WIND AND SOLAR ENERGY ASSESSMENT OF NORTHERN CYPRUS

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Abstract— **In recent years, there is a trend to extract energy from renewable energy resources. Renewable energy sources are considered more and more due to the existing standard resources being depleted, and the fact that they are harming the environment with CO_2 emissions. Solar energy and wind energy are the two main renewable energy resources. In this paper, we assess the wind energy potential as a renewable energy resource for Northern Cyprus, and based on measured data we provide an energy generation scenario in terms of the blade area of the turbines. One important point is how wind energy can be used together in a hybrid system with the high solar potential of Northern Cyprus. Advantages and disadvantages of such a hybrid system along with a cost analysis will also be presented in this paper.**

Keywords: Renewable energy, Wind Energy, Solar Energy, Solar Thermal Energy, Northern Cyprus.

1. INTRODUCTION

Strategically positioned in central Europe and the Middle East, Cyprus has a significant potential of energy harvesting. However, electrical energy demands of the island significantly depend on non-renewable energy resources.

Cyprus is the third biggest island in the Mediterranean Sea in terms of area and depends heavily on imported energy sources such as oil and gas. It is a fact that the world energy consumption significantly depends on oil and gas. Cyprus Turkish Electricity Authority (KIBTEK) generates, distributes and sells power to the Northern part of Cyprus. KIBTEK has two 60 MW steam plant generators for the base load and six 17.5 MW diesel generators in order to catch up with the peak values [1]. There is another energy company named AKSA which provides 92 MW of capacity to the grid [1]. Lastly, there is a solar photovoltaic (PV) power plant and its capacity is 1.27 MW. Among all of these resources, fuel oil is the most prominent one.

A comprehensive study [11] indicates that both solar and wind energy are viable renewable resources. However, the drawback is their unpredictable nature and dependence on weather. A solar-wind hybrid system is analyzed and is introduced in China and the authors in [11] conclude that Hybridization will meet the demand better.

Another valuable study done by Hongxing et. al [12] recommends an optimum design model for hybrid solar-wind systems employing battery banks in south-east cost of China in order to supply energy for telecommunication relay station. Five decision variables discussed in their study that are:

- PV module number
- PV module slope angle
- Wind turbine number
- Wind turbine installation height
- Battery Capacity

They had used 1989 Hong Kong weather data as an example of this analysis.

An extensive study [13] has been carried out to analyze hybrid solar and wind energy systems in China for;

- Improving system efficiency
- Power reliability
- Reducing energy storage

Due to these facts and reasons, in this paper we present the analysis and evaluation of using solar energy (Fresnel collector systems) assisted by wind energy in terms of their efficiency and cost.

The rest of this paper is organized as follows: In Section 2, we provide a general background regarding wind energy systems. We detail system modeling in Section 3, and introduce our evaluation and results in Section 4. We conclude our work in Section 5 and discuss the future work in Section 6.

2. BACKGROUND

2.1. Motivation

Understanding the global energy problems and its influences to the environment may create a better estimation of a solution for future generations. Rapid depletion of fossil fuel resources on a worldwide basis brings about an urgent need to look for alternative energy resources. Wind energy is a viable resource. As expected, wind speed has the most significant role for generating electricity from wind. Based on wind speed data, we present a wind energy harvesting scenario. Available wind speed maps around the world do not guarantee any values due to the fact that wind does not blow consistently. Amount of power is proportional to the cubic factor of the amount of wind speed on a system.

On the other hand, solar energy is one of the most abundant resources in Europe. Incoming solar radiation varies throughout the day; therefore, having a storage option is advantageous. However, solar energy with storage has very expensive. In order to reduce the cost, another renewable energy source, i.e. wind energy, can assist the main system. In this paper, we present a solar energy system hybridized with wind energy assistance.

2.2 Wind Speed Probability Distribution

Following analysis and equations are inspired from [4] and [10]. The wind speed data in time series format is usually arranged in the frequency distribution format. It is because this format is more convenient for statistical analysis. To statistically analyze wind data; we need to convert time- series data into frequency distribution format.

