Chapter I
INTRODUCTION

Being blessed with numerous natural resources (like high mountain ranges, deep sea ports, fertile lands, fresh water flows, natural gas reserves, ores of coal, iron, and copper), Pakistan has an enormous potential of renewable energy sources. However currently, Pakistan is depending heavily upon traditional methods for energy production. Pakistan has an area of 796,096 Km^2 and its population is more than 190 million. It consists of five provinces, namely, Punjab, Khyber Pakhtunkhwa, Sindh, Baluchistan, Gilgit-baltistan and two regions comprising Federally Administered Tribal Areas (FATA) and Azad Jammu & Kashmir (AJK). The country has the world's best irrigation network system. It also has a nationwide electricity transmission grid.

Pakistan has been blessed with various primary energy sources both renewable and nonrenewable. It has rich fossil fuels, water, wind and solar energy reserves. However, the share of hydel power production has been decreasing continuously since last few decades whereas renewable sources share remained negligible (SE4ALL, 2014). In Pakistan, the problem of energy deficiency is persisting from many decades and this problem has worsened under successive governments. During the fiscal year 2014-15 growth in generation of electricity was 0.02 percent whereas the growth of consumers was 4.12 percent which indicates an alarming situation of electricity in the country (NTDC, 2015).

Today, Pakistan needs an appropriate energy strategy for the utilization of available energy resources that can make Pakistan independent in fulfilling the energy needs. The Average 6500 MW of power is required to be added to the national grid

(Shakir et al., 2014). Proper usage of alternate energy resources (wind, solar, nuclear) along with hydropower generation, this gap can be covered.

1.1 POWER SECTOR OF PAKISTAN

Water and Power Development Authority (WAPDA) was established in 1958 in Pakistan. The agenda of WAPDA includes electricity generation, transmission and distribution along with irrigation and flood control. Electricity customers in Pakistan are over 25 million. Along with WAPDA, other major power producers in the country includes Karachi Electric Supply Company (KESC), Pakistan Atomic Energy Commission (PAEC) and Independent Power Producers (IPP's). National Transmission and Dispatch Company (Pvt) limited (NTDC) is responsible for electricity transmission from power plants to distribution companies (DISCO's) which distribute the electricity to end consumers (PPIB, 2016).

1.2 POWER GENERATION AND CONSUMPTION

Available sources of electric energy generation in Pakistan are Hydel, Thermal (Oil, Coal, Gas), Solar, Wind, Biomass, and Nuclear resources. The power sector of Pakistan is majorly based on a mix of hydel and thermal units. Currently, energy generation from different fuels is Oil 35.52 %, Hydro 33.41 %, Gas 23.52 %, Nuclear 5.13 %, Coal 0.11 %, Wind 0.47 % and Imports 1.85%. Whereas, Pakistan's installed capacity of electricity generation by sector wise is WAPDA (hydro + Thermal) is 60 %, IPP's 36.5%, PAEC 3.2% (NTDC, 2015). Electricity consumption by different sectors is Domestic 47%, Industrial 24%, Commercial 7%, Bulk surplus 6%, Agriculture 10.3 %, Public Lighting & Others 5.6 % (NTDC, 2018).

In 2015 electricity demand was 21000 MW whereas the total supply in the country was 15000 MW with the total installed power generation capacity of 25,100 MW (Bhutta, 2016). Because of this gap the country is going back in almost every field of life. Electricity demand-supply gap reaches up to 6,000 MW during summer causing 8-16 hours per day load-shedding.

Though the generation capacity of Pakistan at current scenario is so much so that it can meet the demand of the consumers provided if the electricity generations plants run at their full potential. But, in the existing situations and as per the increasing rate of consumers; the electricity generation is not up to the mark to meet their demands. The number of consumers in the country has been increasing rapidly due to high urbanization, expansion of large cities, and electricity grid extension to villages and un-electrified areas. Number of consumers has been increased to more than 25 million. A comparison between growth in electricity generation and number of consumers is given in Table 1.1.

Table 1.1 Energy Generation and Consumer Growth

FY Ending 30th June	Growth in Energy Generation (%)	Growth in No of Consumers (%)
1964	25.65	16.65
1974	5.02	7.03
1984	9.48	8.46
1994	3.93	5.09
2004	7.89	5.80
2012	-0.94	3.63
2015	-0.02	4.12

Source: (NTDC, 2015)

1.3 POWER PRODUCTION COMPARISON IN ASIA

Table 1.2 gives a comparison of electricity production from different sources between Pakistan and neighboring countries. India and China are relying on their own coal deposits and producing electricity. Iran has locally available oil and gas reserves to fulfill its power demand. But in case of Pakistan imported oil or fastly depleting gas reserves for electricity production rather than using its locally available coal and renewable resources mainly hydro.

Table 1.2 Electricity Production of Neighboring Countries by Source

Country	**Year**	**Coal %**	**Gas %**	**Oil %**	**Hydro %**	**Nuclear %**	**Others (Wind, Solar, Biomass)**
Pakistan	2016	0.1	25	36	29	5	4
China	2014	61.2	1.9	0.2	20.3	1.4	7
India	2016	60.8	8.2	-	15.5	1.9	12
Iran	2011	0.2	66.8	27.6	5	0.1	0.1

1.4 HYDROPOWER, A VITAL OPTION FOR PAKISTAN

Pakistan is generating electricity from different sources, mainly from oil, gas, coal and hydro. Different alternate sources are also in use i.e. wind, solar, and biomass. A brief detail of issues in electricity production from these sources are discussed below.

Electricity from Thermal (coal) is much costly. Pakistan has to import Oil to fulfill its energy demand and rapidly increasing oil prices burden the overall economy of the country. And most importantly, the carbon emissions from production processes are ruining the environment.

Solar production is costly and lacks durability. Solar projects are area specific where sunlight is available in abundance during the long part of the year. Wind production is less sustainable as the wind is not continuous in the country. In Pakistan mainly the coastal line is suitable for wind projects installation. Biomass production plants are costly and need investment from government and private sector. The main hindrance in these projects is that they are seasonal and the private sector is not willing for investment due to illiteracy to these projects.

Electricity production through nuclear reactors is feasible for countries having high reserves of raw material (uranium). Nuclear power plants installation is much costly; their operation requires a highly controlled environment and qualified staff. Proper arrangement for radioactive waste is needed. Proper measures are required to minimize the risk of accidents.

Hydropower is considered to be the best renewable energy source as in hydropower production the main source (water) is not wasted, it can be reused for irrigation, for electricity generation downstream, backwater pumping, ground recharge etc. In Pakistan hydropower is contributing a big share in total electricity demand. Hydropower projects can be mini (less than 1MW), small (1-10 MW) and large (greater than 10MW) (Energypedia, 2017). They can be run-off-river or storage projects depending upon the location as well as feasibility. Large hydropower projects require years for feasibility, designing, and construction. They may become controversial, especially since they require involuntary resettlement of a large population in a positive manner that causes the delay of projects. Large scale hydropower projects thus cannot be a taken as first option for a developing country like Pakistan who is facing great energy crisis. Small or medium projects need less time to complete. Pakistan has world's best irrigation system having much potential for run-off-river projects. As no reservoir is created these projects do not cause problems associated with reservoirs such as displacement of people, sedimentation and environmental impact. (Carrasco et al., 2016).

Northern regions of Pakistan possess most of the hydropower resources whereas small to medium schemes are located on canal falls and barrages of southern part of the country. Most of the installed hydropower capacity is owned by the public sector (WAPDA, 2013).

1.5 HYDROPOWER POTENTIAL IN PAKISTAN

The hydel power generation depends upon the inflow of water in the reservoir, reservoir levels, and discharge of water from the reservoirs which varies from season to season gives a quick glance on the hydropower generation capacity trend in Pakistan. Against the total hydropower potential of 60,000 MW (WAPDA, 2013), installed hydropower capacity in 2018 was 8683MW (NTDC, 2018), which is more than enough for Pakistan to fulfill its present and forecasted energy demands. Large hydropower projects are time taking. If small and medium hydel power projects are installed and proper strategies are adopted for planning, organizing and distribution, Pakistan can be capable to export electricity to other undeveloped countries after fulfilling its own requirements.

Table 1.3 Trend in Pakistan's Hydel Power Generation Capacity (MW)

Period	Punjab	KPK	AJK	Sindh	Baluchistan	Total
Pre WAPDA	23	44	0	0	0	67
1958-1980	63	904	600	0	0	875
198-2000	109	3766	1000	0	0	4875
2001-2006	1697	3766	1000	0	0	6474
2007-2012	1699	3952	1039	0	0	6720
2018*	-	-	-	-	-	8683

Source: (ICCI, 2011), * (NTDC, 2018)

1.6 PROBLEM STATEMENT

Although power production from different sources like oil, coal, hydel, wind, solar, biomass etc.; is also required for sustainability but overall hydel based generations are more economical for Pakistan. Moreover, conservation of water in reservoirs can help Pakistan to improve and expand its irrigation system to supply water to arid areas of the country. The key focus of this research work was the analysis of hydropower potential of Pakistan to overcome the ongoing energy crisis. Electricity generation from coal and oil is expensive creating an overburden on Pakistan's economy and Pakistan being a progressive country cannot afford this burden. Solar energy projects are seasonal, require high initial and maintenance cost. Wind energy production is restricted to specific areas having high wind speed and it can only support the specific areas of energy requirement.

In Pakistan, different hydel based energy production option are possible. However, large hydropower projects require much time for designing as well as for construction. Although, after completion, their impact on the overall economy cannot be ignored. The small and medium projects are more suitable to overcome the current scenario of energy crises in Pakistan. Low head and run-of-river projects are reasonable options in the scenario of distributed energy schemes but they are seasonally based.

The main issue with hydel based production is that less rains during a year may result into low reservoir level in off season. Thus, an entire dependency on hydel energy is not sustainable. So, we must decide a reasonable energy mix ratio with all other formal electricity generation options and renewable sources.

1.7 OBJECTIVES

The main objectives of this research work are:

1) To analyze power production from different sources, their pros and cons.
2) Assessment of prevailing hydropower potential (currently working and planned or streamline projects) to meet current and forecasted electricity demand in Pakistan.
3) To study the effectiveness of hydropower production options in Pakistan and optimization of hydropower share for a sustainable electricity mix ratio.

1.8 UTILIZATION OF RESEARCH RESULTS

This study provides information and realistic data for the upcoming projects. The research work is useful at the national level to cater upcoming problems in different energy projects and to achieve the optimum results. The study is valuable to make hydropower projects compatible with other electricity production mechanisms. The results show whether our planned projects meet energy demand in the country in the long run or not. To overcome the gap between demand and supply for coming years this research guide briefly describes that:

a) Which areas of our planning need to be reviewed?

b) Which energy resources need to be increased or altered?

c) What mitigation and compensation measures must be taken?

d) Which new techniques of renewable sources should be introduced in the country?

Today the water availability for life situation is very dangerous and in coming years it is going to be much critical if appropriate measures are not taken. Construction of reservoirs for hydropower generation not only provide water for power generation but this also fulfills our agriculture, drinking and soil recharge water requirements. The results are helpful in improving our energy policies which will ultimately have a positive impact on our economy.

Chapter II
LITERATURE REVIEW

2.1 RELATED WORK

Dependency on fossil fuels is continuously deteriorating the situation in terms of environmental pollution, sustainable development and economic burden. For a country like Pakistan having limited fossil fuel reserves, this becomes more serious. A large portion of rural areas population (62 % in 2011) doesn't have access to the country's centralized electricity and heavily rely on traditional resources such as animal waste, wood, crop waste and biomass. This huge biomass potential can be used to produce decentralized electricity if properly used but this needs investment and better infrastructure. (Bhutto et al., 2011)

European countries are making efforts to transform their power supply system on renewable sources. Integration of renewable energy sources indicates an optimal share of renewable sources such as in case of Germany 50 % of electricity demand can be met with an optimal mix of wind and solar whereas remaining power requirement can be fulfilled with other flexible power supply options like hydro and thermal. This limit can be increased to 80 % if highly efficient storage devices are added in currently used seasonal less efficient storage devices. (Weitermeyer et al., 2015)

Global Value Chain (GVC) is an effective approach to analyze the country's position in global perspective. Industry and agriculture departments are two major parts which are directly linked to the life system of the entire society. China invested a lot in renewable energy production like wind, solar etc. to reduce its dependency on fossil fuels. Tajikistan has large coal reserves in its remote areas resulting in high cost of mining and transportation. Tajikistan shifted to renewable sources specially Hydropower to fulfill its energy demand. Like these two countries, Pakistan can enhance food security in the country by use of renewable energy. (Kiyani, 2015)

Today Pakistan is lacking with an appropriate energy strategy for the utilization of available energy resources and making Pakistan independent in fulfilling its energy needs. An average amount of 6500 MW is required to be added to the national grid. Proper usage of alternate energy resources (wind, solar, nuclear) along with hydropower generation, this gap can be covered easily. Emphasize should be on the installation of small scale hydro projects because the installation of production plants for renewable energy sources is full of challenges in remote areas. (Shakir et al., 2014)

More than 16% of the world’s total electricity is generated from hydropower. Hydropower is one of the most commonly used renewable sources of energy. Small-scale hydropower systems are successful options for hydropower generation, particularly in small localities and remote areas. Regardless of its low capacity, small-scale hydropower produces cheap, clean, and reliable electricity. Pakistan’s northern areas have many suitable sites which can be utilized to meet the increasing demand of electricity in Pakistan. (Balkhair & Rahman, 2017)

Currently Pakistan is fulfilling its energy needs from fossil fuels which are not environment-friendly. Use of renewable energy sources a safe alternate can be provided to keep pollution within defined permissible limits. China, one of the world biggest economies is an example of shifting from fossil fuels to renewable sources i.e. Nuclear Energy. All the facts show that the current shortage of electricity in Pakistan is due to inefficient approach, mismanagement and following bad practices, otherwise Pakistan is quite capable of generating 10 times more electricity it currently needs (Samad et al., 2016). Economic growth and energy demand are directly proportional to each other. Empirical analysis of data from 1971 to 2012 shows that energy consumption is the main ingredient of GDP growth. A definite and affordable power supply is the need of time. (Zeshan & Ahmad, 2013)

Pakistan has a huge potential of energy sources which are yet unexplored. This unexplored energy sources can satisfy the domestic energy requirements and can also be exported to other energy deficit countries. Co-integration relationship between economic growth and energy consumption exists in case of Pakistan which shows that energy consumption is must for economically strong Pakistan. (Shahbaz et al., 2012)

About 54% of Pakistan's rural population is living a sub-standard life because of insufficient supply of electricity. Alternative energy efficient sources need to be utilized instead of depending on fossil fuels. There is a need to address the on-grid and off-grid challenges in establishing small renewable energy projects in remote areas (including hydropower) through microfinance and other financial tools. (Mirza & Khalil, 2011)

A correlation between energy consumption and economic growth for Pakistan, calculated using co-integration and error correction model, confirms that an energy shock can affect the economic development of Pakistan in the long-run (Ismail et al., 2008). A dependency on fossil fuels for energy needs is not suitable because greenhouse gas (GHG) emission is enormous. This tremendous environmental impact forces to decrease their use for electricity generation. The use of renewable energy resources i.e., hydel, wind, and solar, in a distributed generation style is the solution. (Akorede et al., 2010)

The economic growth impact of renewable energy consumption is different in different countries. For example, in the case of United States it has little impact on economy (Payne, 2011) whereas for India and Italy it contributes much (Tiwari, 2011; Desideri et al., 2011). Empirical results for different countries (Austria, Canada, Germany, Great Britain, Finland, France, Italy, Mexico, Portugal and the U.S.) show that their economic growths are directly proportional to biomass energy consumption (Bildirici & Özgür, 2015). Adoption of renewable energy policies has positively affect the economic growth of Indonesia (Arifin & Syahruddin, 2011).

Total renewable energy potential of Pakistan is about 167.7 GW which means that if exploited with proper infrastructure and policies, it is enough to meet the current electricity demand (Rafique & Rehman, 2017). Among vast potential of renewable energy sources of Pakistan, hydel potential stands at 60,000MW. A good mix ratio of different energy sources can contribute 80.7 % and in this whole, hydropower share can be 40% which is currently just 11 %. (Qureshi et al., 2014)

2.2 POWER PRODUCTION SOURCE

2.2.1 Background

Reliable and sustainable energy plays a basic role in the economic development and growth. During the industrial revolution era and even up till now in 21st century, technological break throughs have transformed and improved the use of energy in our daily lives. Revolution in energy production and distribution strategies have led our today's industries, society and transportation to a new way of evolution. The modern energy systems and electricity is essential for life today. Electricity is needed for industries, agriculture, the functioning of hospitals, food production, food processing, to get clean drinking water, household processes, communication via mobiles & internet. The central role of energy in society has placed energy issues on top priority throughout the world. Different issues relating to selection of energy production source, nature of power plant and energy import/export are mainly controlled by political governments. Power policies are also strictly linked to environmental policies regarding reduction of greenhouse gas emissions. Access to affordable, cheap, clean and reliable energy is a keystone of the world's economic growth and prosperity. A significant portion of energy consumption is linked with economic development therefore energy consumption is projected to increase by 5% between 2016 and 2040 (EIA, 2017). In 2018 the world population was 7.7 billion and according to the United Nations, it will further increase to 11.2 billion in the year 2100 (Wikipedia, 2018). Developing countries of Asia and Africa will lead this population growth. This quickly rising economic growth will lead to additional energy demands.

2.2.2 Sources of Energy

Naturally available sources of energy are called primary sources (Renewable & non-renewable) and it can directly be used different purposes but electricity is not naturally available. We have to produce it from the primary sources via any generating mechanism. A typical electricity system includes i) Electricity production Unit (thermal, hydel, nuclear, windmills etc.); ii) Transmission and distribution; iii) End users (domestic, industry, transport, hospitals etc.).

Different countries adopt different energy mix ratio depending upon the availability and different pros and cons of the energy resources. A few decades back there was dominance of fossil fuels which is still there but with a slight decrease. This fact also varies from country to country. Energy sources are classified as renewable and non-renewable sources. Figure 2.1 shows the detailed classification of different energy sources.

a) Nonrenewable Energy Sources

Non-renewable energy sources are the ones that do not form or regenerate in a short time period. Different fossil fuels were formed after millions of years depending upon the organic material present there, for how long time these matters were buried, temperature and pressure conditions existed as time passed during this whole time period. Nonrenewable energy sources also named as fossil fuels. These come out of the ground as liquids, gasses and solids.

