**IOSR Journal of Engineering (IOSRJEN)** **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 09, Issue 6 (June. 2019), ||S (II) || PP 48-53

# Energy and Cost Analysis for Renewable Energy Technologies in Hot Climatic Regions

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**Abstract:** Egypt's electricity is 91%generatedfrom fossil fuels,this dependance on fossil fuels needs to be replaced by renewable energy sources. This paper analyzes energy, cost and carbon emissions of installing renewable energy systems in Cairo to satisfy the load for a residential area. A comparison is conducted across using of different installation mechanisms of PV panels and a wind turbine using HOMER software.The selection of optimum configuration is chosen based on the mechanism with the least energy consumption from grid, carbon emissions, net present cost (NPC) and cost of energy (COE). Results proved that renewable energy systems saves money and generates less carbon compared toconventional systems . Also, two axis tracking type is the suitable option since it produces excess energy, has lower NPC, COE,and carbon emissions compared to other tracking types. However, the optimum system for Cairo is wind turbine system which generates 295% more energy compared to two axis and is also the cheapest system with 37.5% lower NPC compared to PV panels and 53.8% lower COE. The use of wind turbines proved to be a feasible renewable energy technology for satisfying the load profile of a residential area in Cairo.

**Keywords:** Carbon emissions, Cost Analysis, Energy Analysis, Renewable energy systems.

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Date of Submission: 02-06-2019 Date of acceptance: 17-06-2019

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## I. INTRODUCTION

Since the past few years, technological development and human population growth led to more consumption of energy[1]. Most of the energy worldwide is produced from fossil fuels which negatively affects the environment. Alternative energy sources, i.e.: renewable energy are being currently used to generate electricity in a less costly and environment friendly manner. Renewable power technologies are getting to be progressively competitive resources of electricity production. Nowadays, they represent half of all new power generation capacity additions around the world [2]. It was found that in the year 2013, 91 % of the power generation in Egypt relies on oil and gas, 7.5 % from hydro and 1.5 % from wind and other resources according to an overview of the electricity sector in Egypt and the peak demand for the year 2012 has reached 27,000 MW and it is expected to reach 54,200 MW by the year 2027 [3].This necessitates the need for alternative energy sources that can replace the huge dependance on the fossil fuels.Thus, the aim of the paper is to perform energy, cost and carbon analysis for using PV Panels and wind turbines as the main sources of energy for a residential load in Cairo, Egypt using HOMER software. A comparison is conducted across the different types of solar tracking for the PV panels as well as the wind turbine to reach the maximum energy generation under Egyptian climatic conditions for an on-grid system.In this paper, Sec. 2 presentsa literature review for the topic under study. Section 3 includes the methodology followedto obtain the results presented in Sec. 4. Finally, Sec. 5 includes conclusions obtained fromthe work as well as recommendations for future work.

## II. LITERATURE REVIEW

Previous researchers have analyzed the energy and cost of several renewable systems. Hybrid energy system performance with photovoltaic (PV) and diesel systems are used by (Ramli et al., 2015). The financial and environmental effects of the system are analyzed for Makkah, Saudi Arabia. It was found that the PV/diesel system with flywheel is less costly than the PV/diesel system without flywheel energy capacity[2].(Amutha et al., 2016) performed a hybrid combination of solar/wind/hydro/battery system which proved to be a cost effective, sustainable, techno-economical and environmentally viable alternative to grid extension [4]. Moreover, (Halabi et al., 2017) analyzed the hybrid system that includes all possible standalone diesel

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generators, hybrid PV/diesel/ battery, and 100 percent PV/battery scenarios for the proposed stations. Results showed that hybrid PV/Diesel/Battery system is the best in terms of technical performance compared to all other scenarios [5]. (Khare et al., 2016) simulated and optimized non-conventional energy system of an auditorium of police station at central India. Results are compared to those of Huge Bang Crunch (BBC) algorithm and Game Theory based concept. It has been found that replacing conventional energy sources by solar-wind-fuel cell-Hydrogen tank energy system is a feasible solution for distribution of electric power for standalone application [6]. In addition, (Bhattacharya et al., 2016) investigated the impacts of renewable energy utilization on the financial growth of major renewable energy consuming countries within the world. Findings from long-run output elasticities show that renewable energy consumption has a critical positive affect on the financial yield for 57 % of the chosen countries [7].Thus, this paper aims to apply energy, economic and carbon analysis of different renewable energy systems under Egyptian climatic conditions.

