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Economic and Technical Feasibility Analysis of Hybrid Renewable Energy (PV/Wind) Grid-Connected in Libya for Different Locations

Sadoon K.Ayed, Monaem Elmnifi, Hazim Moria and Laith Jaafer Habeeb

Department of Mechanical Engineering,University of Technology – Iraq, Baghdad

Department of Mechanical Engineering, Bright Star University, Libya

Department of Mechanical Engineering Technology, Yanbu Industrial College, Yanbu Al-Sinaiyah City 41912, Kingdom of Saudi Arabia

Training and Workshop Center, University of Technology – Iraq, Baghdad, Iraq

Abstract: Libya's economic growth and demographic shifts increased investment in constructing traditional power plants to encounter the growing energy request of country'. The continuoususage of fossil fuels as primary source of energy would increase the electricity generation's workingecologicaleffects.As a result, using various renewable sources of energy is perhaps a viable solution to suchtopic.A grid-connected solar PV-wind hybrid energy system has beenprearranged,with amean public load request of (12,000 kWh/day) and thehighestrequest of (1700 KW). The HOMER program is utilized for evaluating the resources capacity of the renewable energy and conductingthe technological and economical evaluations of a grid-connected hybrid system.The climatologicalinformationbeing gathered from NASA Space Agency. Seven cities in different locations in Libya, namely Benghazi, Tripoli, Derna, Ajdabiya, Sirte, Misurata, Tobruk, were selected for analysis. The outcomes of simulation showed that the suggested system is ecologicallyand economically viable. In Derna, Tobruk, and Misurata cities, due to the strong renewable energy penetration, the system in these cities possesses the lowermostNet Present Cost (NPC) and Levelized Cost of Energy (LCOE), the uppermostentire energy that can be vended to the network, and the lowermostemissions of carbon dioxise (CO_2). The proposed design of this grid-connected hybrid system is valid for alikeclimatological and ecologicalcircumstances in the areaas well as around the world. The reduced emissions of certain greenhouse gases in addition to lower electricity prices are significant contributors to this study.

Keywords: HOMER, Wind energy, Solar energy, Grid-connected, Hybrid system

1. Introduction

Around the world, tropical and hot climates are underutilized to generate energy and provide alternative energy resources [1]. Countries in North Africa, for example, are rich in natural resources and hence have less stimulus fordeveloping the projects of renewable energy. Thisis linked to the economical and political unsteadiness preventingthe administrations from investing in new technology [2,3]. Libya is considered one of the best countries that have great solar radiation intensity all over the world. It is also the largest country in North Africa to consume fossil fuels to generate electricity, with per capita electricity consumption reaching 3.4 MW/day [4]. The demand for energy in Libya has augmentedconsiderablyduring the precedingtwenty yesrs [5]. According to a study from the

General Electricity Company in 2012, the national grid's maximum load was (6 GW). Figure 1 revealedthat the entirequantity of electricity produced in 2019 was above(7 GW). Owing to rehabilitation, fastinhabitants expansion, and economical expansion, it is predicted to reach more than (24 GW) by 2030 [6,7].

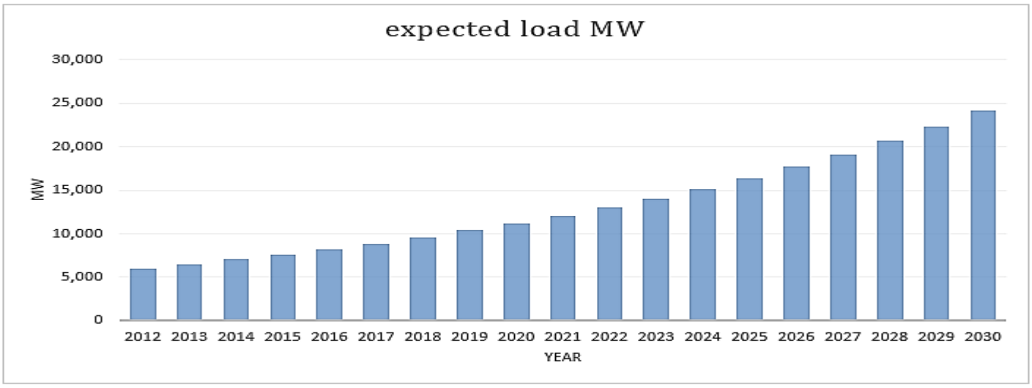


Figure 1: Peak load of the electricity generated

Libya dependsgreatlyupon the fossil fuels to generate the electrical power [8,9]. Crude oil, diesel oil, heavy fuel oil, and natural gas are the fossil fuels kinds utilized in power plants. The evolution of spent fuel for the production of power from 1999 to 2018 [10] is depicted in figure 2. Since commercial and residential loads rapidly increase each year, the adequateproduction of electrical power is needed to encounter these demands. However, relyingupon the fossil fuels as themainorigin of energy would deplete the fuel, emissions, and climate change [11].

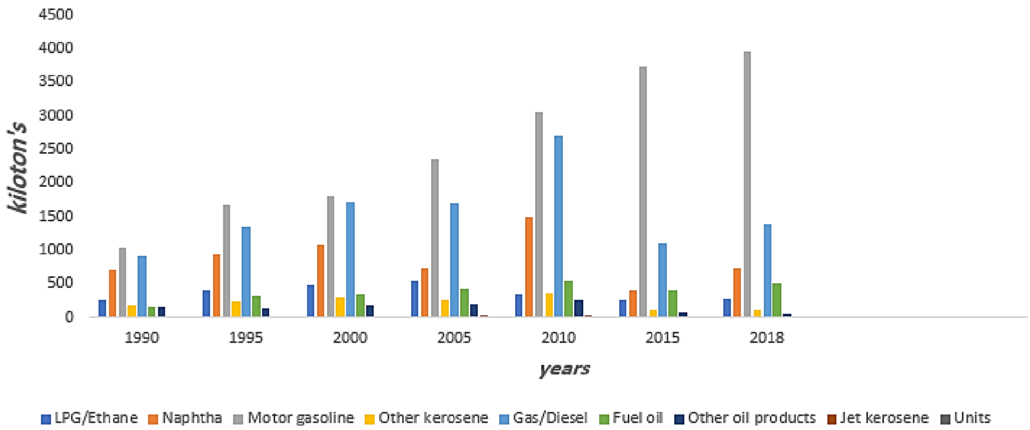


Figure 2: Fuel Consumption in Libya between 1990 and 2018 [10].

