A review of the technical-economic analysis of personal electric vehicle integration in the MENA region

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ABSTRACT

The technical-economic viability of hybrid renewable energy systems that include personal electric vehicles (EVs) in the Middle East and North Africa (MENA) area is assessed in this study. We examined several microgrid configurations using HOMER Grid software, focusing on the effects of electricity prices and subsidy policies. The results show how the hybrid combination of photovoltaic with the grid provided the most significant configuration across the MENA region according to the sensitivity studies that indicate considerable potential for wider application. Eliminating subsidies and modifying power rates are two important tactics for promoting the use of hybrid renewable energy systems. For policymakers and investors in the MENA area, these studies provide practical insights.

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1. INTRODUCTION

Over the past three decades, energy consumption in the Middle East and North Africa (MENA) region has surged significantly, driven by rapid population growth and urbanization. Specifically, energy demand in the region has grown by approximately 8% annually in recent years [1]. Compounding this, many MENA nations heavily subsidize energy, particularly in GCC countries, which explains their high per capita consumption [2]-[4]. This increasing demand is expected to continue, with forecasts indicating that energy consumption, especially of fossil fuels like gasoline and diesel, will quadruple by 2050 [5], [6]. Countries such as Egypt, Tunisia, and Morocco also demonstrate substantial energy consumption in the transportation sector, which significantly contributes to their overall energy use and carbon emissions [7], [8].

Efforts to address these challenges have included policies to promote electric vehicle (EV) adoption in various MENA countries [9], [10]. Despite the high initial costs of EVs compared to conventional vehicles, they offer long-term economic and environmental benefits [11]-[13]. Their energy costs are considerably lower, and they contribute to the reduction of greenhouse gas emissions, aligning with national environmental goals [14]. EV batteries can be charged using the electrical grid or renewable energy, making them a key component in hybrid energy systems, particularly in microgrids (MGs) [15]-[17]. MGs, which can operate in both island and grid-connected modes, present a sustainable solution for managing fluctuating energy supply and demand, especially when integrated with renewable sources like wind and solar [18]-[20].

The optimal configuration of MG components such as photovoltaic panels, wind turbines, and batteries remains a challenge, with numerous optimization methods and software solutions proposed in the literature [21]-[26]. Previous research has explored the viability of renewable energy systems in various MENA countries. For example, Khemariya *et al.* [27] optimized a solar photovoltaic-fuel cell system, while Razmjoo *et al.* [28] evaluated the sustainability of renewable energy sources in Iran. Several studies have also focused on enhancing MG adaptability and integrating electric vehicle charging infrastructure [29]-[33]. However, challenges such as electricity injection restrictions and regulatory barriers to self-production persist in some countries, limiting the potential of renewable energy systems [34], [35].

This study aims to identify the optimal hybrid energy system configuration in the MENA region by analyzing solar, wind, and battery storage technologies from economic, technological, and environmental perspectives. The findings, based on sensitivity analyses, offer valuable insights for policymakers and investors by generalizing the results to other regions within the MENA area. Additionally, the study examines the impact of removing energy subsidies and increasing electricity rates on the cost of energy in selected MENA locations, providing a comprehensive assessment of future energy strategies. We address a significant gap in the literature by focusing on the integration of personal electric vehicles (EVs) into hybrid renewable energy systems (HRES) in the MENA region. Unlike previous studies, which primarily analyze standalone HRES configurations, our research evaluates the sensitivity of these systems to electricity prices and subsidy policies. This study also introduces a comparative technical-economic feasibility analysis of various microgrid systems, uniquely tailored to regional characteristics, including solar, wind, and hybrid configurations.

To achieve this investigation goal, the following tasks are undertaken:

- Conduct a technical-economic analysis of various microgrid configurations.
- Assess the environmental impacts of hybrid systems compared to grid-only systems.
- Perform sensitivity analyses to understand the influence of electricity prices and subsidy policies.
- Propose policy recommendations for enhancing HRES adoption in the MENA region.

2. RESEARCH METHODOLOGY

The research methodology is structured into three key components: (i) Data collection and input, including meteorological, load, and economic data; (ii) Simulation and optimization using HOMER grid software to evaluate various microgrid configurations; and (iii) Sensitivity analysis to assess system performance under varying regional conditions. These steps ensure a comprehensive evaluation of hybrid renewable energy systems integrated with personal electric vehicles in the MENA region.

Given that EV technology is still in its beginning in the MENA region [36], the purpose of this research is to determine the technical and economic viability of several MG systems that include a personal EV. Microgrid systems connected to the grid using renewable energy sources such as solar and wind are investigated in this study, with technical, economic, and environmental considerations, with the most appropriate system for hybridization using solar panels and wind turbines.

It combines grid, WT, PV panels, and a battery bank to meet a household load and an electric vehicle. Energy cost, net present cost (NPC), renewable fraction, stable power generation profile, and emissions of the hybrid configuration are the most accurate system parameters to examine. To achieve so, the HOMER grid software is used to design and plan MG systems to identify the ideal size of its components based on the results of a technical-economic study. The usual HOMER optimization procedure is shown in [21].

