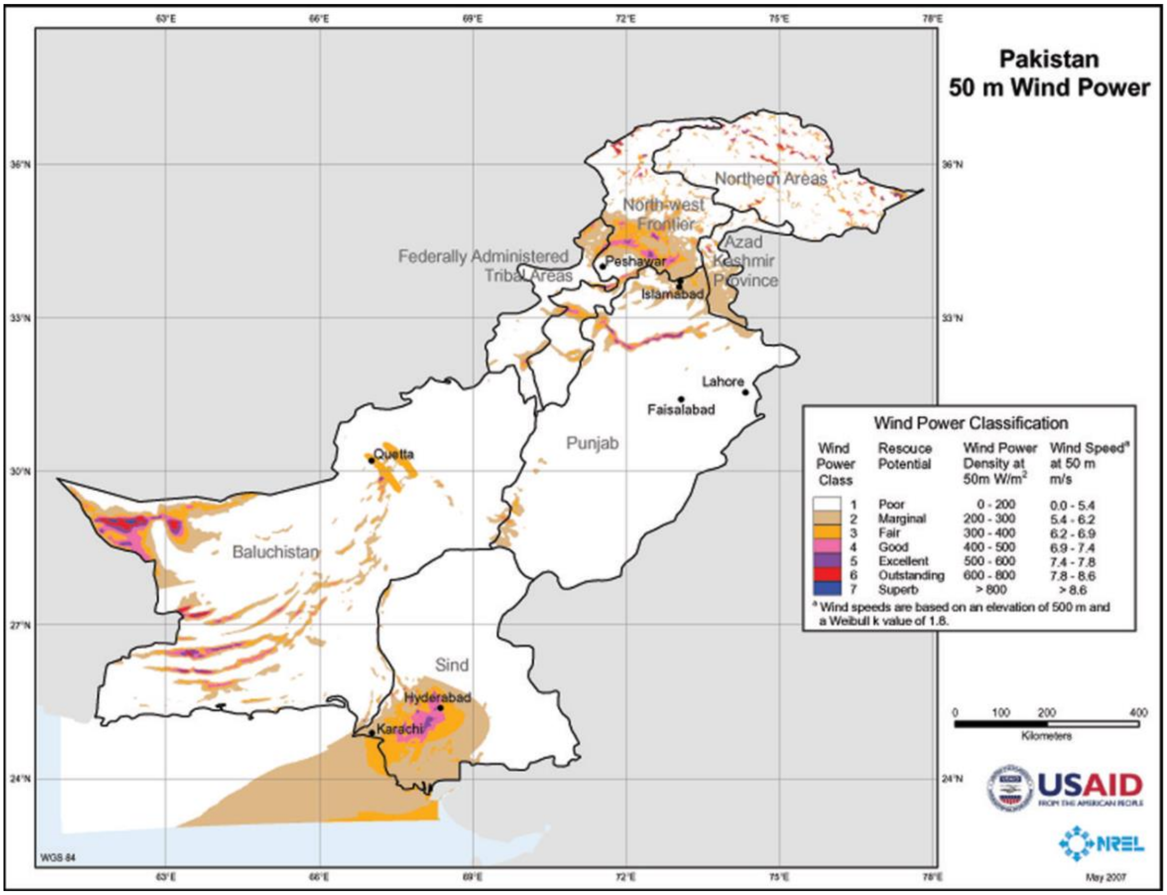

Figure 5-6 ***NREL Wind Map of Pakistan (50m)***

Theoretical wind energy potential estimated by NREL was about 340 GW, but this estimate overlooks the technical and economic constraints associated with the deployment of the projects. Hence there should be a more precise and reliable datum to start with.

Another survey was carried out under the supervision of the World Bank and World Bank-ESMAP was produced showing more precise data of wind because the data was gathered by the ground level wind speed measuring instruments using wind masts of various heights at different locations. Figure 7 is showing the wind potential map generated by the World Bank [5].

