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MSc Energy Systems and the Environment

Energy Crisis in Kurdistan
And
The Impact of Renewable Energy

A thesis presented in fulfilment of the requirements for the degree of

MSc in Energy Systems and the Environment

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Copyright Declaration

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Abstract: -

A reliable supply of energy is vital to all aspects of modern life. At present renewable energy has a significant role in providing a safe, reliable and cheap alternative for all of our energy needs. This role will grow and grow as a result of increasing global energy demands, climate change warning and running out of the fossil fuel resources due to using it at a very large rate.

Unfortunately energy supply in Kurdistan region suffers from a chronic shortage. This problem has not been solved so far because of the historical, geographical and political situation in the region.

Today there is an opportunity to sort out the energy crisis in Kurdistan on the basis of green, safe and sustainable energy by using the renewable resources to meet at least a fraction of energy demands in Kurdistan.

In this study a proper policy for exploiting renewable energy for Kurdistan has been discussed and assessed, after studying market conditions and the available technology for exploiting renewable energy around the world.

In order to study the impact of renewable energy in Kurdistan, a small village has been taken as a model and provided with energy from renewable resources. The result of the case study can be used as a guide to generalize using renewable energy widely in rural and isolated areas in Kurdistan. The positive impact of renewable energy on energy shortage in a village can be considered as a first step in deploying renewable energy technology in the whole of Kurdistan. Recommendations are then made for making use of reasonable resources at a large-scale, strategic level.

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Chapter 1

1.1 Introduction: -

There is a strong link between economic progress and its development with the demand for energy. In the last few years we have seen how energy demand has increased especially in the developing countries. Accordingly, energy prices jumped to their highest rates and it is probable that prices will continue to rise in the future.

After the oil crises in 1973/74 and 1979/80 the tendency in non-oil producing countries was if possible to base electricity generation more on domestic fuels to secure energy supply. But in many cases the ability to do this was limited, and subsequent reduction in oil prices brought stability once more.

But Kurdistan, located in an oil rich area, has experienced energy shortages from the first day of discovering oil in the region until now. Discovering oil and gas in the region in the beginning of last century did not bring wealth to the region but on the contrary, destruction, deportation and genocide was the consequence. Therefore many Kurds took the view that these abundant natural resources were a curse.

This thesis is a brief study of the recurring energy crises in Kurdistan and the possible potential of renewable energy to minimize the shortage of energy in the region which persists today despite its (45 bb - billion barrel) proven reserve of oil and (100 TCF – trillion cubic feet) of gas [1].

Today there is an effort to exploit the reserves oil and gas to generate revenue to build the basic economic, industrial and agricultural infrastructure in the region.

But the energy demand in the region is increasing steadily. There are plans which will be discussed later to use some of the indigenous oil and gas to meet these demands, but the priority is to raise capital to invest in the regeneration of the region. So the domestic consumption of oil and gas must be restricted, and significant shortages of energy supply are likely to persist for many years unless alternatives are found. Renewable energy sources are an obvious possibility, and have the advantage of being sustainable in the long term.

1.2 Aim and Objectives: -

Reducing the impact of green house gas and global warming is the main reason behind investigating alternative sources of energy for the developed countries of the west. For the developing regions, particularly those which have been subjected recently to wars and local conflicts, global issues may seem rather distant. Local concerns are likely to dominate. But there are some matters which are common to all: rising oil prices at present are a compelling reason to develop the renewable energy sector.

Part of this study is aimed to illustrate the importance of renewable energy globally, describe the technological status of its various forms and the developments of the market.

In addition the particular objective of this study is investigating the potential of renewable energy in a region which is basically rich in fossil fuel, but has unexplored prospects of renewable energy which may play a significant role in bridging the gap between the rising of demand and poor energy supply in the region.

The history of energy supply in Kurdistan and in Iraq as a whole (its failure to meet demands, its unreliability and the way in which the consumers pay for it) is forming a background which is very different to that experienced in counties of the west. Altitudes towards renewable energy supplies may also therefore be very different. These aspects, along with technical feasibility, will be examined for Kurdistan at the large, strategic scale and also at small scale for rural applications by way of a case study.

Chapter 2 gives a general review of renewable energy sources. Chapter 3 gives a historical perspective of Kurdistan and summarises the present situation, particularly with regard to energy supply. Chapter 4 examines the general potential for renewable energy in Kurdistan, while Chapter 5 looks at the application of these ideas in rural village.

In Chapter 6 the findings from the previous two chapters are discussed in the context of present projections for energy supply and demand, and attentive strategies are explored.

Chapter 7 gives the final conclusion and recommendations.

1.3 Methodology:-

Because this study is about a region outside the UK, the first step was a site visit to Kurdistan to give an understanding of the problems in the power generation sector in the region, and establish a general background. It was also important to establish ways of collecting recorded climate data. The next step was assessing, classifying and reprocessing the data to use it in calculations to estimate the potentials of renewable energy in Kurdistan. After getting the calculation results a wind and solar map of the region produced.

To understand the possible impact of renewable energy on the energy crisis at a local level case studies have been done.

The results have been examined from technical, economical and social viewpoints. Conclusions have been drown about local, small-scale energy supply and more generally for the whole of Kurdistan.

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Chapter 2

(General view on Renewable Energy)

2.1 Renewable Energy: -

Renewable energy can be defined in more than one way but generally it could be the energy sourced from infinite and continuously available sources which do not rely on fossil fuel like coal, oil and gas or nuclear power or can be defined as energy flows which are replenished at the same rate as they are used.

Today renewable energy has significant contributions towards energy supply worldwide, which represent 18% of total energy consumed in 2006 (see figure 1)[2].

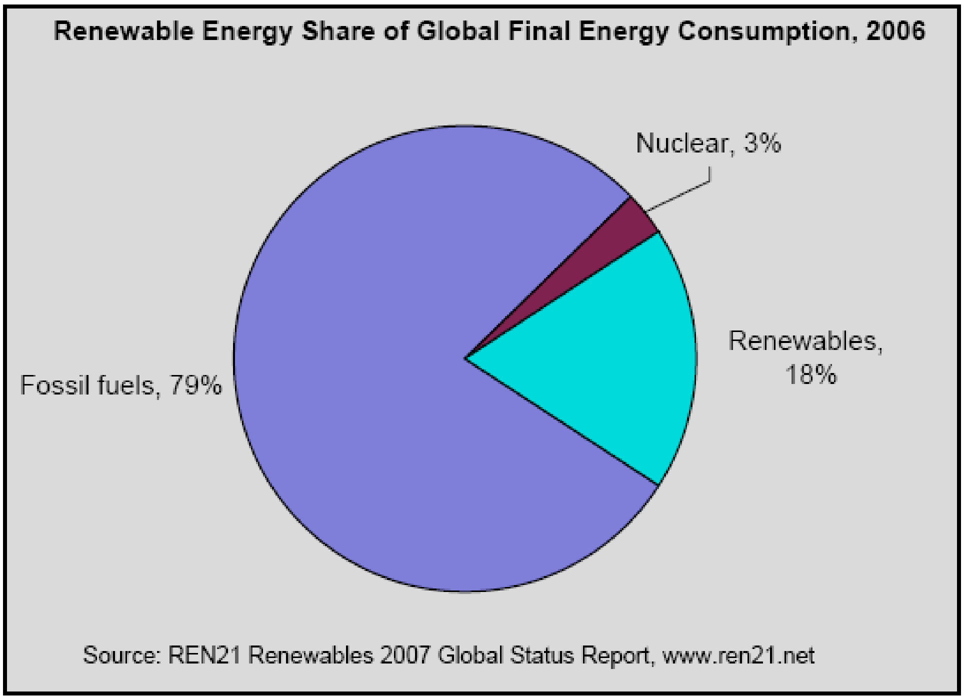


Figure 2 Renewable Energy Contribution / 2006[2]

Hence, renewable energy can offer our planet a chance to reduce carbon emission and supply reliable, clean and cost effective energy. In 2007, more than $100 billion was invested in renewable energy production assets, manufacturing, research and development, giving employment to more than 2.4 million people around the world [2].

Generally renewable energy may be classified as follows:

- Non-Solar renewable energy: this type of energy is not powered by the sun directly or indirectly, and comprises only tidal and geothermal energy.
- Solar renewable energy: this category consists of various types of energy produced by the sun directly or indirectly. Solar radiation for heating and electricity generation can be categorized as direct solar renewable energy. But indirect solar renewable energy includes an extensive range of renewable energy forms like hydropower, wind energy, wave energy, ocean thermal energy and biomass and bio fuel.

2.2 Non-Solar renewable energy:-

2.2.1. Tidal Energy: - Tidal energy represents one of the most predictable sources of renewable energy available on Earth; Each day, billions of kilograms of water are lifted above their normal level under the influence of gravity, increasing the potential energy of the tidal water column beyond that of seawater at low tide. The moon has the greatest influence, but the sun also plays a part; when the sun and the moon pull together (high) spring tidal ranges will occur; when the sun and the moon are at 90 degree to each other the (smallest) Neap ranges will be produced.

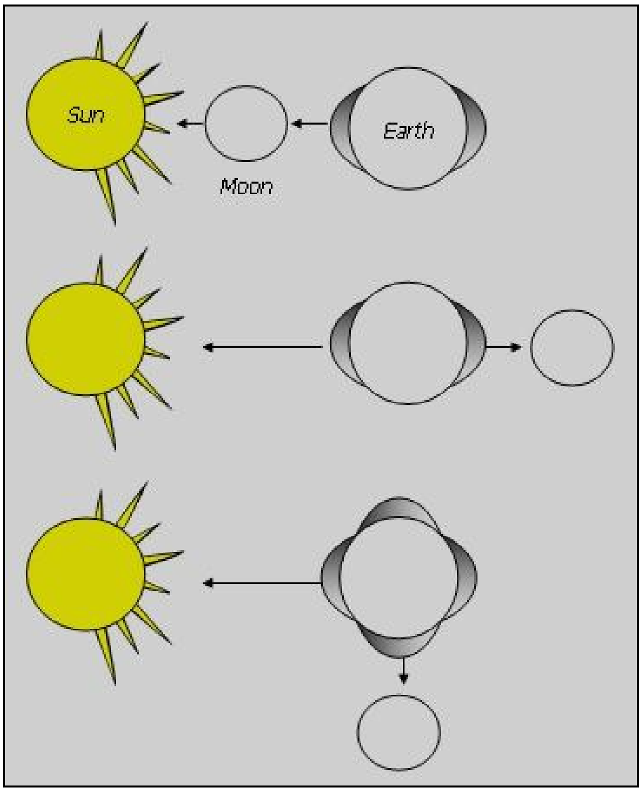


Figure 2 Gravitational effect s of the Sun and the Moon on tidal range (source: www.glf.dfo-mpo.gc.ca)

From this predictable natural phenomenon energy can be extracted by building tidal barrages across suitable estuaries, mounting turbines in water passage in the barrage. A tidal power scheme has been built at La Rance estuary in France rated at 240 MW and a number of smaller schemes have been built around the world, IEA stayed that 565 GWh electricity has been produced from tidal energy around the world during 2005[3]. In the UK there is a proposal for the 8.6 GW Severn Barrage, stretching 16 km across the Severn estuary in the UK. If built this would generate 17 TWh of electrical energy per year, the equivalent of nearly 4% of the electricity generated in the UK in 2006 [4].

In another way tides can be harnessed by means of marine current turbine, which can be installed in the sea at places with high tidal current velocities, or in a few places with fast enough continuous ocean currents, to take out energy from these huge volumes of flowing water. These flows have the major advantage of being an energy resource which is almost as predictable as the tides that cause them. Marine current turbines work, in principle, much like submerged wind turbines, but driven by flowing water rather than air.

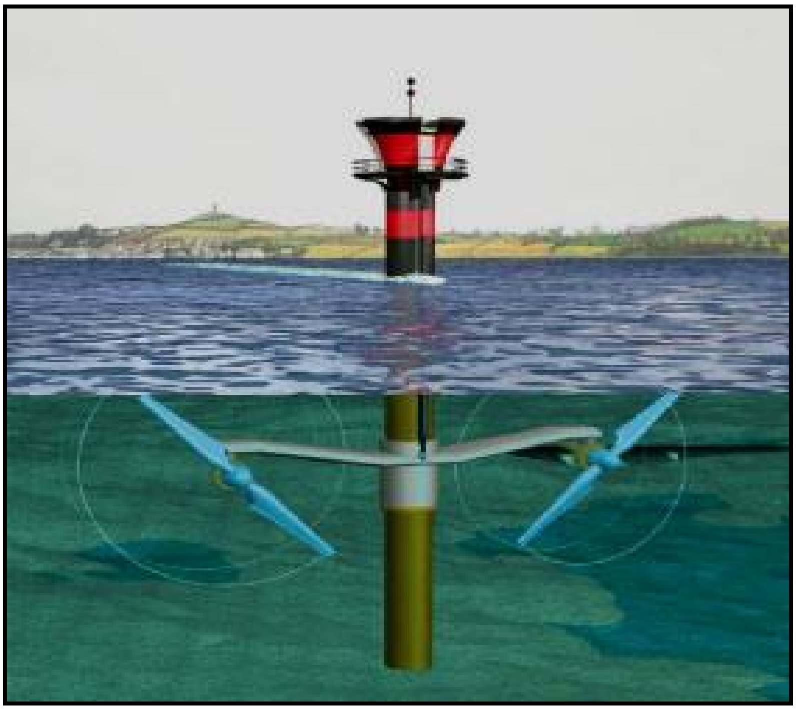


Figure 3 Marine Current Turbines (source: www.geotimes.org)

Marine Current Turbines Ltd (MCT) has now commenced work in Strangford Lough on the installation of its 1.2MW SeaGen tidal system and should complete installation in the summer of 2008 [5].

2.2.2 Geothermal Energy: -

It is refers to the energy flow from the earth in form of a high temperature steam or hot water. Geothermal energy can be used as an energy source in many ways, from large and complex power stations to small and relatively simple pumping systems. Its potential as a global energy source is substantial.

Electricity and heat from geothermal sources are already produced at a cost which is competitive with conventional energy sources.

Generally, electricity is a more valuable end-product than hot water, and so far most attention tends to be focused on those resources capable of supporting power generation.

Figure 4 Larderello Geothermal Power Stations – Italy (source: www.swisseduc.ch)

The first electrical power station using by geothermal resources was established in 1913 at Larderello in Italy rated at 250 kW. Now Larderello power station produces 4.8 TWh per year and is powering about a million Italian households [6]. Total electricity generated from geothermal resources in 2006 was 56679 GWh, which is equivalent to 0.3% of total electricity produced globally in 2005 [7].

In 2005, 24 countries worldwide were generating electricity from geothermal resources, with a total installed capacity of more than 8,900 MW. During the period 1980-2005, the worldwide geothermal installed capacity increased by a factor of about 2.3, equivalent to a steady growth rate of 200 MW/y [7].

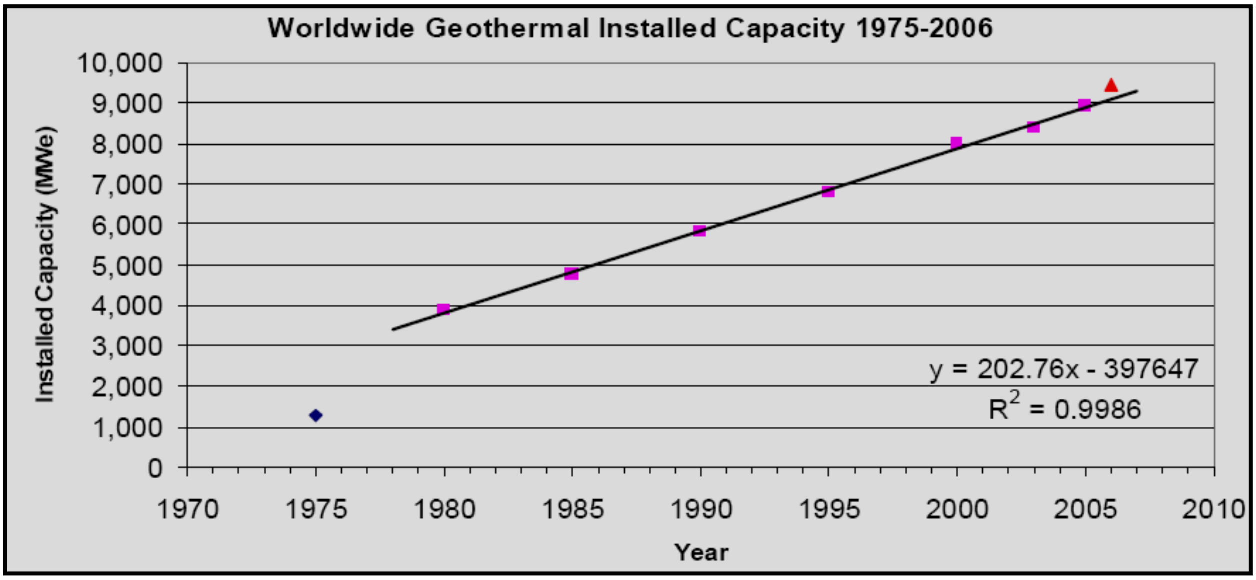


Figure 5 Worldwide Geothermal Installed Capacities during 1976-2006 (7)

In power stations which derived by geothermal energy there are three types of power plant. These are: -

- Dry steam power plant: this type of system can be constructed on wells which produce superheated steam, typically at 180-225°C and 4-8 MPa. The steam passes through turbines which drive a generator, then into a condenser where it is condensed into water and injected back to the well.

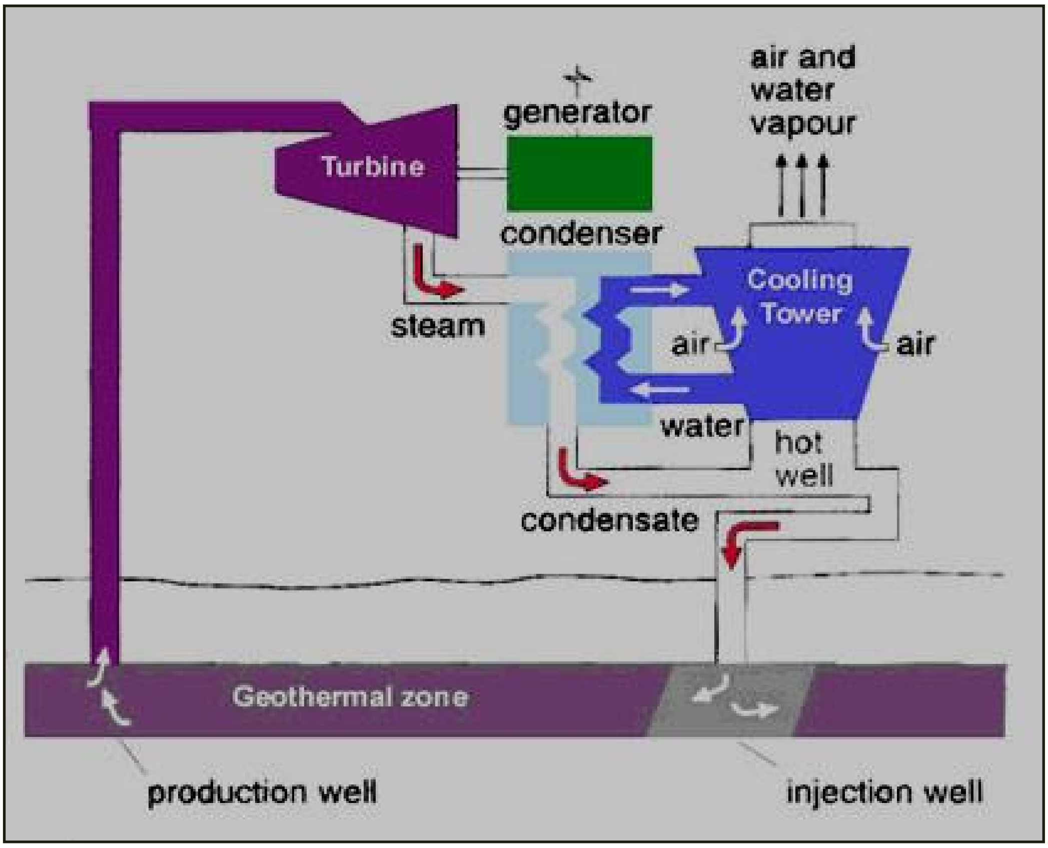


Figure 6 Dry Steam Power Plant (source: www.seas.upenn.edu)

- Flash steam power plant: this is the most common type of geothermal power generation plants in operation today. It uses pressurized water at temperatures greater than180°C. Before fluids enter the plant, the pressure is reduced until it begins to boil, or flash. This process produces both steam and water. The steam subsequently is used to drive the turbine; the water is injected back into the reservoir with the condensed steam.

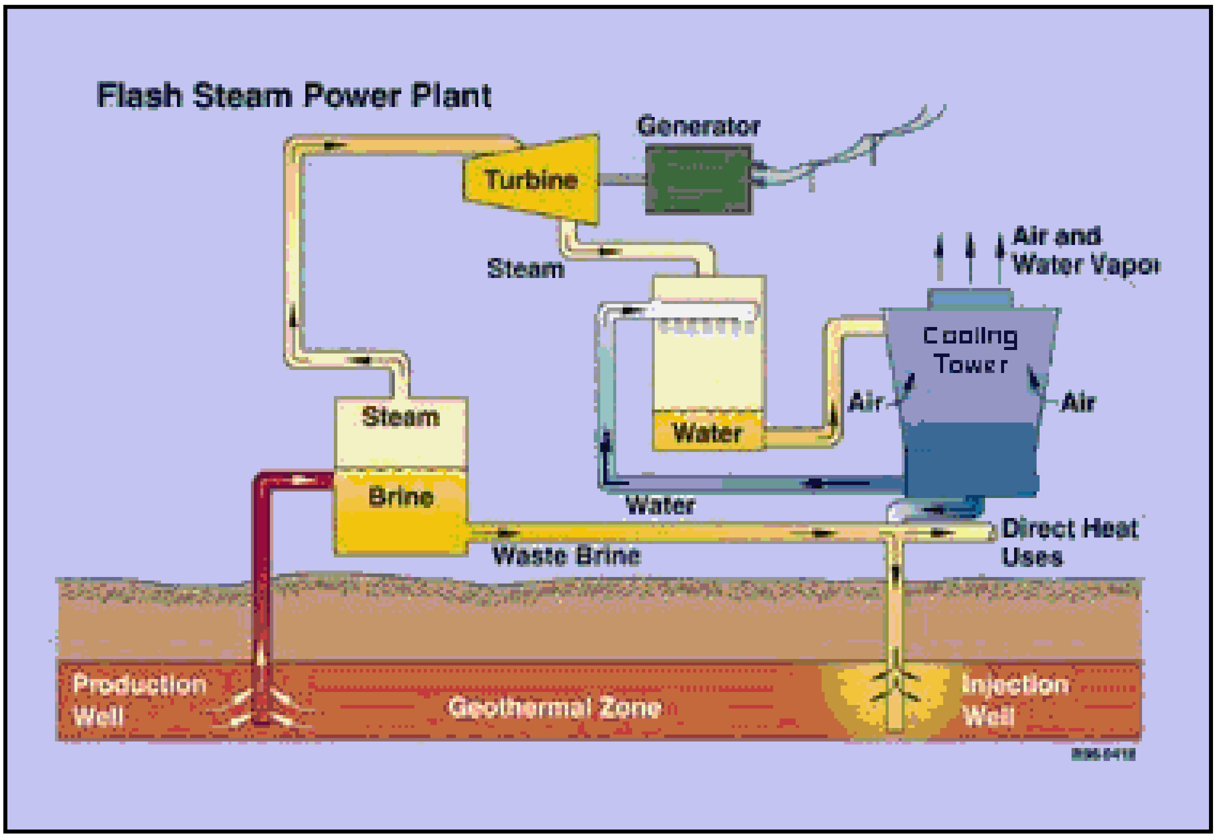


Figure7 Flash steam power plant (source: http://geothermal.inel.gov)

- Binary cycle power plant: this type of power plant can operate with lower temperature water at around 100°C by using heat exchangers to transfer the heat of the water to another working fluid that vaporizes at lower temperatures. This vapour drives a turbine to generate power, after which it is condensed and circulated back in a ‘closed loop’ to the heat exchangers.

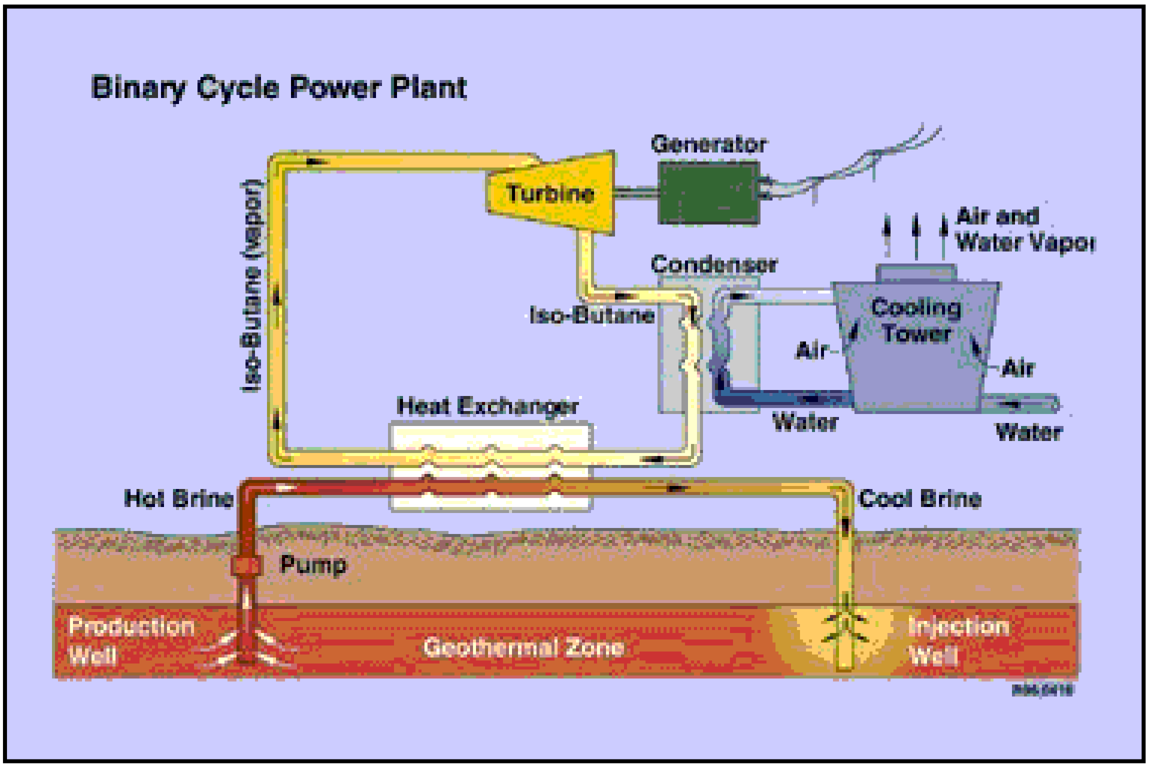


Figure 8 Binary Cycle Power Plant (source: http://geothermal.inel.gov)

This type of geothermal plant has superior environmental characteristics compared to the others because the hot water (which tends to contain dissolved salts and minerals) is never exposed to the atmosphere and is injected back into the reservoir.

Geothermal power plants can operate 24 hours per day, providing base-load capacity. In fact, world potential capacity for geothermal power generation is estimated at 85 GW over the next 30 years [7]. The costs of geothermal energy have dropped substantially from the systems built in the 1970s. Generation costs at current plants in the United States are as low as USD 0.015/kWh to USD 0.025/kWh, depending on the quality of the resource [8].

Challenges to expanding geothermal energy include very long project development times, and the risk and cost of exploratory drilling.

Geothermal heat generation can be competitive in many countries already producing geothermal electricity, or in other regions where the resource is of lower temperature.

2.3 Solar Renewable Energy: -

2.3.1 Direct Solar Renewable Energy: -

The Sun is the source of life on the Earth; generally it can be considered the ultimate source of most of our renewable energy. Total incoming solar radiation on Earth is estimated as 5.4 million exajoules (EJ) per year. Nearly 30% is reflected back into space and the remaining is in principle available for use on Earth directly or indirectly [9].

By using various technologies solar energy can be directly converted to a useful form. Direct solar energy can provide hot water using solar collectors or it may contribute to space heating and lighting requirements using solar passive features in buildings.

Solar heat collectors provide hot water to nearly 50 million households worldwide, and space heating to a growing number of homes [10].

Existing solar hot water/heating capacity is increased by 19 percent in 2006 to reach 105 GW thermal [2].

Solar energy can also be converted directly into electricity using photovoltaic panels (PV). Currently it is expensive but prices are falling and the industry is expanding rapidly (see figure 8) [11].

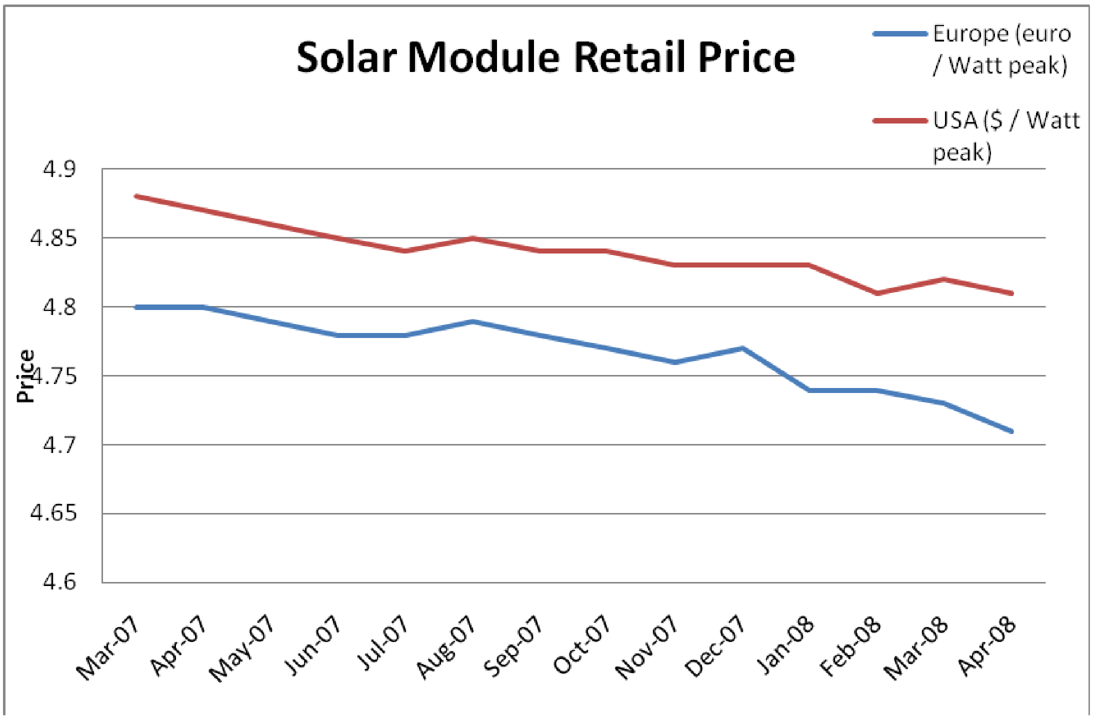


Figure 9 Solar module retail prices in Europe and USA [11]

According to a new assessment by the World watch Institute in Washington, D.C., and the Prometheus Institute in Cambridge, Massachusetts, Global production of solar photovoltaic (PV) cells has raised six fold since 2000 and grew 41 percent in 2006 alone[12]. Although grid-connected solar capacity still provides less than 1 percent of the world's electricity, it increased nearly 50 percent in 2006, to 5,000MW, propelled by booming markets in Germany and Japan [2].

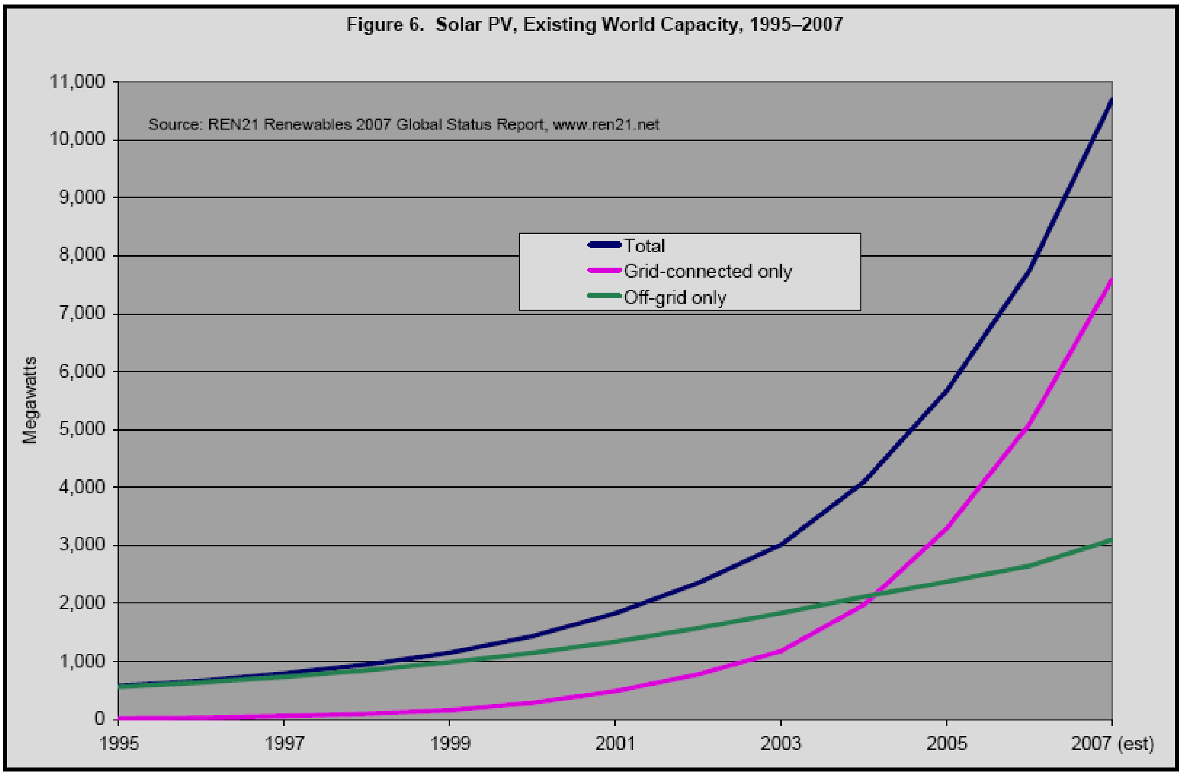


Figure 10 PV existing world capacities [2]

Commissioned in February 2008, a large solar-farm of over 120000 photovoltaic panels has been built and operated in Jumilla Spain, It has a peak capacity of 20MW and it can power up to 20,000 homes—making it the world's largest solar farm to date [13].

