# Analysis of Serhatkoy Photovoltaic Power Plant and Production over the Years it Application to a Central City in Nigeria (Markurdi).

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***Abstract*— Solar power is one of the fastest growing renewable energy technologies in today's world. Solar photovoltaics has proven to be a reliable solar power technology over the years. To maximize the potential of this technology, it is important to pay serious attention to its construction and application. Most analysis of solar PV-plants is based on scientific calculations and most of the parameters for the calculation are done assuming a standard set of parameters. An analysis of a PV-plant (Serhatkoy PV Plant) is done in this research. Although the high construction cost makes some techno-economic analysis unrealistic, it gives the constructional and production details of the plant till date and a brief application of a replica of this power plant to a central city in Nigeria. The payback period and capacity factor were shown based on the data collected from the field.**

**Keywords—** ***Efficiency, Payback Period, Power production, Renewable Energy, Solar Photovoltaic, PV-plant.***

## I. INTRODUCTION

The rapid increase in demand of energy in the last two decades has made energy a crucial commodity. Electrical energy is a form of energy that is practically indispensable to the human race and the world at large. Considering the rise in global energy demand and consumption, and also the threat of carbon emission, it is important to find alternative means by which energy is generated especially electrical energy. Preventing an energy crisis is one of the most crucial issues of the 21st century [1].

Renewable energy is basically the use of renewable sources which includes solar, wind, hydro, biomass, tidal, geothermal etc. to produce energy. Renewable energy has been considered as one of the strong contenders to improve plight of two billion people without access to modern forms of energy, mostly in rural areas [2].

Producing electricity from solar radiation is one the cleanest way of electrical energy production and photovoltaic cell is one of the most popular technology used. Electricity production using solar photovoltaic cell(s) is one of the most promising sustainable energy generations for world's future energy requirements [3]. "The rooftop application of photovoltaic is providing the major application today which causes the market growth. Centralized solar photovoltaic power stations able to provide low-cost electricity on a large scale would become increasingly attractive approaching 2020" [3, 4]. A PV-plant or PV field is a power plant that is based on the use of photovoltaic cell to trap and convert solar radiation to useful energy. The unavailability of solar radiation for 24 hours is a major setback for a PV-plant but this problem is often solved by making the system a hybrid system or having a backup conventional/thermal electricity production system that produces electricity when there is little or no solar radiation. Hence, most large solar PV-plants are connected to the grid.

Turkish Republic of Northern Cyprus is an island located close to Turkey in Europe. The solar irradiation on this island is considered one of the highest in Europe, with more than 300 days of the year having some hours of sunny weather and with an annual solar irradiance of 2000kWh/m$^2$on a tilted surface of 27.5 º and this is much higher than the sunniest areas of the world's largest market, Germany [5]. According to solar electricity handbook website, the average solar insolation figures measured in kWh/m$^2$/day onto a horizontal surface is shown in Table 1 below [7]. The total electricity generation summary for this island is given in Table 2.

Turkish Republic of Northern Cyprus only has a PV power plant (Serhatkoy) presently and this plant is capable of generating 1.2MWp.

The aim of this study is to check the production of Serhatkoy PV-plant and also correlate the as a function of the solar insolation. The study mainly depends on both primary and secondary data. The primary data are the measurement made by the authors and the secondary data is the production data collected from KIB-TEK (TRNC department in-charge of the PV-plant). A bar chart is used to show the production of this plant over the years. The data collected is analyzed using SPSS (crosstab correlation tool) to check the effect of solar insolation on the PV-plant production and a scattered diagram was further to show this relation.