According to the report's reference, Libya is one of the world's primary sources of carbon dioxide emissions (CO_2) [11,12,13]. As a result, implementing renewable energy projects to generate electricity would reduce carbon dioxide emissions in Libya and contribute to revenue growth [12]. Libya has a range of potential locations for renewable energy generation projects. The most promising renewable energy sources in Libya are wind and solar energies [7]. Previous studies for assessingthe various renewable energyresources(RERs) in Libya showed that the Photovoltaic Energy (PV), Concentrated Solar Power (CSP), and Wind energy are the higlyinfluential renewable energy sources. Some researchers have analyzed the technological and economical feasibility of a grid-connected PV system for different world regions. An economicalscrutiny of a network-connected PV system for a facility in South Korea was performed for various configurations taking into account network connectivity and system components. The study indicated that the network-merely system is the minimumfeasiblechoicefor the lowest costs for all other systems [14]. Study the PV system connected to the network for the various chasing systems in Makkah and economicalscrutinyemploying HOMER. The findings showed that continuous adjustment's axis tracker system gives NPC's smallest value and the largest COE [15]. In Nigeria, a connected PV system's technical and economic feasibility was essential in the site electricity cost using HOMER [16]. A study conducted on an apartment building in

Australia showed that a PV system appropriately reduces electricity bills and greenhouse gas emissions [17]. Another study using HOMER about the technological and economical feasibility of a network-connected PV system for thirty five sites in Ethiopia with a(5 MW) of PV at everylocation. It can generate 7.7GW of energy and has the potential to reduce approximately 1,089 tons of greenhouse gas emissions annually [18]. These studies conclude that the network-connected PV systems are feasible technologically and efficient economically. Photovoltaic systems can play an essential role in power generation through connection to the government grid and unstable fossil fuel prices.

Conversely, photovoltaic prices will decline over the coming decades [19]. The growing energy demand in Libya is negatively affecting the decline in oil and gas exports. In Libya, a small number of analytical investigationsdiscover and perform the effectiveness of the resources of wind and solar energy. For the Hybrid system, an investigation acievedvia Jenkins et al. [7]provided insight into the energy stateof Libya as well as its renewable energy prospective.The findings showed that the intensity of solar radiation is high in the majority of Libyan areas,the speed of wind, and the seasidetowns.Alamri and Iqbal[20] illustrated the photovoltaicsgrid light, batteries, converter systems, and wind turbines.NPC was chosen as the premiumworkingcondition. The best shapebeingselected based on the lowermost(NPC) of the different choices. According to the results, a house has to possess an off-grid hybrid renewable energy gridsince it's able to save money. According to outcomes, a house has to possess an off-grid hybrid renewable energy grid that can supply electricity to the home. Glaisa et al. [21] proved that the profile of load within winter is highlymore than in else seasons due to heating.If the renewable resources being limited, PV/wind/diesel generator/battery is the premium option. An excess electricity is maybe utilized in else ways or vended to the grid of power for saving the energy.According to Mustafa et al. [22], the simulation results ofthe most cost-effective and environmentally friendly way to produce electricity for the mosque is to mount a PV/Gen/Battery power system.The profiles of loadwuthin winter and summer being significantly greater than in autumn and spring**.** Extra electricity generated by the hybrid renewable power system within autumn and spring can be consumed within several uses or vended to the grid ofutilityfor reducing the future energy costs.

Based on NASA and other satellite data, a literature review shows solar and wind energy potential. According to the authors' initial observations, most of the current investigations in Libya concentrateupon assessing the (RERs)as well asviability of a small-size renewable energy production, especially solar PV. Investigating capacity is a crucial factor that has been overlooked. A crucial issue that has been overlooked is determining the viability of a network-connected PV/wind hybrid system. To the authors' knowledge, no previous research has looked at the technological aswell asthe economicalfeatures of a big-sizenetwork-connected hybrid system for the climatic circumstances in Libya.Resource assessments and technical and economic analyses of network-connected solar/wind hybrid systems to several towns were conducted as part of this research.The Hybrid Optimization for Multiple Renewable Energy Resources project at the National Renewable Energy Laboratory (NERL) being designed for constructing a network-connected hybrid system model to assess the energy output and identifying the optimal option. The program HOMER was used. This program is regarded as the highest and most straightforward assessment tool [23].

Aqeel et al. [24] presented a look at of 7 sites along the coast of Libya. From meteorological information provided by way of meteoblue, the traits of wind electricity and wind power ability areanalyzed at these web sites at the peak of 10 meters. The results indicated that the production power of the Derna, Misurata, and Tobruk sites was higher than that of the other sites. The output energy of large wind turbines was higher than that of small wind mills in all locations due to their scale.

The applied load was a virtual group load with 12 MWh /day cumulative daily consumption for the selected sites. The topmost of suchburden is anticipated to be occurred in Augustowing to the higher temperatures at (1.7 MW). Simulating the operation of each hybrid device linked to the grid for 25 years - the project's lifespan - was used to conduct the analyses. The simulation includes vital data such as total costs, equipment replacement costs, maintenance, operating expenses, network rates, and project life.The site and sources of wind and solar beingthe crucialparameters analyzed for determining the optimalposition of a hybrid power system dependingupon the costs, energy output, energy bought and vended, and the emissions of carbon dioxide(CO_2) to a grid hybrid system simulation. Ground reflection, air temperature, and wind direction are all crucial factors for accurate performance.

2. Renewable Energy Resources (RERs)

2.1 The solar energy

NASA data was used in the analyses described in this paper. The average monthly sun radiation values for 2020 are studied to overview the solar potential in the seven cities listed in Table 1. In addition, utilizing data from diverse places, this study intends to investigate the availability of solar resources. To do so, we used the solar energy statistics for the research sites.

Table 1. Details of different locations selected in the study.

Location	Longitude (E)	Latitude (N)
Benghazi	20.06667	32.11667
Tripoli	13.19611	32.87222
Derna	22.63917	32.76333
Ajdabiya	20.22528	30.75556
Sirte	16.58889	31.20528
Misurata	15.09194	32.37750
Tobruk	23.96028	32.08000

The data of Direct Normal Irradiation (DNI) is anecessaryparameter for the solar techniques.The values of measured (DNI) for seven sites selected during the 2020 HOMER program are compared in figure 3. It's anecessaryparameter for the installations of (PV) and comprises(DNI)as well as Diffuse Horizontal Irradiation (DHI). In such study,different sites were considered with differentterrains for testing and comparing the solar prospectiveeffectiveness in every town.It’s noticed that the leastyearly mean whole(DNI)is in Derna and the ultimateis in Ajdabiya. The maximum daily average annual was recorded in Tobruk for the DHI indicator as 2714 MW/m^2. The maximum average daily total solar irradiance from Global Horizontal Irradiance (GHI) in Ajdabiya was 7422 MW/m^2, and the minimum in Derna was 6922 MW/m^2.

