OPTIMIZING RESIDENTIAL RENEWABLE ENERGY UTILIZATION IN NORTH CYPRUS: CASE STUDY OF SOLAR ENERGY

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ABSTRACT

North Cyprus is dependent on fossil fuels. In order to overcome this dependency, solar energy can be utilized due to its abundancy on the island. Therefore, in this study, various Retscreen analyses were conducted to install 4.85 kW photovoltaic rooftop systems in Nicosia, Morphou and Dipkarpaz. The main aim was to understand whether the installations were economically feasible. The results showed that Morphou had the most feasible result. Following this, a MATLAB simulation was carried out to determine the optimum number of installations in each city, to maximize the total amount of electricity exported to the grid, by considering realistic constraints. Hence, this study serves as a reference on how to maximize the electricity production, by utilizing solar energy in North Cyprus.

1. INTRODUCTION

Cyprus is situated in the Mediterranean Sea with a population of approximately 1,164,300 (in 2015) [1]. The island has two separate republics; TRNC (Turkish Republic of North Cyprus) and ROC (Republic of Cyprus). Both of the republics have similar problems in terms of fuel import (for electricity use and other purposes). As the fuel is becoming more expensive with time, the price of electricity is increasing every year [2]. It is evident that the interconnection of the island to the mainland would support the energy production of the island and would compose a stronger network [3]. However, this is not the current situation in Cyprus. Due to the above-mentioned problems and many others, the current power plants should be supported by renewable energy power plants.

This study, which is originated from [1], aims to understand the outcomes and advantages of installing 4.85 kW residential PV systems in Nicosia, Morphou and Dipkarpaz, respectively. Also, the demand and supply calculations are carried out in order to understand if the proposed 4.85 kW rooftop installations can be used for future actual projects in TRNC. The total production of these systems (obtained by Retscreen analyses) is compared to the total consumption of the houses in TRNC. The problem is to investigate if the required electricity can be generated from solely the residential PV installations. Hence, an optimization problem (which considers the demand and supply constraints) is designed and solved by using MATLAB. Thus, the number of installations required for each city is calculated. The importance of this study can be stated as follows: Even though there are various studies about solar energy in Cyprus, to the author's knowledge, there is no study on comparing the actual demand to the supply when installing solar energy, and, deciding the number of installations in each city in TRNC.

The rest of this article is organized as follows: Section two provides a brief discussion on previous studies that consider maximizing renewable energy. Following this is section 3, where the renewable energy potential of TRNC/Cyprus is indicated. Section 4 describes the current non-renewable and renewable energy installations in TRNC. The problem is interpreted in Section 5. The Retscreen input parameters; the objective function and the constraints (to be used in MATLAB) are also presented in this section. Retscreen output parameters and MATLAB results are provided in Section 6. Finally, Section 7 concludes with future studies.

2. RELATED WORK

Due to the increasing positive feedbacks from renewable energy sources, various studies ([4], [5], [6], [7]) focused on maximizing the utilization of renewable energy. All of these studies mention one important aim, which is to decrease the amount of carbon dioxide, or in general the greenhouse gas emissions. Another objective of the aforementioned studies is related to one problem that is also faced in Cyprus; the dependency on fuel imports. For example; in a study conducted for Denmark, [4], it was aimed to meet either 50% or 100% renewable energy by 2030 and 2050, respectively. Out of the two mentioned scenarios, the most feasible results were obtained by 50% renewable energy. Another study conducted was in New Zealand [6], where hydropower was used with a higher percentage when compared to other sources. The results showed that an acceptable solution was found to reinstate the current system, by arranging the amount of sources (percentage) in a rational way.

