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Original Article

Assessment of the Economic Analysis of Utility Scale Solar-Wind-Diesel Generator System

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***Abstract** - The efficient use of energy resources is increasingly crucial due to the limited availability of fossil fuels and rising energy demands. This study evaluates a hybrid renewable energy system that combines Photovoltaic (PV) panels, wind turbines, and diesel generators to improve energy efficiency and reduce environmental impact in Northern Cyprus. Using the HOMER software, various system configurations were simulated to meet peak load demands ranging from 139 MW to 335 MW. Key metrics, including Net Present Cost (NPC), Levelized Cost of Energy (LCOE), and carbon emissions, were analyzed. The results show that the most cost-effective configuration, a hybrid solar-wind-diesel system with 250 MW solar and 50 MW wind capacities, achieves an NPC of $22.3 billion and an LCOE of $0.178/kWh while reducing carbon emissions by approximately 13,052 kg/year. These findings highlight the potential of hybrid renewable systems to improve energy efficiency, lower costs, and reduce environmental impact, offering valuable insights for energy policymakers and researchers.*

***Keywords** - Hybrid renewable energy systems, Energy efficiency, HOMER simulation, Techno-economic analysis.*

1. Introduction

The globe has an infinite set of energy resources. However, these resources are used in inefficient ways. For example, residences, cities, cars, factories, and other parts of lifestyle are completely energy inefficient. Designing a new world that is fully capable of using energy efficiently is very challenging. The primary reason for this is the development duration of the cities with the absence of advanced technology and energy efficiency, which requires centuries. The planet now runs 80% on fossil fuels: natural gas, oil, and coal. This is an issue because fossil fuels will run out soon if the consumption rate does not decrease. The future energy budget should exclude fossil fuels.

Another problem is that currently, coal provides 28% of the world's total energy, and the most extended portion, over 40%, of the world is electricity [1]. Researchers and environmentalists have debated due to this problem in recent years. It is because of the growth of the world population and industrialization, which results in the rise of electricity demand that is mostly caused by fossil fuels. Its extensive usage makes these energies rise the emission of greenhouse gasses, carbon dioxide, that causes a risk to our environment. Knowing this, policymakers and researchers start looking for renewable energy resources such as wind, biomass, solar photovoltaics, tidal waves, hydropower, and geothermal energy. These energies are gaining popularity, although they have some drawbacks. However, they are clean and environmentally friendly. Furthermore, they mitigate the issue of greenhouse gas emissions [1].

Therefore, many studies have been carried out in various countries. For example, Hassan et al. (2023) have done a detailed study on the techno-economic analysis of an on-grid hybrid renewable energy system concerning the deanery building of the Engineering College at the University of Diyala, Iraq. This study focuses on how using PV panels, wind turbines, and battery storage is cheaper and eco-friendly.

The study, therefore, determines an optimal system design by modelling and optimizing to provide an average daily load of 25. 0 kWh with a total system cost of $5142 and energy cost of $0.05/kWh. The hybrid system also improves carbon emission eradication, which is estimated to be around 13,052 kg/year of CO2. The new strategy involves correct sizing of the system components to reduce the cases of oversized systems that are expensive and energy-consuming. This study contributes to the practicality of hybrid renewable energy systems in meeting economic and environmental objectives simultaneously through optimal use of electricity and minimizing the use of conventional energy sources [2].

In their state-of-the-art review and bibliometric analysis, He et al. (2023) focused on the sizing optimization of off-grid

HRESs. They reviewed 299 journal papers published over the last five years. Their work broadly covers system configurations, energy control measures, performance assessment criteria and sizing techniques. This way, the analysis results show the tendencies in the field, including the dominance of solar photovoltaics and batteries as the main sources of energy and storage, as well as the wind-photovoltaic-battery-diesel configuration.

The paper focuses on the prevalence of rule-based approaches in energy management because of their simplicity and computational cost. It stresses the significance of economic parameters, with 97.99% of the reviewed articles focused on the techno-economic feasibility aspect. Meta-heuristic algorithms and the HOMER software tool are found to be the most frequently applied sizing methodologies. The authors present potential research avenues for future work in the form of HESS, DRL-based energy management policies, sustainability and resilience metrics, and DRO-based frameworks. This systematic review seeks to offer the practitioners theoretical knowledge to enhance the development of academic literature and off-grid HRES application [3].

Vakili et al. (2023) assess the techno-economic performance of solar Photovoltaic (PV) power, wind turbines and generators for standalone and grid-connected hybrid electrification systems in a large shipyard in Italy. Using a microgrid design optimization tool, the paper evaluates the effectiveness and cost feasibility of different system layouts. Thus, for a standalone system, a solar PV system has a levelized cost of electricity of $0.053/kWh, an IRR of 11 percent and a discounted payback period of 6.2 years.

On the other hand, the grid-connected hybrid system that consists of solar PV, wind, and diesel generators have an LCOE of $0.109/kWh, an IRR of 28 percent, a payback period of 4.9%, and a discounted payback period of 3.53 years. The sensitivity analysis shows that diesel prices impact systems that depend more on generators than on the cost of renewable energy technology. This paper shows that applying renewable energy systems can help minimize negative effects on the environment and enhance the performance of the shipbuilding business [4].

Kumar et al. (2021) perform a techno-economic assessment of an SPV and diesel generator hybrid system using four BES types: lead acid, lithium-ion, vanadium redox, and ZBF batteries for isolated islands in India. HOMER software is used to analyze the feasibility of the solutions and the findings reveal that the SPV/DG/ZBF hybrid system is the most suitable for both Baratang and Minicoy islands. In the case of Baratang island, the system configuration of 20 kW SPV, 7 kW DG, 100 kWh ZBF batteries and 20 kW converter has a net present cost of $ 23,927. 21, the levelized cost of energy was $0. 167/kWh and the operating cost of $338.20. Likewise, the net present cost for Minicoy Island is $22,366. 64, with the levelized cost of energy of $0. 155/kWh and operating cost of $217. 49. The study further expands the comparison to other BES technologies regarding system cost, return on investment, simple payback period, energy generation, emissions, and renewable integration. The ZBF technology is the most efficient, with the highest ROI and renewable energy integration and the lowest payback period and emissions. The study also has a three-dimensional sensitivity analysis to support the system's validity as well [5].

Oladiran et al. (2024) evaluate the techno-economic potential and efficiency of an independent solar PV-biomass system with optimal storage for Grand Bassa, Liberia. Given that only 7% of Liberia's population has access to electricity, this study seeks to contribute to increasing power supply in rural areas. The researchers then simulated the community's annual load and resource data through the HOMER Pro software to assess four different system configurations.

This paper identifies that the best system is a biomass gasifier-solar PV-battery storage system that will produce an annual energy of 77,104 kWh, with an LCOE of $0. 29/kWh, and a Net Present Cost (NPC) of $0. 3979 million. Adopting this system, especially with external support, is expected to raise the rural community's educational, economic and socio-economical status. The study offers significant information that can be useful for the implementation and long-term effectiveness of hybrid energy systems in similar environments [6].

The author optimized hybrid renewable energy grids in Mogadishu, Somalia, using MATLAB and advanced algorithms. They compared diesel-only, PV-diesel, wind-diesel, and PV-wind-diesel systems. The PV-wind-diesel hybrid with PSO was most cost-effective, cutting net present costs by 32-47% and electricity costs by 41-60% while reducing greenhouse gas emissions by 38-59%, demonstrating significant economic and environmental benefits. The primary purpose of this research was to calculate cost analysis, such as life cycle cost and energy cost. Many villages cannot reach the electricity grid in Ethiopia, where Mesfin Jariso et al. conducted an off-grid system analysis.