Weibull and Rayleigh distributions are probability density functions, commonly used in probability theory and statistics. More specifically it is used in wind energy analysis in order to analyze the wind speed and generated output power. The probability density function of the Weibull distribution is expressed as:

$$f_W(v) = \left(\frac{k}{\alpha}\right)\left(\frac{v}{\alpha}\right)^{k-1} e^{-\left(\frac{v}{\alpha}\right)^k} \quad (2\text{-}2\text{-}1)$$

Maximum likelihood method (MLH) estimates shape and scale parameter:

$$k = \left(\frac{\sum_{i=1}^{n} v_i^k \ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1} \ln(v_i)}{n}\right)^{-1} \quad (2\text{-}2\text{-}2)$$

$$\alpha = \left(\frac{1}{2}\sum_{i=1}^{n} v_i^k\right)^{1/2} \quad (2\text{-}2\text{-}3)$$

Where v_i is the wind speed in time stage i and n is the non-zero wind data points.

Rayleigh distribution is the special case of Weilbull distribution; the shape parameter k is 2. To put k = 2 into Equation (2-2-1), we obtain:

$$f_R(v) = \left(\frac{2v}{\alpha^2}\right)^1 e^{-\left(\frac{v}{\alpha}\right)^2} \quad (2\text{-}2\text{-}4)$$

2.3 Vertical extrapolation of wind speed

Height is a factor that affects wind speed. Increasing height may increase the wind speed logarithmically. The most common expression for the variation of wind speed with height is expressed as:

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^\alpha \quad (2\text{-}3\text{-}1)$$

Where, v_1 (m/s) is the actual wind speed at h_1 (m) height and v_2 (m/s) is the actual wind speed at h_2 (m) height. The exponent α depends on topography; surface characteristics determine the numerical value, typically it is $1/7$ [4].

2.4 Beam and Diffuse Radiation

There are two main types of solar radiation, namely beam insolation and diffuse insolation. Beam insolation is typically the insolation that arrives directly from the sun. Diffuse insolation is the type of solar radiation that is reflected from other objects. Common things that convert beam insolation to diffuse insolation on its way to the target are the clouds or trees or any other objects located in that region.

Density of beam or diffuse depends heavily on the topography that is based on the weather characteristics. Therefore, diffuse or beam radiation ratio may differ. To illustrate, depending on the high cloud density and humidity over the year, diffuse irradiation is dominant over the topography of Germany but in Middle East and North Africa (MENA) regions; e.g. Egypt, beam irradiation is dominant over diffuse irradiation.

In this paper, we investigate the Fresnel Type collector which absorbs both beam and diffuse irradiation. The authors in [2] claim that Fresnel type collectors have a higher efficiency compared to parabolic trough collectors in Cyprus due to the effect of diffuse solar radiation. This is because Fresnel type collectors absorb both beam and diffuse solar radiation.

2.5 Electricity Generation Cost in Teknecik Power Plant

In this part of the paper cost analysis for electricity in Northern Cyprus is presented. Fuel cost, transmission cost, capital cost, operation and maintenance cost and externality cost are the types of costs for grid electricity. The following data is obtained from [1]:

Fuel type: No 6. Heavy oil (H/C=1.5)

Fuel usage: 250 g of oil to produce 1 kWh electricity.

Total electricity production in 2008: 1.22GWh

The grid electricity price based on billing data is 0.38 TL/kWh. This price is not a fixed value; it can change depending on the energy consumption. However, we accepted that grid electricity price is 0.38 TL/kWh as a fixed number.

2.5 Cost Analysis

Present value calculations are widely used in business and economics in order to provide a means to compare cash flows [4]. Present value depends on a given date of payment. The payments may be in the future or in the past. Investment rate and inflation rate are factors to calculate the real force of the money in a given day. The formula is expressed as [10]:

$$PV = \left(\frac{1+i_I}{1+i_R}\right)^n P_i \quad (2\text{-}5\text{-}1)$$

Clearly for an investment to make sense, interest rate should be higher than inflation rate ($i_R > i_I$) [10]

Cost components of a plant are described as:

$$Total\ Cost = Capital + O\&M + Fuel \quad (2\text{-}5\text{-}2)$$

Where,

Capital: overnight cost

O&M: operation and maintenance cost

Fuel: Fuel cost

In this study, we present capital and O&M cost of the system; but fuel cost will be beyond the scope this analysis since source of the system is renewable energy. Transmission and distribution costs are also beyond the scope of this paper. To calculate present value of total cost, formula can be expressed as a series sum [10]:

$$PV_{TOTAL} = P_{TOTAL} \sum_{n=0}^{m} \left(\frac{1+i_I}{1+i_R}\right)^n \quad (2\text{-}5\text{-}3)$$

In general, capital cost of a wind plant in Europe ranges from 2000 to 3000 TL/kWh [14]. In this paper, we took 3000 TL/kWh to be on the extreme side. Furthermore, age of the turbine affects operation and maintenance cost (O&M). hence, the O&M cost changes from 1 to 7 kr/kWh.yr in Europe [14]. In this paper, we took 5 kr/kWh.yr for O&M cost of wind turbine.

