Sustainability Assessment of Photovoltaic Power Plants in North Cyprus

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ABSTRACT

The clean, cheap and environmental friendly renewable energy sources, such as solar energy, are good alternatives to fossil fuels for generating electricity, especially in the Middle Eastern countries like N. Cyprus where high solar energy potential exists. Cyprus Turkish Electricity Utility Company (KIB-TEK) is responsible for producing, transmitting and distributing electricity to the consumers in N. Cyprus. Fuel oil no 6 is the only fuel used by KIB-TEK to produce electricity. The present work discusses the first experiences of the 1.275 MWp Photovoltaic (PV) Power Plant installed in Serhatköy. In 2012, with total production of 2,209,322 kWh energy, KIB-TEK saved 516.8 tonnes of fuel oil no: 6 reducing the CO_2 emission by 1590 tonnes.

An emission analysis was conducted for the thermal power plants of N. Cyprus in order to estimate the reduction in emissions in the case of installing PV plants to replace them. It was found that green house gas (GHG) emissions were reduced between 584g/kWh - 886g/kWh of CO_2. The specific fuel consumption of the reciprocating diesel engines and steam turbine thermal power plants was found to be 233.9 g/kWh. From these values the environmental and economical benefits of the Serhatkoy PV Plant was estimated.

Moreover, a life cycle cost analysis is performed for the Serhatkoy PV Power Plant where it is shown that the savings to investment ratio is greater than 1 leading to the conclusion that it is economically feasible.

Keyword: Renewable energy, photovoltaic (PV) systems, N. Cyprus energy system.

ÖZ

Temiz, ucuz ve çevreye dost bir yenilenebilir enerji kaynağı olan güneş enerjisi özellikle güneş ışınım potansiyeli yüksek Ortadoğu ve Kuzey Kıbrıs gibi ülkelerde fosil yakıt ile elektrik üreten sistemler için iyi bir alternatif enerji kaynağıdır. Kıbrıs Türk Elektrik Kurumu (KIB-TEK) Kuzey Kıbrıs'taki tüketicilere elektriği üretme, iletme ve dağıtımından sorumludur. Fuel oil no:6 yakıtı, KIB-TEK bünyesindeki elektrik santralleri için tek enerji kaynağıdır. Bu çalışmada, Serhatköy'e kurulmuş olan 1.275 MW_p fotovoltaik (FV) güneş santralinin performansı incelenmiştir. 2,209,322 kWh lik toplam üretimi ile 2012 yılında KIB-TEK santrallerinde 516.8 ton fuel oil no: 6 yakımı ve 1590 ton CO_2 emisyon tasarrufu sağlanmıştır.

Kuzey Kıbrıs'taki termik santrallerin emisyon analizleri yapılarak, kurulu FV santraller ile emisyon düşümünün tahmini yapılmıştır. Sera gazı etkisi yaratan karbondioksit salınım değerleri 584 g/kWh – 886 g/kWh arasında bulunmuştur. Aynı zamanda, pistonlu dizel makineler ve buhar türbinli termik santraller için ortalama olarak birim yakıt tüketimi 233.9 g/kWh olarak bulunmuştur. Bu değerlerle, Serhatköy FV Güneş Santrali'nin çevreye ve ekonomiye sağladığı fayda hesaplanmıştır.

Bundan başka, Serhatköy FV güneş santrali için hayat boyu analiz metodu uygulanmıştır. Buna göre yatırım tasarruf oranı bir (1)' in üzerinde olduğu görülerek yatırımının uygulanabilir (fizibıl) olduğu sonucuna varılmıştır.

Anahtar kelimeler: Yenilenebilir enerji, fotovoltaik sistemler, K.Kıbrıs enerji sistemi.

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Chapter 1

INTRODUCTION

Burning fossil fuels for producing power has adverse effects on human health, ecosystem and economic growth. The developed countries introduced many regulations in order to limit the exhaust emissions from the power units. Moreover, renewable energy options are proposed as an alternative approach to reduce the emissions and prevent global warming.

The demand of power is increasing simultaneously with the world population, the development of new technologies and expansion of industry. Rapid increase of energy usage rises concerns about the reserves of fossil fuels and causes the prices to go up. One of the most important problems facing the world at present is global warming due to high level of green house gases in the atmosphere. The exhaust gases from the power units increase the concentration of CO_2 gases in the atmosphere which contributes to global warming. Most of the countries still use petroleum products like fuel oil for energy generation. Very high rates of CO_2, CO, NO_x, SO_x, particulate matter and volatile organic compounds (VOC) are emitted to atmosphere after burning of this type of fuel. Cyprus is an island in the Mediterranean Sea which did not enjoy any reserves of oil and gas until recently. Recently some gas reserves were discovered in the south of Cyprus. In terms of water streams or rivers the resources are very poor for hydropower generation; therefore the island is highly dependent on imported energy. The developing countries such as North Cyprus mostly use fuel oil No: 6 in order to generate electricity. North Cyprus is a small country which produces its own electric energy. The local state utility company KIB-TEK is responsible for generating distributing and selling the produced power to all consumers. KIB-TEK has 2x60 MW fuel oil fired steam power plants and 6x17,5 MW fuel oil fired reciprocating diesel engine power plants. The company has also three gas turbines which are not used because of low efficiency and high operating cost. A private company AKSA, which has 8x17.5 MW fuel oil fired diesel power plants, meets the additional requirement of the country's energy need and sells the electrical energy to the utility company KIB-TEK. N. Cyprus has no strict rules about environmentally friendly power generation systems. The KIB-TEK has financial problems so low quality and high sulphur content fuel (fuel oil No: 6, 3.5 % sulphur content by weight) is bought and burned in power plants to generate electricity. Therefore the emissions are quite high. Total power capacity of KIB-TEK is about 350 MW. In June 2012, the peak load reached to 280 MW. The reserve power capacity is not enough for demand side security therefore new investments are unavoidable.

Solar energy can be proposed to be the cleanest and most economical solution for N. Cyprus for reducing the emissions. Cyprus is a Mediterranean island and it has very high rate of solar radiation throughout the year. Daily average sunny periods range between 5.5 and 12.5 hours depending on the time of year. The daily average global radiation drops to a minimum of 2.3kWh/m^2 in winter and reaches the maximum of 8.1kWh/m^2 in summer season. Annual average daily sunny period is 9 h and global radiation is 5.4kWh/m^2 on a horizontal surface [1]. Solar energy has been used for 45 years in N. Cyprus for domestic water heating. A typical household in N. Cyprus consumes an average 7kWh electrical energy in one day. Utilization of solar power for power generation can be an economic way to enhance the electrical reserves and provide a clear opportunity for emission reduction. Solar energy in the form of direct electricity conversion (photovoltaics) is already very popular in countries such as the United States, Germany and Japan [2]. The world's cumulative solar photovoltaic (PV) electricity capacity surpassed 100 gigawatts (GW) in 2012, achieving just over 101 GW. This global capacity to harness the power of the sun produces as much electricity energy in a year as 16 coal power plants or nuclear reactors of 1 GW each. Each year, the world's PV installations reduce CO_2 emissions by 53 million tons [3].

The aim of the thesis is to investigate the effect of the Photovoltaic (PV) Power Plant already established to N. Cyprus. It is the second biggest grid connected PV power plant around Middle East zone. The Plant is established by the European Commission (EC) in 2011. The cost of power plant was about 3.7 million euro and maximum power capacity is 1.275 MW_p. The energy production of this power plant during the year 2012 have been traced and taken for investigation. The performance analysis has also made and compared with the real and theoretical data. General information has given about the electricity production system of N. Cyprus. Efficiency of existence power plants using fuel oil No:6 and emission analysis have been investigated and the benefit of Serhatköy PV plant to emission reduction, environment and economy has been calculated.

In the following chapter the literature reviews are given. Third chapter is about the performance analysis and recordings of Serhatkoy PV power plant. Chapter 4 is about implication for emission reduction. Chapter 5 is about economic analysis and last chapter, conclusion and discussion are evaluated.

Chapter 2

LITERATURE REVIEW

G.K Singh made a review about solar power generation by Photovoltaic (PV) technology. He reviewed the progress made in solar power generation research and development since its inception. He says that solar energy will play an important role in the future where reducing the dependence on fossil fuels and addressing environmental issues area priority. He reviewed 121 research publications on the area of solar power generation technology and gave the list of them. He concluded that energy generation from photovoltaic technology is simple, reliable, available everywhere, in-exhaustive, almost maintenance free, clean and suitable for off-grid applications. But, photovoltaic efficiency and manufacturing costs have not reached the point that photovoltaic power generation can replace conventional coal, gas-, and nuclear-powered generating facilities. Cost comparison between photovoltaic power and conventionally generated power are difficult due to variations in utility power cost, sunlight availability and other variables. But, the electricity production cost is much lower if the PV system is grid connected. Grid off systems require batteries therefore the price to establish the system increase too much [4].

C. Koroneos et al examined and analyzed the energy system of Cyprus and Renewable Energy Systems (RES) available in the island and he says, extend of energy needs could be satisfied with RES. He mentioned about potential of the major renewable energy sources available such as wind, solar and biomass. He says that as a member of EU, it would be obligation for the Cyprus to follow the EU regulations about Renewable Energy System. Therefore the RES should be a part of energy production system. The factors influencing the wind regime of Cyprus was given with the frequency distribution versus wind speed graph. Solar radiation potential and benefits of PV system power generation was mentioned. The CO_2 reduction between 2002 and 2010 could be achieved totally 31300 ton with the 46.95 GWH total energy productions of photovoltaic systems and $1.32x10^6$ ton CO_2 reduction could be achieved with the 1188 GHW wind energy production [5].

M. EL-Shimy investigated feasible sites in Egypt to build a grid connected 10 MW PV power plant. The long term meteorological parameters for the 29 sites collected and analyzed in order to study the behaviors of solar radiations, sunshine duration, temperature and humidity over Egypt. The project viability analysis is performed through electric energy production analysis, financial analysis and Green House Gas (GHG) Emission analysis. The site which name is Wahat Kharga was found the feasible place to build the PV power plant there. The Sanyo 205 W_p PV module with the module efficiency 17.4% has been selected and 48781 modules with the total area 57562 m^2 required for the 10 MW PV power plant. The maximum energy production in Wahat Kharga was found 29.493 GWH/year with 33.7% capacity factor. Green House Gas emission reduction has been found 14538 tons of CO_2 by installing 10 MW PV plant in W.Kharga [6].

M. Díez-Mediavilla et al. investigated the production of two real 100 kWp grid connected PV power plants in the same area with same environmental conditions and same fluctuations in temperature and radiation. Both facilities are located in region of Castilla y León in Spain. Solar irradiation in that place is estimated at approximately 1450kWh/m^2 year. System 1 can generate 101.01 kWp with 185Wp model 546 unit

PV panels and system 2 can generate 108.36 kWp with 180Wp with 602 panels. Both systems has used only one SMA Sunny Central model 100 kW power capacity inverter but input and output voltage and current ranges of both inverters were different. Panel arrangements, protection system structure and measurement system of System 1 and System 2 was also different. Total productions of both systems in 2009 were measured 155803 kWh for system 1 and 144777kWh for system 2. The results show that system 1 panels perform better from every perspective. This study show that arrangement of PV panels in the site, improved wiring design and correct sitting of protection and measurement system are all important to improving the profitability of the PV installation, decreasing the price of generated electrical energy and the payback time [7].

S.M. Besarati et al. searched the potential of solar radiation in different regions of Iran. Solar radiation maps were given for 5 different tracking modes of PV modules to show the potential of 50 sites in Iran. Solar maps provided here can be used as a database for the future investments in the solar sector. Viability analysis has made for the 5 MW PV power plants in 50 different cities of Iran. RETScreen software which is a powerful analytical tool to assess renewable energy and energy efficiency economics and carbon reduction was used for the analysis. The study has been considered in reference conditions of air temperature and solar radiation. Totally 24391 unit crystalline silicon panel with a capacity of 205 Wp were selected for the supposed 5MW PV Power plant. According to the analyses, the highest and lowest capacity factors and energy productions were obtained in Bushehr at 26.1%, 11423.5 MWh and 16.5% 7220.6 MWh in Anzali respectively. The mean capacity factor was found 22.27% for these 50 cities. The analyses are based on radiation data from the NASA. NASA's data are based on satellite measurements therefore the level of dust in the air could affect the measurements of radiation. The mean values of Green House Gas (GHG) emission reduction and consumed fuel reduction of 50 cites have been found 6,112 tCO_2 and 2,616,399 L gasoline according to RETScreen database[8].

Andreas Poullikkas made a feasibility study about installing large photovoltaic (PV) parks in Cyprus with no feed in tariff system. The solar potential of the Cyprus, current Renewable Energy Sources (RES) policy of the government and electricity tariff system were considered in this feasibility study. He made parametric cost-benefit analysis to identify the least cost feasible option for installing 1 MW PV power plant by changing some parameters. Current energy system of Cyprus was given in this study. The island is almost completely dependent on imported fossil fuels. According to this, only 4% solar energy usage takes place in the total energy sources of Cyprus in 2006. By the year 2007 grid connected and stand alone PV system capacity of Cyprus was 173 kWp and 485 kWp respectively. For the 1 MW PV plant, a typical mono silicon 5400 PV module with each capacity of 185 W and 14.2% efficiency was assumed to install with two different orientations as well as solar radiation. 1440 simulations have been carried out by using IPP algorithm version 2.1 (independent power producer technology selection algorithm) software. The results showed that 1 MW PV Power Plant with south oriented modules with 28^0 fixed axis, annual energy production was measured 1820.85 MWh and capacity factor was 20.79% while the two axis tracking modules produced 2310.72 MWh in one year with a capacity factor of 26.38%. The annual avoided CO_2 emissions were estimated 1457 tons and 1849 tons which corresponds to 3024 barrels and 3838 barrels of crude oil not consumed respectively [9].