The study aimed to size and design the appropriate system in Addis Border village, located in the south. In addition, the study compares different resource data, one from NASA and the other from the Ministry of Energy. [7] Norat Mal Swarnkar and Lata Gidwani in India performed financial and economic assessments of combined wind turbines and solar energy systems. The aim is to study the combination of solar and small wind energy interims the energy costs like yearly cost, net present cost, and payback period. The result showed that solar is cheaper than wind energy [8].

Table 1. Total different sources of power installed in North Cyprus

	Steam Power Plant		**Diesel**		**Solar**
	Number	Size (MW)	Number	Size (MW)	Size (MW)
KIB-TEK	2	60	8	17.5	1.25
AKSA	1	8	8	17.5	0
Total Installed capacity = 409.25 MW					

The study compared the suitability of wind or diesel generators or both. Energy Management of an autonomous diesel generator and renewable energy system was done by Adewale Z. Obaro [9]. This paper investigated the optimal management of an autonomous combining energy system using a Mixed-Integer Nonlinear Programming (MINLP) optimization technique.

The results showed that essential savings in fuel consumption could be achieved by adding an autonomous hybrid energy system as compared to applying a single diesel generator system. Nafi Cabacaba and Serkan Abbasoğlu examined wind and solar hybrid systems for residential in North Cyprus. This research aims to reduce the cost, which will help to grow energy production and give a new improvement in manufacturing and technological areas. Also, this research finds out the optimal wind turbine capacity and a number of PV panel sizes to produce power for a residential in Nicosia in North Cyprus [10].

As well as Youssef Kassem et al. have also concluded that solar PV and wind turbine systems are viable for residential use in north Cyprus. The study focused on wind characteristics and the available wind energy in three different urban regions in Cyprus. The study reveals that one of the regions, called Gazimağusa, is the best applicable for harvesting the wind's kinetic energy [11].

The literature review illustrates that many studies and research activities have been performed in various locations, such as Africa, Asia, and Latin America. However, in Cyprus, few studies and research focus on the only climate and cost analysis of renewable energy. Therefore, this study aims to use HOMER simulation software to design demand between 139 MW to 335 MW of hybrid sustainable energy systems in Northern Cyprus. The simulation includes total net present cost and emission analysis and comparisons of various hybrids such us diesel generator-PV-wind systems.

2. History of Electricity in North Cyprus

The energy production in North Cyprus dates back almost two decades. A small part of the electricity requirement was produced from the 1970s by primitive gas turbines and diesel-powered generators. At the same time, a large portion of the energy demand was supplied from the Southern Side. The electricity generation with Turkey's support in the 1990 step was taken seriously. Turkey supported $ 125 million worth of modern Steam Turbine Power Plants according to the investments made to establish Teknecik. 1995, the first steam turbine unit was commissioned, and the second unit was completed in 1996. The power plant has two steam turbine units and a total power of 120 MW. In March 1996, the Southern side completely cut off the Northside's electricity. After that, these two power plants have met most of the country's energy needs [16].

Currently, North Cyprus Electricity produces two companies, AKSA (a private company) and KIB-TEK (a Government Company). Table 1 illustrates the total electricity installed in north Cyprus [17]. As shown in the table, the Teknecik power plant has two steam power, each generating 60 MW, while AKSA produces an 8 MW steam power plant. Both companies have 280 MW diesel power generators. Furthermore, the KIB-TEK generates 1.25 MWp solar photovoltaic; the total installed capacity is 410.5 MW [18]. Finally, more than 90% of North Cyprus's electricity comes from diesel and steam.

3. Methodology

The Homer program requires some input parameters for the process of optimization in different areas. These information parameters are primary load, wind resource, temperature resource, solar resource, size of power produced, and capital cost for each given component. All the information needs to be clearly explained here.

3.1. Load Profile Construction

In this study, North Cyprus has chosen to examine the feasibility of the designed hybrid solar wind-diesel system. North Cyprus has six major districts, which are also divided into twelve sub-districts. The energy consumption in the country is mainly dominated by electricity to power the residential, commercial, hospitals, municipal, agricultural and industrial loads and public road lights.

A typical sample of the daily load profile of the country is shown in Figure 1. It can be seen that the country needs a maximum of 254.3 MW peak demand and a baseload of approximately 139 MW. From the load profile, from 1:00 am to 9:00 am, the load requirements are the lowest since sleep time and early morning. On the other hand, the maximum demand occurs during evening time, which is the time for residential use in their home.

The peak demand is about 225 MW; it occurs precisely at 7:00 pm and 8:00 pm. Figure 2 shows the deviation and average of the monthly load profile for the country. It is clear that the highest load demand occurs in July and August because these months are summertime, and the temperature reaches around 45 degrees; therefore, the majority of demand uses all the cooling equipment, such as air conditioning and fans, while September drops the temperature. While the lowest load demand occurs in February, match, April, October, and November because of these months, the perfect temperature is about 15 to 25-degree centigrade.

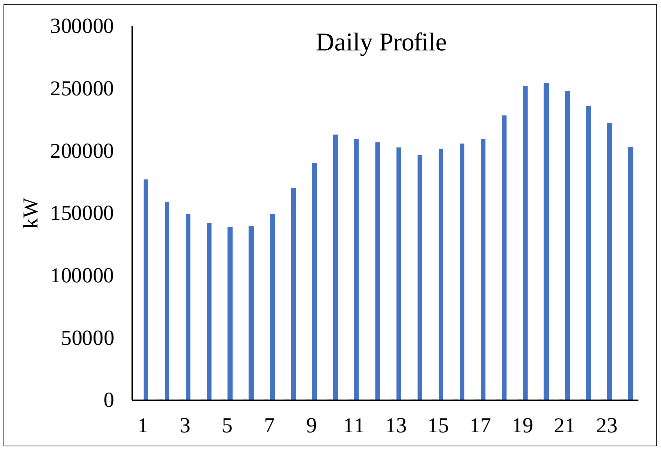


Fig. 1 The daily load profile in Northern Cyprus

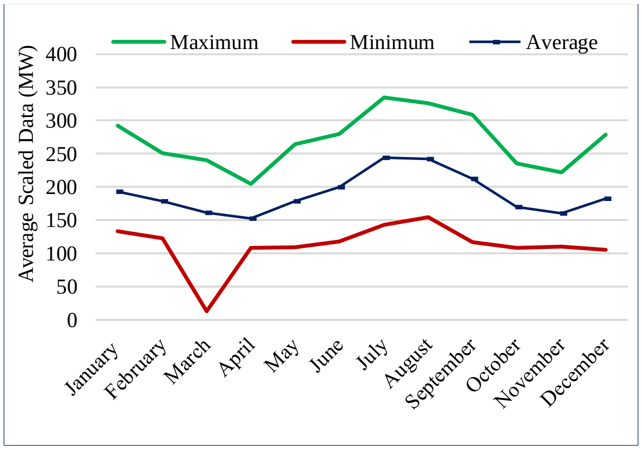


Fig. 2 The alternations of the monthly load profiles in North Cyprus

3.2. Solar Radiation

The solar radiation information is received from NASA [19]. The latitude and longitude of the capital city of Cyprus (Nicosia) are 35°11, 1' North and 33°22.9' east. Figure 3 describes the solar radiation data used in Homer software in this study, as the figure shows the clearness index ranges from 0.474 in December to 0.704 in July.

