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Research Article

The Economic Assessment of Renewable Technologies Integration

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Abstract – A case study was conducted to compare renewable energy technologies with natural gas generators in terms of emissions and costs. The load that was used in the hybrid renewable energy system and the engine system running on natural gas was the same value of 62,500 kW. In the case of using solar panels as the only source of energy, the initial cost was the highest. In the case of using the wind turbine as the only source of energy in the system, the initial cost was lower than the system that works on solar panels, but it was also high. The case in which the system was operated using the wind turbine and solar panels as an energy source was the best case for the system, the initial cost was the lowest compared to wind and solar with no emissions produced. In the case of natural gas generators, the cost was low compared to the hybrid power system, and the operating cost was also low, but the harmful emissions were high. The findings show that integrating renewables into the grid presents the most beneficial alternative for decreasing emissions and minimizing overall costs, compared to the scenario where renewable energy sources are used separately.

Keywords – Climate Change, Fossil Fuel, Integration of Renewables, Solar-Wind Hybrid Systems

I. Introduction

The integration of renewable energy technologies has emerged as a promising solution to combat the adverse effects of excessive CO_2 emissions. Amidst global energy demand and emissions challenges, a critical juncture demands attention. Global population growth is anticipated to drive an escalation in the need for affordable energy. The reliance of the global economy on fossil fuels and the subsequent rise in greenhouse gas emissions are causing significant changes in the climate system, resulting in consequences that affect all continents [1]. The world's largest issues right now include carbon pollution and greenhouse gases [2]. Numerous factors have contributed to the rise in emissions, but the recent rise in energy consumption and the continued reliance on fossil fuels for a sizable portion of energy production are the main ones.

This study aims to explore the integration of renewable energy technologies as a viable strategy for reducing CO_2 emissions. The study will identify the challenges and opportunities associated with this transition by examining the technological, economical, and environmental implications of integrating renewable energy into existing energy systems, through the economic assessment of hybrid renewable energy systems, comparing them to the generator system, also comparing them with renewable energy systems such as wind and solar.

II. Methodology

To assess the integration of renewable energy systems, the city of İzmir was chosen to make this comparison using the HOMER program for simulation. İzmir ranks third in the ranking in terms of wind energy potential in Turkey. Only a small portion of the estimated 11,854 MW of İzmir's wind energy potential, which corresponds to a 2,370 km^2 region, is now being utilized. This potential can create 31 billion kWh of energy annually.

Because of its favorable weather, İzmir has significant potential for solar energy. Izmir receives 1680 kWh/m2 of solar energy each year, which is more than Turkey's average of 1100–1600 kWh/m2. In this regard it can be said that İzmir has the highest average solar energy in Turkey [3]. Fig. 1 shows the concentration of GHI in all parts of Turkey, with a high concentration in the city of Izmir [4].

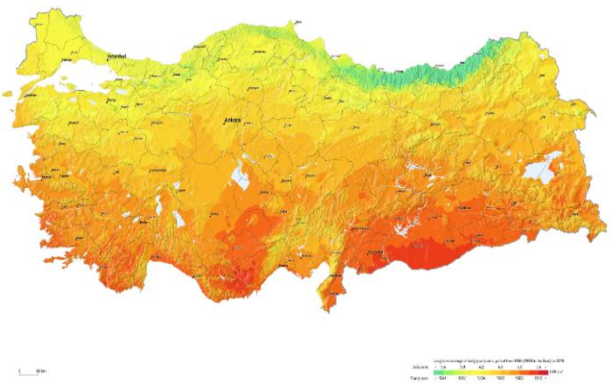

Fig. 1 GHI solar resource map of Turkey [4]

A. Data Collection

Secret Space Encryptor (SSE) files are made available by the NASA Research Center and include information gathered by earth observing satellite programs about solar energy radiation and other meteorological variables [5]. POWER Data view Viewer can view SSE datasets, which include data for Turkey over 30 years, from 1990 to 2019. Annual average temperature and solar radiation datasets are collected for İzmir and illustrated in Table 1. DNI represents direct normal irradiation and GHI shows global horizontal irradiation.

Table 1. Solar Data for Izmir

Area Name	Izmir
Temperature	18.6 °C
Clearness Index	0.541
DNI	1836.1 kWh/m2
GHI	1761.3 kWh/m2
GHI_optimal	1991.2 kWh/m2

Underwriters Laboratories (UL) provides the web tool Windnavigator, which evaluates the potential for wind energy in any place [6]. It enables access to monthly data, wind rise, and wind statistics for given locations. Furthermore, data and statistics are accessible for a variety of heights. shows the average annual wind speed of 5.64 m/s at Izmir.

B. System Model in HOMER Pro

As a start in HOMER, the specifications of inputs, the selection of model inputs, and area determination are required. For example, generator, wind turbine, solar panels, load, component costs, and resources potential must be defined. Fig. 2 shows the model of the system used in the study in HOMER Pro software.