A performance analysis was carried out on two 100KW$_p$ PV-plant grid-connected system in same location [18], although this analysis was clearly to optimize its production but its precise installation is a major way in the optimization process. The ambient temperature was seen as one major factor the influences the performance of the PV-plant and the greatest difference were observed between the two systems in summer when sunlight hours is higher [18]. Also in the analysis of a PV generator in a cloudburst precinct in the india, "The monthly averaged daily array yield, final yield, reference yield, capture loss, system loss and performance ratio for NER as a whole are found to be 2.78–4.50 kWh/kWp, 2.49–4.04 kWh/kWp, 54.28 kWh/kWp, 0.61–1.28 kWh/kWp, 0.28–0.45 kWh/kWp and 62.02–77.58%, respectively" [19]. Also, in the potential and cost-effective analysis of a PV-plant made for a garment zone at Jaipur (india), a 2.5MW plant was proposed for a facility whose demand is 2.1MW. this design is meant to cover 13.14acres of land and due to the land scarcity in the area the PV-plant was design to be and off-site system [20]. Checking the requirements of a PV-plant before its being constructed is highly important and case study of similar plant are also recommendable for an effective and balanced production.

Table 1: Average solar insolation of TNRC [7].

| Month | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|
| Solar insolation ($kWh/m^2/day$) | 2.46 | 3.33 | 4.78 | 5.95 | 7.20 | 8.06 |
| Month | Jul | Aug | Sep | Oct | Nov | Dec |
| Solar insolation ($kWh/m^2/day$) | 7.88 | 7.05 | 5.79 | 4.23 | 2.82 | 2.18 |

Table 2: The KIB-TEK power per station [6]

| Power Stations | Power | Units |
|---|---|---|
| Teknecik | 2x60 MW Steam Turbine | 120 MW |
| Teknecik | 1x20 MW Gas Turbine | 20 MW |
| Teknecik | 1x10 MW Gas Turbine | 10 MW |
| Dikmen | 1x20 MW Gas Turbine | 20 MW |
| Kalecik | 4x17.5 MW Diesel Generator | 70 MW |
| Teknecik | 6x17.5 MW Diesel Generator | 105 MW |
| Total Installed Capacity | | 346.3 MW |
| | | |
| Serhatkoy | 1.2 MWp Photovoltaic Plant | 1.3 MW |

One of the third world countries with a very high renewable energy potential is Nigeria, although for most developing countries specific solar data is not yet available like other developed countries [15]. Nigeria's solar radiation vary from as high as $7KW/m^2/day$ in the northern border region to as low as $3.5KW/m^2/day$ in the south coastal region [15, 16]. The under-utilization of renewable energy resources in Nigeria is highly visible on the energy production state of the country and according to world energy council 2014 update, 48% of the total population of Nigeria has access to electricity [15, 17].

This paper is about an analysis of Serhatkoy solar PV plant operation through the years and its application to a central city (Makurdi) in Nigeria. The data used in this work is directly collected from KIB-TEK solar PV plant section and the other details discussed were recorded during the two trips made to the PV-plant/farm.

## 2.0 OVERVIEW OF SERHATKOY PV-PLANT

The only PV-plant on the entire Island of Turkish Republic of Northern Cyprus is Serhatkoy PV-plant. It was named after/according to the village (Serhatkoy) near which it is located in Guzelyurt part of the island. The coordinates of this station is $35^0$ 12ꞌ 10. 55ꞌꞌ N, $33^0$ 05ꞌ 32. 72ꞌꞌ E and its elevation is 167m.

This PV-power plant is a gift to the Turkish Republic of Northern Cyprus from European Union. The construction of this plant was contracted to an international photovoltaic construction company by the name ANEL-TECH (Turkey branch).

### *2.1 Construction Duration*

The construction of this PV-station started in December 2009 and was completed in December 2010. The construction was meant to be between 3-6 months but was delayed due to inadequate funding of the company at some stage of the construction. Although the construction was completed at the end of 2010, the power station didn't start full operation until May 2011 because there were some grid related connection challenges due to unacceptably large frequency variations.

### *2.2 Cost of Installation*

A one megawatt power was initially budgeted to be installed at this site at the cost of 3million Euros but it was later increased to 1.26megawatt and a total of 3.7million Euros was spent in constructing the power plant. This 3.7million Euros does not include the money used for fencing and constructing an accessible road to the power plant.