The minimum solar daily radiation is 2.2 kWh/m2/day, which occurs in December, while the maximum occurs in June and reaches 8.12 kWh/m2/day. Therefore, the yearly average is 5.19 kWh/m2/day. It is noticed that both clearness index and daily radiation are high in May, June, July, and August, while it is low in November, December, January, and February. The reason these months are lower winter season is also that the daytime is less than the night time. On the other side, the summer night time is less than day time.

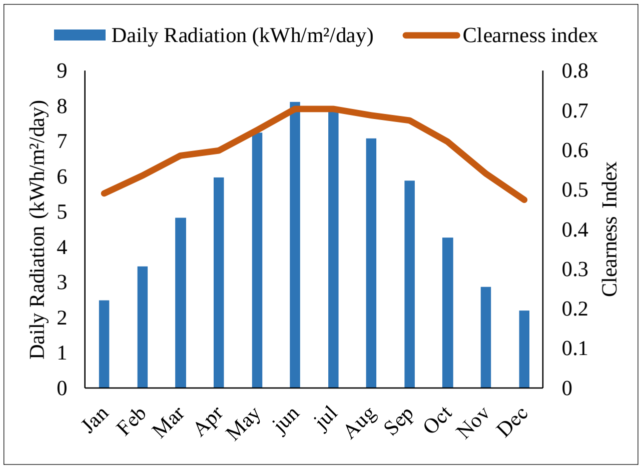


Fig. 3 The annual clearness index and solar radiation for the location of Nicosia, Cyprus [12]

3.3. Wind Speed

The wind speed data are collected from NASA for Nicosia, Cyprus [19]. The monthly averaged wind speed values are collected at 50 meters high on the earth's surface. These values have been collected for more than ten years. Figure 4. illustrates that the minimum wind speed is 4.38 m/s and occurs in May and October.

On the other side, it is clear that February and January have the highest wind speeds with 6.18 m/s and 5.85 m/s, respectively. The average wind speed is 5.05 m/s. Some specific parameters include Weibull distribution, autocorrelation factor, and diurnal pattern strength.

The Weibull k is a measure of the width of the distribution. The data used in the HOMER program fit a Weibull distribution, and the value of k is considered the design. The autocorrelation factor measures hour-to-hour randomness, and the regular pattern force is how strong the wind speed is, which depends upon the time of the day.

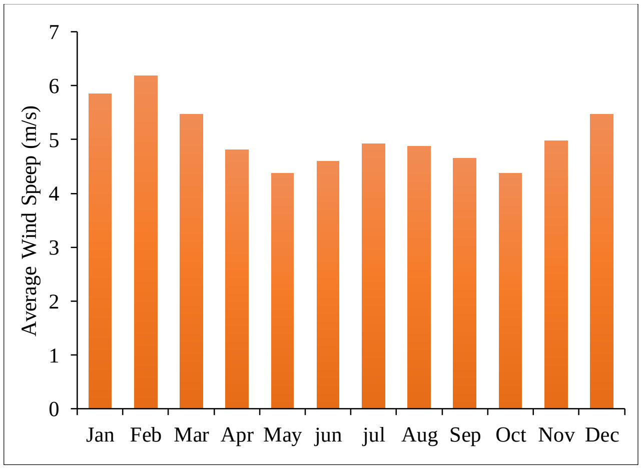


Fig. 4 The wind speed in Cyprus by monthly

3.4. Temperature

Monthly averaged air temperature over 22 years was obtained from NASA [12]. Figure 5 illustrates that the temperature scale is high in June, July, August, and September. Homer uses this ambient temperature to determine the photovoltaic cell temperature and wind turbine.

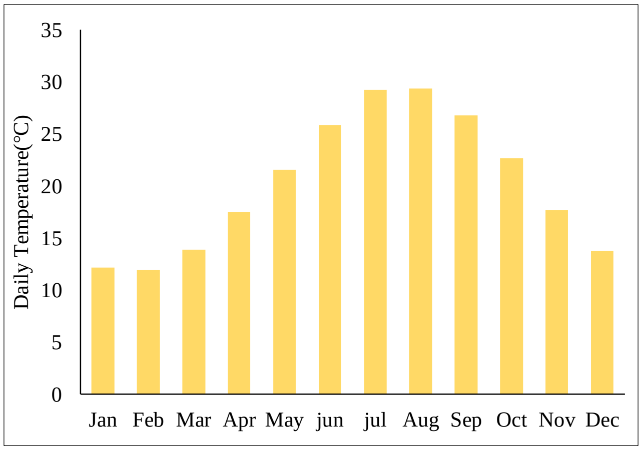


Fig. 5 The temperature in Cyprus by monthly

3.5. Diesel Price

The diesel price varies from time to time, depending on the situation. However, the latest diesel price in Northern Cyprus is $ 0.5/L [13]. The diesel price is classified in this simulation to examine its influence on the system price.

4. System Specification and Descriptions

The hybrid Diesel, PV, and Wind systems have four main components. It includes wind turbines, photovoltaic modules, power conversion units, and diesel generators. Figure 6 illustrates the configuration of the system design as simulated in the software. Table 2 illustrates the input parameters for the chosen components. HOMER software simulates all the different prices of the system based on the US dollar ($). The flowing sub-sections provide each component specification. There will be excess electricity in the study; this occurs when the production of electricity cannot meet the demand.

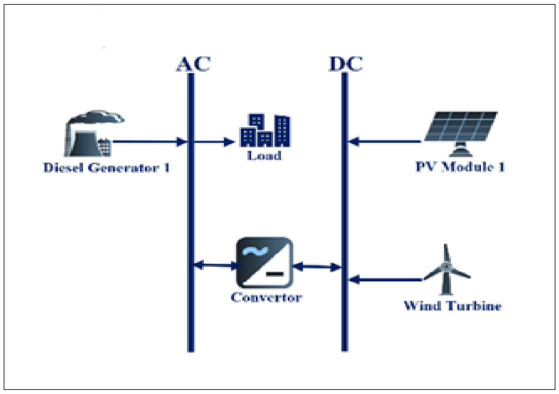


Fig. 6 A schematic diagram of the introduced hybrid wind-diesel-PV energy system

The excess electricity fraction is the proportion of total excess and the total electricity production. HOMER program calculates this amount at the end of individual simulation by using this equation:

$$f_{excess} = \frac{E_{excess}}{E_{prod}} \tag{1}$$

Where, E_{excess} is the total excess electricity while E_{prod} is total production electricity.

Table 2. Technical specification and economical of the hybrid component

Component	Description	Specification
PV Modules	Photovoltaic Model	Fu 300-300P
	Total Power Output (MW)	100, 200, 300 MW
	Capital Cost per kW ($)	$1,100
	Operation and Maintenance Costs per Year ($)	$11
	Operational Lifetime	25 years
Wind Turbines	Type of Wind Turbine	Aeolos
	Rated Power	2 MW
	Capital Cost per kW ($)	$4,350
	Operation and Maintenance Costs per Year ($)	$43.5
	Operational Lifetime	20 years
Inverter	Model	A110E-3.7K
	Rated Power	300 MW
	Capital Cost per kW ($)	$750
	Operation and Maintenance Costs per Year ($)	$7.5
	Efficiency	98%
	Operational Lifetime	15 years
Generator	Rated Power	370 MW
	Capital Cost per kW ($)	$664.75
	Operation and Maintenance Costs per Hour ($)	$0.03
	Minimum Load Ratio	30%
	Minimum Runtime	1 minute
	Operational Lifetime	15,000 hours

4.1. Solar Module Sizing

The Photovoltaic (PV) array capacity is limited to a maximum of 300 MW, which is insufficient to meet the peak load demand of 335 MW. Consequently, excess electric energy cannot be used to charge the battery due to the lower PV capacity than the peak load. Various sizes—50 MW, 100 MW, 150 MW, 200 MW, 250 MW, and 300 MW—are simulated to assess the impact of PV array size on the system's overall cost. The selected PV module is a 72-cell polycrystalline unit, producing 300 Wp [14]. To achieve a 300 MWp output, 1,000,000 PV modules are connected, each occupying a specific surface area of 2m².