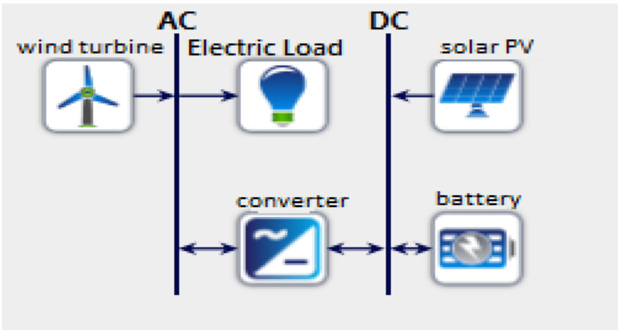

Fig. 2 System model in HOMER Pro

C. The Technical Data of Components

Data for a wind turbine operating at an altitude of 100 meters was obtained from [7]. Table 3 shows data for a wind turbine manufactured by Leitwind, model LTW-101 with a substantial rated power output of 3000 kW. This wind turbine boasts a sizable rotor diameter of 100.9 meters. The turbine's hub height stands at 100 meters, allowing it to access higher wind speeds for optimal energy generation.

Table 2. Wind System Specifications

Manufacturer	Leitwind
Model	LTW-101 3000kW
Rated Power	3000 kW
Rotor Diameter	100.9 m
Swept Area	7996 m^2
Hub Height	100 m
Cut In Wind Speed	2.5 m/s
Cut Out Wind Speed	25 m/s
Required Area	0.39 km^2
Rotor speed, max	14.4 U/min

Table 4 shows solar system specifications with a maximum power output of 340 kW. The solar panels are manufactured by Peimar, and they come with a remarkable 30-year lifespan. These panels are designed with an efficiency rating of 17.5%.

Table 3. Data for Solar

Manufacturer	Peimar Inc
Max. Power	340 kW
Cell Type	Flat plate
Lifetime	30 years
Derating Factor	80%
Nominal Operating Temperature	25 °C
Panel Efficiency	17.5 %
Panel Area (Distancing area included)	3.27 m^2

D. *Costs of System Components*

Costs of system components with the cost details of maintenance, operation and replacement are shown in Table 4.

Table 4. Costs of System Components

Equipment	Lifetime (years)	Capital ($)	Replacement ($)
Wind Turbine	25	1600/kW	1600/kW
PV Panel	30	640/kW	640/kW
Converter	15	300	300
Battery	15	24070	24070

Data for generators is shown in Table 6. The capacity and cost of each generator are Avus 2.5MW with the cost of $2,906,389.61 and Avus 2MW with the cost of $2,406,899.8. It also shows the cost of replacement and maintenance and the efficiency of the two generators.

Table 5. Data for Generator

Equipment	Avus 2MW	Avus 2.5MW
Capacity (kW)	2,000	2,500
Initial cost ($)	2,406,899.8	2,906,389.61
Replacement cost ($)	730,000	775,000
O&M ($/op. hour)	26.2	28.8
Overall Efficiency	88.4	88.7
Fuel price ($/m3)	0.3	0.3
Fuel	Natural gas	Natural gas

E. *HOMER Software Input Data*

The load used in HOMER software was 62500 kW, it was chosen to eliminate excess electricity by the generators used as much as possible.

Monthly solar GHI, average wind speed, and average temperature at the site area are given in Fig. 3,4, and 5, respectively.

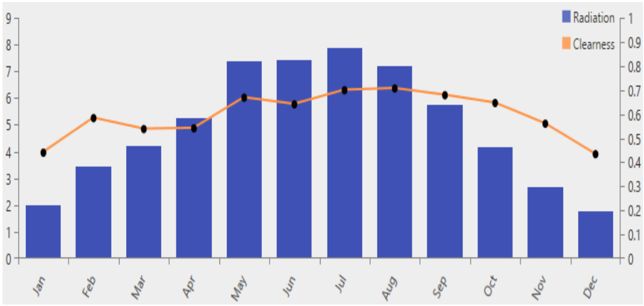

Fig. 3 Monthly average solar GHI

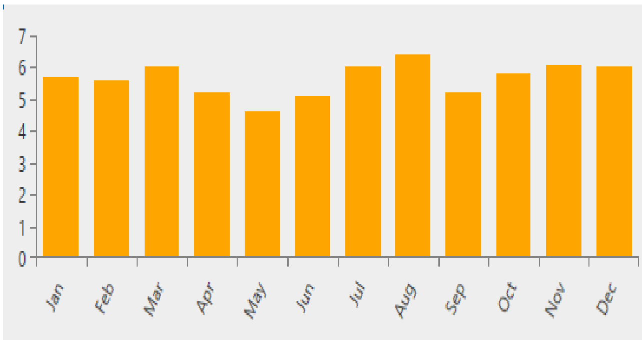

Figure 4. Monthly average wind speed at study areas

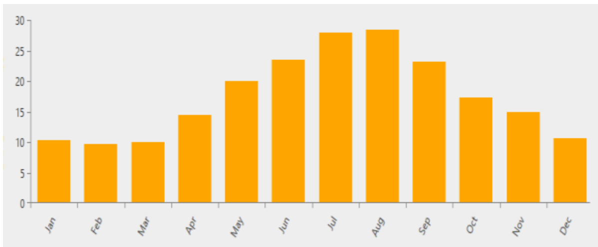

Figure 5. Monthly average temperatures at study areas

III. Results

After entering the wind, solar, and temperature data, we obtained three renewable energy systems in addition to the generator system. The first system is the hybrid system, the second is wind energy, and the third is solar energy system.