2.1. Input data

For simulation and optimization, HOMER requires five categories of data: meteorological data, load profile, equipment characteristics, search space, economic, and technical data.

2.2.1. Meteorological data

To begin, the simulation considers meteorological parameters such as wind speed, solar radiation, and temperature, which are given into the software as time-series data. HOMER uses this input data to determine the wind turbines and solar panels' output power. The investigation was conducted in each capital of the MENA region and in Oujda city for Morocco.

2.1.2. Load profile

The monthly load profile of a typical household is depicted in Figure 1. The average daily consumption and electricity outputs are 28.88 kWh and 1.2 kW, respectively. In February, the peak power output was 2.26 kW. Due to the region's arid climate, energy consumption is higher during the winter than during the summer months (heating demand at lower temperatures).

The minimum and highest demand for each hour is depicted in Figure 2 during the low demand season (summer) and the high demand season (winter) [37]. Along with the primary load, the MG considers the EV load. The electric car used in this study has a maximum power output of 11.3 kW and an average power output of 22.4 kWh. These values are an average of the five most popular electric vehicles on the market [38]:

- 20% Leaf with 6.6 kW max and 15 kWh on average
- 20% Tesla model X with 17.2 kW max and 40 kWh on average
- 20% Tesla Model 3 with 17.2 kW max and 30 kWh on average
- 20% BMW i3 with 7.7 kW max and 12 kWh on average
- 20% Chevy bolt with 7.7 kW max and 15 kWh on average

Assuming the EV is mainly utilized for everyday commuting, it is expected that the EV battery could be charged in 6 hours overnight (11 pm-5 am). Thus, the resulting total load curve is the sum of the main load and the EV load for each hour of the day (Figure 3).