Chapter 3

MEASUREMENTS OF SERHATKOY PV POWER PLANT

In the context of the fifth enlargement of the European Union (EU), the Cyprus acceded as a defacto divided island by the European Union (EU) after the United Nation (UN) plan for a comprehensive solution of Cyprus problem failed to gain support at the referenda held in 2004. Although the Turkish Cypriots approved and Greek Cypriots rejected, the Greek Cyprus entered to the EU as a whole island. But the North area of Cyprus which is under the control of Turkish is outside the customs and fiscal territory of the EU. The EU decided that the suspension has territorial effect on North side but doesn't concern the personal right of Turkish Cypriots as an EU citizen. Therefore the European Commission (EC) agreed €259 million financial support to Turkish Cypriots in 2006 for encouraging the economic development of Turkish Cypriot community with particular emphasis on the economic integration of island and on improving contact between both sides and the EU.

An €11.44 million is allocated for the programme on energy efficiency projects which started in 2008. The program's principal elements can be mainly divided into 3 headlines. These are better monitoring of energy consumption, improved customer awareness and satisfaction, and environmental sustainability. A pilot solar Photovoltaic (PV) Power Plant with a capacity of 1.275 MW_p has been financed by the EU according to environmental sustainability program. A feasibility analysis was conducted and Serhatköy was chosen the best available place for the plant. The consortium of ANEL TECH and Enorqos S.p.a was authorized by the EC for the construction of the plant. The works started in March 2010 and completed in April 2011 and the cost of the project was €3.77 million.

3.1 N. Cyprus Meteorological Data

Cyprus is well known as one of the sunniest countries in Europe. On a surface with optimized inclination the annual incident energy amounts to roughly 2000 kWh/m^2, as is shown in Figure 3.1.

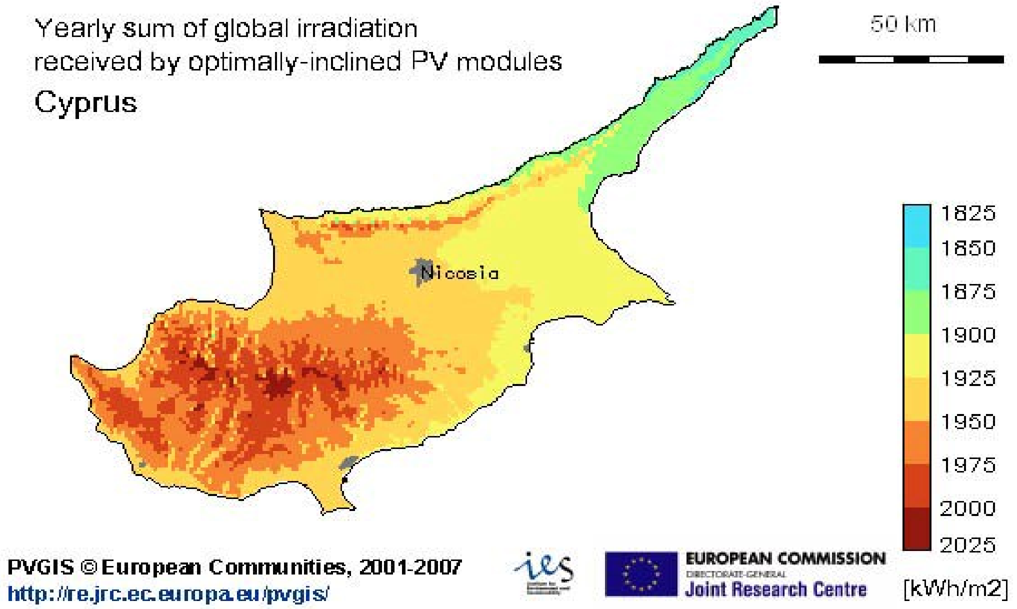

Figure 3.1: Solar radiation in Cyprus [10]

In this figure, it is obvious that the radiation is slightly increasing from north side to south side. The values of this map have been obtained from the meteorological stations, satellite images and the interpolation models therefore the accuracy is limited. More accurate measurements can be taken for specific site studies.

The geometry of incident radiation is as important as the intensity of the radiation. In order to obtain more accurate and detailed radiation data, worldwide meteorological database and simulation PC program METENORM (MN6) has been used by the ANEL TECH Company to calculate radiation on inclined or tracking surface. It is also able to compute the diffuse and direct (beam) radiation separately. The MN6 program has been used to calculate all the radiation data in this section for the DIKMEN site of N. Cyprus. N. Cyprus is a small country that the meteorological data and radiation data doesn't change very much for different sites in it and the data collected for the Dikmen site which is at the centre of country can be considered as reference for the measurements and the analysis. The Table 3.1 includes the various types of radiation values for the Dikmen.

Table 3.1: Monthly solar radiation values for Dikmen [11]

Month	H_Gh (kWh/m^2)	H_Dh (kWh/m^2)	H_Bn (kWh/m^2)	H_Gk (kWh/m^2)	H_Gn (kWh/m^2)	***H_Gh***: Global radiation horizontal ***H_Dh***: Diffuse radiation horizontal ***H_Bn***: Direct (beam) radiation ***H_Gk***: Global radiation on 30^0 tracking surface ***H_Gn:*** Global radiation on tilted plane, 30^0 inclination
January	77	38	92	113	143	
February	100	37	123	137	174	
March	149	59	151	179	226	
April	179	70	167	192	255	
May	217	79	199	211	298	
June	226	72	218	208	308	
July	228	74	219	215	313	
August	217	61	224	223	305	
September	174	51	193	202	265	
October	138	41	180	184	240	
November	94	35	125	139	176	
December	74	30	109	117	152	
Yearly (kWh/m^2)	**1869**	**646**	**2002**	**2121**	**2856**	

The software program MN6 allows determining the optimum inclination angle for solar collector or module. With this information the optimum geometry of solar collector or module array can be designed in order to obtain the maximum energy output for a given investment. In the Figure 3.2 shows the relative annual value of radiation received on the same type of surfaces, defined by percentage, for various fixed and tracking angles. The fixed angles are varying from 10^0 to 50^0 and oriented southwards. For seasonal tracking, the angle is changed monthly to optimum value.

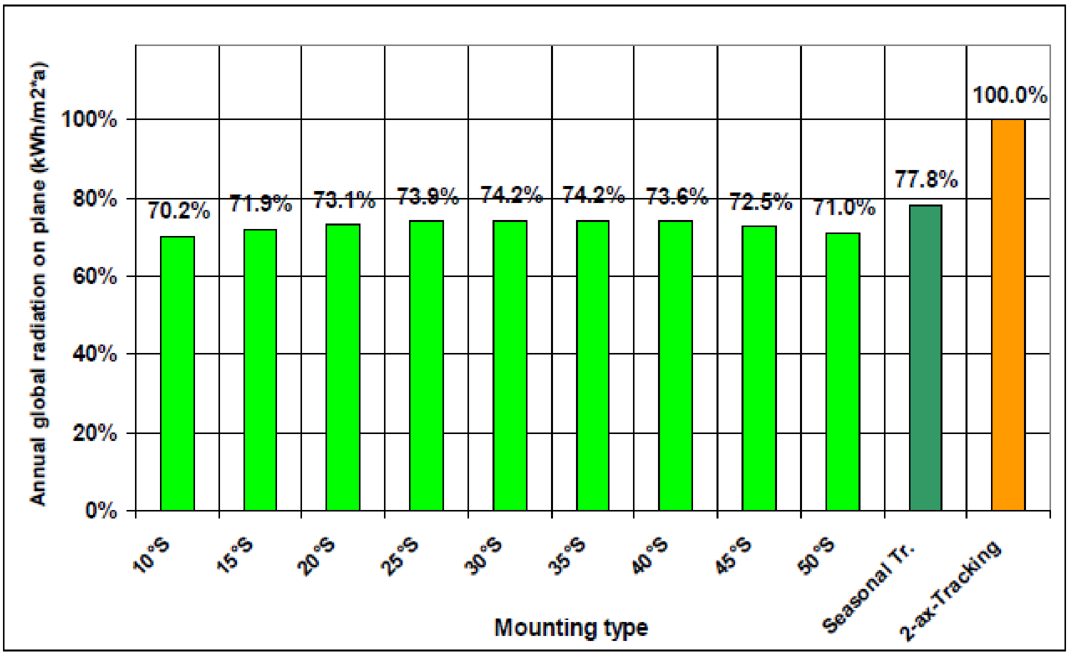

Figure 3.2: Relative annual value of radiation for different geometries [11]

The Figure 3.3 also shows the monthly values of global radiation for different geometries. The figure shows that the solar absorption rate of the 2 axis tracking system has maximum value especially during the summer months.

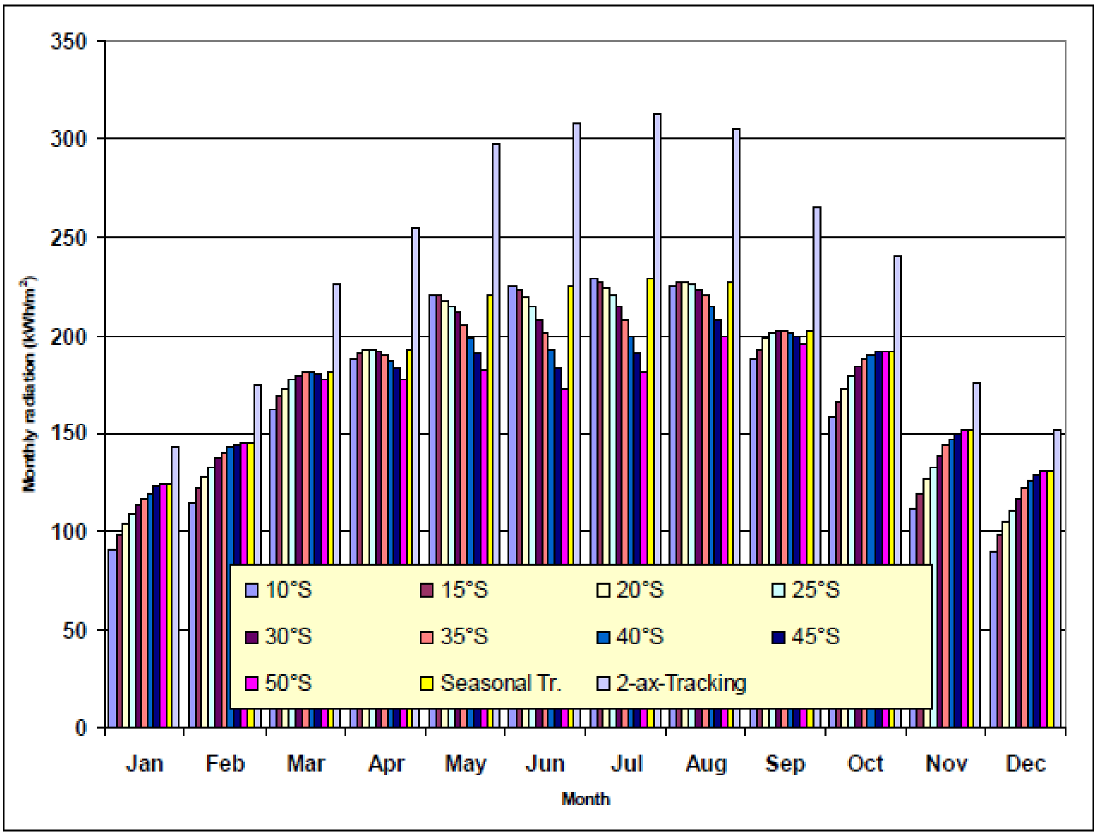

Figure 3.3: Monthly global radiations received by different collector geometries [11]

Solar radiation data calculated with historic data bases generally tend to underestimate the actually available solar energy. In many regions an increase in global radiation has been observed due to the effect of climate change.

The ambient temperature has also influence on the performance of Solar Photovoltaic (PV) Power Plants. The efficiency of the module is decreasing with increasing cell temperature. For crystalline silicon cells, a cell temperature increase of 10 ^{0}C results in a 5 % efficiency reduction. N. Cyprus has Mediterranean climate: summers are dry and hot, the winters are warm and rainy. Table 3.2 gives the monthly ambient temperature data which were taken from the internet for the Nicosia and from calculations of Metenorm V6 (MN6) program [11].

Table 3.2: Ambient temperatures in Nicosia [12]

Months	Mean Temperature(^{0}C)	Mean Maximum Temperature(^{0}C)	Mean Minimum Temperature(^{0}C)	Mean Temperature by MN6(^{0}C)
January	12	14	6	11.8
February	13	16	5	12.2
March	16	18	7	13.5
April	21	23	10	16.9
May	27	29	16	20.4
June	30	33	19	24
July	33	36	22	26.6
August	32	36	22	26.6
September	29	32	19	24.6
October	24	28	15	21.3
November	18	21	10	16.9
December	14	17	7	13.4
YEAR	**22.4**			**19**

It can be seen from the table that the seasonal difference between midsummer and midwinter temperatures are quite large.