3. RENEWABLE ENERGY POTENTIAL IN NORTH CYPRUS

The distinct energy source of the island is solar energy with an average solar radiation of 5.4 kWh/m² per day (on a horizontal surface) [8]. According to [1], solar energy is used for two reasons on the island; electricity and heating purposes. In terms of heating purposes, Cyprus is one of the top countries per capita around the world [18] which installed and uses solar water heating systems [1]. This shows the importance of solar energy on the island. [2] states that the number of hours of sunlight in winter, in lowlands, is 5.5 hours per day. In the summer season however, the number of hours of sunlight is approximately 12.5 hours per day. During the cloudiest time of the year, the mean daily global solar radiation is approximately 2.3 kWh/m² (December and January). Fortunately, in summer however, the mean daily global solar radiation reaches a very high value of 7.2 kWh/m² (July) [2]. Fig. 1 illustrates the solar radiation map of Cyprus. As also inferred from the figure, the cities in North Cyprus with the highest solar irradiation values are; Lapithos, (an area in Kyrenia), and Morphou. These regions have a solar irradiation between 1950 kWh/m² and 2000 kWh/m² per year. The capital city Nicosia has a solar irradiation of approximately 1900 kWh/m² per year. Overall, the rich solar potential of the island is evident from the figure.

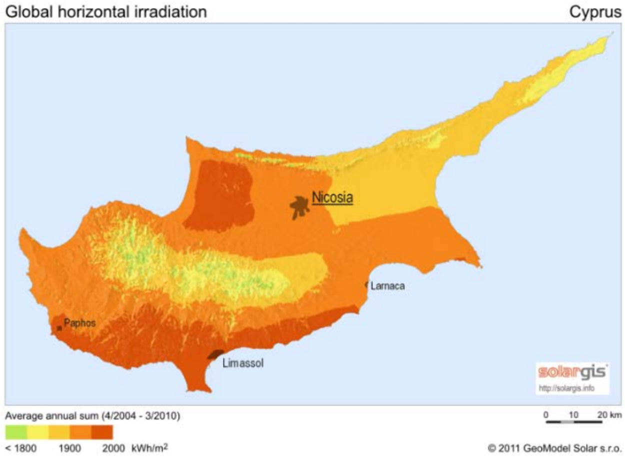

Fig.1. Solar Irradiation Map of Cyprus [9]

The second favourable energy source in the island is wind energy. The potential of wind energy in TRNC is not as good as solar energy. The island has comparably higher wind speeds nearer to the southern coasts of the island [10]. However, there is a low amount of potential of wind energy on the North part of the island. Due to the relatively low wind speeds in TRNC [1], wind energy is not considered in this study.

According to [11], hydropower in the island is simply impossible. It is interpreted that due to insignificant amount of river flow on the island, this energy source is impossible to obtain. Another renewable energy source is marine energy, which can be customized into two types of energy. These energy types are tidal and wave energy. [11], states that there is zero potential for tidal energy in the Eastern Mediterranean. However, in terms of wave energy, the island has slight potential but not enough to achieve the obligatory power [1]. Considering the pre-mentioned facts, hydropower and marine energy is not considered in this study. In Cyprus, main source of biomass is waste or straw. However, due to lack of information on the annual portion of environmentally-safe waste composed in Cyprus [12], this energy source is also not included in the analyses performed in this study. According to [13], due to lack of reserves; the thermal performance of the ground is not available. On the other hand, a study conducted by [11], explains that there is an absence of this energy source. By virtue of this uncertainty, geothermal energy is not covered in this study. Hence, due the reasons mentioned above, this study considers only the solar energy for analysis.

4. POWER INSTALLATIONS IN NORTH CYPRUS

The electricity of North Cyprus is mainly generated by Teknecik power plant with the assistance of 2 x 60 MW steam turbine power plants and 8 x 17.50 MW diesel power plants. AKSA (a private company) supports Teknecik with 8 x 17.50 MW diesel and 8 MW steam turbine power plants [14]. Moreover, 7 MW of the total installed capacity of North Cyprus is the photovoltaic systems [1]. As a summary, North Cyprus has a total installed capacity of 415 MW [1]. As mentioned in the previous section, Cyprus's dominant energy source is solar energy. Thus, the first photovoltaic power plant in TRNC was placed in Serhatköy with a peak capacity of 1.27 MW, [15], [16]. The project, which costed €3.7 million [19], was established with the help of the European Union (EU). The assistance of the EU played an important role in the payment of this project.