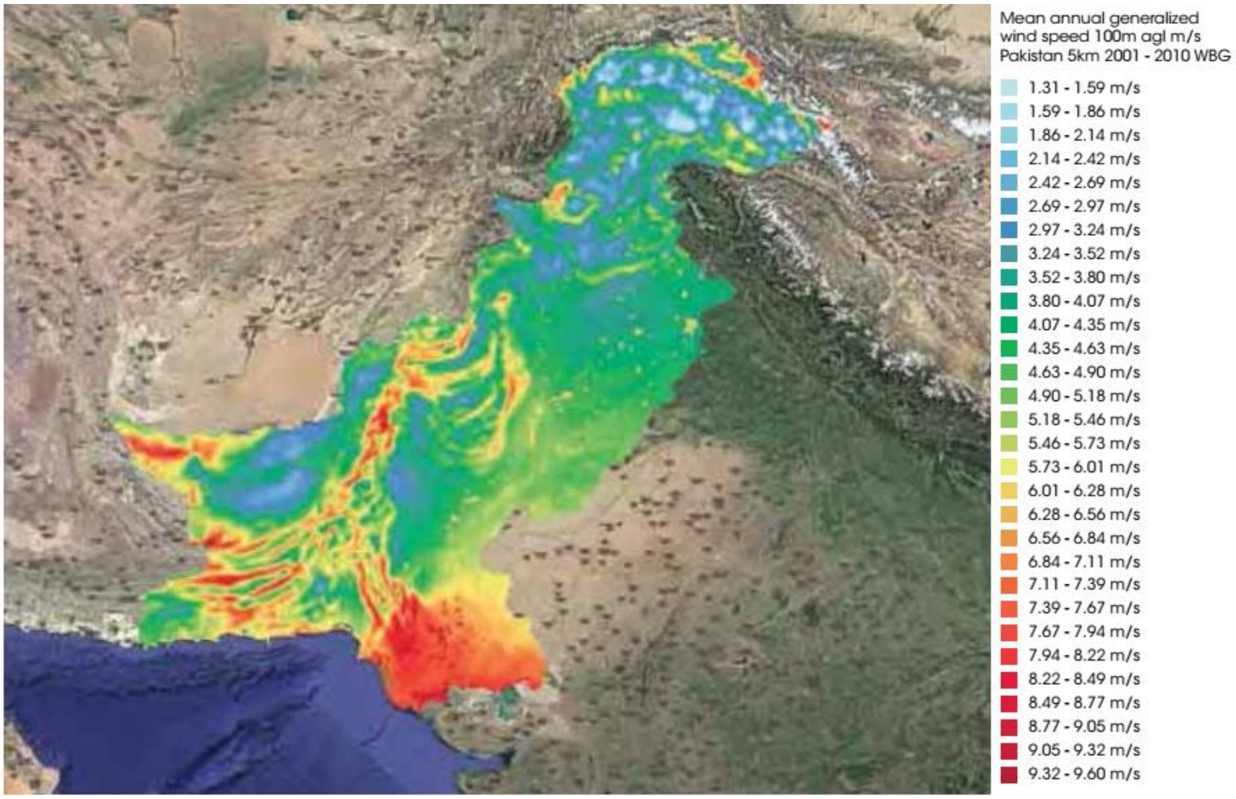

Figure 5-7 ***World Bank Wind Speed Data***

Considering the data according to this map, it was assessed that there is approximately 50 GW of theoretical wind energy potential in Pakistan's southern Sindh and Baluchistan provinces.

AEDB is working along with IPPs to bring wind energy projects into the country's grid. In this regard, AEDB has issued Letter of Intents (LOI) to several IPPs. List of the companies with project status is appended below. [6]

Table 5-1 ***Wind Power Companies Operating in Pakistan***

S No	Name	Capacity (MW)	Location	Status
1.	M/s FFC Energy Ltd	49.50	Jhimpir	Operational
2.	M/s Zorlu Enerji Pakistan (Pvt) Ltd	56.40	Jhimpir	Operational
3.	M/s Three Gorges Pakistan First Wind Farm (Pvt) Ltd	49.5	Jhimpir	Operational
4.	M/s Foundation Wind Energy-II (Pvt) Ltd	50	Gharo	Operational
5.	M/s Foundation Wind Energy-I Ltd	50	Gharo	Operational
6.	M/s Sapphire Wind Power Ltd	52.8	Jhimpir	Operational
7.	M/s Yunus Energy Ltd	50	Jhimpir	Under Construction
8.	M/s Sachal Energy Development Pvt Ltd	49.5	Jhimpir	Under Construction

9.	M/s Metro Power Company Ltd	50	Jhimpir	Under Construction
10.	Tapal Wind Energy Pvt Ltd	30	Jhimpir	Under Construction
11.	M/s United Energy Pakistan Pvt Ltd	99	Jhimpir	Under Construction
12.	M/s Hydro China Dawood Power Pvt Ltd	49.5	Gharo	Under Construction
13.	M/s Master Wind Energy Ltd	49.5	Jhimpir	Under Construction
14.	M/s Tenega Generasi	49.5	Gharo	Under Construction
15.	M/s Gul Ahmed Wind Power Ltd	50	Jhimpir	Under Construction
16.	M/s Jhampir Wind Power Ltd	50	Jhimpir	In the Pipeline
17.	M/s Hawa Energy Pvt Ltd	50	Jhimpir	In the Pipeline
18.	M/s Hartford Alternative Energy Pvt Ltd	50	Jhimpir	In the Pipeline
19.	M/s Three Gorges Second Wind Farm Pakistan Ltd	49.5	Jhimpir	In the Pipeline
20.	M/s Three Gorges Third Wind Farm Pakistan Pvt Ltd	49.5	Jhimpir	In the Pipeline
21.	M/s Tricon Boston Consulting Corporation Pvt Ltd (A)	50	Jhimpir	In the Pipeline
22.	M/s Tricon Boston Consulting Corporation Pvt Ltd (B)	50	Jhimpir	In the Pipeline
23.	M/s Tricon Boston Consulting Corporation Pvt Ltd (C)	50	Jhimpir	In the Pipeline
24.	M/s Zephyr Power Pvt Ltd	50	Gharo	In the Pipeline
25.	M/s Western Energy Pvt Ltd	50	Jhimpir	In the Pipeline
26.	M/s China Sunec Energy Pvt Ltd	50	Nooriabad	In the Pipeline
27.	M/s Burj Wind Energy Pvt Ltd	14	Gajju	In the Pipeline
28.	TransAtlantic Energy Pvt Ltd	50	Jhimpir	In the Pipeline
29.	M/s Shaheen Foundation PAF	50	Jhimpir	In the Pipeline