Over the island of Cyprus, high wind potential is not typical. The winds are usually light or moderate strength and they rarely reach gale force. The wind potential of Cyprus is effected some factors like large temperature difference between the sea and the land. The annual mean average wind speed is about 4 m/s. Southern coastal zone and exposed locations in mountains have higher wind potential then average. From the view of solar power generation, the wind situation in N. Cyprus is not of particular importance. For PV plants, light and moderate winds have a small positive effect since they reduce the heating-up of the modules which results in a slight increase of efficiency.

Dust and sand phenomena is also important for PV power generation systems. Cyprus is sometimes affected by sandstorms from the Middle East deserts. The dust or sand collected on the module surface reduces the solar absorption rate of the cells then decrease the production efficiency.

3.2 Technical Description of the Serhatköy PV Power Plant

The area for the power plant has been chosen according to quality of ground, appropriate infrastructure and solar radiation potential. The Serhatköy was the available place to set up the project. It has been directly connected to 11 kV medium voltage grid network system of N. Cyprus without batteries and it continuously delivers electrical power to the grid whenever the solar radiation is available. The integration of solar power plants into a power grid is different from other production facilities such as diesel or combined-cycle plants. Total installed solar power capacity is dependent to total installed capacity of the power system. Several investigations made for the European countries have shown that the solar power capacity up to 10% of total power capacity doesn't create substantial problems. In case of N. Cyprus it is about 30 MW according to that investigations but it is practically not possible.

The main components of the Serhatköy PV power plant are the module fields or solar collectors and inverters as shown in the Figure 3.4. In this PV power plant totally 6192 unit 205Wp multi crystal modules which were produced by Austrian company KIOTO Photovoltaic GmbH have been used to reach the maximum power capacity value of 1.275 MW. The specifications of the modules are given in the Appendix A. The total module area of the Serhatköy PV Power Plant is 9257 m^2 and total cell area is 8139 m^2.

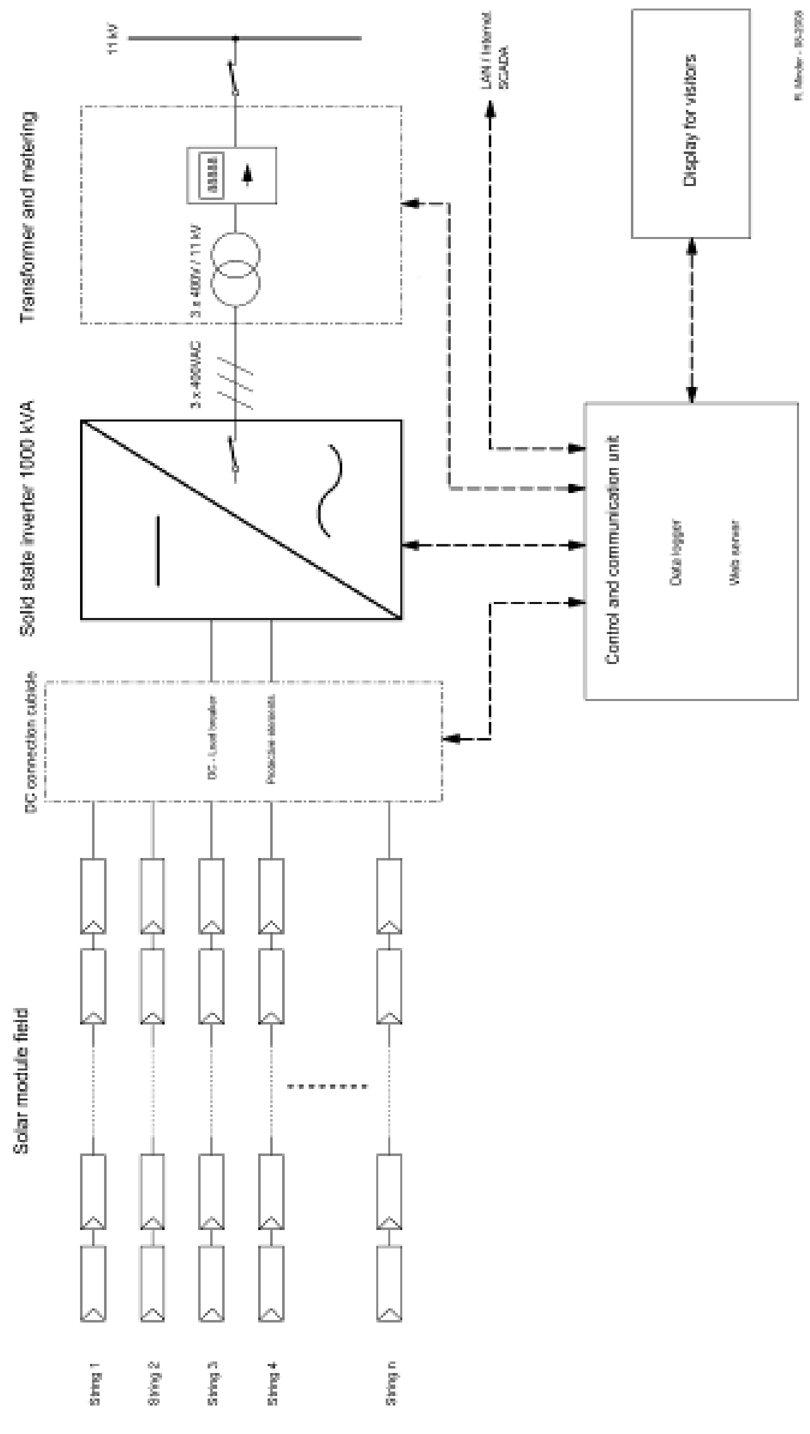

Figure 3.4: Basic schematic of the PV Power Plant connected to medium voltage grid

Photovoltaic cells make use of photoelectric effect and transform the energy of photons coming from the sun directly to electricity without an intermediate mechanical process. A number of cells form a PV module. Most photovoltaic cells are manufactured from the crystalline silicon. It is the most widely used material for power modules. The advantage of crystalline cells is not only the high efficiency but also the reliability and long lifetime.

The modules of the plant are fix angle mounted. Fix mounted system is the simplest solution for PV modules both for installation and maintenance. Fix mounted structures are mostly installed in rows. A metal structure was mounted onto concrete foundations and the weight of foundation has been chosen according to wind load in that area. The distance between the rows was chosen in a way to avoid shading of the modules by the next row. Therefore the module inclination of 25 ^{0} was chosen according to MN6 measurements and shading effect as can be seen in the Figure 3.5.

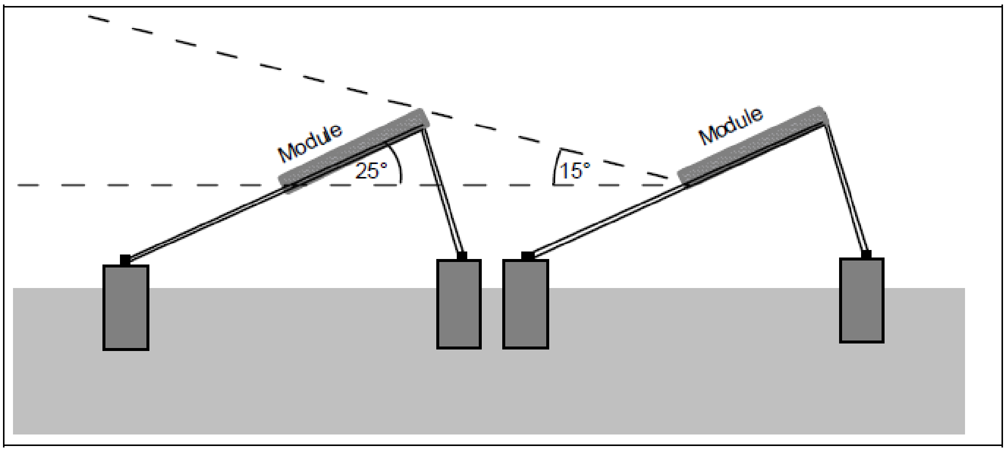

Figure 3.5: PV module geometry of Serhatköy PV Power Plant

Inverters can be considered the heart of the PV power plant. Today's inverters are complex systems not only the power electronics but also containing the systems for controlling the PV power plant, safety and protection components, power quality and grid survey, data acquisition and communication interface. In this power plant, PVI 12.5-OUTD model totally 86 inverters which were produced by POWER ONE Company have been used. The specifications of the inverter are in Appendix B. A number of modules were connected in series to reach the working voltage range of inverter which is 200-850 V. 18 solar modules were connected in series to form a string and reach the voltage range of inverter. One inverter has connected to the 4 parallel connected strings or totally 72 solar modules. 44 strings connected in parallel to form an array. There are totally 8 arrays; four arrays are located at east and other 4 are located at west.

3.3 Recordings of Performance

The construction of the 1.275 MW_p Serhatköy PV Power Plant started in 2010. In the same year some tests and simulations have been made by the ANEL Tech to see the value of some parameters like performance, efficiency and power losses of the power plant. In May 2010, the simulations were made using a programme. According to the simulation result, the graph in the Figure 3.6 shows the monthly normalised productions per installed kW_p in a day with PV array and system losses for one year operation.

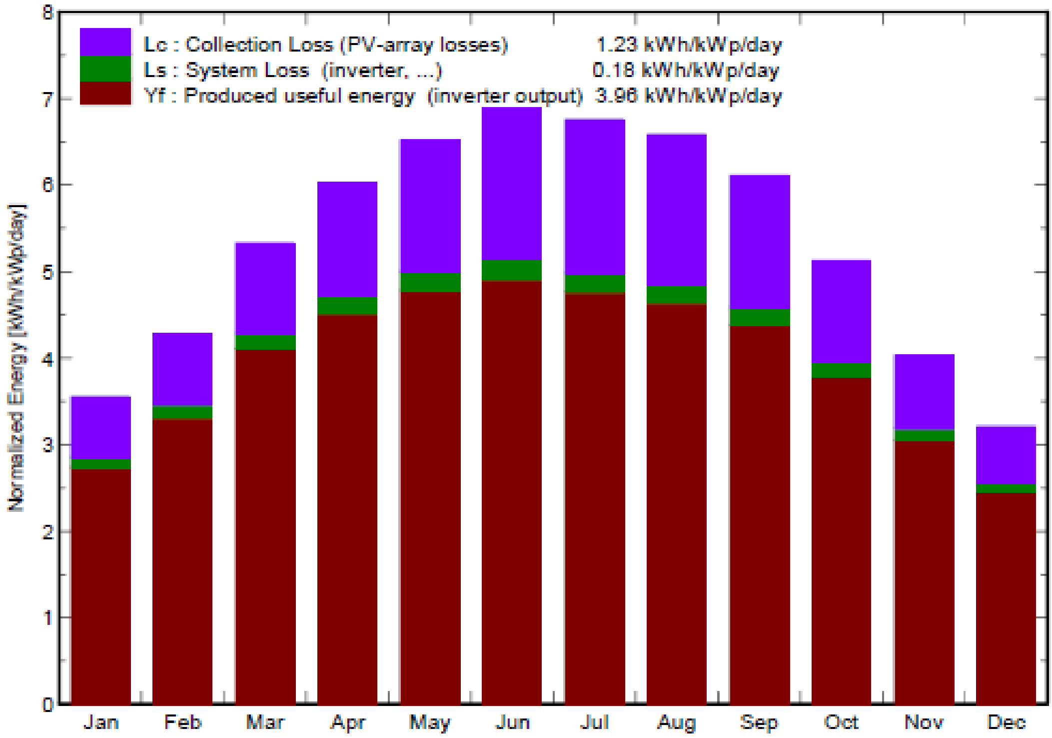

Figure 3.6: Normalised productions: Nominal power 1.275 MW [11]

The performance ratio is the ratio of target production and real production, which is usually called quality factor. It is independent of the radiation therefore useful for comparison of the systems. It takes into consideration of transformer, inverter, thermal and delivery losses. The simulation measures showed that the performance ratio of the PV Power plant is about 0.8 in winters and decreases to 0.737 in the summer months due to the high thermal losses particularly in the solar modules and inverters. The graph of performance ratio can be seen from the Appendix C.

The table in the Appendix D shows the main results of the simulation. Monthly irradiation values, ambient temperatures, productions and system efficiencies are given in this table during one year. The loss diagram in the Figure 3.7 was drawn according to these results.