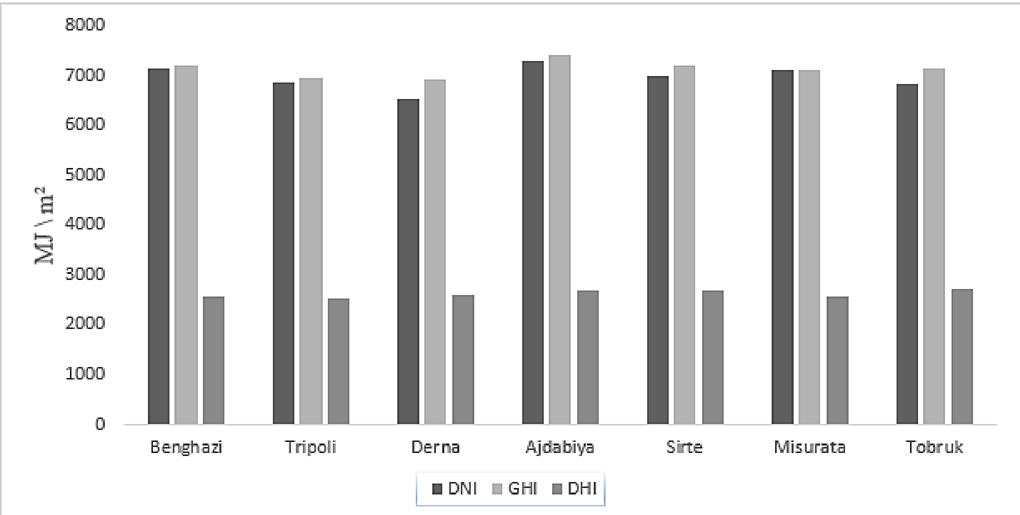
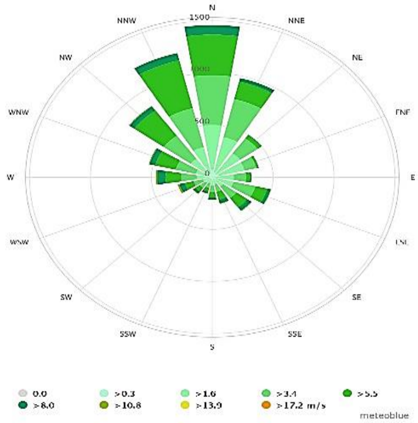


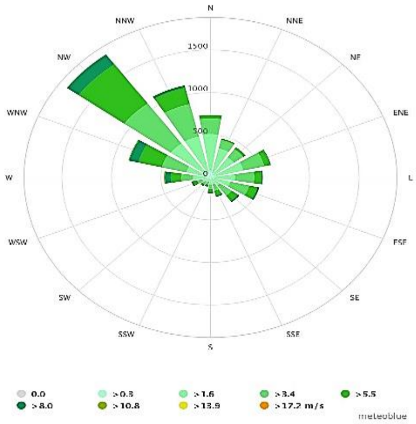
Figure 3. The yearlymeaneverydaywhole(DNI), (GHI) and (DHI).

2.2 The wind data

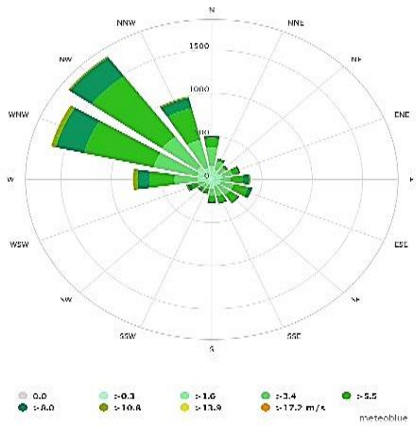
Meteorological data for 2020 were collected by meteoblue. The measured parameters included the direction, the speed of wind, and numerouselsefactors at a(10 m)height overhead ground. Monthly average speed of wind measurements were performed to each site in the study. In the whole suchsites, the climatological measurements being done at various altitudes.The utilized data in such analysis is coveringthe measurements of twelve months spanning January through December 2020. Selectingmerely one year is dueto findingcertain data lost for certain past years. Wind direction is the highly critical parameter in the wind farmhouse projects. Therefore, the prevalentdirection of wind at the chosen sites should be evaluatedfor achieving theoptimal design of a wind power plant. The present research applied a wind rosette simulation of the sites to be studiedfor providing the blueprints 80 meters high above the ground. As shown in Figure 4, each wind rose diagram has 16 primary directions and the frequency and speed of the winds when considering rendering the diagrams at 10 meters above the ground. The designers are able to do their own verdicts about a specific locationvia scrutinizing flower layouts. It is noted from suchmaps that the highly common direction of wind is Derna, Tobruk and Misurata.