### *2.3 Field Arrangement/ Spacing*

The PV farm covers an approximate length of 120m and a breadth of 180m giving an approximately area of $21,600m^2$ and the solar panels covers approximately $8,412m^2$. The farm is basically arranged in two columns (north-south) and a power house of approximately $70m^2$ is located in between the two columns in the PV-field. Each column is further divided into two sub-columns with one sub-column consisting of 21 rows of PV panels and the other consisting of 22 rows of PV panels. Each row of a sub-column consists of 72 PV panels connected to an inverter. Total of 86 inverters are used on the field and this makes a sum of 6,192PV panels. Connection arrangement of PV panels, inverters, junction boxes is discussed in detail in the following sections. An aerial view of the field is shown in figure 1.

Wire fencing is done for this PV plant in other to prevent just any individual from accessing the field and also to prevent any kind of accident that may occur due improper handling by inexperienced or solar energy illiterates. This fencing has also helped to prevent any electrocution in the field due to ignorance.

Figure 1: Aerial view of Serhatkoy PV Power station.

Performance of a series connected string of solar cells is adversely affected when all its cells are not equally exposed to solar radiation (partially shaded) [11]. Even though a few cells under shade produce less photon current, these cells are forced to carry the same current as the other fully illuminated cells. If the system is not appropriately protected, hot-spot problem [10] can arise and in several cases, the system can be irreversibly damaged.

The spacing in this PV field was adequately done. The distance between the power house and the PV arrays both to the left and right is 7.5m and the spacing between each column on each side is 2m. The pitch between the PV arrays is 5.46m. The 7.5m space was left between the power house and the filed in order to prevent it from shading the cells at any time of the day.

## 3. CONSTRUCTION

To get a better understanding of the way this power plant is constructed and arranged, the main elements of the system are individually discussed below.

### *3.1 The PV Panel*

Polycrystalline PV panels are used in this farm and each panel is of the size 1.434m x 0.96m.Monocrystallinesolar cells have historically had higher peak efficiency, and were more readily available than polycrystalline solar cells

The general statement that monocrystalline panels are better than polycrystalline cells, however, is not extremely perfect when comparing the performance of PV cells on the field, each panel and its manufacturer should be considered on a case-by-case basis [9, 20], and a slight difference [3% - 5%] is mostly recorded in the efficiency of the two systems . The complication in the manufacturing of monocrystalline cells also gives polycrystalline cells an edge over it [20].

These panels were produced by KIOTO photovoltaics with the model number KPV 205 PE. According to the manufacturers manual, it is rated as 205Wp ($Pmpp_{[WP]}$), 26.39V ($Umpp_{[V]}$), 7.80A ($Impp_{[A]}$), 33.08V ($Uoc_{[V]}$), 8.33A ($Isc_{[A]}$). It has a rated efficiency of 13.71% and a 1kWp PV panel is expected to cover 7.26 $m^2$. The panels have a guarantee of 5 years and an efficiency guarantee of 90% for 10 years and 80% for 25 years [8].

The PV panels are positioned at an angle $30^o$ facing the south. This positioning was done based on the location (latitude) of the PV field. The polycrystalline panel as installed on this field is shown in figure 2.

Figure 2: A cross-sectional view of the PV arrangement of Serhatkoy PV-plant.

### *3.2 Inverter*

Grid connected inverters must supply AC electricity in sinusoidal form, synchronized to the grid frequency, limit feed in voltage to no higher than the grid voltage and disconnect from the grid if the grid voltage is turned off [12, 14].Solar inverters may connect a string of solar panels and a solar micro-inverter is connected at each solar panel in some PV installations [13].

The inverter used in this field is AURORA and it has an efficiency of 98%. This inverter converts direct current (DC) to alternating current (AC) just like most solar PV inverters. 86 inverters were installed on this field and each inverter is connected to 72 PV panels.