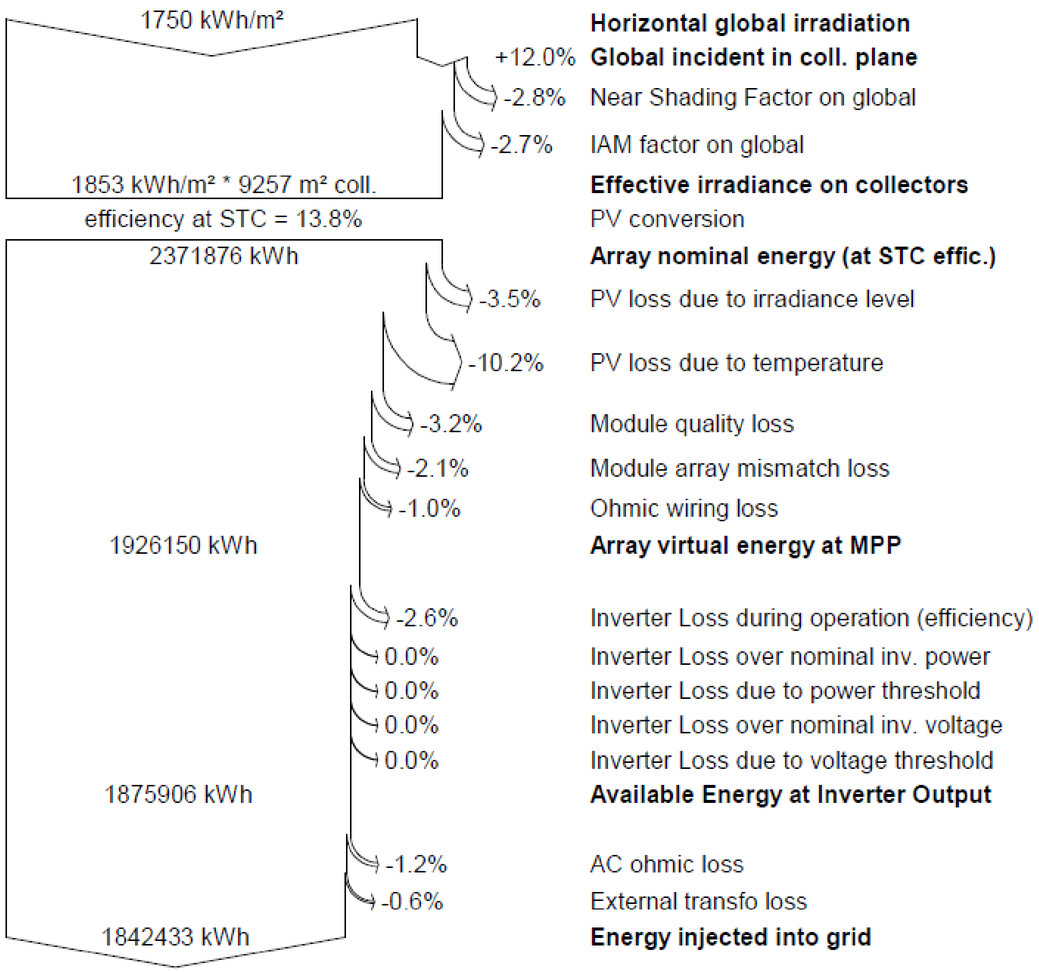

Figure 3.7: Loss diagram over the whole year [11]

The diagram shows that irradiation level of 1853 kWh/m^2 falls onto collector surface and 2,371,876 kWh energy is produced by the plant with 13.8% module efficiency. Only 1,842,433 kWh energy is delivered to the grid after the losses. These are all theoretical results.

The Power Plant is in connection with the SCADA computer centre which is the main control centre of the KIB-TEK, and it continuously takes information from the Serhatköy PV power plant. The real productions are being recorded after the PV plant started to deliver energy to the grid in May 2011. The energy production of the PV Power Plant was recorded during the year 2012 for the analysis. Total energy production of the plant was found **1,985,215 kWh**. The graph in the Figure 3.8 shows the monthly actual productions. According to this graph, the minimum and maximum productions occurred in December and August as 86,433 kWh and 227,272 kWh respectively. The problem is that the plant has stopped many times in 2012. Totally 30 days stopped in the April, May, June, October, November and December. Therefore the data shown in Fig. 3.8 is not complete.

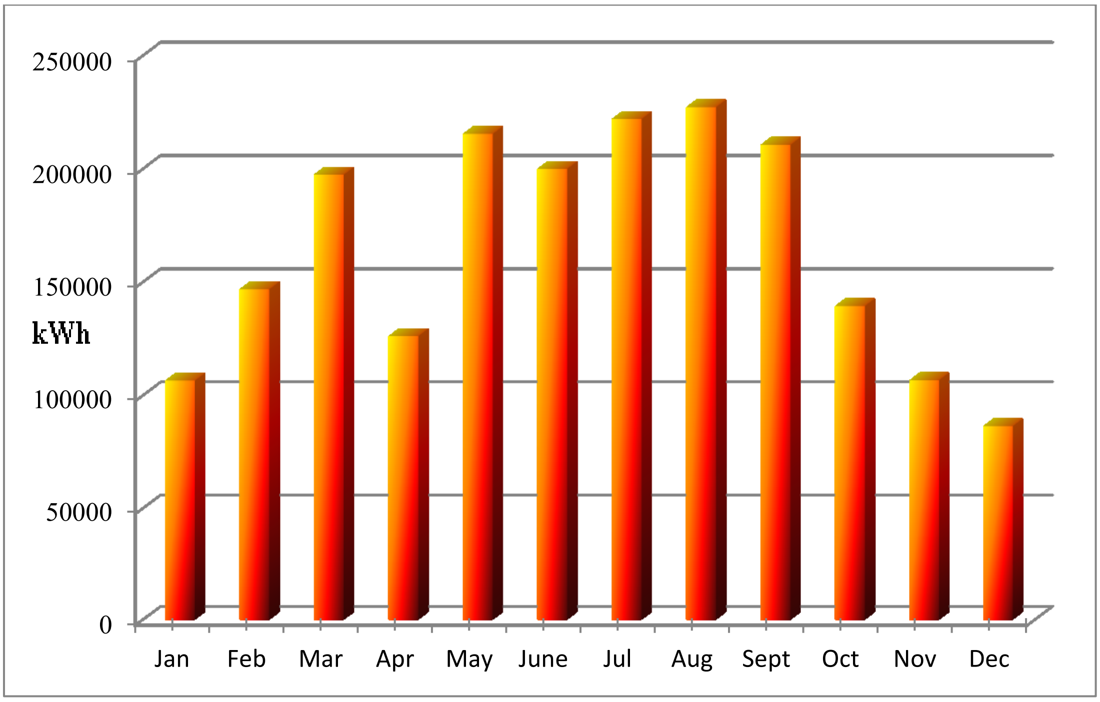

Figure 3.8: Actual electricity production (kWh) of Serhatköy PV Power Plant in 2012

Assuming that the production is continuous throughout the year it is possible to complete the missing days by projecting the recordings of the previous days or months. The results are shown in Figure 3.9.

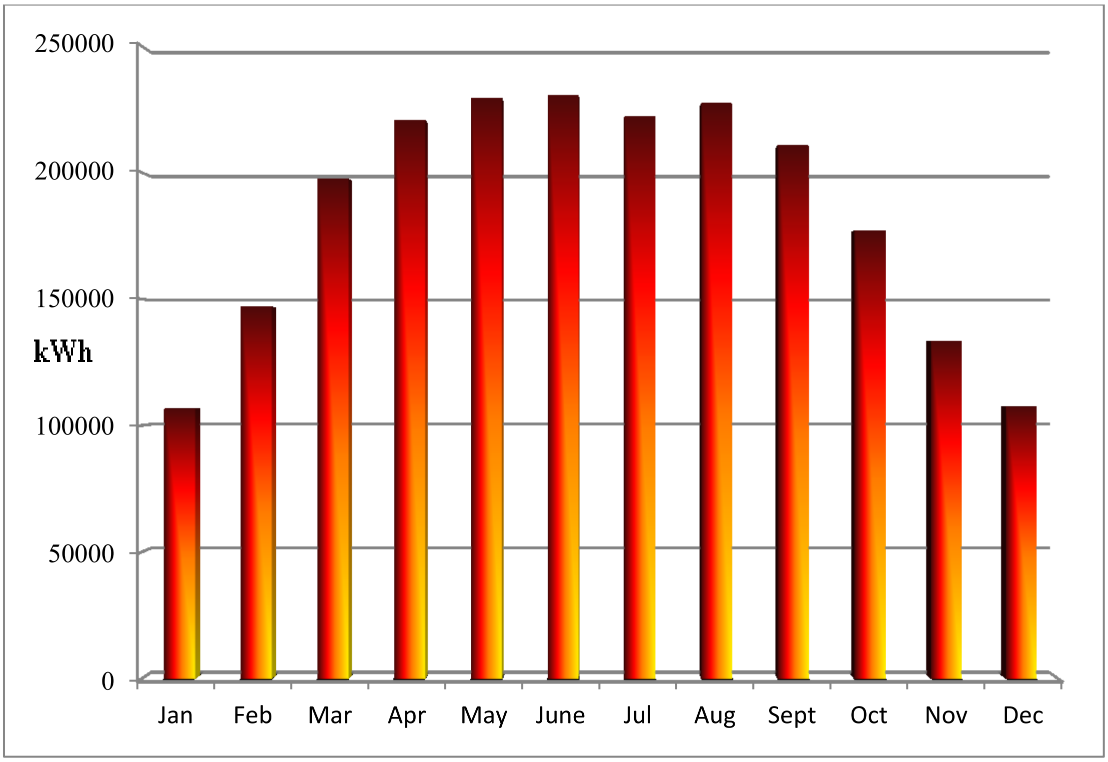

Figure 3.9: Electricity production of Serhatköy PV Power Plant in 2012 with estimated projections for missing days.

The total production is found **2,209,322 kWh** after estimation. The minimum production occurred in January as 106,560 kWh and maximum production occurred in June as 230,602 kWh. The capacity factor of the plant according to the actual production and correlated production value can be found 17.77% and %19.78 respectively.

Chapter 4

EMISSION ANALYSIS

4.1 Fuels and Combustion Analysis

The materials that can be burned and release thermal energy are called fuels. The fuels can be classified as solid, liquid and gases. Most fuels consist of hydrocarbons and the general chemical formula can be written as C_nH_m. Coal, Fuel Oil, Diesel fuel, Kerosene, Gasoline and natural gas are the main examples of the hydrocarbon fuels [13].

The solid hydrocarbon fuel is the coal. It is mainly composed of carbon. It has also different amounts of hydrogen, oxygen, ash, moisture, sulphur and nitrogen. The physical properties include the heating value, volatile material content, moisture and ash content. The coal is classified into three major types namely anthracite, bituminous, and lignite. The exact properties of the coal cannot be given because it changes according to geographical field. There are two methods to analyse the coal. The proximate analysis determines the weight percentage of fixed carbon, volatile materials, ash and moisture content. The carbon content is directly in connection with the heating value of the coal. The volatile material content helps to find the ignition point. Ash content is important for emission control equipments. Ultimate analysis is the second method to analyse the elemental components of the coal. The ultimate analysis should be made by skilled persons in laboratory. This method determines all the elemental chemical constituents like oxygen, nitrogen, sulphur, carbon, mineral matter etc. This method is useful to find the volume of air required for stoichiometric combustion and find the flame temperature. The volume and composition of combustion gases can also be found from the elemental constituents.

The gaseous fuels are the other types of hydrocarbon fuels. Although the energy content per unit volume is lower than liquid fuels, it is the most preferred because of easy handling and distribution and also lower emission values. The types of gaseous fuels can be divided in four categories. Gaseous fuels found in nature, made from solid fuels, made from petroleum products and made from fermentation process respectively. Natural gas is found in nature and produced from gas or oil wells. It is mainly composed of methane (CH_4) and other constituents like ethane, propane, butane, pentane, nitrogen, helium and carbon dioxide (CO_2). This gas is lighter than air. It doesn't contain sulphur and doesn't produce soot or smoke. The calorific heat value is quite high. The natural gas is often called as methane because of the high methane percentage of 95%. Other type of gaseous fuels made from solid fuels can be derived from coal, waste and biomass. Liquefied Petroleum Gases (LPG) is a gaseous fuel made from petroleum products. It is produced from crude oil refining and also from natural gas processes. The main constituent of the LPG is propane and butane. The vapour of the LPG is denser than air because the propane and butane is almost two times heavier than air. LPG also contains small amounts of propylene and butylenes. The LPG is gaseous state at room temperature and atmospheric pressure. It is liquefied by compressing it. Almost 250 litres of LPG gas are produced when one litre of condensed LPG evaporates. Therefore, it is condensed in pressurised vessels and transported in liquid. Relative density, higher heating value, air fuel ratio, flame temperature and flame speed are properties of gaseous fuels.

The liquid fuels can be obtained from the crude oil by distillation and they are the mixtures of many hydrocarbons. For convenience, they usually called single hydrocarbons. The more volatile hydrocarbon fuels vaporises first during distillation process. For example, the gasoline which is called octane (C_8H_{18}) vaporises first and it is more volatile than diesel fuel, dodecane ($C_{12}H_{26}$). Ethyl alcohol (CH_3OH) and methyl alcohol which are also called ethanol and methanol are the other types of hydrocarbon liquid fuels. Ethanol is produced from grains, corn and organic waste. Methanol is obtained from natural gas, coal and biomass. Both ethanol and methanol are low emission fuels therefore used as additives for other liquid hydrocarbon fuels like gasoline. The quality and composition of the liquid fuel is dependent on the source of crude oil and refinement quality. The properties of liquid fuels are specific heat, calorific value, density, specific gravity, viscosity, flash point, pour point, sulphur content, ash content, and carbon residue. Specific heat of the liquid fuel is the amount of heat energy needed to raise the temperature of 1 kg of liquid fuel by 1 ^{0}C. This specification is important to calculate the energy amount for heating the fuel to the desired ignition temperatures. Calorific value is the measurement of the energy produced from one kilogram of fuels after combustion process. Density is the ratio of fuel mass to fuel volume at the reference temperature 15 ^{0}C. This property is important for calculations of ignition quality. Specific gravity is the ratio of weight for given volume of fuel to the weight of same volume water at the same temperature. Kinematic or dynamic viscosity is one of the most important properties of the liquid fuels. It is a measure of internal resistance to flow. It is inversely proportional to the temperature. The viscosity value of the fluid is meaningless without knowing temperature. This property is very useful especially for the fuel oil storage and pumping. It is also necessary characteristic for the oil burners to calculate the desired atomisation needed to prevent formation of carbon deposits on the burner tips and boiler walls. Flash point is the minimum evaporation temperature of the fuel after heated. Pour point is the minimum temperature of the fuel start to flow. Sulphur content in the liquid fuel is dependent to quality of crude oil and refining process. The sulphur amount is higher in fuel oils No: 5 and No: 6 therefore it is one of the quality measures of fuel oils. High sulphur has bad affects on fuel oil No: 5 or No: 6 burning boilers. The sulphuric acid which is very corrosive substance is formed after combustion. It especially effects the chimney or air pre heaters when condenses. Carbon residue of the fuel indicated the tendency of carbon deposit on a hot surface. The ash content is the measure of inorganic material or salts content in the fuel oil. The residual oil has more ash content than distillate oils. Excessive ash content has erosive effect on combustion equipments and cause deposits. High temperature corrosion is another reason of excessive ash content [14].