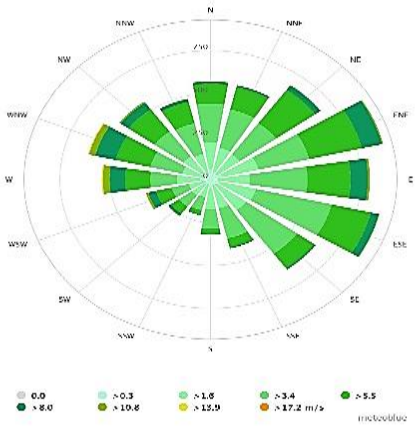
Benghazi



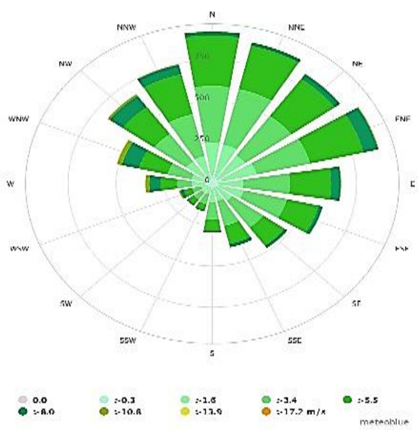
Ajdabiya



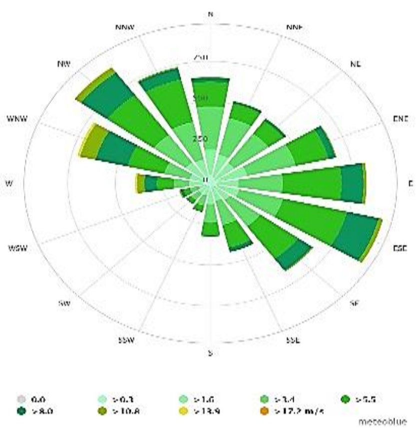
Derna



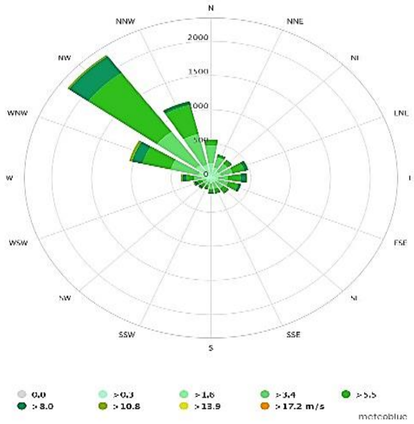
Tripoli



Sirt



Misrata



Tobruk

Figure 3. Models of wind rose at 10 m in different locations

Due to the wind energy cost, the manufacturebeing strongly reliant upon the available resources of wind at such locations.Also, it is vital to search that the system of wind energy prior to launching any project of wind energy [25].The wind speed in a certain location has a significant impact on its resources. As a result, determining the prospective of the wind energy of any location requires knowing the meanspeed of wind [26].According to the literature, a number of density functions are employed for defining the distribution of the speed of wind.Weibull functions being the utmost widely used distributions. In the presnet paper, the Weibull distribution being used to analyze thewind dispersal for the chosenlocations. Such form is defined via scale factor (c) in (m/s) as well as the formfactor(k), which is a dimensionless.There are various ways for measuring these two Weibull distribution parameters in wind speed analysis [27,28]. The power density method was utilized to determine the size and shape parameters based on the averaged data of the speed of wind. Then, from Table 2, the outcomes being compared withreal data, also the determination coefficient (R^2) was calculated for examiningthe proper way the distribution functions matched the set of data. These findings show that that the functions accurately reflect the observed wind speed values. Moreover, Figures 4 and 5 show the Weibull distribution at 10 m height for the specified sites.The premiumsite among suchtownsto producethe energy of wind is Derna, Tobruk, and Misurata, due to the high wind speed.

Table 2. Annual Weibull Parameters.

Location	Average speed (m/s)	Deviation Rate	Average Power/Diameter (w/m^2)	C	K	R^2
Benghazi	5	2.62	350.52	6.32	1.95	0.95
Tripoli	4.6	2.39	321.54	5.82	1.98	0.96
Derna	6	3.12	419.52	7.43	2.5	0.957
Ajdabiya	3.9	2	271.4	5	1.5	0.94
Sirte	5	2.62	350.52	6	1.89	0.96
Misurata	6	3.12	419.52	7.34	2.5	0.97
Tobruk	6	3.12	419.52	7.23	2.5	0.97