The table above can be summarized as [6]

Projects	**Capacity (MW)**
Commissioned Project Capacity	308.2
Under Construction Project Capacity	477
In the Pipeline	663
Total Wind Projects Capacity	**1,448.2**

Project sites in three provinces can be seen in the figure below. The towers are representing the deployment areas of the projects [7], [8].

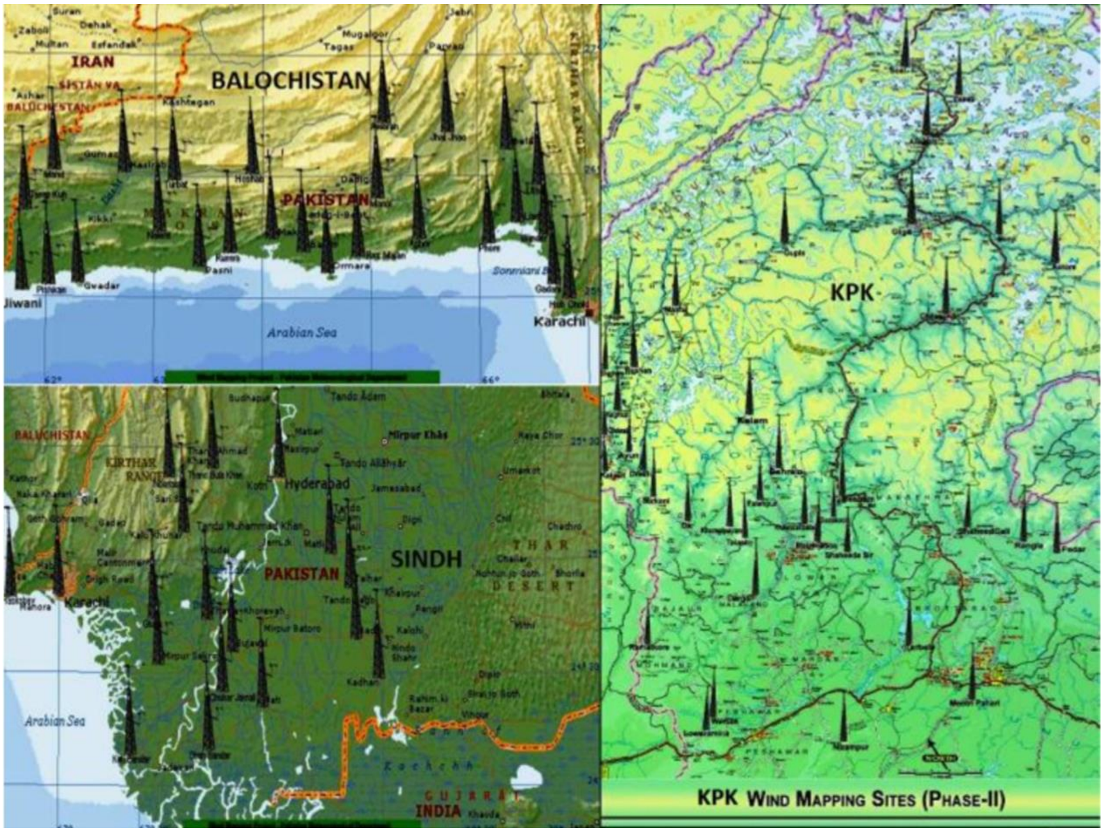

Figure 5-8 ***PMD Wind Maps of Pakistan***

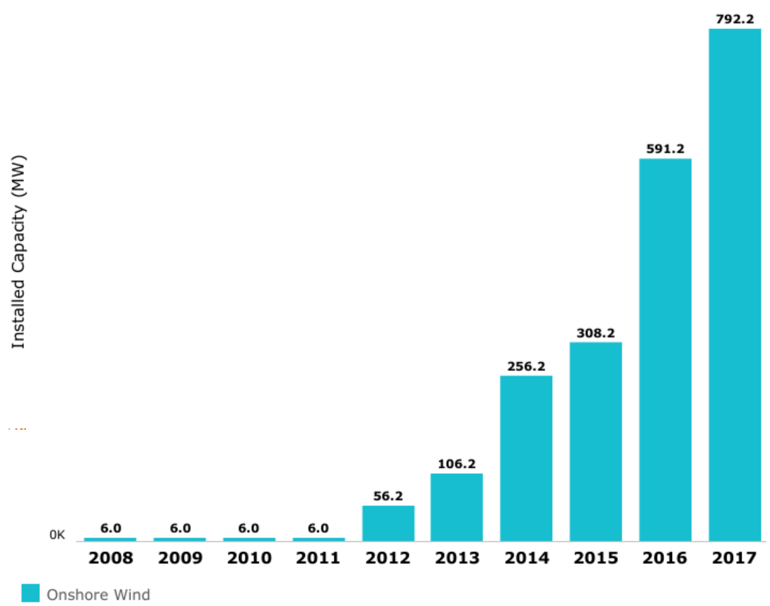

Figure 5-9 ***Increase in Pakistan's installed capacity of Wind Power in the last decade***