Combustion is the oxidation of fuel by chemical reaction and energy is released in the form of heat and light after the reaction. Air is the most often used oxidiser of the combustion reactions, because it includes 20.9% percent of pure Oxygen inside. Other constituents of the air are 78.1% Nitrogen, 0.1 percent Argon and small percentages of Carbon dioxide, Helium and Neon. The Argon gas is accepted as Nitrogen and the others are negligible in the combustion analysis. Therefore, the air composition can be said roughly 79% nitrogen and 21% oxygen by mole numbers. It means that the air enters the combustion process includes 21 moles of oxygen with 79 moles of Nitrogen. In other words, 1 mole of O_2 in the air is combined by 3.76 moles of N_2. However the chemical equation of the air is written as;

$$1 \text{ mole } O_2 + 3.76 \text{ mole } N_2 = 4.76 \text{ mole}$$

The Nitrogen in the air sometimes accepted as inert gases. It means that it doesn't react with other elements during combustion. But in reality it has effect on the combustion efficiency. It reduces the combustion intensity therefore reduces the combustion efficiency. Large quantities of Nitrogen in the air also increase the volume of combustion product. The hazardous effect of Nitrogen is that it combines with the oxygen especially in the high temperatures then forms Nitrogen Oxides (NO_x) which is hazardous toxic pollutant. The air includes moisture or water vapour. The hydrogen in the fuel combine with the oxygen in the air also forms water (H_2O) and water vapour. At high temperatures the water vapour can be disassociated into H_2, O_2 or H, O, OH during combustion. The Sulphur in the fuel combine with the oxygen in the air then form sulphur dioxide and release 2224 kcal of energy for each kilogram of sulphur.

$$S + O_2 = SO_2 + 2224 \text{ kcal}$$

It is important that the water in the fuel can react with sulphur dioxide and form sulphuric acid (H_2SO_4). Therefore the dew point temperature should be taken into attention to prevent water droplets forming in the combustion gases.

The good combustion must be achieved for higher efficiency and lower emission values. The carbon in the fuel normally combines with oxygen and form carbon dioxide (CO_2) in good combustion then release energy.

$$C + O_2 = CO_2 + 8084 \text{ kcal}$$

In some conditions the Carbon in the fuel forms carbon monoxide and less energy is released after combustion.

$$C + O_2 = 2CO + 2430 \text{ kcal}$$

Forming of CO and C (soot) are less and combustion efficiency is higher in good combustion. The fuel amount is also has an effect for Carbon monoxide forming. For the given volume of oxygen, too much or too little amount of fuel results unburned fuel or carbon monoxide forming. Generally for good combustion, the fuel temperature for ignition, mixing quality of fuel with oxygen and enough time for complete combustion are the important conditions. The fuel temperature must be reach to ignition temperature and the proportion of fuel and air should be in specific range to start the combustion process. Otherwise the combustion doesn't start. In perfect combustion process the fuel is completely burned and only CO_2, N_2, H_2O and SO_2 elements are formed. The Air –Fuel (AF) ratio is used to quantify the amount of fuel and air for the combustion. It is the ratio of mass of air to mass of fuel. It is very important to arrange the ratio of air and fuel to achieve complete combustion of fuel. The minimum amount of air for the complete combustion is called Stoichometric air or theoretical air [15, 16].

Sometimes extra air is applied to guarantee for complete combustion. This is defined as excess air factor which the O_2 is formed in the product side of chemical reaction.

4.2 Emission Analysis of Conventional Thermal Power Plants

The main principle of electrical energy production is that the electrical generator rotation in proper speeds by other external moving force. The motion energy needed for rotation can be gained from the potential energy of water like in hydro power plants or the turbine rotation in thermal power plants and wind turbines and shaft rotation of reciprocating engines. Other method is photovoltaic (PV) technology which uses the sun light to produce electrical energy without any rotating machine. The thermal power systems use the heat energy for electricity production. Thermal energy source can be the sun, nuclear materials or fuels. Most of the thermal power plants use the internal energy of fuel to produce heating energy to get high temperature and high pressure water vapour for turbine rotation. Conservation of energy principle which is the first law of thermodynamics is the main principle of the thermal power systems. The energy cannot be created nor destroyed; it only changes forms [13]. The principle of fuel fired thermal power plants is that the chemical energy of the fuel is converted to heating energy, heating energy to motion energy then motion energy to electrical energy by electrical generators. The utility boilers, reciprocating engines and gas turbines are the main electricity production systems using thermal energy. The utility boilers use the Rankine cycle which is the ideal cycle for vapour power plants. The simple rankine cycle is explained that the water is pumped to boiler at high pressure, high pressure water is heated until it change phase to vapour at high temperature and pressure then that vapour rotates the turbine. The generator is connected to turbine and thus the motion energy is converted to electrical energy. The fuel used in utility boilers can be solid, liquid or gas.

The gas turbine systems use the Brayton cycle which is simply explained that the air is compressed by air compressor and fuel is injected to high pressure and high temperature compressed air, then the combustion products rotates the turbine. The compressor, turbine and generator are connected to same shaft and rotate together. Distillate fuel oil and natural gas are the main fuel used for this type of power systems.

Power production from the reciprocating diesel engines use conventional two or four stroke compression ignition type engines which works with diesel cycle. The crankshaft of the diesel engine is connected to electrical generator thus the motion energy produced from the diesel engine rotates the generator and electrical energy is produced in the same principle like the other power systems. Distillate or residual fuel oil and natural gas can be the fuel of these engines.

The fuel oil can be categorised as distillate oils and residual oils. These oils are distinguished by grade numbers from No: 1 to No: 6. The distillate oils which the grade number No: 1 and No: 2 are more volatile and less viscous then residual oils. The kerosene and diesel fuel are distillate fuels and they are used mainly in domestic and small applications. The Ash and Nitrogen content is very low in distillate oils and can be neglected. The Sulphur content is usually less than 0.3 % by weight. Residual oil is graded as No: 5 and No: 6 which are heavier and more viscous than distillate oils. It should be heated before ignition for proper atomisation. The sulphur, ash and nitrogen contents are significantly high with respect to distillate oils. Residual fuel oils are mainly used in large applications like utility or commercial systems.

The economical reasons push the governments or companies to use cheapest fuel available for the power production systems. Therefore residual fuel oil is most preferred fuel in some countries like in the North Cyprus where the other type of energy sources are not available for electrical power production systems. Therefore the emission values from the distillate fuel oil fired energy production systems have to be analysed for seeing the effects to the environment.

4.2.1 Compression Ignition (Diesel) Engine

This is the reciprocating compression ignition diesel engine, often called diesel generator is also designed to work with fuel oil No: 6. Exhaust gases emitted from these engines are composed of nitrogen, oxygen and combustion products: Carbon Dioxide (CO_2), water vapour (H_2O) and minor quantities of Carbon Monoxide (CO), Sulphur Oxides (SOx), Nitrogen Oxides (NOx), partially reacted and non-combusted hydrocarbons (HC) and Particulate Matter (PM) [17].

The generators used in North Cyprus electricity production system is the production of WARTSILA /FINLAND Company. The engines are called WARTSILA V46 which is 4 stroke, non-reversible, turbocharged and intercooled diesel engine with direct fuel injection. The name V46 means that the pistons are designed in V form and the diameter of one piston is 46 cm. It has totally 18 pistons. The maximum electricity power capacity of the engine is 17550 KW. There are totally 14 diesel generators which are installed in Teknecik Power Plant and Kalecik Power Plant in North Cyprus for electricity production of North Cyprus.

4.2.1.1 Diesel Engine Exhaust Components

In the following table the typical composition of the exhaust gas from diesel engines are presented.

Table 4.1: Typical exhaust gas composition of Diesel Engine [17]

Main Exhaust Gas Component	Approx % by volume	Approx g /kWh
Nitrogen N_2	74.0-76.0	5020-5160
Oxygen O_2	11.6-12.6	900-980
Carbon Dioxide CO_2	5.2-5.8	560-620
Steam H_2O	5.9-8.6	260-370
Inert gases	0.9	75
Sulphur Oxides SO_x	0.08	9.6-16
Nitrogen Oxides NO_x	0.08-0.15	12
CO, THC and VOC	0.02-0.09	0.8-2

The intake air mainly consists of nitrogen and oxygen which do not influence the combustion process. The main combustion products are CO_2 and H_2O. Secondary combustion products can be listed as sulphur oxides (SO_x), hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), particulates materials (PM) and soot. CO_2 emission is one of the main contributors to the greenhouse effect and is not limited as it is the result of the combustion process of fossil fuels. The air /fuel ratio is high during the combustion process of diesel engines therefore the hydrocarbon and carbon monoxide emissions are lower than other internal combustion engines [16]. For this reason, their emissions are not regulated.

Nitrogen Oxides (NOx)

The Nitrogen oxide emissions are generally referred as NOx emissions. Nitrogen oxides are often called inert gases but it can react with oxygen at high temperatures and form Nitrogen dioxide (NO_2) and Nitric oxides (NO). Therefore the combustion temperature is very important for NOx calculations. Predominant oxide of nitrogen found inside the diesel engine cylinder is NO. Some elements inside the fuel root can react chemically with the oxidised nitrogen in the fuel then form nitrogen oxide emissions. The emitted NO in the exhaust gas of the engine is in high temperature. It reacts with oxygen in the air and very quickly changes the form to NO_2. 5% part of the total NOx emissions are NO_2 emissions [17]. NOx contribute to acid rain, ozone and smog formation in the lower atmosphere especially in urban polluted areas and over-fertilization of lakes and soil.

Sulphur Oxides (SOx)

Sulphur oxides (SOx) are formed during combustion process from the combination of oxygen in the air and sulphur in the fuel-oil No: 6. The small amount of SO_2 can be further oxidized to sulphur trioxide (SO_3). SOx contribute to acid rains, potential detrimental effect on vegetation, human health and buildings.

Particulate Matter (PM)

The particulate material emissions are complex mixture of organic and inorganic materials. These materials can be fuel oil ash, soot (carbon), hydrocarbon components of lube oil and fuel, carbonates and nitrates. Particulate Matter can affect human breathing system. Larger particles are generally filtered and do not cause problems, but Particulate Matter smaller than about 10 µm (PM10) can settle in the bronchi and lungs and cause health problems. Particles smaller than 2.5 µm (PM2.5) tend to penetrate into the gas-exchange regions of the lung [17].

Smoke

The colour of smoke can be white, black, blue yellow or brown. Black smoke mainly consists of carbon particulates (soot). Blue smoke shows an indication the products of the incomplete combustion of the fuel or lubricating oil. The condensed water (H_2O) vapour can be seen white in the exhaust gas. Yellow smoke is the result of NOx emissions. The brown colour the exhaust gas shows the condensed NO_2 component [17].

4.2.2 Utility Boilers

The emission of nitrogen oxides (NOx) and particulate materials (PM) are the primary concerns from distillate fuel oil furnaces. Burning coal and residual (heavy) oils provides additional amount of NOx emissions with respect to burning natural gas and light distillate oils. The sulphur oxides should also be considered when the residual fuel oil is burned. The fuel oils contain little percentages from 0.1% to 1.5% non combustible ash depending on type and quality of fuel oil. Ash, soot and sulphates are the main sources of particulate emissions from the residual fuel oil burners. Big percentage of Sulphur which is approximately %95 in the fuel oil is converted to sulphur dioxide (SO_2) and little amount is converted to SO_3. Vanadium in the fuel oil is important because it acts as a catalyst to convert SO_2 to SO_3. The SO_3 can go to sulphuric acid (H_2SO_4) and calcium, magnesium, sodium sulphate. Therefore the increased vanadium means increased particulate emissions. Sodium and vanadium has also effects on boiler surfaces. They form sticky ash compound on boiler pipes therefore decrease the heat transfer efficiency. Some additives like alumina, dolomite and magnesia are used to reduce effects of these compounds. Therefore they can be removed easily with soot blowing. Some other fuel oil additives often increase the emissions of particulates. The best way to control the soot is good burner design. Smoke is an opaque combustion product which consists of soot and ash particles. Soot can be formed in fuel rich zones of combustion at high temperatures. The empirical formula of fresh soot is C_8H. It is identified by bright white yellow radiation thus it transfers heat to the boiler walls. Nitrogen oxides can be formed from the nitrogen in the fuel and combustion air. The distillate and residual fuel oils contains different amounts of Nitrogen. No: 6 fuel oil contains from 0.1% and 0.5% nitrogen. The distillate fuel oils contain approximately 0.01%

nitrogen. About 10% to 60% of nitrogen in the fuel is formed to NO after combustion. This fraction is dependent to oxygen amount during combustion. In fuel rich region of combustion, much of nitrogen forms to N_2. It means that reduced air flow or reduced excess air in combustion also reduce the NO formation.

