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MODELING OF HYBRID RENEWABLE ENERGY SYSTEM: THE CASE STUDY OF ISTANBUL, TURKEY

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ABSTRACT

Traditionally, the stand-alone hybrid electricity system has been viewed as an alternative renewable energy source. Therefore, the primary objective of this paper will be to look at a stand-alone hybrid system combination that will generate electricity, from a mix of renewable energy sources, to fulfill the electrical needs of an off-grid remote apartment in Istanbul, Turkey. Both solar photovoltaic systems and wind turbine will be considered as renewable energy sources. The paper will also demonstrate the residential demand in the HOMER PRO analysis and define the optimal off-grid system. The solution obtained from the studies shows that a hybrid combination of renewable energy and generators at an off-grid location can be a suitable alternative to grid extension (by considering the life cost cycle for 25 years). This is because it is both techno-economically viable and environmentally sound.

INTRODUCTION

Many modern countries are experiencing a major rise in energy demands as they begin to work towards raising productivity and improving national living standards. In order to meet these new demands, countries typically start expanding their supply base without paying attention to the energy efficiency of the energies being used [1]. However, the combination of global warming as well as the continued depletion of fossil fuels has led to new alternative technologies being created and depended upon to supply today's new energy demands. Alternative energy sources, mainly renewable energies, have become the front-runners in the new renewable energy push, attracting more attention than ever before [2].

Solar and wind energy sources provide new ways to control and diminish fossil fuels. However, they face a few drawbacks when considering their high capital costs and dependence on climate. Wind energy technology in particular, is being developed in many modern countries and can be found both commercially as well as in smaller sized domestic wind turbines. These wind energy technologies can vary from just a few kilowatts to utility interconnected wind farm applications that go up to megawatts [3]. A lot of countries with high average daily solar radiations in the range of 3-6 kWh/m^2 are currently looking to reduce their fossil fuels usage [4-7].

In these countries, the current ability to supply power to residential areas mainly depends on "stand-alone" diesel or hybrid generation systems that are capable of supplying the power demands for the residential sector in a connected or off-grid style. The rural communities, who do not have access to the grid, are the ones that typically settle on a "stand-alone" hybrid system. These rural communities can be found across the globe from Denmark, India, Morocco, Kingdom of Bahrain, and Iran [8].

It is important to note that when investigating the costs, component size, and other economic factors associated with using a hybrid system, environmental conditions must be analyzed [9]. In this paper, Hybrid wind/photovoltaic (PV) systems have been studied extensively and it was found that irregular patterns of wind and solar energy must be considered in regards to the energy storage system for hybrid energy systems [10-13]. In addition, combined "stand-alone" diesel generators are generally expensive to operate and maintain at low load levels [14].

This study proposes a hybrid energy system that can be used for a typical residential house located in Istanbul, Turkey

(41° 0' N, 28° 58' E). It also analyses the energy production of a hybrid energy system in terms of energy and economic aspects. In addition, a sensitivity analysis was conducted to compare the systems performance under various conditions including different solar panels slope, variable wind speed, and changing electricity load.

SYSTEM DESCRIPTION

As shown in Fig.1, the proposed hybrid energy system includes two renewable sources (solar panels and wind turbine), a boiler, a electrical converter, a battery, and a diesel generator to supply the 22kWh/d (3.82kW peak load) electric demand and the 11.26 kWh/d (2.09 kW) thermal load. This is because the electricity, which is produced by the solar panels and stored in the battery, alongside the electricity produced by the wind turbine, will supply some demand but is not enough to satisfy the total amount needed. Therefore, a diesel generator is used to help the two renewable energy sources supply the total amount of electricity needed. This system uses a smart controller to switch the components by taking their production into consideration.

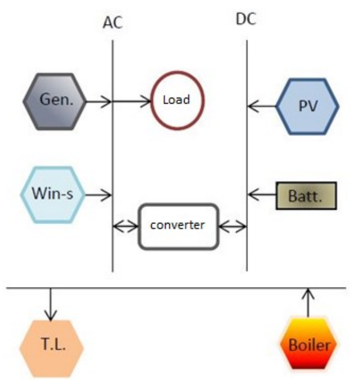

Figure 1. System schematic

Renewable energies

The wind and solar energy resources of Istanbul are considered for this study.