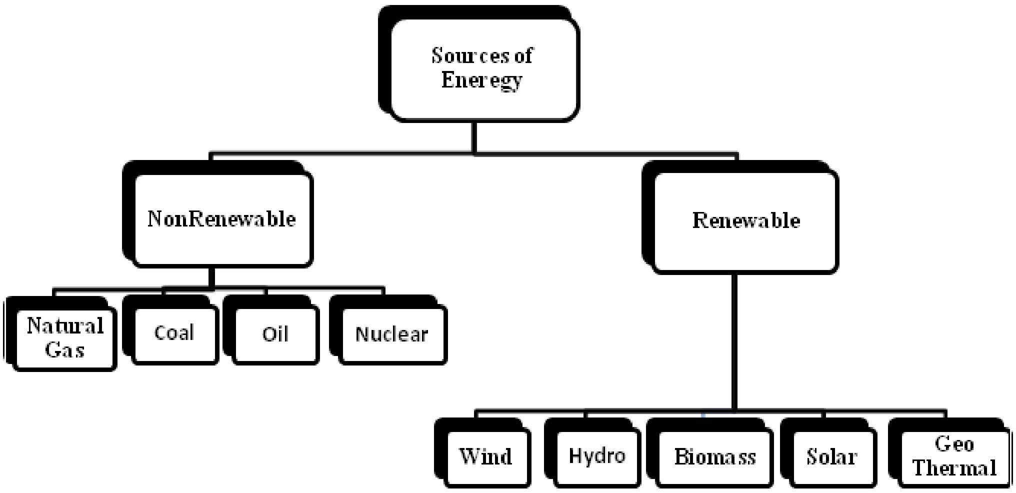

Fig. 2.1 Classification of Energy Sources

b) Renewable Energy Sources

Renewable energy sources are regenerated and can be reused. Solar, wind, biomass, hydel and geothermal are known as renewable sources of energy.

2.3 DIFFERENT ELECTRICITY GENERATION MECHANISMS

2.3.1 Coal Based

Coal has a significant role in power generation globally. Coal-fired power plants are generating 40.8 % of global electricity. Coal extracted from coal mines is transferred to coal power plants where it is crushed to a fine powder so that it could burn more efficiently and quickly. This powder is driven into the combustion chamber at an extreme temperature. Heat and high temperature converts water (adjacent to combustion chamber) into steam. This steam moves the turbine blades at high speed which in turn rotate the tightly wound wire coils and a strong magnetic field is generated and electricity is produced. This electricity is transported to the end users through power grid lines.

Among all the fossil fuels coal is in the most abundant quantity. Due to its wide spread large reserves and easy access, it is comparatively inexpensive to buy from the open market. Most of the coal is easy to pit and this makes it less expensive. Coal burns at low temperatures making the coal-fired plants cheaper and simple that's why the countries having large deposits not only make their first option to generate electricity but also earn a handsome amount through its export. The by-product of burning (ash) can be used for concrete and roadways.

But coal burning is not environment friendly because it releases many toxic gases such as carbon dioxide which is a green house gas (GHG), sulphur dioxide and nitrogen oxide. These gasses have a deep impact on the environment, human health and social communities living near sites, plants and waste sites. Coal is the major source of carbon dioxide emission in the world with a share of 45% in 2015 (IEA, 2017) and this will increase to 60 % by 2030 (GreenPeace, 2008). Coal gives the lowest energy per ton of fuel. Coal has different types depending upon the carbon content present in it such as anthracite, bituminous, sub bituminous and lignite. Heating value or calorific values (stored energy potential in fuel) of different fossil fuels are given in Table 2.1.

Table 2.1 Heating Values of Different Fossil Fuels

Fossil Fuel Type	**Heating Value (BTU/lb)**
Anthracite Coal	14000
Bituminous Coal	11500 - 14000
Sub Bituminous Coal	8500 - 11500
Lignite Coal	7000 - 9000
Oil (No. 1)	19850
Oil (No. 2)	19500
Natural Gas	1024 - 1032 (BTU/ft^3)

Despite all drawbacks, coal is an important energy source. Global primary energy consumption and power production share by coal is 28.6% and 41% respectively. Top ten countries with maximum coal production and maximum share of electricity generated from coal are given in Table 2.2 (IEA, 2017).

Pakistan has huge coal proven reserves of 186 billion tons (ranked sixth worldwide). Most coal fields are in Sindh (Lakhra, Sonda, Jherruck, Thar), Baluchistan (Khost, Sharigh, Harnai, Sor-range/Degari, Duki, Mach, Ziarat) and Punjab (Salt Range Field, Makarwal). Detail of these reserves is given in Table 2.3. This coal can provide

20,000 MW electricity for the next 40 years (Bhutto et al., 2007) but due to lack of interest and expertise and unavailability of new mining and gasification techniques, it is still unexploited.

Table 2.2 World's Top Countries with Coal-Based Electricity

Country	**Coal Production (%age of World Total)**	**Electricity Production by Coal (TWh)**	**%age Share in Domestic Electricity**
China	45.8	4109	79
United States	10.5	1471	43
India	9.0	1042	68
Japan	6.6	343	27
Germany	6.1	284	45
Korea	4.5	237	43
South Africa	3.3	229	94
Australia	2.4	159	68
Russia	1.8	159	16
Poland	1.4	133	87
Pakistan	---	0.15	0.1

Currently total coal production is only 3.34 million tons against 6.56 million tons consumption that means overburden coal is being imported. It is mainly imported from South Africa, Afghanistan, Australia, Indonesia, USA and Canada. Coal contribution in primary energy supply and power generation is 5.4% & 0.2% respectivel (MPNR, 2015). A major part of imported coal is used in steel and cement industry. We can use this expenditure for alternate purposes like, for the development purposes of coal industry such as the installation of coal-fired power plants, research and technology development. To make coal a feasible option Government of Pakistan need to take solid steps.

Table 2.3 Pakistan Coal Reserves as of June 2014 (Million Tons)

Province	Measured	Indicated	Inferred	Hypothetical	Total
Sindh	7664	19370	44290	114132	185456
Khyber Pakhtunkhwa	1.5	4.5	84	-	90
Punjab	55	24	11	145	235
Baluchistan	54	13	134	16	217
Azad Kashmir	1	1	7	-	9
Grand Total	7775.5	19412.5	44524	114293	186007

Source: (HDIP Energy Year Book, 2015)

Most of the coal in Pakistan is lignite in nature having a low amount of carbon, high moisture content and low energy, making this a low quality coal. Even then many countries are generating electricity using coal. Coal characteristics of China, India and Germany and their respective electricity production data is summarized in Table 2.4 to have a comparison with Pakistan. China, India and Germany are generating 946,244 MW, 192,162 MW and 22,774 MW respectively from the coal having characteristics same as of Pakistan but Pakistan has not yet used its reserves properly.

Table 2.4 Coal Characteristics of Different Countries

Country	Moisture (%)	Volatile Matter (%)	Sulphur (%)	Heating Value (Mj/Kg)	Electricity Generation (MW)
China	32 – 50	40- 55	0.58 - 1.27	10-21.4	946,244
India	48	25.6	0.6	10 – 17	192,162
Germany	40 – 60	---	0.15-2.5	8.9	22,774
Pakistan	46	28.0	0.7 - 1.1	11.6	0

Source: (LV et al., 2015), (MPNR, 2015), (Msih, 2018)

Carbon dioxide emission is the biggest disadvantage of coal use. China is producing its 79 % electricity from coal and also the world's largest country with 9085 Mt of CO_2 emission (IEA 2017), and approximately 44 % of these emissions are from power generation. Now China has a promising plan to reduce the emission intensity to 60 – 65% below the level of 2005 by 2030.

China is adopting many approaches to reduce CO_2 emissions from coal-fired plants such as clean coal technologies (CCT), oxy-combustion and CO_2 capture and storage (CCS), integrated gasification combined cycle (IGCC) and carbon capture utilization and storage (CCUS), use of super critical and ultra-super critical instead of currently in use sub critical technology (Chang et al., 2016). Old subcritical plants are being transformed into super critical plants providing 6-8 % increased efficiency. Installed ultra-supercritical generation capacity is 100 GW. A 250 MW IGCC, 600 MW supercritical and 1000 MW supercritical double reheat ultra-supercritical power plant with 47 % efficiency have been built in china. All these are few examples of how China is using coal in an efficient, economical and environment friendly manner. (Chang et al., 2016) (Fan et al., 2018)

Along with the efficiency improvement of coal-fired power plants efficiency by using the above mentioned technologies, china is also increasing its share of renewable power to its power sector. According to EIA (Figure 2.2) in the new policies scenario of Chinese government, there will be 26 % reduction in coal share whereas collective 27 % increase in renewable share (solar, wind and biomass) from 2016 to 2040.

In Pakistan now investment is being started under the China-Pakistan economic corridor (CPEC) scheme. Sindh Engro Coal Mining Company (SECMC) started work on Thar coal project in 2017 with a target of 660 MW electricity production by June 2019, 1320 MW by December 2019 and 3300 MW by 2022. But there are still many deterrent issues in terms of land rights of the people of Thar, availability of fresh water for power plant operation, groundwater depletion, and environmental deterioration (Abubakar, 2017). Following the example of China, Pakistan can adopt clean coal technology to harness its coal power capacity and also through CPEC there is a great opportunity to import these technologies from China.

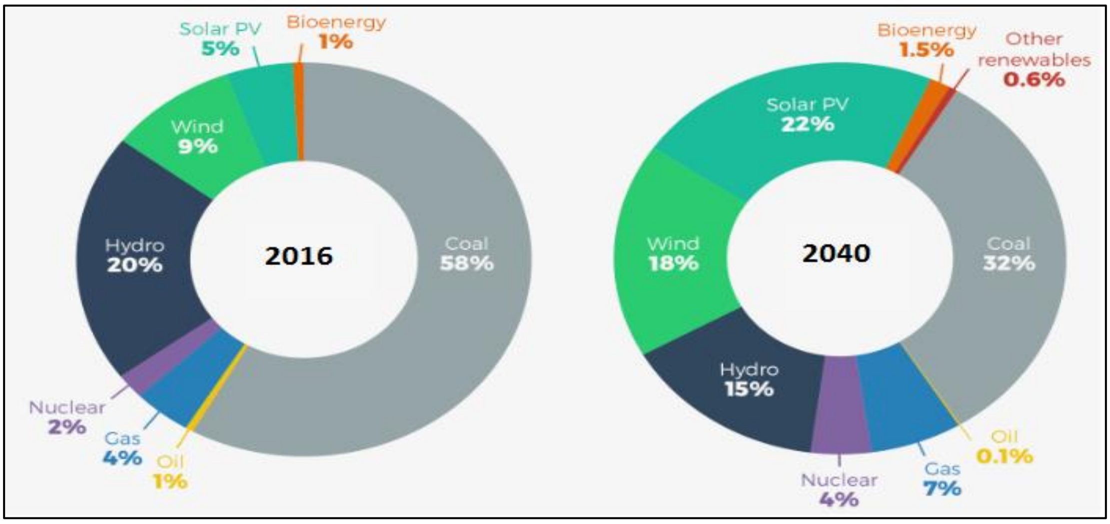

Figure 2.2 China installed Generation Capacity (EIA, 2017)

Another big hurdle in way of coal power development is that huge area of the coal fields is remote and mountainous where basic infrastructure is not available. A few infrastructure requirements for these coal fields are listed as:

- Roads for light and heavy traffic
- Water supply lines (drinking and mine usage)
- Power supply lines

– Transportation (domestic and coal Transportation)
– Coal loading and unloading facilities
– Coal stock area
– Residential, health and educational facilities
– Mining equipment & machinery
– Mine training and rescue facilities
– Adequate infrastructure for the development of power plant
– Transmission lines to connect the main grid
– Environmental monitoring

Developments of all these facilities at the site need a huge investment from provincial and federal governments as well as from the foreigner investors. The absence of these infrastructures in these areas is the main hurdle in the rapid development of coal mining. Comparison of investment and electricity generation ratio also does not convince such a huge investment. However, it doesn't mean that we should not exploit this huge energy source for Pakistan but we need to know that coal is not a solution to the sustainable energy in Pakistan. Last but not least coal is a finite source after a due time it will end up. Thus, renewable sources must be used side by side with coal-based production.

2.3.2 Oil

The general principle of electricity generation from crude oil is the same as for other fossil fuels. In oil-fired power plants heat energy is converted to mechanical energy and then into electricity. Oil has high calorific value as compared to coal. Calorific value of all types of coal ranges between 10 to 24 MJ/Kg, whereas for liquid fuel this ranges between 42 to 47 MJ/Kg which makes it an ideal option to get maximum electricity against per unit of the fuel. But like coal, oil burning is also not environment friendly. A major part of oil transportation between different countries is carried through ships; this can lead to oil spills which endanger the environment and ecosystem (deep-water horizon oil spill in April 2010, Gulf war oil spill in 1991 etc. (CNN, 2017). Oil is a key fuel providing 32% of global primary energy supply. Worldwide countries with highest electricity generation using oil are listed in Table 2.5 (IEA, 2017). Iraq, Kuwait and Saudi Arabia are at top in producing their electricity by oil with 73.3%, 66.3% and 48.8% respectively.

Table 2.5 World's Top Countries with Oil Based Electricity

Country	**Electricity Production by Oil (TWh)**	**%age Share in Domestic Electricity***
Saudi Arabia	150	48.8
Japan	103	9.0
Iraq	50	73.7
Kuwait	43	66.3
Pakistan	41	39.7
Iran	40	21.7
United State	39	0.9
Egypt	38	12.2
Mexico	32	10.2
Brazil	29	6

Oil has fewer shares in global electricity generation (4.1%) because oil and other petroleum products are used in other sectors like transport, industry, domestic need, agriculture etc. Figure 2.3 shows that only a few countries with large oil reserves fulfill their electricity demand from oil rather they prefer to import this to other countries. Saudi Arabia and USA own world's 27% oil followed by Russia with 12% approximately. Saudi Arabia generates its 50% power demand from oil and also the largest oil exporter. Unites States and Russia produce 1% each of their domestic power requirement.

Pakistan is the 5th largest country to produce electricity from oil. In Pakistan crude oil reserves are 498 MTOE and if growth in demand and supply remains the same they will end in nearly 13 to 16 years. Pakistan uses 33% of domestic oil for power generation. To fulfill the oil consumption by different sectors, a significant amount of oil and oil-based products are imported (mainly Saudi Arabia) (Mahmood et al., 2014).

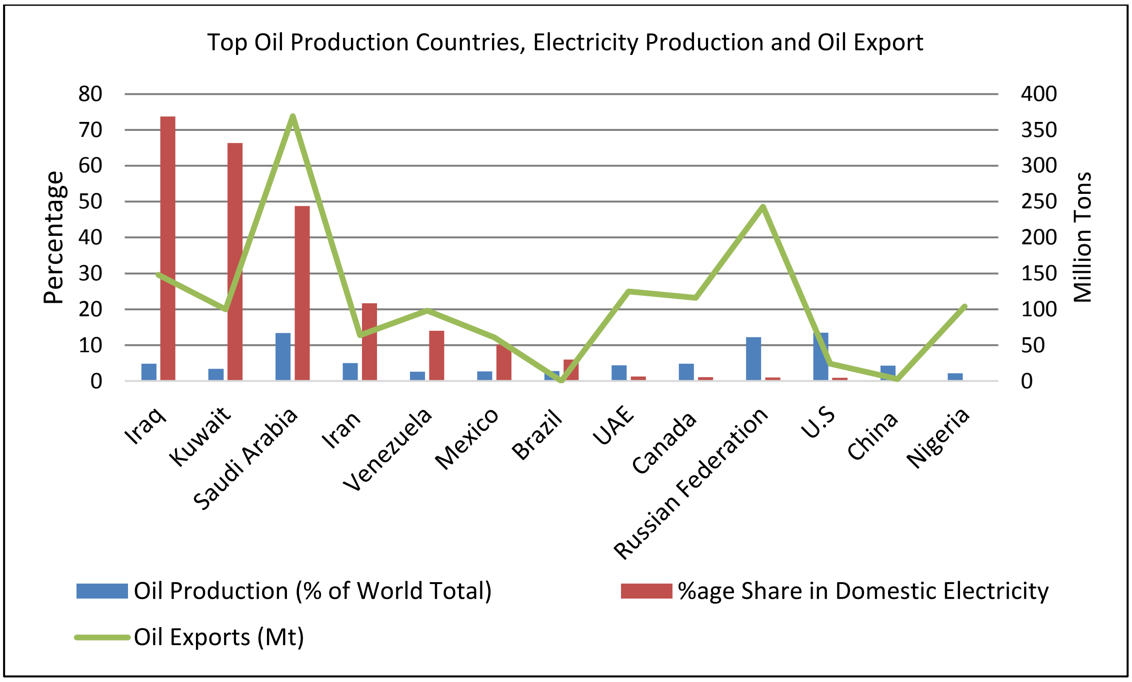

Figure 2.3 Comparison of Countries with Large Oil Reserves and Imports

Figure 2.4 clearly shows the gap of crude oil production and consumption in Pakistan. These huge imports of oil overburden the economy of the country and a developing country like Pakistan cannot afford this in the long run.

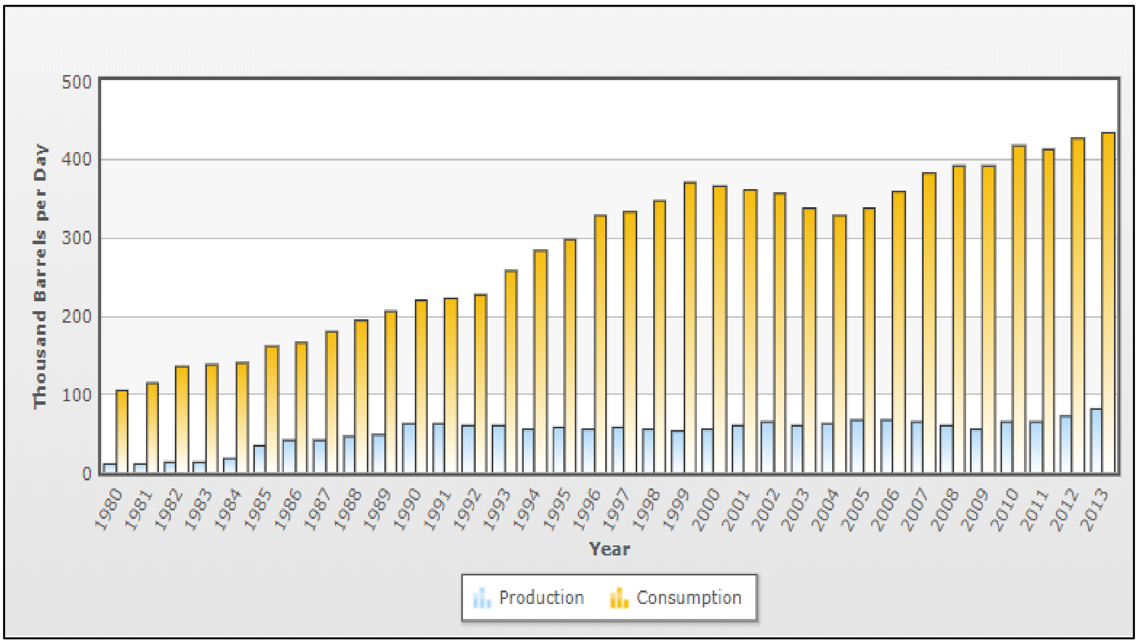

Figure 2.4 Pakistan Crude Oil Production and Consumption (World Bank, 2015)

Fuel prices are increasing day by day which in turn cause an abnormal rise in power tariff for consumers. Lack of funds results in delayed and interrupted power supply. For an effective and sustainable solution to overcome the current energy crisis, we can't rely on these expensive oil imports. We should let these oil imports for other sectors like transport, industry and domestic but for power generation renewable sources that nature has awarded to Pakistan like hydel, solar and wind.