The thermal power plant in Teknecik, North Cyprus is a fuel oil fired steam power plant, in which the No: 6 residual fuel oil is used as fuel. The steam thermal power plant is designed according to Rankine cycle which the water is heated in boiler and superheated then superheated steam is expanded in turbine. The plant overview can be seen in Appendix E. There are twin steam power plants in Teknecik both have maximum power capacity of 60 MW.

The boiler in the plant is a water tube type boiler which the heated water rise to drum then steam is reheated in the super heaters. There are totally 6 steam atomisation type burners used for ignition and injection of fuel for combustion. Superheated steam at about 515 ^{0}C and 87 bars rotates the steam turbine at 3000 rpm and produce maximum power of 60 MW. The expanded steam is cooled by sea water in a condenser. The condensed water is pumped into feed water tank. The water is heated in low pressure heaters in the way to feed water tank. The heated water is pumped from the feed water tank and heated again in high pressure heaters and economiser then reaches to boiler drum.

The combustion air is supplied with draft fans and heated with steam pre heaters and air pre heaters. The combustion gas is used as heat source in air pre heaters.

4.3 Emissions of Power Plants in N. Cyprus

Teknecik power plant consists of 6 reciprocating diesel generators and 2 twin steam turbines as mentioned earlier. The private company AKSA have also 8 diesel generators in Kalecik power plant. Diesel generators in Teknecik and Kalecik power plants are same type WARTSILA V46 engines.

All the electricity production system in N. Cyprus uses No: 6 type residual Fuel Oil which is the worst quality of fuel oils. The properties are given in the Table 4.2. These parameters are the guarantied limits by the Turkish Cyprus Electricity Utility Company (KIB-TEK). The properties can be change between these limits.

Table 4.2: Properties of fuel oil used in N. Cyprus Power Plants [18]

Heavy Oil ASTM NO:6					
PROPERTY	Viscosity, SSF at 50 ^{0}C	Pouring Point, ^{0}C	Flash Point, ^{0}C	Specific gravity at15^{0}C, g/lt	Water content (volume %)
GUARANTIE	***Max 300***	***Max 27***	***Min 70***	***Max 0.993***	***Max 0.5***
PROPERTY	Sediment Content,wt %	Ash, weight %	Sulfur, weight %	HHV (kcal/kg)	LHV (kcal/kg)
GUARANTIE	***Max 0.5***	***Max 0.1***	***Max 3.5***	***Min 10150***	***Min 9600***
PROPERTY	Hydrogen, weight %	Nitrogen, weight %	Vanadium, weight	Sodium, weight	Asphalten, weight %
GUARANTIE	***10.7***	***0.7***	***Max180ppm***	***Max 35ppm***	***Max 7***

The KIB-TEK asks for quality test reports made by independent laboratories before accepting the fuel oil. One example of a quality test report made by Tüpraş can be seen in Appendix F.

There are some methods to find the emissions of the fuel oil in utility systems. Mass balance is a method using mass conservation theory. According to this theory the total mass of reactant in chemical reactions are equal to the products. In this method, ideal conditions are considered during combustion reaction. The combustion is considered as Theoretical combustion. It means that the combustion is complete thus all the carbon in the fuel oil burns to CO_2, hydrogen to H_2O and sulphur to SO_2. It is difficult to obtain complete combustion in real conditions. C, H_2, or CO can be in the product side of the chemical reaction of incomplete combustion reaction. Theoretical air is used in the combustion process and that combustion is called Stoichiometric combustion. It means that the minimum amount of air is used for complete combustion and no excess air is used. In normal combustion process the combustion is not complete and the amount of air can be more or less. Deficiency or excess of air is possible during combustion process. Air composition in the ideal conditions is composed of only oxygen and nitrogen. Others small constituents are neglected or added to nitrogen side. The chemical formula of air is accepted as 1 mole of Oxygen (O_2) with 3.76 moles of Nitrogen (N_2).

It is necessary to know the molar mass of the elements and elemental analysis of the fuel to find the molecular formula.

Table 4.3: Molar mass of some elements

Molar Mass of the Elements		
Symbol	Element	Atomic weight (g/mol)
C	Carbon	12
H	Hydrogen	1
O	Oxygen	16
S	Sulphur	32
N	Nitrogen	14

The elemental weight analysis of the Fuel Oil No:6 used in North Cyprus power plants is given that

C: 83.87 %

H: 11.34%

S: 3.5%

O: 0.78 %

N: 0.39 %

A small fraction of H_2O (0.03%) in the fuel evaporates and it doesn't affect on emissions therefore it is neglected during mass balance analysis.

It is assumed that the fuel is burned completely without excess air and theoretical combustion occurs. All the carbon in the fuel burns to CO_2 and all the hydrogen to water (H_2O), sulphur to SO_2 and nitrogen to N_2. Stoichiometric amount of air (a_{th}) is used.

The mole numbers of the elements can be found from the weight percentage value and molar mass.

N: Mole number, m_x: Weight percentage, M_x: Molar mass

$N_C=m_c/M_c$: 83.87/12 = 6.9892 moles of Carbon

$N_H=m_H/M_H$:11.34/1 = 11.34 moles of Hydrogen

$N_S=m_s/M_s$:3.5/32 = 0.109395 moles of Sulphur

$N_O=m_O/M_O$:0.78/16 = 0.04875 moles of Oxygen

$N_N=m_N/M_N$:0.39/14 = 0.02786 moles of Nitrogen

The chemical equation for the mass balance is written below.

$$6.9892\,\mathbf{C} + 11.34\,\mathbf{H} + 0.109395\,\mathbf{S} + 0.04875\,\mathbf{O} + 0.02786\,\mathbf{N} + \mathbf{a_{th}}\,(\mathbf{O_2} + 3.76\mathbf{N_2})$$

$$\rightarrow \mathbf{x\,CO_2 + y\,H_2O + zSO_2 + wN_2} \ldots\ldots (1)$$

C: 6.9892 =x **x**= 6.9892

H: $11.34 = 2y$ $\mathbf{y}= 5.67$

S: $0.109395=z$ $\mathbf{z}=0.109395$

O: $0.04875+2a_{th}=2x + y + 2z$ $\mathbf{a_{th}} =9.90922$

N: $3.76\ a_{th}.2 = 2w$ $\mathbf{w}=37.2587$

$6.9892\ \mathbf{C} + 11.34\ \mathbf{H} + 0.109395\ \mathbf{S} + 0.04875\ \mathbf{O} + 0.02786\ \mathbf{N} + \mathbf{9.90922\ (O_2+}$ $3.76\mathbf{N_2)}$

$\rightarrow \mathbf{6.9892\ CO_2 + 5.67\ H_2O + 0.109395\ SO_2 + 35.2587\ N_2}$.................................... (2)

The stoichiometric coefficient of air a_{th} is found 9.90922.

It seems from the formula that if 100 kg of fuel is burned with air, 6.9892 mole of Carbon dioxide CO_2, 5.67 moles of water (H_2O), 0.109395 mole of sulphur dioxide (SO_2), 35.2587 moles of N_2 is released to environment. The weight of the components can also be found.

- 6.9892 moles of CO_2: 307.52 kg
- 5.67 moles of H_2O : 102.06 kg
- 0.109395 mole of SO_2: 7 kg
- 35.2587 moles of N_2 : 987.24 kg

The other method to find the emissions use the emission factors already measured for specific utility systems. The emission factors according to the U.S. EPA AP-42 for residual fuel oil fired utility boilers and large diesel fired stationary engines are given in the Table 4.4 below.

Table 4.4: Emission Factors (U.S EPA AP-42)

	Residual Fuel Oil Fired Utility Boilers			**Large Diesel Fired Stationary Engines**		
Contaminant Name	*Emission Factor (lb/10^3 U.S.gal)*	*Emission Factor (gr/Liter)*	***Emission Factor (gr/kg)***	*Emission Factor (lb/MMBtu)*	*Emission Factor (gr/kcal)*	***Emission Factor (gr/kg)***
CO_2	25000	2995.7	**3016.72**	165	0.2970028845	**2849.34**
CO	5	0.59914	**0.6034**	0.85	0.0015300149	**14.688**
Methane	0.28	0.03355	**0.03379**	8.1x10^{-3}	1.458x10^{-5}	**0.148**
Nitrous Oxide (NO)	0.53	0.06351	**0.06396**	-	-	
Oxides of Nitrogen (NO_2)	55	6.59054	**6.637**	3.2	0.005760056	**55.3**
PM10	5.9 x (1.12***S*** + 0.37)	*2.4142*	***2.4312***	0.0496	8.9281x10^{-5}	**0.857**
PM2.5	4.3 x (1.12***S*** + 0.37)	*1.7595*	**1.772**	0.0479	8.6220837377x10^{-5}	**0.827**
SO_2	157***S***	*5.495*	**5.534**	1.01***S***	*0.03535*	**339.36**
Total Particulate Matter	9.19***S*** + 3.22	*3.542*	**3.567**	0.062	1.1160108387x10^{-4}	**1.1137**
Volatile Organic Compounds	0.76	0.09107	**0.09171**	0.0819	1.4742143176x10^{-4}	**1.413**

S represents the sulphur percentage which is 3.5% for the fuel oil no: 6 used in N. Cyprus power plants. Particulate materials and SO_2 values are calculated for S: 0.035 in the tables above.

The operating values of the power plants in N. Cyprus are given in the Table 4.5 for the year 2012. Gross and net electricity productions and total fuel consumption of the plants are taken from the technical office of Teknecik Power Plant. The specific gross and net fuel oil consumptions are found from those values. The Net Specific consumption is considered during emission calculations, because the internal consumption of the PV power system is not taken into considerations.

Table 4.5: N. Cyprus Power Plants operating values in 2012 [18]

<table>
<tr><th></th><th>Teknecik Steam Turbines</th><th>Teknecik Diesel Generators</th><th>AKSA Diesel Generators</th></tr>
<tr><td rowspan="2">Gross Energy Production (kWh)</td><td rowspan="2">490,538,139</td><td>234,920,357</td><td>638,462,016</td></tr>
<tr><td colspan="2">873,382,373</td></tr>
<tr><td rowspan="2">Internal Consumption (kWh)</td><td rowspan="2">33,604,200</td><td>3,703,922</td><td>9,422,726</td></tr>
<tr><td colspan="2">13,126,648</td></tr>
<tr><td rowspan="2">Internal Consumption Rate (%)</td><td rowspan="2">6.85</td><td>1.58</td><td>1.48</td></tr>
<tr><td colspan="2">1.50</td></tr>
<tr><td rowspan="2">Net Production (kWh)</td><td rowspan="2">456,933,939</td><td>231,216,435</td><td>629,039,290</td></tr>
<tr><td colspan="2">860,255,725</td></tr>
<tr><td rowspan="2">Fuel Oil Consumption (ton)</td><td rowspan="2">131,730</td><td>46,658</td><td>129,312</td></tr>
<tr><td colspan="2">175,970</td></tr>
<tr><td rowspan="2">Specific Consumption (g/kWh)</td><td rowspan="2">268,54</td><td>198,6</td><td>202,54</td></tr>
<tr><td colspan="2">201.5</td></tr>
<tr><td rowspan="2">Specific NET Consumption (g/kWh)</td><td rowspan="2">288,3</td><td>201,8</td><td>205,6</td></tr>
<tr><td colspan="2">204,5</td></tr>
<tr><td>Specific Net Average Consumption (g/kWh)</td><td colspan="3">233.6</td></tr>
</table>

The diesel engines consume about 0.5 g/kWh lube oil. Then the specific net consumption is **205 g/kWh** for the reciprocating diesel generators. The specific net consumption for the Teknecik steam turbines is taken **288.3 g/kWh** for the emission calculations. The average net specific consumption without lube oil consumption of diesels is 233.6g/kWh. It increases to **233.9 g/kWh** with lube oil consumption.

The emissions of the power systems can be calculated according to balanced combustion reaction equation and from EPA emission factors. The specific net consumption values are used for calculating the unit amount of emissions released to environment per one kilowatt hour energy production. The emissions of the fuel oil fired steam turbine power plants and reciprocating diesel engines have been calculated and given in the following table.

Table 4.6: The emissions of Electrical Power Units in N. Cyprus

	Teknecik Fuel Oil Fired Utility Boilers		**Teknecik and AKSA Diesel Generators**	
Contaminant	Mass Balance Analysis (g/kWh)	Emission Factors EPA AP-42 (g/kWh)	Mass Balance Analysis (g/kWh)	Emission Factors EPA AP-42 (g/kWh)
CO_2	886.58	869.72	630.42	584.115
CO		0.17396		3.011
Methane		0.009742		0.03034
Nitrous Oxide (NO)		0.01844		
Oxides of Nitrogen (NO_2)		1.913447		11.3365
PM10		7		0.17568
PM2.5		0.5108		0.16954
SO_2	20.181	1.5955	14.35	69.569
Total Particulate Matter		1.0284		2.2831
Volatile Organic Compounds		0.02644		0.2897
N_2	2846.2	-	2023.8	-

Energy generated in Serhatköy PV power plant replaced the fossil fuel that is combusted in the Teknecik and Kalecik (AKSA) power generation plants in N. Cyprus. Hence the absorbed solar energy resulted in a reduction of emissions.