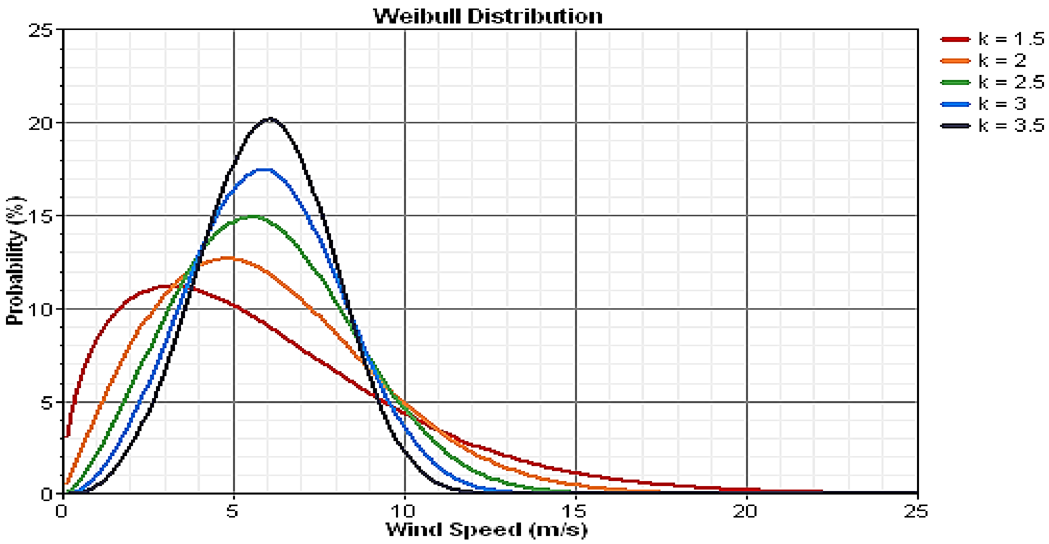


Figure 4. Calculated Weibull distribution in different locations at 10 m

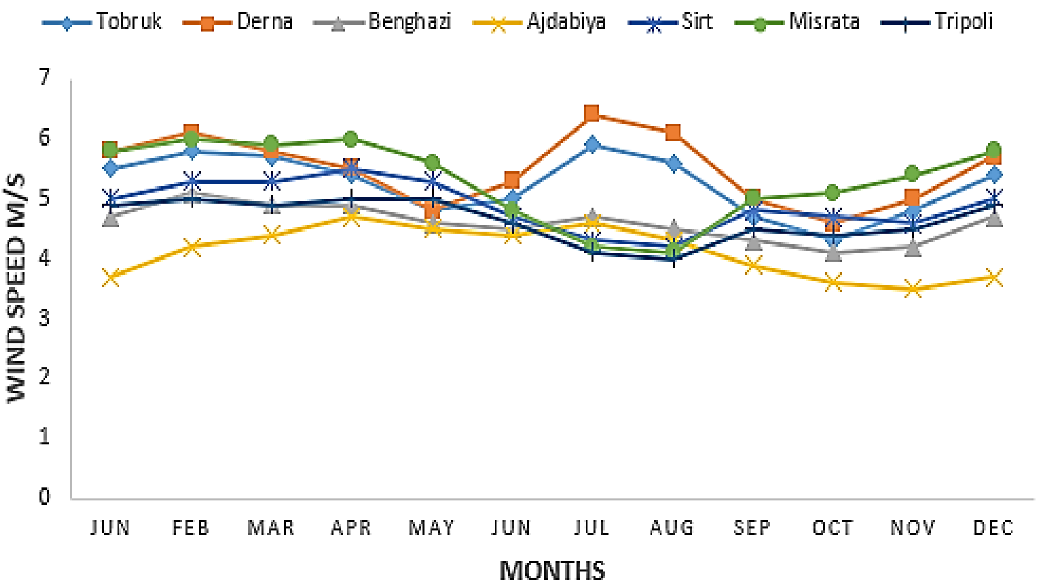


Figure 4. Average wind speed for all locations

3. The Proposed Specificatons of Design

In this study, the expected load is 12 MWh/day of group load. The engineered equipment must fulfill this substantial AC electrical loadfor avoiding an unmet burden.Apart from the burden, the system comprises(4)else elements shown in Figure 5, the network system, the inverter to convert the direct current (DC)into alternative current (AC), the solar (PV) arrayand the wind turbine(1 MW). Inverter being required for converting current to the**(**DC) in a grid-connected system. The PV array generates electricity, then fed to the (AC) bus tape, where the load is connected. The utility network will continue to run despite the lack of a backup mechanism in this design due to electrical outages caused by renewable energy sources as a reliable load resource. Figure 6 shows an average monthly load profile, with peak demand from May to August and a gradual decrease from September to end of year. Such rise being chiefly due to the elevated temperatures in Libya throughout summer, which resulted in a widespread use of the air conditioners. The mean daily energy consumption is (12 MW), with an ultamteof (1.7 MW)throughout the August.

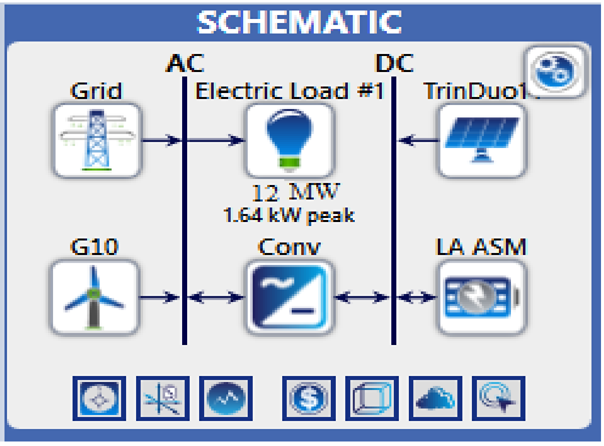


Figure 5. The hybrid network-connected system diagram

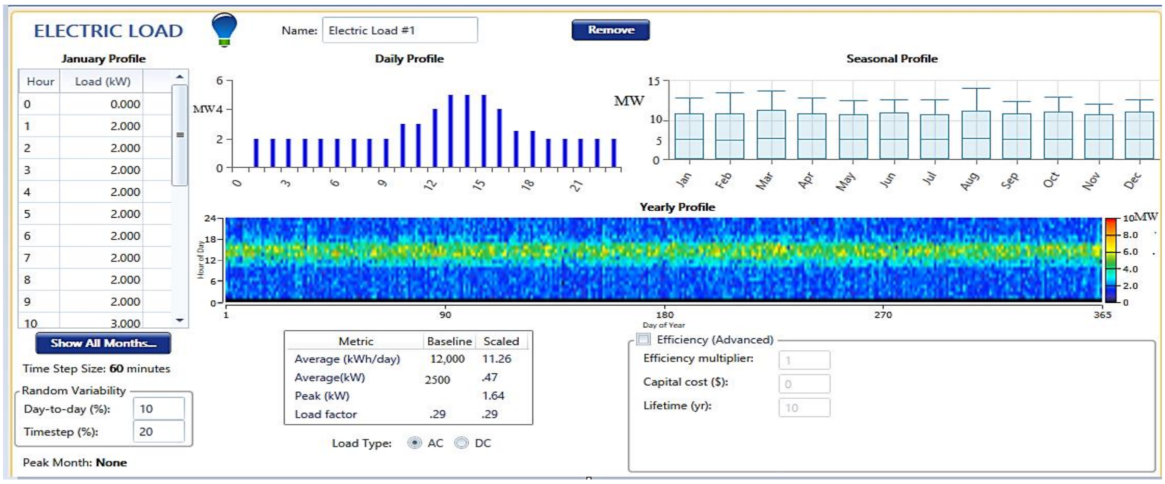


Figure 6. Monthly average load profile.

3.1. Hybrid system (solar PV/wind)

This solar PV/wind hybrid systemstudy being a grid-connected system decreasing the dependency upon the fossil fuels as a chief energy origin. The restrictions of system determine the grid-connected size. The proposed hybrid power system size shall be such that it meets at minimum(60%) of the ultimate load request, determining the hybrid grid-connected system's required output capacity. Thus, they can be used in HOMER to measure PV output capacity. For all of the indicated sites, wind speeds were determined in the previous sections. Figure 7 manifests the expected technical and budgetary requirements for a wind turbine (1 MW).The technical and economic parameters for several PV/wind and inverter models are evinced in figure 3. These types of PV and transformers have performed brilliantly in Libya.