The increasing trend of Wind Power installed capacity in Figure 9 shows that Pakistan's wind energy market is growing with the passage of time. To cater to the increasing demand of the wind sector, it is imperative that government put efforts in producing the required technical skills and human resource by enforcing focused policies towards wind energy specific knowledge. Moreover, local manufacturing of parts for wind turbines should be explored to reduce our reliance on imported parts. At present Descon Engineering Pvt Ltd is manufacturing the wind towers indigenously in their facility at Karachi. Wind tower manufactured, is a 4 m of diameter pipe made up in sections and then joined together up to 80 m height. The only wind turbine is imported from international manufacturer and installation till grid connectivity is carried out locally. It is the need of the hour to look for local manufacturers who can develop turbines or any part of it locally. Below is the list of few companies that are manufacturing windmills at small scale.

Table 5-2 ***Wind Mill Manufacturing Facilities in Pakistan***

S No.	Company	Product	Capability
1.	Merin Pvt Ltd, Karachi	Wind Mill	Can manufacture windmills of 10,15 and 20 feet blade dia. That can extract 20,000 gallons of water from 70 ft depth.
2.	Engineering Concern Pvt Ltd, Karachi	Wind Mill	Pumping water and electricity generation.
3.	Agro Tools Pvt Ltd	Wind Mill	Pumping water and electricity generation.
4.	Pak Wind Energy Ltd, Karachi	Wind Mill	1KW – 15KW
5.	Quetex International, Karachi	Wind Mill	0.5 kW – 20 KW

In Pakistan, there are companies working on composite materials and manufacturing different products like doors, window frames etc. These companies can be explored for wind turbine blade manufacturing. Moreover, PAC Kamra is having the facility of manufacturing aircraft wings. Their ability to manufacture wind turbine blades can be explored. Potential of PAEC and SUPARCO need to be explored for blade manufacturing.

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3. Global Statistics, Global Wind Energy Council. Available[online]: http://gwec.net/global-figures/graphs/ [Accessed: September 02, 2018]
4. NREL: Pakistan Resource Maps. Available[online]: https://www.nrel.gov/international/ra_pakistan.html [Accessed: September 02, 2018]
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7. Wind Mapping Project Phase-I: PMD wind mapping of coastal areas of Pakistan. http://www.pmd.gov.pk/wind/Wind_Project_files/Page558.html
8. Wind Mapping Project Phase-II: PMD wind mapping of northern areas of Pakistan. http://www.pmd.gov.pk/wind/Wind_Project_files/Page917.html
9. IRENA online source: http://resourceirena.irena.org

Chapter 6 INTELLECTUAL PROPERTY RIGHTS IN PAKISTAN

Intellectual Property Organization (IPO) Pakistan Services

Following is a list of intellectual property services provided by the IPO-Pak;

- Patent
- Industrial Design
- Copyright
- Trademark
- Plant Breeders Rights

Patent

A patent is a grant of exclusive rights for an invention to make, use and sell the invention for a limited period of *20 years*. The patent grant excludes others from making, using, or selling the invention. Patent protection does not start until the actual grant of a patent[*].

Any person devising any improvement in a manufactured article or in machinery or methods for making it, may upon disclosure of his improvement at the Patent Office demand to be given a monopoly in the use of it for a limited period. After that period, it passes into the public domain.

Conditions for Patentable Inventions in Pakistan

To be patentable, an invention should have the following characteristics:

- The invention should be process or product
- The invention should be novel or new
- It involves an inventive step
- It is capable of industrial application

Patent Procedure

There is a standard procedure followed by IPO Pakistan before the patent is awarded. That includes a through paperwork and detail data search of the design or technology that is to be patented. This is necessary to ensure that the product is genuine and the inventor deserves the sole rights for its production on a commercial level. The figure below illustrates the procedure from the first step till the end;