Solar energy resource

The monthly average solar radiation of Istanbul is illustrated in Fig.3. Data has been extracted from a national environmental organization for the year of 2014. The average solar radiation is 3.94 kW/m2/d and the clearness index has been found by Homer for latitude at 41° 0' N, 28° 58' E.

Solar panel

In this system, Generic Flat Plate PV was chosen as the solar system of our system. The solar panel slope is considered 33^o degree. Sensitivity analysis has been performed to find the optimum slope of solar panels. The capital cost of each solar panel with 1kW generated power is considered to be $1,500 to $2,000 when taking into account replacement costs. These solar panels also need $10 per month as their operation and maintenance costs (O.M.).

Battery

Generic 1kWh Lead Acid battery has been used to store excess electricity in low demand loads. In this part, $300 and $10 per month are considered the capital costs and OM costs. It is crucial to use a cost-effective battery because it has the same replacement price as its capital cost.

Wind turbine

The wind turbine relies greatly on another accessible renewable energy, which is the wind. The wind turbine assessment is usually higher compared to the average electrical load. Windera S is the most suitable wind turbine for our system because despite its small size it has good energy efficiency. For this type of turbine, $1,000 to $1,200 are considered as the capital and replacement costs.

Generator

The 10 kW genset diesel generator is chosen for this “stand-alone” system. For larger generators the costs per kW are lower and for smaller units the costs are higher. Since the peak power demand in this analysis is less than 5 kW, the cost is taken as $500/kW. Replacement and operational costs are assumed to be $500/kW and $0.03/h, respectively.

Wind energy source

According to Fig.2 wind energy monthly information of Ataturk Istanbul airport (41° 0' N, 28° 58' E) has been extracted from the national governmental environmental organization for the year 2014. (The wind speed is 5.76 m/s.)

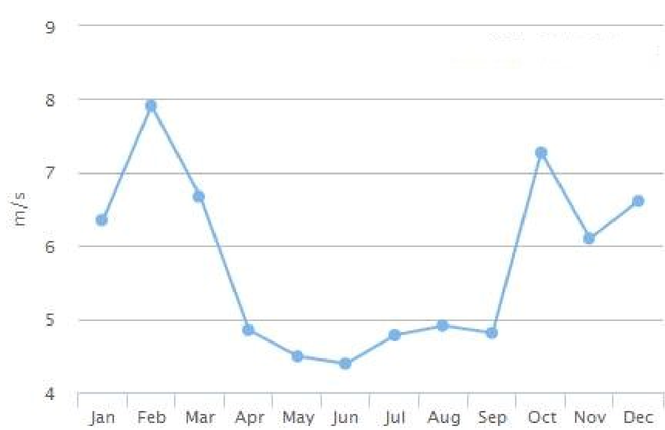

Figure 2. Monthly average wind speed (m/s)