2.3.3 Natural Gas

Natural gas is the third most important source has a vital share in global primary energy supply. During the last few decades natural gas has become a very significant source of energy. In 1973 natural gas production was 1224 bcm (16.0% of world's total) whereas in 2015 it has increased to 3613 bcm (22% of World's total). Similarly natural gas share in electricity generation has also increased with the same growth rate i-e.12% (1973) to 30% (2015). In 1970s and 1980s most electricity production plants were being operated on nuclear or coal. The main reason for this transfer from coal to gas its clean burning as compared to coal. It produces approximately 70% lesser carbon dioxide than the other fossil fuels which helps in improving the quality of air and water.

Russia has world largest gas reserves and top gas exporter in the world. Main Russian gas import markets are European Union. The countries with gas and coal reserves have a high thermal share in electricity production. According to the World Bank data in 2015, the countries that wholly achieving their power demand by Natural gas were Qatar 100%, Turkmenistan 100%, Brunei Darussalam 99%, United Arab Emirates 98.4%, Belarus 98%, Oman 97.4% and Algeria 97.8%. The countries with large gas reserves, available technology and low electricity requirement as compared to the world (For example Qatar just 36 TWh) are using this economical option. Top countries with max gas production and electricity production using natural gas are given in Table 2.6.

In Pakistan gas is a dominating energy source with a contribution of 47% of the primary energy supply in the country. First natural gas reserves were discovered in Baluchistan (Sui) in 1952 and supply of gas was started in 1955. Later the other gas fields were also discovered in Sindh & Baluchistan. Major gas fields are in Sui, Qadirpur, Uch, Badin, Sawan, Zamzama, Mari, Bhit, Kandhkot and Manzali.

Table 2.6 World's Top Countries with Natural Gas Based Electricity

Country	Natural Gas Production (%age of World Total)	Electricity Production by Natural Gas (TWh)	%age Share in Domestic Electricity
United States	21.1	1373	32
Russia	16.3	530	50.2
Qatar	5.1	36	100
Iran	5.7	222	71.3
Saudi Arabia	3.1	189	51.2
Mexico	1.3	186	59.8
China	3.9	145	2.0
Egypt	1.2	129	78.7
Thailand	1.1	127	68.3
UAE	1.7	125	98.4
Pakistan	1.2	---	25

Source: (World Bank, 2015)

Usage of gas has decreased a lot of environmental pollution because residential consumers prefer gas over other fuels like LPG or wood due to its low price. In the last 5 years 0.3million consumers have been added (Total 8.5 Million in 2017) which results in the interrupted supply of gas to other sectors like power generation, commercial, Industry, cement and fertilizers. To cover this gap in demand and supply the government has to import Liquefied Natural Gas (LNG) from Iran and Turkmenistan. Total supply of natural gas in the country in 2017 reached to 4,131 MMcfd. OGRA (Oil & Gas Regulating Authority) regulates the Oil and Gas supply mechanism in the country. There are two main and few other independent companies are in authority for gas supply and distribution in the country under the licenses from OGRA.

(i) SSGCL (Sui Southern Gas Company Limited)

(ii) SNGPL (Sui Northern Gas Pipelines Limited)

Natural gas is also used in the form of LPG and LNG. The use of LPG (Liquefied Petroleum Gas) in the domestic sector has provided a cleaner alternative to dung based source and biomass. Its use in domestic, commercial and industrial sectors accounts 0.7 percent of total primary energy of the country. RLNG (Regasified Liquid Natural Gas) is mostly imported and gives 16% share to total gas supply in the company.

Natural gas consumption in the country is increasing rapidly and total supply of gas from SSGCL & SNGPL is insufficient to meet this demand of the country. In FY 1996-1997 overall gas consumption was 1700 MMcfd and in FY 2016-2017 it has increased to a value of 4,131 MMcfd. Current demand is 6,436 MMcfd and supply is 4,331 MMcfd for 2016-2017. Sindh has the maximum share in domestic gas supply with 56% share whereas Baluchistan, KP and Punjab have 13%, 12% and 3% respectively with 16% RLNG. Punjab has a minimum share in gas supply but maximum consumption of 47%. Sindh consumes 43%, KP 7% and Baluchistan 2% of the total. Detail of gas consumption in different sectors is given in Table 2.7.

Gas is no doubt a cleaner and cheaper option for power production but Pakistan Gas industry is not fulfilling the domestic needs. Due to which government of Pakistan has to decrease the gas supply of other sectors including power generation. This problem gets much severe in winter when domestic requirements are increased. Although other gas reserves are adding up supply but the rate of supply is less than the rate of growth of consumers. A large portion of the gas is used in the transportation sector.

Table 2.7 Sector-wise Gas consumption 2016-17 in Pakistan

Sectors	Gas Consumption (MMcfd)	%age Share
Residential	796	21
Commercial	90	2
General Industry	326	9
Fertilizer	771	21
Cement	2	0
Captive Power	393	11
Power	1,180	32
Transport	184	5

Source: Petroleum Industry Report (OGRA)

As the total gas supply is not enough to meet the domestic, transport and industrial requirement of the country, so power production from gas is not feasible. Only a small share of gas can be used with other economical, affordable and locally available sources.

2.3.4 Wind

The wind has ever been a source of energy for a long time. It has been used to pull sailboats along the river Nile in 5000 BC. The real interest in wind energy was developed in the 1970s during the global oil shortage period. Wind provided a reasonable alternative of oil for electricity generation. The main reason and advantage of shifting to renewable sources is CO_2 emissions and rapidly depleting fossil fuels. With the passage of time, a lot of development has been carried out in wind power production technology and now it has become the fastest growing energy source. The basic principle of windmills or wind turbines or is to convert the moving wind energy into mechanical energy or electric energy.

Wind is an inexhaustible, continuous, clean and abundant source of energy. Windmills projects are area-based projects where the wind velocity is sufficient for power production which can increase the job opportunities in the specific area. Wind turbines are very effective to bring power to remote areas. A small remote village can easily be powered using wind energy. Electricity obtained from windmills is directly proportional to the wind velocity. Velocity increases with altitude. Most wind turbines generate electricity at wind speed between 4 m/sec to 15 m/sec. (Ellabban et al., 2014).

According to GWEC (Global Wind Energy Council) in 2017, there were total 90 countries with the total installation of 539 GW. 30 countries have installed capacity more than 1,000 MW and 9 countries with more than 10,000 MW installed capacity. Table 2.8 enlists the top ten countries with maximum installed capacity for 2017. Spain is at the top with maximum wind share in its domestic power sector (18%) followed by Germany (12 %).

Exhausting local available fossil fuels, the high economic burden of imported thermal resources and gradually polluting the overall environment, Government of Pakistan gave attention to other renewable sources of the country. Pakistan has 1046 Km long coastline in the south of Sindh and Baluchistan. Presence of Thar Desert creates a high wind speed from coastline towards the desert and this one directional wind is available through the year with a little difference in wind speed in winter and summer. The most favorable wind corridor exists from Gharo to Keti Bandar. Pakistan Meteorological Department (PMD) first started recording necessary wind data in 2002.

Table 2.8 World's Top Countries Installed Wind Power

Country	Electricity Production by Wind (MW)	%age of World Total	%age of wind in total Domestic Electricity
China	188,392	35	3.2
United States	89,077	17	4.5
Germany	56,132	10	12.2
India	32,848	6	3.1
Spain	23,170	4	17.6
United Kingdom	18,872	4	11.9
France	13,759	3	3.7
Brazil	12,763	2	3.7
Canada	12,239	2	3.9
Italy	9,479	2	-
Pakistan	789	0.15	0.47

Source: (GWEC, 2018)

Based on the acquired data, PMD and National Renewable Energy Laboratories (NREL, USA) developed a map depicting the country's 340,000MW wind potential in 2007 (Figure 2.5).

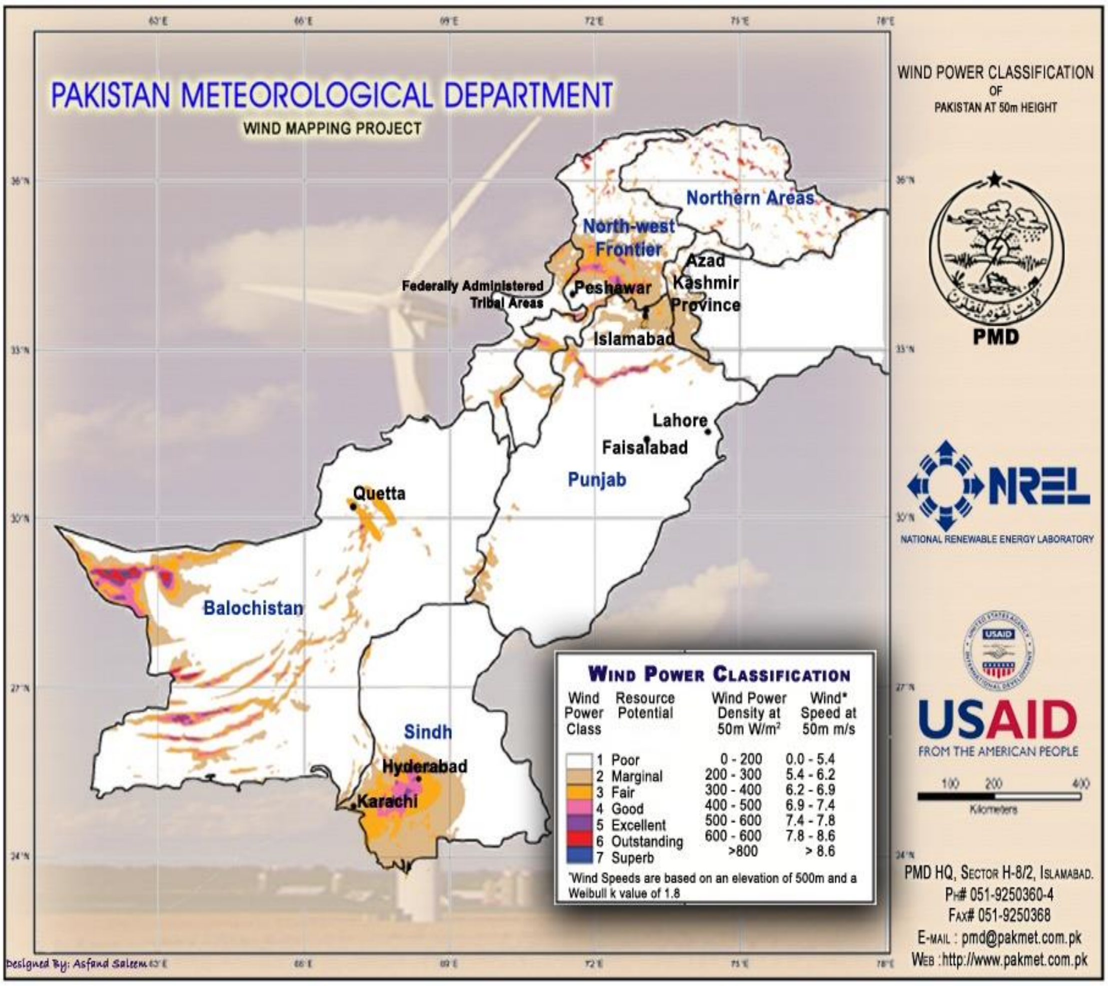

Figure 2.5 Pakistan Wind Potential Map (pmd, 2018)

After the data collection and detailed studies, Gharo-Jhimpir corridor was identified as the most suitable site for wind power installation having Gross potential of 50,000 MW with average wind speed 7 meters per second. Jhimpir Wind Power Plant was completed in 2002 by Zorlu Energy Pakistan having an initial capacity of 50MW. List of commissioned and under construction wind projects in the country are listed in Table 2.9. Besides these projects, 663 MW projects are in pipeline in Jhimpir, Gharo, and Nooriabad.

Table 2.9 Wind Projects of Pakistan

Projects	**Capacity (MW)**	**Location**	**Status**
M/s FFC Energy Limited	49.50	Jhimpur	Operational
M/s Zorlu Energy Pakistan (Pvt.) Limited	56.4	Jhimpur	Operational
M/s Three Gorges Pakistan First Wind Farm (Pvt.) Limited	49.5	Jhimpur	Operational
Operational M/s Foundation Wind Energy II (Pvt.) Limited	50	Gharo	Operational
M/s Foundation Wind Energy-I Limited	50	Gharo	Operational
M/s Sapphire Wind Power Company Limited	52.8	Jhimpur	Operational
Total Commissioned Project Capacity =		**308.2**	
M/s Yunus Energy Limited	50	Jhimpur	Under Construction
M/s Sachal Energy Development Pvt. Limited	49.5	Jhimpur	Under Construction
M/s Metro Power Company Limited	50	Jhimpur	Under Construction
Tapal Wind Energy Pvt. Limited	30	Jhimpur	Under Construction
M/s United Energy Pakistan Pvt. Limited	99	Jhimpur	Under Construction
M/s Hydro China Dawood Power Pvt. Limited	49.5	Gharo	Under Construction
M/s Master Wind Energy Limited	49.5	Jhimpur	Under Construction
M/s TenegaGenerasi Limited	49.5	Gharo	Under Construction
M/s Gul Ahmed Wind Power Ltd	50	Jhimpir	Under Construction
Total Under construction Project capacity =		**477**	

Source: (AEDB, 2018)

Pakistan can use this wind potential present in coastal areas of Karachi, Jiwani, Thata, Baluchistan coastal belt and a few sites in Northern areas and Azad Kashmir to get a massive amount of electricity in the national grid. The areas for wind projects are coastal or near the Thar Desert in Sindh where basic life necessities and main infrastructure is not available which makes the initial cost of project very high. Most of the machinery and equipment for wind power is imported which overburden the total cost of the project. As compared to the total area of the country (796,096 Km^2) a very minute area (9,700 Km^2) data support the wind power production. Currently, a few projects are producing just 0.47 % of total electricity. For the transfer of generated electricity from these remote areas to the main grid long transmission lines are required. The longer the transmission lines greater are the line losses and the net power output will be more reduced. Micro localized grid stations are required to avoid these line losses.

Keeping in consideration all above mentioned constraints it can be said that wind power can provide its share in country's electricity mix ratio in terms of area-based power supply be but cannot be relied heavily upon to overcome the national energy crisis. Along with wind projects other renewable energy sources must go side by side to provide sustainable energy in the country.

2.3.5 Solar

The history of solar radiation use as a source of energy expands over the period from 400 B.C to present day. Greeks were the first to trap the solar heat energy in their houses. The phenomenon of electricity production directly from the sun (photovoltaic effect) was discovered by Henry Becquerel in 1890. The twentieth century brought much knowledge and improvement in this field. Energy crisis of 1970 made realization of the importance of solar energy and its replacement with other fossil fuels. Now-a-days solar power is used from household appliances to cars and to generate electricity in large power houses.

There are two technologies used for solar power generation one is photovoltaic and other called solar thermal system. Photovoltaic technologies directly convert solar energy to electricity commonly called a solar cell or PV. Whereas a solar thermal plant generates electricity by concentrating the sun's energy.

Solar energy is available in abundance and solar system can provide electricity in remote areas having no access to the national grid. A large area is required for the installation of solar panels to produce a large amount of electricity. This energy is weather and season dependent. Winter season and a few rainy or cloudy days can reduce electricity production. Solar energy can be obtained only during the day time so there must be some alternate arrangement for night time. The best solution for this problem is to get electricity from solar panels during the day and from the grid during night.

Solar share in global electricity in 2015 was just 1% but this share is increasing day by day as a clean and cheap alternative to fossil fuels but in Pakistan, this growth rate is very slow. Still the government is focusing on building and improving fossil fuel power plants. World top ten countries with maximum electricity generating from solar are listed in Table 2.10. At present solar power has a negligible part in the country’s power sector. China is producing maximum solar-based electricity of 45 TWh whereas Italy is at the top with the largest share in its domestic electricity with 8%.

Table 2.10 World's Top Countries with Solar Electricity Production

Country	**Electricity Production by Solar (TWh)**	**%age of World Total**	**%age of Solar in total Domestic Electricity**
China	45	18.3	0.8
Germany	39	15.7	6.0
Japan	36	14.5	3.4
United States	32	13	0.7
Italy	23	9.3	8.1
Spain	8	3.4	2.9
United Kingdom	8	3.1	2.2
France	7	2.9	1.3
Australia	6	2.4	2.4
India	6	2.3	0.4

Source: (IEA, 2017)

Global Horizontal Irradiance (GHI) is the amount of radiations received at earth surface. This value is important for PV installations. According to the analysis done by International Finance Corporation (IFC) with Alternate Energy Development Board (AEDB), Pakistan has ideal climatic conditions with approximately average nine hours of sunshine per day having 1500 kWh/m^2 in over 90 % of country's land area.