When simulating the system using solar-wind hybrid system, the net present cost (NPC) is $202,178,600, Batteries constitute the highest percentage of the total cost of the system, amounting to $152,315,138.7. The number of wind turbines is 5, the number of solar panels was 33,510. Total load consumption is 22,804,623 kWh/year and the system total production 106,593,542 kWh/year.

When running the system using only the wind energy system, NPC is $269,779,400 and the batteries constituted the largest percentage of the total cost, amounting to $190,988,241. The number of turbines is 14, the number of batteries is 4499, and the system total production is 144,306,569 kWh/year.

When running the system using only the solar panels, NPC is $329,982,300. Also, the batteries constituted the highest percentage of the total cost, amounting to $218,326,855. The number of solar panels was 177,172 and the number of batteries was 5,143 and the system total production 291,086,690 kWh/year.

AVUS is the greatest thermal and power system utilized by 2G, with an output range of 527 to 4500 kW. In this study, we use two generators with a total capacity of 4500 kW to meet the load 65,200 kW without excess. Total NPC for system is $33,202,730. The total system production reached 22,815,840 kWh/year. Total production of Avus 2.5MW is 15,276,268 kWh/year and the total production of Avus 2MW is 7,539,572 kWh/year. where the amount of total CO_2 is 8,033,464 kg/yr, total CO is 1,759,048 kg/yr, and total nitrogen oxide is 351,810 kg/yr.

HOMER calculates payback by comparing one system with another. In general, payback tells you how many years it takes to recover an investment. When comparing our system with another system by HOMER, the payback period values were 6.12 year for hybrid system, 8.17 year for wind energy system and 17 year for solar energy system.

Table 6. Summary of the Results

	Wind-Solar system	Wind Energy System	Solar Energy System	Generator (Current) System
Total NPC ($)	202,178,600	269,779,400	329,982,300	33,202,730
Levelized COE ($)	0.686	0.9153	1.12	0.1126
Operating cost ($)	5,332,198	7,165,016	7,017,830	2,157,370
Initial capital ($)	133,246,563	177,153,521	239259213	5,313,289
Payback (year)	6.12	8.17	17	

IV. DISCUSSION

In the case of solar panels as the only source of energy, the initial cost and NPC were the highest, with no harmful emissions, the reason for the high cost is the increase in the number of solar panels is 177,172 and the increase in the number of batteries is 5,143.

In the case of wind turbine as the only source of energy in the system, the initial cost and NPC were lower than the system that works on solar panels, but it was also high because the number of wind turbines increased by 14, and the number of batteries was also large number of 4,499.

The case in which the system was operated using the wind turbine and solar panels as an energy source was the best case for the system, the initial cost and NPC were the lowest compared to wind and solar with no emissions produced, as the number of wind turbines decreased to 5 and the number of solar panels to 33,510. Also, the number of batteries decreased to 3588, and this had a major role in reducing the cost.

In all previous cases, the cost of storage was very high, due to the high value of storage batteries and their large numbers. In the case of natural gas generators, the cost was low compared to the hybrid power system, and the operating cost was also low, but the harmful emissions were high. The cost of fuel was almost a third of the total cost of the system. The first Avus 2.5MW produced 67 percent of the total production and its efficiency was 42.6%. Table 6 provides a summary of the results for all scenarios.

V. CONCLUSION

The findings show that the integration of renewable energy sources into the energy grid presents the most beneficial alternative for decreasing emissions and minimizing overall costs compared to the scenario where renewable energy sources are used separately. While the integration of various energy sources leads to cost reduction in comparison to individual renewable sources, it is important to note that the initial investment required for such integration remains much higher when compared to fossil fuel sources.

Energy storage plays a crucial role in renewable energy systems and accounts for the largest proportion of the overall system cost. Due to the abundance and comparatively low cost of fossil fuels in relation to renewable energy sources, coupled with the absence of a need for additional infrastructure, a significant number of countries continue to depend on fossil fuels for energy production.

The case study included a comparative analysis of natural gas generators, renowned for their cost-effective energy generation, and a Wind-solar hybrid system. The study shows that the emissions stemming from natural gas generators were much greater in comparison to renewable energy sources. Nevertheless, it is important to note that renewable energy sources often involve more expenses in terms of their initial installation, ongoing maintenance, and the development of supporting infrastructure.

Despite the higher initial costs of implementing renewable energy technologies, this study recognizes that the long-term economic advantages of using sustainable energy sources surpass the immediate financial consequences.

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