Figure11 Jumilla solar farm / Spain (source: www.ecofuss.com)

On the other hand solar energy can also be concentrated by mirrors to achieve high temperatures for generating electricity. These types of solar thermal-electric power stations already exist and some are commercially operated in the USA.

Figure12 Solar two power station (10MW) in Daggett, California (source: www.rise.org.au)

2.3.2 Indirect Solar Renewable Energy: -

A large fraction of the incoming solar energy is absorbed by the oceans which increases water vapour in the air. Later the vapour will condense as rain to feed rivers (hydropower).

As a result of solar radiation especially in tropical regions which are heated to a greater degree than Polar Regions, massive heat flow towards the poles is carried by currents in the ocean and the atmosphere (The latter may be exploited wind and wave power).

Temperature differences within the oceans themselves forms the source of Ocean Thermal Energy.

Solar radiation is the key element of photosynthesis in plants to convert water and carbon dioxide into carbohydrates (bio energy).

2.3.1.2.1 Hydropower Energy: -

Hydropower is the oldest and most established form of the renewable energy technologies, and contributes about 15% of the total electricity generated on the globe; it grew during the five-year period 2002–2006 at a global average of 3 percent per year (less than 1 percent in developed countries) [2].

But it remains the lowest cost energy technology (typical energy cost 0.04-0.07 $/kilowatt-hour) [2].

There are three different forms of hydroelectric schemes: -

Run-of-river: - is suitable for stream or river which does not experience massive differences in flow rate during different seasons of the year. In this type of scheme the turbine and generator are located either in the dam or found along side it. The dam uses the flow of a river to create the hydrostatic head; this method can also be applied in tidal barrage systems.

Figure 13 Cordell Hull (run-of-river) scheme / Tennessee USA (source: www.industcards.com)

In many cases of Run-of-river scheme, additional flow passages may be required to prevent upstream flooding or for the progress of shipping along the river.

Diversion: - scheme is where the supply of water is taken from a dammed river or lake to a remote powerhouse containing the turbine and generator. A canal or low-pressure tunnel transports the water to this end point and then back to the river to continue its course.

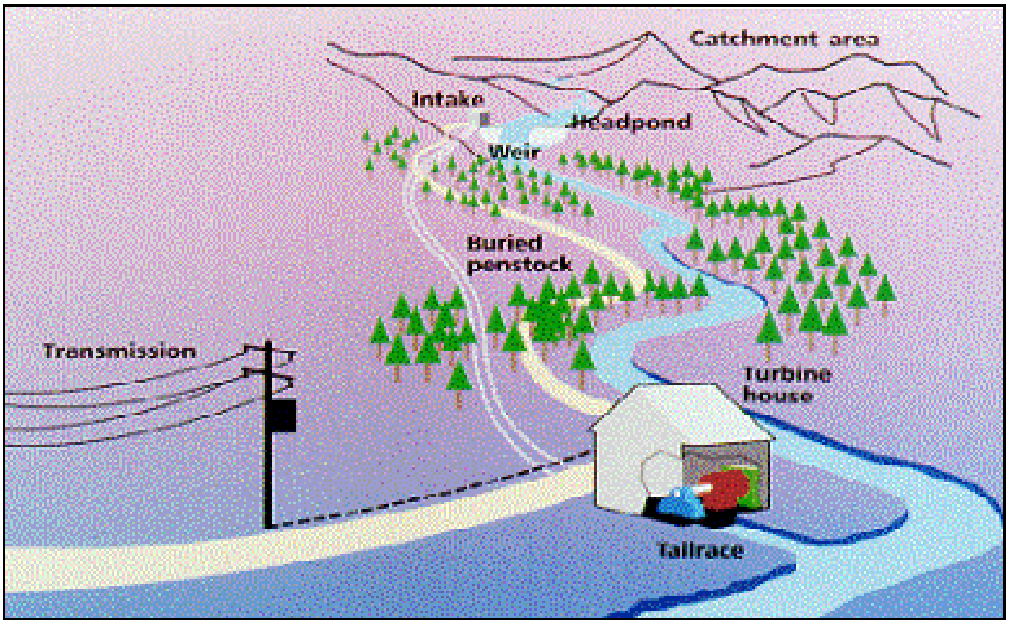


Figure 14 Diversion scheme (source: www.intuser.net)

Catchment schemes: - a man made or natural reservoir will used to collect water and rainfall, also to produce a sensible hydrostatic head. Turbines are installed at a lower level and fed by pipes or tunnels. The water is finally discharged into a suitable low-level outlet.

Figure 15 Hoover Dam. Nevada/Arizona border (catchment scheme) (source: http://photo.net)

A pumped storage system, which uses the basic principle of hydropower technology, is a scheme that incorporates two reservoirs. At times of low demand, electricity is used to pump water from the lower to the upper basin. This extra water can then be released to create power at a time when demand is high. This enables the scheme to perform as a reasonable energy store for the purpose of matching supply and demand.

2.3.2.2 Wind Energy: -

Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's topography, bodies of water, and vegetative cover. This wind flow, or motion energy, can be harnessed by modern wind turbines to generate electricity.

Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or we can convert this mechanical power into electricity to power homes, businesses, schools, and the like.

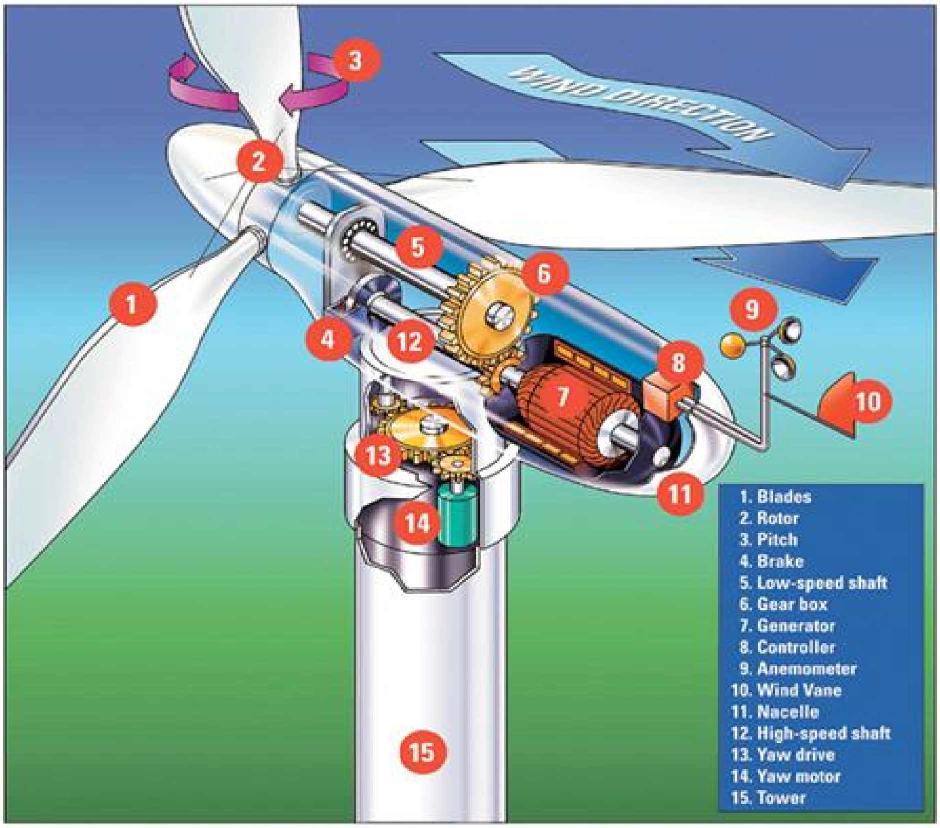


Figure 16 Typical wind turbine tower (source: www.alliantenergy.com)

Various technologies may be used in wind power. Basically wind turbines can be horizontal axis or vertical axis machines, but the first of these has come to dominate the market. Wind turbines are increasingly being deployed on offshore sites.

The offshore wind resource is stronger and more consistent than the wind resource onshore, accordingly leading to higher power outputs per turbine and more hours spent generating each year. Offshore wind power installations involve higher costs and maintenance concerns compared with booming on-shore markets; therefore the energy costs more (0.05-0.08$/kWh and 0.08-0.12$/kWh for offshore and onshore respectively) [2].

Today over 70 countries around the world take advantage of wind energy to generate electricity and expenditure is about 47% of the total annual investment in new renewable energy in the world ($71 billion) [2]. Wind power capacity increased more than any other renewable power technology in 2007 with an estimated 21 GW added. This represented a 28% increase over 2006. Two-thirds of global wind power additions in 2006 (15 GW total) were concentrated in just five countries: the United States (2.5 GW), Germany (2.2 GW), India (1.8 GW), Spain (1.6 GW), and China (1.4 GW) [2].

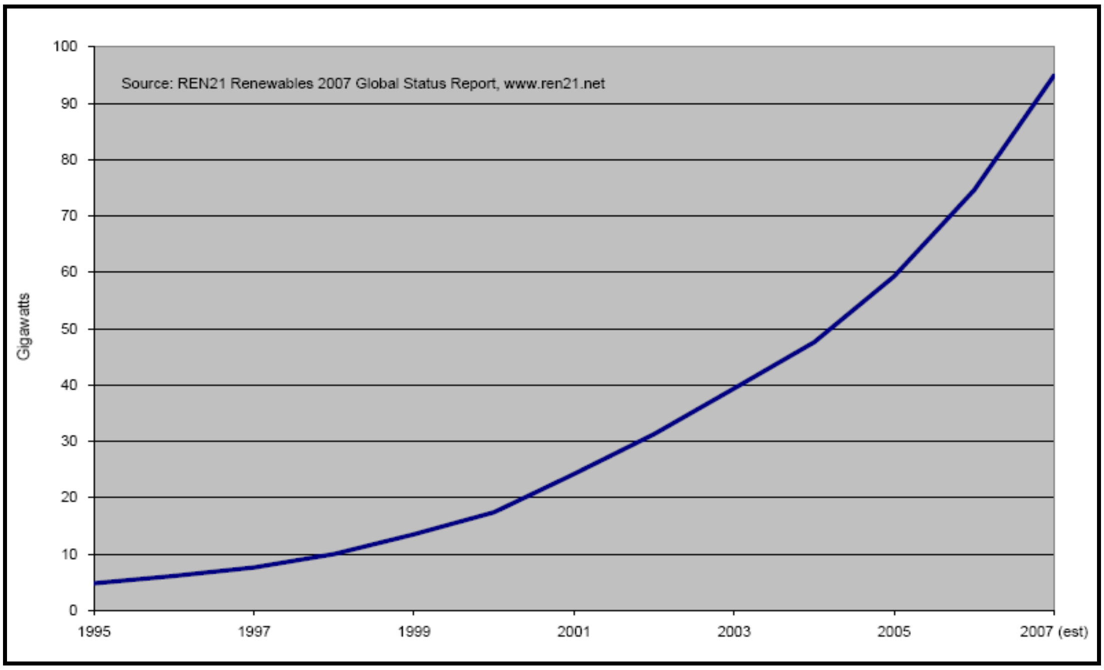


Figure 17 global installed wind power capacity [2]

The number of wind farms in the UK is steadily increasing. The first wind farm was set up in November 1991. In 2007 according to the British Wind Energy Association, there were 165 wind farm projects in the UK, with 1,944 turbines producing 2.392 GW which is 1.5% of UK electricity needs [14].

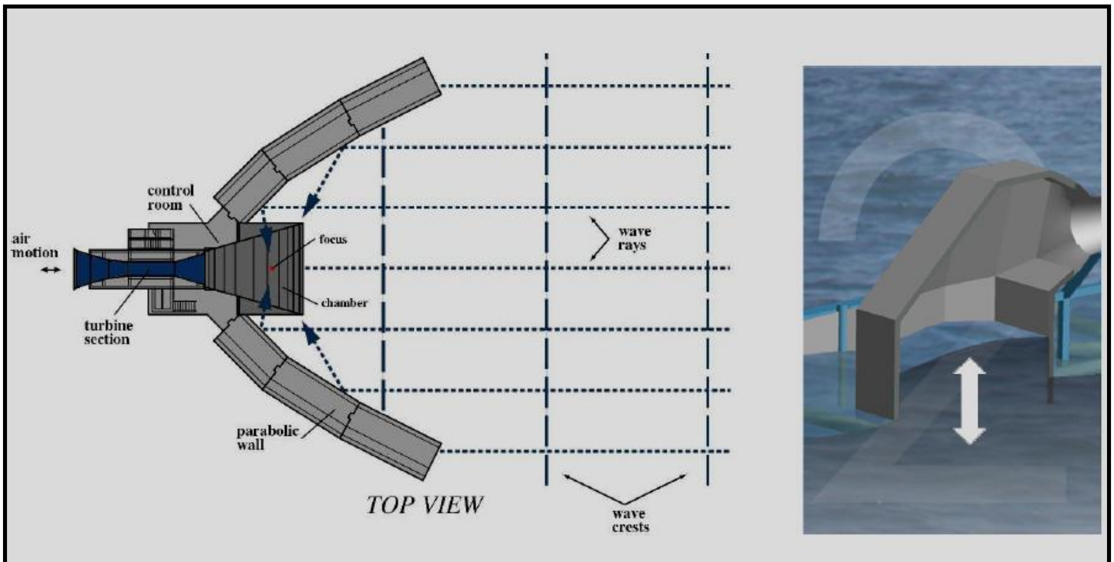
2.3.2.3 Wave Energy: -

Ocean waves represent a form of renewable energy created by the interaction of wind with the surface of the sea. Because wind is generated by uneven solar heating, wave energy can be considered a concentrated form of solar energy. Incoming solar radiation levels that are on the order of 100 W/m2 are transferred into waves with power levels that can exceed 1,000 kW/m of wave crest length [15]. The transfer of solar energy to waves is greatest in areas with the strongest wind currents (primarily between 30° and 60° latitude), near the equator with persistent trade winds, and in high altitudes because of polar storms. Waves have the potential to provide a completely sustainable source of energy which can be captured and converted into electricity by wave energy converter (WEC) machines; the worldwide economically recoverable wave energy resource is estimated at (140 to 750 TWh/yr) by using existing wave capturing technologies [16].

A range of technologies have been proposed to capture the energy from waves, all of these different technologies are still in the development phase to a greater or lesser extent, and it is impossible predict which technology or mix of technologies would be most prevalent in future commercialization.

Briefly we focus on the following wave energy convertors: -

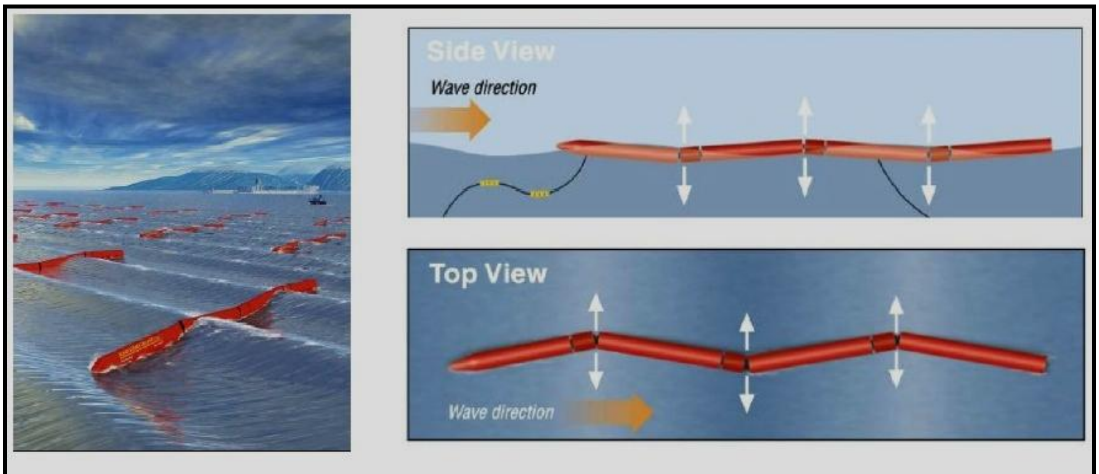
- Terminators: these devices extend perpendicular to the direction of wave motion and capture the power of the wave.



Oscillating Water Column (Source: Energetech 2006)

Figure 18 Oscillating water column

- Attenuators: are long structures aligned parallel to the direction of the wave travel. The attenuator with the most advanced development is the Pelamis device.



Pelamis Wave Energy Converter (Source: Ocean Power Delivery Ltd. 2006)

Figure 19 Pelamis wave energy converter

- Point absorbers: Point absorbers have a small horizontal dimension compared with the vertical dimension and utilize the rise and fall of the wave height at a single point for WEC.

Figure 20 Point absorber devices (source: www.foxnews.com)

- Overtopping: Overtopping devices have reservoirs that are filled by impinging waves to levels above the average surrounding ocean. The released reservoir water is used to drive hydro turbines or other conversion devices.

Figure 21Overtopping devices (source: www.sut.org.uk)

Wave power is still in its infancy, but it may possibly play a considerable role with wind energy in Scotland to achieve its aims to produce 40 per cent of Scotland's electricity from renewable schemes by 2020.

2.3.2.4 Biomass Energy: -

Biomass is biological material derived from living, or recently living organisms. On the bases of previous concepts of biomass, biomass energy can be described as any type or form of energy produced from organic matter. It can be used "directly", as in household fires or wood burning cookers (especially in the developing countries), or "indirectly" after conversion into a secondary form of energy, such as bio-power (electricity), biodiesel or biogas. It is the only renewable that can easily be processed into all of these three forms of secondary energy and also it's the only type of renewables can be stored easily.

In 2006 about 45 GW of biomass power capacity existed, which is nearly 13% of global final energy consumption according to the renewable energy policy network for the 21st century [2].

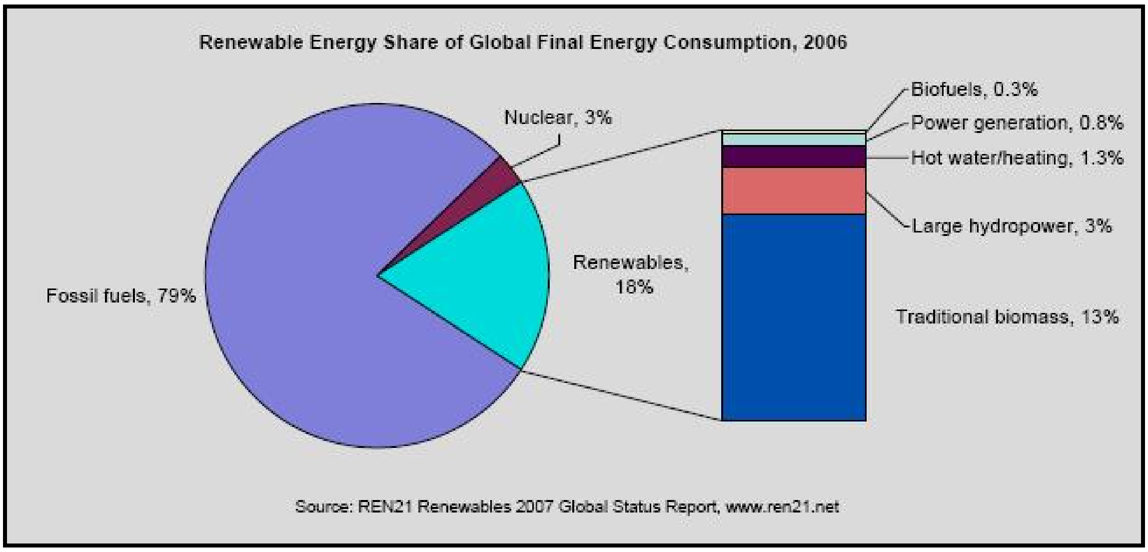


Figure 22 Biomass share of global energy consumption 2006 [2]

Recently biomass use in a number of European countries has increased particularly Austria, Denmark, Germany, Hungary, the Netherlands, Sweden, and the United Kingdom. According to the international energy agency nearly 2% of electricity produced in the UK in 2005 was derived from biomass [17].

Chapter 3

Kurdistan

3.1 Historical background: -

Kurdistan literally meaning "the land of Kurds", generally is a mountainous region expanse of some 200,000 square miles [18] across the present state boundaries of Turkey, Syria, Iraq, Iran, and the former Soviet republics of Armenia and Azerbaijan (figure 23). Kurdistan comprises southeast of Anatolia, the eastern Taurus and northern Zagros mountains and expands out until the upper reaches of the Mesopotamia and the Jazira region in north-eastern Syria. Kurdistan has been an important historical contact zone in south Eurasia, isolated only by its mountainous terrain.

The histories of all ancient civilizations in the middle-east in various ways related to that of the Kurds. Modern Kurdish political history, however, began on August 23, 1514 at the Battle of Chaldiran in northern Kurdistan, where the disputing Ottoman and Safavid empires found the limits of their reach and established the first significant division of Kurdistan.

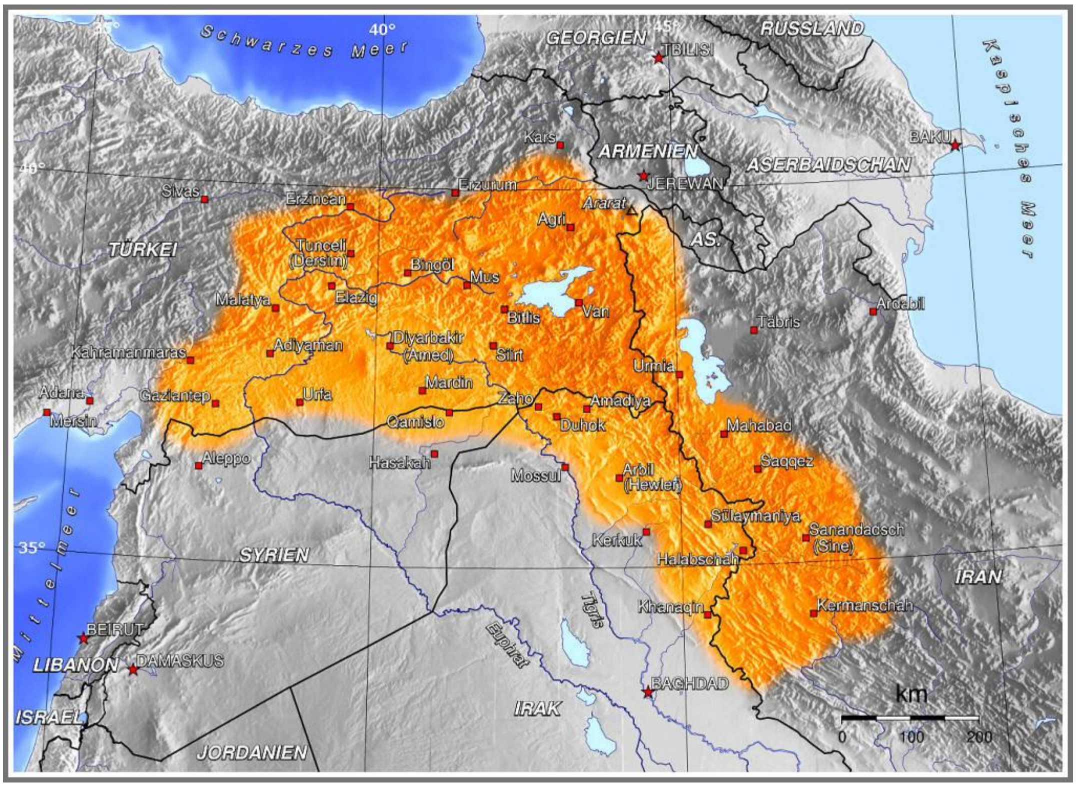


Figure 23 Map of Kurdistan (source: www.djaso.com)

Before World War I, most Kurds lived within the boundaries of the Ottoman Empire. After the collapse of the Ottoman Empire, the Allies agreed to partition up the land. In the dividing up of the Ottoman Empire which took place after World War I, the new country of Iraq was formed in 1921 from the Ottoman wilayets (states) of Baghdad and Basra; afterwards in 1926 the northern wilayets of Mosul with its Kurds and its oil fields was added to the new formed country under British mandate.

3.2 Geographical Location: -

This study will focus on Iraqi Kurdistan (Northern Iraq), which is governed by the Kurdistan Regional Government (KRG) since 1992, and comprises of the three governorates of Erbil, Sulaimanyah and Duhok. The area of the region is about 40000 km² (figure 24) and is located between latitudes 34° 42' N and 37° 22' N and between longitudes 42° 25' and 46° 15' east, sharing borders with Syria to the west, Iran to the east, and Turkey to the north. The lowest point in the region is Kifri (140m), and the highest point is the Peak of Halgurd (3660m) in Erbil Governorate.

Kurdistan region is traversed by the Tigris River and its tributaries, the Upper Zap, the Lower Zap and Sirwan.

Figure 24 Map of Kurdistan region (source: www.globalsecurity.org)

Now Kurdistan Region is a federal region of Iraq and recognised in the Iraqi Federal Constitution of 2005. The Kurdistan Regional Government cabinet formed a Ministry for Extra Regional Affairs which is especially devoted to the reintegration of originally Kurdish areas confiscated and arabized by the

Saddam Hussein regime according to article 140 from the Iraqi new constitution, which includes Kirkuk, Mosul, Khanaqin, Mendeli, Zurbatiya, Makhmour, Shai Khan, Zumar and Singar.

3.3 Population of Kurdistan:-

The population of Kurdistan is 4.2 million. The region has a young and growing population, with 36% aged 0-14 years, and only 4% aged over 63. More than 50% of the population are aged less than 20 years [19].

Traditionally, the majority of people in the Kurdistan Region lived in villages and survived on farming and animal husbandry of mainly sheep and goats. Today this has reversed, with the majority living and working in the three cities of Erbil, Duhok and Suleimaniah and working in the government, construction, and trade.

3.4 Climate of Kurdistan: -

The climate of Kurdistan is characterized by extreme conditions, with large temperature differences between day and night and between summer and winter.

In summer, the temperature reaches 45ºC and beyond in daytime at the southern boundaries of the three Governorates. Kurdistan region may experience some of the highest temperatures anywhere in the world. These hot conditions are often accompanied by a dusty, north-westerly wind, which adds to the unpleasantness. Occasional droughts, heat exhaustion and even heatstroke are hazards.

In winter the region comes under the effect of cyclones from various sources, bringing an appreciable amount of rain to lower parts of the region and snow to higher elevations. The amount of precipitation increases from southwest to northeast and the daily temperature ranges from about -15C° to 15°C. Accordingly, the climate of Kurdistan has been classified as semi-arid continental, that is to say hot and dry in summer and cold and wet in winter. Spring and autumn are short in comparison to summer and winter [20].

3.5 Energy Crisis in Kurdistan: -

During the 1970s when the oil price boomed, a number of countries in the Middle East utilized oil income to build up a foundation of a modern state and create other sources of income rather than oil. This is what happened in UAE, Qatar and Kuwait, while other countries tended to use the huge oil income to buy weapons and build a militarized society, an example Saddam's regime in Iraq.

Being Iraq is comprised of multi nations (Arab, Kurd, Turkmen and others), and all previous governments were not elected by the people, but came to power by military codetta, so conflict and instability was the main character of Iraq. During the modern history of Iraq we have seen bloody conflicts, wars and massacres. Saddam's regime and the previous administrations were never concerned to build economical, industrial and agricultural infrastructure in the Kurdistan region, in order to keep it undeveloped and dependent totally on central government for food, fuel, electricity . . . etc.

Eventually Kurdistan region was left without economical, agricultural and industrial infrastructure which resulted in prevailing poverty and famine in a region that once was described as the bread basket of Iraq for the reason of its ample fertile arable lands and water resources.

Pre-1990 Gulf War I Iraq had a large electrical network consisting of 32 thermal, gas turbine and hydro power stations with the installed capacity of 10,200 MW [21].

Only two of these stations are located in Kurdistan region, Dukan and Derbendikhan hydropower stations with a total installed capacity of 640 MW. This means that only 6% of installed capacity of electricity generation in Iraq has been built inside the Kurdistan region. If this compared with the Kurdistan region population which is nearly 17% to 19% of Iraqi population, then it can be said there is uneven in distribution of power stations over Iraq.

Today, after the collapse of the former regime, and as a result of a long period of destructive policy Kurdistan region suffers from extreme shortage of energy resources, despite huge reserves of fossil fuel. Local government still is not able to guarantee fuel and energy supply to the region perhaps because of Kurdistan region's neighbours (Turkey, Syria and Iran), which are feeling uncomfortable to find a semi independent Kurdish entity across their borders.

According to the Directory of Kurdistan Region Despatch Control Centre, which is operating the power transmission and distribution network within the region, Kurdistan electricity demand reached over 1400 MW at the end of 2007 and is expected to grow by 11% for the next two years due to development and reconstruction. This rapid growth is due to lack of investment in the previous decades, and will subsequently grow at a lesser rate of 5% from 2011 (see table 1) [21].

Year	(MW) Generate	Imported	Power (MW)	from	Planned	Total		Estimated	Demand			power
	in Kurdistan	Federal net.	Turkey	Iran	Generation (MW)	Power (MW)	Erbil	Sulaimanyah	Duhok	Total	Growth %	Shortage (MW)
2004	184	0	0	0	0	184	300	335	250	885		-701
2005	180	0	0	0	0	180	354	395	295	1044	18	-864
2006	186	134	155	0	0	475	442	476	322	1240	19	-765
2007	186	172	155	0	0	513	522	562	380	1464	18	-951
2008	200	200	155	0	650	1205	615	663	448	1726	18	-521
2009	850	200	0	200	600	1850	708	762	516	1986	15	-136
2010	1450	200	0	200	200	2050	786	846	572	2204	11	-154
2011	1650	200	0	200	200	2250	872	939	635	2446	11	-196
2012	1850	200	0	200	200	2450	942	1014	686	2642	8	-192
2013	2050	200	0	200	200	2650	989	1065	720	2774	5	-124
2014	2250	200	0	200	0	2650	1038	1118	756	2912	5	-262
2015	2250	200	0	200	200	2850	1090	1174	794	3058	5	-208

Table 1 Existing and projected power stations and demands in Kurdistan.

This huge demand is impossible to be met by a poor electricity production infrastructure with two hydropower stations which barely produce 180-200 MW which is equivalent to 14% of the region's present demand. Add to this a power transmission and distribution network severely suffering from deterioration, lack of spares, lack of preventative maintenance, repeated load shedding operation, and disabling of protection systems to cater for over loads. The distribution system suffers from inadequate capacity to meet present demand, low reliability, low voltage profiles, and high loss levels.
Apart from the electricity shortage, the Ministry of Natural Resources in the Kurdistan Region states that Kurdistan needs 4 million litres auto petrol plus same amount of diesel and 4.5 million litres of domestic heating fuel with 800 tonnes of LPG on a daily basis for year 2008, but fuel supply is insufficient and only one third of the region's demand can be guaranteed.
To address the electricity problem in Kurdistan region, local government is starting to bring planned power projects into practice, which consist of three power stations: -

- 500 MW power station in Erbil using natural gas. It will start to feed the power network in the second half of 2008 with 400 MW in the first stage and full capacity in 2009,
- 750 MW power station in Sulaimanyah which is using natural gas as well, firstly it will generate 200 MW by the end of 2008 and full capacity

in the next couple of years. Both power stations will be supplied by gas produced within the Kurdistan region boundary.

- 50 MW Tasluja power station will start in the second half of 2008. Heavy fuel will be used in this station, because Iraqi refineries are inefficient and produce a large amount of heavy fuel as a residue. There is a trend to build other power stations of this type all over Iraq.