On the other hand, solar thermal energy has a range of 780 to 1800 TL/m^2 [15]. In this paper, we took 1500 TL/m^2.

3. SYSTEM MODELING

3.1. Wind Power Plant Modeling

There are some fundamental concepts in order to calculate energy extracted from wind. The equation that is used to find the power obtained by a wind turbine is given as [4]:

$$P = ½\, \rho\, A\, v^3 \ (Watts) \quad (3\text{-}1\text{-}1)$$

Where,

ρ = density of the air (kg/m^3)

V= Velocity of the air (m/s)

A= Span Area of the turbine (m^2)

P = Output power (W)

Equation 3-1-1 shows that the power obtained from a wind turbine has a cubic relation with wind speed. So hourly data of wind speed obtained from the measurements can be very useful in order to find the amount of predicted wind energy.

Wind power density function is extracted from Weibull probability density function, expressed as follows:

$$P_w = \frac{1}{2}\rho\alpha^3 \Gamma\left(1+\frac{3}{k}\right) \quad (3\text{-}1\text{-}2)$$

In this equation, α is Weibull scale parameter in (m/s) and Γ is the gamma function

$$P = \frac{V_{rated}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (3\text{-}1\text{-}3)$$

For Rayleigh model, k is equal to 2 and scale parameter is extracted, the formula is expressed as:

$$P_R = \frac{3}{\pi}\rho V_{rated} \quad (3\text{-}1\text{-}4)$$

There are still some facts that elevation and temperature also affect wind speed. Simple wind energy simulations use Equation 3-1-2 for analysis to account for the correction in the wind speed. In order to use wind speed data, it is first corrected with respect to the elevation and temperature. For the correction of wind speed data with respect to elevation and temperature the equation can be written as:

$$v_{rated} = v\left[\frac{1}{exp\left(\frac{-E}{27000}\right)\left[\frac{T_0}{T_{db}}\right]}\right]^{1/3} \quad (3\text{-}1\text{-}4)$$

Where,

V = wind speed data files (m/s)

V_{rated} = effective wind velocity after temperature and wind corrections (m/s)

E = site elevation (ft)

T_o = temperature at standard conditions (K)

T_{db} = hourly dry bulb temperature (K)

3.1.1 Air Density Factor

Air density is another factor that affects wind power calculations. In order to calculate density of air, we have to account for elevation and temperature. Air pressure is the factor which affects density. It depends on elevation from the sea level.

To begin with air pressure calculation, it is presented by using the basic approach to the Pressure Theory. The derivation is based similarly on a subset of the International Standard Atmosphere (ISA) model which is formulated by the International Civil Aviation Organization (ICAO). Atmospheric pressure "p" to altitude "h" relationship is [5]:

$$p = p_0 \left(1 - \frac{L.h}{T_0}\right)^{\frac{g.M}{R.L}} \approx p_0.\exp\left(-\frac{g.M.h}{R.T_0}\right) \quad (3\text{-}1\text{-}1\text{-}1)$$

The formula extracted from Equation 3-1-1-1 is,

$$p = 101325.(1 - (2.25577 \times 10^{-5}).h)^{5.25588} \quad (3\text{-}1\text{-}1\text{-}2)$$

According to the ideal gas law:

$$\rho = \frac{P}{R_{specific} \cdot T} \quad (3\text{-}1\text{-}1\text{-}3)$$

Where,

ρ = density of air (kg/m^3)
p = air pressure (Pa)
R = specific gas constant = 287.058 J/(kg.K)
T = absolute temperature (K)

According to IUPAC [6], at sea level, standard temperature and pressure is 0 ^0C (273 K) and 101325 Pa); the density of air is 1.2754 kg/m^3.

3.1.2 Efficiency of the System

Since we have the wind profile of Northern Cyprus, what is next is to calculate the possible electrical power generation out of a wind power plant (WPP). In order to calculate the electrical power output, there are number of assumptions that we make since this work is still on abstract level. Our assumptions are explained in Table 3.1.2.1 and Table 3.1.2.2 summarizes the necessary properties of the wind turbine model chosen [7].