Figure 3: Inverter

### *3.3 The Power House*

For most PV plants, the power house is constructed to monitor the performance of the PV-plant. The power house for this field is divided into three compartments,

The first compartment consists of the switches which is used to turn on or off the wing of the system connected to it. It is important to have this in other to minimize risk and also to reduce the tendency of shutting down the whole plant during minor repairs.

The second compartment houses a transformer. This transformer is used to step-up the voltage of production of the power plant before it is sent to the grid. A 1600KVA step-up transformer is installed for this power plant.

Other materials such as junction boxes, busbars, scada systems, different connection cables, iron stands for the panels etc. were also used in the PV plant.

## 4. CONNECTION DETAILS OF THE PV-FIELD

12 PV panels each of 25.98V, 7.93A are connected in series to give one array with 311.76V, 7.93A. 6 of these arrays are connected to one inverter in parallel to increase the current to 47.58A while the voltage remains the same. The output of the inverter, which is rated as 15 KW, is threephase415V, 50Hz.The 86 inverter used are divided to 4 groups, where 2 of the groups have 21 inverters each and the other two have 22 inverters each. The output from each inverter of a group of inverters is connected at a junction box in parallel arrangement. The four junction boxes are then connected to the busbar via MCCB switch.

The other side of the busbar is connected to the step-up transformer before is it finally connected to the grid.

Note that a SCADA(Supervisory Control And Data Acquisition) system is also connected to monitor the production and to give an alert in case of any damage or problem. This smart grid SCADA system (which is use for the distribution and monitoring of the PV-plant and switches it off in case of overloading or any other fault so as to protect the plant from serious damage) is linked to a corresponding SCADA system at the KIB-TEK office. The PV plant electrical connection principle is shown schematically in Figures 4(a), 4(b) and 4(c).

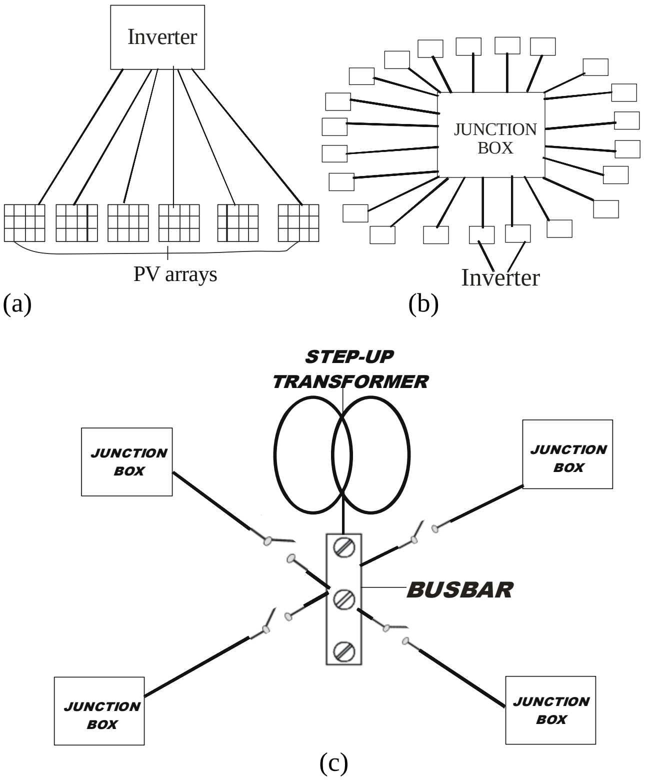


Figure 4a, b, c: showing the three stages of connection of Serhatkoy PV plant.

## 5. EFFICIENCY/CAPACITY FACTOR

The efficiency of most PV cells is between 12%and 25% although a cell with an efficiency of 44.7% has been produced by Fraunhofer.. Most PV cells have their efficiency written in its manual and for the cells used for in Serhatkoy PV station, its efficiency is stated as 13.71%. The overall efficiency of the system can be determined by also considering the efficiency of the inverters used. For this power plant, the inverter is 98% and this drops the overall efficiency to 13.43%.