	Year								
Power Plants	2007	2008	2009	2010	2011	2012	2013	2014	2015
Existing/under construction									
Dukan & Darbandikhan HPP	186	200	200	200	200	200	200	200	200
Erbil 500 MW GPP	0	400	500	500	500	500	500	500	500
Sulaimaniya 750 MW GPP	0	200	400	600	600	600	600	600	600
Tasluja HFO Power Plant	0	50	50	50	50	50	50	50	50
Iraqi Federal Grid	172	200	200	200	200	200	200	200	200
Import from Turkey	155	155	0	0	0	0	0	0	0
Import from Iran	0	0	200	200	200	200	200	200	200
To be built									
Duhok HFO Power Plant Plant	0	0	300	300	300	300	300	300	300
Thermal Power Plant	0	0	0	0	0	200	400	400	400
Hyropower Plant	0	0	0	0	200	200	200	200	400
Total	513	1205	1850	2050	2250	2450	2650	2650	2850
Projected Demand Load	1463	1727	1986	2204	2446	2642	2774	2913	3059

Table 2 planed power station in Kurdistan region

3.6 Energy Supply in Kurdistan: -

At present the only electricity producers in Kurdistan are the hydropower stations in Dukan and Derbendikhan, which have been built mainly to prevent flooding and to serve as peaking stations during periods of high demand. The main features of the existing hydropower stations are as follows: -

Dukan Dam: - is located on Lower Zap River (latitude 35° 95' and longitude 44° 58’) adjacent to Dukan town (55 km North West of Sulaimanyah). Civil work was accomplished in June 1959 to operate as an irrigation system and to prevent risk of flood. The total storage capacity of the dam is 6.8 billion cubic meters at a level of 511 m above mean sea level with catchment area of 11960 km^2. Dukan Power Station became fully operational in 1979 (figure 25).

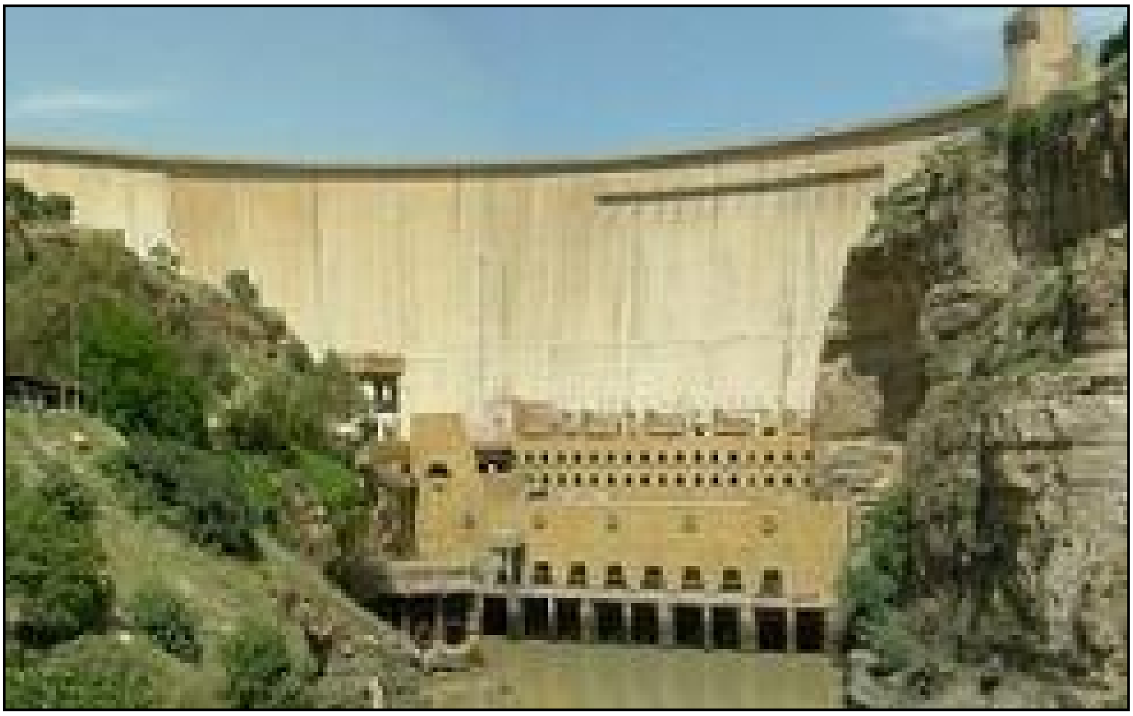


Figure 25 Dukan Dam

It consists of five turbines; each one drives an 80 MW generator (total 400 MW). Repair and maintenance have been inadequate because of unavailability of spares and equipment. These factors have contributed to long interruptions of the power source and unreliable performance. Moreover, due to the long operational period (29 years) the power plant is now due for refurbishment.

Derbendikhan Dam: - it is located on Sirwan River (latitude 35° 11' and longitude 45° 70') near Derbendikhan town (60 km south east of Sulaimanyah). Construction of the dam was completed in September 1961 with the total storage of 3 billion cubic meters at a level of 485m above mean sea level. It consists of three turbines, each one generates 83 MW (totally 249 MW).

Figure 26 Derbendikhan Dam

The power station was added to the project after two decades in 1983 but operation commenced in 1990 due to a delay in construction of the overhead line to connect the power plant to the national grid. Only one unit was commissioned by the contractor, who had to leave the site because of the First Gulf War. The other two units came into operation without proper commissioning. A combination of this and faulty design of the hydraulic system are considered to have contributed to unsatisfactory performance of this power plant since its commissioning.

The generation capacity of these dams however, was insufficient to meet the demand. Both dams and associated power stations have sustained considerable damage and suffer from lack of spare parts and funds to ensure proper maintenance. They are in need of major and urgent rehabilitation. Both power stations have been operated according to a time table with regard to both storage level and the discharges of the rivers. This is to try to maintain continuous electricity generation along the year. Table (3) and table (4) show the winter and summer program in Dukan dam. Power generation has been decreased from January to the end of May with the minimum generation rate of 16 MW in April.

Date	Average Generation (MW)	Outflow (m³/s)	Inflow (m³/s)	Pool elevation (m)
01/01/07-01/02/07	43	83	80	479.83
01/02/07-01/03/07	39	72	283	485.15
01/03/07-01/04/07	22	38	232	489.43
01/04/07-01/05/07	16	26	410	496.05
01/05/07-01/06/07	22	31	247	499.12
01/06/07-01/07/07	109	154	92	498.17

Table 3 Dukan dam operation program / winter

From July to the end of November power generation has been increased with the maximum rate of 183 MW in July.

Date	Average Generation (MW)	Outflow (m³/s)	Inflow (m³/s)	Pool elevation (m)
01/07/07-01/08/07	183	275	43	493.68
01/08/07-01/09/07	172	245	35	489.24
01/09/07-01/10/07	120	200	30	485.65
01/10/07-01/11/07	81	150	55	483.29
01/11/07-01/12/07	54	100	60	482.24
01/12/07-01/01/08	53	100	70	481.39

Table 4 Dukan dam operation program / summer

Because Kurdistan is considered as a hot climate country and the peak demand for electricity normally occurs in summer, the hydropower stations in Kurdistan are trying to produce electricity during the hot season.

3.7 Reliability and Cost: -

The power generation sector in Kurdistan is unreliable because current power generation represents only 14% of its demand. With the power imported from Turkey and Iraqi federal network (see table 3) the average power availability in the region is lying between 6 to 8 hours a day.

This situation encouraged some people to invest in procuring big diesel generators and setting permission from the authorities to operate them in the different quarters within the cities of Kurdistan. These private energy producers are selling power in ampere units, every single ampere for 8 hours a day for one month costs 12000 NID equivalent to $10 or 227.3 NID/kW.hr ($ 0.19/kW.hr). The price of electricity in Iraq and Kurdistan region for domestic use is shown in table (5) [22].

Price by $/kW.hr	Price by New Iraqi Dinar/kW.hr	Class (kW)
0.08	100	1 - 1500
0.33	400	1501-2100
0.58	700	2101-3000
1.25	1500	3001-5100
2.5	3000	5101 more

Table 5 electricity price in Iraq for domestic use

The difficulty that faces the authority in Kurdistan to apply electricity prices is the lack of a suitable mechanism to collect electricity revenue from consumers; this problem arose after 1992 when nearly all power stations in Iraq had been destroyed during the first Gulf War and the people experienced complete loss of electricity or they had electricity for intermittent periods.

Generally we can say that electricity presently provided by the ministry of electricity in Kurdistan is free. National and private power providers together can supply the consumer with power for 16 hours a day as a maximum in best conditions.

<u>3.8 Social Aspects: -</u>

During the availability of national electricity in any area of Kurdistan the consumers are trying to enjoy electricity services as much as possible by operating all electrical appliances at home, especially if they know that they are not paying for it.

But there is a different scenario with private electricity providers, because the quantity of electricity units is limited and the electrical appliances which consume large amounts of electricity cannot be operated. Also it’s a payable service and costs money.

This sort of behaviour will change if the government succeeds to provide reliable electricity that people can use at any time when they need it. Because the present supply is intermittent and unreliable, it does not support the authority’s argument that the consumer should pay for it. It happens in different areas of Kurdistan that they get their portion of electricity after midnight when they are in bed. If the authorities managed to provide reliable and continuous electricity the people may feel that it worth to pay for electricity that it has been consumed by them at the time they want without any restriction.

Also, payment for units of energy used rather than per ampere connected may influence consumer behaviour.

Chapter 4

4.1 Renewable Energy in Kurdistan

Except for the two hydropower stations Kurdistan has not have any other facility to exploit renewable energy. This is because the concept of renewable energy and its expected major role around the world still in its pre-elementary stage in Kurdistan. An intensive education and encouragement will be needed to establish the concept of renewable energy for the people in all classes of Kurdish community.

Renewable energy in Kurdistan is relatively unexplored and needs to be further investigated. The recorded climate conditions will be used in the investigation. Rainfall rate, wind speed, sunshine, temperature and solar radiation act as indicators to predict specific types of renewable energy. Kurdistan region’s location restricts the types of renewable in Kurdistan to include only hydropower, wind power, solar power, biomass and geothermal.

4.2 Hydropower in Kurdistan: -

The early society in Kurdistan was dependent on agriculture, therefore grain mills were common, and water flow was the only source of energy to spin them. Currently hydropower is the only source of power generation in Kurdistan region; however hydropower potential has not been utilized perfectly in the past, for a variety of reasons as described earlier.

From annual rainfall rate and discharge information of existing rivers and streams in the region a reasonable judgment on hydropower availability can be laid out.

Therefore collecting information from weather stations will be the first step. There are meteorological stations throughout Kurdistan region supervised by the local government, but unfortunately they have no reliable recorded data for long periods. Fortunately during the years 2000 to 2003 the Food and Agriculture Organization of the United Nation (FAO) installed and operated a number of agro-meteorological stations in Kurdistan region to investigate and study the climate of the region for agricultural research purposes. These stations have properly recorded and organized information which can be used in other fields than agricultural researches [23].

No	Station Name	Latitude (º) N	Longitude(º)E	Altitude (m)
1	Erbil	36.2	44.01	420
2	Khabat	36.27	43.65	252
3	Koya	36.08	44.61	605
4	Shaqlawa	36.41	44.32	975
5	Sulaimanyah	35.55	45.45	890
6	Chamchamal	35.53	44.83	718
7	Kalar	34.62	45.32	320
8	Chwarta	35.72	45.57	1128
9	Penjwin	35.62	45.94	1302
10	Halabja	35.19	45.98	692
11	Duhok	36.85	43.01	583
12	Zakho	37.16	42.65	404
13	Malta	36.86	42.94	525

Table 6 Agro-meteorological station locations (FAO)

These stations are spread out in different areas in Kurdistan and could be reasonable sources of information about climate elements.

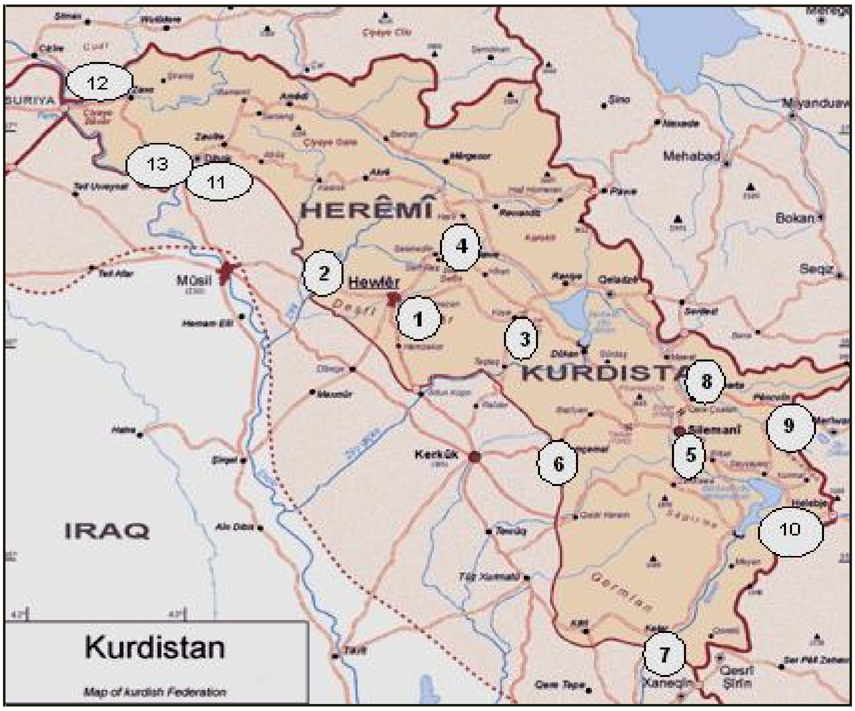


Figure 27 Location of Agro-meteorological stations around Kurdistan

A monthly precipitation average is collected from all these stations and used to produce the following chart figure (28)

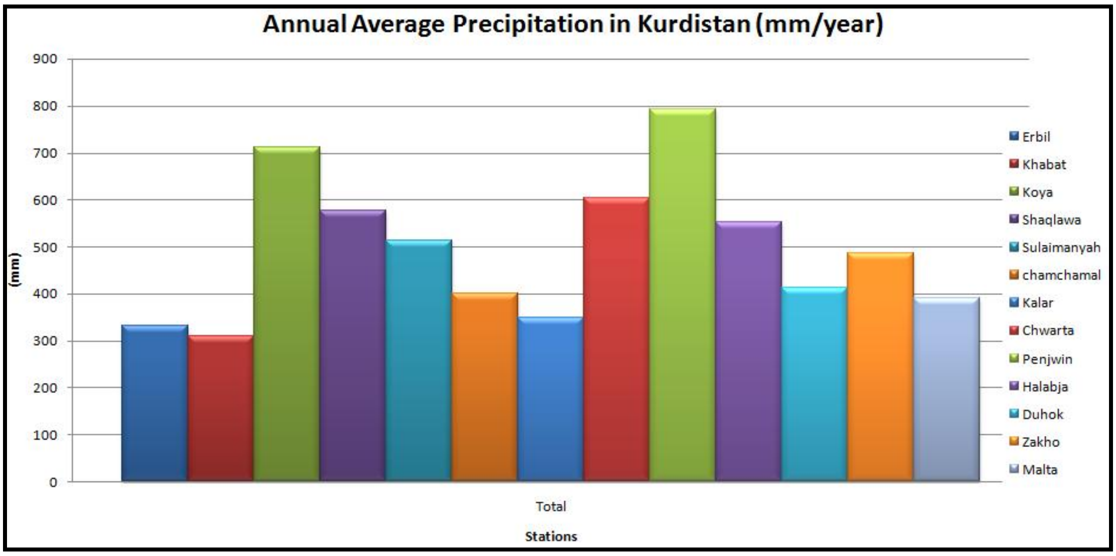


Figure 28 Annual Average Precipitation in different areas in Kurdistan

Generally the precipitation in Kurdistan region starts in September and usually ends by May. The annual rainfall in the region is not much less than annual rainfall in Europe, but the annual rainfall in Europe is more evenly distributed.

There are other factors which influence the rainfall regime of Kurdistan region, often on a very local scale. These include height and general configuration of land. During the rainy season, westerly and north-westerly air are the main rain-bringers, producing a rainfall maximum on the south and south-east slopes, such as in Erbil and Sulaimanyah cities, while valley winds are the main cause of local rainfall in Duhok city [20].

The following rainfall distribution map showed that precipitation increases from southwest to northeast, with annual averages ranging from 350mm in Erbil area to more than 1100mm at Sherwan-Mazen in the high mountains bordering Iran.

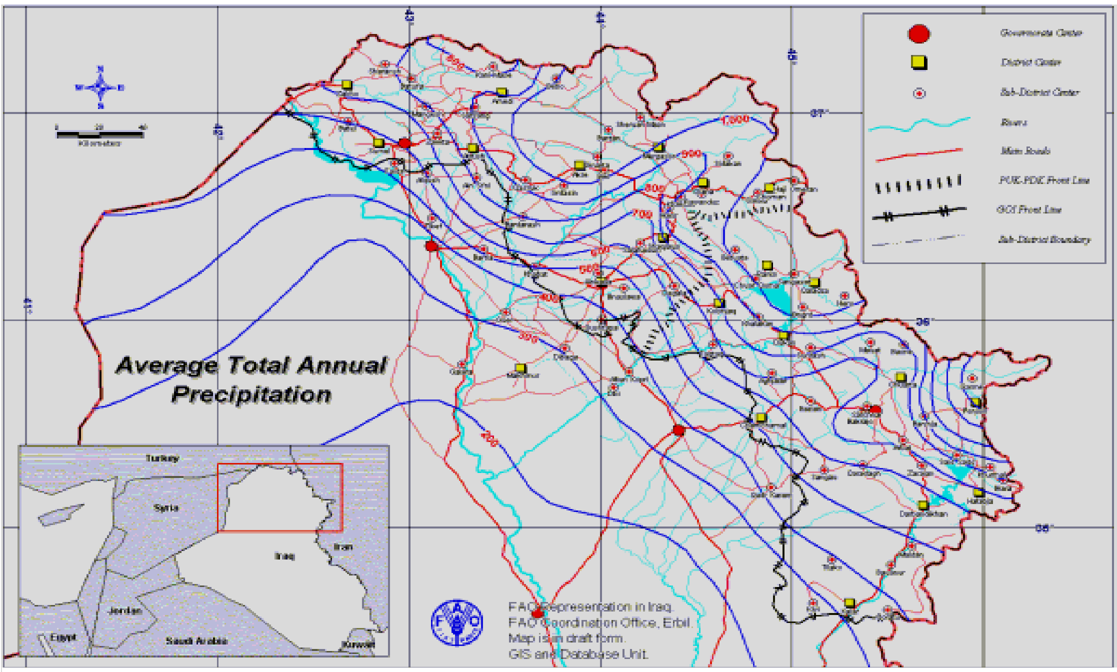


Figure 29 Precipitation distribution map of Kurdistan region (FAO)

In addition to the annual rainfall in Kurdistan region, the Tigris River and its tributaries can be considered as a main water resource in the region plus a few dozens of other smaller streams and springs [24].

River	Average annual discharge billion m^3	Catchment area km^2
Tigris	18.8	235000
Upper (Greater) Zap	14.32	26700
Lower (Lesser) Zap	7.07	11960
Sirwan	5.86	17850
Khabur	2.1	5200*

Table 7 Main rivers in Kurdistan region and average annual discharge

The total annual discharge of the rivers in table (7) is over 48bm³, which is meaning that in a single second over 1500 m^3 is flowing on average.

But in fact only a very tiny fraction of that enormous energy is presently exploited, at just two points on the Lower Zap and Sirwan rivers in Kurdistan region. The hydropower sector still has a great potential to be developed to support the energy sector in the region. Apart from the main rivers there are other rivers and smaller streams and springs which are presently used only for domestic and agriculture purposes. The following table lists number of streams in Erbil governorate [24].

Stream/ Spring	Sub-District	Average Maximum Discharge (m^3/sec)	Average Minimum Discharge(m^3/sec)
Alana	Khalifan	4.95	0.63
Balakian	Soran	165.76	1.26
Basan	Galala	7.06	2.23
Bekhal	Rewanduz	7.98	2.55
Hujran	Selaheddin	0.91	0.11
Jundian	Soran	68.07	7.96
Khalan	Khalifan	111.41	13.03
Razga	Selaheddin	3.81	0.03
Rezan	Barzan	80.36	20.05
Ruste	Smilan	7.78	0.49

Table 8 Number of streams, springs and average discharge rates

These small rivers and streams in addition to their traditional usage could be used in mini and micro hydropower schemes especially in rural and isolated areas in the region.

Generally hydropower projects in Kurdistan can be classified into three categories:-

- Existing hydropower stations: - as stated earlier at present hydropower is the only source of electricity in Kurdistan which includes two large hydropower stations and several micro hydropower stations in rural and isolated region.
- Under construction hydropower stations: federal government in Iraq is managing and supervising strategic projects, like large hydroelectric dam projects, and such huge projects require a safe and stable environment.

Because Kurdistan region relatively is safe and secure compared with other parts of Iraq, they have started to undertake the Bechme project [25].

I. Bekhme dam: the project is located on Upper Zap River (80 km North of Erbil), the main purpose of the project is irrigation, power generation, controlling flood and developing tourism and fishery.

Figure 30 Location of Bechme dam (source: www.ikconseng.co.yu)

Catchment area of the project is 16600 km² and the total capacity storage is 17 bm³. Installed capacity of the power house of the project is 1500 MW, with the annual generated electricity 4800 GWh.

- Proposed hydropower stations: - with a huge gap found between energy demand and supply, certainly there will be lots of efforts and endeavours to minimize or bridge that gap. Regardless of three new power stations (powered by natural gas) under construction in Kurdistan region, there is trend to take advantages of hydropower in the region. Probably the driving force for this policy is not climate change and global warming issues but security of supply. Therefore, a long list of proposed dams has been issued by the ministry of water resources. Nearly all of them consist of an electricity hydropower system, among them 27 large, 11 medium, 13 small, 29 mini and micro schemes. These proposed hydropower stations would have a positive impact on energy production and put in more than 5000 MW capacity to the electricity generation sector in the future [24]. The most significant of these proposed schemes are: -

I. Mendawa dam: will be built on upper Zap River (60 km North West of Erbil). Purposes of the project are preventing the risk of flooding, providing water for irrigation, power generation and controlling the water, coming launched from the Bekhme dam plus developing tourism and fishery. Its total storage capacity is 2.3 bm^3 with a hydropower station capacity of 620 MW.

II. Taqtaq dam: it will place on lower Zap River (70 km South East of Erbil). The purpose of the project is power generation, irrigation, flood control and controlling water delivered from Dukan dam.
Total storage capacity is 2.85 bm^3 with the total capacity of 270 MW power generation.

III. Bakirman dam: this project will be established on Khazer River, one of the tributaries of the Upper Zap River (150km North West of Erbil). The goal of the project is avoiding flood threat, irrigating nearly 36900 hectares of land, power generation and developing tourism. Its total power generation capacity is 210 MW, plus storage capacity of 490 million cubic metre of water.

4.3 Wind Energy in Kurdistan: -

Wind energy may be considered one of the renewables that is expected to perform a major role in reducing green gas effects and providing clean, reliable and cost effective energy.

Unfortunately, in Kurdistan, wind energy has never been brought to mind as source of energy, but it has used traditionally in winnowing and drying.

It is not easy to investigate something had been neglected; a lack of proper data and information is making our job harder.

4.3.1 Wind Sources in Kurdistan: -

Climate records in the region show that Kurdistan falls under the influence of Mediterranean anticyclones and sub-tropical high pressure belts in summer, and the wind tends to move from west, south west to north, north east strengthening and drying out over Arabian peninsula, on occasion a southerly wind blows developing dust storms and bringing dust into the region, raising daily temperature to a maximum value of more than 45 °C.

However, in winter the region is invaded by Mediterranean cyclones moving east to north east over the region, also Arabian sea cyclones moving northward passing over the Persian gulf which cause a large amount of precipitation in the region; and very cold polar air mass migrates with the polar jet stream downward to the Persian gulf.

Nevertheless local wind patterns blowing as a result of the variation of the topography of the region over very short distance, remains a most important feature.

4.3.2 Data analysis: -

Wind speed of course is the most important aspect of the wind resource, because of the direct relationship between wind speed and wind turbine power output. All collected data about wind speed from the agro-meteorological stations which are spread around Kurdistan are measured at 2m above ground.

4.3.3 Height Extrapolation: -

In order to utilize these data in calculating and assessing wind energy within the designated location in the region, the first step is to extrapolate the wind speed data collected at 2m height to the required height.

The variation of wind speed with height is called ‘’wind shear’’. Wind energy engineers usually use one of two mathematical models, the logarithmic profile or the power law profile. The second one is used in this assessment.

The power law profile assumes that the ratio of wind speeds at different heights is given by the following equation:

$$\frac{s_1}{s_0} = \left(\frac{h_1}{h_0}\right)^{\alpha} \quad \text{---------------} \quad \textbf{Equation 1}$$

Where:

h_1= the hub height of the wind turbine [m]

h_0= the anemometer height [m]

α = the power law exponent

s_1= wind speed at the hub height of the wind turbine [m/s]

s_0= wind speed at anemometer height [m/s]

The power law exponent is a dimensionless parameter and is equal to about 1/7 for turbulent flow over a flat plate. However, it has been found that in practice the power law exponent depends on temperature, season, terrain roughness, and several other factors. Table (9) provides power law exponent values for different types of landscape [26].

Terrain Description	Power Law exponent, α
Smooth, hard ground, lake or ocean	0.10
Short grass on untilled ground	0.14
Level country with foot-high grass, occasional tree	0.16
Tall row crops, hedges, a few tree	0.20
Many trees and occasional buildings	0.22-0.24
Wooded country-small towns and suburbs	0.28-0.30
Urban areas with tall buildings	0.4

Table 9 power law exponent values for different types of landscape

These values are generally accepted for extrapolating wind velocities from 10m (the standard measuring height for western meteorological stations) to greater heights. There is very little information on extrapolating from other heights. However, a research study in Salahaddin University – Erbil in Kurdistan used the mean wind speeds from 2 and 10m to calculate an average power law exponent in a landscape covered in grass to a height of 0.3m [27]. The result was α = 0.34 (see figure 31).

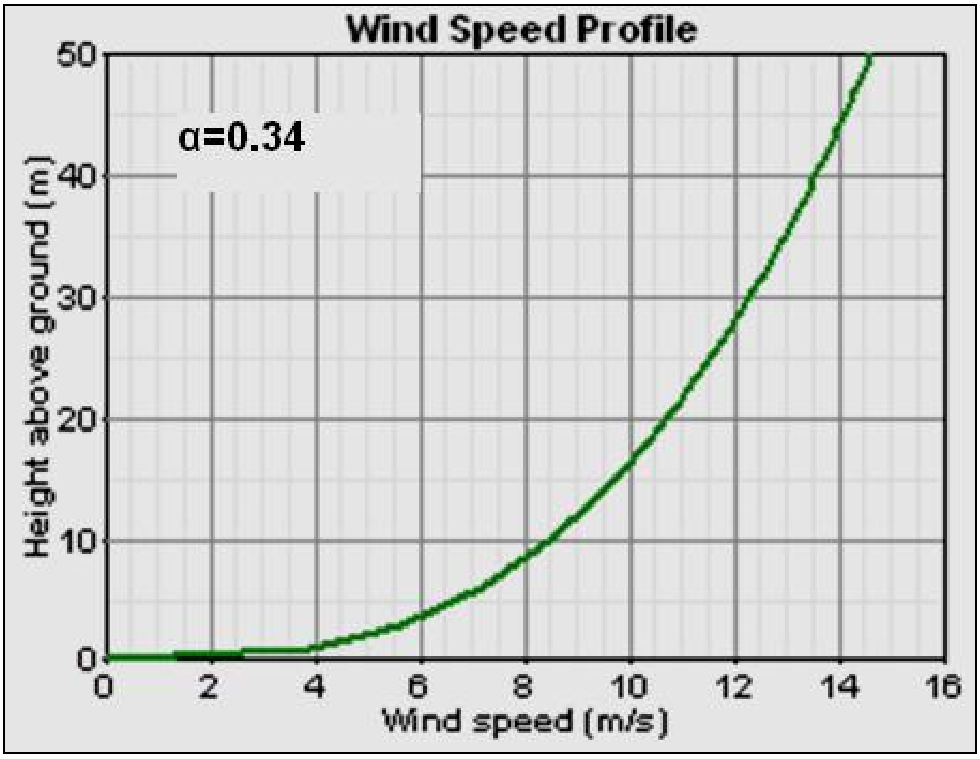


Figure 31 wind speed profile with α = 0.34

This is very different to the value in table (9) for the same ground conditions, but of course it is dealing with a different part of the boundary layers.

Therefore, in this study, the extrapolation will be carried out in two stages. Firstly from 2m to 10 α = 0.34 will be used, then from 10m t0 50m α = 0.16 will be used.

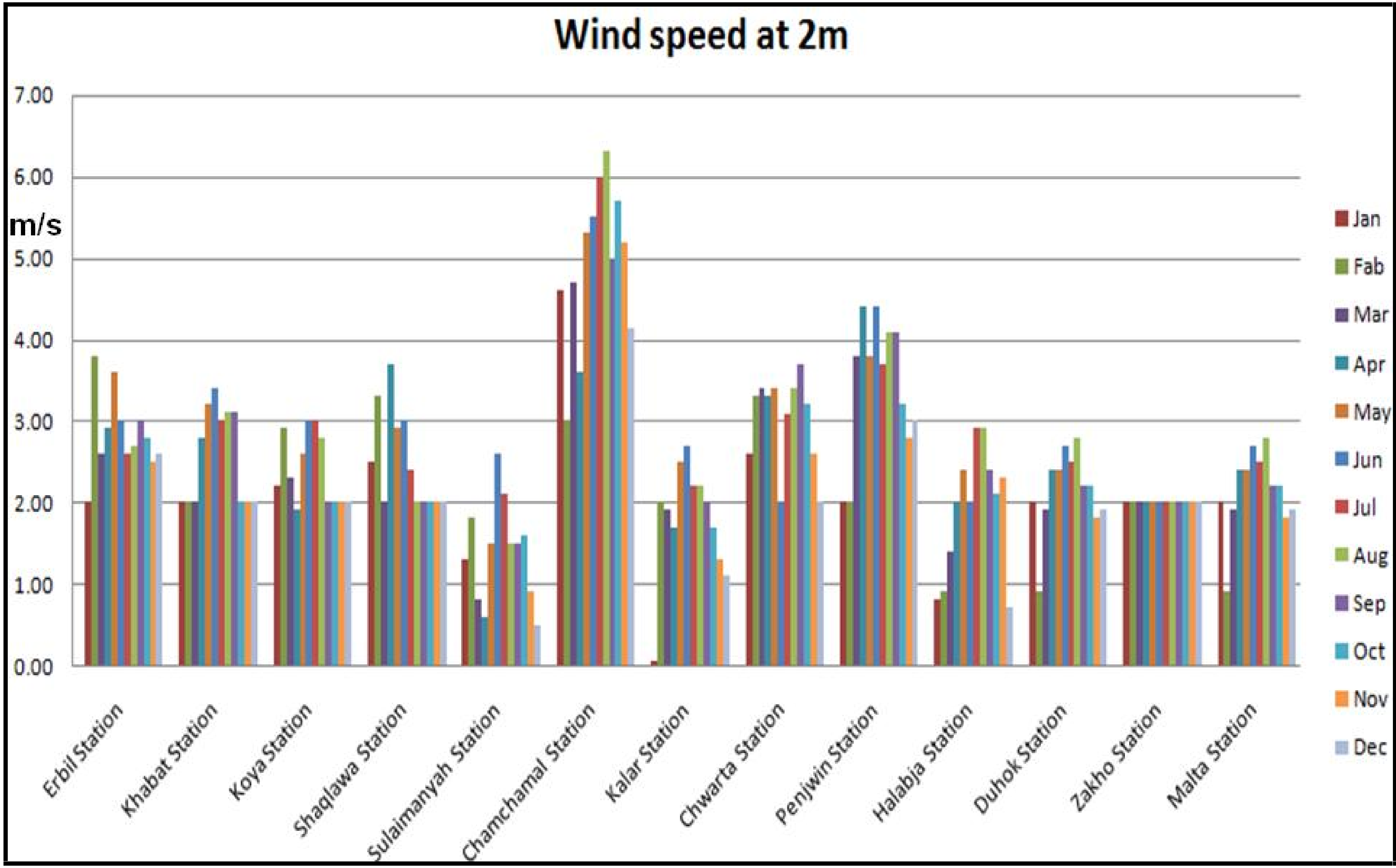


Figure 32 monthly wind speed records at 2m height

Wind speed values from 13 stations have been taken throughout Kurdistan to assess the potential of wind energy. It is necessary to examine the records carefully, therefore classification and selection of data will be essential.
In Zakho station wind speed has one value during the whole year, which is not credible. Khabat station, Shaqlawa station and Koya station have recorded the same values for several months which is not likely in reality. These errors could be from anemometers or caused by the operators in those stations. Finally Malta station has the same reading as Duhok station, this may both station are sharing the same anemometer because both station being adjacent and there is only 6km between them (see figure 25 and table 3).
Consequently data analysis will be carried out just in 8 stations.
After extrapolation from 2m to 10m using $\alpha = 0.34$ the following chart was produced:

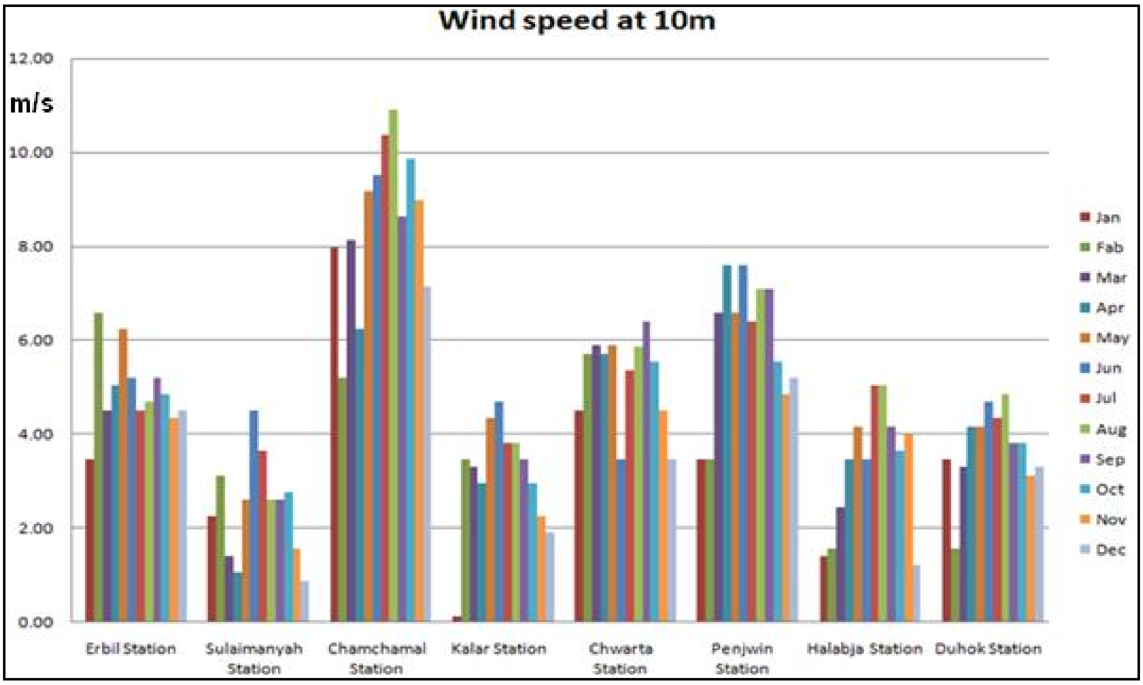


Figure 33 Monthly average wind speed extrapolated to 10m height in 8 selected stations

A second extrapolation from 10m to 50m using α = 0.16 was carried out to produce the final wind speed chart as follows: -

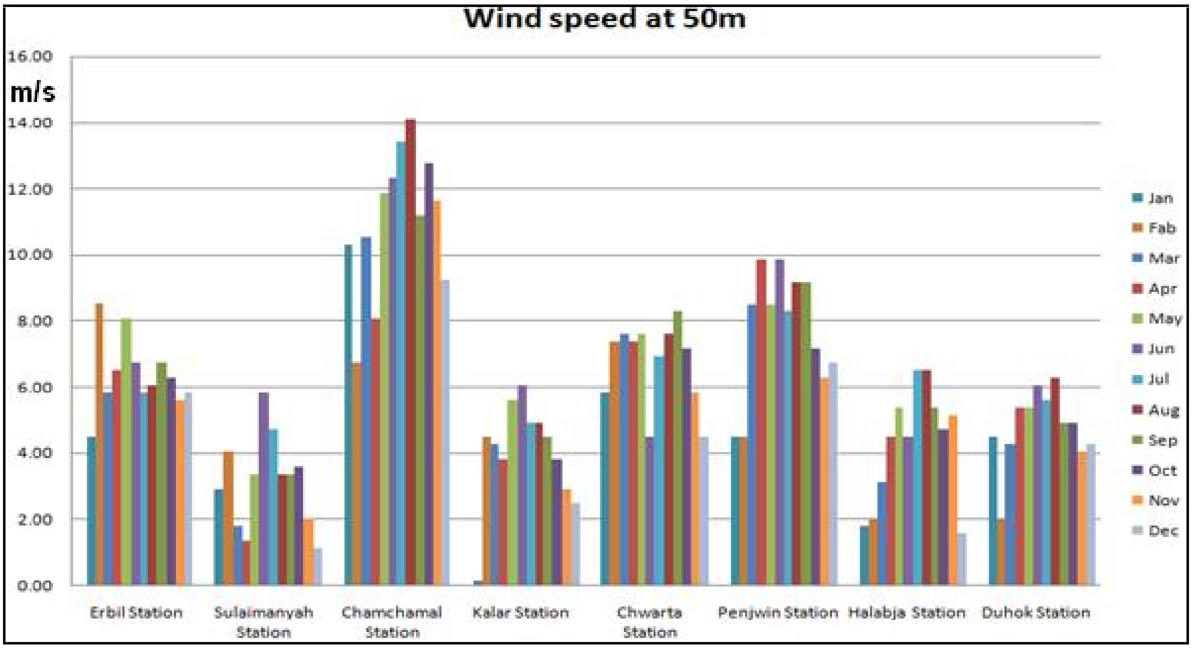


Figure 34 Monthly average wind speed extrapolated to 50m height in 8 selected stations

Now another short list will be selected. As is seen from figure (34) Sulaimanyah and Kalar are showing a poor potential of wind source, so it is better to focus on the sites that are showing reasonably high wind speed which are 6 stations.