Table 3.1.2.1. Assumptions made to estimate the power generated by the WPP.

Wind Turbine Model	Vensys70 1.5MW
Gear efficiency	75%
Generator efficiency	95%
Converter efficiency	80%
Inverter efficiency	80%

Table 3.1.2.2. Specifications of Vensys 1.5MW Wind Turbine

Frequency	50 Hz
Cut-in wind speed	3 m/s
Cut-out wind speed	25 m/s
Blade diameter	70.34 m
Height	60m

The area of the blades subject to wind is:

$$A = \frac{70.34^2}{2} \times \pi = 3884 \text{ m}^2 \quad (3\text{-}1\text{-}2\text{-}1)$$

Taking the efficiency of the electricity conversion process, assuming certain standard efficiency values, we have an overall efficiency of:

$$\eta_{Tot} = 0.75 \times 0.95 \times 0.80 \times 0.80 \times 0.80 = 45.6\% \quad (7)$$

3.2. Solar Power Plant Modeling

The analysis in this section is inspired from [2]. For this modeling, we chose Fresnel Type collectors in accordance to the high beam and applicable diffuse irradiation of Northern Cyprus. An extensive study has been carried out to extract which solar thermal energy system has the best efficiency according to the incoming solar irradiation [2].

3.2.1 Organic Rankine Cycle (ORC):

For this analysis, a nominal thermal efficiency of the ORC ($\eta_{th,o}$) of 10% is assumed corresponding to hot (Q_H at T_H) and cold (Q_c at T_c) heat transfers at T_H=373 ^oK and T_C=298 ^oK. T_O is the reference temperature and is equal to T_C. As the Carnot efficiency suggests, the actual thermal efficiency of the ORC will vary with the values of T_H and T_C. The actual ORC at Middle East Technical University Northern Cyprus Campus (METU NCC) is designed to operate with T_H = 373 ^oK with an ignorable hit rate, and therefore in this analysis, T_H is assumed as constant at 373 °K. However, T_C is related to and therefore will vary with the environmental conditions. Since a wet cooling tower is used, T_C will vary with both the dry bulb temperature (T_{db}) and relative humidity (φ) of the environment. However, modeling the impact of both dry bulb and relative humidity on T_C and the resultant variation in thermal efficiency with T_C requires relatively complex modeling which is beyond the scope of our analysis. Therefore, actual thermal efficiency (η_{th}) is assumed to only vary with T_{db} according to the following model in (1), based on Carnot efficiency's variation with T_C.

$$\frac{\eta_{th}}{\eta_{th,0}} = \frac{\eta_{carnot}}{\eta_{carnot,p}} = \frac{\left(1-{T_{db}}/{T_H}\right)}{\left(1-{T_0}/{T}\right)} \quad (3\text{-}2\text{-}1\text{-}1)$$

Solving (3-2-1-1) for ηth yields as in (3-2-1-2):

$$\eta_{th} = \eta_{th,p}\left(\frac{T_H - T_{db}}{T_H - T_0}\right) \quad (3\text{-}2\text{-}1\text{-}2)$$

As mentioned earlier, T_o = 298 °K and T_H = 373 °K. Based on the definition of Carnot efficiency.

$$Q_{orc} = W_{orc} / \eta_{th} \quad (3\text{-}2\text{-}1\text{-}3)$$

Equations (3-2-1-2) and (3-2-1-3) are combined to yield (as in [12]):

$$W_{orc} = max\left[\underbrace{\eta_{th}\dot{Q}_{PTC}}_{Solar\ Only\ Mode}, \underbrace{\dot{W}_{demand,0}}_{Propane\ Combined\ and\ Propane\ Only\ Mode}\right] \quad (3\text{-}2\text{-}1\text{-}4)$$

The rate of heat transfer to the ORC is described as:

$$Q_{orc} = \frac{W_{orc}}{\eta_{th}} \quad (3\text{-}2\text{-}1\text{-}5)$$

3.2.2 Fresnel Collector Model:

In comparing Fresnel Lenses with PTC collectors, collector model based on aperture area was used from the SRCC sheets [8]. The approximated formula for Fresnel is explained in (3-2-2-1), where diffuse radiation is also accounted, different than that of PTC.

$$\frac{Q}{A_a} = \underbrace{F'(\tau\alpha)_{en}K_{\theta b}(\theta)G_b}_{Beam\ Radiation} + \underbrace{F'(\tau\alpha)_{en}K_{\theta d}(\theta)G_d}_{Diffuse\ Radition} - c_1(t_m - t_a) \quad (3\text{-}2\text{-}2\text{-}1)$$

In the analysis, the price used is approximated from deposited commercial cylinder of 10 kg used in home cooking. The propane is assumed to be in its gaseous state and the density is taken as 0.51 lt/kg at 15 degrees Celsius [8].