In Northern Cyprus, the average daytime duration ranges from 8 to 10 hours throughout the year, necessitating the use of diesel generator sets and wind turbines during the night. A derating factor of 85% is considered in this study to account for losses due to snow cover, wiring, soiling of panels, ageing, and shading. The derating factor is a scaling parameter linked to the PV array's power output to compensate for performance degradation. PV efficiency decreases with rising temperature; hence, the influence of temperature is included in this analysis. The Hybrid Optimization of Multiple Energy Resources (HOMER) software employs the following equation to calculate the PV array output [19]:

$$P_{\mathrm{PV}} = Y_{\mathrm{PV}} \times f_{\mathrm{PV}} \times \left(\frac{\bar{G}_T}{G_{T,STC}}\right)\left[1 + \alpha_P\left(T_c - T_{c,STC}\right)\right] \quad (2)$$

- Y_{PV} is the rated size of the PV array, representing its electric output under standard test conditions [kW].
- f_{PV} is the PV derating factor [%].
- G_T is the solar radiation incident on the PV array at the current time step [kW/m²].
- $G_{T,STC}$ is the incident radiation under standard test conditions [1 kW/m²].
- α_P is the temperature coefficient of power [%/°C].
- T_c is the PV cell temperature at the current time step [°C].
- $T_{c,STC}$ is the PV cell temperature under standard test conditions [25°C].

4.2. Wind Turbine Specifications

The Aeolos-H 2 MW (AC) wind turbine model is chosen for this simulation [15]. HOMER calculates the wind turbine's power output for each computed level by wiring and installing the turbine on a hilltop and then adjusting for actual air density effects during operation.

The wind speed at hub height is analyzed at each time step using the Wind Resource page and wind shear inputs. HOMER computes the hub height wind velocity with the following equation [19]:

$$U_{\mathrm{hub}} = U_{\mathrm{anem}} \times \frac{\ln(z_{\mathrm{hab}}/z_0)}{\ln(z_{\mathrm{anem}}/z_0)} \quad (3)$$

Where,

- U_{hub} is the wind speed at hub height [m/s].
- U_{anem} is the wind speed at anemometer height [m/s].
- z_{hab} is the hub height of the wind turbine [m].
- z_{anem} is the anemometer height [m].
- z_0 is the surface roughness length [m].
- ln represents the natural logarithm.

4.3. Mathematical Financial Assessment

HOMER simulates the entire system concerning the Net Present Cost (NPC) to determine the optimal configuration. The Cost of Energy (COE) is considered for comparison, as it is a relevant metric. Parameters such as project lifetime, real interest rate, and discount rate are inputs for calculating economic metrics.

The real annual interest rate, which includes the inflation rate and the nominal discount rate proportion, is calculated using the following formula [12]:

$$i = \left(\frac{1+i'}{1+f}\right) - 1 \quad (4)$$

Where,

- i is the annual real interest rate.
- i' is the nominal interest rate.
- f is the annual inflation rate.

In this study, the discount rate is 4%, and the annual inflation rate is 12%, as per data from Northern Cyprus [19].

The Net Present Cost (NPC), also known as the life cycle cost, represents the present cost of operating and installing the system over its lifetime. HOMER ranks optimization results based on total life cycle cost, calculated using the following equations [12]:

$$C_{\mathrm{NPC}} = C_{\mathrm{ann,tot}} \times \left(\frac{1-(1+i)^{-N}}{i}\right) \quad (5)$$

Where,

- $C_{\mathrm{ann,tot}}$ is the total annual cost ($/year), including replacement, capital, fuel, and operating and maintenance costs.
- i is the real interest rate [%].
- N is the project's lifetime in years.

The Levelized Cost of Energy (LCOE) represents the average cost per kWh of electricity generated by the system. HOMER calculates the LCOE by dividing the annualized cost of producing electricity (excluding heating, cooling, or ventilating costs) by the total electric load served using the following equation [12]:

$$\mathrm{COE} = \frac{C_{\mathrm{ann,tot}} - c_{\mathrm{boile}}\, H_{\mathrm{served}}}{E_{\mathrm{served}} + E_{\mathrm{surplus}}} \quad (6)$$

Where,

- $C_{\mathrm{ann,tot}}$ is the total annualized cost of the system ($/year).
- c_{boile} is the marginal cost of the boiler ($/kWh).
- H_{served} is the total thermal load served (kWh/year).
- E_{served} is the total electrical load served (kWh/year).
- E_{surplus} is the total surplus energy produced (kWh/year).

For PV and wind energy systems without thermal load, $H_{thermal} = 0$

5. Results and Discussion

5.1. Standalone Diesel Generator

The alone diesel system is the most expensive system among all the configuration alternatives. The size of this system is 370 MW. This size is enough to satisfy the peak demand load, which is 335 MW. Based on sensitivity analysis, the total operation and net present cost of energy costs increase with the diesel price, as shown in Table 3. In this system, a diesel system alone has the cheapest system among the capital costs, with a total of $ 246 million. While it has the lowest excess electricity, which is 135,000 kWh/year, this energy is minimal, according to the production, which is 1,661,510,172 kWh/year, which means the percentage of total excess electricity is 0.00810%. To sum up, although this system has disadvantages; however, it also has some advantages over other systems; these advantages include cheap investment of less than >1 excess electricity.

Table 3. Simulation result of standalone diesel system

Diesel Fuel Price ($/L)	NPC ($)	COE ($/kWh)	Operation Cost ($/yr.)
0.50	24.1 B	0.913	317 M
1	40.7 B	0.325	537 M
1.50	57.2 B	0.457	757 M
2	73.8 B	0.59	976 M

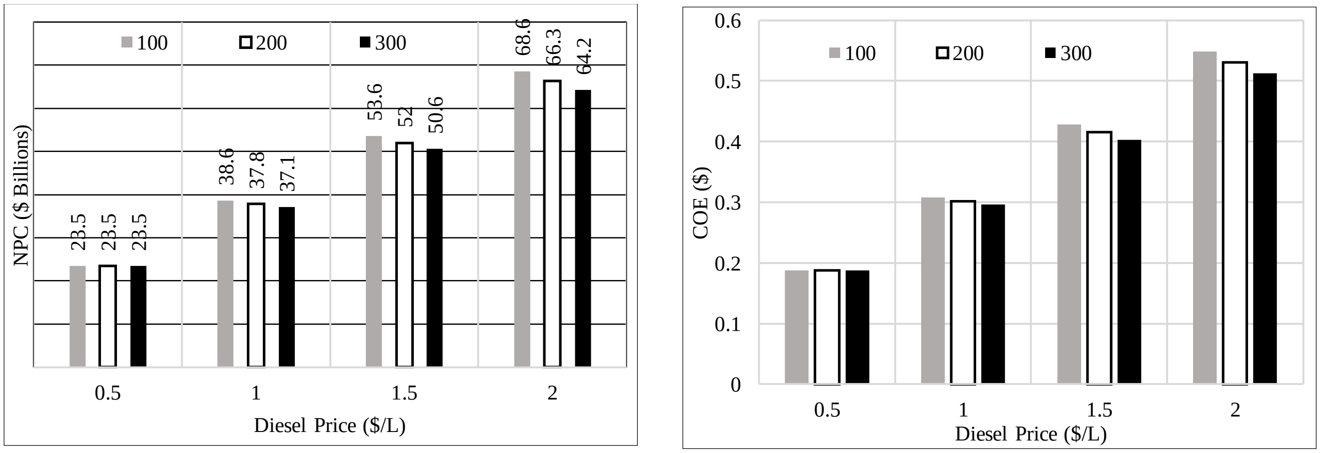
5.2. Hybrid Wind and Diesel Generator

Figure 7 illustrates the graph of NPC, COE, and operation cost values against various capacity and diesel prices. All three costs rise with the rise in diesel prices. The total NPC values range between $ 23.5 billion to $ 68.6 billion, the COE range is between $ 0.188 to $ 0.548 $/kWh, and the operation cost ranges from $ 289 million to $ 901 million. On the other side, the graph provides information about the various capacity of the system. Both the NPC and COE do not have a huge influence on the capacity; it means whether taking 300 MW or 100 MW, the cost change is little, but operation cost does make more when the diesel price is $ 0.5/L.