4.3.4 Wind speed distribution: -

If height extrapolation of wind speed is required in case of lack of wind speed at a desired height, then information of the probability distribution of wind speed will be significant at all time to estimate wind energy in a specific location. As seen from previous figure wind speed in all sites are highly variable throughout the whole year. Generally in most areas strong gale force winds are rare, while moderate and fresh winds are quite common; to understand the wind variation for a typical site statistical analysis usually is been used. Among various analytical expressions for determining this, the Weibull distribution typically been used to describe wind speed distribution.

Basically in the Weibull distribution two-parameter are used to characterize wind regimes. The probability density function is given by the following equation:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1}.exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad \text{- - - - Equation 2}$$

Where

v is the wind speed, *k* is a dimensionless shape factor, and *c* is a scale parameter with the same units as *v*.

The cumulative distribution function is given by the following equation:

$$f(v) = 1 - exp\left[-\left(\frac{v}{c}\right)^{k}\right]$$ - - - - - - -- - **Equation 3**

The two parameters c and k are related to the average wind speed by the following relation:

$$\overline{v} = c\Gamma\left(\frac{1}{k} + 1\right)$$ - - - - - - - - - - - - - - - **Equation 4**

Where Γ Is the gamma function.

Finally any Weibull distribution can be described by the average wind speed and the Weibull *k* value, where the Weibull *k* value is an indication of the breadth of the distribution of wind speeds.

In order to calculate *k* and *c* values plus producing daily wind speed, probability function (PDF), cumulative distribution function (CDF) and wind speed duration curve, a simulation can be run in order to simplify calculation.

To carry out such a simulation the code HOMER was selected, which is a computer model, developed by the National Renewable Energy Laboratory from the U.S. Department of Energy that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote,. HOMER models both conventional and renewable energy technologies [28].

4.3.5 Wind Energy in Erbil: -

The monthly and the average annual wind speed in Erbil after extrapolation from 2m to 50m are shown in table (10), the wind speed varied between 4.34 m/s in January, and 7.79m/s in May.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
m/s	4.34	8.23	5.63	6.28	7.79	6.5	5.63	5.85	6.5	6.06	5.41	5.63	6.34

Table 10 monthly average wind speed at 50m in Erbil station

The following graph was produced by running the simulation using the data in table (10).

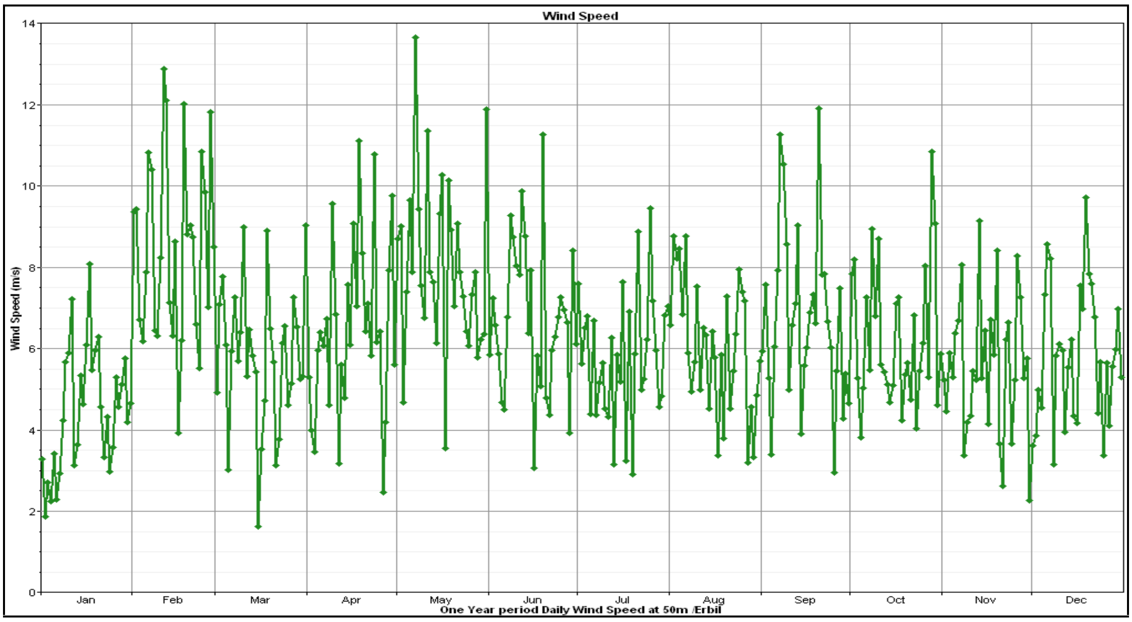


Figure 35 Daily wind speed variation in Erbil station

Figure (36) shows the probability distribution of the extrapolated 50m wind speed data for Erbil and the resulting best fit Weibull distribution. The Weibull parameters were found to be k=2.03 and c=7.16 m/s. Knowing these parameters for a site makes it easy to estimate the wind energy production of a particular turbine without needing hourly wind data for a whole year.

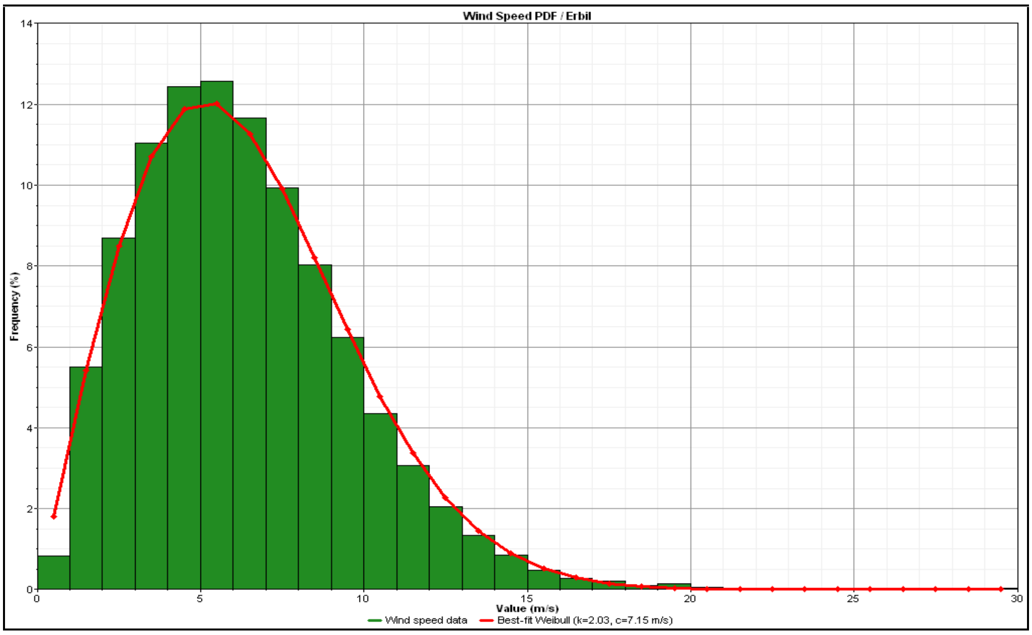


Figure 36 Probability distribution of wind speed for Erbil station

Fig (37) shows that wind with minimum speed of 5m/s is available for over 5200 hours a year which is nearly 60% of the whole year, this figure is quite enough to encourage thinking about exploiting wind energy in Erbil.

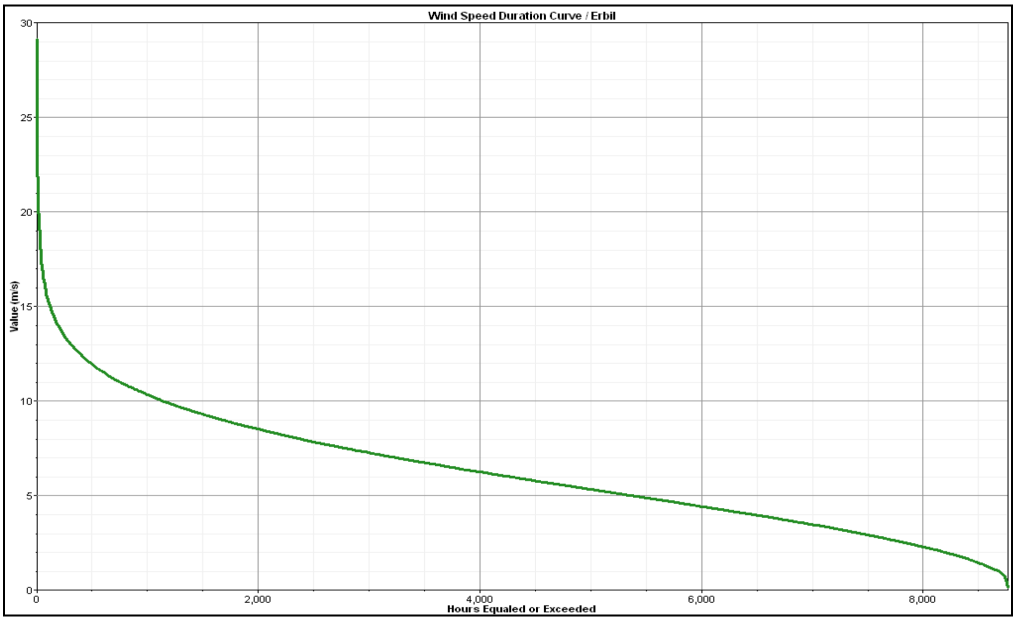


Figure 37 wind speed duration curve for Erbil station

4.3.6 Wind Energy in Chamchamal: -

In this station the highest wind speed was recorded, and it fluctuated between 6.50m/s in February and 13.66m/s in August.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
m/s	9.96	6.50	10.19	7.80	11.49	11.92	12.99	13.66	10.83	12.36	11.26	8.95	10.69

Table 11 monthly average wind speed at 50m in Chamchamal station

After simulation using the values from table (11), the following figure was obtained which shows daily wind distribution during the whole year (see figure 38).

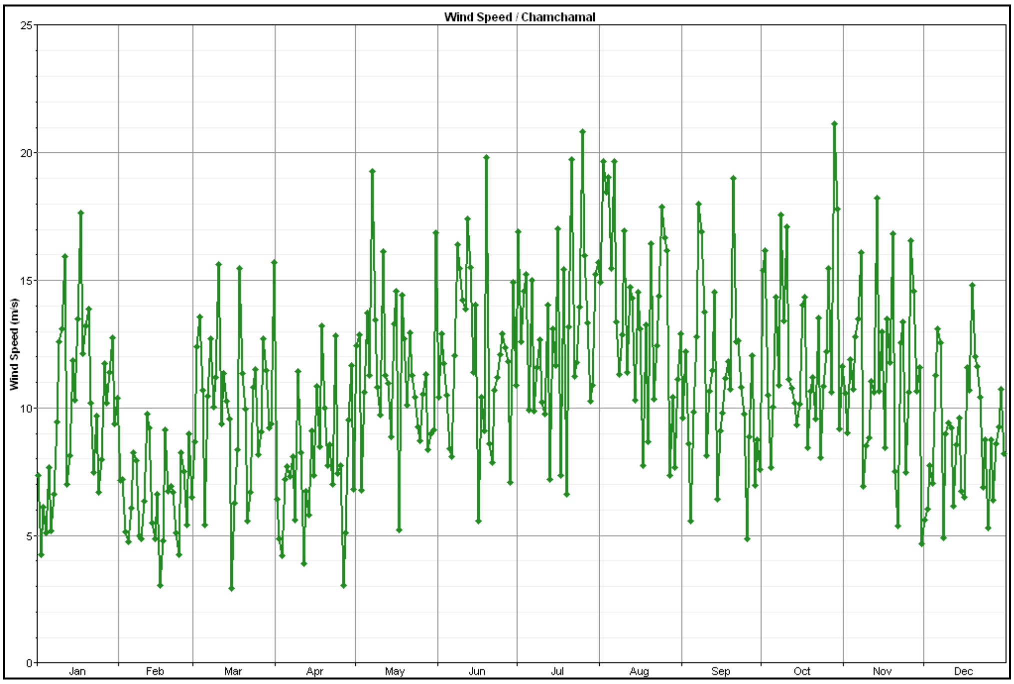


Figure 38 Daily wind speed variation in Chamchamal station

Figure (39) shows the probability distribution of the extrapolated 50m wind speed data for Chamchamal and the resulting best fit Weibull distribution. The Weibull parameters were found to be k=2.03 and c=12.09 m/s.

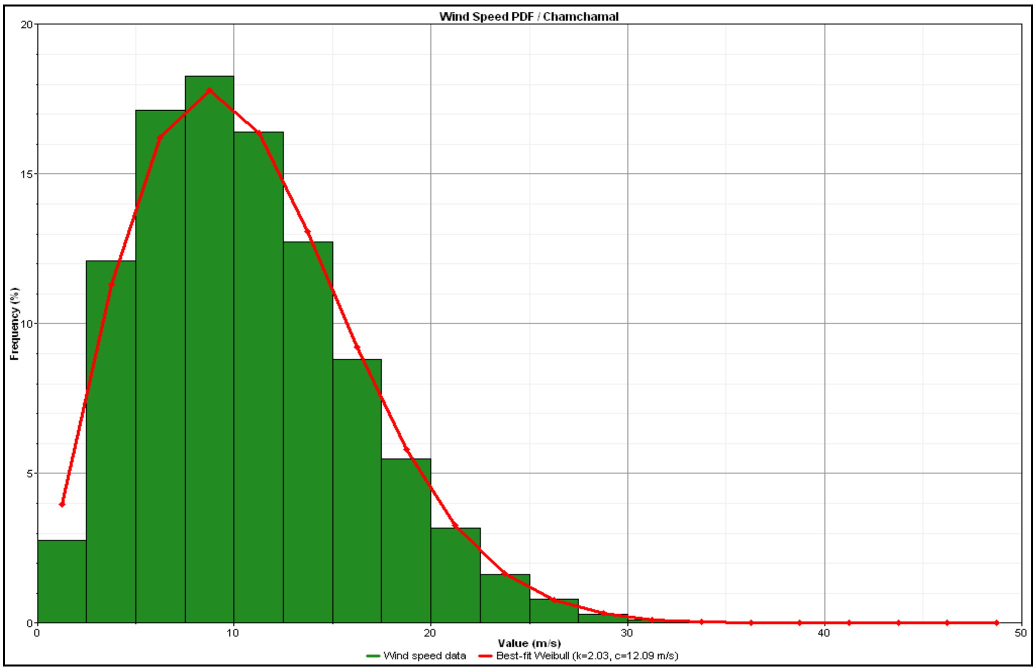


Figure 39 Probability distribution of wind speed for Chamchamal station

Figure (40) shows that wind with a minimum speed of 5m/s is available for over 7000 hours a year which is nearly 80% of the time, it would clearly be worth thinking about exploiting wind energy in Chamchamal at a large scale.

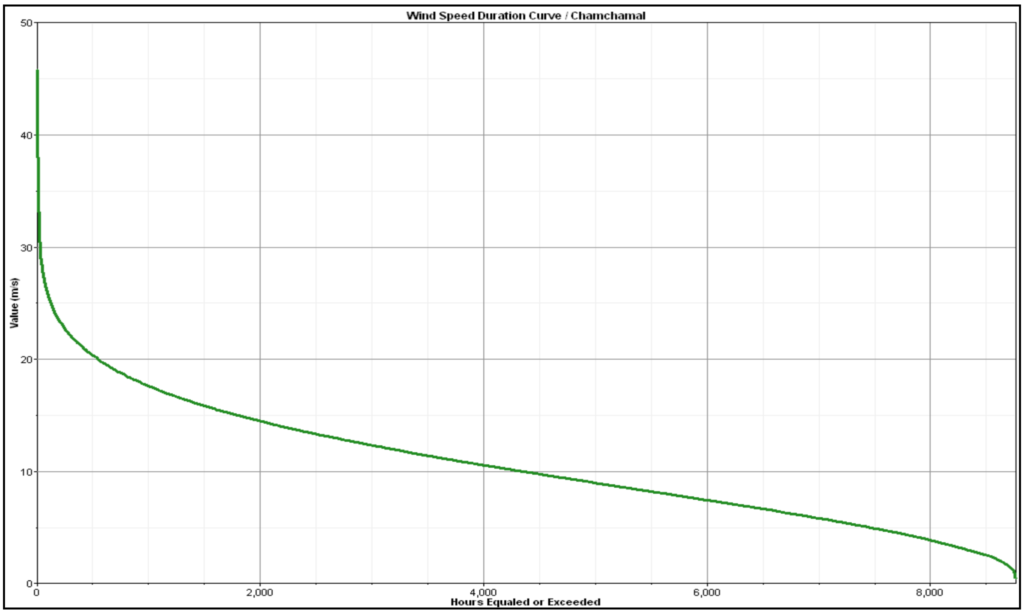


Figure 40 Wind speed duration curve for Chamchamal station

4.3.7 Wind Energy in Chwarta: -

A reasonable wind speed was recorded in Chwarta station table (12) shows the average monthly wind speed, the highest was recorded in September and lowest in June.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
m/s	5.64	7.14	7.37	7.14	7.37	4.34	6.69	7.34	8.01	6.93	5.63	4.34	6.49

Table 12 wind speed at 50m in Chwarta station

After the simulation the daily wind speed variation has been reconstructed and shown in figure (41)

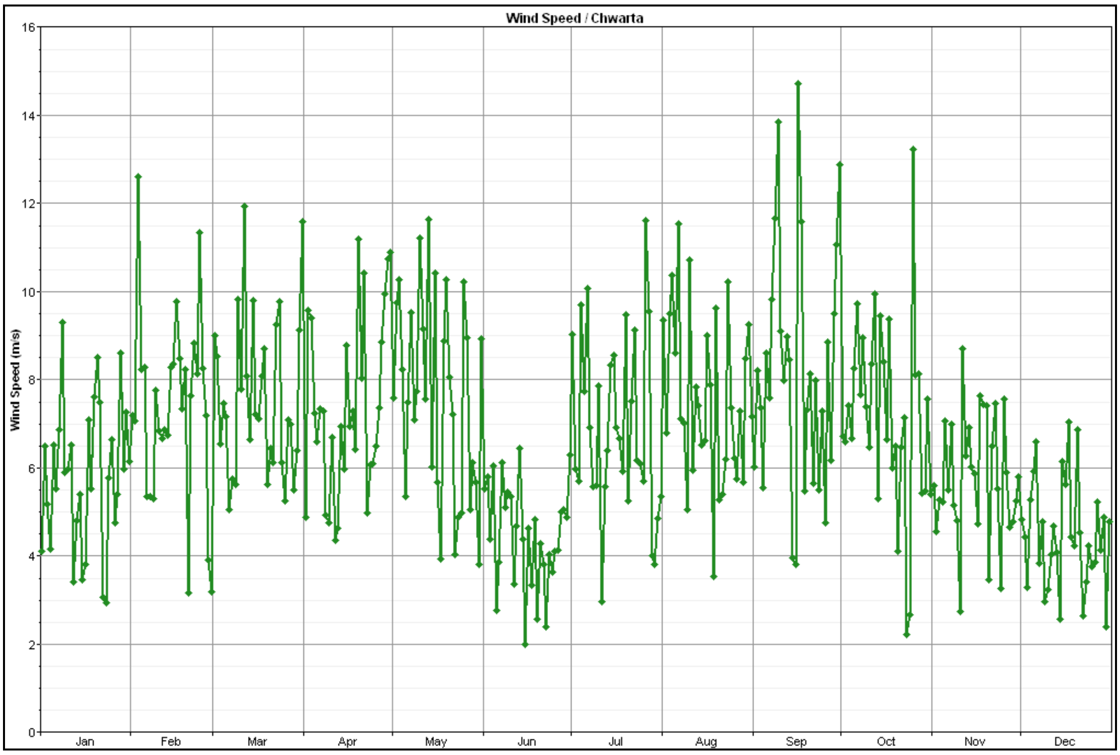


Figure 41 Daily wind speed variation in Chwarta station

Also the probability distribution of wind speed has been produced and shown in figure (42), and the best fit Weibull distribution k = 2 and c=7.57m/s

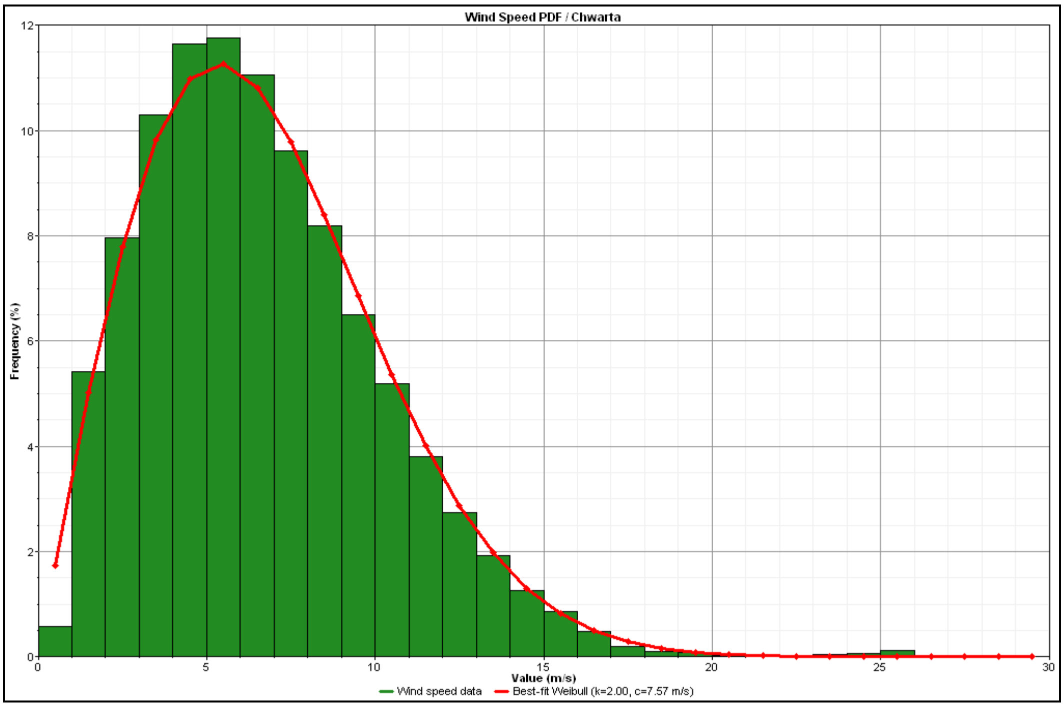


Figure 42 Probability distribution of wind speed for Chwarta station

Figure (43) shows the wind speed duration curve, and estimates that 5500 hr a year the wind speed of 5m/s and over are exist which is equal to 63% of the time.

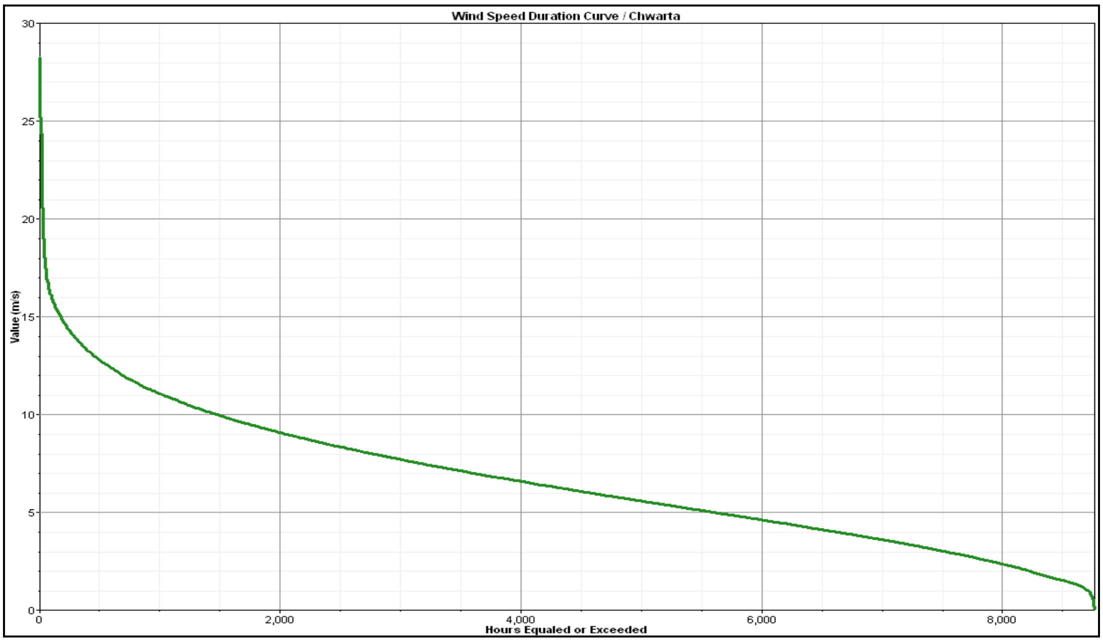


Figure 43 Wind speed duration curve for Chwarta station

4.3.8 Wind Energy in Penjwin: -

Wind speed at Penjwin station was selected because it is values are fairly good, table (13) holds the monthly average wind speed there. The highest wind speed was in April and June and the lowest was in January and February.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
m/s	4.34	4.34	8.22	9.52	8.22	9.52	8.01	8.88	8.88	6.93	6.06	6.50	7.46

Table 13 wind speed at 50m in Penjwin station

The daily wind speed variation shown in figure (44) which reconstructed by using HOMER.

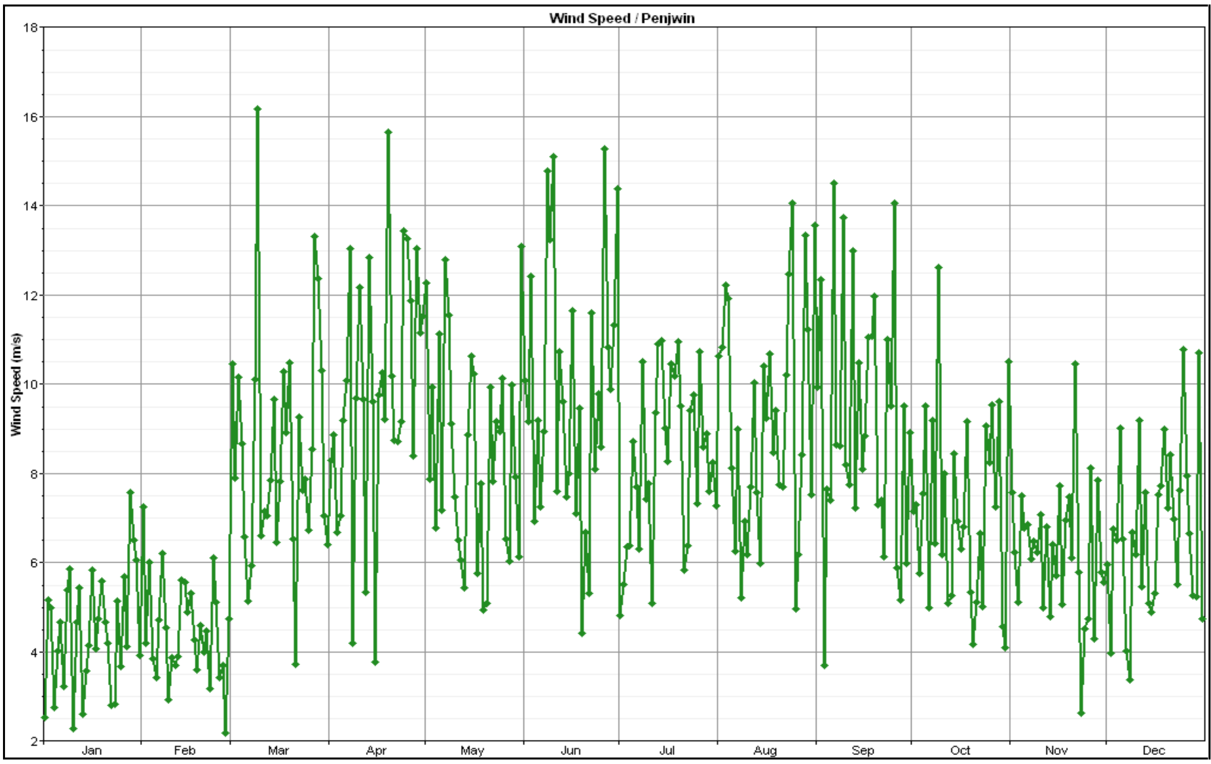


Figure 44 Daily wind speed variation in Penjwin station

The wind speed distribution probability presented in figure (45) the best fit Weibull distribution k = 1.98 and c=8.72m/s

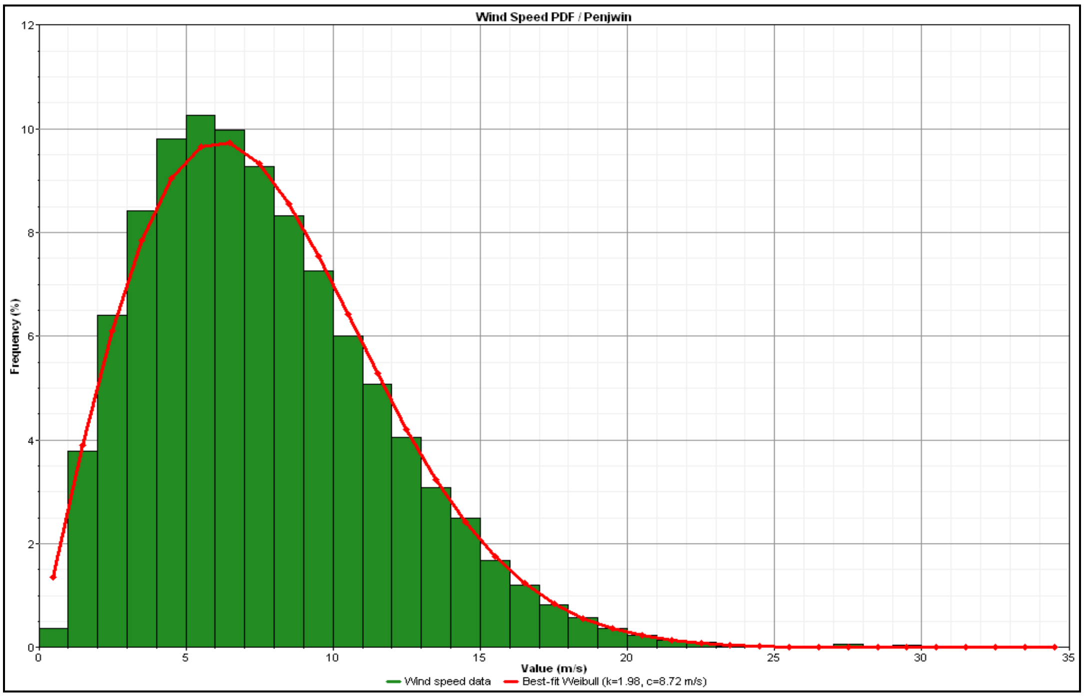


Figure 45 Probability distribution of wind speed for Penjwin station

Below in figure (46) wind speed duration curve produced and shown that over 6000hours a year the wind speed over 5m/s is available in Penjwin which is more than 64% of the time.