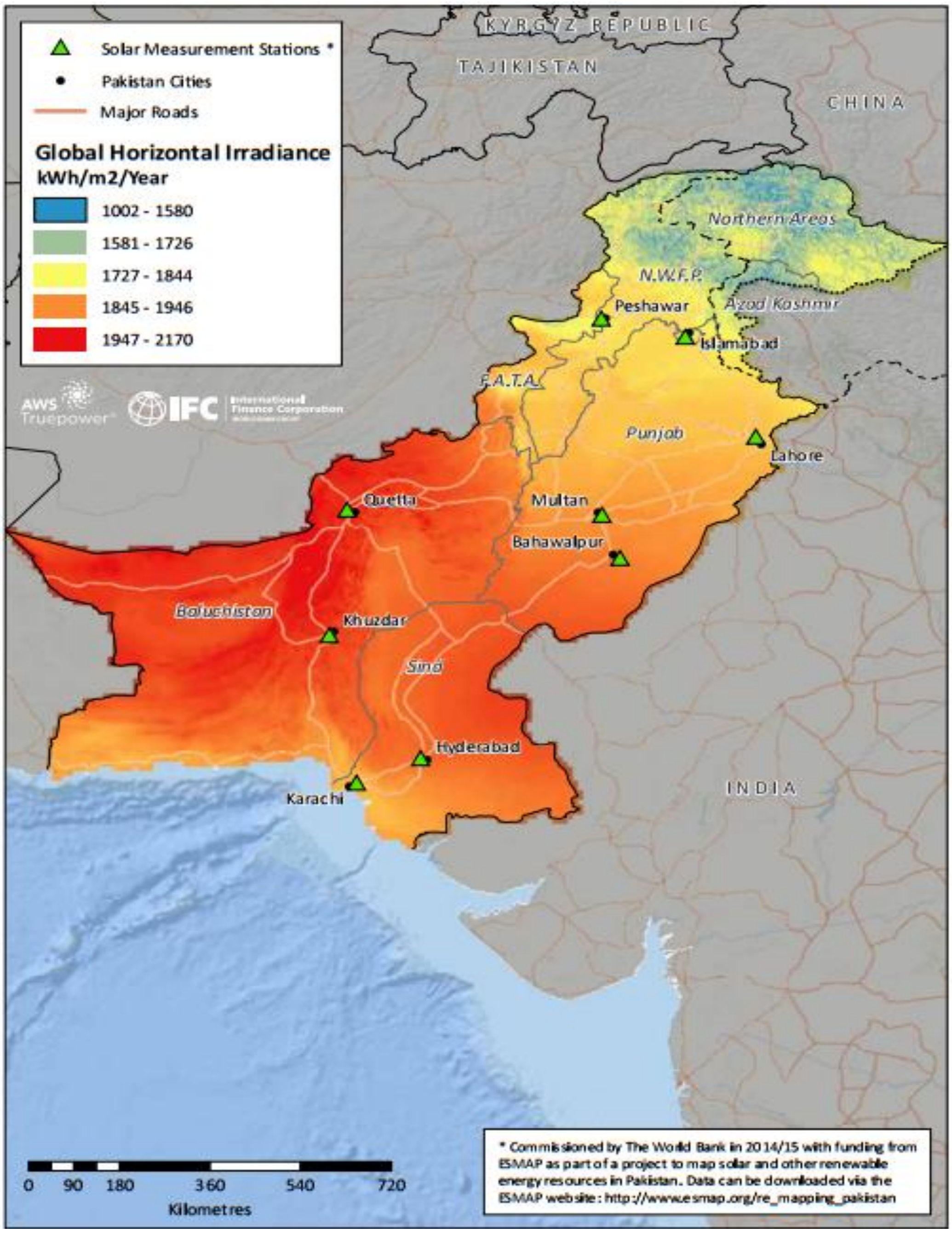

Figure 2.6 Global Horizontal Irradiance (GHI) Map of Pakistan **(IFC, 2016)**

Figure 2.6 shows the GHI Map of Pakistan prepared by IFC. The mean annual value of GHI is 2071 kWh/m^2. Highest values are found in Punjab, Sind and Baluchistan whereas lowest values are estimated in Khyber PakhtunKhwa, Northern Areas and Azad Kashmir. Pakistan stepped into solar power production in 2006 when the Government of Pakistan announced its policy for increasing the renewable energy generation. But till today this has been proved just a policy without any significant development in solar production.

Table 2.11 Pakistan Solar Power Projects

Projects	**Capacity (MW)**	**Location**	**Status**
Pakistan Parliament	1.0	Islamabad	Operational since Feb 2016
Quaid-e-Azam Solar Park	400	Bahawalpur	Operational since Dec 2016
Fatima Jinnah Park	1.0	Islamabad	Operational since Dec 2016
POF Sanjwal Factory	5.0	Islamabad	Operational since Mar 2017
Service Industries Limited	1.0	Muridke	Operational since Sep 2017
SECMC	5.0	Thar	Operational since Feb 2018
Harrapa Solar (Pvt) Ltd.	18	Sahiwal	Operational since Mar 2018
Total Operational Projects capacity = 431 MW			
Bukhsh Solar (Pvt) Ltd.	10	Punjab	Under Construction
Access Electric (Pvt) Ltd	10	Punjab	Under Construction
Safe Solar Power (Pvt) Ltd	10	Punjab	Under Construction
Acess Solar (Pvt) Ltd	11.5	Punjab	Under Construction
Blue Star Hydel (Pvt) Ltd	1	Punjab	Under Construction
Safe Solar Power (Pvt) Ltd	10	Punjab	Under Construction
AJ Power (Pvt) Ltd	12	Sahiwal	Under Construction
Scatec Solar	50	Sindh	Under Construction
Oursons Pakistan Ltd	50	Sindh	Under Construction
Total Under construction Project capacity = 264.5 MW			

Pakistan has 2.9 million MW solar power generation capacities. According to AEDB 35 projects with 1111.4 MW capacities are under different stages of development (IFC, 2016). Pakistan current operational and under construction solar projects details are given in Table 2.11.

Other than above mentioned projects there are several projects which are on different development stages but overall progress in solar power production is very slow. Solar panel prices are much high in Pakistan. In 2013-2014 Pakistan imported solar panels of 350 MW to 400 MW whereas in 2017 this import increased to 1500 MW capacity panel per year mostly from China, Germany and USA. Import cost, Initial purchase cost and installation make this option less feasible. Solar panel efficiency is linked with their proper cleanliness. If we further analyze the Figure 2.6, it is clear that the areas having high radiations are deserts, dry mountains, and remote areas much away from the developed cities where availability of water, main infrastructure and basic life needed facilities are not easily possible.

Pakistan's largest solar project is Quaid-e-Azam Solar Park (QASP) Bahawalpur having an aggregate capacity of 1GW. This project is producing 400 MW at first stage but most of the critics take this as an inefficient project. The output of 18.5 MW (initial stage planned 100 MW) at the cost of 13.5 billion spanning over 500 acres land is obviously not cost efficient. The main reasons for this reduced power output are manual cleaning of solar panels, dusty environment of Cholistan, less water availability and rains in the desert, fewer rains and unsuitable weather conditions.

No doubt Pakistan has such GHI value which can give a lot of energy to national grid but with some restrictions associated with weather (sunny, cloudy, rainy) and season (summer or winter). There must be a backup or power supply from the grid at night. Above mentioned all facts show that in spite of having high GHI value many dependencies on solar power is not a better option. It can assist the other options like thermal based and hydroelectricity.

2.3.6 Nuclear Energy

Controlled nuclear fission process is used in the nuclear power plants. These power plants heat water to produce electricity. Steam from heated water is used to run large turbines that generate electricity. The first nuclear power station (Obninsk Nuclear Power Plant) with 5MW capacity was constructed in 1954. World's first commercial nuclear power plant was Calder Hall in England in 1956 with an initial capacity of 50MW later that was extended to 200MW. From 1956 to present date nuclear power has a significant and continuously increasing share in global electricity. It is a clean, powerful and efficient source of electricity and much feasible for the countries having less quantity of other fuels. Advancements in technologies have made this a preferred option than other fuels but still in many countries nuclear option has not been yet adopted.

The main aspect of nuclear power generation is safe controlled fission process. Nuclear power generation has great potential for huge disasters. Chernobyl disaster (26 April 1986 in Ukrainian SSR, Soviet Union) and Fukushima Daiichi nuclear disaster (March 2011 in Japan) are the two catastrophic incidents in the nuclear power history which resulted in many causalities and lifelong disabilities due to release of radioactive material. These incidents affected electricity production. Several planned nuclear power plants were decommissioned. Each and every stage in nuclear power plant process from mining, transportation, controlled fission process and storage of waste material is much expensive making this an expensive option for electricity generation.

Figure 2.7 World's Top Countries Nuclear Power Trend (Evans, 2018)

The amount of electricity from a nuclear reactor grew very steadily since 1960s with a peak of 2800 TWh in 2006. Currently nuclear power provides 11% of global electricity with about 450 nuclear reactors. Figure 2.7 shows electricity generation trend in top countries. Till 2011 Japan was at the top with maximum generation but after the Fukushima Daiichi nuclear disaster, Japan shut down its nuclear reactors. This also reduced nuclear power share in global electricity. (Evans, 2018)

According to International Atomic Energy Agency (IAEA) and International Energy Agency (IEA), world's top ten producers of nuclear electricity and having maximum sharing in domestic generated electricity for 2015 are listed in Table 2.12. France is producing maximum electricity from nuclear with its 58 nuclear reactors.

77% of its total electricity of France is produced from nuclear which is maximum in the world.

Table 2.12 World's Top Countries with Nuclear Power

Country	Electricity Production by Nuclear (TWh)	%age of World Total	%age of Nuclear in total Domestic Electricity
United States	830	32.3	19.3
France	437	17.0	77.6
Russia	195	7.6	18.3
China	171	6.7	2.9
Korea	165	6.4	30
Canada	101	3.9	20.9
Germany	92	3.6	14.3
Ukraine	88	3.4	54.1
United Kingdom	70	2.7	20.9
Spain	57	2.2	20.6
Pakistan	5.5	0.22	5.13

Today's France energy mix is the result of French Government Decision taken in 1974 in the form of Messmer Plan. After the Oil crisis in the world and with limited indigenous energy resources French government decided to use the nuclear raw material and make France completely independent of oil-rich countries. In 2016 France produced gross 556 TWh among which 42 TWh is exported to the neighboring countries. France in the leading net exporter of electricity due to the low cost of generation. (Greenage, 2018)

In Pakistan Nuclear electricity history is not much old. Karachi Nuclear Power Plant (KANUPP) was first nuclear power plant inaugurated in November 1972 with a capacity of 137 MW. Detail of different nuclear power plants of Pakistan is given in

Table 2.13. According to Pakistan Atomic Energy Commission (PAEC) other than above mentioned projects Government is planning to increase the total capacity to 8,800 MW till 2030 by installing 10 more nuclear power plants at six sites. Pakistan needs trained and qualified local manpower to reach the planned target of 8,800 MW. Approximately 200 to 300 professionals are required per plant and 600-800 overhead manpower for project design, management, construction and installation. Currently available manpower is just 150. To recruit new employees and their proper training is a big challenge. (Mustafa, 2018)

Table 2.13 Nuclear Power Plants in Pakistan

Plant	**Capacity (MW)**	**Location**	**Status**
KANUPP (K1)	100	Karachi	Operational (Nov 1972)
CHASHNUPP (C1)	325	Mianwali	Operational (Jun 2000)
CHASHNUPP (C2)	325	Mianwali	Operational (Mar 2011)
CHASHNUPP (C3)	340	Mianwali	Operational (Oct 2016)
CHASHNUPP (C4)	340	Mianwali	Under construction
KANUPP (K2)	1100	Karachi	Under construction
KANUPP (K2)	1100	Karachi	Under construction

Safety of the nuclear power plant is the utmost question in every plant all over the world. In Chernobyl disaster 1986, 30 Km radius was declared hazardous. Karachi is within the 30 Km radius of KANUPP and in case of any unfortunate accident` it can affect more than 8 million population of Karachi which is the largest number of population around any nuclear power plant in the world. The coastal area of Pakistan (Sindh & Baluchistan) have a long history of earthquakes from minor to high magnitude (5 to 7.7) which have the capability to damage the nuclear reactors in Karachi and can cause the release of radiation and heat (DAWN, 2005). In 2011 Fukushima Daiichi nuclear disaster Japan was due to an earthquake followed by a Tsunami. Considering these two incidents there is strong opposition and question mark against nuclear power reactors in Pakistan from local people and different NGO's. There are strict safety guidelines from the International Atomic Energy Agency (IAEA) that must be followed.

The cost to power production ratio in nuclear power is not much satisfying. Against huge investment from design to safe operation of the project currently nuclear reactors are providing just 5% of the total nation's electricity and this result in just overburdening the economy of the country. Nuclear power can be a good option against per year expenditure on import of oil and coal but this cannot replace thermal power production in the country. It can play a supporting role to the other power production option (renewable or non-renewable).

2.3.7 Hydropower

Hydropower is a scheme in which water flows in a stream and falls down from a certain height called "head" to the lower end of the scheme where turbines are located at powerhouse to convert the potential energy into electrical energy. This scheme totally depends on the quantity of flow and head. Hydroelectric power projects are providing electricity for over 100's of years to the industry, agriculture and home owners. Hydropower shares a considerable amount for the global requirements with the other sources related to power. At present, it is a very attractive source of electricity in the commercial renewable energy market. Hydropower is a clean, economical and plenty renewable source all around the world. Construction of dams is the basic key to hydel power generation and it gives many benefits other than electricity water supply, flood control, irrigation, industrial and human use etc. Depending upon the water availability different schemes of hydropower can be adopted. The main problems associated with dam construction for hydropower generation are long construction time, huge population relocation, land acquisition and heavy investment.

Currently hydropower is providing 16 % of world's total electricity. China has a key role in hydropower history. China is at top with maximum installed capacity of 332 GW in 2015. World's top countries with maximum hydel power generation and maximum %age share in domestic electricity are listed in Table 2.14. Norway is producing 95% of its electricity from its water resources. Canada, Brazil, France, Venezuela and Sweden all are fulfilling more than 50% of their electricity demand from hydel power. As compare to these countries Pakistan has just 16% share in total domestic electricity which is very minute as compared to its total available capacity. Pakistan Hydropower potential and projects is discussed in further sections.

Table 2.14 World's Top Countries with Hydropower

Country	**Hydropower Production (TWh)**	**%age of World Total**	**%age of Hydel in total Domestic Electricity**
China	1130	28.4	19.3
Canada	381	9.6	56.8
Brazil	360	9.0	61.9
United Stated	271	6.8	6.3
Russia	170	4.3	15.9
Norway	139	3.5	95.9
India	138	3.5	10
Japan	91	2.3	8.8
Sweden	75	1.9	46.6
Venezuela	75	1.9	63.7
Pakistan	34.4	0.9	34

Source: (WEC, 2016)

2.4 HYDROPOWER IN PAKISTAN

The energy produced by water is termed as water power. Power generation methods which produce electric energy by using water power are called hydropower generation. Hydropower fulfills approximately one-fifth electricity demand all over the world. Worldwide, hydroelectric power projects are providing electricity for over 100 years to the industry, agriculture and homeowners. In comparison, hydropower shares a considerable amount for the global requirements with the other sources related to power.

The first hydropower generator was built and installed in 1895 at Niagara Falls, New York. Afterward, that has become the standard for the other hydroelectric projects. On that time the developments were limited to low heads from 4 to 7 meters but the use of a greater fall was being made by canals in subdivisions, each a unit of about 7 meters. Before 2000 B.C., and in the middle of ages, the Greeks and Egyptians used to grind the grains to floor with the help of water power. Similarly, Romans constructed paddle wheels that circulate by the flow of water. History of hydropower development on different rivers worldwide including Pakistan is given in Table 2.15. During the 20th century, the hydropower generation increased in Europe and North America that became useful in financial viability whereas, in Asia only China exceeded in the development of hydropower potential. Europe and North America have completed their development on the hydropower projects up to 65% and on the other hand, Asia, South America, and Africa at present operate only small fraction of their present energy resources.

Table 2.15 World's Hydropower Development History

2000 B.C.	The first water wheel was prepared to grind wheat grains.
1880	Hydropower was first used to light up lights by Michigan's Grand Rapids Electric light and Power Company.
1886	Approximately 45 plants had established in Canada and North America
1888	200 hydroelectric power plants were installed worldwide.
1895	First hydropower generator was built and installed in 1895 at Niagara Falls, New York.
1902	First Aswan Dam was constructed on the Nile River.
1910	World's biggest Vemorck hydel power plant was prepared in Norway for electricity.
1932	The Dnepr Dam was completed in the Soviet Union.
1933	Grand Coulee Dam was started to construct which is still the largest power production plant in North America.
1936	World's largest Hydro Power Plant, Hoover Dam on the Colorado River with 1345 MW capacity.
1940	Approx. 40% need of U.S. energy demand was covered by hydropower.
1942	Grand Coulee Dam with 1974 MW Washington
1954	Owen Falls Dam was prepared in Uganda with the world's large most reservoirs.
1960	Reconstruction of Aswan High Dam began on Nile River that completed in 1971.
1966	First power production was established by ocean tides on the Rance River, France.
1967	Mangla Dam construction completed with an initial capacity of 400 MW in Pakistan.
1971	World's biggest Itaipu Dam construction was begun between Brazil and Paraguay.
1976	World's biggest volume Tarbela Dam in Pakistan was completed outside from USA.
1986	Approx. 2.3 % annual power production was maintained in 1986 to present.
1993	Approximately twenty percent of electricity worldwide demand was generated.

2003	Power Producers (IPP) stands at 17713 MW electricity out of which 12335 MW (70%) Thermal, 4916 (28%) Hydel and 462 MW (2%) by Nuclear) produces in Pakistan.
2004	Ghazi Barotha Hydropower Project, Pakistan's largest Run-off-river with 1450 MW capacity completed
2006	Three Gorges Dam with World's maximum installed capacity of 22,500 MW started power Generation.
2017	Hydropower becomes the world's largest source of renewable energy with 4185 TWh electricity generation and 16.4% share.
Sep 2018	Pakistan achieves highest hydel power generation (7571 MW) of its history.
Up to 2025	Pakistan has planned to generate 40,000MW electricity in their Vision 2025 program to fulfill the country demand.

2.4.1 Classification of Hydropower Projects

A brief detail of hydropower projects classification is explained below:

a. Run of River Type Project

Run of river type of projects generate electricity by using the natural flow of water flow, therefore there is no need for the impoundments. These plants are mostly designed under a large flow rate with small heads and gentle gradient on the large rivers or small rivers with steep gradients. Therefore, these types of projects are characterized into two types as follows;

Low Head Run-of-River Projects: Projects in which small water retaining, infrastructures and turbines are anchored to the large river bed of gentle gradient. "Chashma Hydropower Project" in Pakistan is the best example of such types of projects.

High Head Run-of-River Projects: Such hydropower projects are sited at waterfalls or by constructing a dam using water flow at the site in which, powerhouse, penstocks and switchyard are underground whereas no impoundments take place. These projects produce more power than low head schemes. “Warsak Dam” in Pakistan is the best example of such type of projects.

b. Reservoir Type Projects

These types of projects in which water impoundment takes place behind the dam that regulates flow throughout the year on daily, monthly or on the multi-annual basis to fulfill the peak energy demand even into dry seasons. These schemes are used on gouges or on canyon systems to obtain high output and efficiency. Tarbela and Mangla Dam in Pakistan are the examples of this kind.

c. Pumped Storage Type Projects

These projects are considered as advanced and efficient technologies which have upper storage basins where water is pumped during off-peak hours by using energy from baseload power plants and to generate electricity during the daily peak load period. High cost for appropriate sites, equipment and for construction is associated with such types of projects; therefore there is a need to identify cost-effective sites, higher heads range near about 300 m to 800 m with steep topography.

d. Power Generation Capacity

Generally, no definitions exist for such types of plants all over the world but normally, plants of low output generation are considered as micro, small and medium projects with their respective capacity. For example, according to China, plants not more than 25 MW are in this category. In Pakistan, hydropower plants are classified by their energy generation and head. Plants on irrigation canals such as Nandipur, Shadiwal, Rasul, Chichoki Mallian, Daraghi etc. are low head plants, but they are considered as "small hydropower plants" because of their generation that is less than 20 MW. Similarly, the plants such as Mangla, Tarbela and Warsak have higher capacity and are referred as “large hydropower plants". They are also called medium head plants (WAPDA’s GTZ 1999).