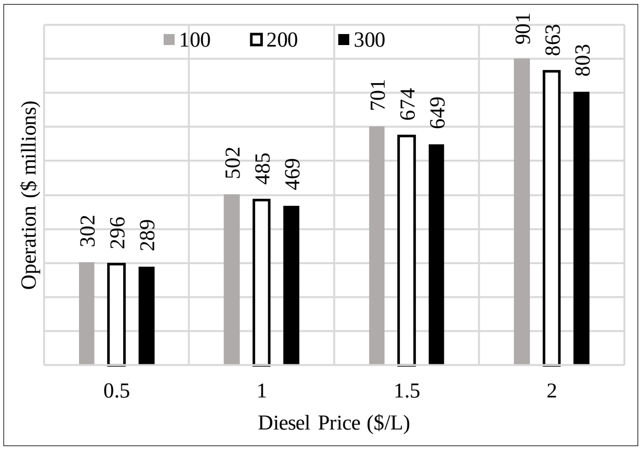
The NPC is about 23.5 billion, and the COE is about $ 0.188. However, other diesel prices NPC, operation, and COE increase whenever it increases the wind turbine's capacity. Table 4 illustrates the excess electricity produced and electric production by a hybrid wind-diesel system. The percentage of the excess range is about 4.98% to 21.1%. This means that whenever the capacity of wind turbines increases, it will also increase excess electricity.

Table 4. Energy production and excess of the hybrid wind-diesel generator system

Wind Capacity	Electrical Production		Excess Electricity (kWh/yr.)	
	Energy (kWh/year)	Percentage of Wind (%)	Energy (kWh/year)	Percentage (%)
100	1,752,035,879	14.8	87,205,190	4.98
200	1,924,793,146	27	258,183,135	13.4
300	2,113,242,209	36.9	445,173,158	21.1



(a) (b)



(c)

Fig. 7 Simulation result of hybrid wind-diesel generator system with capacity along with various diesel prices (a) NPC value, (b) COE value, and (c) Operation cost value.

5.3. Hybrid PV and Diesel Generator

Figure 8 illustrates the graph of the operation cost of the system, levelized Cost of Energy (COE) and Net Present Cost (NPC). In contrast, Table 5 illustrates the generation and excess electricity by the hybrid PV diesel system with three various PV size designs. It can be seen that the NPC, COE, and operation costs increase as the diesel price rises. Conversely, with the increase in PV size from 100 MW to 300 MW, all (NPC, COE, operation) costs decrease. From the table, the PV electric production increases the excess electricity increase. The greater the PV size, the higher the amount of energy produced by PV during the daytime whenever the electricity generated by the PV exceeds the load demand.

Table 5. Energy production and excess of hybrid PV-diesel generator system

PV Capacity	Electrical Production		Excess Electricity (kWh/yr.)	
	Energy (kWh/year)	PV (%)	(kWh/year)	(%)
100	1,673,750,035	9.7	9,312,279	0.556
200	1,748,750,066	18.6	82,528,544	4.72
300	1,865,722,022	26.1	198,573,305	10.6

5.4. Hybrid Wind-PV-Diesel System

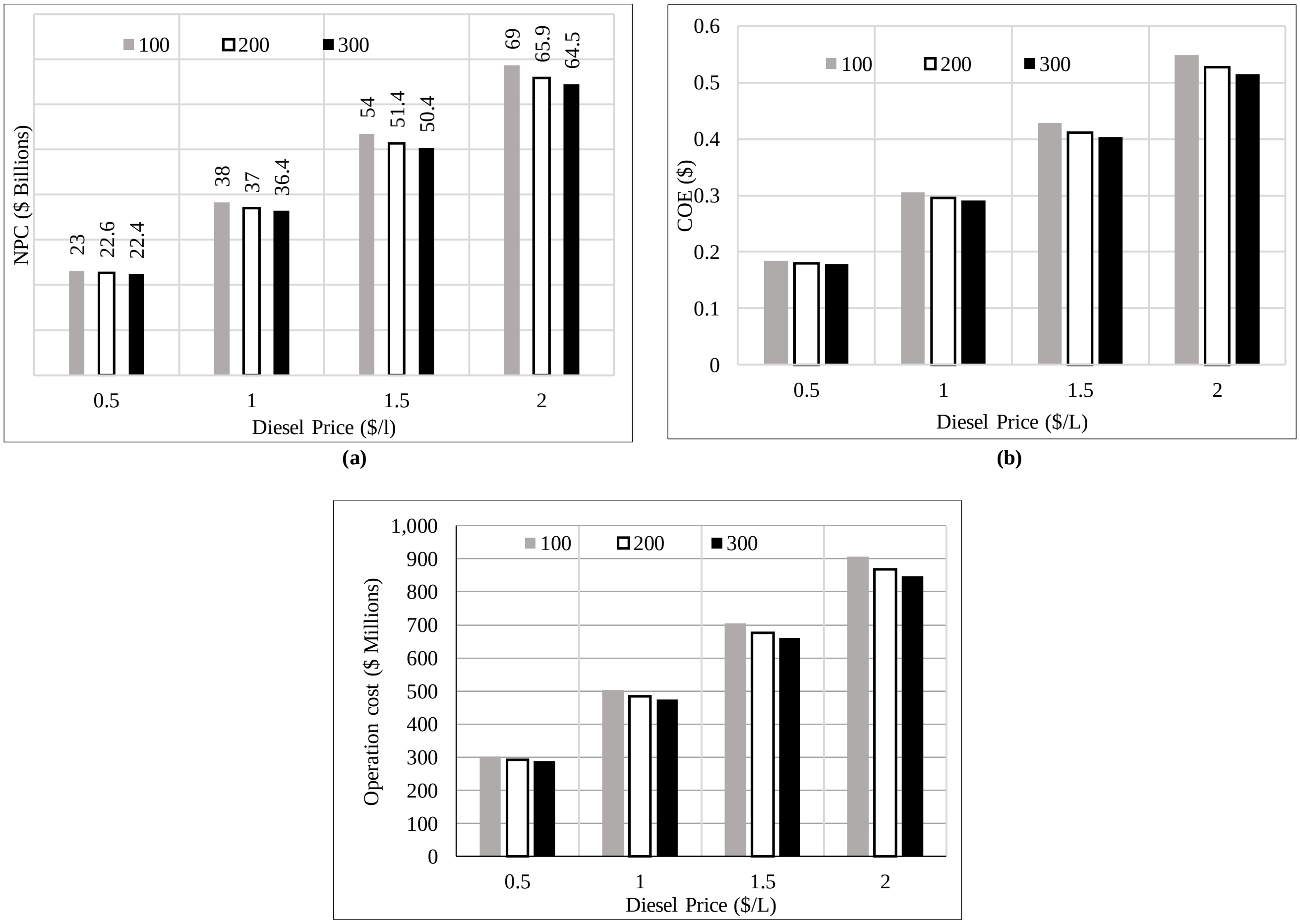
Astounding the study simulation, hybrid wind, PV, and diesel are the cheapest systems among the configurations, with a total NPC which is 22.3 billion and COE is 0.18 kWh. Figure 9 illustrates the operation costs, cost of energy, net present cost, energy production, and electric excess of the system against fifteen various capacities of wind and PV 50, 100, 150,200, and 250 MW with various diesel prices of $0.5/L to $2/L. Similarly, the study examined two diesel generator sizes, 300 and 315 MW, to reduce the excess electricity. The figures clearly show that the NPC, COE, and operation costs decrease as wind and PV sizes grow from 50 MW to 250 MW. To specify the graph, the first number stands for the PV installed power, and the second number stands for the wind installed power (i.e., 50-50 means 50PV-50W), same as the next section. On the other hand, the increasing diesel price is also increasing all the costs.