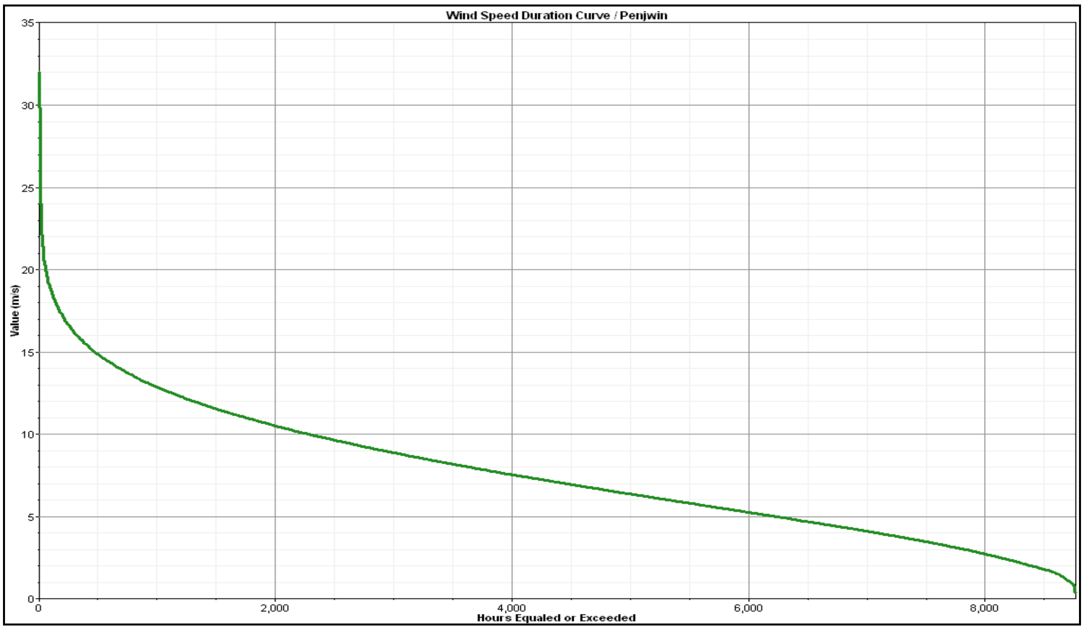


Figure 46 Wind speed duration curve for Penjwin station

To estimate the potential of wind energy for the last four stations the wind power will be calculated. In the calculation the value of *k* will be used as stated in the following equation:

$p = \frac{1}{2}\rho k v^3$ – – – – – –Equation 5

Where:

p Is wind power per unite area (W/m²)

ρ Is air density (kg/m³)

k Is dimensionless shape factor Weibull distribution factor and

v Is wind speed (m/s)

The expected wind power per unite area listed in table (14), all locations have a promise potential of wind energy especially Chamchamal.

	Erbil *k*=2.03	*Chamchamal* *k*=2.03	*Chwarta* *k*=2	*Penjwin* *k*=1.98
Month	*p* (W/m²)	*p* (W/m²)	*p* (W/m²)	*p* (W/m²)
Jan	101.32	1229.11	219.61	98.83
Feb	692.45	340.79	446.32	98.83
Mar	221.72	1316.44	489.95	673.55
Apr	307.98	589.22	446.32	1047.36
May	588.65	1886.23	489.95	673.55
Jun	340.79	2106.58	99.83	1047.36
Jul	221.72	2726.29	366.98	623.70
Aug	248.50	3166.13	484.97	848.19
Sep	340.79	1577.72	630.00	848.19
Oct	277.00	2346.30	407.57	403.49
Nov	197.21	1774.95	218.44	270.18
Dec	221.72	891.14	99.83	332.39

Table 24 Expected average monthly wind power per unit area

The average expected wind energy potential for Chamchamal during 9 months is over 1kw/m² which is fairly optimistic result.

Finally because of lack of wind map of Kurdistan and also to lay out a general view on wind speed distribution in the Kurdistan region a wind speed distribution map at 50m height (see figure 47) has been produced on the basis of the data recorded by the Agro-meteorological station in Kurdistan. It is essential to say that the map is a very roughly one and it not quite accurate, but at least it may help to find a reasonable wind source in different areas in Kurdistan.

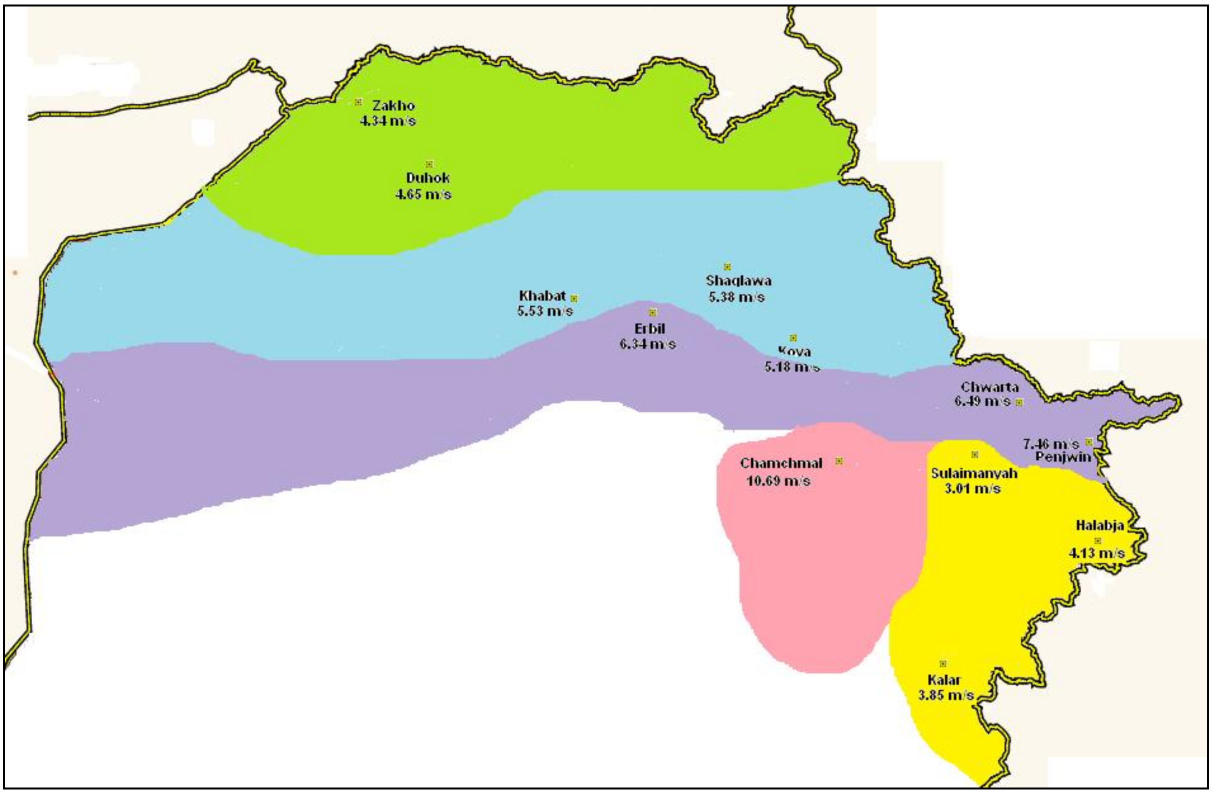


Figure 47 Kurdistan region wind distribution map at 50m height

4.4 Solar Energy in Kurdistan: -

Solar energy technologies offer a clean, renewable domestic energy source, and are essential components of a sustainable energy future. Kurdistan lies in a sunny belt between 34° 42' N and 37° 22' N latitudes and is geographically well situated with respect to solar energy potential. Kurdistan solar energy potential can be evaluated on the basis of the data measured and recorded by the FAO Agro-meteorological stations in Kurdistan. The evaluation revealed:

- The annual average total sunshine duration as 2979.5 hours (8.16hours/day)
- Average annual solar radiation as 1803 kWh/m²/year (4.94kWh/m²/day) Monthly solar energy potential of Kurdistan is set out in table (15).

Month	Average Monthly Sunshine (h/month)	Average Monthly Solar Radiation (kWh/m²/month
Jan	158.10	77.21
Feb	160.79	91.03
Mar	208.22	134.26
Apr	209.00	154.51
May	303.80	207.53
Jun	375.00	237.22
Jul	360.12	231.50
Aug	360.12	219.73
Sep	301.00	173.06
Nov	255.49	131.97
Oct	175.50	84.31
Dec	112.38	60.78
Total	2979.51hr/year	1803.09 kWh/m²/year
Average	8.16 h/day	4.94 kWh/m²/d

Table 15 Kurdistan average monthly solar energy

.Sunshine duration and average annual solar radiation according to the geographical regions of the Agro-meteorological stations are shown in figure (48) and (49) respectively.

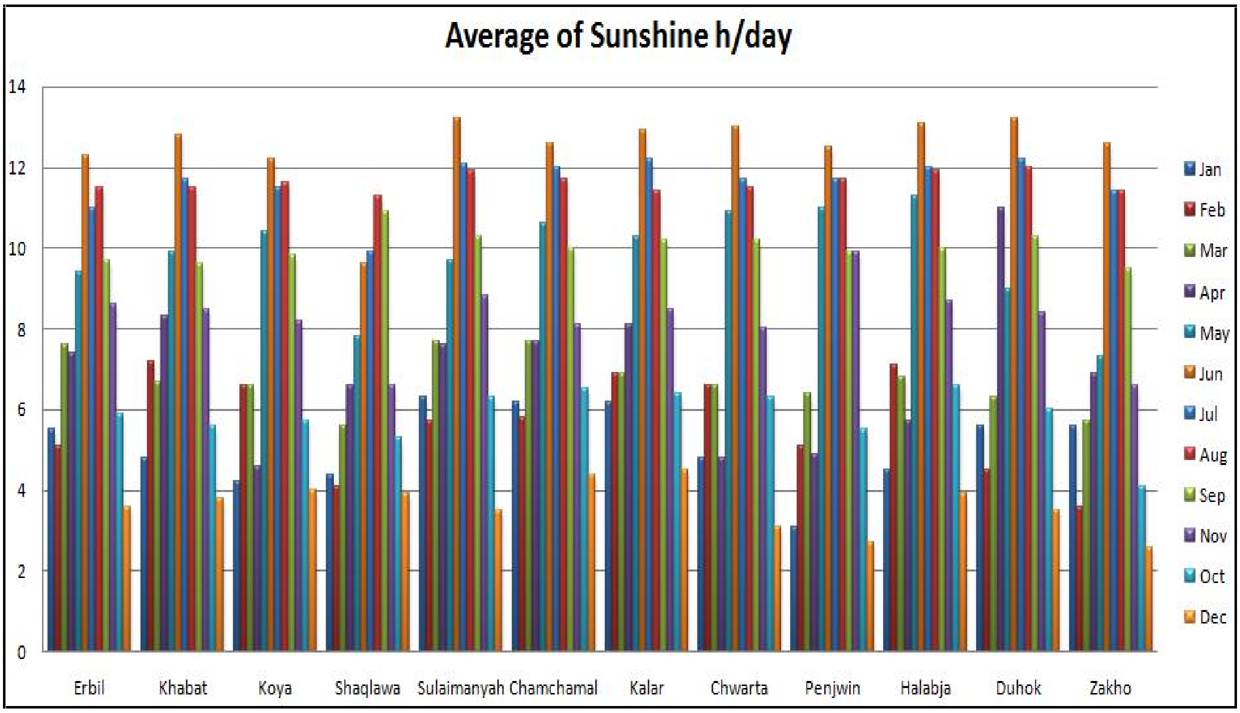


Figure 48 Sunshine duration in different region in Kurdistan

Figure (49) show that the recorded solar radiation in the all stations is comparatively close, except for Shaqlawa and Zakho, the solar radiation is relatively less because the location of these two towns where mountains are located on the south side of both and shedding factor reduces the solar radiation.

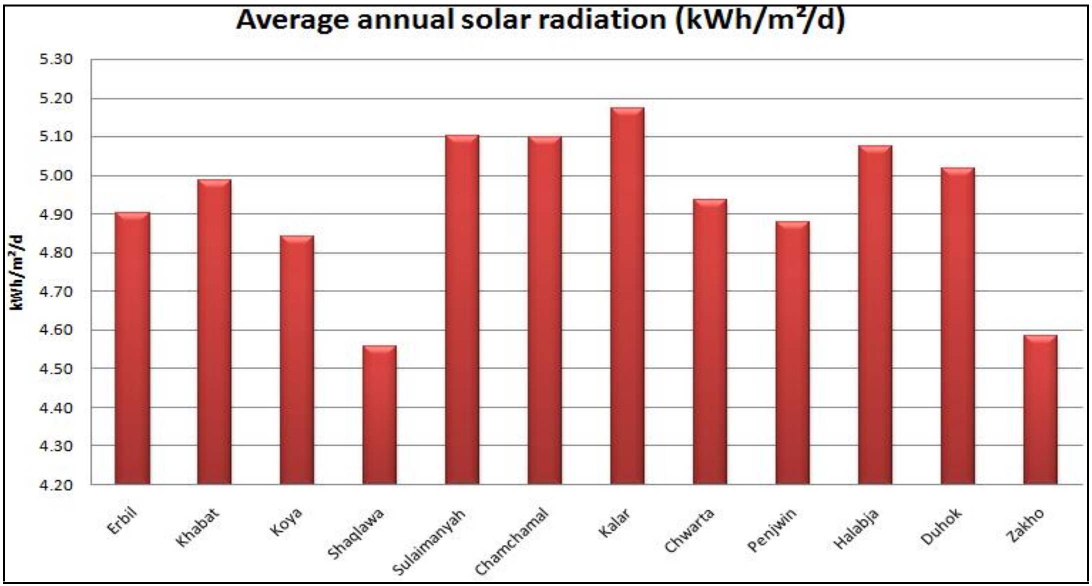


Figure 49 Average annual solar radiations by regions

Solar energy in Kurdistan is clearly abundant and well distributed (see figure 50), but unfortunately this plentiful energy source has been ignored in the past while the people suffered from extreme shortage of energy sources.

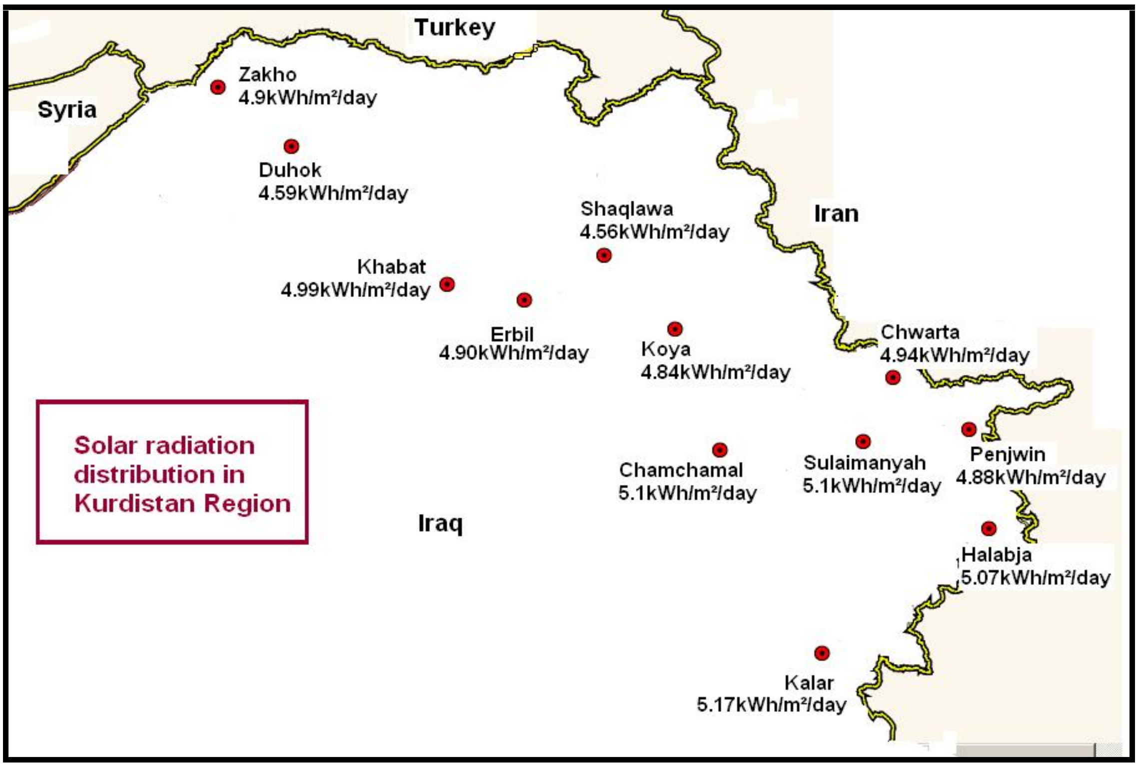


Figure 50 Kurdistan solar radiation distribution map

In a rich region with solar energy like Kurdistan many solar energy technologies can be applied:

- Solar water and space heating, in the big cities and villages. This will reduce dependence on electricity, LPG and Kerosene especially in winter when all these types of fuel are in short supply,
- Steam generation, for electricity generation instead of using conventional fuel,
- Solar cookers, especially in the rural and isolated mountain areas, and
- Photovoltaic (PV) systems, for producing electricity directly especially in rural areas. This technology is expanding rapidly around the world in the last few years, because of falling prices and government incentives in some countries.

Recently solar collecting panels take its way to Kurdistan region's markets slowly, but because of lack of a sensible background about renewable energy in general and solar energy in special in the society and absence of encouragement and funding from the government makes the popularity of these new technologies more difficult.

4.5 Biomass in Kurdistan: -

It is widely known that Kurdistan region has fertilized land plus sufficient solar and water sources, which taken together are the crucial elements of agriculture. Therefore it is not strange that the majority of Kurdistan's population is involved in farming as their livelihood and major source of employment. The farming population resides in thousands of villages scattered all over the mountain areas. But frequent political violence and wars has displaced considerable numbers of villagers from their households and they are now available as seasonal farm labour.

Generally biomass energy is sourced from forestry products, agricultural and municipal solid waste; and it could be used directly or indirectly.

The forest area in Kurdistan region covers 1.9 million hectares [29], or about 36% of the region despite of devastation and burning policy during the last decade.

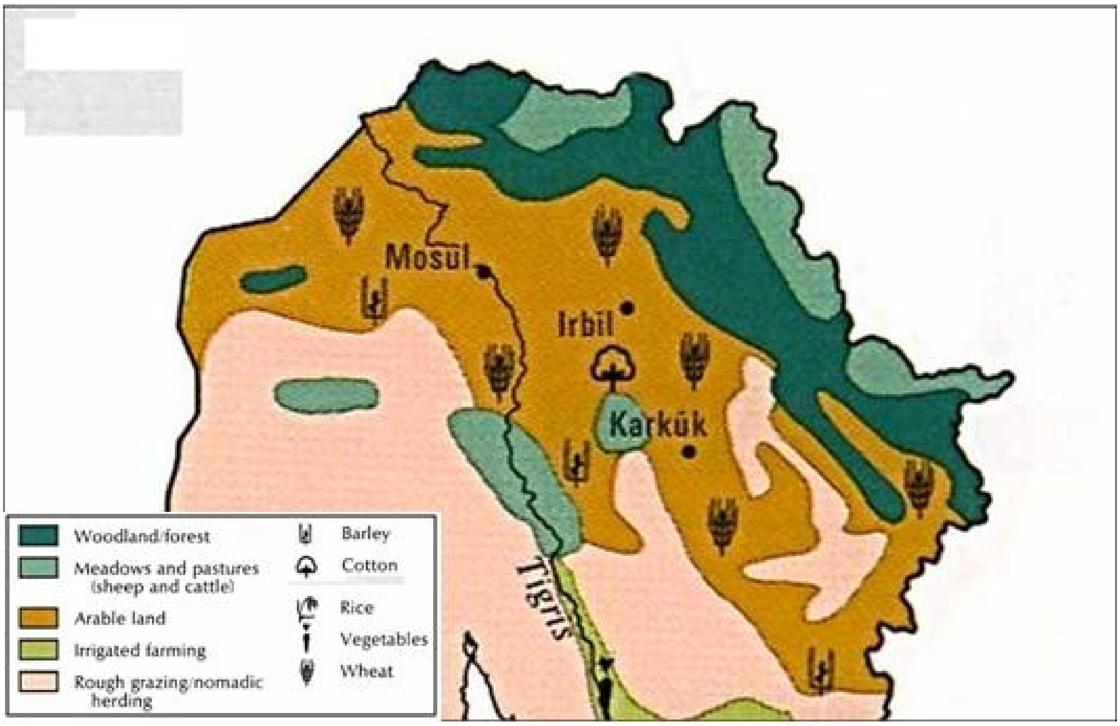


Figure 51 Forest and use of land in Kurdistan (source: http://map.vbgood.com/Iraq/Iraq_map.htm)

The tree cover of the region's mountain slopes reaches elevations of 600m to 2000m and is dominantly made up of oak woodlands forests.

Kurdistan region arable land covers 3.25 million of the 4 million [20] hectares of agricultural land. Most of the cultivated land is rain fed, falling in different micro-climatic zones.

From the above brief information, it can be said that the Kurdistan region has a reasonable potential for biomass, unfortunately lack of strategic plans for using modern biomass technology means that the people at present use this type of energy only in traditional ways instead of converting it to high grade forms.

4.6 Geothermal Energy in Kurdistan: -

The possibility of finding geothermal sources in Kurdistan is considerable due to the location and nature of the composition of the land in Kurdistan.

Unfortunately there is no geological survey of Kurdistan. But hard evidence like hot water springs and observed local volcanic activity will support the possibility of significant geothermal energy sources in Kurdistan.

Chapter 5

5.1 Introduction: -

In order to understand exactly the impact of certain types of renewable energy in Kurdistan we have to have an example which could be a simple start of deploying renewable energy technology in the region.

For our case study, a small village has been chosen called ''Wasan''.

Figure 52 A typical dwelling in Wasan

5.2 Wasan Location: -

Wasan (130km north-east of Erbil city) is located in the Balaiyan valley (Choman Area) in the north-east of Kurdistan region near the Iranian border (see figure 53).

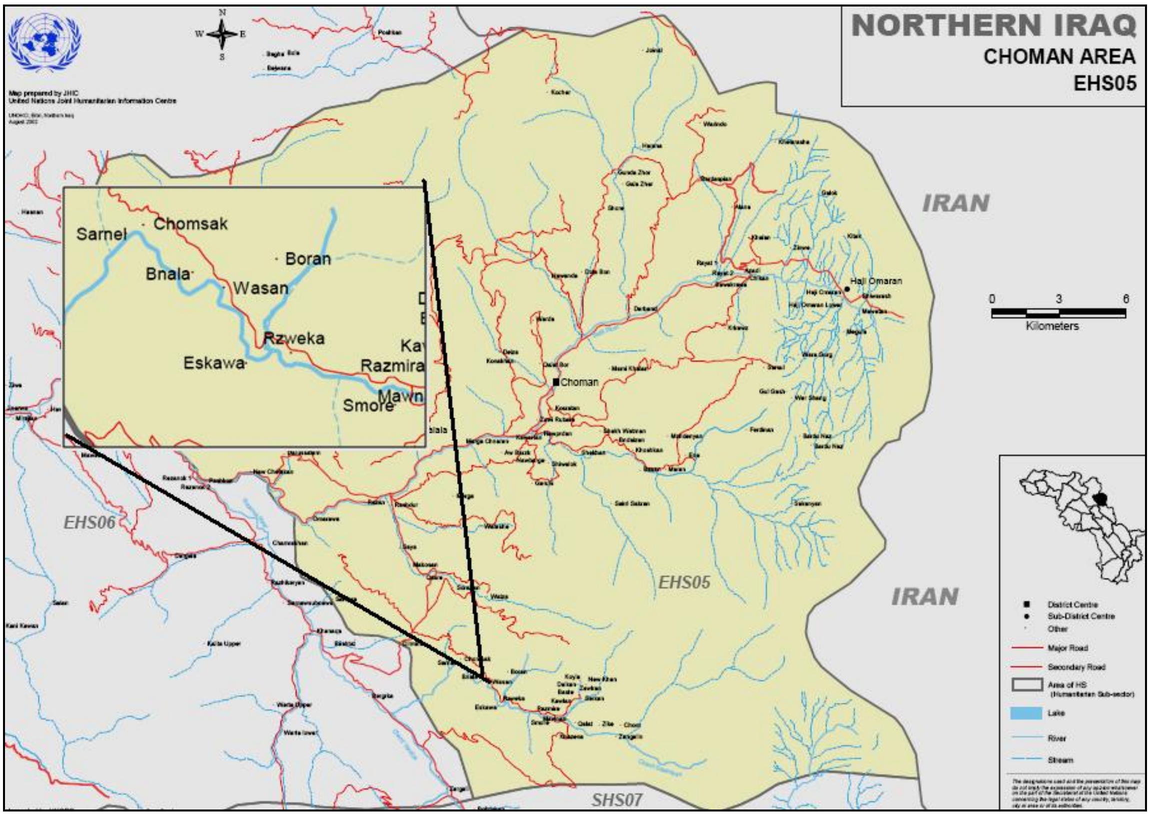


Figure 53 Location of Wasan (source: United Nations Joint Humanitarian Information Centre)

5.3 Wasan Population: -

Due to wars and conflicts in Kurdistan many towns and villages have been destroyed more than one time during the second half of twentieth century. Wasan is one of these villages; last time was during the Iraq-Iran war. Now it has been reconstructed again and comprises 53 houses.

Figure 54 An orchard in Wasan

The population changes during summer and winter; normally summer has more occupancy. In winter the number of families is reduced to less than 40 and population to less than 200 due to the nature of employment in that region. Most of the population are working as a farmers and orchardists and a few as a government officials.

5.4 Climate of Wasan: -

Wasan is cool in summer, but certainly cold in winter, because it is located in a mountain area.

Figure 55 Mountains around Wasan

The temperature is 25C° to 35C° in summer and below zero in winter. The main source of water in Wasan and other villages in the valley is the melting snow from Qandil Mountain which is covered by snow during the whole year.

5.5 Energy sources in Wasan: -

Because Wasan located in a rural and isolated area, connection to the national power network does not exist. There was a micro-hydropower scheme on the stream, but unfortunately this was damaged due to flood in 2007. There was an effort from the villagers and local authority to rebuild it again but unfortunately because of Iranian artillery and Turkish aircraft bombardment the reconstruction was delayed. Hopefully they will start to build it again after the situation becomes more settled.

Figure 56 Former micro-hydropower system in Wasan

Presently the local authority provides Wasan with a diesel generator and this has been used as a source of electricity. Diesel shortages make it impossible o operate the generator for more than 6 hours a day and every household receives 3 amperes of electricity without paying for it, because the government covers the cost of fuel, operation and maintenance.

Apart from this, LPG and kerosene are presently used for cooking and space heating in Wasan, along with wood.

5.6 WASAN Electricity Demand: -

Style of life and individual behaviour will define the demand of a community; in a small and rural community like Wasan electricity demand is certainly not the same as in a big modern city. Electricity is in short supply, and is used just for the basic daily requirements where no other energy source will do, like lighting, cooling and entertainment.

It means they do not use electricity for cooking, space heating or water heating that would consume large amounts of electricity, but instead use LPG, kerosene and wood. Also they do not need air-conditioning because they have a cool climate in summer.

At the present the barrier that is facing electricity demand evaluation generally in Iraq and particularly Kurdistan is lack of electricity bills. Therefore to assess electricity demand especially in the rural areas in Kurdistan, the only feasible method is to identify the commonly used electrical appliances, ownership rate and energy consumption and make a number of assumptions to specify the rate of daily usage for each appliance.

Table (16) shows the common electrical appliances used in Wasan plus ownership rate (this estimation is depending on the life style and average income per family in a typical Kurdish village) and the average consumption of each appliance.

Appliance type	Ownership percentage	Consumption
TV	100%	200
Sat Receiver	100%	30
Light	100%	200
Fridge	100%	115 ()
Wash machine	19%	1200
Computer	11%	350
Water Heater	23%	2000
Fan	100%	120

Table 16 Used appliances in Wasan plus ownership rate

To produce electricity demand profile for Wasan there are another set of assumptions to specify the daily usage rate of each electrical appliance, based on individual employment and daily behaviour. These are summarized in Table (17).

Appliance type	Operation time
TV	17:00-01:00
Sat Receiver	17:00-01:00
Light	All day at different rate
Fridge	All day
Wash machine	09:00 to 11:00
Computer	14:00-19:00
Water Heater (Summer)	06:00 -07:00
Water Heater (winter)	06:00-07:00 and from 15:00-16:00
Fan (Summer)	11:00 to 17:00

Table 17 Duration of using different appliances

According to the previous assumptions the following graphs were produced in figure (57) summer consumption profile and figure (58) winter consumption profile.

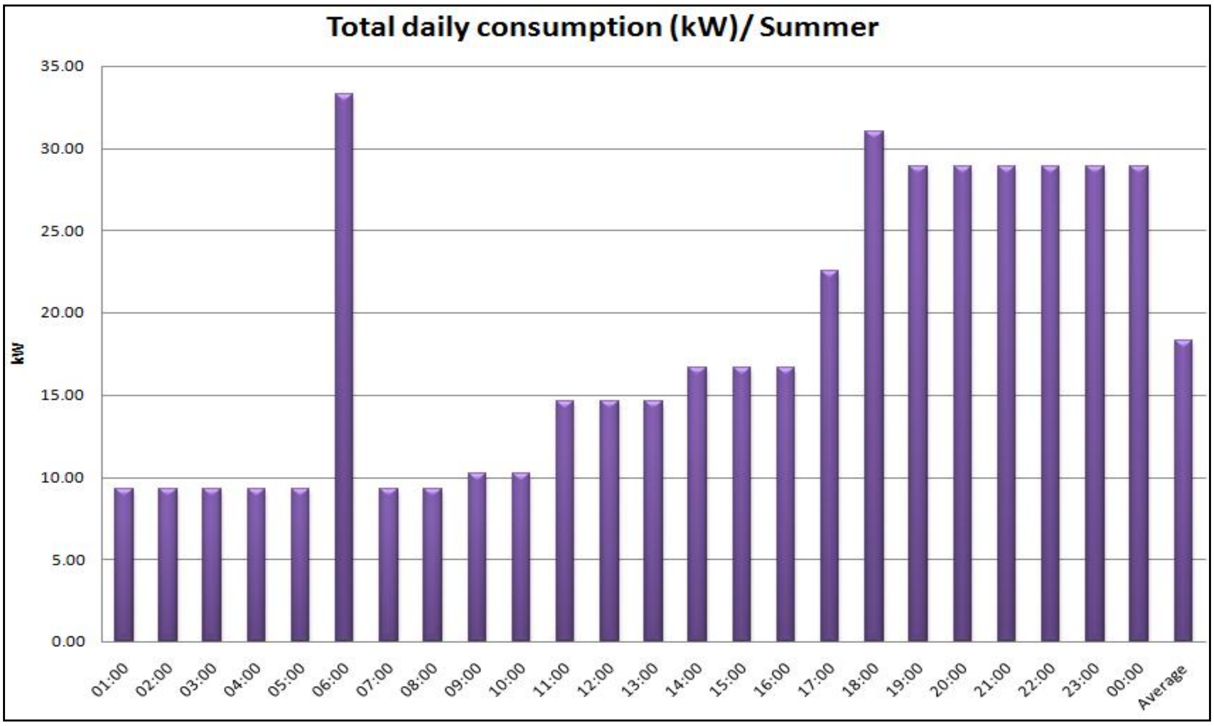


Figure 57 Electricity demand profile for Wasan / summer

The average consumption in summer is higher than the winter profile, because occupancy rate in Wasan for summer is more than in winter.