3.2. Cooling Tower Model:

The interest in modeling the cooling tower is to perform an order-of-magnitude analysis for the water consumed during system operation. For this purpose, a simple model of the cooling tower is sufficient in which all of the low temperature heat transfer from the ORC (Q_c) is used to evaporate water at 25 °C; e.g., only isothermal latent heating are modeled.

$$\dot{Q}_c = \rho_{H_2O}\dot{V}_{H_2O}h_{fg} \quad (3\text{-}2\text{-}1)$$

In (3-2-1), ρ_{H2O} represents the density of liquid water, V_{H2O} stands for the volumetric rate of water consumed by the cooling tower and h_{fg} is the enthalpy of evaporation for water. For the base case analysis, we assume ρ_{H2O} as 1.0 kg/liter and h_{fg} is evaluated at 25 °C as 2442 kJ/kg [6].

4. RESULTS AND EVALUATION

The data for solar system in the present calculation was obtained from Larnaca Airport, in Southern Cyprus, in 1995. The solar data was obtained during the period of 2010 to 2012, but it measures only global solar radiation. It is necessary to obtain beam and diffuse solar insolation for tracking system analysis such as one-axis tracking and two-axis tracking systems. Hence, we used nearest available solar radiation data. The data for wind energy system was obtained during the period of 2011 to 2012 taken from METU NCC wind measurement station. This station is at 2 meters high. We extrapolate the wind data to 60 meters high using Eqn. 3-1-1 in order to calculate rated wind speed, temperature and air pressure values. The main results obtained from the present study can be summarized as follows:

The efficiency of the solar system is described as solar fraction. Table 4-1 presents monthly efficiency (f_s), amount of incoming solar radiation (Q_{FS}), output energy generation (W_{ORC}) and amount of water consumption (V_{H2O}). Using Table 4-1, we can conclude that available W_{ORC} from the collectors are greatly increased in winter months. The fact for increasing efficiency in winter months is low ambient temperature compared to summer months. Consistent with the theory, $Q_{fresnel}$ is high mainly due to the diffuse solar radiation.

For Northern Cyprus, one would expect to get higher solar fractions within winter months due to low ambient temperatures. However, the optimal temperature and available solar radiation are in September. This is because the solar radiation is high and the ambient temperature is sufficient.

One of the main issues in this system is water consumption. Solar thermal energy system consumes water in order to generate electricity. The water consumption is presented in Table 4-2. For a kWh of electrical energy, annual water consumption is approximately 13 liters. Water consumption depends on seasonal temperature. Summer months need more water in comparison with winter months.

Operation cost of solar thermal energy system is presented in Table 4-2. Cyprus Electricity cost per kWh is 0.38 TL. For water case, 5 TL per ton of water is taken for this analysis. Table 4-3 presents electricity generation cost, water consumption cost and the difference between each other. It is assumed that this remaining value may be operating cost of the total system. As a result of analysis, electricity generation from solar thermal plant is 44.6 W/m^2.day. On the other hand, cost of electricity generation from solar plant is 1.7 kr/m^2.day. Capacity factor of solar plant is 10.3%, which is expected.

The generation per area is 49 W/m^2.day. As a result of analysis, electricity generation from wind power plant is 1.9 kr/m^2.day.

For Northern Cyprus, one would expect to get lower wind speed. However, the optimal design and available wind data at 2 meter indicates that energy generation from wind is approximately same as solar in the west side of Northern Cyprus. However, the wind capacity factor is 12.8 percent which is not a good number.