Figure 9 (d) illustrates each system's total electric production, including diesel generator, solar and wind, consistently lower production of the diesel generator; according to the simulation, solar and lower production than wind turbines even if the capacity is the same. On the other side, Figure 9 (e) describes each system's excess electricity (kWh/year). It can be observed that whenever renewable production energy rises, excess electricity rises. However, this surplus electricity is too much according to the consumption energy (1,661,375,172 kWh/year). The maximum excess electricity is 339,684,450 kWh/year, a 16.9% loss—this 50 MW solar and 250 MW wind turbine system is shown in the figure. Furthermore, the minimum excess electricity is 18,834,658 kWh/year, a 1.1% loss. This is because renewable energy production is 50 MW solar and 50 MW wind turbine.

5.5. System Comparison

The winning system in this study is the hybrid solar-wind-diesel generator system due to net present cost and energy cost. Figure 10 (a) shows the total net present cost among the various sizes of renewable energy. The wind turbine is the issue whether alone with diesel or hybrid with solar and diesel, although the best system includes a wind turbine, but, the size of the wind turbine is 50 MW. On the other side, Solar is excellent as the capacity increases. For example, when the PV 300 with a diesel generator, this system is the second best one among net present costs with almost $22.4 billion. In addition to this, there were two cheapest systems which different sizes. One is PV 200MW and wind 50MW, and the other is PV 250MW and wind 50MW. These two systems have the same value. The net present cost is $22.3 billion.

Figures 10 (b) and (c) demonstrate the cost of energy and operational costs. It is also the same as the net present cost of the size of the wind turbine, as the cost of energy and operational costs will increase. The lowest cost of the energy system is hybrid PV-wind-diesel with a capacity of PV 250MW and wind 50MW, which is $0.178 kWh. The operational lowest cost system PV 200MW and 50MW of wind turbine with approximately $283 million.

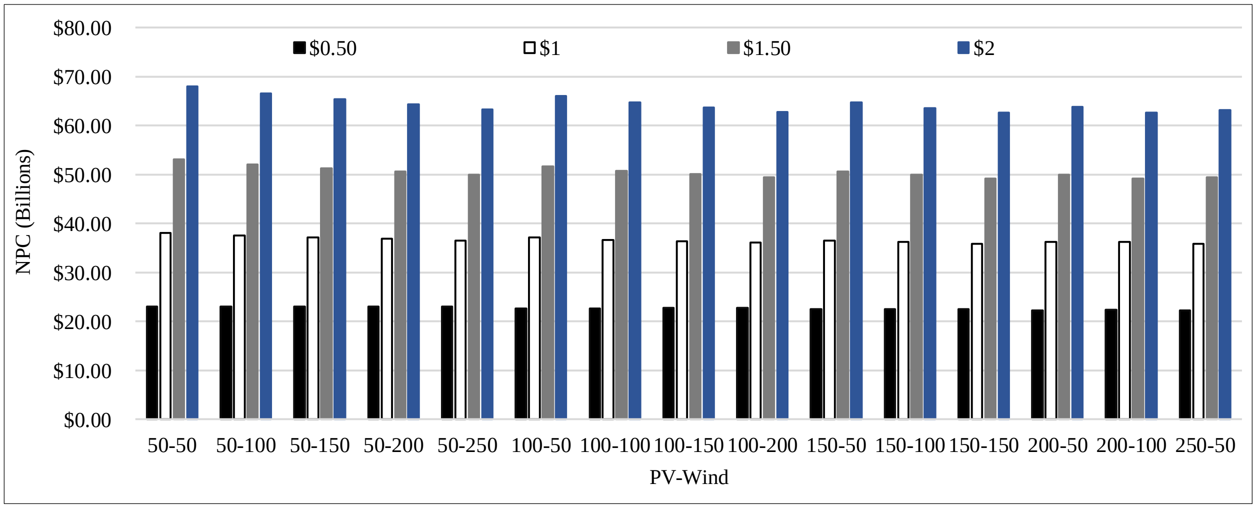


(a)

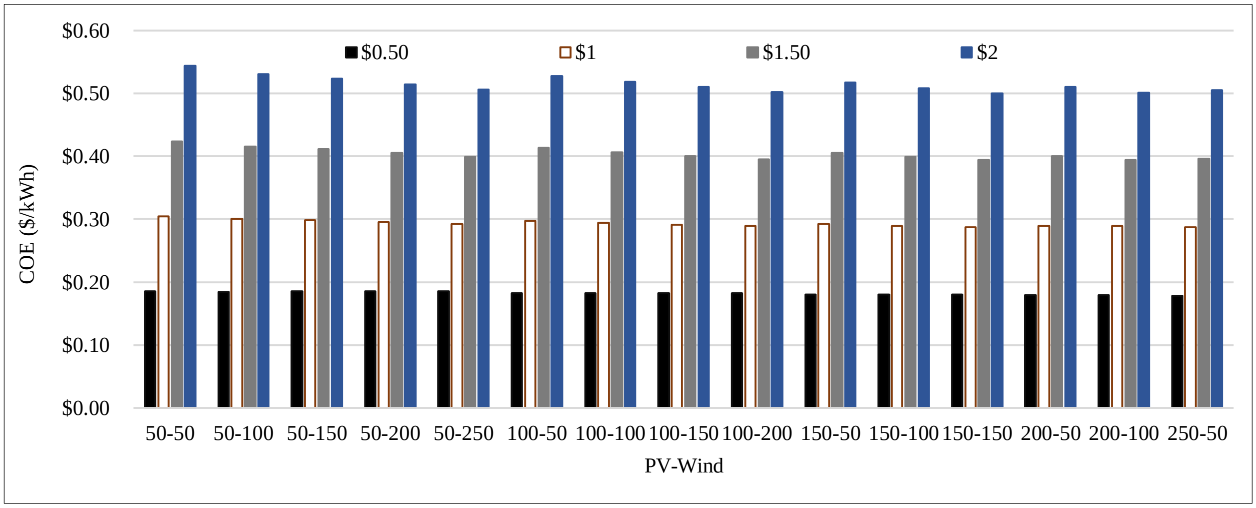
(b)

(c)