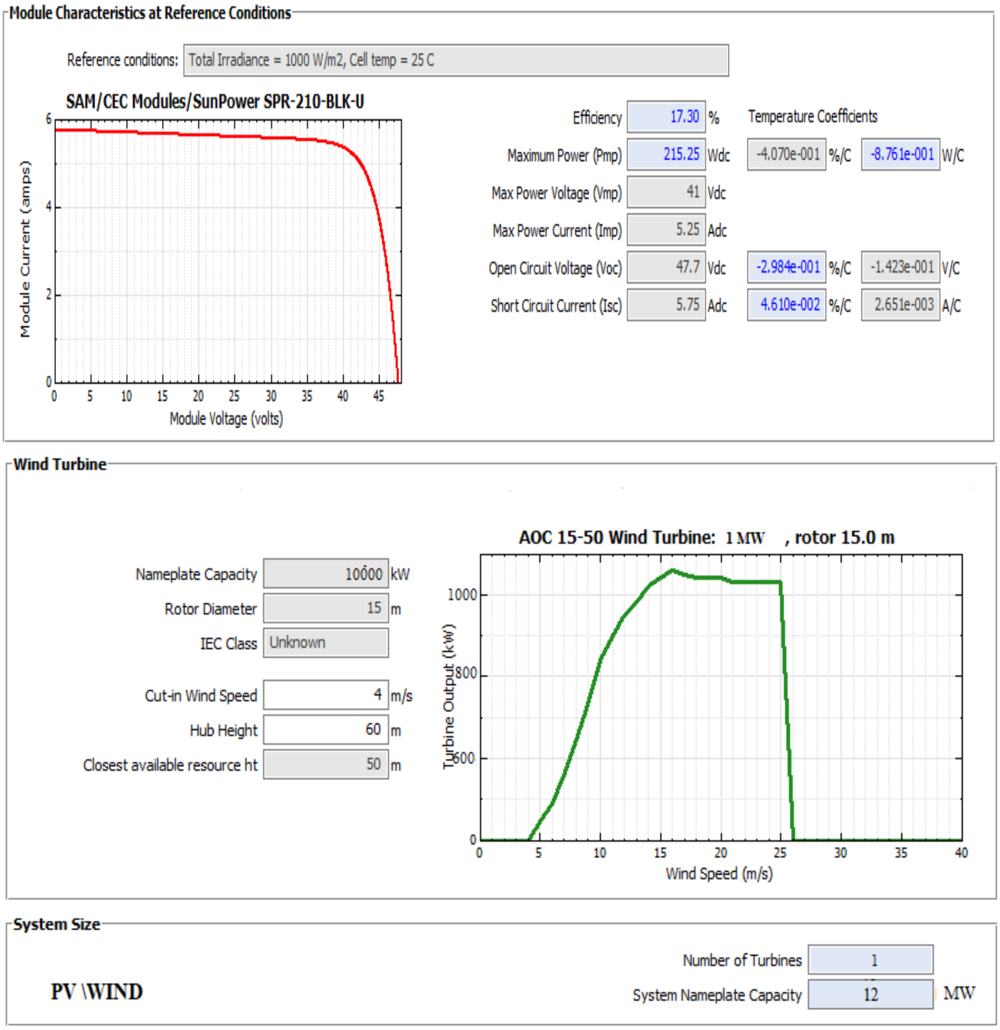


Figure 7. System specifications.

Table 3. The hybrid system's economical and technical specifications

Wind Turbine	PV (SunPower 210 SPR)	Converter
Initial Costs 1,200,000.0 $	Capacity 0.2 MW	Capacity 1 KW
Replacement 1,200,000.0 $	Replacement 1840 $/KW	Capital 250 $
O&M 1200 $/yr	Capital cost 1840 $/KW	Efficiency 96 %
lifetime 25 Year	life time 25 Year	lifetime 15 Year
Height 80 m	O&M 100 $/yr	Replacement 250 $
Capacity 1 MW	Tracker 1000 $	
	Efficiency 18 %	

4. Results and Discussion

The section dicusses the effectiveness of the network-connected solar PV/wind hybrid system in chosen towns. First, technological and economical statistics and electricity output to seven various scenarios being compared. After that, the keptCO_2 emissions to given statesbeing analyzed.

4.1. Production of electricity in the system

The wholeyearly electricity manufacture from the network, wind turbines, and solar (PV) systems and wind turbines are depicted in figure 8.This graph illustrates the impact of renewable energy adoption on the grid demand.In Derna and Tobruk, the yearly electricity manufacture from the renewable energy system is about 70% of the total due to high production capacity, specifically from wind turbines, and this represents 50% of the total. However, the yearly power boughtreduced from the network to (1,680,400 KWh/year),which is merely(30%) of the whole energy spent annually.The wind turbines capacity factorwithin the cities of Derna and Tobruk was higher in this study due to the difference in wind speeds from other cities. The annual cumulative generation of renewable energy in Derna is 2890 MWh/year and Tobruk 2569 MWh. Wind power accounts for 60% of the total energy production in this region, with solar photovoltaics accounting for around 18% and the remainder coming from the grid. Among the cities, Ajdabiya and Sirte have the highest solar radiation. Therefore, the photovoltaic system generates 20% of the annual electricity demand. However, as shown in Figure 8, the consumption of purchased wind and electricity is nearly identical. Given the low renewable production capacity in Tripoli and Benghazi, the city has purchased most of the electricity from the grid.

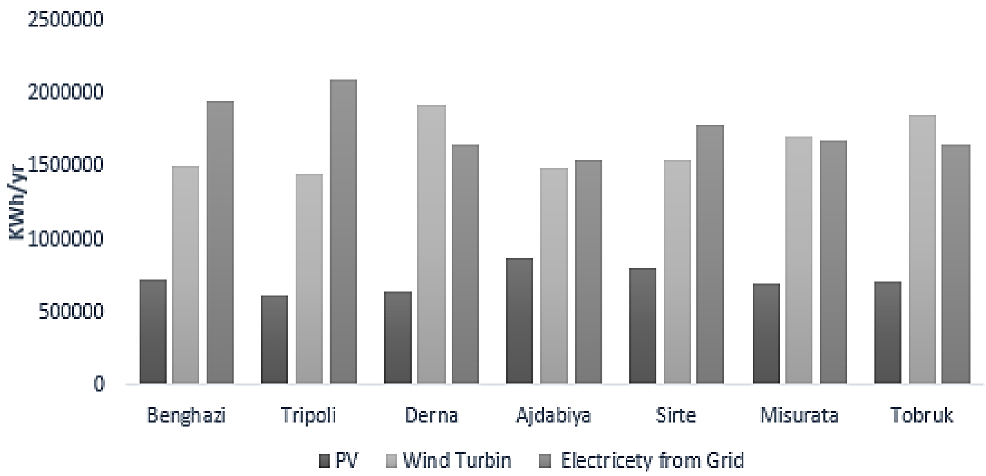


Figure 8. Yearly electricity manufacture from PV, wind turbines, andgrid

Fossil fuel-based power plants are Libya's primary source of electricity. As a result, the electricity industry produces the vast majority of CO_2 emissions. Figure 9 depicts the amount of CO_2 pollution that could be avoided if the renewable hybrid device was linked to the grid in kilograms per year. The annual CO_2 emissions from the grid-only system (without the hybrid system) are 1,832,635 kg/year, indicating that the system linked to the hybrid grid has made a significant contribution to CO_2 emissions reduction. The system output in Derna can reduce CO_2 emissions by nearly 60%, or 1,119,565 kg/year, followed by Tobruk, Misrata, Sirte, Benghazi, and Tripoli. Thus, the capacity factor is highly importantproductivity measure of the syste of renewable energy