In addition to the one in Serhatköy, there are two more photovoltaic installations in TRNC, placed in university campuses. One is situated in the Middle East Technical University North Cyprus campus (METU-NCC). The power plant has an installed capacity of 1 MW. The second one is situated in the Cyprus International University (CIU) campus. This system has an installed capacity of 1.3 MW and incorporates four different mounting types. The mounting types are as follows; inclined roof, on terrains, levelled roof and on carports. The sum of the two capacities is 2.3 MW, and not 7MW that was referred as the total installed capacity of PV systems before. Unfortunately, the details of the remaining installations (the residential/industrial installations) could not be obtained due to the lack of data.

5. PROBLEM SETUP AND ANALYSIS METHODS

5.1. Determination of the System Size

The size of the system used in this study is decided by considering the rules and regulations of Renewable Energy Council of North Cyprus. According to [17], it is declared that for single phased and three phased systems, the maximum capacities of installations allowed for residential purposes are 7kW and 15kW, respectively. As it is not possible to differentiate the phase of each house, every house was assumed as single-phased in this study. However, the upper limit (7 kW), was not considered as the installation size, as not every house in the mentioned cities has the same area appropriate for installation. The installed capacity used in the proposed research is 4.85 kW for each house [1].

5.2. Retscreen Related Parameters

5.1.1. Economic Input Parameters

Many economic parameters are used as inputs for the Retscreen software. One way, in which the values are identified, is to assume the values according to previous studies. Due to having insufficient information on TRNC specific values of some parameters, most values are assumed based on the reasoning explained in [1]. The main method used for the assumptions is taking the average of related parameters obtained from relevant studies, [1], [11]. Table 1 shows the parameters entered into the software. For more detailed information, the study conducted in [1] can be analyzed. The prices of the photovoltaic panels and inverters are obtained from [1] and are the actual market prices. The average annual solar radiation values (required for the analyses) of Nicosia, Morphou and Dipkarpaz are already available in Retscreen database.

Table 1. Economic Input Parameters

Parameter	Input
PV Manufacturer	Solar World
Model	Mono-silicon SW255
No. of Units	19
Panel cost	€830/kW
Inflation Rate	4.89%
Project Life	25 years
Debt Interest Rate	6%
Debt Ratio	50%
Electricity Export Rate	€0.133/kWh
Discount Rate	10%
Debt Term	10 years
Base Case Electricity System	Fuel number 6 : 98.3% Solar: 1.7%
Inverter model	SMA Sunny Boy 5.0
Cost for each Inverter	€1610
O&M cost	€45.9/ kW
Development cost	€101.88/kW
Feasibility cost	€102.8/kW
Balance of System and Miscellanous cost	€271.4/kW
Engineering cost	€11.04/ kW
Fuel Cost Escalation Rate	2%

5.3 Renewable Energy Utilization Optimization

The aim of the optimization is to understand how many houses/consumers should install the photovoltaic systems. The number of houses for each city/region is identified as a result of this analysis. The values used for the objective function are the energy production values obtained as the results of Retscreen analyses. The numbers of houses/consumers are represented by V, Y and Z for Nicosia, Morphou and Dipkarpaz, respectively. In order to understand what the outcomes would be if there was no capacity limit (for renewable energy) in TRNC, the consumption constraint is set to be 425,095 MWh [14], which is the total residential consumption value of 2015. The objective is to maximize the electricity exported to the grid to match the demand. This is done by solving a linear programming problem. For detailed information about the application, the interested reader is referred to [1]. The sum of the energy produced (MWh), is the objective function of the analysis;

$$8.292V + 8.788Y + 8.527Z \quad (1)$$

The production is limited to 425,095 MWh as shown in Eq. (2).