It is very difficult to define their limits and classification of hydropower plants because it varies from country to country but the main types used in Europe and USA is as follows in Table 2.16. Keeping in view, the shortages, in the number of sites for the large-scale hydropower plants, most of the countries are now thinking for small-scale hydropower plants to improve designs and review development plans that in the result increase economic development.

Table 2.16 Power Plant Classification

Micro Capacity Plants	< 100 kW
Mini Capacity Plants	100 – 5000 kW
Small capacity Plants	5000 –15000 kW
Medium Capacity Plants	15000 – 50000 kW
High Capacity Plants	50000 – more

e. Size (Large, Small, Micro)

Hydropower plants based on the height of dam which in turn relates to an available head for power generation are classified into three categories namely small, medium and large. According to European Small Hydropower Association (ESHA) and International Finance Corporation (IFC), low head lies between 2-30 m, medium head 30-100m and high head is more than 100 m.

f. River Diversion Type Projects

These are further divided in two types:

Stream Diversion: In this type, river water is diverted through the mountains by diversion tunnels and discharge back into the downstream which decreases the river between the diversion and the power plant tail bay and gives the mitigation for ecological environment. “Ghazi-Brotha Hydropower Project” in Pakistan, is the best example of it.

Cross Watershed Diversion: In this type, river water is diverted into another river flow, increasing the receiving river flow where the power plant is located and decreases the flow into the downstream areas that can cause of the dryness of associated tributaries.

2.4.2 Hydropower Development in Pakistan

As the world is moved into the new origin of life, worldwide energy demand and consumption of electricity is increased to a higher extent that is continuously increasing at a rate faster than its availability. Today, approximately 75 % of the total demand is being fulfilled from the thermal resources like coal, gas and oil; but further increase of demand globally, creates the shortage of these resources that is questionable for the long term energy planning and strategic decisions.

Hydropower lies into the renewable source category which works like the hydrological cycle by taking its energy from the sun and renewable chain of water. Out of the total, it covers approximately ninety percent of power generation and it is peaking up as the most feasible sources of new power generation in the prospect. Keeping in view the disturbance in fossil fuel markets and price inflations, there is a need to focus on sustainable energy policies and in response to, significant development may come true for renewable energy supplies which also exist in many forms. At present, the modern way to produce power relates to blustery weather, lunar energy and out of these, the largest renewable energy producer is “hydropower”.

The first hydropower plant constructed in the area of the subcontinent was Renala Khurd Hydropower Project with a capacity of 1MW in District Okara, Punjab. The second power plant before the creation of Pakistan was Jaban (Malakand-I) Hydropower plant with an initial capacity of 10.7MW which was later upgraded to 20MW. After the independence in 1953 Malakand-II Hydropower plant with a capacity of 20MW was commissioned in Dargai. The power production competence was 119MW when WAPDA came into being in 1959. Power development assignment was undertaken by WAPDA for executing different energy generation projects, which could bear the rapid increase in load of electricity. After five years of its operation up to mid-sixties, the aptitude of electricity rose to 636 MW from 119MW. The rapid progress witnessed a new sign of relief in every aspect of life like the economic, social and technical condition of the country. Industrialization and mechanized agriculture processes picked up the general living standards. (PPIB, 2011)

Afterwards, two major dams (Tarbela in 1976, with 3478MW generation & 9.30 MAF storage capacity at Indus and Mangla in 1967, with 1000MW generation capacity & 4.82 MAF storage capacity at Jehlum, 5 barrages (Marala on river Chenab, Rasul on river Jhelum, Sidhnai on river Ravi, Qadirabad on river Chenab and Chashma on river Indus), 8 link canals (Chashma Sulemanki, Qadirabad Sulemanki, TrimmuS idhnai, Sidhnai Mailsi, Mailsi Bahawal, Rasul Qadirabad and Taunsa Punjned) were constructed to fulfill the demand and the generating capability increased from 636 MW to 13,313 MW, with installation of number of thermal and hydel power units. Total installed capacity in 2012 was 23,556 MW and reached to 35,372 MW in 2018 (NTDC, 2018). This is a very nominal increase as compared to the severity of the energy crisis during this time period.

2.5 HYDROPOWER CAPACITY OPTIMIZATION

To achieve the objectives this research analysis of the electricity production system and detailed study of the demand-supply balance till the year 2025 was required. For this besides the power production data from all the sources, a forecasted demand by 2025 was also required. Keeping in consideration the WAPDA Vision 2025 calculations were performed to assess the gap between power demand and supply in the country. In further sections more emphasize is given on hydropower projects and its maximum share that can be optimized to overcome the persisting shortfall and also to provide cheap electricity in the country. In the following sections, approaches for demand forecasting are being discussed.

2.5.1 Demand Forecasting

Energy management plays an important role in the economic development of a country. And in energy management future demand forecast leads to proper planning of new projects execution and investment. Different techniques used worldwide to forecast energy demand can be categorized as “Econometric” and “End-use”. The Econometric approach uses economic theories, rules and models for forecasting. Whereas in later one is a comprehensible accounting approach using the past data of energy consumption at different levels. In this stud, End-Use approach was used at the sectorial level from 2005 to 2017 to forecast electricity demand till 2025. In the past a lot of approaches have been used to forecast the electricity demand, consumption, daily demand, peak demand and future fuel consumption, among which a few are being explained further.

a) Artificial Neural Network Models

Artificial Neural Network (ANN) model creates a relationship between input and output variables to forecast output values. (Romera et al., 2008) forecasted monthly electricity demand for Spanish. Different models of ANN are applied to predict electricity demand in one of the provinces of China (Ruiyou & Dingwei, 2008).

b) Time Series Models

A time series is generated using the past data and by recording the variable values at fixed time intervals, in sequence. Models use past data to predict the future values of the variables. Autoregressive Integrated Moving Average (ARIMA) is an example of a time series model. Different authors used time series models to forecast short term and long term electricity demand in different countries like (Shang, 2013) in South Australia, (García-Ascanio & Maté, 2010) in Spain and (Rana et al., 2015) in Australia and United Kingdom.

c) Fuzzy Logic

Fuzzy Theory resolves the forecasting problem by using mathematical analysis in "if-then" form. The main advantage of this logic is that it can use incomplete (fewer observations) data for prediction however the results are not always acceptable (Hong & Lee, 2008). To analyze the future electricity consumption trend in Northern Cyprus, fuzzy logic was used (Abiyev et al., 2009). (Chang et al., 2011) forecasted the monthly electricity demand in Taiwan.

d) Auto Regression models

These models like ARMA, ARIMA and SARIMA are a specific class of regression models. Stationary Time Series can be forecasted by ARMA (Auto-Regressive Moving Average) containing trend, seasonality or both Whereas ARIMA model performs differentiations with autoregressive terms and moving average terms to achieve a stationary process. The Seasonal Auto Regressive Integrating Moving Average (SARIMA) model uses both the seasonal and the non-seasonal factors. (Kareem and Majeed, 2006) forecasted monthly peak load for Iraq by applying the SARIMA model. (Ohtsuka et al., 2010) predict the electricity consumption for Japan by applying the ARMA model. A demand of daily peak electricity consumption was forecast by (Asad, 2012) for New South Wales, Australia using ARIMA model.

e) Gray Prediction

This prediction theory deals with systems having poor data or small samples. The grey prediction system have partially known and partially unknown data values. Most of the times grey prediction is used in combination with other techniques of forecasting, as used for China (Zhou et al., 2006) and Turkey (Liu et al., 2008).

f) Regression Models

Regression models use one or more independent variables, calculate a dependent variable value, and forecasts the demand. These models are further classified as Linear and Non-Linear Regression Models. (Ismail et al., 2008) used the multilinear regression model to analyze the electricity consumption rate in Malaysia.

g) Econometric Models

The econometric model uses socio-economic data, economic models, and mathematical statistics combined for forecasting future demand. Econometric model estimates the forecasted data by developing a mathematical model based on economic hypothesis.

This hypothesis is then tested and forecasted. (Dey et al., 2011) and (Mtembo et al.,2014) used econometric models for forecasting in Bangladesh and Zimbabwe respectively.

2.5.2 Optimization Modelling

In general, optimization means a process or methodology to make the best possible use of anything or in mathematical terms finding the maximum or minimum value of a function considering all the variables and constraints. In other words, we can say that optimization is rearranging the data to improve the efficiency or output of a given system. Different approaches and models have been used in past to get the optimization of energy mix of a specific country or area. The main use of these approaches is to get the maximum electricity mix from all available sources against minimum cost. Some studies include electricity mix forecast against reduced CO_2 emissions and affordable electricity tariff. Approximately all these models provide the optimal solution by finding the values for the identified decision variables with satisfying the constraints and minimizes or maximizes the objective function, using linear or non-linear method.

Smith proposed a linear optimization model for the planning of New Zealand's energy supply and distribution system (Smith, 1980). Groscurth and Kümmel developed a linear optimization model for evaluating industrial energy-saving potentials in several developed countries such as Germany, USA, The Netherlands and Japan (Groscurth & Kümmel, 1980). (Tiris et al., 1994) developed a linear optimization model and a multi-attribute value model to coordinate long term interactions among energy, the economy, and the environment in Turkey

There were also a number of software packages, such as Long-range Energy Alternatives Planning System (LEAP), New Earth 21 Model (NE21), National Energy Modeling System (NEMS) and Energy 2020, which were developed to evaluate environmental and economic effects of energy. (Papagiannis et al., 2008) applied LEAP 2006 to a number of European countries. Based on MARKAL, (Jiang et al., 2008) estimated future consumptions of natural gas in three Chinese cities: Beijing, Guangzhou and Shanghai. As an effective method for investigating the role of renewable energy resources for mitigating GHG emissions within many EMSs in Australia, the so-called Australian Energy Policy System Optimization Model (AEPSOM) was used by Islam (Islam, 1995)

Chapter III
METHODOLOGY

To achieve the objectives this research analyzes the electricity production system of Pakistan with a detailed study of the demand-supply balance till the year 2025. Figure 3.1 explains the steps followed to accomplish the research objectives. The research work is accomplished in four steps, namely, survey of related data, data collection, data analysis, and hydropower optimization.

3.1 SURVEY OF RELATED DATA

A survey of related data was performed in Chapter 2. International and national energy data was surveyed for electricity production from coal, gas, oil, wind, nuclear, solar, and hydel. Comparison between world's top electricity producing countries from each source was reviewed and compared with Pakistan. Pakistan electricity installed capacity data was surveyed for the WAPDA history i.e. from 1959 to 2018**.** Whereas electricity projections made by NTDC for the period of 2018-2025 was surveyed.

3.2 DATA COLLECTION

International electricity production data from Coal, Oil, Gas, Nuclear, Solar, Wind and other renewables (Biomass, Bagasse) was collected from International Energy Agency (IEA), US Energy Information Administration (EIA), Global Wind Energy Council (GWEC), World Energy Council (WEC), International Atomic Energy Agency (IAEA), B.P Statistical Review of World Energy and World Bank Energy Data.

Data collected regarding Pakistan electricity can be divided in three groups; forecasted electricity generation, installed capacities, and demand data. The data was collected from WAPDA, NTDC and NEPRA. The details are as:

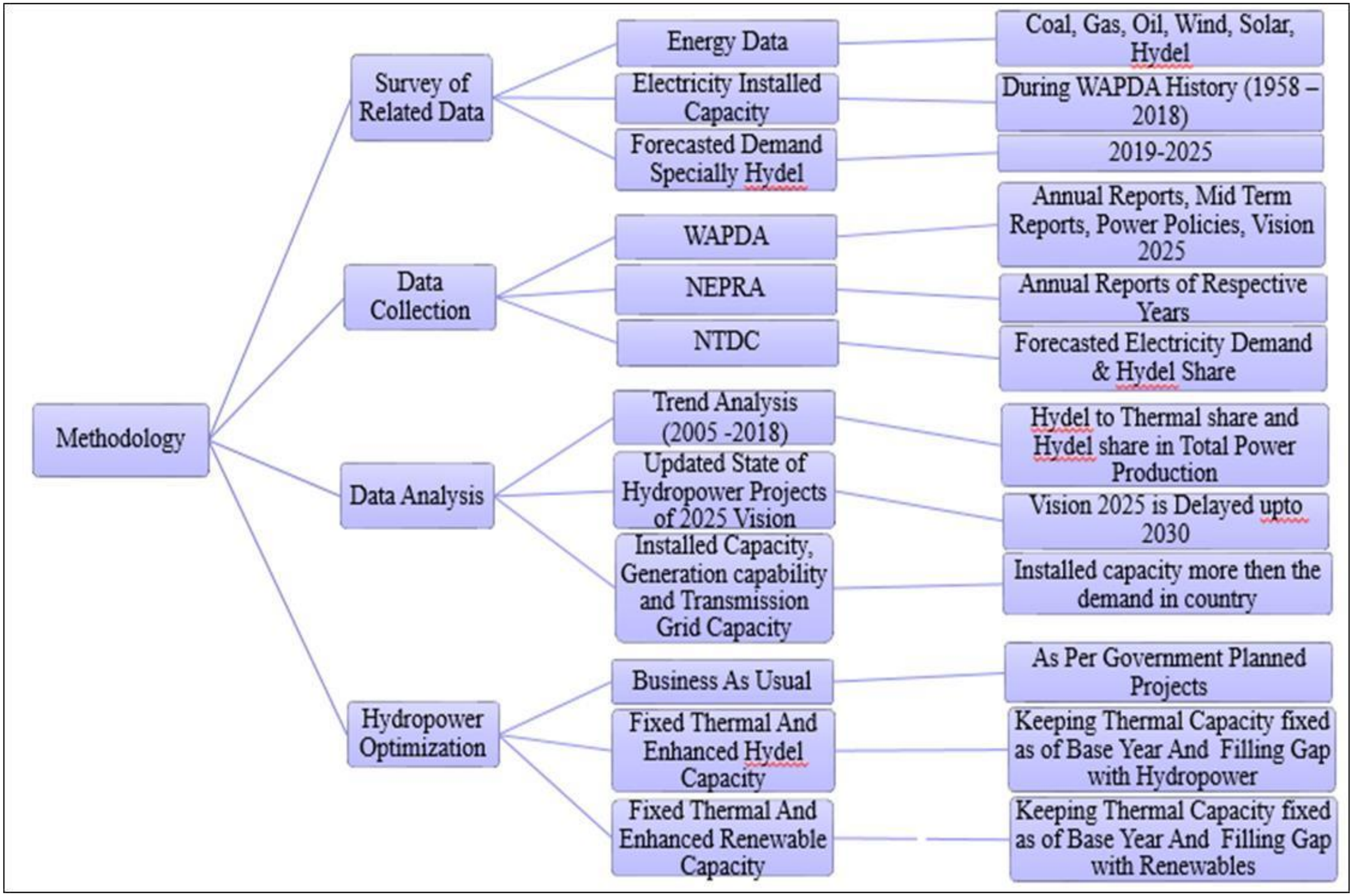

Figure 3.1 Methodology Used

WAPDA: Annual Reports, Mid Term Reports, Power Policies, Vision 2025

NEPRA: Annual Reports of Respective Years

NTDC: Forecasted Electricity Demand &Hydel Share

3.2 DATA ANALYSIS

The electricity production from 2005-2018 was analyzed to check the trend of hydel and thermal share in the total electricity of the country. Updated State of under construction and streamline hydropower projects was reviewed to check the status of WAPDA vision 2025 plan. To get projected electricity demand of electricity in the country "End-Use" approach was used by following the below given steps.

a. Identify all the electricity consuming sectors.

b. Identify the demand drivers.

c. Calculate the total electricity consumption of the base year (2018).

d. Calculate average growth rate for actual data from 2013-2018.

e. Based on average growth rate projected electricity for the period of 2019-2030 was calculated against three different scenarios as Low, Normal and High growth rate.

f. Projected growth was used to calculate the deficit/surplus till 2030.

3.4 HYDROPOWER OPTIMIZATION APPROACH

As discussed in previous sections maximum hydropower share in Pakistan's total energy mix ratio can lead to a prosperous and developed Pakistan is by providing a cheap, clean and affordable electricity to the consumers. Currently the power sector is dominated by high thermal share (64%). Linear Optimization approach was used in MS Excel to get an optimal hide to thermal mix against different proposed scenarios.

3.4.1 General and Specific Details

Some main points are discussed below for making all the calculations related to forecasting and optimization.

- For forecasting 2018 was taken as base year. Base year actual data was taken from (NTDC, 2018).
- Projected capacities data from all sources was taken from (NEPRA, 2017)
- Imports are not included.
- As NTDC Forecast is not available after 2025, for further calculations after 2025, electricity share from all sources other than Hyde was kept constant as of 2025.
- Private sector projects are not included after 2025 due to unavailability of data.
- Transmission and distribution losses were not included. During the FY 2017-2018 average load shedding of 6000 MW was recorded whereas the gap between generation capability and demand is just 1341 MW.
- Projects not connected to national grid were not included.
- For calculation of the generation capabilities of different projects from different fuels capacity factor was also considered to get the exact values. Capacity factor for different sources taken were as; Thermal 90%, Hyde = 50 %,
- Nuclear = 95%, Wind = 35%, Solar & other renewables = 25%

3.5 LINEAR OPTIMIZATION

Linear optimization is widely used to fin d the value of decision variable by satisfying all the constraints and minimizing or maximizing the objective function value. Decision variables value will be calculated, decided by the total capacity from each electricity generating source and load factor for each technology. Excel spread sheet was used due to simplicity and reliability. Spread sheet is straight forward and easy to modify.

3.5.1 Objective Function

It is the main function whose value is to be calculated for the suitable values of decision variables. In this study objective function is minimization of thermal capacity against possible maximum hydropower capacity with respect to different constraints

3.5.2 Decision Variables

- **Plant Load Factor:** It is the ratio between the annual electricity generation and the ideal capability of the plant. It can be written in the equation form

$$PLF(\%) = \frac{Annual\ electricity\ generated\ (MWh)}{Plant\ capacity\ (MW) \times No\ of\ Hours} \times 100$$

- **Plant Capacity (GW):** The generating capacity of the plant depends upon many factors such as the build rate, PLF, policy etc.

3.5.3 Constraints

The objectives function is subjected to some constraints / limitations that will be a non-negative values. In this study following constraints were used.

- **Annual Demand:** The most important constraint is to meet the annual electricity demand in the country which is summation of electricity generated from each source and it should be equal or more than the targeted annual demand.
- Peak Demand: The optimized mix should also meet the targeted peak demand (especially for summer peak hours) which depend upon the installed capacity and maximum capacity factor for summer is given in section 3.4.1.