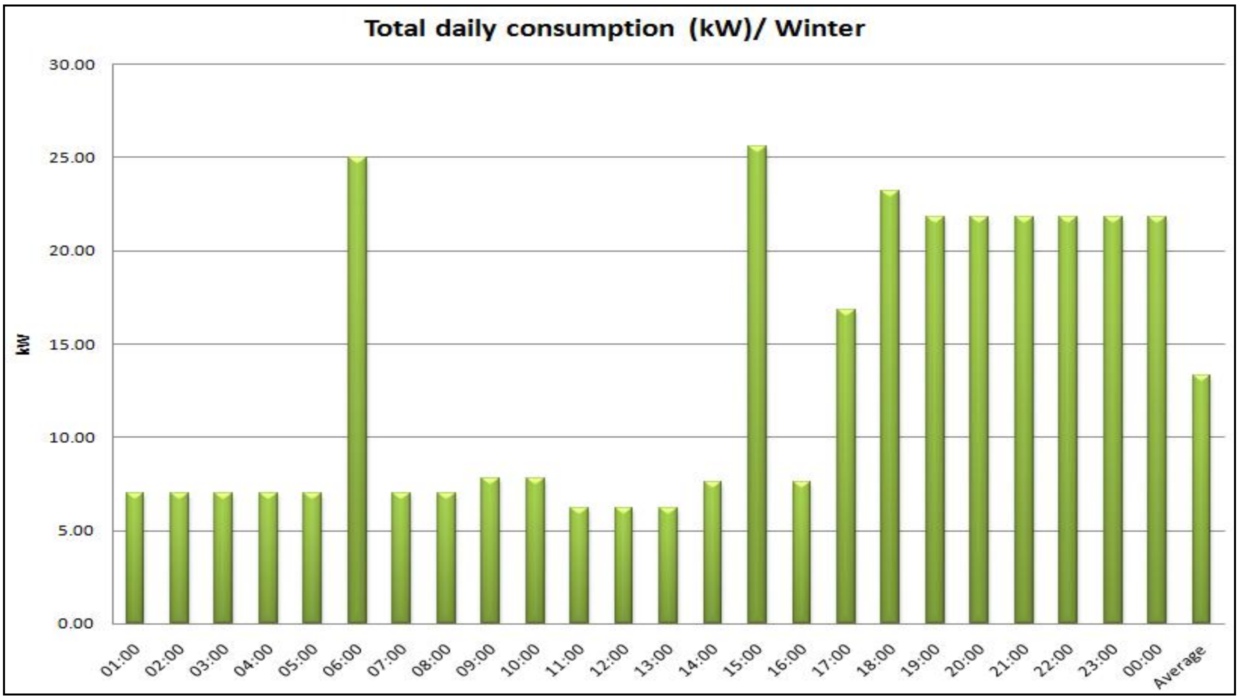


Figure 58 Electricity demand profile for Wasan / winter

The electricity demand for Wasan in summer fluctuates between 9.28 to 33.28 kWh with a daily average of 18.3 kWh and for winter is between 6.20 to 25.6 kWh with a daily average of 13.33 kWh.

5.7 Renewable Energy for Wasan: -

Wasan being located in a valley in a mountain area on a stream called Binari Qandil, the topographical specification of the region gives Wasan and other villages in the valley an opportunity to use the stream as a power producer. Furthermore the solar and the wind energy potential in this region are reasonably high. Hydropower is well established in the region, and damaged facilities will hopefully soon be repaired.

To bring the attention of other types of renewables in Kurdistan, solar and wind will be chosen for examination to supply Wasan with some of its power demand.

Wind energy in Wasan: - Wasan is located in a region where wind speed over 5m/s is available (see figure 47) for more than 5000 hours a year (nearly 60% of the time). The wind potential in the region could be used to produce electricity along with micro-hydropower.

Solar energy in Wasan: - The distribution of solar energy in Kurdistan is very uniform, therefore Wasan solar energy potential can be taken as Kurdistan average solar radiation 4.94 kWh/m^2/d with sunshine duration of 8.16 h/day (see table 15).

5.8 Before Simulation: -

To simplify the evaluation of the renewable energy project for Wasan, again the code HOMER [28] was used to carry out a simulation.

To run a simulation for a model consisting of wind turbine and solar PV panels, the listed information below is required: -

- Wasan profile of electrical demand
- Wind speed and solar radiation for the region
- Specification and cost of possible used wind turbine, solar PV panels and converter
- Specification and cost of the existing diesel generator, and
- Diesel price.

5.9 Components: -

To feed a fraction of electricity demands of Wasan with power from renewable sources we need: -

- wind turbines
- PV panels
- inverter
- 40 kW diesel generator which already has been installed in Wasan

Along with these components the price of diesel in the local market is required, at present it is 0.5 $/litre. Summer electricity demand profile was used in the simulation in order to cover the highest demand peak which takes place in summer.

5.10 Simulation: -

As is mentioned Wasan electricity demands are presently served by a 40 kW diesel generator, the profile of performance if the estimated summer load is met entirely by the generator is produced in figure (59).

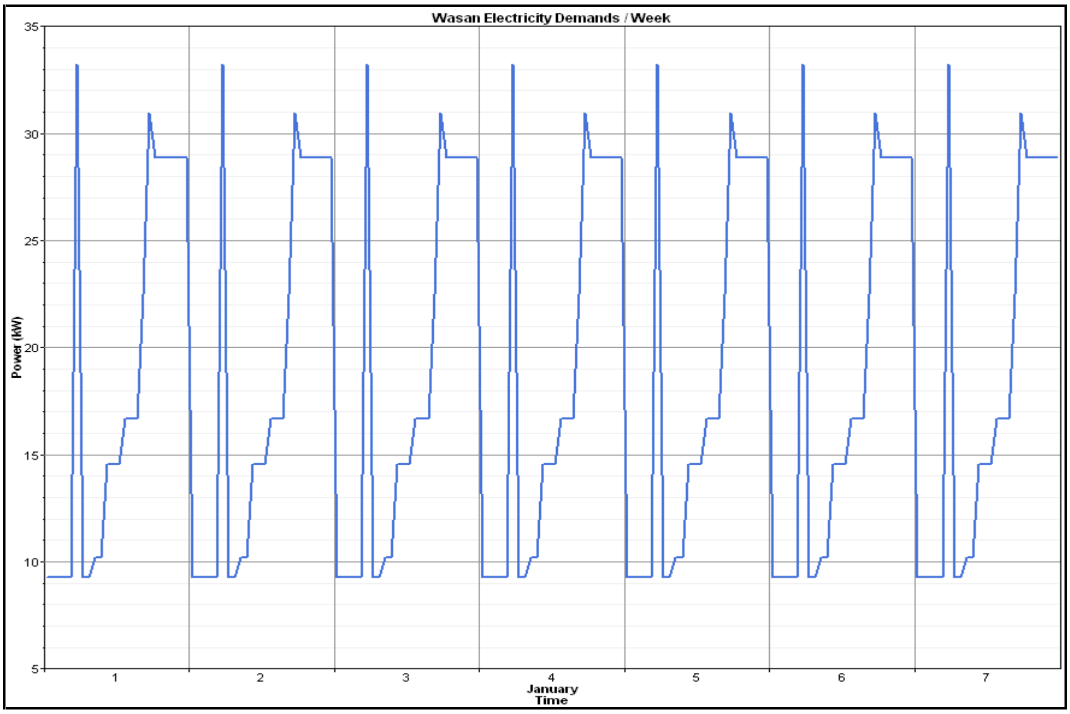


Figure 59 Electricity demands for Wasan

In order to find the proper system to provide Wasan with reliable electricity three scenarios have been chosen: -

Scenario 1

4 kW PV @ $ 19000

10 kW BWC Excel-S wind turbine @ $ 27900

40 kW diesel generators, and

3.2 kW converters @ $ 2900

The results of the simulation have two options. The first one presented in figure (60) included PV panels, wind turbine and generator. Over 20% of all energy produced was from renewables, but the renewable energy supplies less than 20% the demands because of over-production.

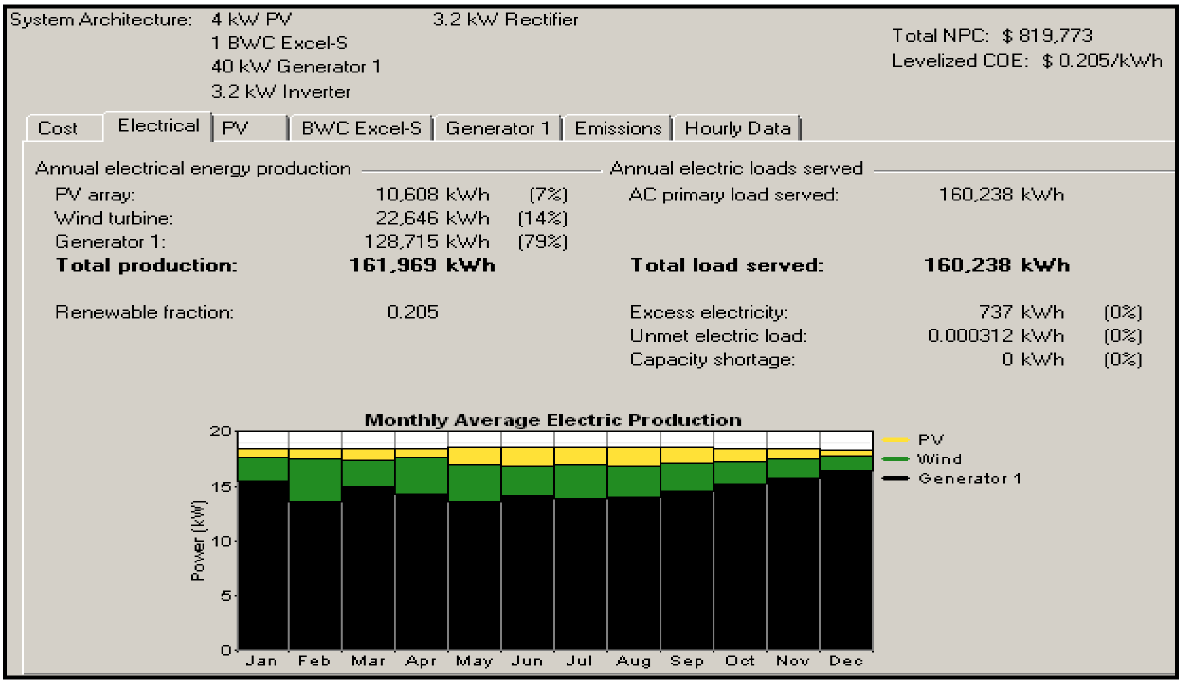


Figure 60 First option of the first scenario

The fraction of electricity demands which is met by renewable energy is shown in figure (61).

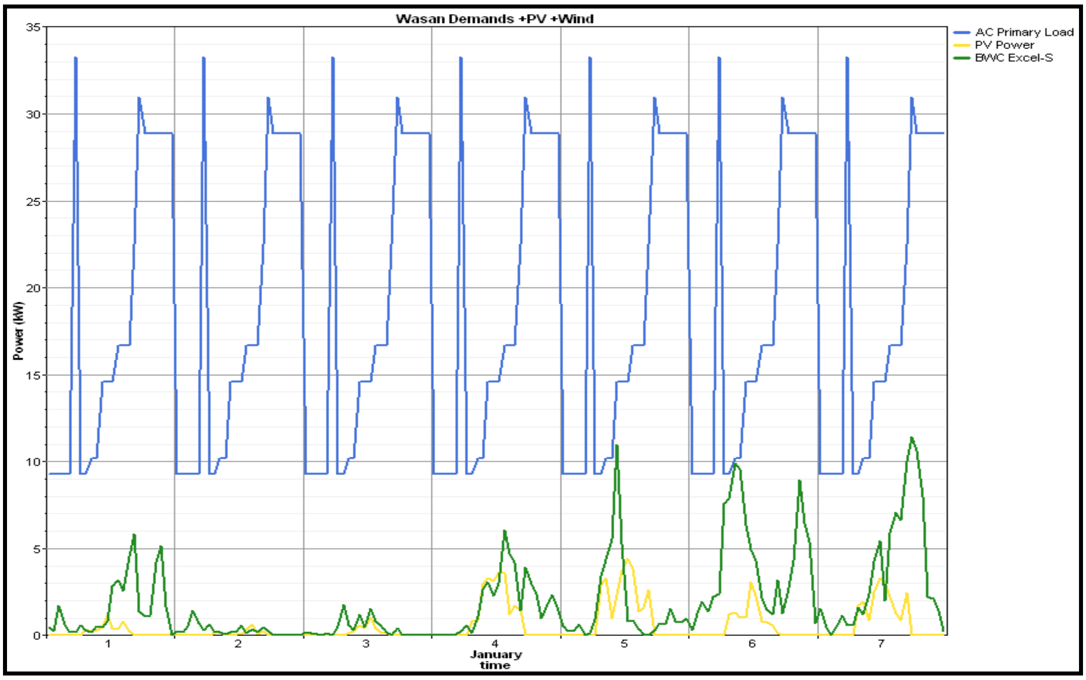


Figure 61 Renewable energy sharing / first scenario-first option

The gap between demands and production is clear, the energy produced from the generator will fill the gap, figure (62).

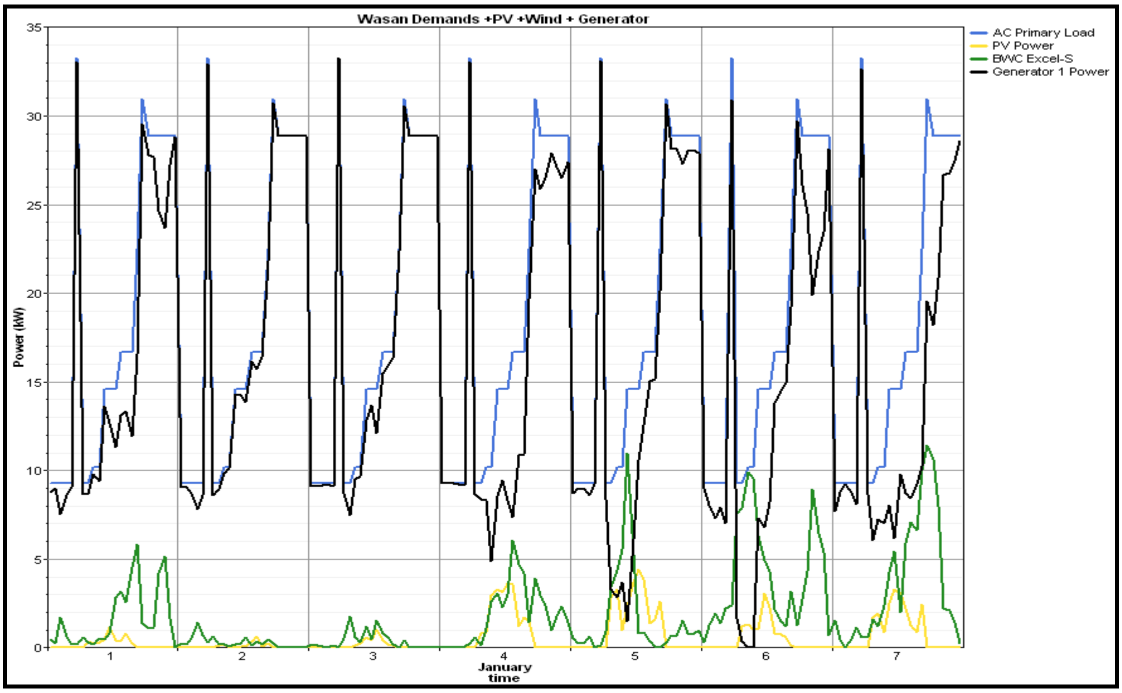


Figure 62 Demand and total supply / first scenario-first option

This option will reduce emission by 20.75 tonnes of carbon dioxide in a year.

Second option of the first Scenario is presented in figure (63). The contribution of renewable energy in this option is 14% of the all energy produced within the system. Also by the same ratio of the demand is supplied by renewables.

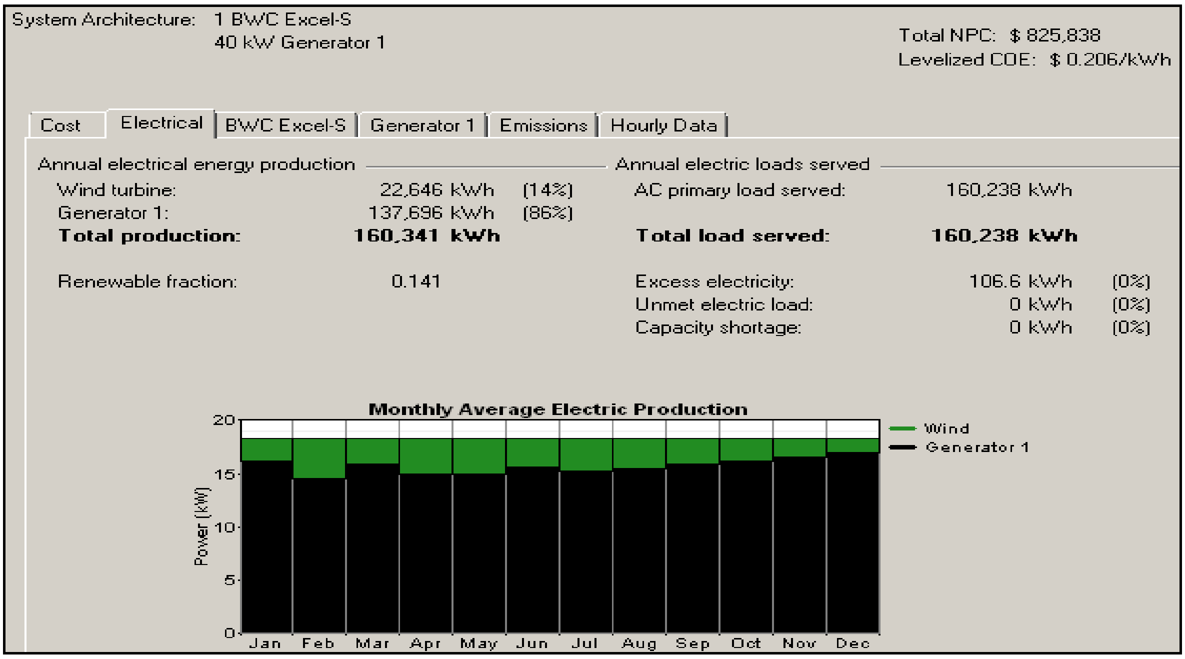


Figure 63 Second option of the first scenario

The demand profile and renewable energy produced from the system are presented in figure (64).

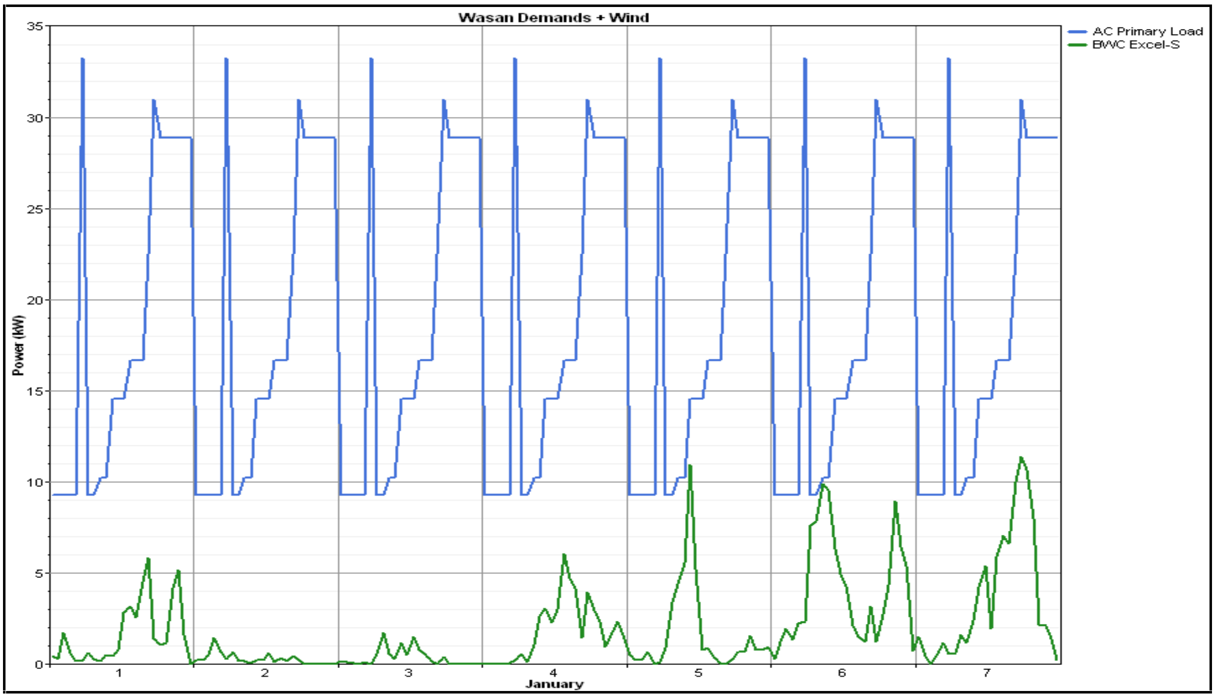


Figure 64 renewable energy sharing / first scenario-second option

The demand profile and the total energy supply are presented in figure (65).

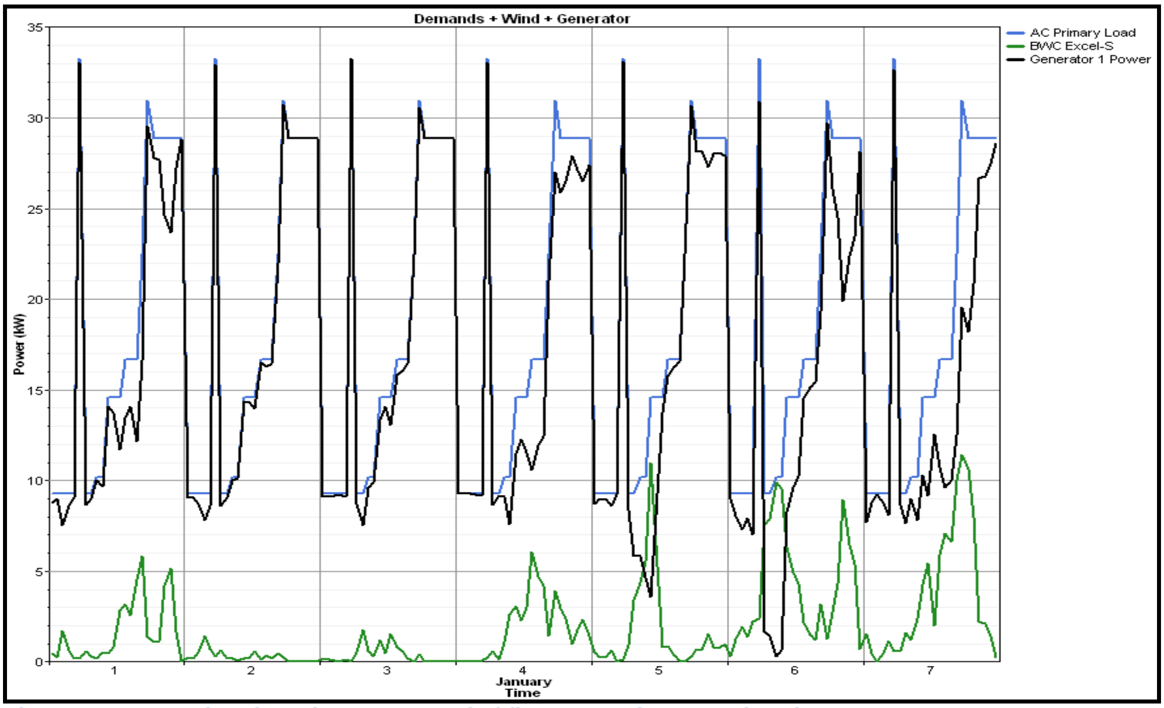


Figure 65 Demand and total energy supply / first scenario-second option

This option will reduce emission by nearly 15 tonnes of carbon dioxide in year.

Second scenario

8 kW PV @ $ 38000

20 kW wind turbine @ $35000

40 kW Generator, and

5.1 kW converter @ $3600

The first option of the second scenario is illustrated in figure (66). Over 42% of the total energy produced was from renewable energy. At the same time this system has 13618 kWh/y excess of energy production. The percentage of renewable energy that supplies the demands is 37%.

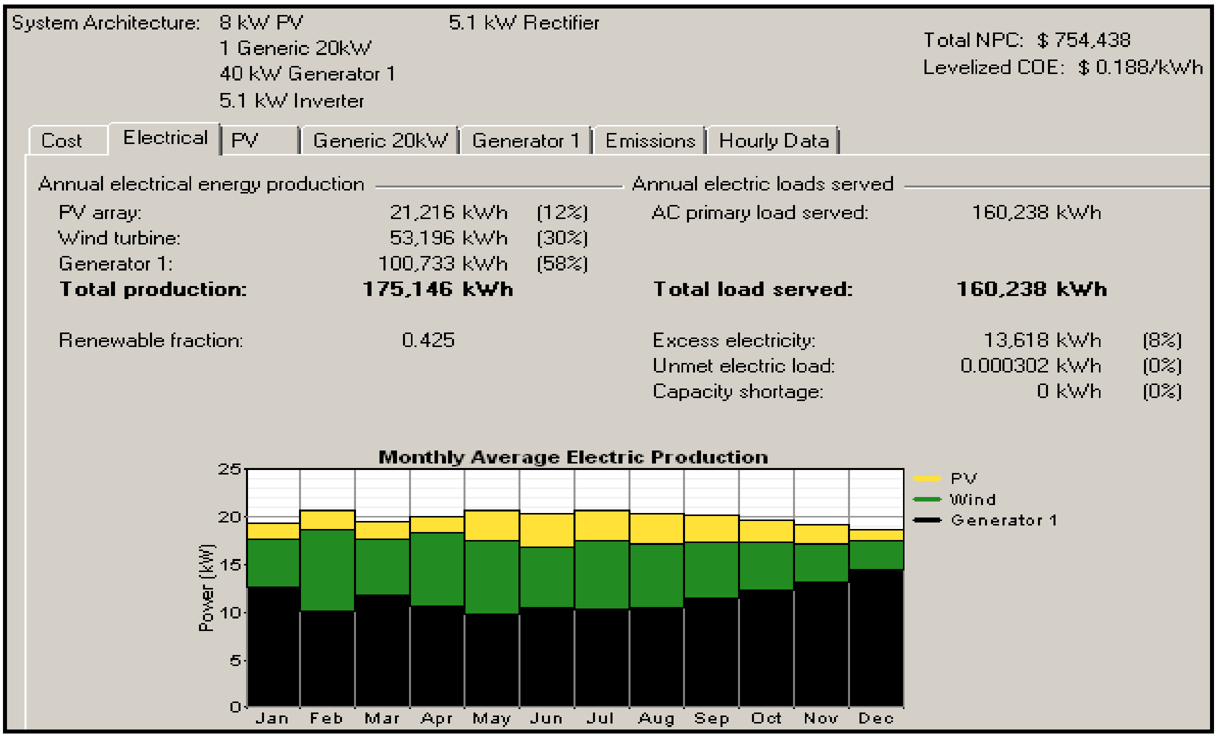


Figure 66 First option of second scenario

The demand profile and renewable energy produced from the system are presented in figure (67).

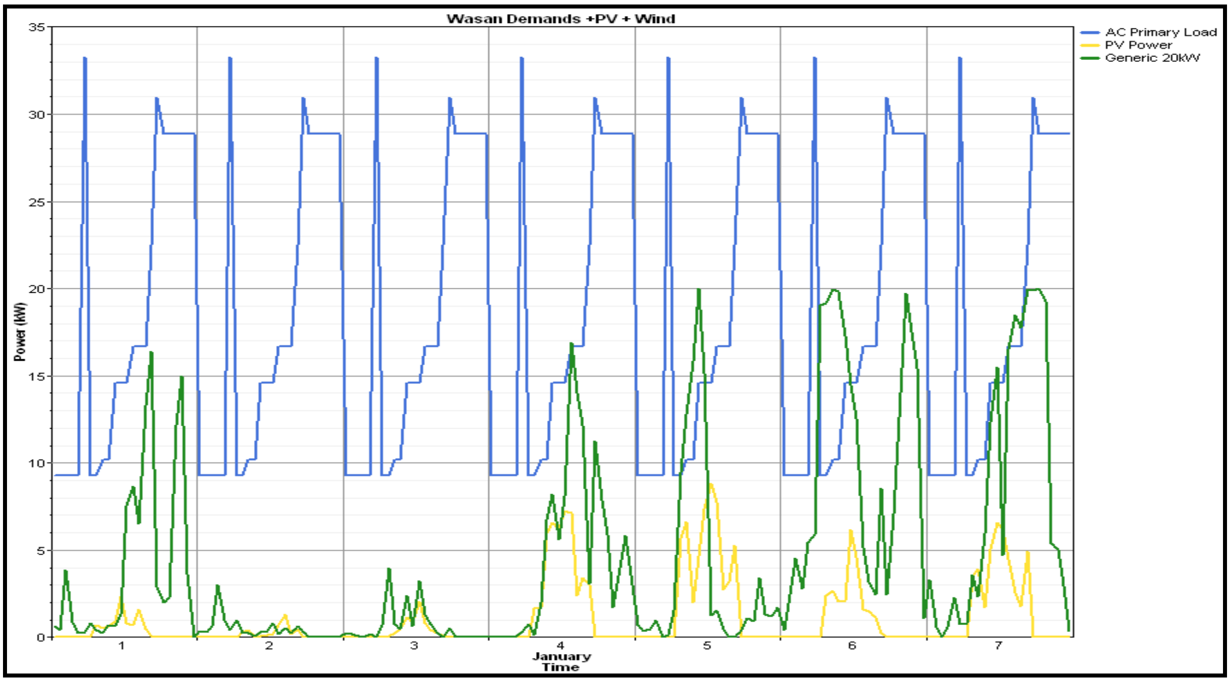


Figure 67 Renewable energy input / second scenario-first option

The demand profile and the total energy supply are presented in figure (68).

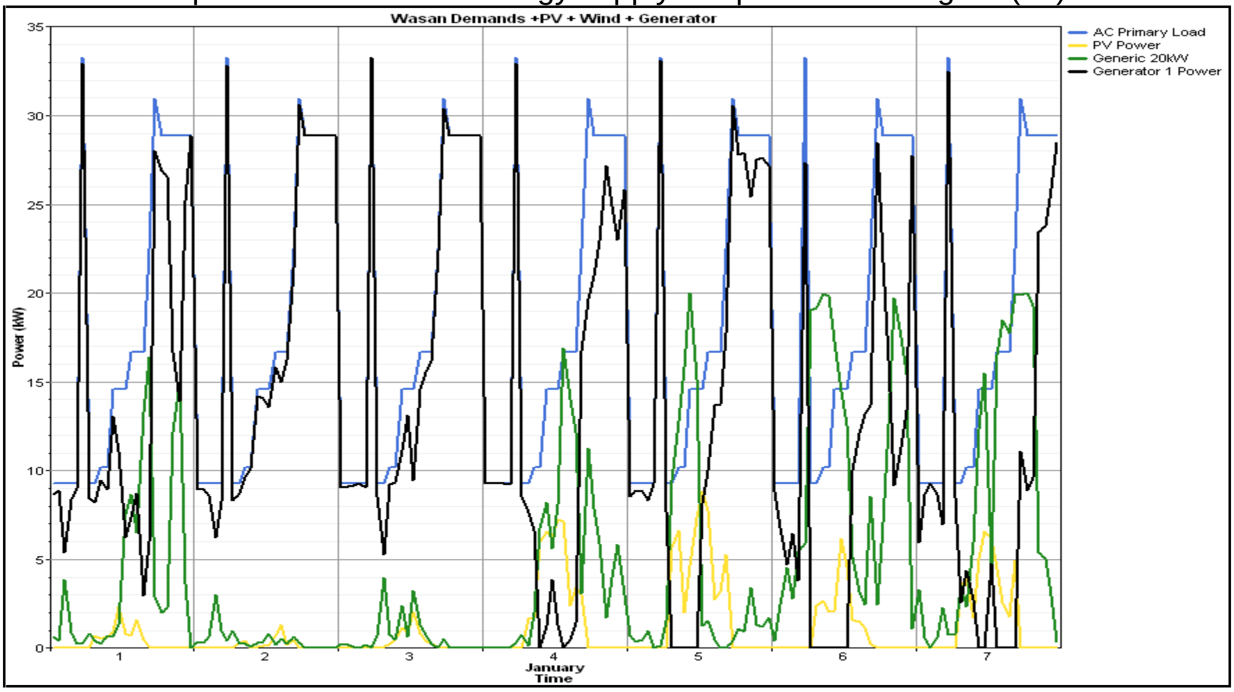


Figure 68 Demand and total energy supply / second scenario-first option

This option will reduce carbon dioxide emission by 41 tonnes a year.

The second option of the second scenario is presented in figure (69). The renewable energy in this option makes more 32% of the total energy produced.

Also there is 5333 kWh/y excess of energy. Nearly 30% of the demands are covered by renewable energy.