$$8.292V + 8.788Y + 8.527Z \leq 425{,}095 \quad (2)$$

This means that the total energy production of Nicosia, Morphou and Dipkarpaz, should be less than the total current residential consumption in TRNC. The other constraints used in the analysis are shown as follows;

$$V \leq 42{,}599 \quad (3)$$
$$Y \leq 11{,}176 \quad (4)$$
$$Z \leq 12{,}464 \quad (5)$$

In (3), (4), and (5), the values represent the number of consumers in each city/region, which are obtained from [11]. An important point to consider is that, Dipkarpaz is connected to a city called Iskele. As the number of consumers in Dipkarpaz is not available, to obtain an upper bound, the *no. of consumers* value of Iskele is considered for Dipkarpaz. Hence, in this study, the no of consumers stated for Dipkarpaz region represent the all residential consumers connected to Iskele. The second set of constraints is as follows;

$$V \geq 0, Y \geq 0, Z \geq 0 \quad (6)$$

This indicates that each city shouldn't have negative number of consumers (with installation). The fourth set of constraints is determined according to the number of consumers. Thus, the city with the higher number of consumers should have a higher amount of installations (in terms of number of houses).

$$V \geq Y \quad (7)$$
$$V \geq Z \quad (8)$$
$$Y \leq Z \quad (9)$$

This means that, Nicosia (V) should have the highest number of houses that should install the system. The second largest number should belong to Dipkarpaz. The analysis is conducted in three different scenarios. At the end of each scenario, the percentage distribution for each city is also calculated.

These scenarios are explained in the following subsections.

5.3.1 Scenario One

In scenario one, the consumer related constraints are not included which are equation 7, 8 and 9. This means that the idea of having more installations for those cities which have more number of consumers is abandoned.

5.3.2 Scenario Two

In scenario two, all pre-mentioned constraints are used; none are excluded from the analysis.

5.3.3 Scenario Three

In scenario three, the simple payback periods obtained by Retscreen results are included to the analysis. Constraints expressed in Eqs. (7), (8) and (9) are replaced with (10), (11) and (12). The common aim of these constraints is to increase the number of houses with installation, for the city/region in which the lowest payback period is obtained.

$$V \leq Y \tag{10}$$

$$V \leq Z \tag{11}$$

$$Y \geq Z \tag{12}$$

So, Morphou should have a higher number than Nicosia and Dipkarpaz. Secondly, Dipkarpaz should have a higher number than Nicosia. The results of the above-mentioned scenarios are presented in Section 6.

6. RESULTS

6.1 Retscreen Related Results

Table 2 expresses the Retscreen results for three analyses: Nicosia, Morphou, and Dipkarpaz. Morphou has the lowest simple payback period (6.7 years), and hence, the most feasible city is Morphou. As revealed in Table 2, the net present value, (NPV), of Morphou is also the highest compared to the other analyzed cities. The highest simple payback (SP) period is observed in Nicosia (7.2 years); this means that Nicosia is less feasible. The cumulative cash flow diagram of the analysis conducted for Morphou is shown in Fig. 2. In the pre-mentioned figure it can be said that the profit of an installation in Morphou is very close to €8000.

Table 2. Retscreen Results

	Nicosia	Morphou	Dipkarpaz
SP (Years)	7.2	6.7	7
NPV(€)	216	816	500

In the case of Dipkarpaz, the results show that the profit at the end of the project lifetime is approximately €6500. Following this result, is the worst case, which is Nicosia, the total project profit obtained at the end of 25 years is around €6000.