[*] Click on the links to visit IPO Patent Filing Guidelines and Fee & Forms

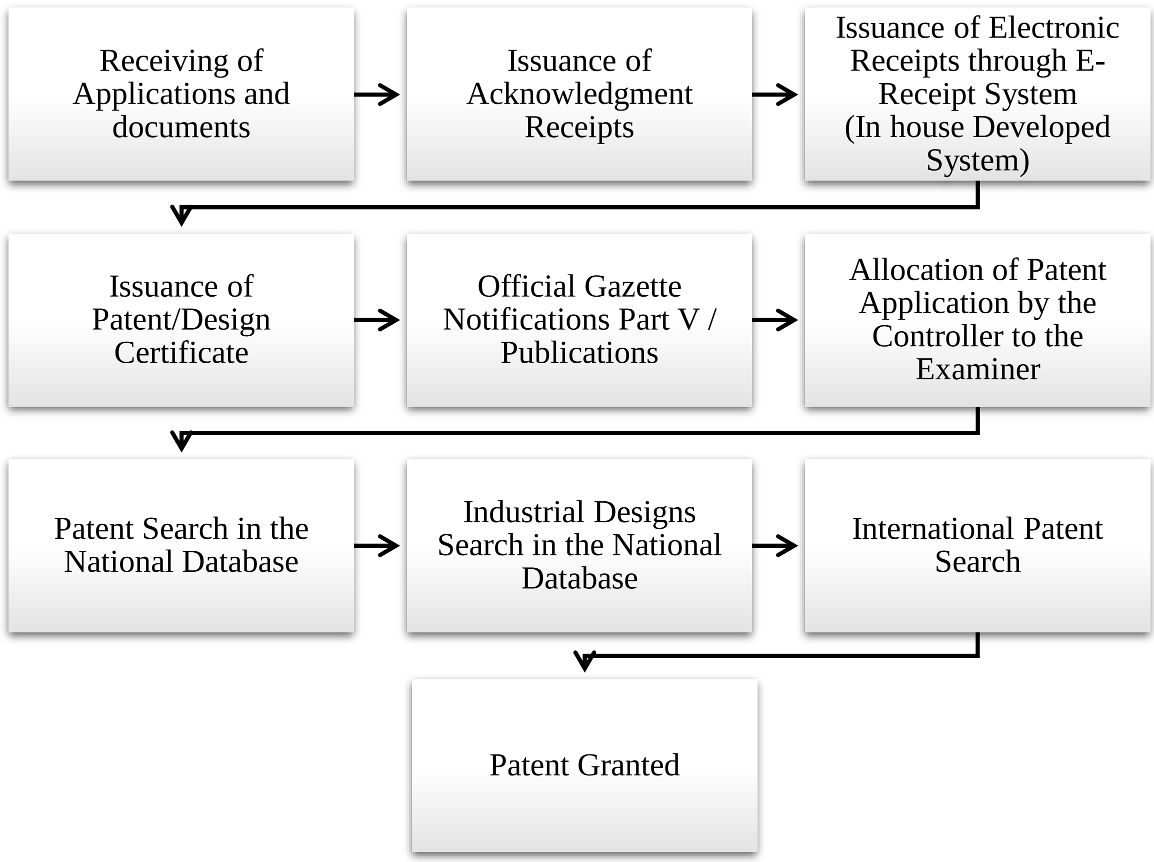

Figure 6-1 ***Patent Procedure***

Enforcement

It's done through *Enforcement Coordination Committee.* The enforcement strategy of IPO-Pak is A top-down gradual and selective approach based on special and differential treatment principle of World Trade Organization (WTO) is being followed under which the developed regions like Karachi, Lahore, and Islamabad of Pakistan have been prioritized for IPR enforcement. The less developed areas of Pakistan will be focused on later.

Enforcement Agencies

Enforcement coordination is logically structured at the policy level, supervisory level, and operational level as follows:

Policy Board Interface	Policy Level
Organizational Interface	Supervisory Level
Enforcement Coordination Committee Interface	Operational Level

Following is the list of enforcement agencies;

District Police	Overall enforcement

Federal Investigation Agency (FIA)	Production control
Pakistan Customs	Border control
PEMRA	Signal piracy control
Judiciary	Litigation management
IPO-Pakistan	Overall enforcement coordination

IPO Offices

- IPO HQs, Islamabad
- The Patent Office, Karachi
- Trademarks Registry, Karachi
- Copyright Office, Karachi
- Regional Office, Lahore
- Regional Office, Peshawar

IP Tribunals in Pakistan

Intellectual Property Tribunal established under the Intellectual Property Organization of Pakistan Act, 2012. At present Intellectual Property Tribunal is working at Islamabad, Lahore, and Karachi (Ministry of Law and Justice, 2018).

The Federal Government may, by notification in the official Gazette, establish as many Tribunals as it considers necessary to exercise jurisdiction under Intellectual Property Organization of Pakistan Act, 2012, appoint a Presiding Officer for each of such Tribunal and where it establishes more Tribunals than one, it shall specify in the notification the territorial limits within which each of the Tribunal shall exercise its jurisdiction.

Intellectual Property Rights including copyrights, trademarks, patents, designs, layout, designs of integrated circuits, trade secrets and other intellectual property laws; supported by other laws are powerful tools for economic growth. The protection of these and similar intellectual property rights of the citizens is essential to foster creative thinking, stimulate creativity, provide incentives for technological innovations, and attract investment.