3.6 OPTIMIZATION SCENARIOS

Three different scenarios were defined to get the optimal hydel to thermal ratio while meeting the constraints and fulfilling the criteria defined for decision variables. The first scenario BAU (Business as Usual) was taken as reference in which the government planned strategy was analyzed to get a higher hydel share than thermal. Second scenario was proposed by fixing the thermal capacity as of base year (2018) and replacing the gap in forecasted additions with hydel share whereas in third scenario the gap was replaced by renewables to minimize the thermal share till 2030.

Chapter IV
RESULTS AND DISCUSSIONS

4.1 POWER PRODUCTION SOURCES

4.1.1 Worldwide Energy Reserves

According to the international agencies review, the available reserves of fossil fuel of the world in year 2016 are: oil is 240.7 thousand million tones, coal is 113.93 thousand million tones, and natural gas is 186.6 trillion cubic meters. The Middle East has largest oil and natural gas reserves of 47.7% & 42.5% of the total world reserves, respectively. Out of which Saudi Arabia has 15.6% of oil and Iran has 18% of natural gas reserves. The Asia pacific owns a reasonable share in coal reserves which is 46.5% of the total world coal reserves. Out of these coal reserves, china has 21.4% share. Electricity generated by these fossil fuels is 24816.4 TWh among which Pakistan shares a small amount of 115.4 TWh that is just 0.5 % of the total generated amount. (BP , 2017)

Pakistan's fossil fuel reserves and their relative production for the year 2014 is given in Table 4.1. It shows a substantial gap between the reserves and their local production. These reserves can fulfill the country's energy requirements up to much extent. But the need is to exploit them with proper management.

Table 4.1 Pakistan Energy Reserves and Production

Fuel Type	Reserves	Production
Oil (Million Barrel)	371.028	27.84
Natural Gas (BCF)	24740.980	1505.84
Coal (Mt)	3179.061	3.18

Source: (PPIB, 2014)

4.1.2 Worldwide Electricity Production

Electricity has a dominating role in our daily life. It has become the most important blessing of science and without electricity modern life is impossible. Pakistan is blessed with numerous resources (both fossil and renewable) having the capability to generate electricity more than its own needs. Historical data reveals that Pakistan electricity production is ruled by fossil fuels. But when comparing with overall world scenario, Pakistan's reliance on fossil fuel is increasing till present. Comparison of global and Pakistan electricity mix ratio historical data is presented below. Worldwide electricity generation trend by sources from 1971 to 2015 is shown in Figure 4.1. In 1971 electricity production stands at approximately 4000 TWh whereas this value reaches to 15000 TWh in 2015. The Nuclear share has increased from minimal to 2500 TWh. Same trend can be seen in hydro and renewable sources.

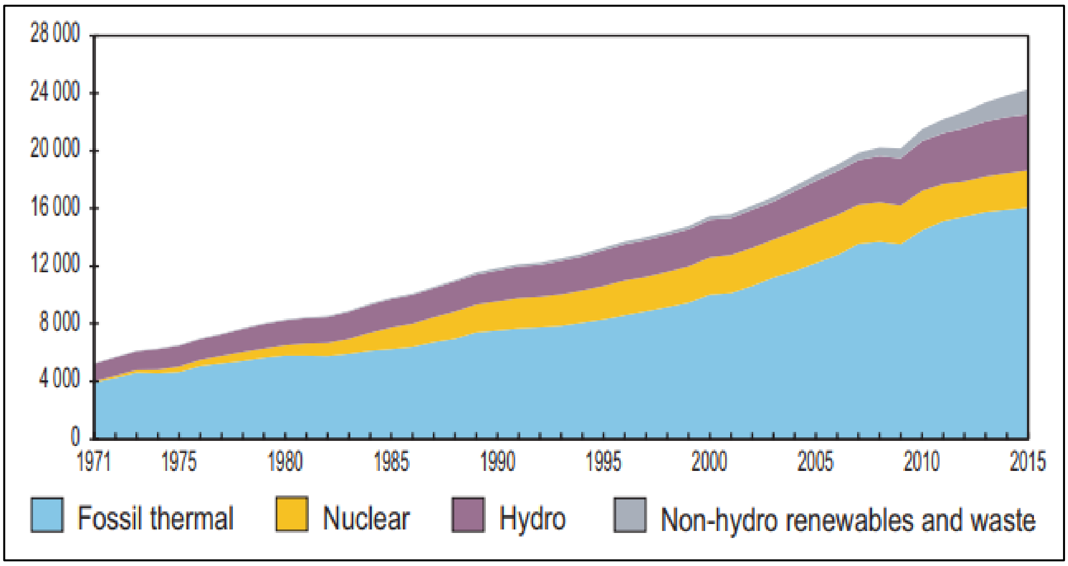

Figure 4.1 Global Electricity Trend by Source (EIA, 2017)

A percentage share of different fuel sources for the years 1973 and 2015 is given for comparison in Figure 4.2. In 2015, 66.3 % of world electricity production was from non-renewable sources whereas in 1973 it was 75.2%, approximately 9% less.

Hydroelectric provided 16.0%, nuclear 10.6%, geothermal, solar, wind and other sources 4.9%, and biofuels and waste remained with a share of up to 2.2%. There is a significant decrease in electricity production from oil whereas an increase in hydel and other renewable source production is observed. (IEA, 2017)

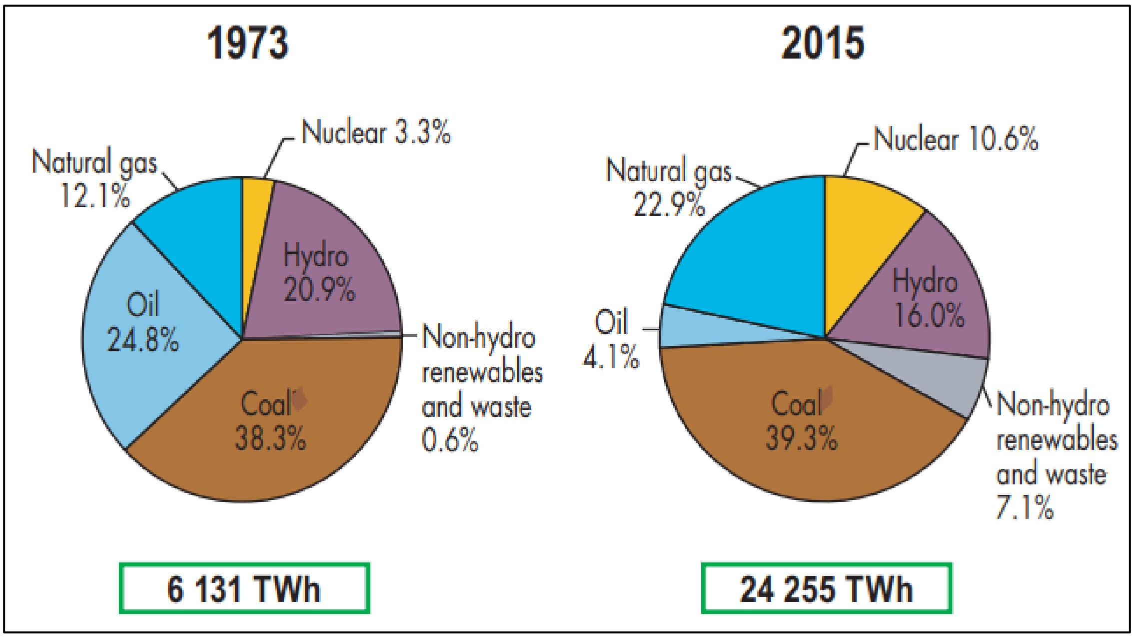

Figure 4.2 Global Electricity Mix Ratio

4.1.3 Pakistan Electricity Production History

In 1990, Pakistan had total installed capacity of 6546 MW which increased to 17,532 MW in 2005. This value reached to 35,372 MW in 2018. Table 4.2 but still can not meet the demand in the country. Overall thermal power is dominating the power sector of Pakistan. Renewable sources have very nominal share of just 356 MW. The installed capacity development trend is shown in Figure 4.3. The ratio of hydel to thermal installed generation capacity in the country, was about 67% to 33% in 1985 but with the passage of time, due to different reasons more thermal power was added thereby reducing the hydel share. In 2015 the ratio of hydel to thermal installed generation capacity became 30% to 65% which should be reverse for ideal case.

Table 4.2 Pakistan Installed Power Capacity Development

Year	Total Installed Capacity	Thermal		Hydel		Nuclear		Renewables / Imports
	(MW)	MW	%	MW	%	MW	%	MW
2005	19,560	12,605	64.4	6493	33.2	462	2.4	0
2006	19,550	12,595	64.4	6493	33.2	462	2.4	0
2007	19,681	12,745	64.8	6474	32.9	462	2.3	0
2008	20,232	13,215	65.3	6555	32.4	462	2.3	0
2009	20,556	13,539	65.9	6555	31.9	462	2.2	0
2010	21,614	14,597	67.5	6555	30.3	462	2.1	0
2011	23,502	16,070	68.4	6645	28.3	787	3.3	0
2012	23,556	16039	68.1	6730	28.6	787	3.3	0
2013	23,725	15,941	67.2	6947	29.3	787	3.3	50
2014	23,702	15,693	66.2	7116	30.0	787	3.3	106
2015	24,961	16,619	66.6	7116	28.5	787	3.2	439
2016	25,421	16,701	65.7	7116	28.0	752	3.0	852
2017	28,399	18,676	65.8	7116	25.1	1142	4.0	1465
2018	35,372	20,800	64	8683	27	1345	4	1691

Source: **(NEPRA, 2017)**

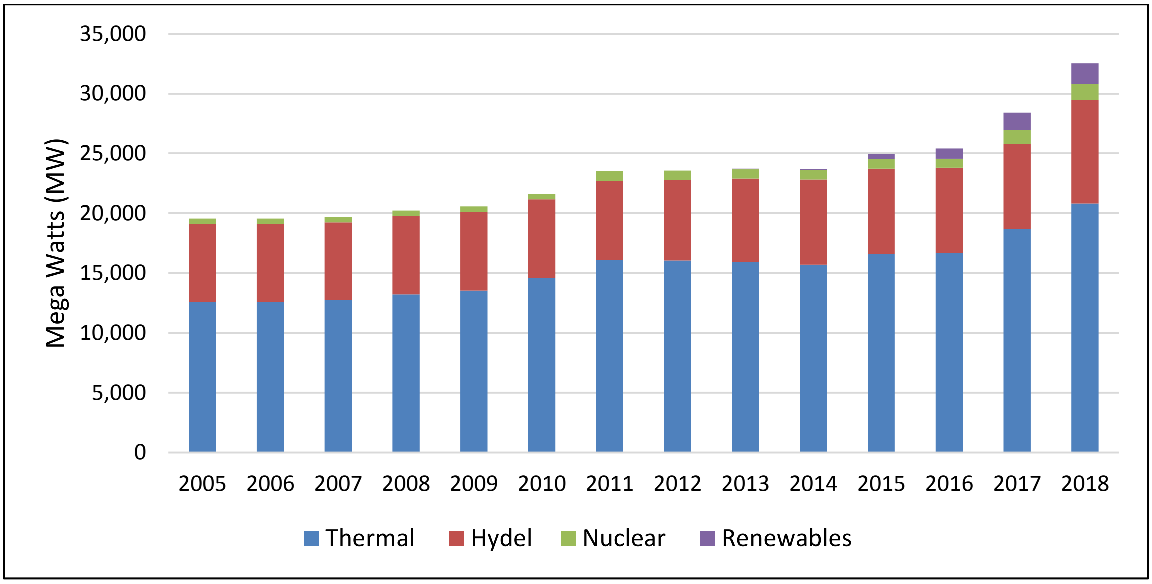

Figure 4.3 Installed Capacity Development since 2005 (NEPRA, 2017)

The problem for Pakistan is that its power production is dominated by thermal power plants running on oil and gas. According to the state of the industry reports of respective years by NEPRA, a comparison of installed generation capacity from 1959 to 2017 is given in Table 4.3.

Table 4.3 History of Hydel and Thermal Capacity

Year	Thermal (%)	Hydel (%)	Remarks
1959	56.3	43.7	
1970	50	50	Ideal For Economic Development
1980	42	58	
1985	33	67	
1990	55	45	
1996	58	42	
2000	67	33	
2005	64	33	
2015	66.6	28.5	
2016	65.7	28.0	
2017	65.8	25.1	
2018	64	27	

The industry and economy of a country is totally dependent on electricity generation capability of the respective country. A country having more primary sources can produce more electricity. Electricity generation, electricity consumption, GDP (gross domestic product), per capita energy consumption (energy consumption per person of a particular country) are the key indicators of economic development of that country. Table 4.4 shows that developed countries have high per capita electricity consumption. Canada, United States and Japan have 14,502 kWh, 11,974 kWh and 7383 kWh per capita electricity consumption respectively and consequently lead to economic development in the world.

In Pakistan per capita electricity consumption was 471 kWh in 2014. As shown in Figure 4.4, this reached to a maximum value of 486 in 2006 during the past 48 years and with a minimum of 93 kWh in 1971. In neighboring countries of

Pakistan, the value per capita consumption for the year 2014 in India, Sri Lanka, Bangladesh and Nepal were 805 kWh, 531 kWh, 310 kWh and 139 kWh respectively. (World Bank, 2015).

Table 4.4 Electricity Production & Consumption for 2016

Country	Electricity Production (TWh)	Electricity Consumption (TWh)	Per capita Electricity Consumption (kWh)
China	6015	5219	4292
United States	4327	3867	11,974
Russia	1088	887	6257
Japan	1013	927	7383
Germany	653	533	6385
Canada	643	498	14,502
Brazil	580	509	2414
France	553	448	6499
South Korea	549	512	9711
Pakistan	104.5	85.9	419

Source: (Enerdata, 2017)

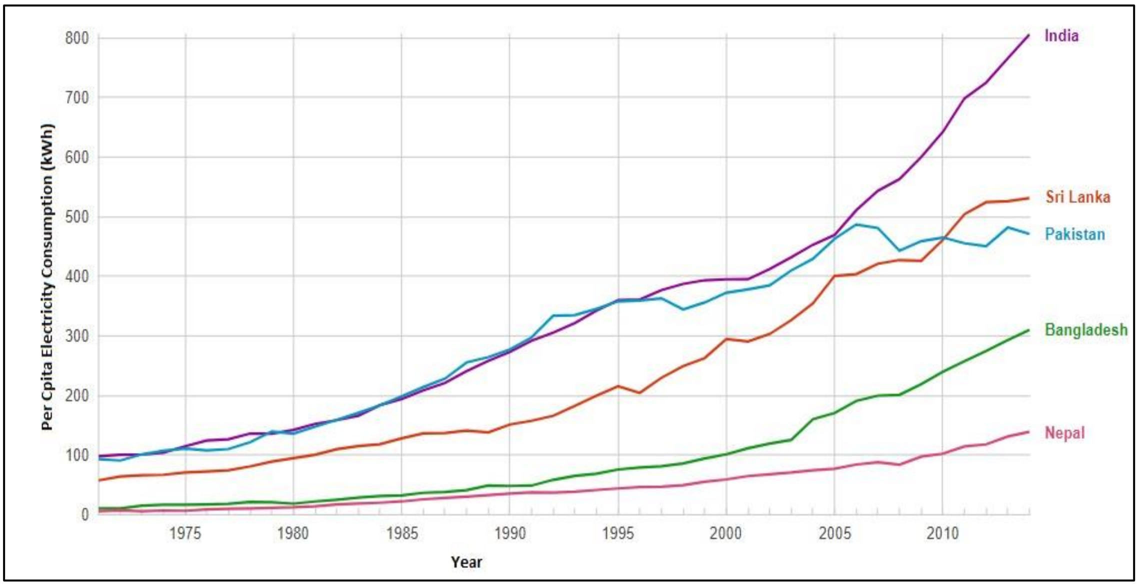

Figure 4.4 Per Capita Electricity Consumption of South Asian Countries

4.2 ELECTRICITY CONSUMPTION FORECAST

Electricity consumption is an important factor in planning the upcoming expansion of electricity sector of any country's forecast. The mainly identified electricity consumption sectors of the energy consumers of Pakistan are domestic, industrial, agricultural, transport, construction, commercial, public light or bulk supplies. Many small sectors are merged into the bigger ones. Following steps are required to forecast electricity consumption of a country.

4.2.1 Base Year Consumption

The first step in demand forecasting is to calculate the base year electricity consumption. In this study 2018 was taken as the base year. Electricity consumption data in all above-mentioned sectors in absolute form was collected from NEPRA (annual reports & state of the industry reports of respective years) and NTDC (power system statistics reports of respective years).

4.2.2 Generation Mix of Base Year

The total electricity supply in Pakistan mainly consists of gas, oil, nuclear and hydropower. The detail is shown in Figure 4.5. According to NTDC at the end of the fiscal year 2017-2018 Pakistan had a total installed capacity of 35,372 MW among which 20,800 MW (64%) was from thermal whereas hydel share was just 8683 MW (27%). Nuclear power imparts 1345 MW (4%) and remaining 1691 MW (5%) includes all other renewables and imports. It is clear from this figure that there is a small contribution of nuclear and renewables.

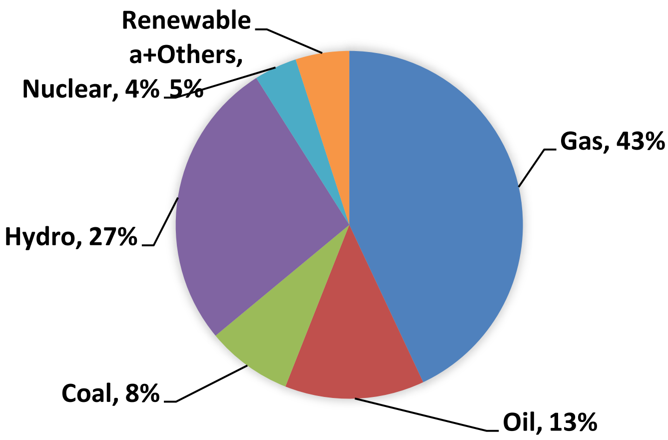

Figure 4.5 Pakistan Electricity Mix by Fuel 2018

4.2.3 Demand drivers

All the parameters that can influence the electricity demand are called demand drivers. The major drivers are lifestyle improvements, economic and population growth. Historical data and future plans are used to estimate driver values. Uncertainty is always present in this process. To overcome these uncertainties, projects are made with different assumptions called as scenarios. These scenarios are affected by the variations in demand driver values. To check the growth rate, electricity consumption data from 2005 to 2018 from all sectors was collected. From 2005 to 2012 there was a fluctuation in consumption growth but from 2013 onwards electricity consumption was continuously increasing with an average growth rate 6.6% as given in Table 4.5.