Annual production:

**E = A * r * H * PR or E= P.H.PR ---------------------[21].**

**E** = Energy (kWh)
**A** = Total solar panel Area ($m^2$)
**r** = solar panel yield (%)
**H** = Annual average solar radiation on tilted panels (shadings not included)
**PR** = Performance ratio, coefficient for losses (range between 0.5and 0.9, default

P= Installed peak power rating (number of panels x peak power rating of each panels)
For this plant:

P: installed peak rating: 1269.36kwp
H: 2000 kwh/$m^2$ on tilted 27.5° …..2000 hr @1000w/$m^2$
PR: assumed to be approximately 85% (excluding the inverter losses) [22]

Estimate of annual production: 1269.36*2000*0.875= 2221380 kwh/yr

According to the data collected, the total production of the PV-field in 2013 is 2152368.97kWh/yr.
The theoretical total yearly net production for 2013 may be estimated by deducting the inverter loses from the PV field production, as;

Inverter losses = Annual Production x Inverter efficiency
= 2221380 x 0.98 = 44427.6
The theoretical total yearly net production for 2013 = Yearly total theoretical production – Inverter loss
The theoretical total yearly net production for 2013 = 2221380 – 44427.6 = 2176952.4kWh/yr.

The little difference between the estimated production and the real yearly production is a sign that the PV plant is working very well.

The capacity factor of a solar station is the comparison of the production of the station currently and the possible production if solar irradiance is available for 24 hours. For Serhatkoy PV plant the capacity factor is calculated as

Capacity Factor = {Annual production / (rating x 24 x 365)} x 100%

= {2152368.97 / (1269.36 x 24 x 365)} x 100% = 19.4%.

## 6. MAINTENANCE OVER THE YEARS

Thus far, the PV-plant has been well taken care of thereby reducing the maintenance cost. Although no special personnel is assigned to be solely in charge of this power station, the fencing and gate constructed round the PV plant has reduced human/animal damage to the plant. Since 2011 till date, only two inverters and two PV panels have been replaced due to damage. The PV panel was believed to be damaged by a shepherd while throwing stone at his animal that were grazing close to the field.
The total cost of replacing the 2 inverters was 5,000 Euros and the PV panels were replaced from the excess panel the plant had during installation. The maintenance section of KIB-TEK was able to handle this replacement due to the training they received after the PVs were initially installed. There has not been any need for special personnel to either repair or replace anything on the power station till date which makes the total amount spent on major maintenance of the plant for over 3 years 5,000 Euros.

The only minor maintenance which has been done on the PV panels is to wash them and this has only been done once till date.

## 7. POWER PRODCUTION/REVENUE GENERATED AND PAYBACK PERIOD

The summary of the production of this power plant is shown in the chart below.

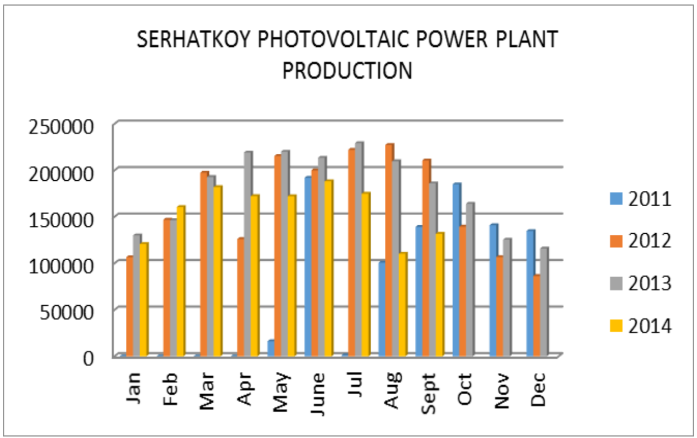


Figure 5: Serhatkoy Photovoltaic Power Plant Production (in Kwh) between 2011 and 2014.