Advantages of Specialized IP Tribunals

Advantages of IP tribunals are; (11th ACE Session WIPO-HQs, Geneva, 2016)

- Creation of subject matter experts/expertise
- Effectiveness of decisions
- Ability to create special court procedures to enhance efficiency and accuracy
- Consistency and predictability of case outcomes
- Progressive or dynamism

Tribunal Locations

1. Intellectual property tribunal, headquarter (Islamabad)

   NTC Headquarter Building, Ataturk Avenue (East), G-5/2, Islamabad.

2. Intellectual Property Tribunal (Karachi)

    04th Floor of SLIC Building No.3, Dr. Zia-ud-Din Ahmed Road, Karachi.

3. Intellectual Property Tribunal (Lahore)

    Old Sessions Court Building, New Judicial Complex, C-2, 2nd Floor, Lahore.

Patent Regionality Behavior

The grant and enforcement of patents are governed by national laws, and also by international treaties, where those treaties have been given effect in national laws. Patents are granted by national or regional patent offices. A given patent is therefore only useful for protecting an invention in the country in which that patent is granted. In other words, patent law is ***territorial in nature***.

PCT – The International Patent System

The Patent Cooperation Treaty (PCT) assists applicants in seeking patent protection internationally for their inventions, helps patent Offices with their patent granting decisions and facilitates public access to a wealth of technical information relating to those inventions.

By filing one international patent application under the PCT, applicants can simultaneously seek protection for an invention in a very large number of countries.

The PCT is an international treaty with more than *150 Contracting States*.1 The PCT makes it possible to seek patent protection for an invention simultaneously in many countries by filing a single "international" patent application instead of filing several separate national or regional patent applications.

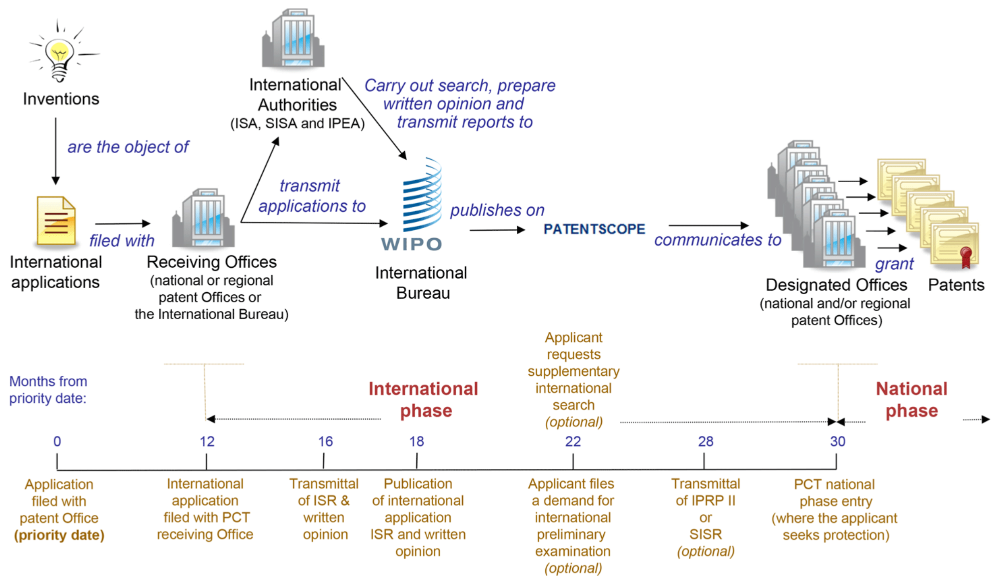

Figure 6-2 ***Overview of the PCT System***

Requirement for PCT contracting state

The Contracting States; (World Intellectual Property Organization, 1970)

- ➢ Desiring to contribute to the progress of science and technology.
- ➢ Desiring to perfect the legal protection of inventions.

- Desiring to simplify and render more economical the obtaining of protection for inventions where protection is sought in several countries.
- Desiring to facilitate and accelerate access by the public to the technical information contained in documents describing new inventions.
- Desiring to foster and accelerate the economic development of developing countries through the adoption of measures designed to increase the efficiency of their legal systems, whether national or regional, instituted for the protection of inventions by providing easily accessible information on the availability of technological solutions applicable to their special needs and by facilitating access to the ever-expanding volume of modern technology.
- Convinced that cooperation among nations will greatly facilitate the attainment of these aims.

PCT and Pakistan

Pakistan has a keen interest to be a part of this PCT and to include in PCT contracting countries in near future. It will help IPO-Pak and inventors to secure their inventions not only nationally but internationally as well.