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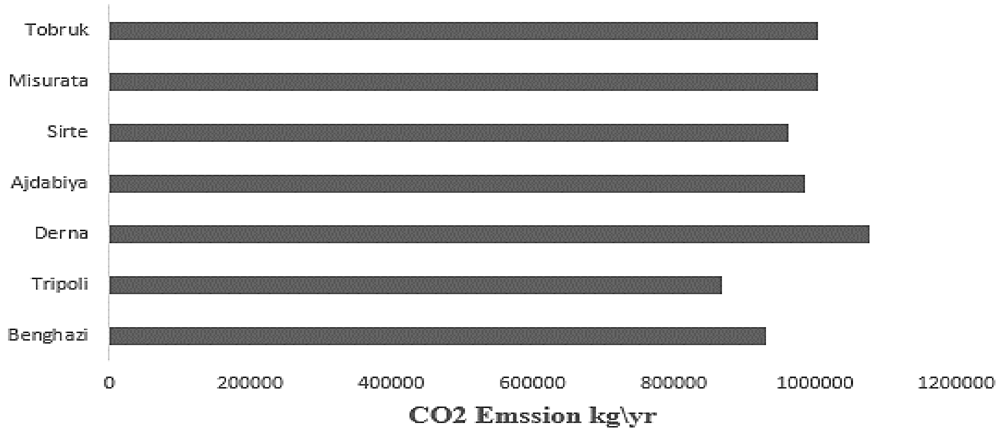

Figure 9. Reducing CO_2 by using a hybrid system

It is considered the most critical metric in assessing the system efficiency of renewable energyowing to the straight impact upon the produced electricity cost. Ratio of the real energy manufacture to the theoretical total power manufacture over a certain period is referred to as [29,30].Wind and solar energy's annual capacity factor and annual output powerwere calculated using HOMER. In order to assess efficiency, several parameters were considered for both solar and wind power, including temperature, emission reduction parameter, pursuing system, vigilance, axis height of turbine, and around(15%) of wind turbine generation losses. The annual amplitude factors for the seven systems analyzed are summarized in Figure 10. The findings demonstrate that the availability of (RERs) has a substantial influenceupon the annual capacity factor. For instance, Derna possesses the uppermostcapacity factor of the energy of wind. In contrast, Tripoli city has the lowest ability to build wind turbines, as seen in the graph. The capacity factors of the system of PV, from the other side, do not vary significantly in any of the cities studied.

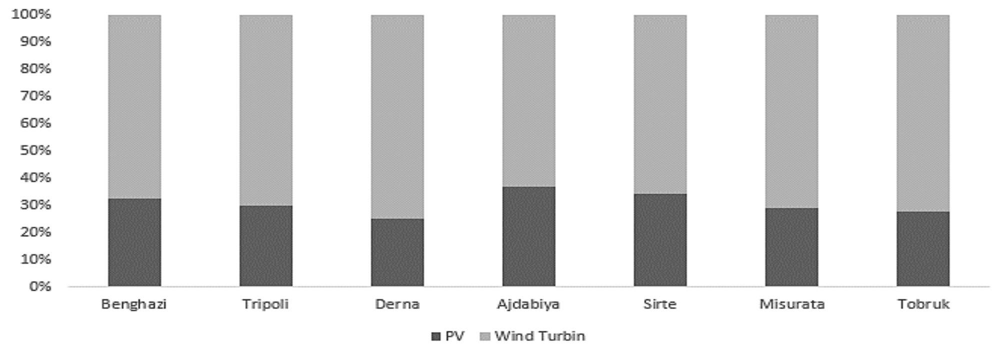

Figure 10. The solar (PV) and the capacity factor of windwithin the cities.

4.2 Economicalanalysis

Viathe sum of the entire annual cut-pricemoney flows throughout the lifespan of project, it was NPC for each system in the HOMER findings. Fromfigure 11, the Derna townsystem showed the lowermost value as well asthe low cost of electricity of $ 2,060,732.00 and $ 0.03530 / kWh, respectively. In the cities of Misurata and Tobruk, the system of NPC being priced at $ 2,557,746 and has a LCOE of ($ 0.03784/kWh). In Benghazi, Sirte Ajdabiya, the system's performance was reasonable, even with the rise of NPC and LCOE. Tripoli is not particularly suitable for installing off-grid hybrid systems dependedupon the yearly solar irradiance and the average energy density of wind. In addition, electrolysis and economics revealed that utilizing the merelynetwork system within Tripoli townbeing the premium economic choiceowing to higher cost as well as lower manufacture. However, Derna, Tobruk, and Misurata have more practical resources of renewable energy,preciselythe technology of wind turbine, making them most suitable places because they profit during the project's life.

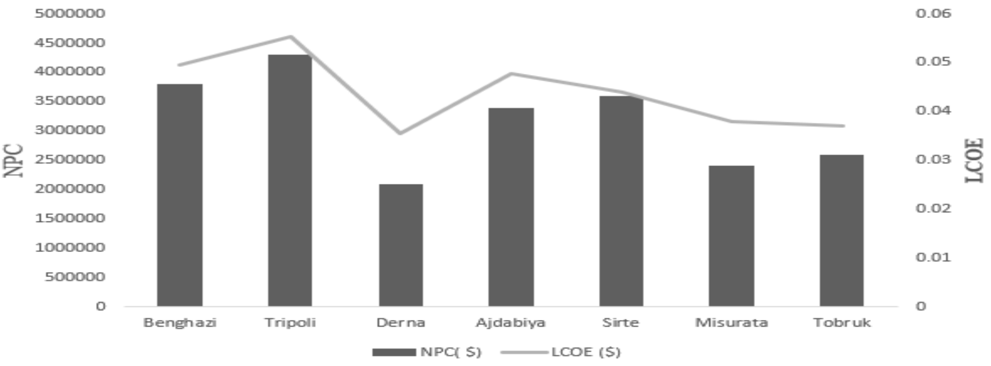

Figure 11. NPC and LCOE of the hybrid system.

Figure 12 presented the annual energy flow to the grid for the seven systems studied. Consequently, all systems have some quantity of energy vended to the annual network, except for the city of Tripoli. Higher than (50%) of the wholeyearly power vended to the network for the whole systems took placethroughoutsuchtime. Nevertheless, due to higher demand, combined with higher temperatures throughoutthe most of year,the whole systems get more network-dependent. Among the wholetowns, the connection system of Derna town with the network has the largest amount of energy sold to the network, 980 MWh/year, followed by Tobruk, Ajdabiya, Misurata, Sirte, and Benghazi with 912 MWh/year and 806, 720, 559 and 270 MWh/year respectively.