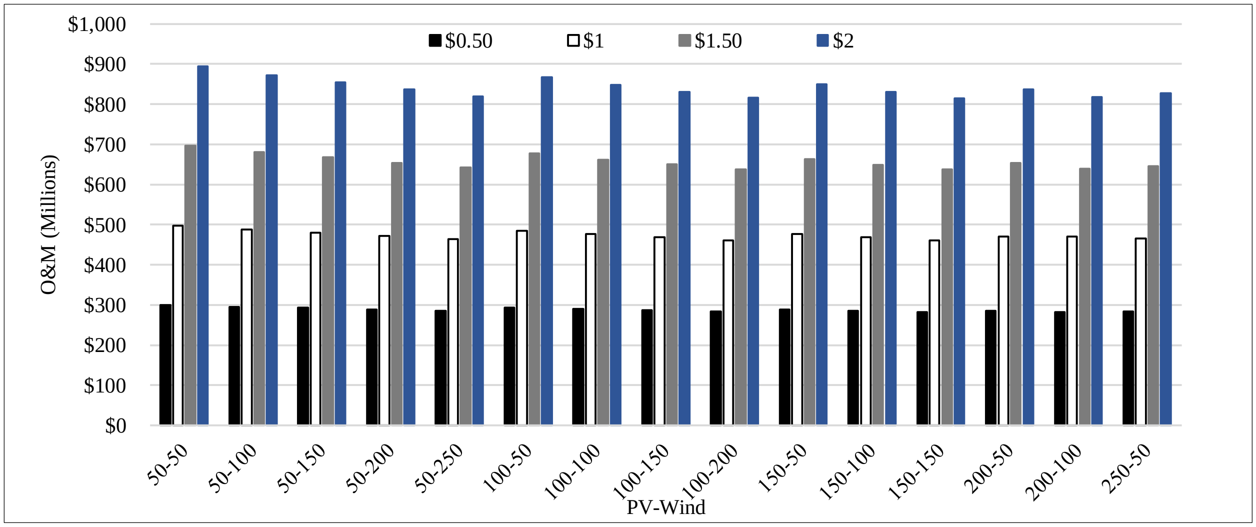
Fig. 8 Simulation result of hybrid PV-diesel generator system with size along with various diesel price (a) NPC value, (b) COE value, and (c) Operation cost value.



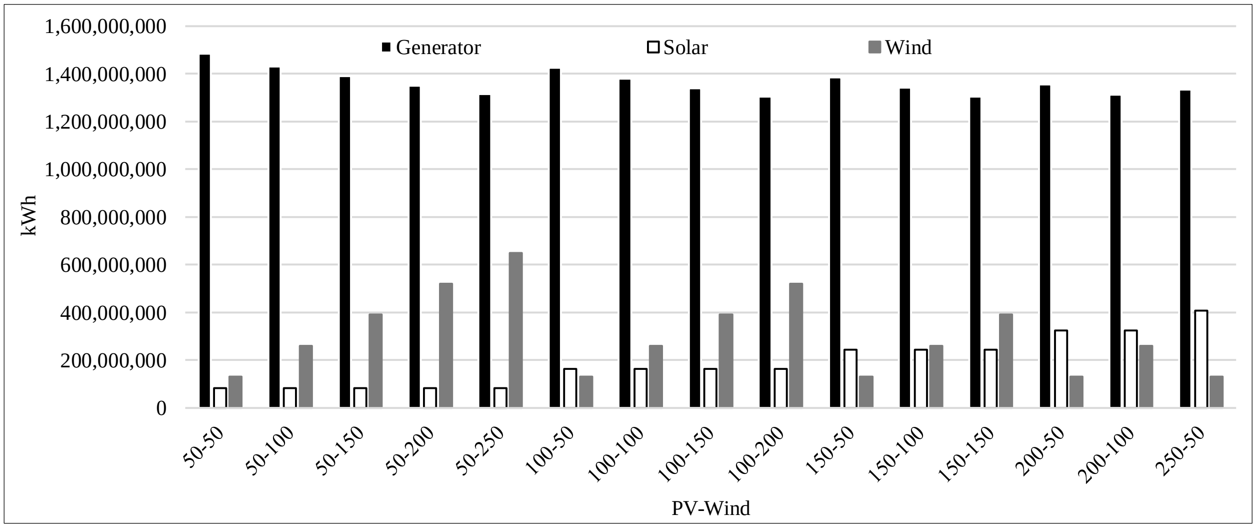
(a)


$0.60
$0.50
$0.40
$0.30
$0.20
$0.10
$0.00
■ $0.50
□ $1
■ $1.50
■ $2
COE ($/kWh)
50-50
50-100
50-150
50-200
50-250
100-50
100-100
100-150
100-200
150-50
150-100
150-150
200-50
200-100
250-50
PV-Wind

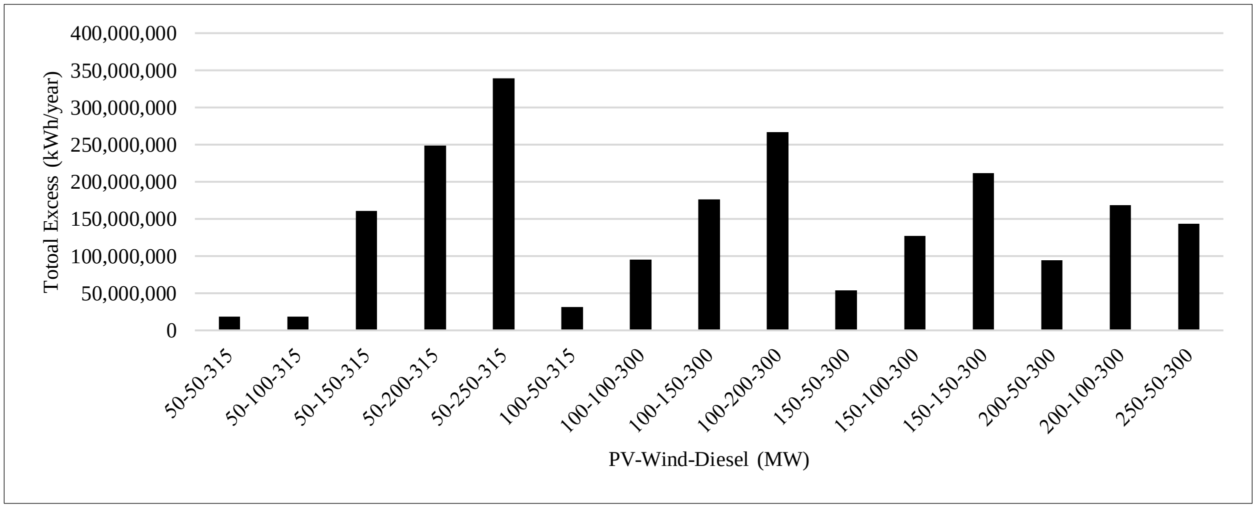
(b)


$1,000
$900
$800
$700
$600
$500
$400
$300
$200
$100
$0
■ $0.50
□ $1
■ $1.50
■ $2
O&M (Millions)
50-50
50-100
50-150
50-200
50-250
100-50
100-100
100-150
100-200
150-50
150-100
150-150
200-50
200-100
250-50
PV-Wind

(c)