Patents awarded by IPO

Following graph represents the patents that are awarded by IPO Pakistan till to date;

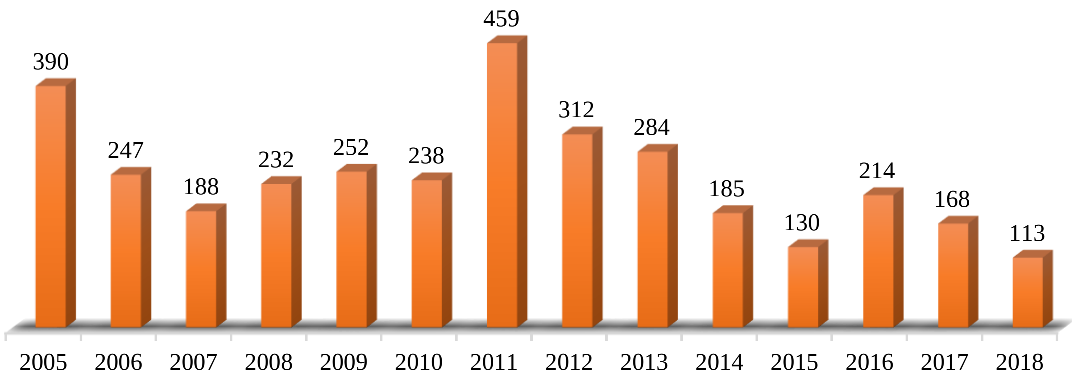

Figure 6-3: ***Number of Patents Awarded by IPO***

Chapter 7 THE WAY FORWARD

Pakistan's power sector is facing multiple challenges such as huge dependence on thermal energy resources (furnace oil and gas), transmission and distribution losses and increasing supply-demand gap. According to the World Energy Council's Energy Profile ranking of 2017, Pakistan lies in bottom 25 % countries based on the country's performance in Energy security, Energy Equity, and Environmental Sustainability. Although Pakistan has made impressive efforts to develop renewable energy resources for power generation in recent years, still the country needs long-term policy framing and implementation to ensure sustainability. In the light of literature review, industry talks, and interviews, the following recommendations are being put forward to promote manufacturing and development of RET in Pakistan.

Focus on Long-Term RET Planning

Despite so many institutions working on the policy development and research in RET, no proper integrated implementation plan is set up. The Pakistan Vision 2025 gives details about the formulation of an integrated plan to maximize the utilization of indigenous and renewable energy sources for the social and economic well being. An integrated energy plan involves policy framing and implementation with the involvement of all stakeholders including researchers, manufacturers, suppliers, end-users, transmission and distribution companies, regulatory companies and financial institutions. Such a plan assist policymakers in setting up priorities according to economic, technology, environmental and human resource constraints of each RET. This process also evaluates the social and economic benefits of each RET, thus guiding the concerned organizations about RET deployment routes and targets.

Public-Private Partnership

To increase our indigenous production and skilled workforce, it is imperative to include private manufacturers of RET in policymaking. Additionally, technical support should be provided to local RET manufacturers in the shape of technical workshops, seminars, and conferences. In this regard, public organizations like AEDB and PCRET can play a vital role in utilizing the unemployed workforce for training and capacity building in RET.

Financial incentives

To create an amicable environment for investors, financial incentives such as income tax and sales tax rebate should be offered. Concessions in import duties for high-tech equipment should also be considered. State Bank of Pakistan has already announced a policy for the development of RET which allows investors to get loans at suitable interest rates from banks and other financial institutions for RET projects.

Technology transfer

To ensure the production of high-quality RET products, it is necessary to use the latest and updated technology, machinery and human resource. To ensure this, a condition should be introduced for the foreign companies working on RET projects in Pakistan to manufacture some percentage of their equipment and machinery locally. Apart from this, local teams should be sent to countries with the most updated technologies and methods for the learning process.

Improvement in Transmission and Distribution Sector

About 15% of power generated in Pakistan is lost because of inefficient Transmission and Distribution system. With the recent surge in deployment of RET in Pakistan, extra efforts should be poured to develop an efficient and adequate transmission and distribution system. This involves long-term planning by carefully evaluating and estimating the amount of energy that will enter the national grid in the next twenty or thirty years. It is difficult for the current grid system to respond to ever-changing and rising power demands. A solution to this would be the introduction of Smart grid system: a technology that allows two-way communication between the utility and end user for more efficient transmission and better integration of RET technologies in the grid.

Industry-Academia linkage

Creating an environment of Research, Design, and Development (RDD) between RET industry and Science and Technology universities is essential to tackle different technical and production issues that arise during product development. A unique way to promote this kind of culture in Pakistan is to establish research groups for common goals, which will include members from different industries and universities, all trying to achieve one goal.

Development of small and medium industries for RET

Small and medium enterprises (SME) are the economic backbone of most developed countries. In China, SMEs contributes to more than 50% of the GDP, creates 75% new jobs every year and have a share of more than 50% in exports. Pakistan should emulate this concept of upbringing and developing the SMEs in the country. Establishment of RET SMEs would not only bring the power supply-demand gap closer but will also ensure the productive use of renewable energy through socio-economic benefits.

Utilization of already established industry

Pakistan has a very productive fans and pumps industry established in Gujrat and Gujranwala cities of Punjab province. Other components like motors, transformers, and farming machines are also fabricated here. The potential of this industry should be explored to assess their manufacturing capabilities of RET like wind and hydro turbines runner, generators and other related components.