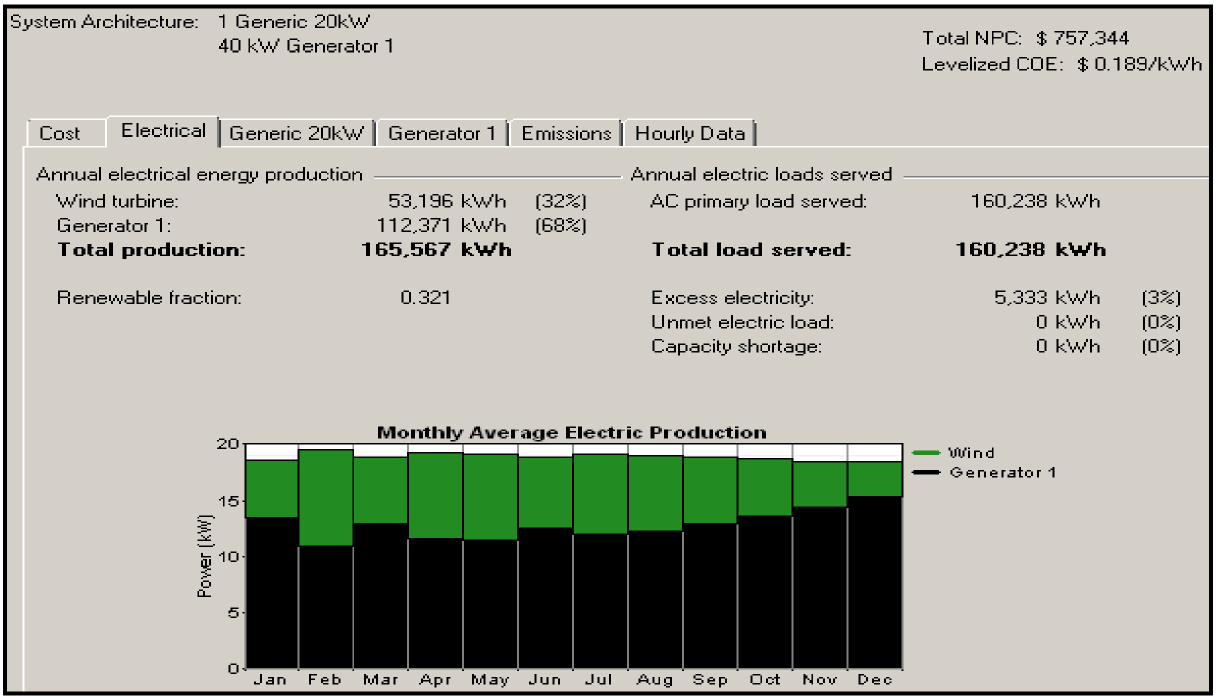


Figure 69 Second option of second scenario

The demand profile and renewable energy produced from the system are presented in figure (70).

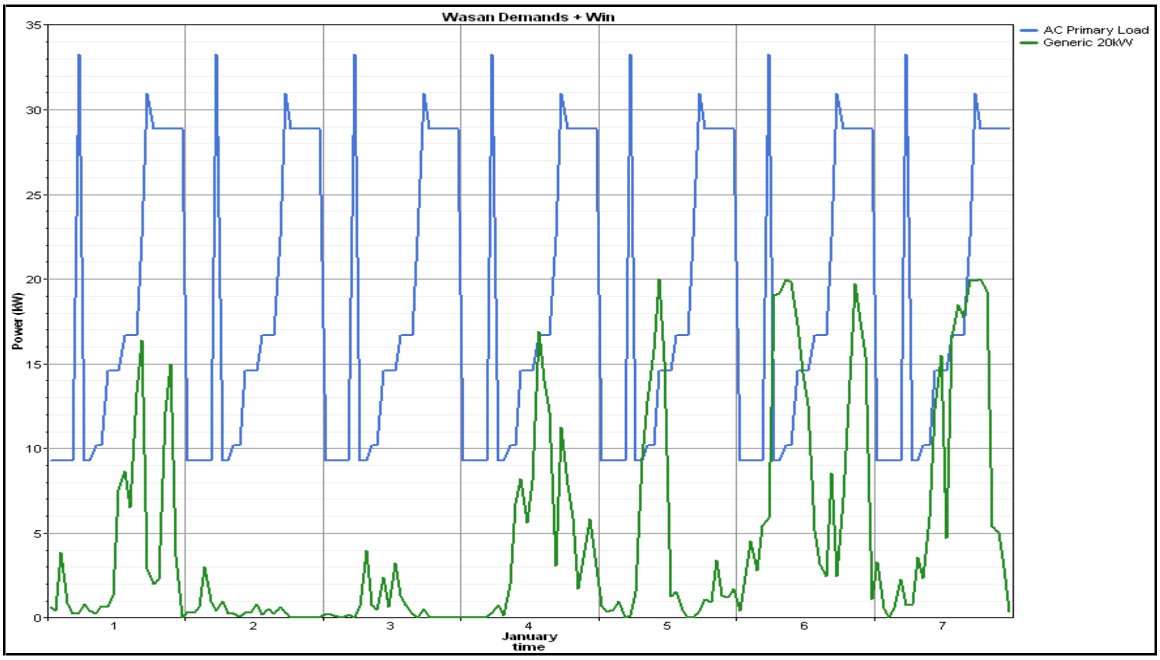


Figure 70 renewable energy input / second scenario-second option

The demand profile and the total energy supply are presented in figure (71).

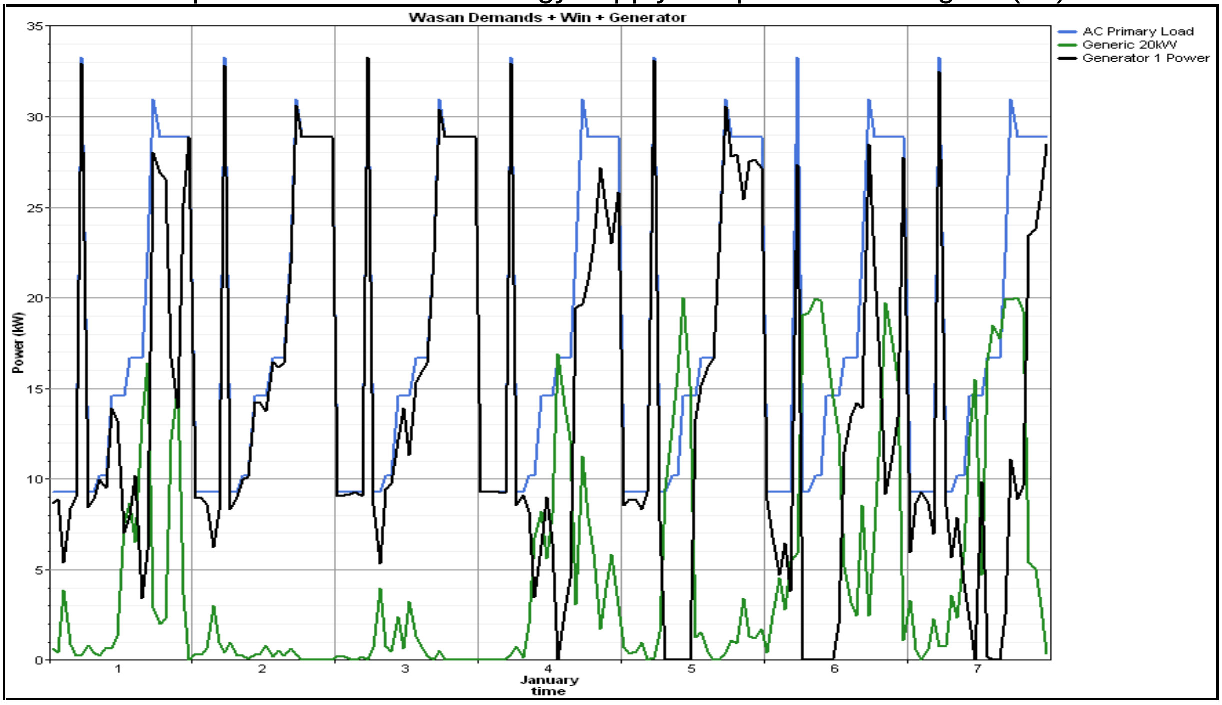


Figure 71 Demand and total energy supply / second scenario-second option

This option will reduce carbon dioxide emission by 32 tonnes a year.

Third scenario: - includes the following components:
2x20 kW generic win turbine @ $7000

4 kW PV @ $19000

40 kW Generator, and

3.2 kW converter @ $2900

The second option of the second scenario is presented in figure (72). The renewable energy in this option makes more 58% of the total energy produced. Also there is 40582 kWh/y excess of energy. More than 47% of the demands are covered by renewable energy.

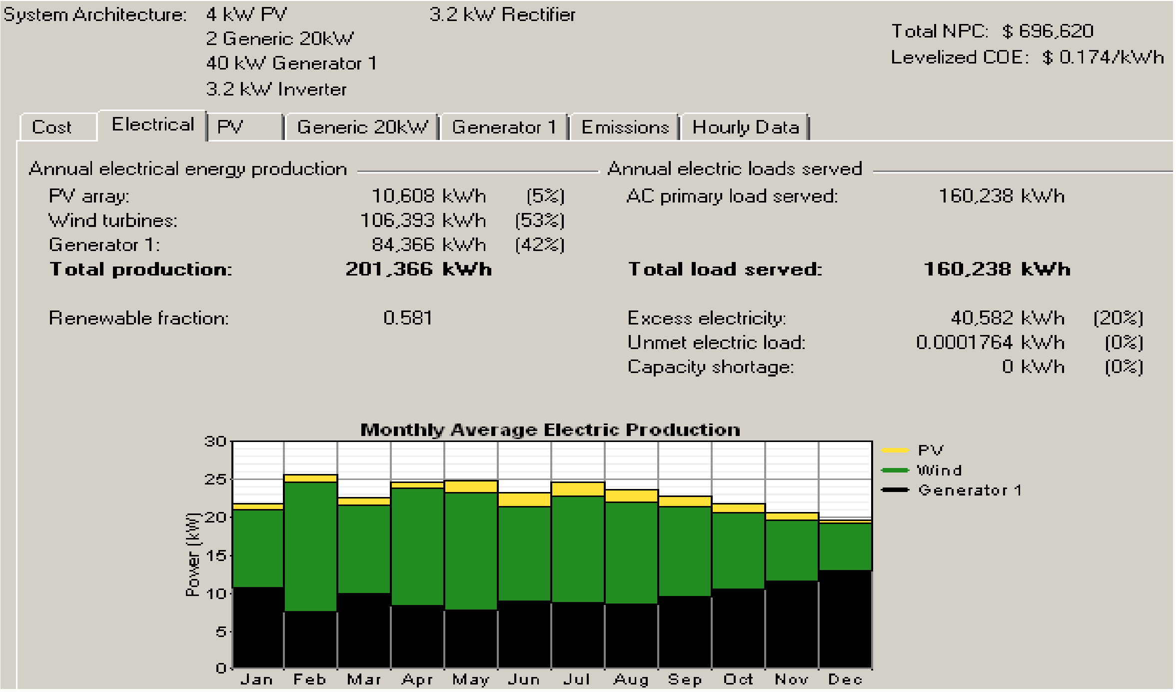


Figure 72 First option of the third scenario

In figure (73) the combination of energy demand and energy supply by renewable energy sources has been presented.

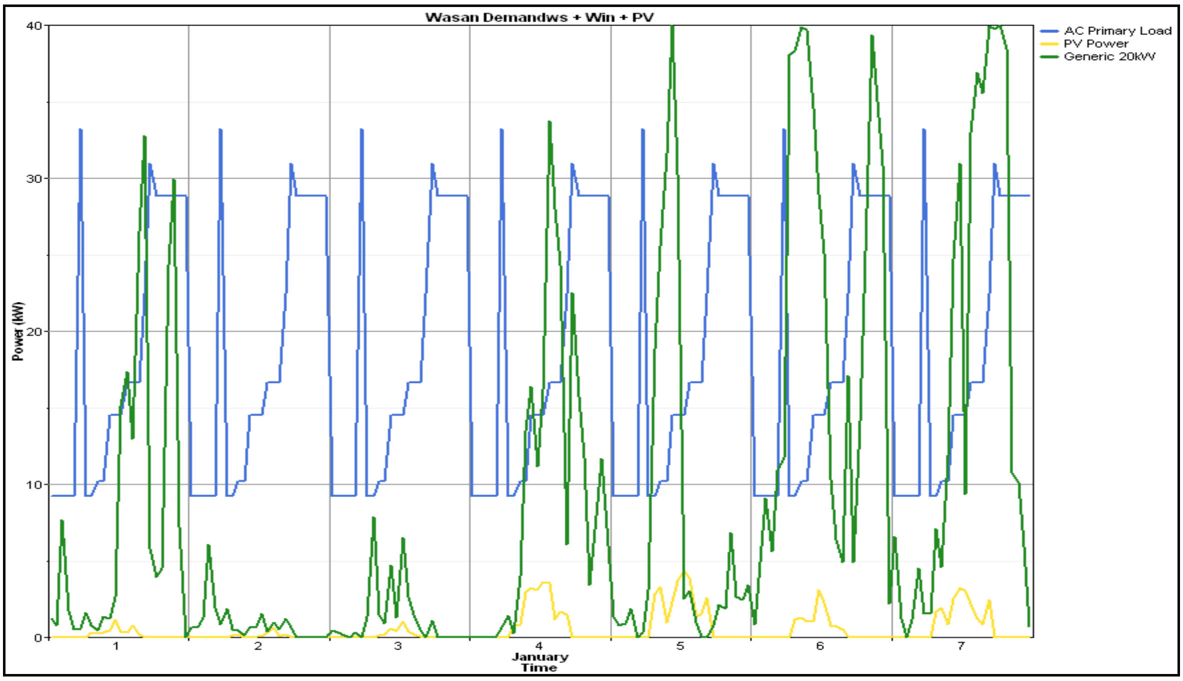


Figure 73 Renewable energy input / third scenario-first option

Figure (74) shows energy demands and total supply.

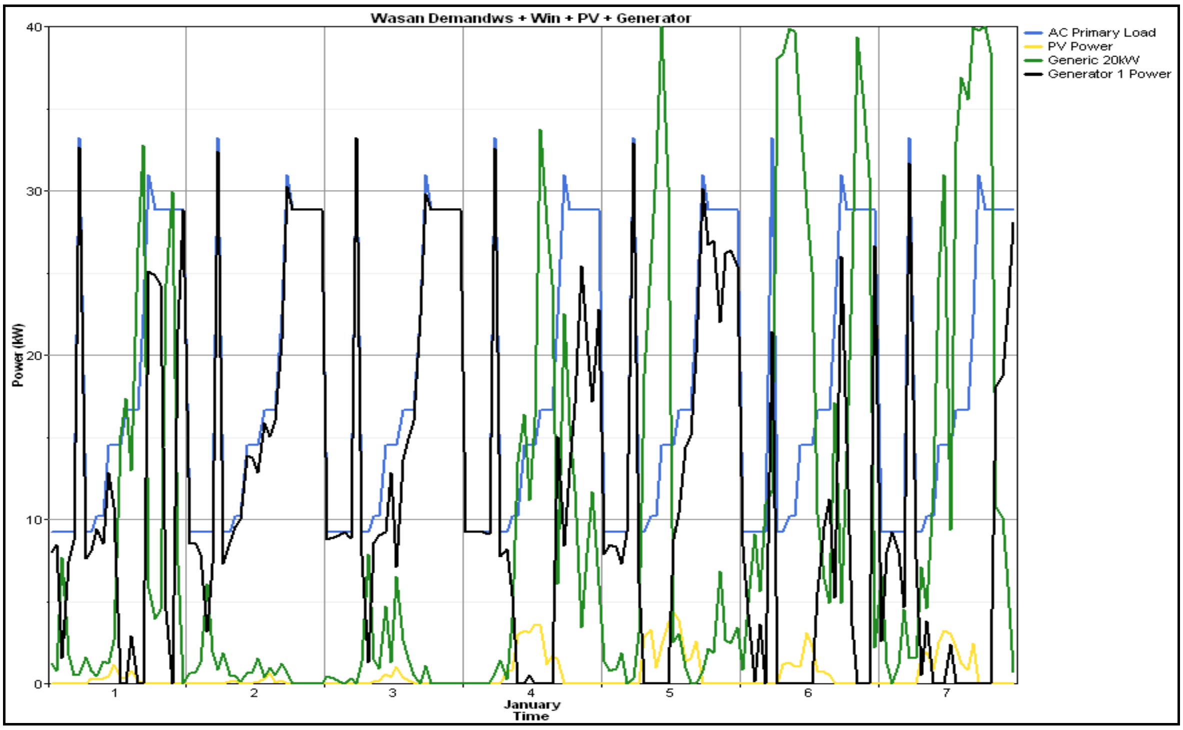


Figure 74 Demand and total energy supply / third scenario-first option

This option reduces carbon dioxide by 60 tonnes a year.

In the second option of the third scenario presented in figure (75) which includes wind turbine and diesel generator, renewable energy represents over 54% of the total energy produced. But only 44% of demands are supplied by renewable energy.

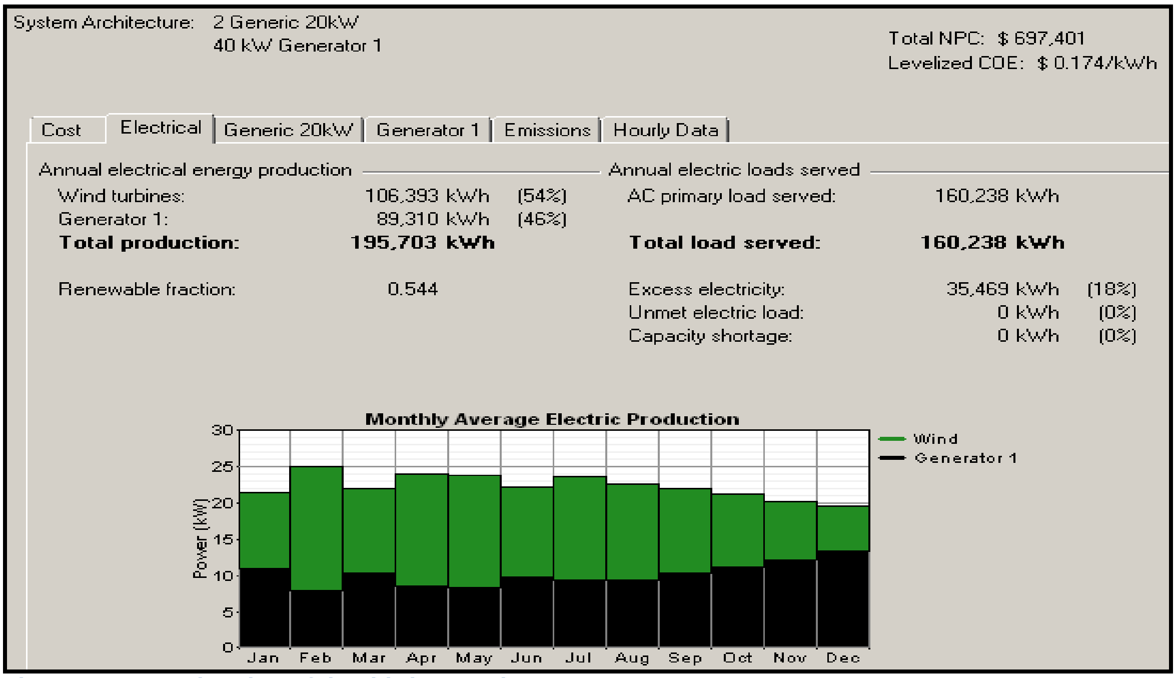


Figure 75 Second option of the third scenario

Figure (76) shows the demands and the renewable energy supply.

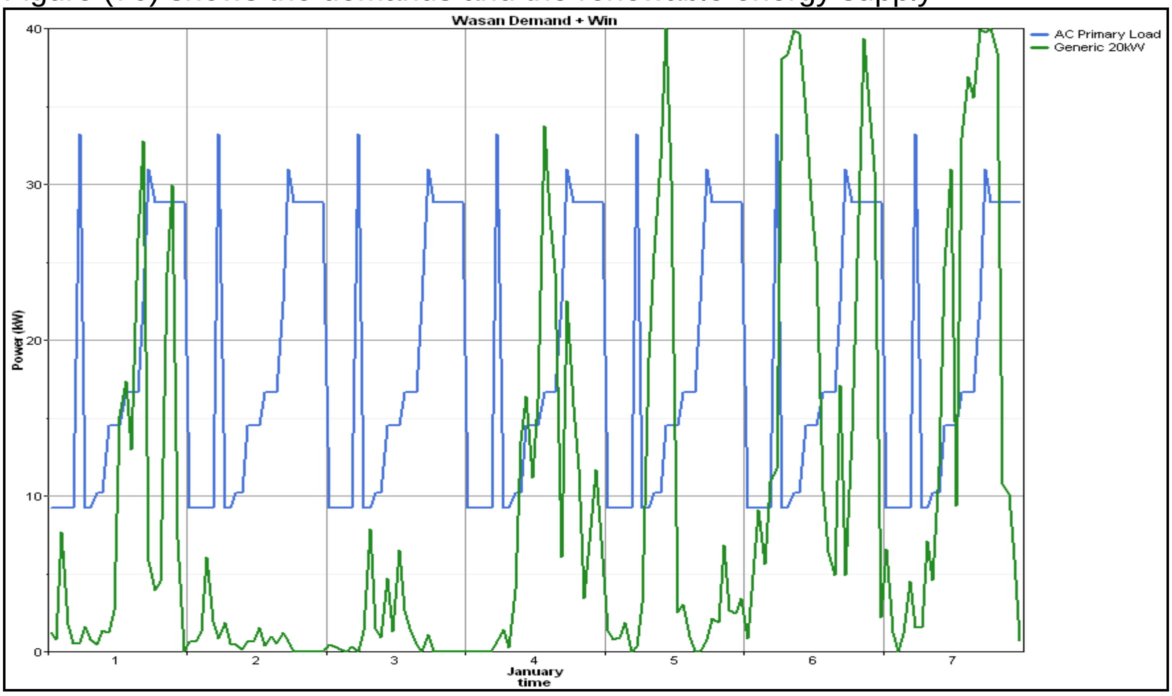


Figure 76 Demands and renewable energy input / third scenario-second option

Figure (77) presents the demands and total supply of energy.

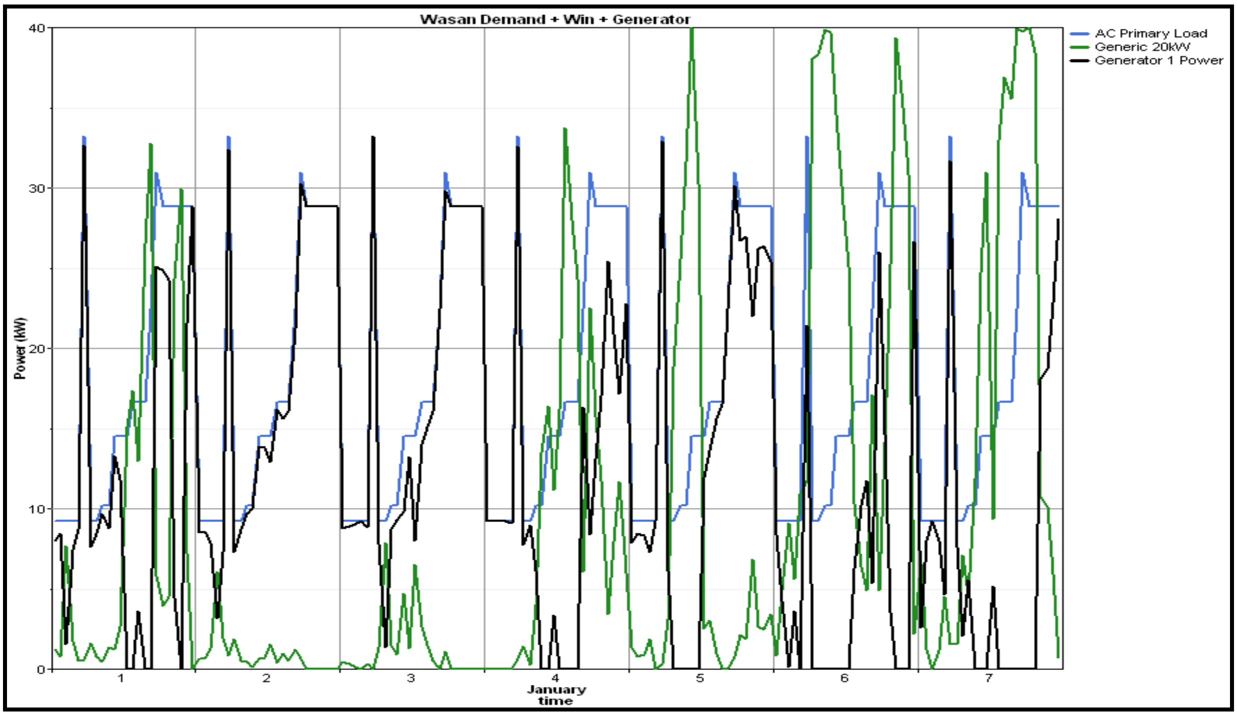


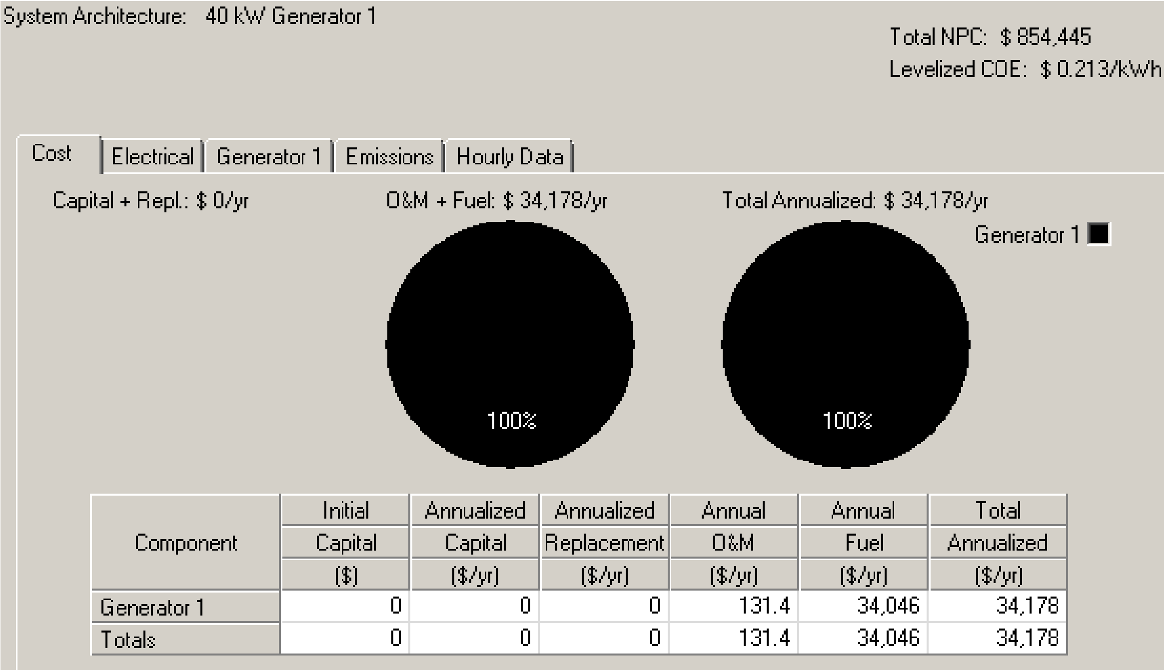
Figure 77 Demand and total energy supply / third scenario-second option

This option reduces carbon dioxide by 55 tonnes a year.

5.11 Cost analysis: -

To be able to compare the cost of electricity in each scenario there should be a reference line. A system including diesel generator only can be taken as a base and the three scenarios will be compared with this.

Figure (78) shows a system which includes only a diesel generator. This is generator already installed in Wasan therefore the capital cost is zero. The other expenses come from operating, maintenance and fuel cost. The annual cost of energy production for the simulated Wasan demand is $ 34178 or $0.213/kWh and produces 180 tonnes of carbon dioxide a year.



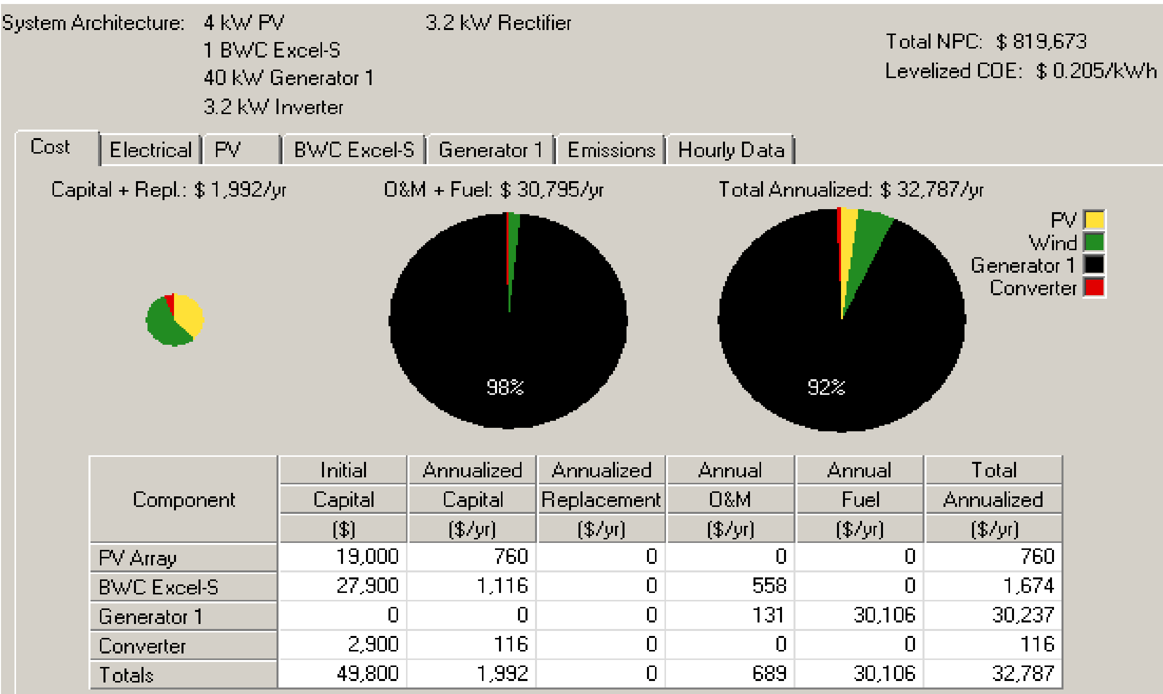
Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
Generator 1	0	0	0	131.4	34,046	34,178
Totals	0	0	0	131.4	34,046	34,178

Figure 78 Cost of diesel generator system

Scenario 1

First option costs are presented in figure (79), the capital cost is $ 49800 and

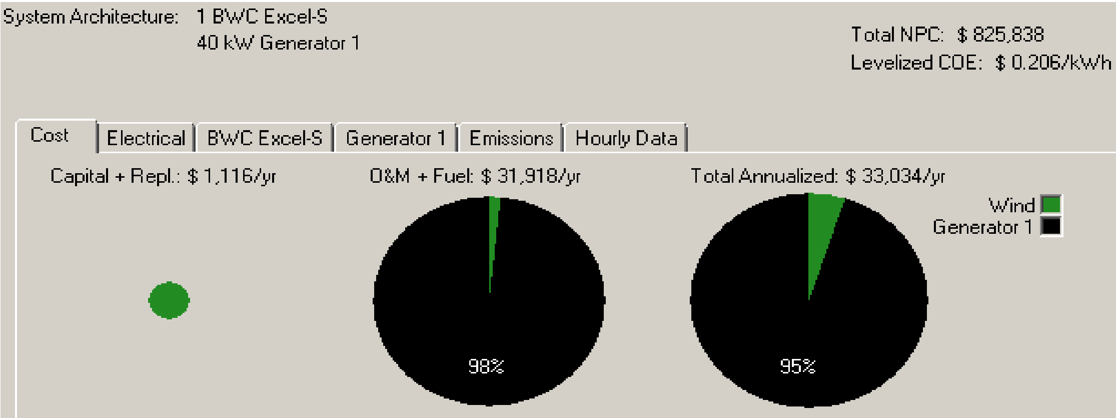
the annual energy cost is $ 32787 to produce 161969 kWh/y or 0.205 $/kWh.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
PV Array	19,000	760	0	0	0	760
BWC Excel-S	27,900	1,116	0	558	0	1,674
Generator 1	0	0	0	131	30,106	30,237
Converter	2,900	116	0	0	0	116
Totals	49,800	1,992	0	689	30,106	32,787

Figure 79 Cost of the first option of the first scenario

Figure (80) shows the cost of the second option of the first scenario, the annual cost is $ 33034 to produce 160341 kWh/y or 0.206 $/kWh.