4.2.4 Total Electricity Consumption

On the basis of the average growth rate from 2013 to 2018, three scenarios were defined as “low growth rate” (5%), “normal growth rate” (7%) and “high growth rate” (9%) to forecast the electricity consumption till 2030. Total electricity consumption of the base year was accessed as 97.2 TWh (NTDC, 2018).

Table 4.5 Electricity Consumption Growth Rate

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Electricity Consumption (TWh)	55.3	62.4	67.5	66.5	65.3	68.9	71.7	71.4	70.5	76.5	78.1	81.7	86.8	97.2
Growth Rate (%)	12.9	8.2	-1.4	-1.9	5.5	4.1	-0.4	-1.2	8.6	2.1	4.7	6.2	12	12.9

The main point to be noted that load shedding share is not included here. If load shedding of 6000 MW (25-30 TWh) is also added then it can be concluded as total consumption for the base year 2018 that becomes equal to approximately 125 TWh. Then a very near to real forecast can be done for the future (Figure 4.6).

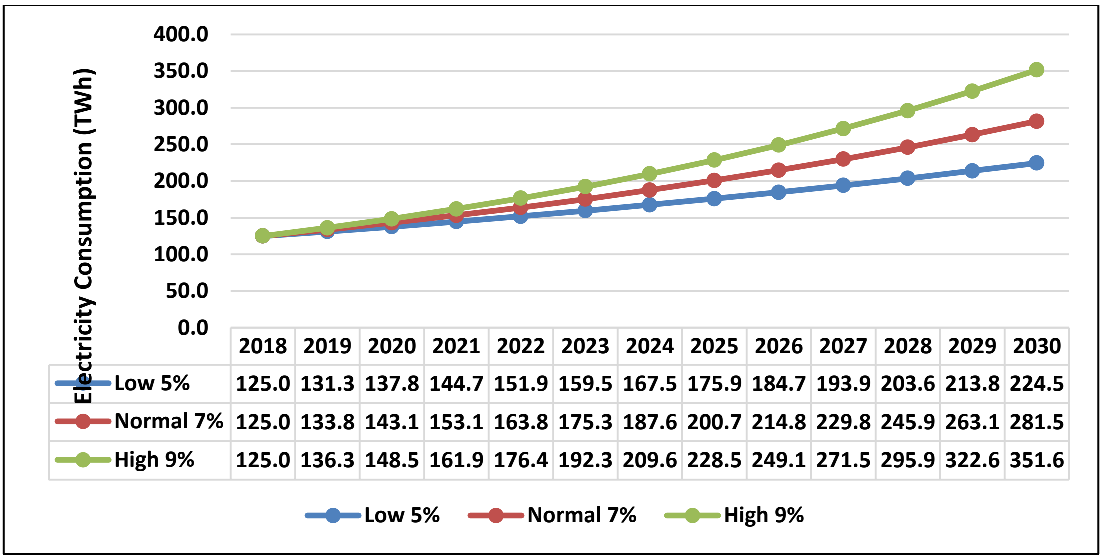

Figure 4.6 Electricity Consumption Forecast Scenarios

4.3 NEED FOR HYDROPOWER DEVELOPMENT

The overall demand of electricity in the country is increasing day by day. The power policy of 1994 by the government of Pakistan encouraged IPP's (Independent Power Producers) to produce thermal electricity by giving them many incentives. According to NEPRA, in 2018 the hydel-to-thermal mix ratio in the country is 25:66, which is almost the reverse of an ideal hydel-thermal mix, which should be 70:30 for overall economic development of any country. Thermal power generation can be a suitable option for continuous supply to overcome the load shedding but it resulted in an increased power tariff. A cheap hydropower production through multipurpose storages is a viable option to keep the cost of electricity within affordable limits (GOP, 2009).

4.4 PAKISTAN HYDROELECTRIC POTENTIAL

GOD has blessed Pakistan with numerous large rivers having identified hydropower potential of 60,000 MW (WAPDA, 2013). Indus has a potential of 39797 MW, Jhelum has a potential of 5624 MW whereas remaining potential is on other rivers as shown in Figure 4.7.

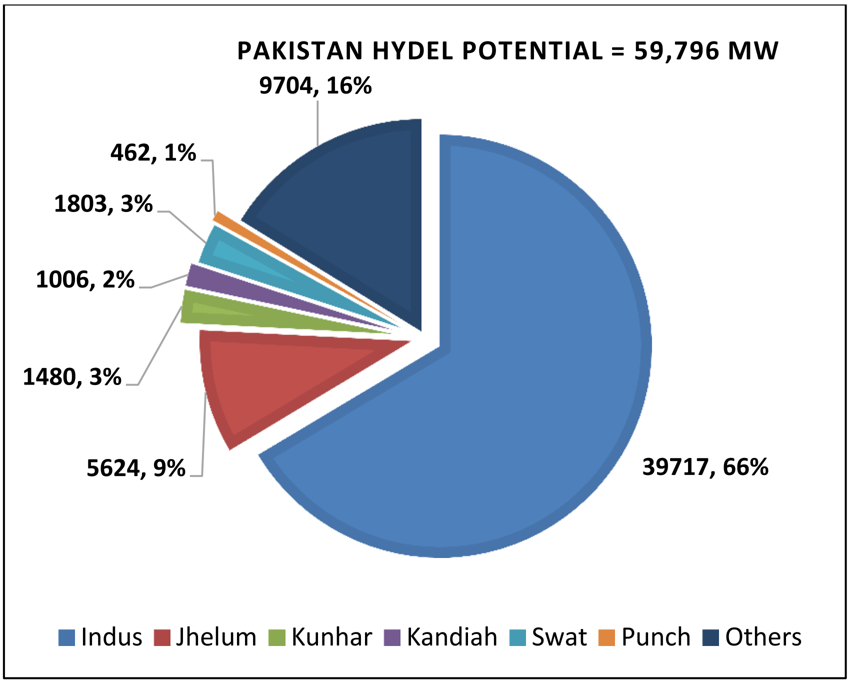

Figure 4.7 River wise Hydel Potential of Pakistan

Northern areas of Khyber Pakhtunkhwa possess 24736 MW, Punjab 7291 MW, Sindh 193 MW, Baluchistan 1MW, Gilgit Baltistan 21125 MW and AJK has 6450 MW potential sites among which just 12 % potential has been harnessed yet (Figure 4.8) (NEPRA, 2017).

Large hydropower projects are time taking but payback ids high in long run. If small and medium hydel power projects are installed and proper strategies are adopted for planning, organizing and distribution, Pakistan can be capable to export electricity to other undeveloped countries after fulfilling its own requirements.

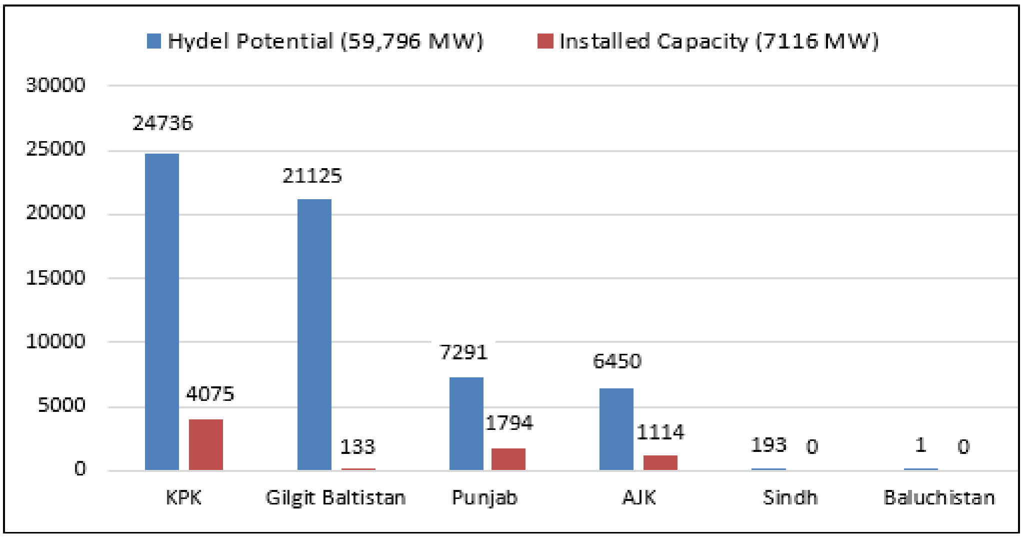

Figure 4.8 Pakistan Hydroelectric Potential

4.5 WAPDA VISION 2025

On 7th January 2001 the Government of Pakistan (GOP) approved a development program "Water Resources and Hydropower Development Vision 2025 Program" in order to meet the increasing power and water needs of the country which would take a critical turn for the coming years. According to this program, Pakistan's economically viable hydropower potential is about 40,000 MW. Detail is given in Table 4.6. Among this total potential, about 591 total numbers of sites have been identified for small hydropower projects on canal falls and barrages with the total potential of 550MW. The vision 2025 program envisaged exploitation of the water resources of the country for irrigation, hydropower generation and water supplies. The vision 2025 program includes: (i) Review of previous studies, (ii) Propose and undertake new feasibility studies, (iii) Review and undertake detailed engineering designs, (iv) Prepare tender documents, and (v) Encourage and manage the implementation of water resources and hydropower development projects. The hydropower projects execution can be by both the public and the private sectors.

Table 4.6 Pakistan's Hydroelectric Potential

Sr. No.	Project	Capacity(MW)
1.	Hydel station in operation	4,916
2.	Under implementation	1,653
3.	Project with feasibility study completed • Run of river • Multipurpose	 2,875 4,340
4.	Project with feasibility studies in hand • Run of river • Multipurpose	 2,565 3,412
5.	Projects with planned feasibility studies	21,222
	Total	**40,938**

(Source: WAPDA 2025 Vision)

4.5.1 Objectives of Vision 2025

- To prevent the water shortage in the future
- To compensate/adjust for the predicted climatic change
- To protect the agriculture sector from drought
- To increase reservoir capacities lost due to siltation and develop new storages to cater for the future need
- Develop 16,000 MW of Hydropower for providing cheap electricity to consumers
- To invest 33$ Billion in next 22 years to achieve the above vision

WAPDA developed a list of eight priority projects which includes Bunji

Hydropower project, Diamir Bhasha Dam, Kurram Tangi Dam, Terbela 4th Extension Project, Golen Gol, Kohala Hydropower Project, Mohmand (Munda) Dam and Dasu Hydropower Project. Completion of these projects will substantially increase the water productivity to fulfill the future requirement for irrigation and agriculture, storage growth.

4.6 NTDC 2025 PROJECTIONS ANALYSIS

National Transmission and Dispatch Company (NTDC), of Pakistan is responsible for electricity demand forecasting and publishing on regular basis. These projections are done frequently after 4 to 5 years by using extensive economic growth. Relying on such data for a long span of 20 to 30 years is not suitable. Data collection, calculations and analysis were made to forecast the projections realistic. Moreover, hydel power generation was dealt with more depth by gathering data from WAPDA, NTDC, NEPRA and PPIB about the current status of under construction, in process and future projects to check:

- The maximum hydel share in the future with the completion of the upcoming projects
- The decrease/depletion of shortfall with the completion of upcoming hydropower projects
- The gap between available hydel share and optimized hydel share

In "State of Industry Report 2017" published by NTDC electricity generation projections from all sources were made till 2025 including private & public sector projects. Figure 4.9 shows Pakistan's electricity installed capacity development from 2005 to 2017 and further projections from 2018 to 2025 made by NTDC. The main drawback in these projections is that the shortfall of 600 MW present in the base year suddenly disappears in next year that is unrealistic. And obviously, this will affect the whole projections.

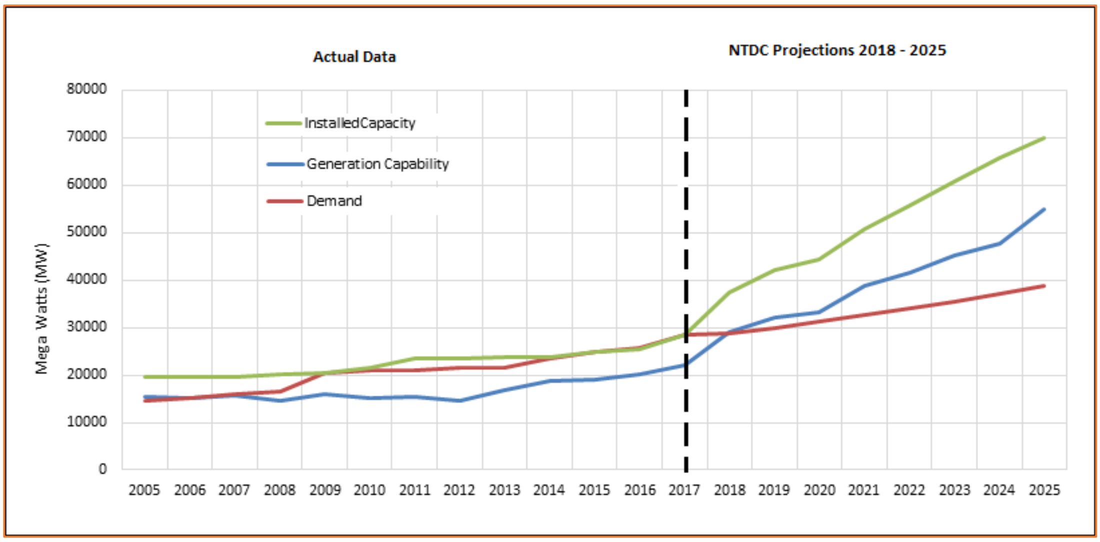

Figure 4.9 Electricity Supply and Demand Development and Projection (2005-2025)

If this analysis is limited to only hydropower development (Figure 4.10) then a sudden increase in hydel share from 2017 to 2018 that is also not up to real situation even at the end of 2018 this share has not been met. In further sections of the thesis, a comparison is made with these projections by calculating the hydropower share in total electricity mix and then to estimate optimized hydel share to provide sustainable and cheap electricity to the consumers.

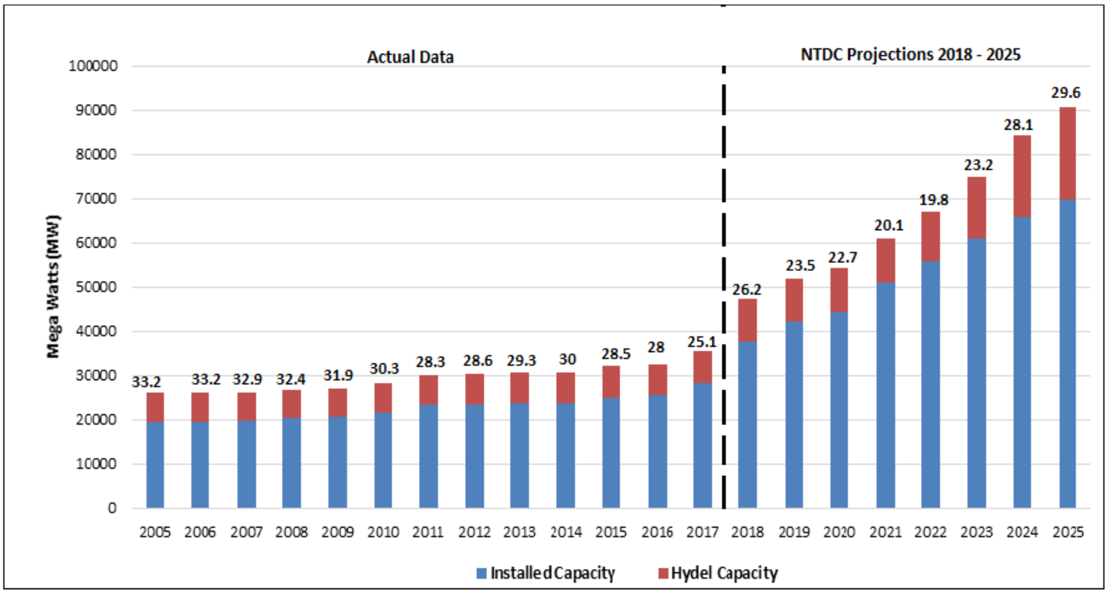

Figure 4.10 Hydel Share Forecast till 2025

4.7 INSTALLED HYDEL CAPACITY OF PAKISTAN

Major hydropower production units are Mangla, Terbela, and Chashma and Ghazi Barotha hydropower projects. List of the hydropower projects which are connected to the national grid is given in Table 4.7. Hydropower is seasonal based that's why in winter it has less amount due to the water shortage. To assess the critical capability of the system, generation during winter is used.

Table 4.7 Pakistan Installed Hydel Capacity

Power Station	Type of Power Station	Location	Capacity (MW)	Capability * (MW)	Date of Completion
Major Hydel Units			**7244**	**3960**	
Terbela	Reservoir	Terbela, KPK	3948	1874	1976
Ghazi Barotha	Run of River	Ghazi Barotha, Punjab	1450	1160	2003
Mangla	Reservoir	Mangla, AJ&K	1000	450	1967
Warsak	Reservoir	Warsak, KPK	243	20	1960
Chashma	Run of River	Chashma, Punjab	184	184	2001
Khan Khwar	Reservoir	Shangla, KPK	72	68	2012
Allai Khwar	Reservoir	Battgram, KPK	121	68	2013
Jinnah Hydel	Run of River	Mianwali, Punjab	96	68	2013
Duber Khwar	Reservoir	Kohistan, KPK	130	68	2013
Small Hydel Units			**128 MW**	**41 MW**	
Dargai	Run of Canal	Dargai, KPK	20		1953
Rasul	Run of Canal	Rasul, Punjab	22		1952
Shadiwal	Run of Canal	Shadiwal, Punjab	14		1961
Chichoki Malian	Run of Canal	Chichoki Malian, Punjab	13		1959
Nandipur	Run of Canal	Nandipur, Punjab	14	41	1963
KurramGarhi	Run of Canal	KurramGarhi, KPK	04		1958
Renala	Run of Canal	Renala, Punjab	01		1925
Chitral	Run of Canal	Chitral, KPK	01		1975
GomalZam	Reservoir	South Waziristan, KPK	17		2013
Malakand/Jabban	Run of River	Malakand, Jabban	22		1935

Hydel IPP's			**342 MW**	**342 MW**	
Jagran	Hydro	Jagran, AJ&K	30	30	2000
Malakand III	Hydro	Malakand, KPK	81	81	2008
Patrind	Hydro	Muzaffarabad, AJ&K	147	147	2018
Laraib Energy	Hydro	Jhelum River, AJ&K	84	84	2018
Total			**8683 MW**	**4343 MW**	

*Winter Derated capacity

4.8 MODIFIED HYDROPOWER DEVELOPMENT PLAN UPTO 2030

A detail data of under construction/future, private and public sector hydropower projects were collected to find an accumulative installed hydel capacity, with the completion of WAPDA Vision 2025 hydel projects. Installed capacity data till 2017 from NTDC was used but the projects completed in 2018 also have been added resulting in a total installed hydel capacity of 8683 MW, (Figure 4.11). It shows only the hydropower capacity increase with the completion of each project. With the completion of all these projects in mid of 2029 the total hydel capacity becomes 32,840 MW which is approximately equal to the total capacity of the country in 2018 (35,372MW).