Figure 3. Monthly average solar radiation

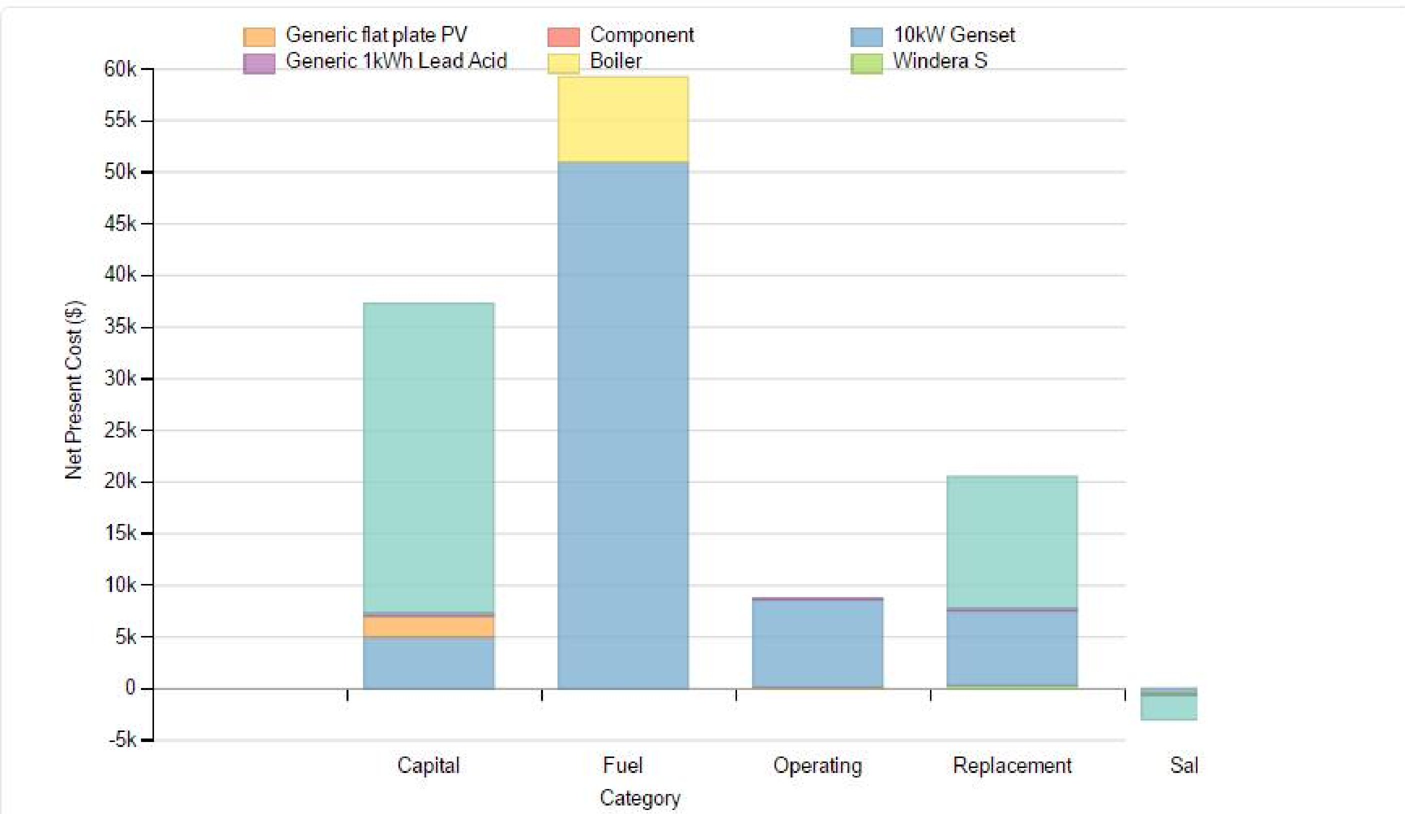

Figure 4. Net present values

RESULTS AND DISCUSSION

As it is shown in Fig.5, it is clear that a diesel generator has the most important role in supplying the energy demand. In this figure it shows that during the months with higher solar radiation and wind speed the generator uses less fuel to supply demand. It also shows that February and October have the most wind power and July and August have the highest solar power. By considering February as the highest load demand, system production has increased significantly. In addition, the economic term is the most important part of analysis. The aim of reaching the most suitable component is done by reducing the costs and increasing the system efficiency. Fig. 4 shows the present value of the system for each type of costs including capital cost, fuel cost, operating cost, and replacement cost separately. It is logical that fuel cost has a more powerful effect