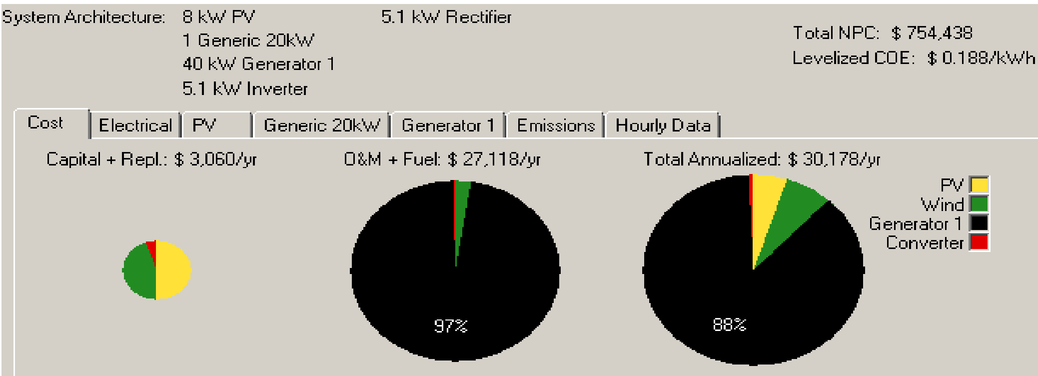


Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
BWC Excel-S	27,900	1,116	0	558	0	1,674
Generator 1	0	0	0	131	31,228	31,360
Totals	27,900	1,116	0	689	31,228	33,034

Figure 80 Cost of the second option of the first scenario

Scenario 2

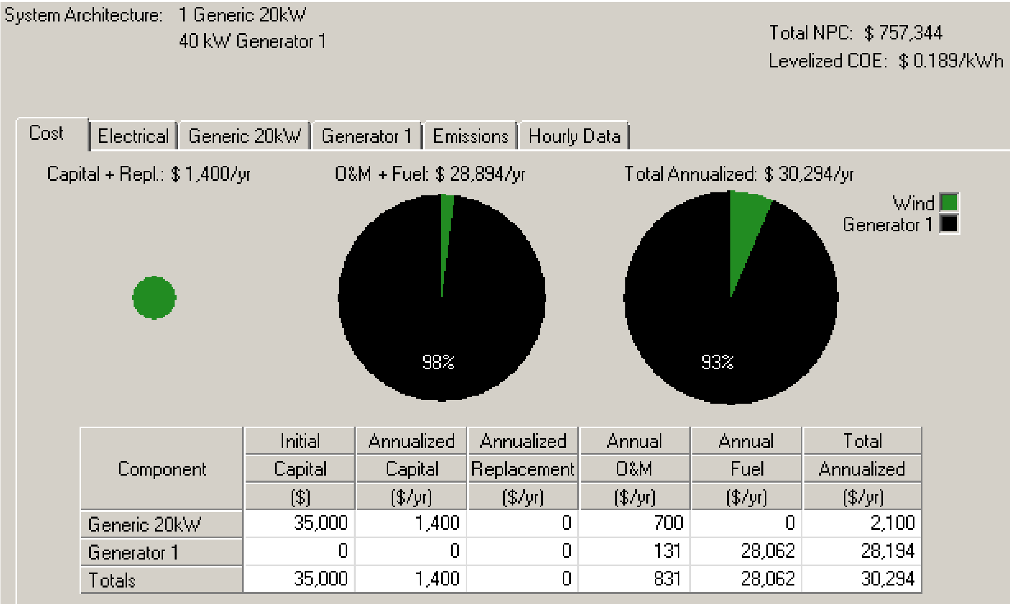
First option cost is presented in figure (81), the capital cost is $ 76500 and the annual energy cost is $ 30178 to produce 175146 kWh/y or 0.188 $/ kWh.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
PV Array	38,000	1,520	0	0	0	1,520
Generic 20kW	35,000	1,400	0	700	0	2,100
Generator 1	0	0	0	128	26,289	26,418
Converter	3,500	140	0	0	0	140
Totals	76,500	3,060	0	828	26,289	30,178

Figure 81 Cost of the first option of the second scenario

Figure (82) shows the cost of the second option of the second scenario. The annual cost is $ 30294 to produce 165567 kWh/y or 0.189 $/ kWh.

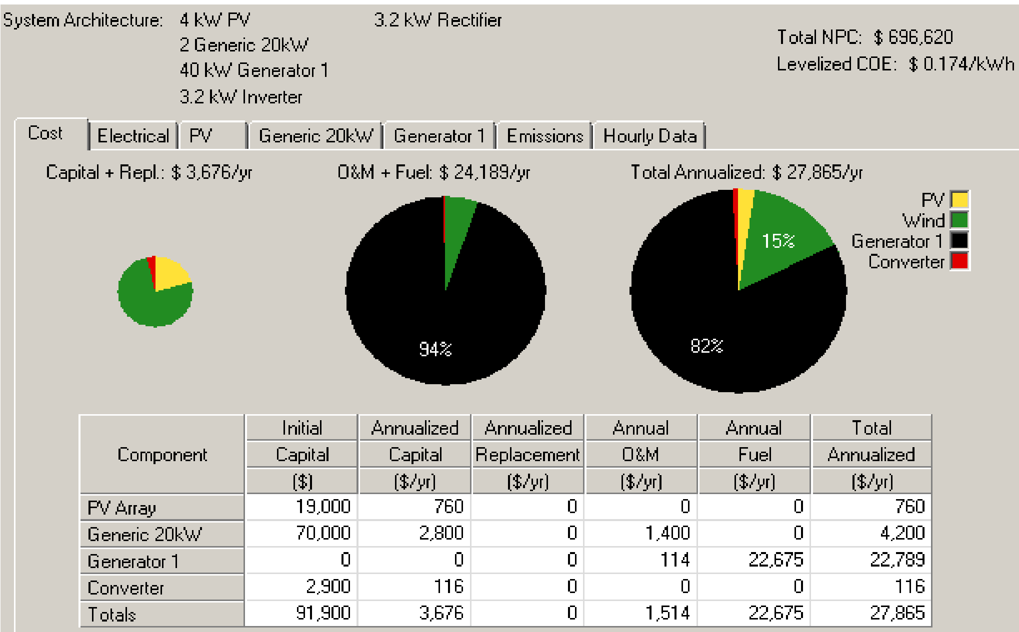


Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
Generic 20kW	35,000	1,400	0	700	0	2,100
Generator 1	0	0	0	131	28,062	28,194
Totals	35,000	1,400	0	831	28,062	30,294

Figure 82 Cost of the second option of the second scenario

Scenario 3

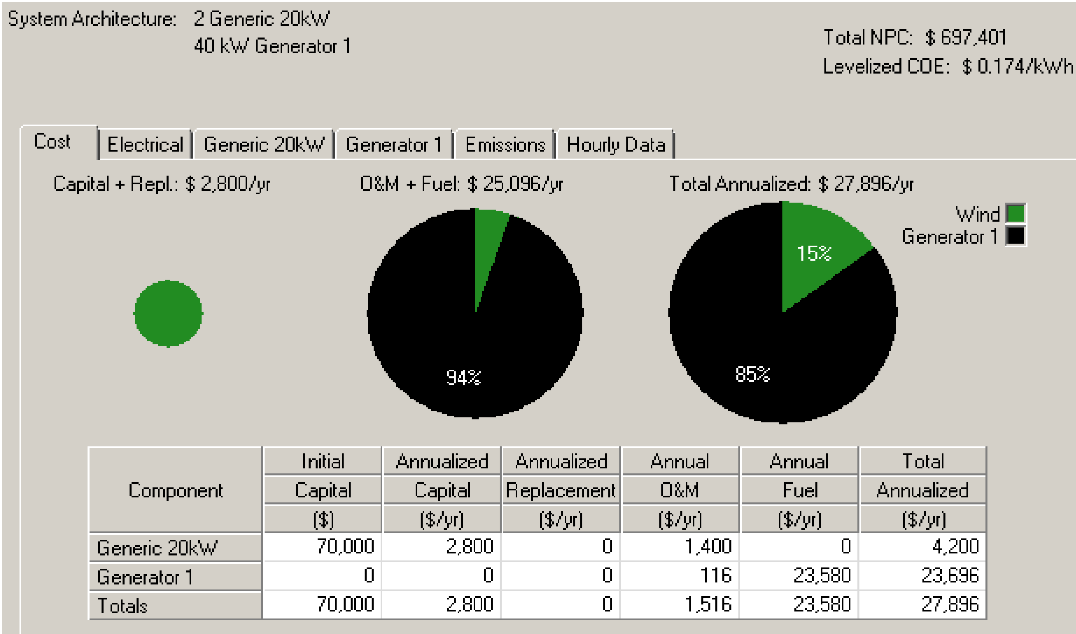
The first option cost is presented in figure (83), the capital cost is $ 91900 and the annual energy cost is $ 27865 to produce 201366 kW/h/y or 0.174 $/ kWh.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
PV Array	19,000	760	0	0	0	760
Generic 20kW	70,000	2,800	0	1,400	0	4,200
Generator 1	0	0	0	114	22,675	22,789
Converter	2,900	116	0	0	0	116
Totals	91,900	3,676	0	1,514	22,675	27,865

Figure 83 Cost of the first option of the third scenario

Figure (84) shows the cost of the second option of the third scenario, the annual cost is $ 27896 to produce 195703 kWh/y or 0.174 $/ kWh.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
Generic 20kW	70,000	2,800	0	1,400	0	4,200
Generator 1	0	0	0	116	23,580	23,696
Totals	70,000	2,800	0	1,516	23,580	27,896

Figure 84 Cost of the second option of the third scenario

5.12 Discussion: -

The cost of energy produced by the diesel generator is 0.213 $ /kWh (see figure 78). At present the diesel price in Kurdistan is 0.5 $/l which is very cheap. But there is no guarantee that it will be kept at the same level in future, because fuel markets in Kurdistan (as in the rest of the world) fluctuate depending on political and security status, in this case in the middle and south regions of Iraq where the petroleum refineries exist. Solar and wind energy have chosen to examine in this case study to draw attention to sources of renewable energy which have not previously been considered in the region.

Before discussing the results of the proposed scenarios it is useful to know that the minimum price of each kW of wind turbine (rated at 20 kW) is $ 1750, and the minimum price of 1 kW of solar PV is $ 4750. The solar PV price is 2.7 times the price per kW of the wind turbine.

The components used in the scenarios have been chosen on the basis of Wasan's demand profile and the need to keep the capital cost as low as possible. All examined systems have produced different amounts of excess energy from the renewable energy components. Unfortunately most of the time this energy production occurred when the demands were at the lowest point, therefore it is not useful energy (See figures 61, 64, 67, 70, 73 and 76) unless if there is an energy storage facility like batteries. The electricity could of course be used to produce hot water if there is a demand for it. The calculated energy price by HOMER at first considered that all energy produced in the system will be consumed. Therefore the energy prices should be reviewed considering that the excess energy is lost energy. This will affect the final price of each unit of energy. Table (18) summarizes the price changes for all options.

	Scenario 1		**Scenario 2**		**Scenario 3**	
	Option 1	Option 2	Option 1	Option 2	Option 1	Option 2
Demands (kWh/y)	160238	160238	160238	160238	160238	160238
Annual energy production (kWh/y)	161969	160341	175146	165567	201366	195703
R.E. Percentage	20.50%	14.10%	42.50%	32.10%	58.10%	54.40%
Excess energy (kWh/y)	737	106.6	13618	5333	40582	35469
Used R.E. For Demands	31523	22542	59505	47867	75872	70928
% of R.E used by demands	19.60%	14%	37%	30%	47%	44%
Prices of generated energy ($/ kWh)	0.205	0.206	0.188	0.189	0.174	0.174
Prices of used energy ($/ kWh)	0.206	0.206	0.204	0.195	0.218	0.212

Table 18 Summary of the all options

In all options considered, the cost of fuel, maintenance and operating the generator makes 82% to 95% of the energy price (see figures 79, 80, 81, 82, 83 and 84). Table (18) shows two particularly interesting options which are: -

- Option 2 of the second scenario shows best performance regarding the cost (0.195 $/kWh). The components of this option include 40 kW diesel generator and 20 kW wind turbine. The cost of fuel, maintenance and operating of the generator makes 93% of total cost. Renewable energy can meet 30% of the demands.

- Option 1 of the third scenario in which renewable energy has the highest contribution to the demand (47%). The components of this option involve the 40 kW diesel generator, 2 x 20 kW wind turbines, 4 kW solar PV panels and 3.2 kW converter. The cost of fuel, maintenance and operating the diesel generator makes 82% of the total cost. The price of each energy unit is $ 0.218.

Option 1 of the third scenario is the least dependent on diesel fuel and produces 47% of demands from renewable energy. This option is the best that could be built in Wasan, given the present lack of diesel fuel which means the existing generator in Wasan cannot be operated for more than six hour a day. It should increase the amount of energy which can be supplied in Wasan, although supply may not always coincide with demand. But it does incur the highest costs per kWh.

5.13 Conclusions: -

The system that has been recommended for Wasan (option 1 of the third scenario) comprises of only 4 kW of PV energy which helps to build a multi energy source and also it could helps to reduce the intermittency of producing energy. The high costs of solar PV panels make large-scale use of this technology unattractive at present. Without storage, it is of course unable to supply power at night when much of the demand occurs. However, it is worth considering cheaper types of technology to exploit the abundant available solar energy in Wasan. This could be the use of solar panel collectors for hot water which may decrease the use of wood and other types of fuel.

Wind energy could clearly play significant role in power production in rural areas such as Wasan. But it is important to realise that it is fundamentally unreliable. The choice of wind turbine capacity in relation to the demand profile is not a simple one. Consumer behaviour and the possibility of load management are an important factor here, expanding the potential contribution from wind energy.

In the case of Wasan, the presence of a diesel generator should ensure that essential needs can be met at all times. Output from the wind turbines and PV panels should be used whenever possible, to allow diesel fuel to be saved. However, over capacity for the wind turbines and PV panels should be avoided, unless there is an opportunity to make profitable use of the excess power.

Chapter 6

6.1 Discussion: -

During the last two chapters calculations and analysis have been carried out to investigate renewable energy in Kurdistan region. The results of the investigations confirm that Kurdistan region has a massive potential for using hydropower, wind energy, solar energy and biomass. A serious attempt at establishing the foundation of a sustainable energy supply certainly needs more research and a great deal of commitment if the region is eventually to be self sufficient in energy production.

Lack of specialist centres or associations in the energy sector in Kurdistan is responsible for shortages of data that can be used in energy and renewable energy researches. To overcome this difficulty the recorded climate data from Agro-meteorological stations been used in this study. This may cause some uncertainty because of the limited range of data available. There has also been the need to classify and reprocess the data especially in the wind energy estimation.

As was indicated in the study Kurdistan region suffered from a long period of energy shortage and this led to the breakdown of the system of collecting electricity revenue, which would normally be considered one of the main sources of income that keeps the power system in Kurdistan (generation, transmission and distribution) able to serve the consumers.

The consequences of this crisis were that much of the system fell into disrepair. Also, there developed a social behaviour among consumers of using the electricity during the short time of its availability in a careless way to recompense the very long time of its absence.

Therefore reconstruction most be carried out in both sides of supply and demand, by installing necessary power stations (renewable or conventional) and by encouraging people to consume energy sustainably and take responsibility to preserve precious resources as a national wealth.

The power generation sector in Kurdistan has a great opportunity to be reconstructed again as a clean and sustainable system by exploiting the huge potential of renewable energy in the region.

At present the authorities in Kurdistan region implement an emergency plan to construct a number of power stations to fill the energy shortage in the region. As revealed in chapter 3 none of these stations use renewable sources.

Fortunately there is a long-range plan for future to develop of more than 80 hydropower schemes which have promising characteristics. If followed through, this will exploit as much as possible the hydropower potential of the region.

Unfortunately there is no interest at present in wind and solar energy in Kurdistan region, probably this is because these types of renewable energy are relatively new and need more time to be investigated. As was established in chapter 4 Kurdistan is blessed with reasonable potential for wind and solar energy. This study found that the area around Chamchamal has a very good wind energy resource. Only 120 km² of land in Chamchamal (5% of the total area of Chamchamal which is about 3000 km²) if used to build a series wind farms comprising 650X 1.8 MW wind turbines. Assuming a 30% capacity factor (a reasonable figure given the high quality of the wind resource in the region), these will produce more than 3000 MWh/y which is 25% of the present demands in Kurdistan.

Also Kurdistan has a massive potential for solar energy. Exploitation in this case is not so straightforward, and thought needs to be given to how this daily abundant energy can serve the needs in the region. Solar thermal collectors are well developed and reasonably cheap, and could be used throughout Kurdistan. Large-scale solar plant to produce electricity is less straightforward and would require a lot of investigation. It could be considered in the long term.

During the conflicts, war and embargos the people in Kurdistan managed to survive and fill the gap of energy shortage by using Kurdistan's potential of biomass namely wood stock. This sector need to be rehabilitated again and developed for use in a sustainable way.

The attitudes which make problems for renewables in many developed countries may not apply in Kurdistan. The reliability of some sources (especially wind) is less of an issue when the existing supply is unreliable. And when the demand for energy is not satisfied, local environmental issues such as visual impact are likely to be less important.

However the way in which energy is presently paid for (or in some cases not paid for) in Kurdistan has created behaviour which would have to change if the costs of investing in renewables are to be met.

Establishing a system of paying per unit of energy consumed should creat a more responsible attitude, provided that costs were high enough to actively discourage waste. It is generally accepted that renewable energy schemes are most effective if adopted along with energy efficiency measures.

Chapter 7

7.1 Conclusions: -

The potential of renewable energy in Kurdistan is extensive and could play a great role in power generation to meet the growing demands. Therefore it is essential for Kurdistan to have a proper policy for renewable energy management to find out a suitable way to use this abundant energy to serve the energy consumers in the region.

In Kurdistan hydropower is very popular, because it has been the only source of electricity during the last 16 years and will play a great role in the future. Unfortunately wind energy and solar energy have not received the same attention as hydropower. It is clear from this study that Kurdistan has abundant source of both solar and wind. Both deserve serious consideration. So too does geothermal energy, although careful research is required to determine its potential. Finally the use of biomass can clearly be expanded, providing this is done in a sustainable manner.

7.2 Recommendation: -

To provide greater security of supply in the future at the large-scale, strategic level, revenue raised from sales of oil and gas should be invested into the development of long-term sustainable sources of energy:

- The present proposals for the development of hydropower should go ahead.
- In the short term, exploitation of wind energy should begin. The region around Chamchamal appears to be the most favourable.
- Also in short term, solar thermal collectors for water heating could be more widely introduced, at both urban and rural levels.
- In the longer term, as the costs of oil and gas rise exploitation of solar photovoltaic at larger scale, and also the possibilities for generating electricity from solar-thermal plant could be considered.
- Use of biomass should be expanded, but in a carefully managed way.
- All these measures should be accompanied by education of the Kurdish people about the benefit of renewable sources in providing secure and sustainable energy supplies.

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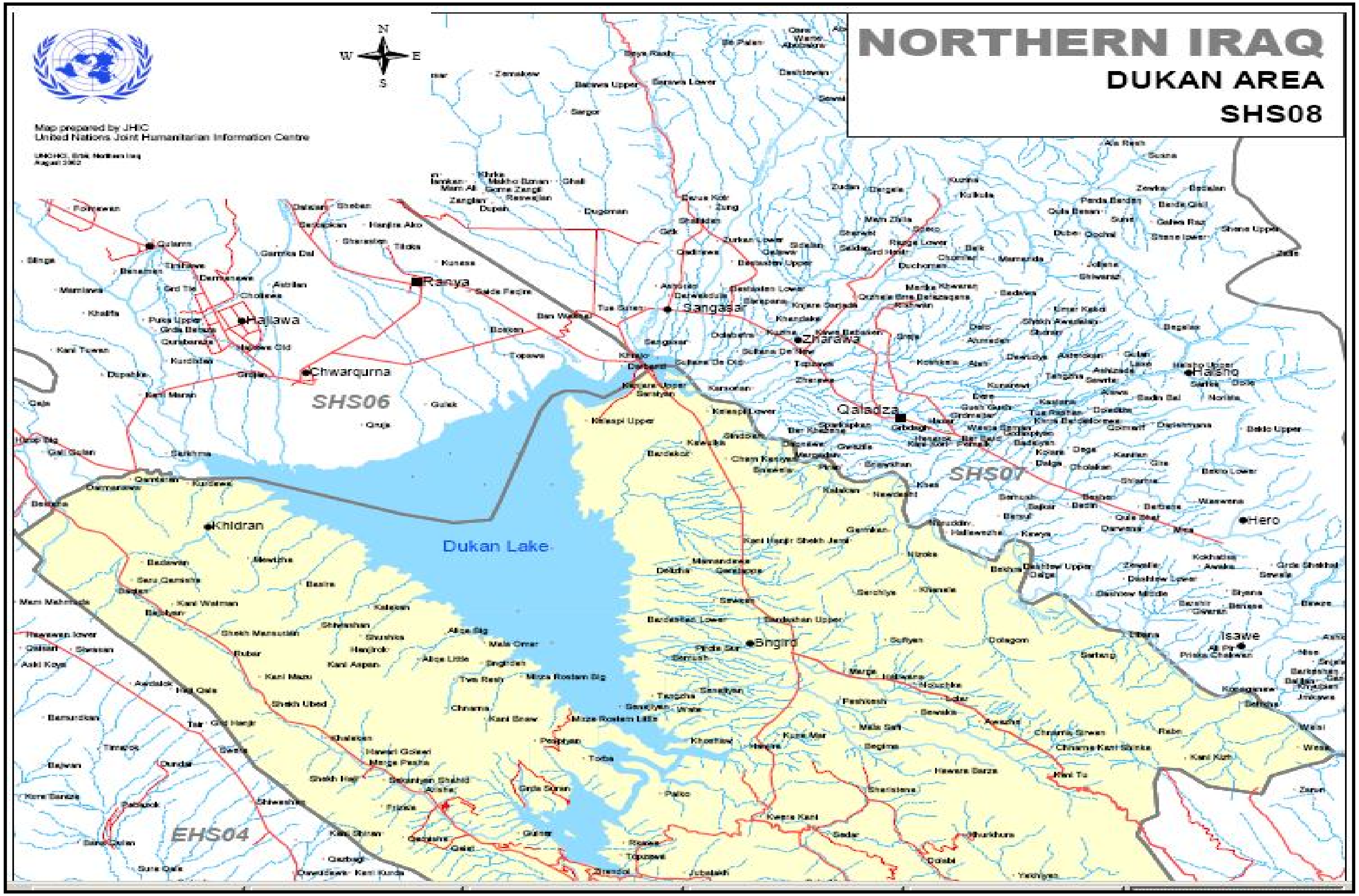
Appendix 1: Rainfall in different areas in Kurdistan (mm/month)

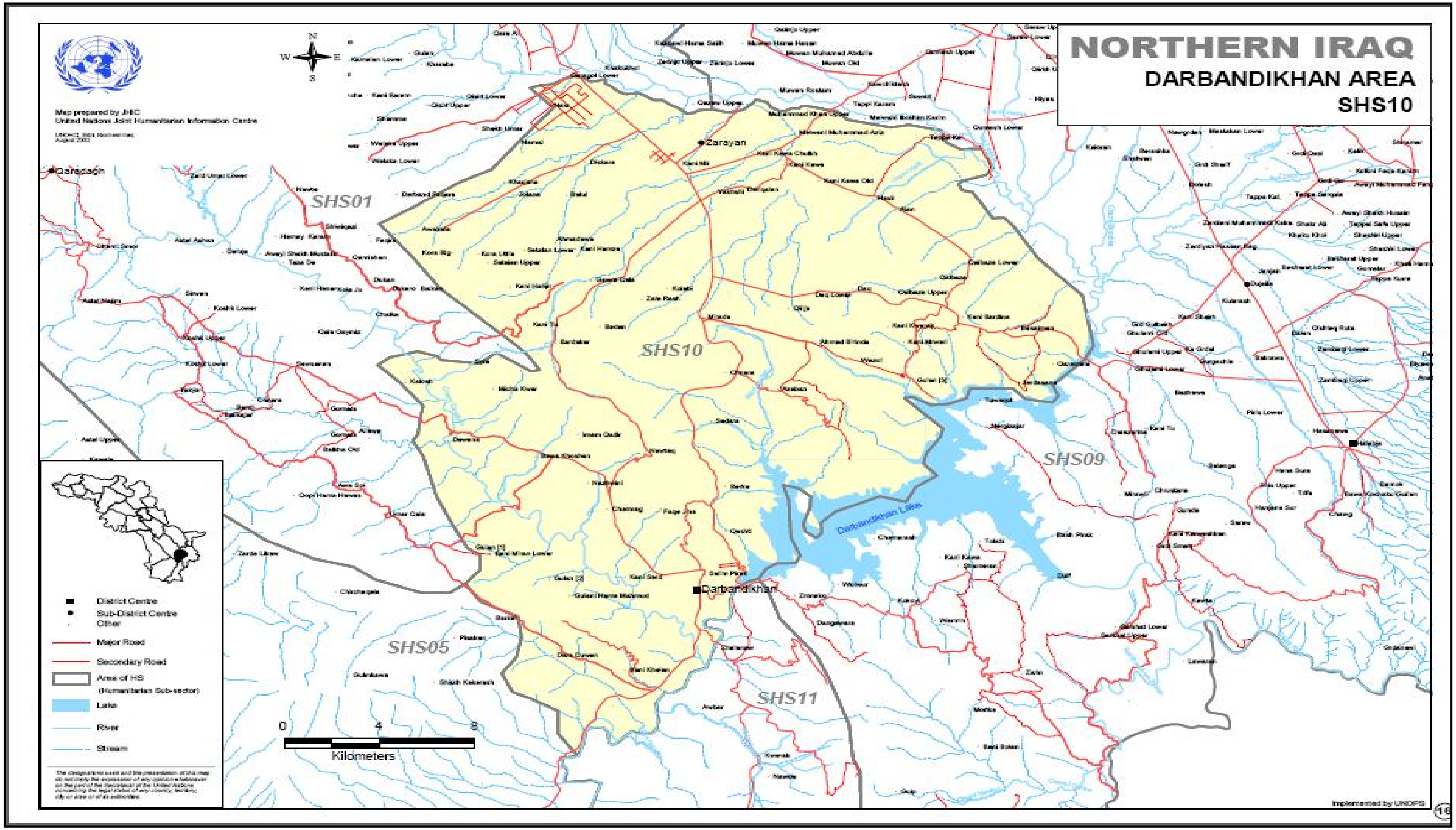
month	Erbil	Khabat	Koya	Shaqlawa	Sulaimanyah	chamchamal	Kalar	Chwarta	Penjwin	Halabja	Duhok	Zakho	Malta
Jan	32.5	63.3	231.1	36.2	82.6	78.1	131.8	74.8	78.5	53.3	36.6	49.3	39
Feb	42.6	21.6	38.8	139.3	83.9	64.6	30.8	82.1	138.5	119.3	101.1	102.2	93.2
Mar	96.5	116.1	138.8	127.4	81.9	73.7	64.2	98.9	115	85.6	84.3	88	78.3
Apr	35.7	24.9	80.3	40.4	35.3	20.7	10.7	45.9	57	19	47.3	37.2	39.8
May	12.4	15.5	15	30	12.6	6	0.6	38.5	12	16.4	18	51.8	29.2
Jun	0	0	0	0	0	0	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0.1	0	0	0	1.7	0	0	0
Aug	0	0	0	0	0	0	0	0	0	0	0	0	0
Sep	2.2	0	0	0	3.7	11	0	3	4	6.1	0	0	0
Oct	4.4	4.5	9.3	4.7	21.8	5.1	0	19.4	36.5	2.6	8	5.9	8.3
Nov	19.6	10.1	36.3	63.2	42.9	29.8	12.3	64.2	107.5	52	25	25.3	19
Dec	85	54.4	161.7	135.5	148.1	111.3	97.5	176.8	244.5	195.1	91.9	126.1	82.6
Total	330.9	310.4	711.3	576.7	512.8	400.4	347.9	603.6	793.5	551.1	412.2	485.8	389.4

Appendix 2: Map of Kurdistan Region

Appendix 3: Map of Dukan



Appendix 4: Map of Derbendikhan



Appendix 5: Monthly Average Solar Radiation (kWh/m²/d)

	Erbil	Khabat	Koya	Shaqlawa	Sulaimanyah	Chamchamal	Kalar	Chwarta	Penjwin	Halabja	Duhok	Zakho
Jan	2.56	2.39	2.25	2.28	2.83	2.81	2.86	2.44	2.00	2.39	2.56	2.53
Feb	3.03	3.64	3.47	2.72	3.25	3.28	3.67	3.50	3.08	3.69	2.81	2.53
Mar	4.61	4.31	4.28	3.92	4.69	4.69	4.47	4.31	4.25	4.39	4.14	3.92
Apr	5.31	5.64	4.25	5.00	5.42	5.44	5.64	4.33	4.36	4.69	6.64	5.08
May	6.53	6.72	6.92	5.89	6.67	7.03	6.92	7.14	7.19	7.31	6.36	5.67
Jun	7.83	8.03	7.78	6.75	8.19	7.94	8.08	8.11	7.92	8.17	8.17	7.92
Jul	7.22	7.50	7.42	6.78	7.67	7.64	7.72	7.50	7.50	7.64	7.67	7.36
Aug	7.03	7.03	7.08	6.94	7.22	7.14	7.06	7.06	7.14	7.22	7.19	6.94
Sep	5.64	5.58	5.67	6.06	5.89	5.78	5.92	5.83	5.75	5.81	5.81	5.50
Nov	4.33	4.31	4.22	3.72	4.47	4.25	4.44	4.19	4.81	4.44	4.22	3.67
Oct	2.81	2.72	2.75	2.64	2.94	3.00	3.06	2.94	2.75	3.06	2.78	2.28
Dec	1.94	1.97	2.03	2.00	1.94	2.17	2.25	1.86	1.78	2.08	1.86	1.64
Annual	4.90	4.99	4.84	4.56	5.10	5.10	5.17	4.94	4.88	5.07	5.02	4.59

Appendix 6: Wind speed (m/s) in different areas in Kurdistan at level of 2m height

	Erbil	Khabat	Koya	Shaqlawa	Sulaimanyah	Chamchamal	Kalar	Chwarta	Penjwin	Halabja	Duhok	Zakho	Malta
Jan	2.00	2.00	2.20	2.50	1.30	4.60	0.06	2.60	2.00	0.80	2.00	2.00	2.00
Feb	3.80	2.00	2.91	3.30	1.80	3.00	2.00	3.30	2.00	0.90	0.90	2.00	0.90
Mar	2.60	2.00	2.30	2.00	0.80	4.71	1.90	3.40	3.80	1.40	1.90	2.00	1.90
Apr	2.90	2.80	1.90	3.70	0.60	3.60	1.70	3.30	4.40	2.00	2.40	2.00	2.40
May	3.60	3.20	2.60	2.90	1.50	5.31	2.50	3.40	3.80	2.40	2.40	2.00	2.40
Jun	3.00	3.40	3.00	3.00	2.60	5.51	2.70	2.00	4.40	2.00	2.70	2.00	2.70
Jul	2.60	3.00	3.00	2.40	2.10	6.00	2.20	3.09	3.70	2.90	2.50	2.00	2.50
Aug	2.70	3.10	2.80	2.00	1.50	6.31	2.20	3.39	4.10	2.90	2.80	2.00	2.80
Sep	3.00	3.10	2.00	2.00	1.50	5.00	2.00	3.70	4.10	2.40	2.20	2.00	2.20
Oct	2.80	2.00	2.00	2.00	1.60	5.71	1.70	3.20	3.20	2.10	2.20	2.00	2.20
Nov	2.50	2.00	2.00	2.00	0.90	5.20	1.30	2.60	2.80	2.30	1.80	2.00	1.80
Dec	2.60	2.00	2.00	2.00	0.50	4.13	1.10	2.00	3.00	0.70	1.90	2.00	1.90

Appendix 7: Electricity Demands in Wasan for summer and winter

Hour	Total daily consumption kW/ Summer	Total daily consumption kWh/Winter
01:00	9.28	7.00
02:00	9.28	7.00
03:00	9.28	7.00
04:00	9.28	7.00
05:00	9.28	7.00
06:00	33.28	25.00
07:00	9.28	7.00
08:00	9.28	7.00
09:00	10.22	7.80
10:00	10.22	7.80
11:00	14.58	6.20
12:00	14.58	6.20
13:00	14.58	6.20
14:00	16.68	7.60
15:00	16.68	25.60
16:00	16.68	7.60
17:00	22.51	16.80
18:00	30.99	23.20
19:00	28.89	21.80
20:00	28.89	21.80
21:00	28.89	21.80
22:00	28.89	21.80
23:00	28.89	21.80
00:00	28.89	21.80
Average	18.30	13.33

Appendix 8: Number of Proposed hydropower schemes in Kurdistan

Project name	**province**	**River**	**Estimated power capacity (MW)**
Mendawa	Erbil	Upper Zap	620
Taqtaq	Erbil	Lower Zap	270
Baros	Erbil	Upper Zap tributary	109
Degala	Erbil	Lower zap tributary	97
Litan	Erbil	Sidekan	68
Zarawa	Erbil	Upper Zap tributary	42
Askikalek	Erbil	Upper Zap tributary	60
Nile	Erbil	Upper Zap tributary	34
Khomaria	Erbil	Upper Zap tributary	19
Saylam	Erbil	Upper Zap tributary	19
Omerawa	Erbil	Upper Zap tributary	15
Shiwan	Erbil	Upper Zap tributary	15
Derane	Erbil	Upper Zap tributary	16
Kawlos	Sulaimanyah	Lower zap tributary	165
Mawat	Sulaimanyah	Lower zap tributary	120
Kili	Sulaimanyah	Lower zap tributary	80
Bawanoor	Sulaimanyah	Sirwan	55
Khewate	Sulaimanyah	Qalachwalan	20
Khazene	Sulaimanyah	Lower zap tributary	35
Awa	Sulaimanyah	Lower zap tributary	65
Kalosh	Sulaimanyah	Lower zap tributary	16
Hosam	Sulaimanyah	Lower zap tributary	32
Noreba	Sulaimanyah	Lower zap tributary	30
Sorbe	Sulaimanyah	Lower zap tributary	24
Tili	Duhok	Upper Zap tributary	280
Amedi	Duhok	Upper Zap tributary	250
Bajooke	Duhok	Upper Zap tributary	150
Dole	Duhok	Khapur	120
Rewan	Duhok	Khapur	130
Deldal	Duhok	Khapur	110
Zakho	Duhok	Upper Zap tributary	100
Bewan	Duhok	Upper Zap tributary	130
Begove	Duhok	Khapur	67
Kovki	Duhok	Khapur	70
Basi	Duhok	Khapur	70
Bisar	Duhok	Khapur	50