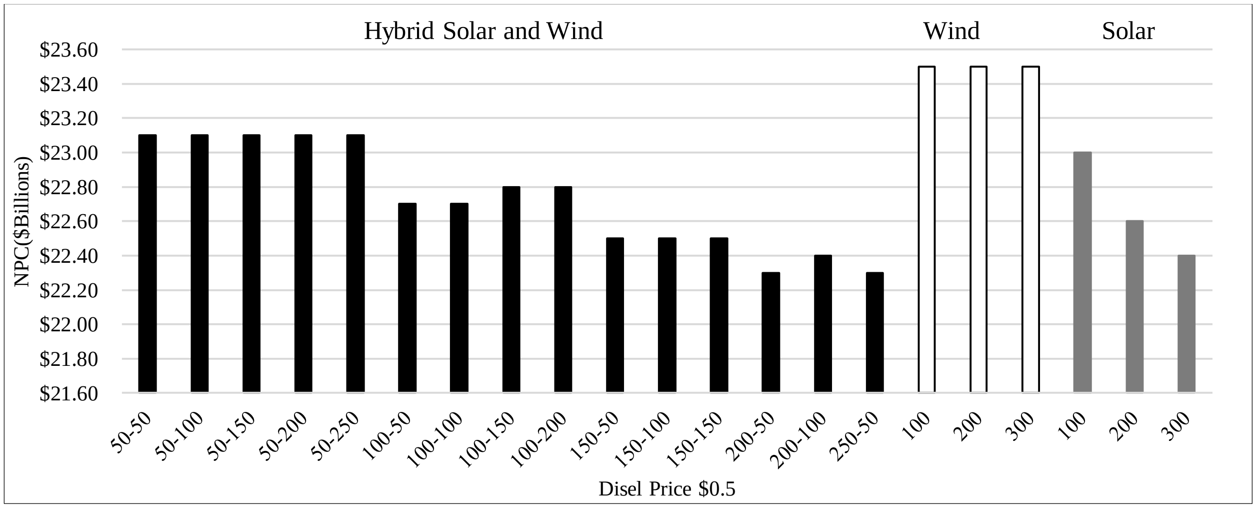

1,600,000,000
1,400,000,000
1,200,000,000
1,000,000,000
800,000,000
600,000,000
400,000,000
200,000,000
0
■ Generator
□ Solar
■ Wind
kWh
50-50
50-100
50-150
50-200
50-250
100-50
100-100
100-150
100-200
150-50
150-100
150-150
200-50
200-100
250-50
PV-Wind

(d)

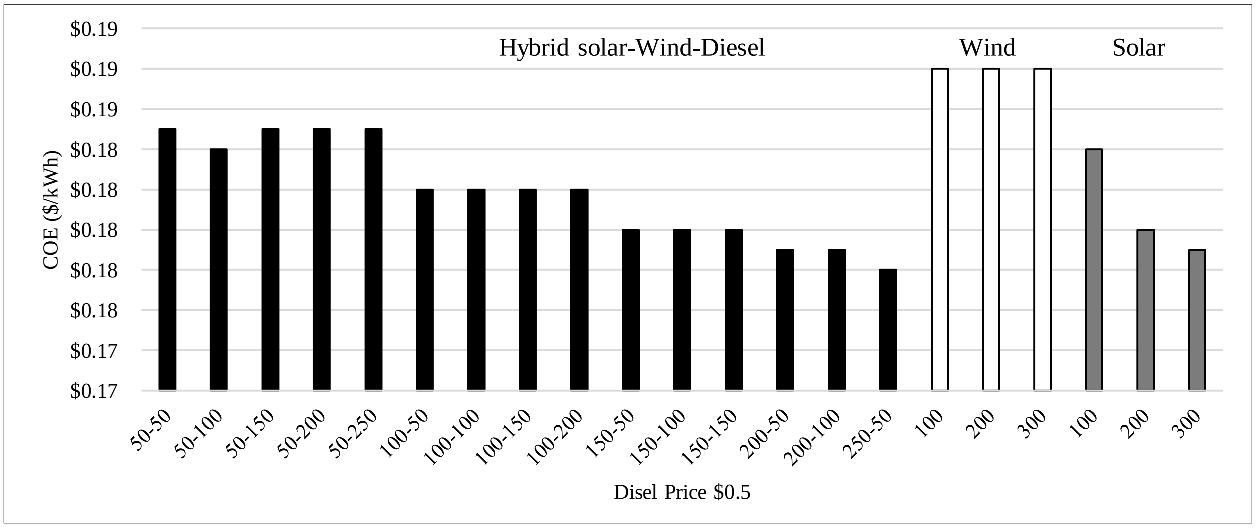


(e)

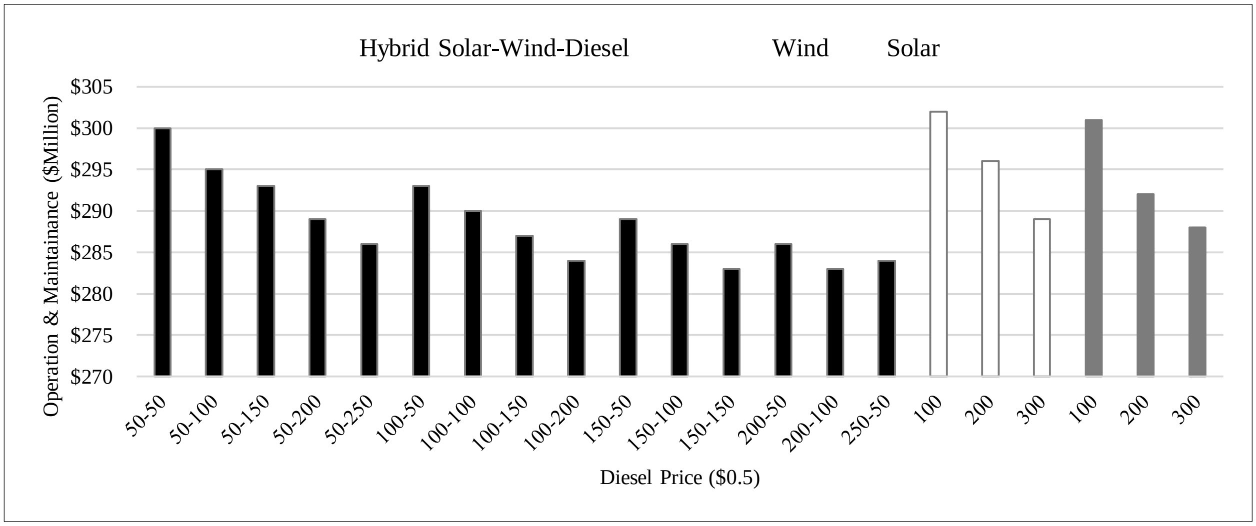
Fig. 9 Simulation result of hybrid wind-pv-diesel generator system with size along with various diesel prices (a) NPC value, (b) COE value, (c) Operation cost value, (d) Electric production, and (e) Excess electricity.



(a)



(b)



(c)

Fig. 10 Comparison system result of hybrid and alone PV-wind-diesel generator system with size along with $0.5/L diesel price (a) NPC value, (b) COE value, and (c) Operation cost value.

6. Conclusion

This study has simulated four systems: hybrid photovoltaic and diesel generator system, hybrid diesel generator and wind turbine system, hybrid wind-solar-diesel generator system, and standalone diesel generator system. In this study, the diesel price is classified into $0.5, $1, $1.5, and $2. Furthermore, the size of renewable energies (solar and wind) is also classified as 50MW, 100MW, 150MW, 200MW, 250MW, and 300MW. After hundreds of configurations have been simulated by Homer software. The winning system became a hybrid solar-wind-diesel generator system, along with wind and solar 500MW wind and 250MW solar and $0.5 diesel price. The reason is it has the smallest energy cost life cycle cost-the highest excess electricity production with almost 18.4% with solar 50MW and 250MW wind turbine. Although the standalone diesel generator system has the minimum excess electricity production and the lowest initial capital cost, this system has the highest life cycle cost and energy cost, even $0.5 diesel price.

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