Table 3: production and revenue generated by Serhatkoy power plant for 2013

| 2013 | Energy [kWh] | Price( 0,45YTL/kwh) |
|---|---|---|
| Jan | 130011.56 | 58,505.20 YTL |
| Feb | 146467.19 | 65,910.24 YTL |
| Mar | 192874.67 | 86,793.60 YTL |
| Apr | 219072.76 | 98,582.74 YTL |
| May | 220037.4 | 99,016.83 YTL |
| June | 213484.9 | 96,068.21 YTL |
| Jul | 229208.31 | 103,143.74 YTL |
| Aug | 209777.13 | 94,399.71 YTL |
| Sept | 185991.55 | 83,696.20 YTL |
| Oct | 164084.66 | 73,838.10 YTL |
| Nov | 125461.83 | 56,457.82 YTL |
| Dec | 115897.01 | 52,153.65 YTL |
| TOTAL | 2152368.97 | 968,566.04 YTL |

Note that the data for the production for the month of October, November and December for the year 2014 was not yet available at as the time of compilation of this analysis.

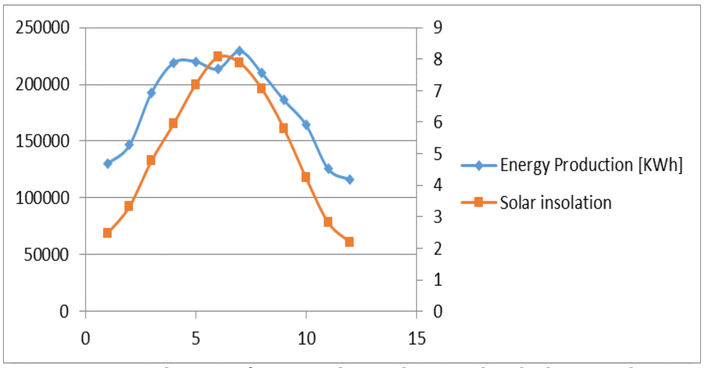


Figure 6: scartter diagram of TRNC solar insolation and Serhatkoy PV-plant production in the year 2013.

Table 5: correlation tabular result of TRNC solar insolation against Serhatkoy PV-plant production.

**Symmetric Measures**

| | | Value | Asymp. Std. Error[a] | Approx. T[b] | Approx. Sig. | Monte Carlo Sig. Sig. | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|---|---|---|---|
| Interval by Interval | Pearson's R | .954 | .023 | 10.093 | .000[c] | .000[d] | .000 | .221 |
| Ordinal by Ordinal | Spearman Correlation | .930 | .060 | 8.006 | .000[c] | .000[d] | .000 | .221 |
| N of Valid Cases | | 12 | | | | | | |

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

d. Based on 12 sampled tables with starting seed 624387341.

The production of this PV-plant has been very consistent since the second year of operation. Analyzing the solar insolation (using Chi-square tool in SPSS software) against the production in the year 2013, there is no significant difference between the production and the solar insolation as shown in table 4. This implies that a change in the insolation value of the PV-plant location affects the production of the plant. The scattered diagram in figure 6 also shows that the solar insolation correspond to the PV-plant production although a little drop in production was witnessed in the month of June with the highest solar insolation. This satisfies the theory which says PV cells production drops in extreme cases of solar insolation.

From the table and chart above, the production for the 4 years was shown and the revenue generated for the year 2013 is also given as 968,566.04 YTL.

Assuming that the revenue generated above remain constant and using a conversion ratio of 1Euros to 2.7 Turkish Lira, the revenue generated per year amounts to 358728 Euros yearly. From here, the simple payback period of this solar PV plant can be estimated to be 10.31years. Taking into consideration that the PV panels have a 10 years guarantee to work at 90% efficiency, this will possibly extend the visible payback period to 11,46years.Note that this value calculated excludes any maintenance costs.