Table 4-1: Electricity generation from 3884 m^2 Fresnel Collector Solar Power Plant

Month	**Q_{FS}**	**W_{ORC}**	**V_{H2O}**	**f_s**
	kWh/day	kWh/day	lt/kWh	-
Jan	4489.74	507.76	11.56	0.113
Feb	2620.79	292.89	11.72	0.112
Mar	3102.45	338.87	12.02	0.109
Apr	3534.95	375.65	12.40	0.106
May	3335.84	339.37	13.02	0.102
Jun	3797.39	367.06	13.78	0.097
Jul	3792.45	352.70	14.38	0.093
Aug	3610.21	336.01	14.36	0.093
Sep	6736.64	648.55	13.84	0.096
Oct	5599.92	561.07	13.24	0.100
Nov	5541.70	588.07	12.42	0.106
Dec	3726.95	408.99	11.96	0.110
Annual	**4157.42**	**426.42**	**12.89**	**0.103**

Table 4-2: Operation Cost of Electricity Generation from 3884 m^2 Fresnel Collector Solar Power Plant

Month	**Elec. Gen.**	**Water Con.**	**Remaining**
	TL/Month	TL/Month	TL/Month
Jan	5981.45	909.89	5071.56
Feb	3116.33	480.45	2635.88
March	3991.92	631.48	3360.44
April	4282.42	698.62	3583.80
May	3997.84	684.70	3313.14
June	4184.50	758.55	3425.95
July	4154.82	785.99	3368.84
Aug	3958.23	748.16	3210.07
Sept	7393.45	1346.26	6047.19
Oct	6609.40	1151.38	5458.02
Nov	6704.04	1095.40	5608.65
Dec	4817.88	758.16	4059.72
Ann	4932.69	837.42	4095.27

Table 4-3: Cost of Electricity generation from 3884 m^2 Wind Power Plant

Month	**Wwind**	**Wwind**	**Cost**
	kWh/Month	kWh/Day	TL/Day
Jan	157634.86	5085	1932.30
Feb	149067.02	5324	2023.05
March	155370.01	5012	1904.54
April	154664.38	5155	1959.08
May	146147.26	4714	1791.48
June	139662.94	4655	1769.06
July	150386.72	4851	1843.45
Aug	124270.12	4009	1523.31
Sept	109029.66	3634	1381.04
Oct	108604.12	3503	1331.28
Nov	143242.92	4775	1814.41
Dec	134035.92	4324	1643.02
Ann	**139342.99**	**4587**	**1743.00**

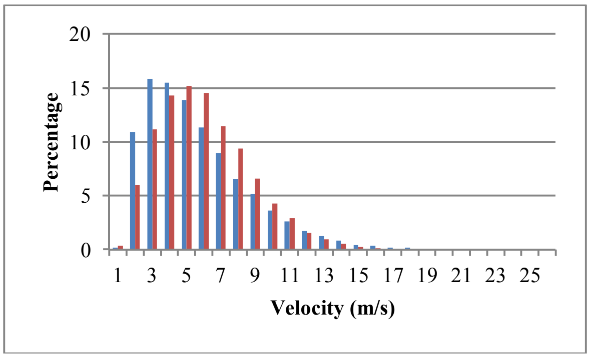

Figure 4-1: Wind velocity graph with real data and extrapolated data (blue is real 2 meter data and red is 60 meter extrapolated data).

5. CONCLUSION

In this work, we analyze, model, evaluate and compare wind energy assisted solar thermal energy systems, namely Fresnel systems hybridized with wind over Northern Cyprus topography. We pointed out the importance of the topography and weather conditions of a region while deciding on how wind energy can be hybridized into the high solar potential of Northern Cyprus. As a result of our work, Fresnel systems have an advantage in this region of the world and assisted with wind power plant may reduce the cost rather than constructing a solar system with storage.

Complete system, solar energy with wind assistance, pay back cost is 8 years. However, pay-back cost of the solar system with battery storage is 15 years. Grid connected system of solar – wind hybrid is more cost effective than a solar system with storage.

In the future, material availability and cost will play an important role for energy area and will continue to drive technological competitiveness. Solar and wind energy are two main renewable resources. Generating electricity from using solar means should be big part of the energy portfolio in Cyprus and it helps the cost if it is assisted by wind energy.

6. FUTURE WORK

The work we conduct in this paper consists of solar panels and wind energy systems in general: Fresnel systems hybridized with wind energy. Further work may be done to carry this over to a more general and detailed range by including photovoltaic solar panels (PV) or two-axis tracking systems. Furthermore, an extensive cost analysis might be done by estimating externalities.

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