The emission analysis is made according to **2,209,322 kWh** energy production of PV system in Serhatköy in 2012. The Power generation plants in N. Cyprus use only fuel oil no: 6 to produce electricity; therefore the energy supplied by the Serhatköy PV plant has replaced only the fuel oil. The table 4.7 shows the potential reduction of GHG emission (CO_2) and other environmentally harmful emissions according to energy production of Serhatköy PV plant in 2012. The emission values in Table 4.6 for utility boilers and reciprocating diesel engines are used as reference for calculation.

Table 4.7: Potential reduction of emissions in 2012

	Teknecik Fuel Oil Fired Utility Boilers		**Teknecik and AKSA Diesel Generators**	
Contaminant	Mass Balance Analysis	Emission Factors EPA AP-42	Mass Balance Analysis	Emission Factors EPA AP-42
(GHG) CO_2 (tones)	1958.74	1921.49	1391.87	1290.5
CO (kg)		384.33		6652.36
Methane(kg)		21.52		67.03
Nitrous Oxide (NO) (gr)		40739		-
Oxides of Nitrogen (NO_2) (kg)		4227.42		25045.98
PM10 (kg)		15485.47		388.14
PM2.5 (kg)		1128.67		374.56
SO_2 (kg)	44586	3524.87	31703.8	153699.8
Total Particulate Matter (kg)		2271.99		5044.07
Volatile Organic Compounds (gr)		58414		639963
N_2 (tones)	6288	-	4471	-
Serhatkoy PV Power Plant Production in 2012 = 2,209,322 kWh				

The emission values found from EPA emission factors are different than mass balance analysis method. The ideal and theoretical combustion was assumed in mass balance analysis method while the EPA emission factors are calculated in a specific test conditions. Although the fuel is same, the power units used in EPA tests can be different than N. Cyprus power plants.

Chapter 5

ECONOMIC FEASIBILITY

5.1 Financial Analysis Method

The LCC method considers all the costs involved to system and uses Net Present Value (NPV) method to determine the lowest cost among the alternative systems. The savings to investment ratio (SIR) which is the ratio of operational savings to difference in capital investment cost can also be found to see whether the investment is feasible or not [20]. There are other methods for economic analysis of an investment project such as simple pay back method. These are short-sighted and only focus on the initial investment and do not consider the time value of the money.

5.2 Electricity Generation Cost in 2012

Total net electrical energy generation of KIB-TEK and costs involved in power generation are presented in Table 5.1. See Appendix G for detailed calculations.

Table 5.1: Net electricity generations and power generation costs

Net Productions	
Steam Turbine	456,933,939 kWh
Diesel Generators	860,255,725 kWh
Total Production	1,317,189,664 kWh
Power Generation Costs	
Fuel	642.6 $ /tonne
Service, spare parts and maintenance	0.0023 $/kWh
Personnel Cost	0.01 $/kWh
Redemption Fund	0.02 $/kWh
Total Cost excluding fuel cost	0.0323 $/kWh
Average Fuel Cost	0.15 $ /kWh
Total Cost	**0.1823 $/kWh**

This cost does not include the expenses of transmission and distribution. It is the power generation cost.

5.3 Electricity Selling Price

In 2012, 65.31% of the total electricity generation of North Cyprus was produced by Diesel generators; the remaining 34.69% part was produced by steam turbines in Teknecik Power Plant. The KIB-TEK has transmitted the total energy produced in 2012 to the consumers with average of 9% transmissions and distribution losses.

The selling tariff of KIB-TEK for the different consumer types are presented in Table 5.2.

Table 5.2: KIB-TEK electricity selling price in 2012 and current price [21]

Tariff Name	Year 2012 (TL/kWh)	Current (2014) (TL/kWh)
Temporary Current	1.02	1.26
Residence Tariff (0-250 kWh)	0.38	0.45
Residence Tariff (251-500 kWh)	0.44	0.55
Residence Tariff (501-750 kWh)	0.52	0.67
Residence Tariff (751- above)	0.65	0.84
Commercial Tariff	0.40	0.46
Industrial Tariff	0.40	0.46
Tourism Tariff	0.40	0.46
Water Pumps	0.40	0.46
Street Lamps	0.45	0.59
Army Tariff	0.38	0.45
Government Office	0.60	0.68

The KIB-TEK company sold the electricity to the different consumers. The percentage of energy used in 2012 by different consumers is presented in Table 5.3.

Table 5.3: Energy usage of consumer groups in 2012

Consumer Groups	Usage (%)
Commercial, Industrial and Tourism	38.25
Residence	32.95
Army Usage	7.04
Water Pumps	4.82
Government Office	4.14
Street Lamps	2.45
Temporary Current	1.36
LOSS	8.99

After finding the energy usage of the consumers, the sale price of the energy which was produced by the Serhatköy PV Power plant in 2012 can be found by using consumer usage percentage and electricity selling tariffs.

Table 5.4: The sale price of energy produced by Serhatkoy PV Power Plant

Serhatkoy PV Plant Production= **2,209,322 kWh**					
Consumer Groups	**Usage (%)**	**Usage (kWh)**	**Tariff (TL/kWh)**	**Sale Price(TL) 2012**	**Sale Price (TL) 2014**
Commercial , Industrial and Tourism	38.25	845065.6	0.40/0.46	338026	388730
Residence	32.95	727971.6	0.40/0.50 (average)	291189	363986
Army Usage	7.04	155536.3	0.38/0.45	59104	69991
Water Pumps	4.82	106489.3	0.40/0.46	42596	48985
Government Office	4.14	91465.9	0.60/0.68	54880	62197
Street Lamps	2.45	54128.4	0.45/0.59	24358	31936
Temporary Current	1.36	30046.8	1.02/1.26	30648	37859
LOSS	8.99	198618	-		
TOTAL	**100**	**2209322**	**-**	**840801**	**1003684**

The KIB-TEK has sold the 2,209,322 kWh energy produced in Serhatkoy PV power plant and received **840,801** Turkish Lira (TL) from the sales in 2012. The sale price is **1,003,684 TL** according to today's electricity tariff. This amount is the **annual income** of Serhatköy PV Power Plant to the KIB-TEK in 2012.

5.4 Life Cycle Costing Calculations

The LCC analysis in this work will be performed by using a LCC program prepared in excel spread sheet on utilising fossil fuel fired power plants and solar PV power plant in N. Cyprus, and taking advantage of annual savings. The LCC deals with the net present value (NPV) savings-to-investment ratio (SIR), internal rate of return (IRR) and simple payback period (SPP). The equations for evaluating these parameters as follows;

$$\text{NPV} = \sum_1^n \text{AS} - \sum_1^n \text{LCI} \quad (3)$$

$$\text{SIR} = \sum_1^n \text{AS} \,/\, \sum_1^n \text{LCI} \quad (4)$$

IRR= Discount rate, where SIR=1, or NPV=0................................(5)

SPP=Initial investment /Annual savings................................(6)

Where *AS* is the present value annual savings, *LCI* is the present value life cycle investments. Economic life-time of the projects is *n* years. *SPP* is straight forward calculation that does not take into account the time value of money and it is not meaningful unless it generates results which are less than one year. The following data are required for the calculations.

- **Initial Investment**: Initial cost of Serhatköy PV Power Plant; 3,770,823 Euro =5,184,882 Dollars. * 1 Euro = 1.375 Dollar (05.2014)
- **Energy Conservation Measure (ECM)**: Replacement and future costs (operational and maintenance) for new and old technologies.

Replacement Cost for Old Technology: 750,000 Euro = 1,031,250 Dollars

- **Operational and Maintenance Cost**: The maintenance annual cost of the PV power plant in Serhatköy is estimated to be $ 30,000.

The operational and maintenance cost of old system (fossil fuel fired systems) is calculated as $ 26,500 annually.

Period of Analysis: 20 years; the solar panels' efficient period given by the manufacturer.

- **Residue value:** The remaining salvage or resale value after 20 years. 1/5*initial cost =1,036,976 $
- **Interest/ Discount Rate:** The discount rate used in the analysis is 6%.

- **Annual Savings:** It was calculated in the previous section that total power generation cost is 0.1823 $ /kWh. The annual income of Serhatkoy PV Power plant to the KIB-TEK in 2012 is given that;

  Annual Savings: 2,209,322 kWh x 0.1823 $ /kWh: **402,760 $**

All the data mentioned above were used in (LCC) analysis program and economical feasibility of the PV Power plant was analysed. In Case 1, the annual savings of the PV Plant is calculated according to 2012 tariff and residual value of the Power Plant is accepted as zero. In Case 2, the recent tariffs are used and residual value is accepted as one third of initial investment of the PV Plant.

Table 5.5: Life Cycle Costing Analysis

	Results
Net Present Value (NPV)	750,274 $
Savings to Investment Ratio	1,2
Internal Rate of Return (IRR)	8%
Simple Payback (years)	10,3

The life cycle cost analysis showed that the Serhatkoy PV power plant will result in about 10 years payback of initial investment and net positive cash flow will start after 10 years. It is shown that savings to investment ratio is above one (1), which show that the investment is economically feasible.

Chapter 6

DISCUSSION AND CONCLUSION

This study investigates the sustainability of installing PV power plants in N. Cyprus including the possible benefits on the environment and economy. The Serhatköy PV power plant is compared with the conventional fossil fuel fired power plants in N. Cyprus.

The measurement results according to the Metenorm V6 (MN6) [11] program showed that the solar potential is quite high compared with wind and other renewable energy sources. Annually, 2000 kWh/m^2 of global solar radiation reaches on an optimally inclined surface (between 25^0-35^0) according to MN6 program for Dikmen side of N. Cyprus.

The largest grid connected PV power plant of Cyprus with maximum capacity of 1.275 MWp located in Serhatköy was investigated thoroughly in this thesis. The measurements showed that the total electricity production of Serhatkoy PV Power Plant in 2012 was 1,985,215 kWh with 30 days of stoppage. Assuming that the power plant was operated during these days as well it was estimated that the annual energy production was 2,209,322 kWh. A realistic assumption for the capacity factor is therefore 19.78% assuming full operation throughout the year.

The emission analysis was conducted in chapter 4 for the fuel oil fired power plants in N. Cyprus. Firstly, the mass balance analysis method was used to find the specific GHG emissions and other harmful emissions according to elemental weight percentage of fuel oil No: 6 used in the thermal power plants of N. Cyprus. Then the emission factors of EPA were used to compare the emissions. The operating values of the Teknecik and Kalecik Power Plants were collected to find the specific fuel consumption of both reciprocating diesel engines and steam turbine power plants. The results showed that averagely 516.76 tonnes of fuel oil No: 6 were needed to produce the Serhatkoy PV Plant's energy production in 2012. It means that the 1,958 tonnes of CO_2 according to mass balance analysis would be emitted to the atmosphere if 637 tonnes of fuel oil had burned in steam thermal power plants. It would reduce to 1,392 tonnes of CO_2 and 453 tonnes of fuel oil No: 6 if it had burned in more economic diesel engines.

The Life Cycle Cost (LCC) method was used to find the feasibility of Serhatkoy PV power plant. The electricity production cost and sale price of KIB-TEK was used to find the annual savings. The annual income from the PV power plant was found 1,003,684 TL according to today's electricity tariff. The LCC analyse showed that savings to investment ratio is higher than one (1) and thus the PV Power Plant in Serhatköy is economically feasible.