A comparison between the proposed payback period by the contractor and the calculated payback period won't be scientifically correct in terms of analysis because the price of construction of this plant was not a commercial price. The decrease in price of PV panels and inverters due to the expansion in this fast growing market also makes this comparison very difficult. Presently, a PV power station of the same capacity would cost at 50% of the construction price of this station.

## 8. APPLICATION

Makurdi *(7°43′50″N 8°32′10″E / 7.73056°N 8.53611°E)* is a city in central part of Nigeria along Benue river. It is the capital of Benue state and is popularly known as the food basket of the nation. According to solar electricity handbook 2015 edition, the average solar insolation monthly data for Makurdi is given in table 4.

Table 4: Average solar insolation of Makurdi [7].

| Month | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|
| Solar insolation ($kWh/m^2/day$) | 5.82 | 5.94 | 5.78 | 5.40 | 5.08 | 4.66 |
| Month | Jul | Aug | Sep | Oct | Nov | Dec |
| Solar insolation ($kWh/m^2/day$) | 4.34 | 4.12 | 4.39 | 4.82 | 5.44 | 5.67 |

The yearly average solar insolation of this town is 5.12 which almost the same as that of Turkish Republic of Northern Cyprus (5.14). This make this city a perfect site for the location of a Photovoltaic Power Plant similar to the one analysed in this paper. Constructing a power station like this which can be constructed for half of its original price today and having the same or better efficiency will give a payback period as low as 5-6years and this makes it strong enough to be recommended for use especially in a country with inadequate power supply.

The tilt angle of the PV-panels for this location will be between $20^0$-$30^0$ (facing south), and the constructional arrangement of Serhatkoy PV-plant can be emulated for this location too only that the power house can be located outside the PV-field to reduce the expanse of land used.

The power plant must also be grid connected to ensure to have a backup power supply when there is bad weather or at night when the solar irradiation is not sufficient to power plant.

Although there maybe a little positive/negative change in the production of this PV-plant if located in Makurdi because of the climatic condition but this change will be minute cause of its solar irradiance.

## 9. CONCLUSION

Serhatkoy PV plant shows a typical real and visible PV field plant. Although the cost of constructing this power plant seems very high (making some techno-economic analysis unrealistic) compare to commercial proposed ones, but its purpose to serve and improve the community power supply is being achieved. This power plant has contributed to the power production of the Turkish Republic of Northern Cyprus generally and has also helped this island improve it power supply to individuals. Presently this island can boast of a highly reasonable level of uninterrupted power supply. The production of this PV-plant also dropped insignificantly in the month of June when the solar insolation was above 8.0.

Although the unavailability of solar insolation still makes this technology unreliable for total production in terms of large power production but the carbon free emission during production makes it more desirable to achieve a better environmental sustainability. The nearly perfect production of this plant when making comparison between the real production and the scientifically estimated production shows how efficient the plant is.

The planning/construction and maintenance of this power plant are commendable for the approximate 4 year's period of existence and such can be recommended. For an installation that is very sensitive in terms of expense of land used, the power house should be located outside the PV field or directly behind the panels at some distance. This will reduce the area of land but longer cables will be needed to connect the field to the power house. Provided all things remain constant, from this analysis, this power plant is capable of producing useful power for at least the next 25 years.

Constructing a power station like this in the central part of Nigeria (Makurdi) will also boast the power supply in that area. Although 1.2MWp power plant seems small compare to the current demand of electricity in Nigeria but this will solve part of the problem and construction of 10-20 of this kind of power plant will go a long way in boasting the power sector of the country. the little drop witnessed in the month of June by the PV-plant will not be witness if located in Nigeria (Markurdi) because the average monthly solar insolation didn't go beyond 8.0 rather better production will be witnessed in the month of November and December when this new location enjoys a better sunshine than TRNC.

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