Energy Efficiency

It is better to save 1 kWh already available instead of generating a new 1 kWh. Keeping this in mind, we should be more focused on energy saving than its production. Nowadays energy efficient buildings are the new way to attract customers and tenants. Different organizations in the world are researching on conserving energy in residential, business and industrial buildings. Employing RET in your building can lead to a Net Zero or Green Building. In this regard, the RET industry in Pakistan should work closely with Pakistan Green Building Council to provide standardized and high-quality products to ensure maximum energy saving. A mandatory energy audit for industrial buildings would identify the energy leakages and make certain the use of highly efficient energy sources.

Appendix A

S. No	Form	Description	Fee (PKR)
1	P-1	Application for patent when the true and first inventor is sole or joint applicant.	4500
		For each additional page of specification beyond 40 pages.	60
		For each additional claim beyond 20 claim.	150
2	P-1A	Application for patent when the true and first inventor is NOT a party to the application.	4500
		For each additional page of specification beyond 40 pages.	60
		For each additional claim beyond 20 claim.	150
3	P-1B	Application for patent of addition when the true and first inventor is sole or joint applicant.	4500
		For each additional page of specification beyond 40 pages.	60
		For each additional claim beyond 20 claim.	150
4	P-1C	Application for patent of addition when the true and first inventor is NOT a party to the application.	4500
		For each additional page of specification beyond 40 pages.	60
		For each additional claim beyond 20 claim.	150
5	P-2	Convention application for patent when the true and first inventor is sole or joint applicant.	4500
		For each additional page of specification beyond 40 pages.	60
		For each additional claim beyond 20 claim.	150
6	P-2A	Convention application for patent when the true and first inventor is NOT a party to the application.	4500
		For each additional page of specification beyond 40 pages.	60
		For each additional claim beyond 20 claim.	150
7	P-2B	Convention application for patent of addition.	4500
		For each additional page of specification beyond 40 pages.	60
		For each additional claim beyond 20 claim.	150
8	P-2C	Convention application for patent of addition when the true and first inventor is NOT a party to the application.	4500
		For each additional page of specification beyond 40 pages.	60
		For each additional claim beyond 20 claim.	150
9	P-3A	Application for Complete Specification.	3150
10	P-3	Provisional Patent Application.	1350
11	P-4	Application for extension of time Under Section 16(6) (a) Application for extension of time Under Section 27(3) &32(2) and 88(1), per month.	750
12	P-5	Application for the deletion of a reference.	500
13	P-6	Application for substitution of applicant.	1000
14	P-7	Notice of opposition.	1500
15	P-8	Notice of intention to attend hearings.	1500
16	P-9	Application for third party observations on Patentability.	10000
17	P-10	Request for sealing.	4500

18	P-11	Application for the amendment of a patent granted to a deceased person.	5000
19	P-12 5to8	Application for renewal of a patent. Before expiration of 4th year in respect of 5th year. Between 5th to 8th year.	6000
20	P-12 9to12	Application for renewal of a patent. Before expiration of 4th year in respect of 5th year. Between 9th to 12th year.	9000
21	P-12 13to16	Application for renewal of a patent. Before expiration of 4th year in respect of 5th year. Between 13th to 16th year.	12000
22	P-12 17to20	Application for renewal of a patent. Before expiration of 4th year in respect of 5th year. Between 17th to 20th year.	16000
23	P-13	Application for restoration of a patent.	9000
24	P-14	Application for revocation of a patent.	2700
25	P-15	Application for surrender of a patent.	1500
26	P-16	Application for amendment of pending specification / accepted specification.	1500
27	P-17	Application to amend specification when the amendment is made to meet an objection contained in an examiner's report.	500
28	P-18	Application for directions of Controller under sub-section (1) of section 35.	2000
29	P-19	Request for decision of Controller under section 36(1)	2000
30	P-20	Application to determine a dispute as to rights in an invention undersection 36(1).	2000
31	P-21	Application for the correction of clerical error.	1500
32	P-22	Application for grant of non-voluntary license.	2700
33	P-22A	Application for grant of exclusive marketing rights.	3000
34	P-22B	Application to the Federal Government for Exploitation of a patent.	3000
35	P-23	Application for alteration of a name, nationality, address or address for service.	1500
36	P-24	Application for recordal of an assignment etc., by the assignee.	1500
37	P-25	Application for recordal of an assignment etc. by the assignor etc.	1500
38	P-26	Request for certificate of the Controller.	1500
39	P-27	Request for Search.	300
43	P-28	Form for Authorization to Agent.	-
41	P-29	Application consequent upon a Court order.	1500
42	P-30	Application for issuance of a duplicate patent	1500
43	PTA1	Application for registration of a patent agent.	-
44	PTA2	Application for restoration of the name of a patent agent.	-
45	PTA3	Application by a patent agent for alteration of name, address, business address or qualifications.	-