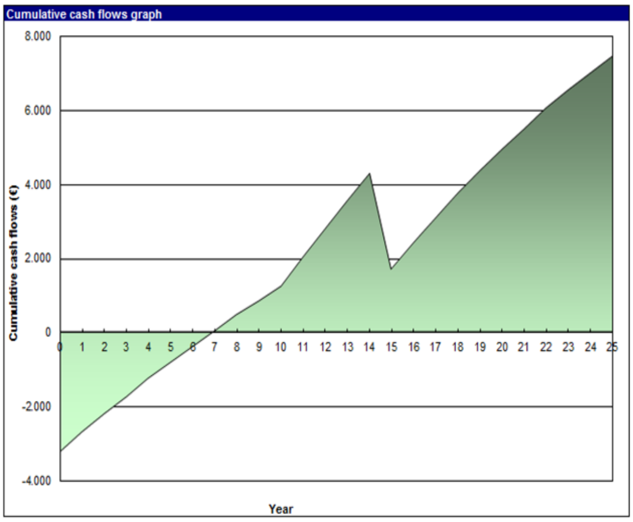

Fig.2. Cumulative Cash Flow Diagram of Morphou

For all three cases, the rate of increase in profit changes after 10 years. This is due to the debt term which can be observed in Table 1. Another change point is at year 15, in which there is a decrease in all three cases. The reason for this is the change of inverter after 15 years. The lifetime of the inverter is 15 years, due to efficiency reasons [1].

6.2 MATLAB Related Results

6.2.1 Scenario One Related Results

According to scenario 1, without including the consumer related constraints, the distribution is as follows;

- Nicosia: 26,604 installations
- Morphou: 11,176 installations
- Dipkarpaz: 12,464 installations

The afore-mentioned values are the optimum results according to MATLAB software analysis. This means a total value of 50,244 installations. The total distributed installations make up 243,683 kW. As can be observed from the results, the highest number of installations are integrated in Nicosia. The second best result is Dipkarpaz. The percentage of consumers which installed the 4.85kW systems for each city is also simulated. The results are shown below in Fig. 3.

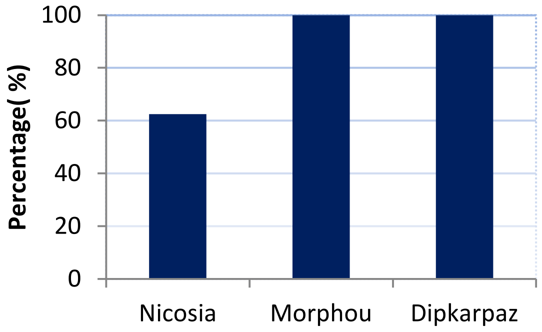

Fig.3. Scenario 1 Percentage Distribution for Cities

By observing Fig. 3, it can be understood that all of Morphou and Dipkarpaz regions should install the proposed systems. Thus, in Nicosia only 62% should install.

6.2.2 Scenario Two Related Results

Scenario two used the idea that the city/region with the highest number of residential consumers should have larger number of houses with installation. Following this, the results showed;

- Nicosia: 26,604 installations
- Morphou: 11,176 installations
- Dipkarpaz: 12,464 installations

As obvious from the results, the highest number of installations is distributed to Nicosia and Dipkarpaz. The reason of this distribution is the consumer related constraints. The constraints that; Nicosia should have a larger or equal number of installations with Morphou or Dipkarpaz. However, Dipkarpaz should also have a larger or equal value of installations with Morphou. The total number of installations is stated as 50,244 installations. The results remained the same with Scenario 1, which means that the consumer related constraints have no effect on the optimal result. The percentage distributions obtained by the simulation are as follows;

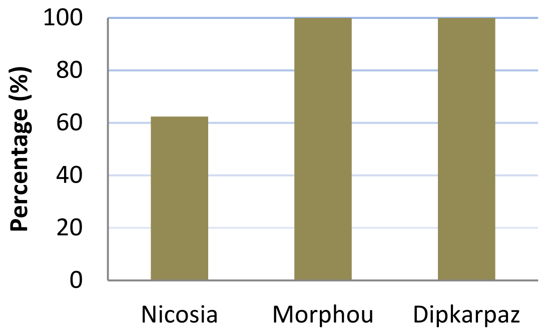

Fig.4. Scenario 2 Percentage Distribution for Cities

The percentage distribution for scenario 2 is illustrated in Fig. 4. Morphou again and Dipkarpaz have higher percentage distributions followed Nicosia, where only approximately 62% of the residential consumers installed the systems. This is due to Nicosia having a relatively higher number of residential consumers than the other cities.