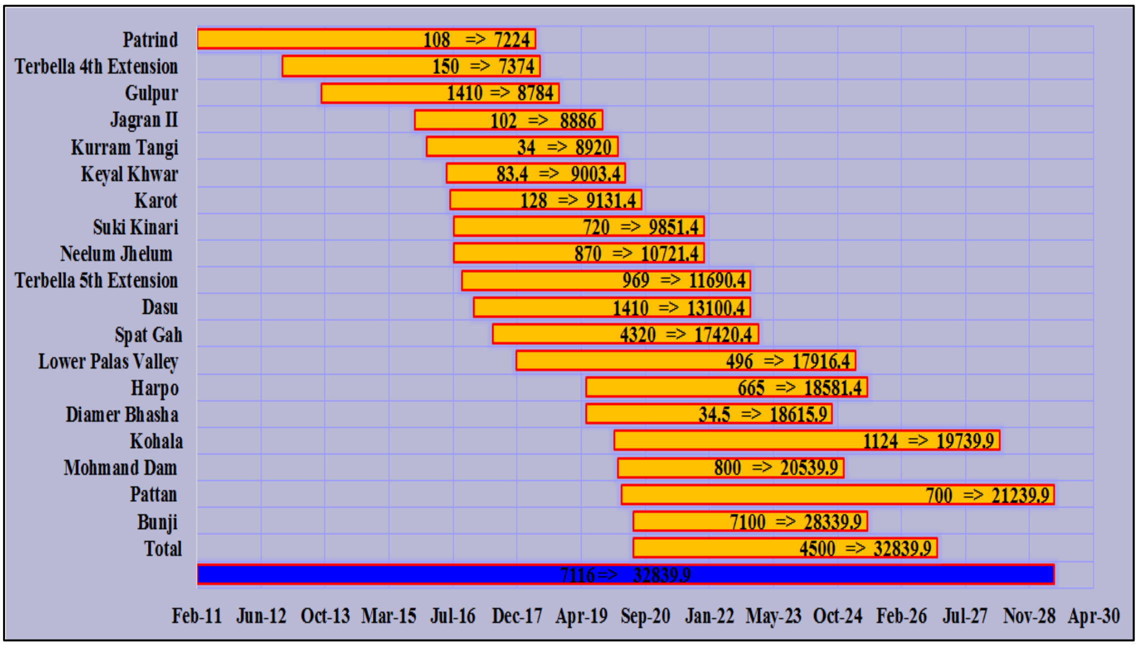

Figure 4.11 Hydropower Development till 2030

After analyzing the data, installed capacity development till 2030 with the share of each resource is presented in Figure 4.12. At the end of 2030 with the completion of simultaneous planned projects hydel share reaches to 42% with 17 % increase from 2018. Thermal share reduces and becomes approximately equal to hydel share (42.8%). Nuclear stands at 5.7% whereas wind solar and bagasse holds the share of 3%, 2% and 4.4% respectively. The deficit of 1341MW eliminates in 2020 and turns into the surplus of 3334 MW in 2021 with the commissioning of under construction GolenGol, Terbela 4th extension, and Gulpur and Kurram Tangi hydropower projects. Further completion of upcoming projects leads to continuous surplus generation till 2030. This surplus value can be made real if load shedding amount and transmission losses are added in the calculations.

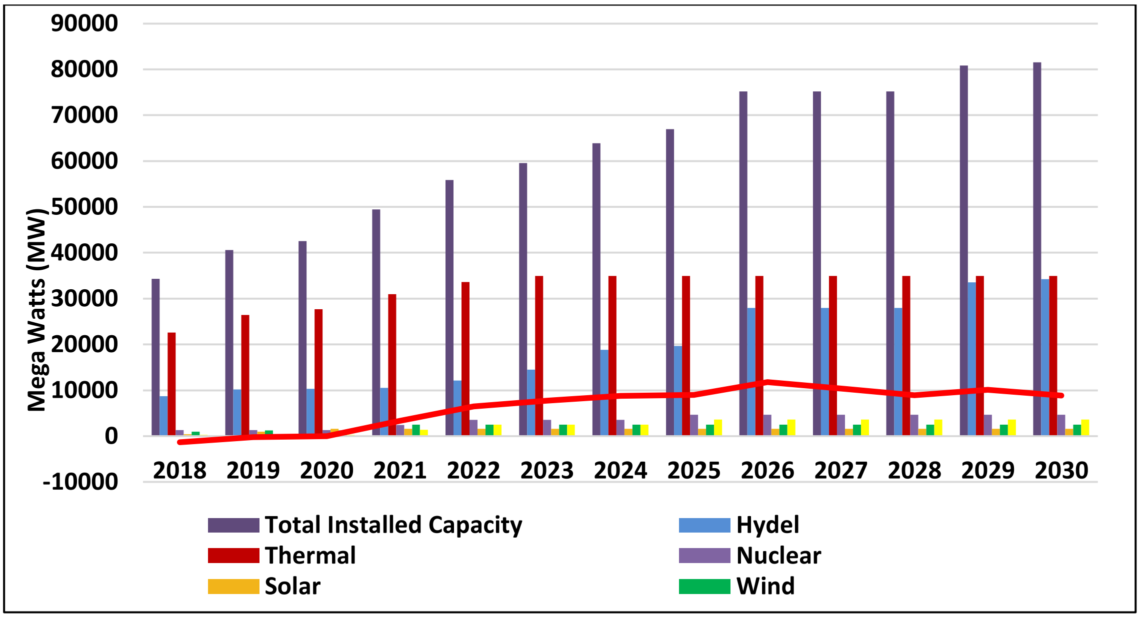

Figure 4.12 Electricity Mix till 2030

4.9 OPTIMIZATION SCENARIOS

In this section, hydropower optimization means to get an optimal hydel capacity against increasing thermal share. In different government policies, emphasis is done on reducing the thermal generation and replacing this by cheap and clean hydropower. Three different scenarios were developed to get a suitable required optimal solution. The first scenario taken was Business as Usual (BAU). In second and third scenario by fixing the thermal capacity as of the base year and filling the gap produced in total capacity either by increasing hydel or renewable share. In all these scenarios optimization solution were made using linear optimization approach in MS Excel.

4.9.1 Business as Usual (BAU) Scenario

This BAU scenario was studied as a reference case, keeping the forecasted plan as per newly estimated schedule, given in Figure 4.11. According to the government planning, thermal plants installation is less encouraged compared to the hydropower generation. As a result hydel share will increase from 27% (2018) of the total capacity to 42% (2030), equal to thermal share. Remaining 14% will comprise on nuclear, wind, solar and bagasse (Figure 4.13).

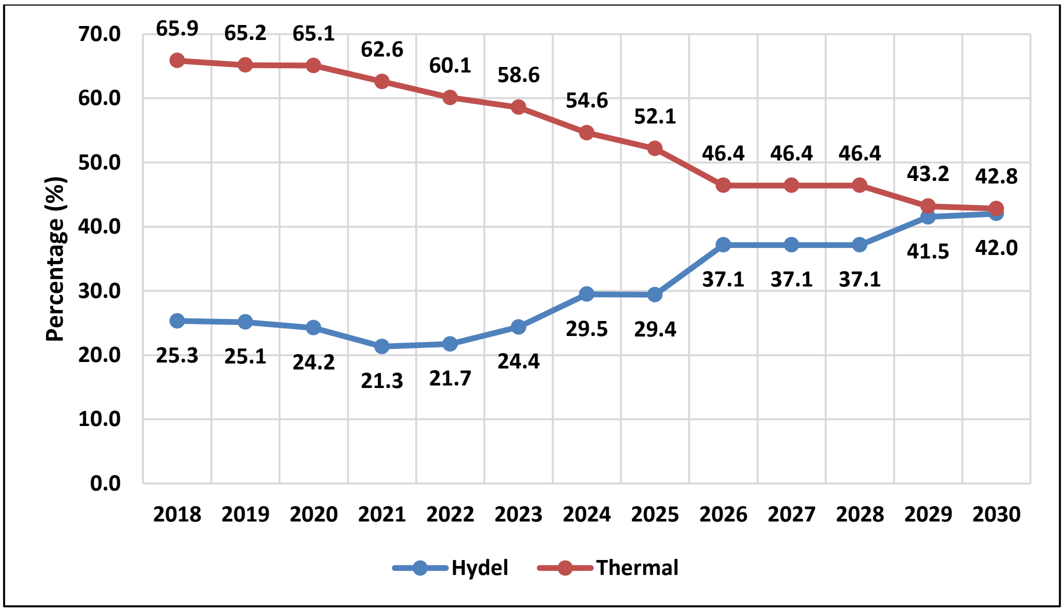

Figure 4.13 BAU Scenario

4.9.2 Fixed Thermal Capacity with High Hydel Scenario

The second scenario with fixed thermal capacity was aimed to examine the effect of keeping thermal share constant. In this scenario thermal share of the base year 2018 was assumed to be kept fix till 2030. This assumption leads to the situation that after 2018 there will be no thermal plant installation so as to make the less thermal share possible (Figure 4.14). Keep the thermal-based plants in running condition not only will play a vital role in fulfilling the electricity demand in the country but also provide sustainability to the power sector.

After fixing the thermal capacity at 22603MW (64.3% of total) and keeping the hydel same as in BAU case, gap/deficiency will be generated. This gap provides free opportunity whether to increase hydel, nuclear or renewables to meet the required capacity. If all this deficiency is managed to fulfill using hydel then the hydel share can be increased up to 57% and simultaneously thermal share will reduce to 27% of the total. As discussed in earlier sections hydel to thermal ratio of 67:33 is considered as ideal for economic development of any country. According to this scenario, Pakistan will attain this ideal situation in 2030.

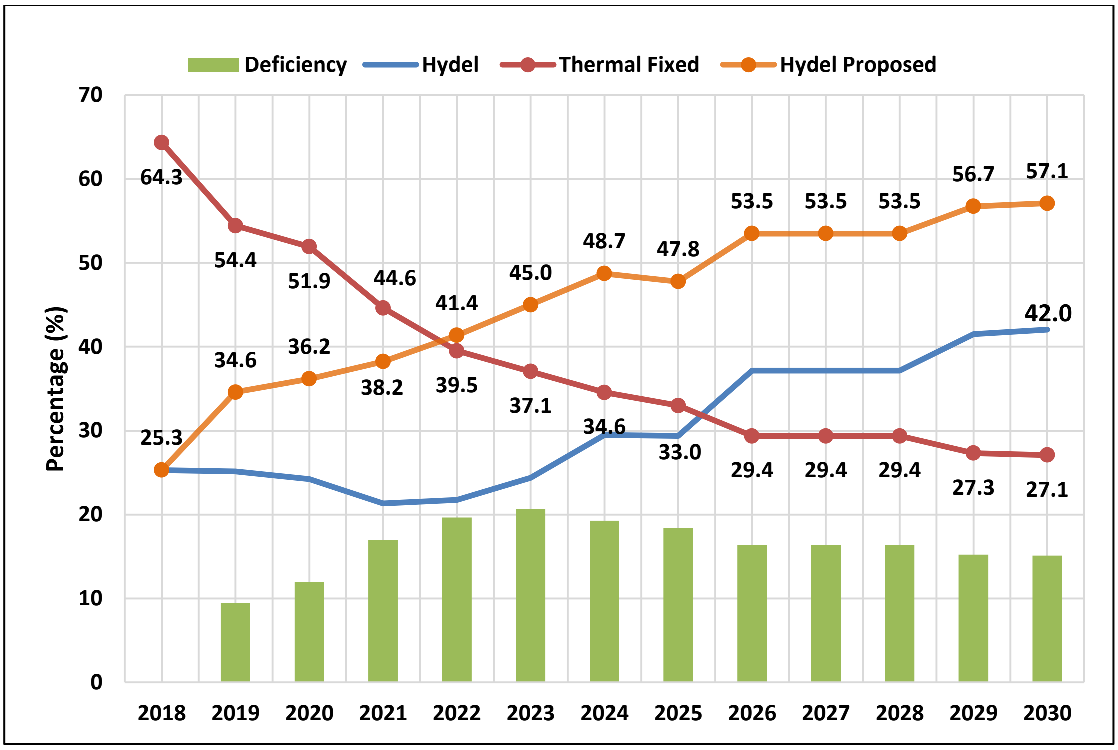

Figure 4.14 Fixed Thermal Capacity with High Hydel Capacity Scenario

4.9.3 Fixed Thermal Capacity with High Renewables Scenario

This third scenario was developed to investigate the impact of high renewable share in the total energy mix ratio. Phenomena was kept same as of second scenario. The only difference would be that the deficiency/gap generated because of keeping thermal share constant will be fulfilled with more induction of renewable sources like solar, wind or bagasse. This will result in increasing the renewable ratio from 4.9% to 24.6% from 2018 to 2030 (Figure 4.15). The main reason to include this scenario was that a sudden increase in hydel capacity is not feasible. Hydropower projects especially large multipurpose projects are time taking. Whereas induction of renewable could be made within a year or so. Thus increasing renewable share seems to be more realistic than the second scenario.

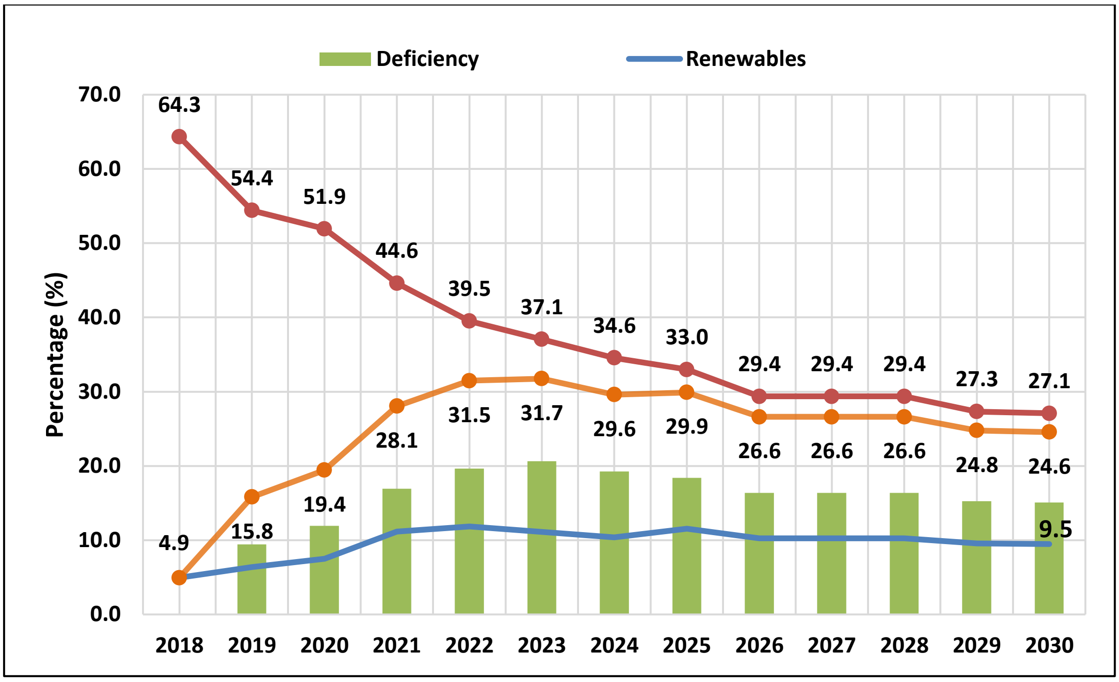

Figure 4.15 Fixed Thermal Capacity with High Renewables Scenario

4.10 GENERATION & TRANSMISSION SYSTEM ANALYSIS

The data analyzed from NTDC Power System Statistics Reports of respective years shows that even having the total installed capacity more than the total demand, Pakistan is facing continuous shortfall of average 5500 MW from 2010 to 2018. Same views were shared by (Bhutta, 2016). Which means that the main problem exist in generation, transmission and distribution of electricity. Overall thermal and nuclear fired plants generation capacity is reduced by approximately 15-20%. Hydel capacities are reduced up to 50% and renewable sources derate the total capacity up to 25-35%. Similarly average transmission and distribution losses from 2010 to 2018 were recorded as 20.2% being the main reason of shortfall. (NTDC, 2018)

4.11 FUTURE PERSPECTIVE

Most of the under development hydropower resources of Pakistan are in its northern areas. Exploitation of these resources is the government’s foremost priority.

An expansion of the transmission system toward the northern areas and strengthening of existing lines between the southern and northern lines is among the future targets of the NTDC (ADB, 2015). More transmission lines are also required to connect the wind, solar and other renewables sources' output to the national grid mostly in the south west part of the country. Without these expeditions, increasing the total capacity each year will be in vain.

Chapter V
CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The main focus of this research work was to analyze that how Pakistan can utilize its hydropower potential to overcome the ongoing energy crisis. It was concluded that:

1. Power Generation growth (0.02%) is very slow as compared to consumption (4.12%) (2015).
2. Just 12% of total Hydel Potential have been harnessed yet. Due to high thermal share Pakistan's economic development slowed down.
3. Hydropower potential of 100,000 MW (60,000 MW Identified) can play a vital role to overcome the current energy crisis in Pakistan. Large Hydropower projects require much time for designing as well as for construction. A sound and comprehensive planning addressing socio-economic issues should be done before launching the new projects.
4. A most near to realistic data analysis was made till 2025, which shows that WAPDA vision 2025 plan will be completed till 2030, if delayed and postponed projects get completed during the new estimated duration.
5. Current shortfall of 6500 MW is expected to be eliminated in 2020-2021, however WAPDA Vision 2025 should be completed well in time to avoid further complications.
6. If planned projects are commissioned as per schedule (BAU scenario) then at the end of 2030, thermal to hydel share gains a point with 50, 50 shares. If hydel capacities are being enhanced low cost power will be produced.

7. Reliance on thermal power should be reduced gradually so that power shortfall may not be aggravated suddenly. As concluded from second scenario the hydel share should be 40% in 2022.

5.2 RECOMMENDATIONS

From the findings of this work, we conclude few recommendations. These recommendations can be categorized as for new researchers and for government institutes. For further research perspective following recommendations are being made:

- The optimization of hydel and thermal share was done without cost analysis. Detailed cost analysis should be done further.
- Initial cost of major hydropower projects is a main factor that effect the project. Further research work can be done to reduce the initial cost, possible resulting tariff and estimating the turnover period of each project.

A few recommendations for government institutes for provision of sustainable energy in Pakistan;

- Recent hydel projections must be increased to overcome the energy crisis in the country.
- Delay in hydropower projects planning and execution phases must be dealt with strong a strategic approach.
- To overcome the delay in projects execution policies have to be formulated considering geographical, geological and environmental factors, involving all stakeholders.

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