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APPENDICES

Appendix A: Technical Specifications of Solar Module

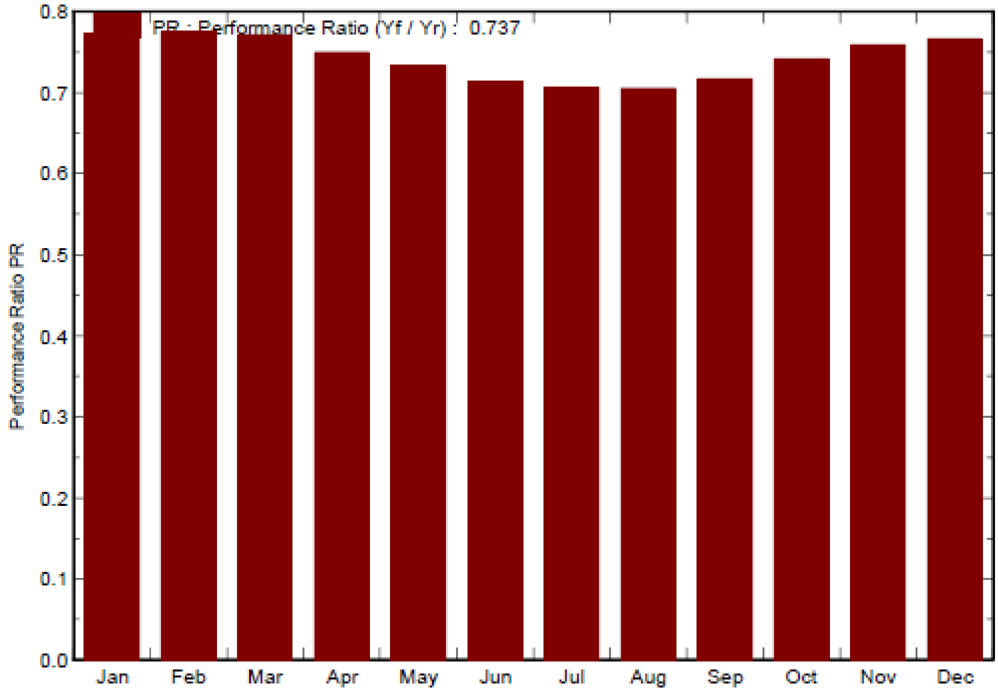
Power Class					
Type	$Pmpp_{[WP]}$	$Umpp_{[V]}$	$Impp_{[A]}$	$Uoc_{[V]}$	$Isc_{[A]}$
KPV 205 PE	**206.02Wp**	**25.98V**	**7.93A**	**32.57V**	**8.44A**
	$Pmpp_{[WP]}$: *Maximum power capacity*	$Umpp_{[V]}$: *Voltage at maximum power*	$Impp_{[A]}$: *Current at maximum power*	$Uoc_{[V]}$: *Open circuit voltage*	$Isc_{[A]}$: *Short circuit current*
54 multi crystalline cells , 156mm X 156mm Tyco-Solarlok connection systems, maximum system voltage 1000 V DC Power Tolerance (+/-%3) * Temperature Coefficients : Pmpp= -0.46%K , Uoc= -116.1 mV/K, Isc=+4.40 mA/K *Standard Test Conditions (STC) : AM 1.5 /1000W per m^2/ 25 ^{0}C Ambient temperature: +85 ^{0}C bis -40 ^{0}C					

Technical Data	
Dimensions	1507mm X 992mm X 33mm (+/-2mm) with aluminium frame
Weight	16.5 kg
Glass specification	Solarglas ESG 3.2 mm
Encapsulation material	Etimex
Backside material	Isovolta, krempel
Test Certificate	Protection class II **, IP 65, IEC 61215, Ed. 2 incl. Mechanical Load Test up to 5400 Pa **up to 1000 V

Appendix B: Technical Specification of Inverter

INPUT PARAMETERS (DC Side)	
Nominal DC power	**13 kW**
Maximum recommended DC power	**14.3 kW**
Operating MPPT Input voltage range	**200-850 Vdc (580 Nominal)**
Full power MPPT range	**360-750 Vdc**
Maximum DC current	**18 Adc (22Adc short circuit)**
OUTPUT PARAMETERS(AC Side)	
Nominal AC power (up to 50 ^{0}C)	**12.5 kW**
Maximum AC power	**13.8 kW**
AC grid connection	**3 phase ,400Vac ,50 Hz**
Nominal AC voltage	**3x400Vac**
Maximum AC voltage range	**311-456 Vac**
Maximum AC Line current	**20 A / 1 faz (22A short circuit currnet)**
Maximum efficiency	**97.7%**
Stand by Consumption	**12 W**
Environmental Parameters	
Cooling	**Natural cooling**
Ambient Temperature range	**-20/+60 ^{0}C (Output power derating above 50 ^{0}C)**
Mechanical	
Size (WxHxD)	**650x620x200 mm**
Weight	**38 kg**

Appendix C: Performance Ratio of the Serhatköy PV Power Plant



Appendix D: The Main Simulation Results

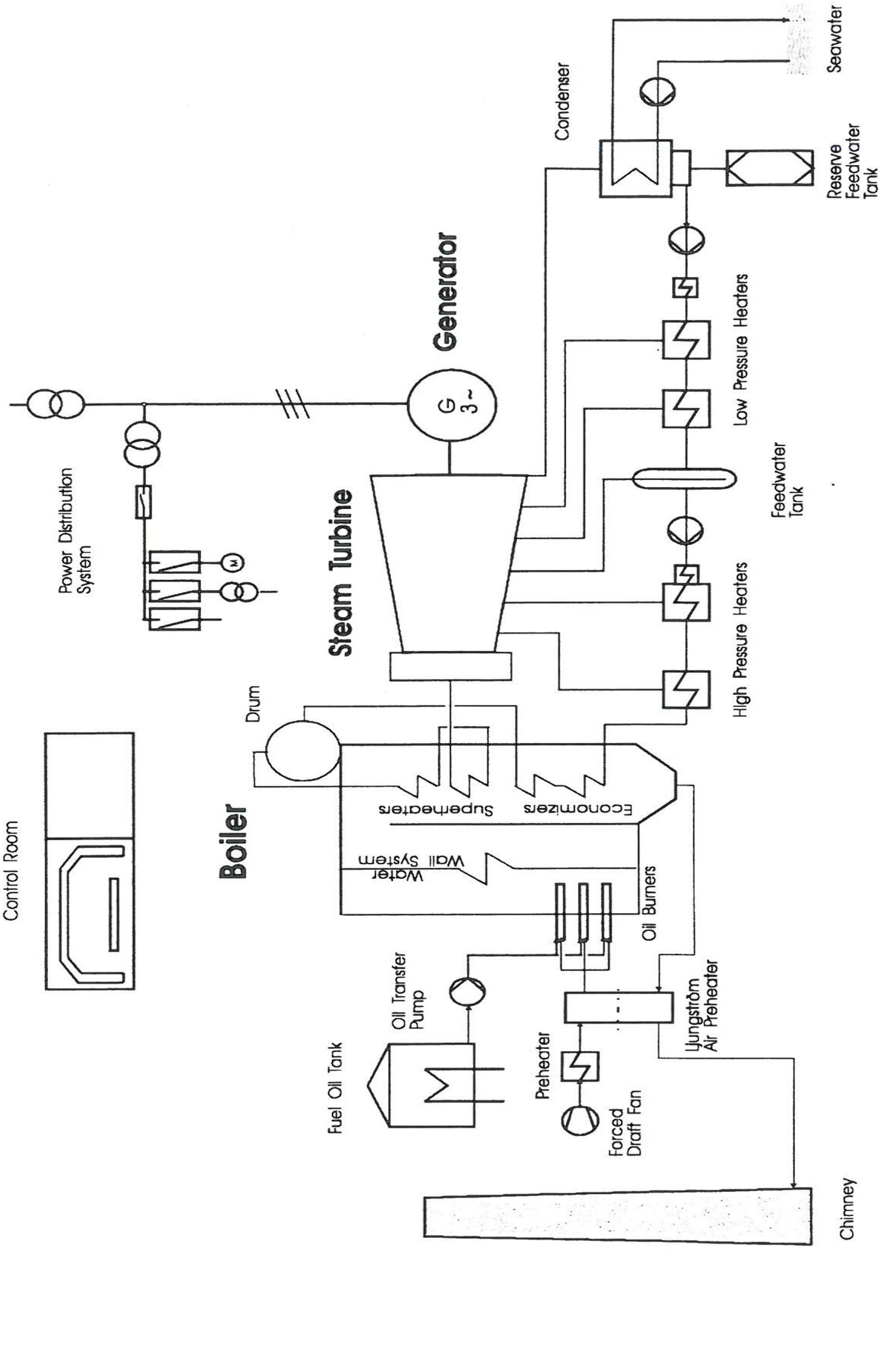
Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	76.3	11.50	109.9	102.3	112930	108227	11.10	10.64
February	91.6	11.70	119.6	113.2	123515	118218	11.16	10.68
March	139.2	13.60	165.1	156.3	169595	162236	11.10	10.62
April	169.5	16.80	180.9	171.4	181061	172909	10.82	10.33
May	205.2	21.20	202.2	191.3	197880	189186	10.57	10.11
June	217.8	25.10	206.6	195.5	196698	188008	10.28	9.83
July	217.0	27.80	209.4	198.3	197120	188508	10.17	9.73
August	198.1	27.70	204.0	193.6	191967	183493	10.16	9.71
September	160.2	25.10	183.2	174.3	175376	167647	10.34	9.88
October	123.7	21.60	158.7	150.6	156791	150045	10.67	10.21
November	84.3	16.90	120.9	113.7	122041	116961	10.91	10.45
December	67.3	13.30	99.3	92.1	101176	96997	11.01	10.55
Year	1750.1	19.40	1959.8	1852.5	1926150	1842433	10.62	10.16

Legends:

GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

Appendix E: Basic Schema of Steam Thermal Power Plant in Teknecik, N. Cyprus



Appendix F: Fuel Oil Quality Test Report

Tüpraş

TÜRKAK
TURKISH ACCREDITATION AGENCY
Expiry date:11.05.2015

TUPRAS Izmir Reflery Analysis Laboratory, 35800 Aliağa İzmir

TÜRKAK AB-0120-T

AB-0120-T	
Acreditation no	AB-0120-T
Report Number	6041
Date of Report	27.10.2013

CERTIFICATE OF QUALITY - FUEL OIL PRODUCT TEST REPORT

CUSTOMER NAME AND ADDRESS		:	Turkish Petroleum International Company Limited 15 Esplanade, St Helier, Jersey JE1 RB Channel Islands
DATE OF TEST		:	27.10.2013
SAMPLE	RECEIVED	NAME :	Tüpraş İzmir Refinery
	RECEIVER	PLACE :	Operation Department
		ADDRESS :	Tüpraş İzmir Refinery (35800) Aliağa - İZMİR
	RECEIVING	METHOD :	TS-900-1 EN ISO 3170 DATE : 27.10.2013
		PLACE :	TANK : Tk-3109**
TANKER		:	M/T SICHEM RIO
FULL TEST ENTRY NO			2797
DELIVERING	NAME		Operation Department
	ADDRESS		Tüpraş İzmir Refinery (35800) Aliağa - İZMİR
	DATE	:	27.10.2013 NO :

PROPERTY	TEST CODE	UNIT	REFERENCE LIMIT VALUES		MEASUREMENT UNCERTAINITY		RESULT	METHOD
			MIN	MAX				
Ash,	510	Wt Pct	-	0,1	±	0,003	0,038	EN ISO 6245
Density at 15 deg C	100	kg/lt	-	0,9980	±	0,0001	0,9934	EN ISO 12185
Flash Point	200	Deg C	70	-	±	3,3	74	EN ISO 2719
Pour Point	220	Deg C		5	±	-0,3	-18	ISO 3016
Sediment and Water	120	Vol pct	-	0,3	±	0,03	0,2	EN ISO 12937
Sediment by Extraction	140	Wt pct		0,2	±	0,000	0,017	EN ISO 3735
Sulphur	540	Wt pct	-	3,5	±	0,07	3,45	EN ISO 8754
Viscosity at 100 deg C,	110	cSt	-	50	±	0,2	20,02	EN ISO 3104
Vanadium	130	ppm	-	180	±	2,44	122	IP-501
Conradson Carbon Residue	250	Wt pct	-	18,0	±	1,3	15,2	ASTM D-4530
Asphaltenes	340	Wt pct	-	7,5	±	0,27	7,4	IP-143

REMARKS

"*" marked analyses are not under the guarantee of accreditation.
**Test item is taken by operator of the Operations Department.
The Turkish Accreditation Acency(TURKAK) is signatory to the multilateral agreements of the European co-operation for the Accreditation(EA) and of the International Laboratory Accrediation(ILAC) for the Mutual recognation of test reports.
The testing and/or measurement results, the uncertainties(if applicable) with confidence probability and test methods are given on the following pages which are part of this report.
This report shall not be reproduced other than in full except with the permission of the laboratory. Testing reports without signature and seal are not valid.

TÜPRAŞ-TURKISH PETROLEUM REFINERIES CORP
GUNEY MAH.PETROL CAD. NO:25
41790 KOCAELI/ TURKEY

TURKISH PETROLEUM REFINERIES CORP. * İZMİR REFINERY * Tüpraş

Seal

1173
Chemist

... analysis witnessed by us. Our responsibility ... ensure that the analysis is conducted to standard test methods in accordance with industry accepted practice. We are not responsible for all apparatus, instruments and measuring devices, calibration of same and working order. Reagents and solutions are acceptable as provided.

İZR.TSM.FRM.0300/Rev.08/07.07.2006

1/1

Appendix G: Power Generation Costs

Steam Turbine: 456,933,939 kWh

Diesel Generators: 860,255,725 kWh

Total Production: 1,317,189,664 kWh

- **Fuel**

-Freight charge for cargo: 50 $ / tonne fuel oil

-Fuel Oil price (average): 580 $/ tonne

-Letter of credit costs: 580+50= 630*0.02 =12.6 $/ tonne

-Total Cost of Fuel Oil: 630+12.6= **642.6 $/tonne**

- **Service, Spare Parts and maintenance of Steam Power Plant and Diesel Generators:** 3,000,000 $ (average in 2012), 0.0023 $/kWh
- **Personnel Cost of Teknecik and Kalecik Power Plants:** 13,000,000 $, 0.01 $/kWh
- **Redemption (Amortisation) Fund for improvement of systems:** 0.02 $/kWh
- **Total Cost excluding fuel cost:** 0.0023+0.01+0.02 **= 0.0323 $/kWh**
- **Steam Turbine Fuel Cost:** 0.2883 kg/kWh**:** 0.1852 $ /kWh
- **Diesel Generators Fuel Cost:** 0.205kg/kWh: 0.1317 $/kWh

Average Fuel Cost: 0.2339 kg/kWh: **0.15 $/kWh**

TOTAL Cost: 0.15 $/kWh + 0.0323$/kWh **= 0.1823 $/kWh**