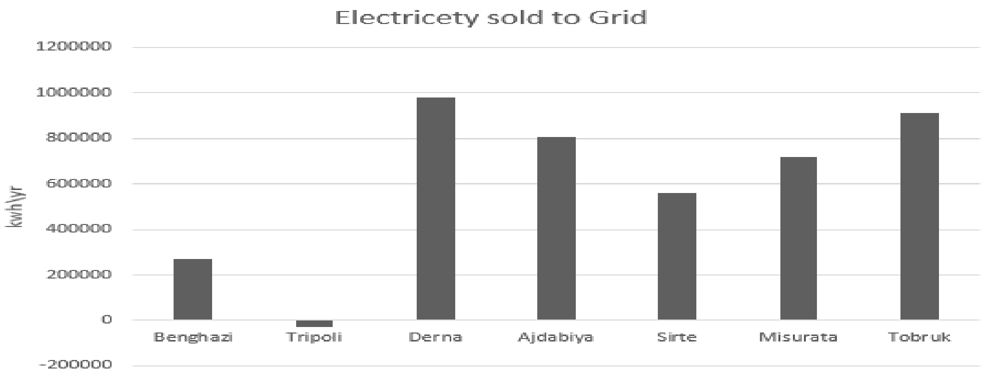

Figure 12. Annual energy sold to the grid.

The comparison between the cost of capital and the cost of energy manufacturedviaPV/wind system within everytown is presented in figure 13.Such outcomesdenote the cost of energy at the network rate above a specified lifespan. Within(HOMER), the capital costbeing ashare of (NPC).Because a single model was implemented in the whole specified sites, the costs of capital are similartoevery system. Nevertheless, itcoststhe energy produced over project's life, and applicable grid rates are $ 0.04/kWh and $ 0.07/kWh during off-peak and peak times, respectively. In the city of Derna, the wholeyearly electricity manufacturedvia the PV/wind systems is about(2575 MWh/yr), also the cost of suchyearlyquantityis foundedupon the network prices surpasses 393,2500 thousand dollars per year.The capital costs of system in the city of Derna ismerely(30%) of the cost of energy.The model shows a total annual production of 2563 MWh/year in Tobruk and Misurata from PV/Wind system. Beyondtwo decades and a half,the projected cost of energy is around 341,930 thousand dollars. The costs of capital are about 37% of suc value; Sirte, Ajdabiya, Benghazi, and Tripoli elucidated the lowermost energy manufacture 2349, 2356, 2220, and 2070 MWh/yr, respectively

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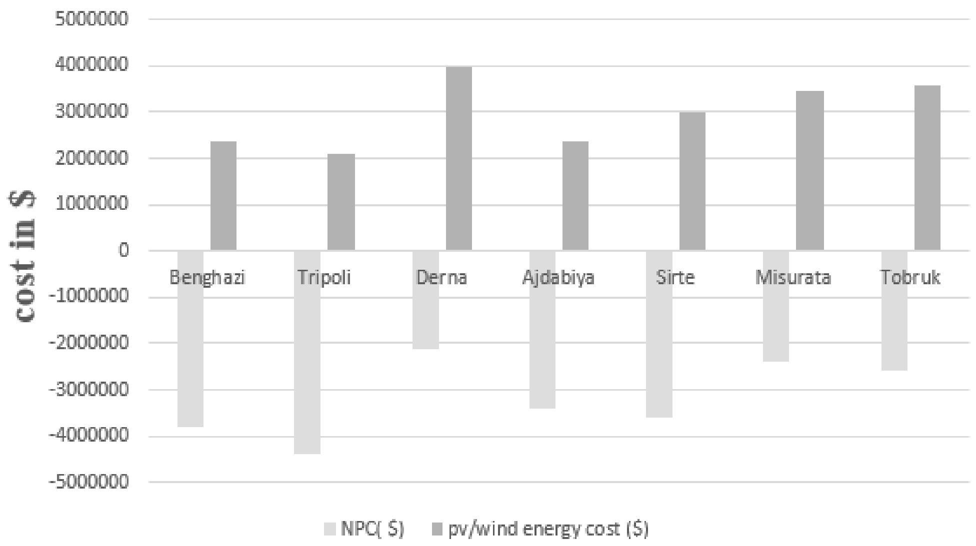

Figure 13. The whole energy producedcost via system of PV/Wind versus the cost of capital

5. Conclusions

A study of the resources of the solar and wind energy was discussed together with the technological and economical review of a network-connected hybrid system for seven different sites.This study summarized the current situation of the generation of power as well as a projected rise in the electricity request over the next ten years in Libya. The HOMERtool for optimization that evolved via(NREL)was utilized to pick the premium device output based on accurate data given by Libya renewable resources atlas.Influences of differentresources of renewable energyupon the generation of power were investigated.Seven variousnetwork-connected hybrid systems with the similarconstituentswere compared in terms of costs.Since the speed of wind and the intensity of solar radiation of every location vary throughout a period of year,variousconfigurations of power generation are required for meeting the exactburdenrequests.The outcomes of simulation evinced thatthe Derna city has the lowest LCOE of($ 0.03535) due to its solar and wind resources capacity, followed by Tobruk, Misurata, Sirte, Ajdabiya, Benghazi, and Tripoli.According to the systems capacity factors at each site, Derna possesses the largestproduction power of renewable energy, especially the power of wind turbine, which accounts for 60% of total annual generation.Athough the systems possess a high (NPC) and (LCOE), Sirte and Ajdabiya show fair power production and lower CO_2 emissions. However, when compared to other systems, the power factors of the solar (PV) and wind turbine power factors of Benghazi and Tripoli being insufficient.As a result, it is not financially viable. The results of this paper may have a significant impact on the techniqueas well as thesite of the wind and solar power plants of energy within Libya.Furthermore, the suggesteddesign of system as well asthe techno-economicalscrutinycan be used in everysiteglobalfor boosting the network-connected hybrid solar/wind systems efficiency while regarding the variations in the costs of constituent, profiles of burden and other factors.It should be noted that the use of long-lasting data scrutiny will aid better comprehending the yearly variance of the resources of renewable energy, which is one of the limitations of the study. As a result, emphasis must be placed on collecting renewable energy data for long-term forecasting.

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