## III. METHODOLOGY

A residential load in Egypt is chosen to be the load center which needs to be satisfied using on-grid renewable energy systems. The renewable systems are chosen to be either PV panels or wind turbines. The PV panels are compared in terms of energy generation, cost and carbon emissions for different solar tracking mechanisms using HOMER pro software as well as the use of wind turbines versus PV panels.

### 3.1 Energy Analysis

The systems are analyzed through measuring the consumption of the load in the system, the amount of energy that will bepurchased from or sold to the grid, the energy production from the renewable system and the amount of carbon dioxide produced.

### 3.2 Cost Analysis

The costs of the systems are compared in terms of net present cost (NPC) and the cost of the energy (COE) of establishing the chosen models.

### 3.3 Emissions

There emissions generated from the system are analyzed and compared for the different tracking mechanisms of the PV panels and the wind turbine.

First, the location of the simulation is chosen to be Cairo (30°2.7'0" North, 31°14.1'0"East). Then the load of the system is added as shown inFigure 1which shows the seasonal profile over a year based on the average consumption of residential in Egypt [8] .The total load added for the selected location is 878 kWh/day and the peak of the load is 81.89 kW.

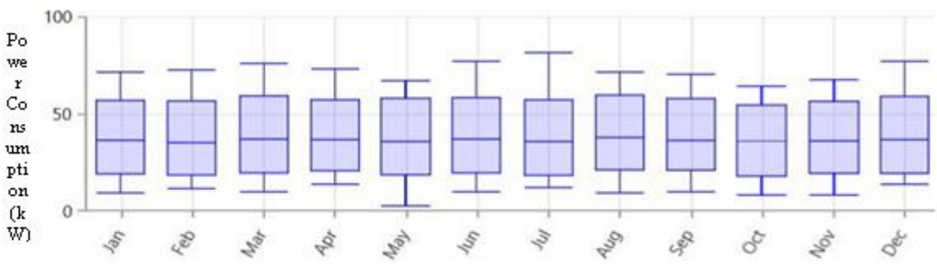


**Figure 1.** Seasonal load profile of Cairo

Then, a grid is added to the system to purchase electricity during the electricity shortage timings and to sell the electricity produced from PV panels or wind turbines when there is an excess in the production of the renewable technologies.Based on Egyptian electricity prices, the grid power price is 0.016 \$/kWh [9]and the the grid net excess price is 0.04 \$/kWh [10].

### 3.4 PV panels model

Based on the load profile, 6 PV panels are needed to satisfy the load consumption. Huawei SUN 2000 25 kW Generic PV systems are chosen. The average solar insolation in Cairo is 5.35 kWh/m$^2$/day.The energy generated from the PV system is based on the amount of solar radiation received by the PV panels which depends on the angle of incidence.

Thus in order to reach the maximum possible energy generation, different types of solar tracking are used and compared. The solar tracking mechanisms used are: horizontal axis monthly adjustment, horizontal axis weekly adjustment, horizontal axis daily adjustment, horizontal axis continuous adjustment, vertical axis continuous adjustment and finally two axis tracking. A Leonics MTP-4117H 300 kW convertor is used to convert the DC output to AC that is supplied to the grid. The design of the system is shown in Figure 2

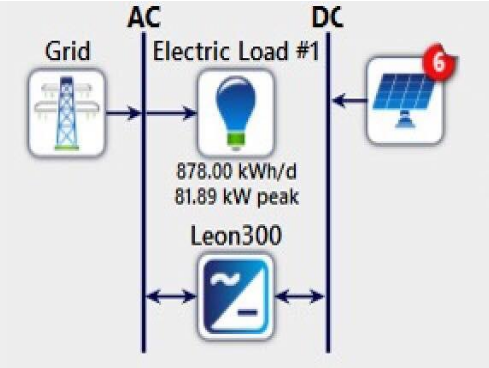


**Figure 2.** Simulation of PV panels model

### 3.5 Wind turbine model

A suitable wind turbine is choosen to satisfy the load and operate at the wind speeds of Cairo which is on average 4.76 m/sec at the elevation of 50 m from the sea level. Two WES 30 250kW wind turbines are used to provide the load with electricity. The design of the system is shown inFigure 3 .