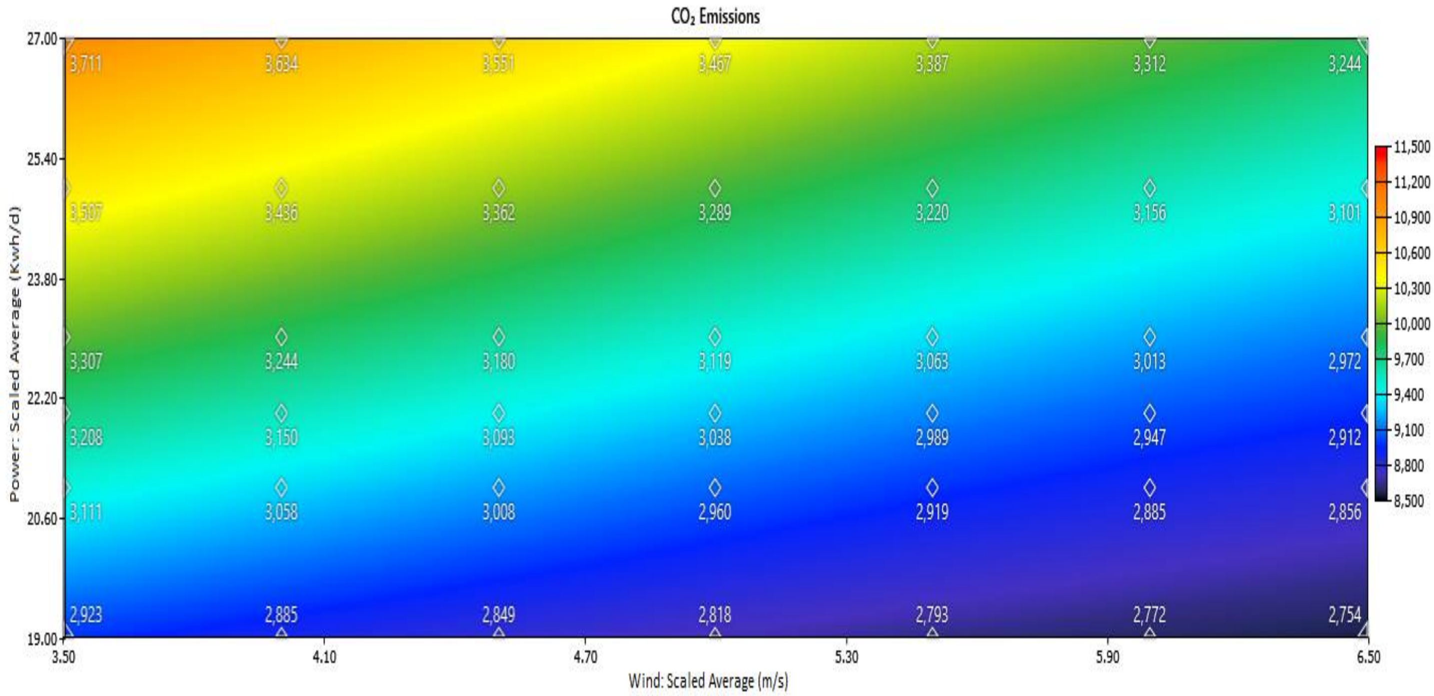

Figure 6. Produced power, wind speed and CO_2 emission

on the present value because the diesel generator works more than the two renewable energy sources.

Table 1. Generator specifications

Quantity	Value	Units
Hours of operation	2190	hours/year
Number of starts	365	starts/year
Operational life	7	year
Fixed generation cost	1.26	\$/hour
Marginal generation cost	0.37	\$/kWh
Electrical production	6931	kWh/year
Mean electrical output	3	kW
Min. electrical output	3	kW
Max. electrical output	3	kW
Fuel consumption	3034	L/year
Specific fuel consumption	0.44	L/kWh
Fuel energy input	29850	kWh/year
Mean electrical efficiency	23	%

Fig.6 illustrates the CO_2 emission rate for varying wind speeds from 3.25 m/s to 6.5 m/s. Sensitivity analysis shows that by increasing the wind speed, the diesel generator works less than with low speed wind blowing. This reduction in generator working capacity can cause less CO2 emission. So by increasing the wind speed, CO2 emissions will decrease. In addition annual emission data has been illustrated in Table 2.

The performance assessment and economic feasibility of the stand-alone hybrid energy system will be discussed in this section. Fig.4 shows the present value of the system for each type of costs including capital cost, fuel cost, operating cost, and replacement costs for each system component separately. It is logical that the fuel cost has a more powerful effect on the present value because a diesel generator uses more fuel than the two renewable energy sources. A power electronic converter is needed to convert electricity between the AC and DC components, AC being the generator, load, and wind turbine and DC being the PV and battery. For the 1kW system the installation and replacement costs are taken as \$300 and \$300, respectively.

Table2. Annual emissions

Pollutant	Emissions(kg/year)
Carbon dioxide	9288
Carbon monoxide	20
Unburned hydrocarbons	2
Particulate matter	1
Sulfur dioxide	19
Nitrogen oxides	176

CONCLUSIONS

In more recent times, the stand-alone energy system has become highly demanded due to diminishing oil resources and elevated prices. This study proposes a hybrid energy system consisting of solar panels, a wind turbine, a diesel generator, a battery, a converter, and a boiler capable of supplying 22kWh/d electric load and 11.26kWh/d, thermal load. The results show the proposed system is energetically and economically feasible by considering a 25-year lifespan. Sensitivity analysis and energy analysis have been conducted to find the parameter effects on electricity production and CO_2 emission.

NOMENCLATURE

T.L.	Thermal Load
Gen.	Generator
Batt.	Battery
PV.	Photovoltaic
O.M.	Operation and Maintenance
SHES	Smart Hybrid Energy System
WIN-s	wind turbine system

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