6.2.3 Scenario Three Related Results

The results obtained by scenario three states that the installation distributions (how many consumers should install 4.85 kW PV systems among all the consumers in that region) are equal for all cities.

- Nicosia: 11,176 installations
- Morphou: 11,176 installations
- Dipkarpaz: 11,176 installations

The simple paybacks of all three cities are stated in Table 2. As can be seen from the pre-mentioned table, all simple payback periods are very similar and all round up to 7 years. Thus, the no. of installations turn out to be equal for each region. The total number of installations throughout all three cities/regions is 33,528. The percentage distribution for scenario three is shown in Fig. 5.

Correspondingly, Morphou has the highest installed percentage. In this scenario, in Dipkarpaz region, approximately 90% of the consumers install the system. Like the previous scenarios, Nicosia again has the least percentage distribution (26%).

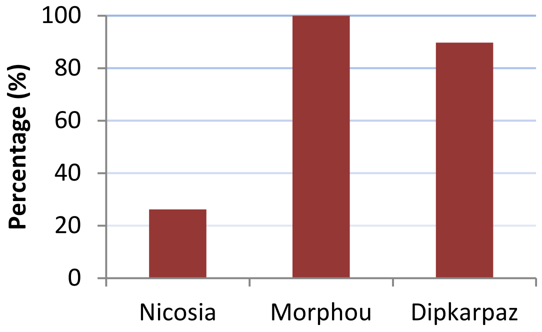

Fig.5. Scenario 3 Percentage Distribution for Cities

Fig. 6 expresses the comparison of all three scenarios. Here, it is detected in a clearer manner that both scenario 1 and 2 distributes the highest percentage in each city.

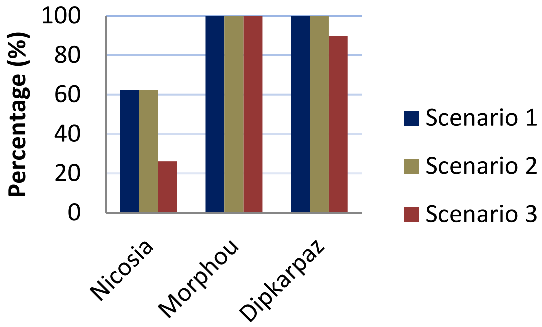

Fig.6. Comparison of Distribution for Cities

Hence, Fig. 6 reveals that if the simple payback periods are considered as the main criteria, the demand can be matched with comparably less number of consumers installing PV systems.

7. CONCLUSION

A well-known fact is that the cities with higher potential of solar energy offer a higher performance. This can also be observed in the study. In this study, Retscreen and MATLAB simulations were carried out. The results from Retscreen show that the city with the most feasible results is Morphou, with a simple payback period of 6.7 years and a net present value of €816. This result can be verified by Section III, where it is stated that Morphou has a solar radiation value between 1950 kWh/m² and 2000 kWh/m² per year. The worst case is obtained as Nicosia, with a simple payback period of 7.2 years and a net present value of only €216. According to MATLAB simulation results, it can be said that the scenario with the lowest number of installations is Scenario 3. In all three scenarios, it is plainly obvious that the distribution for Morphou is 100%. This is due to the number of consumers in Morphou. As it has a relatively smaller number compared to Nicosia and Dipkarpaz, and better potential, the percentage distribution is higher. It should be noted that, in this study, the conducted analyses were only theoretical. Future work is needed in order to understand whether there is a possibility of increasing the capacity limits in the island for a more realistic result.

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