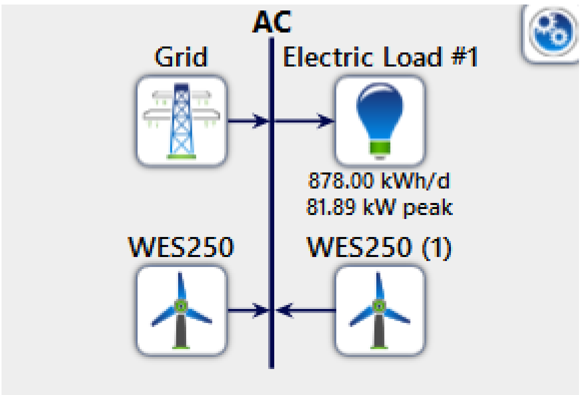


**Figure 3.** Simulation of Wind Turbines model

## IV. RESULTS AND DISCUSSIONS

Results of the simulation scenariors for the different solar tracking mechanisms and the wind turbine are presented in the below sections.

### 4.1 Energy and carbon analysis

For each type of solar tracking for the PV panel and the wind turbine, the amount of energy generated from the renewable system annually (kWh/year), the annual net energy (kWh/year) which is the energy consumed minus the energy generated and the amount of carbon dioxide produced while using the technologies (kg/year) are shown in
Table **1**.

**Table 1.** Energy and carbon analysis

| | Energy | | Emissions |
|---|---|---|---|
| | Energy generated (kWh/year) | Net energy (kWh/year) | $CO_2$ (kg/year) |
| Horizontal axis monthly adjustment | 48,594 | 40,567 | 118,217 |
| Horizontal axis weekly adjustment | 48,764 | 39,602 | 123,509 |
| Horizontal axis daily | 48,771 | 39,552 | 123,508 |

| | | | |
|---|---|---|---|
| adjustment | | | |
| Horizontal axis continuous adjustment | 50,084 | 31,984 | 120,821 |
| Vertical axis continuous adjustment | 57,428 | -10,315 | 118,217 |
| Two Axis | 61,699 | -34,919 | 118,660 |
| Wind Turbine | 243,372 | -166,274 | 102,633 |

It can be seen from

Table 1that as the interval of adjustment of the PV panels decreases, the energy generation increases. In other words, the contiuous adjustement generates more energy compared to the daily adjustement and same with the week adjustement that produces more energy than the monthly adjustement. Results showed that the vertical axis and the two axis tracking causes excess energy generation from the system. Also, the two axis solar tracking is the best among other tracking methods because the PV panel in that case is exposed to the maximum amount of solar radiation and thus produces the maximum amount of energy which is equal to 61,699 kWh/year. The two axis tracking causes a percentage increase in the energy generation by approximately 27% compared to the monthly adjustemnt. However, the two axis tracking produces only 0.37% more carbon dioxide compared to the monthly adjustsment and produces 3.9% lower carbon dioxide compared to the horizontal weekly adjustment. Comparing all the PV panel tracking mechanisms with the wind turbine, it can be seen that the turbine produces 243,372 KW/year and helps in decreasing the power purchased from the grid. The wind turbine model generates 294.5% more energy compared to the two axis tracking mechanism and 13.5% lower carbon emissions. Thus from the energy and carbon point of view, the wind turbines are better options for the residential load of Cairo.

**4.2 Cost Analysis**

For each type of tracking for the PV panel and the wind turbine, the Net Present Cost (NPC)($) and the Cost of Energy (COE) are calculated and presented.

**4.2.1 Net Present Cost (NPC)**

The net present cost (or life-cycle cost) of a component is the present value of all the costs of installing and operating that component over the project lifetime, minus the present value of all the revenue that it earned over the project lifetime. The costs that occur in the system are the capital cost, replacement costs, operation and maintenance costs. The total NPC is calculated using HOMER software usingEquation 1) [11].

$$C_{NPC} = \frac{C_{ann,tot}}{C_{RF}(i, R_{Proj})} \qquad \text{Equation 1}$$

Where,
$C_{NPC}$: Total NPC ($),
$C_{ann,tot}$ = Total annualized cost in $/year,
i = Interest rate (%),
$C_{RF}$ = capital recovery factor,
$R_{proj}$ = Project lifetime (years)

Figure 4shows the NPC for the different renewable energy systems. It can be seen that the NPC for the wind turbine is lower than that of the PV panels by approximately 37.5%. Also, the NPC for the different PV solar tracking mechanisms are approximately within the same range.

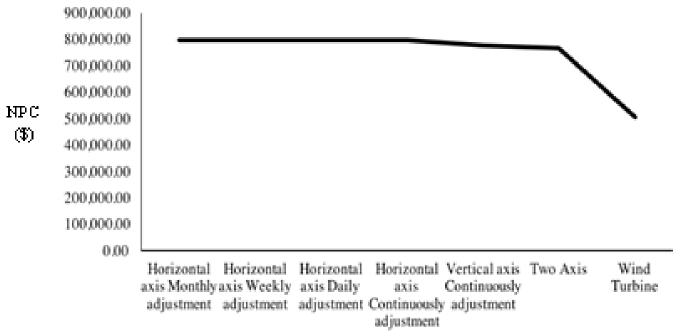


**Figure 4**. NPC for renewable energy systems

4.2.2 Cost of Energy (COE)

The levelized cost of energy (COE) is defined as average cost per kWh of useful electrical energy produced by the system. COE used in HOMER is calculated using Equation 2) [12].

$$\mathrm{COE} = \frac{C_{ann,tot}}{E_{Primary} + E_{Defferable} + E_{Gridsales}} \quad \text{Equation 2}$$

Where,
COE: Cost of Energy,
$C_{ann,tot}$ : Total annualized cost in $/year,
$E_{primary}$ : Primary load served (kWh/yr),
$E_{defferable}$: Deferrable load served (kWh/yr),
$E_{Gridsales}$: Total grid sales.

Figure 5shows the COE for the different renewable energy systems. The wind turbine has COE that is approximately 53.8% lower than that of the single axis tracking PV panels. Moreover, the two axis tracking has COE that is 15.3% lower than that of most single axis tracking mehacnisms. The system with the highest COE is the horizontal axis monthly adjustment type.

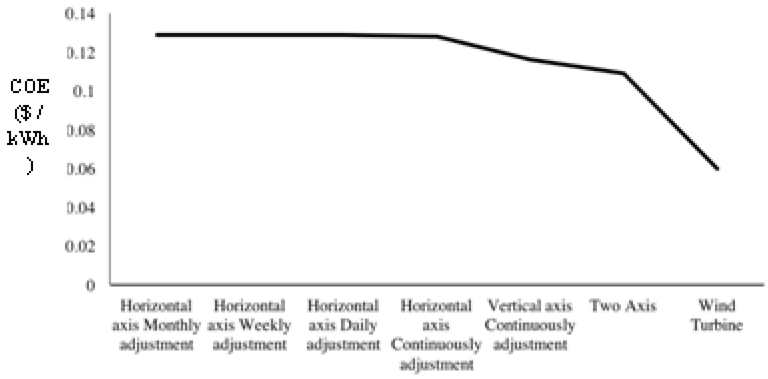


**Figure 5.** COE for renewable energy systems

Thus, it can be seen that the chosen wind turbine is the best option for satisfying the load profile of Cairo since it produces the highest energy quantity, has low carbon emissions and has the lowest NPC and COE among all the options.

## V. CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

This paper examines the energy, the cost and carbon emissions of installing a renewable energy system in Cairo necessary to satisfy the load for a residential area. The main aim is to choose the optimal system that decreases the dependence on the grid, decreases the carbon emissions and decreases the NPC and COE. The study compares different types of solar tracking as well as the use of wind turbines as renewable components using HOMER software. Results showed that installing a renewable energy system saves money and generates less carbon compared to the conventional systems. The two axis tracking type of PV panels is the most suitable option since it produces the most energy, generates excess energy that is sold to the grid, has lower NPC and

COE and low carbon emissions compared to the other types of solar tracking. However, the wind turbine system is the most suitable option for the load profile of Cairo as it produces 295% more energy compared to the two axis and it is also the cheapest system to apply with 37.5% lower NPC compared to PV panels and 53.8% lower COE. Also, the wind turbine produces 13.5% lower carbon emissions compared to the PV panels. The use of wind turbines proves to be a feasible and successful renewable energy technology for satisfying the load profile of a residential load in Cairo. This work can be used by researchers and practitioners in testing and comparing different renewable energy sources under Egyptian climates and choosing the optimum type of energy source that staisfies the load profile of Egypt. This can be further used to study the energy, economic and carbon outputs of the different renewable energy systems in Egypt. It is recommended for future studies to use hydro turbine and compare the results with those obtained in the study. Also, it is recommended to find the optimal renewable source based on the desired multi-objective functions.

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