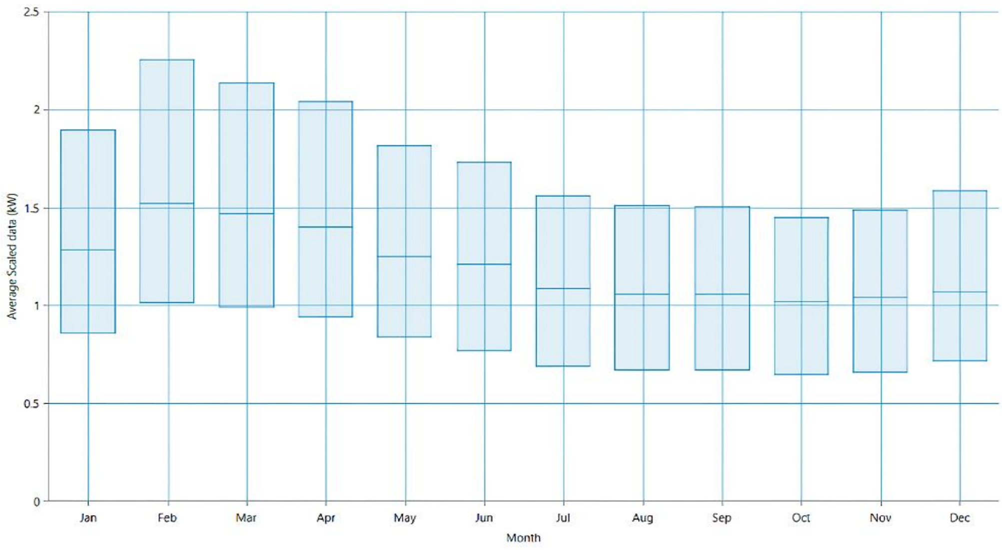

Figure 1. Monthly average data of primary load

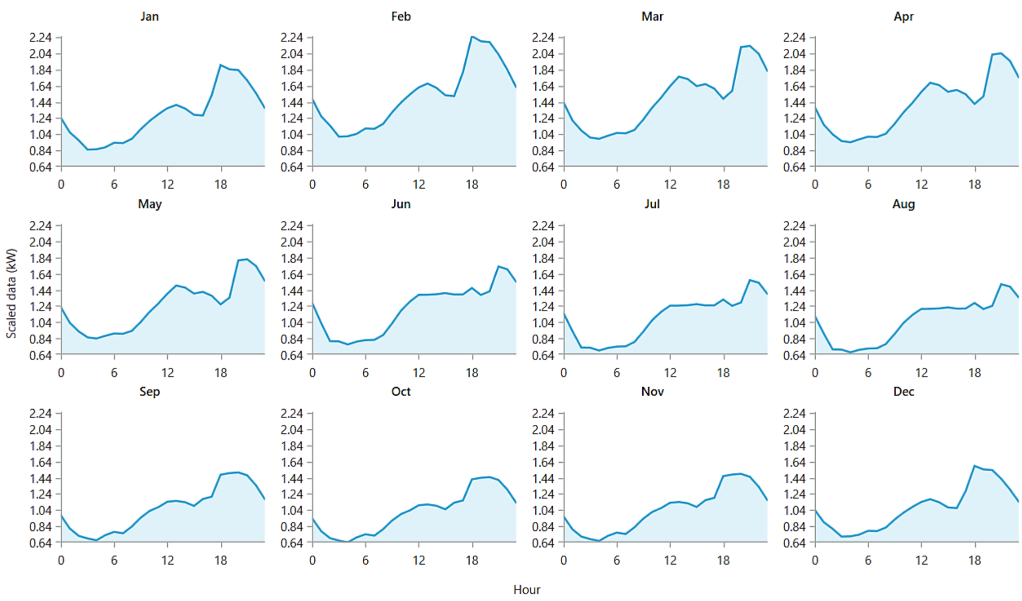

Figure 2. Hourly data of primary load

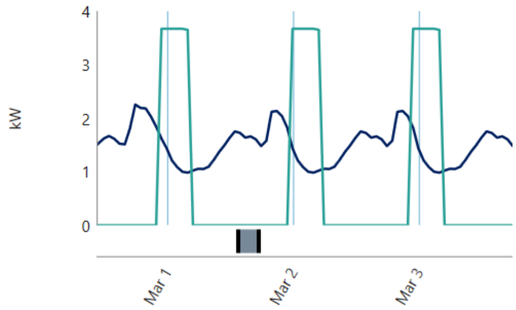

Figure 3. Load profile for the day on which the largest demand occurs (March)

2.1.3. Search space

Since the components of MGs, including the WT, PV panels, battery, and converter, have varying sizes, simulation and optimization consider a search space. The components of a particular MG with varying sizes are listed in Table 1. Thus, the search space encompasses $2 \times 63 \times 11 \times 4 = 968$ systems (combinations of various components) for which the simulation and design stages will be optimized.

The MGs investigated for a residential load consider the project's lifetime to ensure a cohesive and logical analysis. As a result, the maximum number of turbines per residence is one. In addition, the installed power for the PV panels is based on an average roof surface area of 100 m^2. Therefore, the effective surface area (adjusted for spacing and inclination) allows for the installation of up to 62 panels (325 W/panel).

Table 1. Search space for a potential MG system

Component	Wind turbine (number)	PV Pannels (kW)	Battery (number)	Converter (kW)
Max	1	20.15	10	6
Min	0	0	0	0
Step	1	0.325	1	2

2.1.4. Economic data

The project's life is estimated to be equal to the 25-year lifespan of the hybrid system's main renewable energy producing components. It is expected that nominal interest rates and anticipated inflation will be 6% and 1%, respectively [39]. Regarding the MENA region's power tariff system, the end customer paid between 0.004 and 0.127 dollars per kWh (Table 2). Since the resale price is frequently less than the purchase price in countries that have adopted the measure of excess resale to the network, the resale price is assumed to be half the purchase price for each country in the MENA region. Therefore, if the net purchase value of the network is negative, the MG sold more than it purchased during the billing period. Thus, the utility compensates the client based on the resale price. Each component of the MG has a capital cost associated with it. These costs are accounted for during the simulation and optimization phases. The NPC of any system is calculated on this basis (Table 3).

Table 2. Electricity prices indicators for MENA countries [1]-[3], [40]

Country	Cost of electricity ($/kWh)	Electricity consumption per capita (kWh/capita)	Subsidies of electricity per capita ($/capita)	Country	Cost of electricity ($/kWh)	Electricity consumption per capita (kWh/capita)	Subsidies of electricity per capita ($/capita)
Algeria	0.051	1236	88.27	Libya	0.016	4707	217.31
Bahrain	0.008	17395	1536.24	Morocco	0.123	875	NA
Egypt	0.033	1700	88.96	Oman	0.026	6095	275.63
Iraq	0.009	1474	47.21	Qatar	0.022	16183	1108.09
Jordan	0.092	2357	207.64	Syria	0.004	1222	NA
Kuwait	0.007	15722	1431.21	Tunisia	0.127	1411	127.37
KSA	0.013	8405	636.98	UAE	0.08	10463	630.88
Lebanon	0.046	3102	456.13	Yemen	0.041	170	21.47

Table 3. Economic data for the MG components

Component	Model	Capacity	Capital ($)	O&M ($)	Ref
PV Panel	Canadian Solar Max Power CS6X-325P	325 W	179	1% Capital/year	[41]
Converter	Schneider Conext XW+7048	2 kW	252	1% Capital/year	[42]
WT	AWS HC	5.1 kW	28 375	175/year	[43], [44]
Battery	Generic Li-Ion	1 kWh	271	1% Capital/year	[45]
EV Charger	Single-phase	3.67 kW	400	1% Capital/year	[46]

2.1.5. Technical data

HOMER requires specific technical data for each component to simulate the MGs systems (Table 4). The technical data that reflect appropriate microgrid design choices. The design of PV panels, batteries, wind turbines, and converters takes regional conditions into account to optimize efficiency, durability and cost. The PV efficiency is high, the battery performance is good, and wind turbines integrate well. But, increasing battery and converter lives and replacing PV panels with temperature-resilient ones may increase system performance.

Table 4. Technical data for the MG components

Component	Property	Value
PV Panel	Slope	35°
	Ground Reflectance	20%
	Efficiency at 25 °C	21%
	Temperature effects on power	-0.41 %/°C
	Electrical Bus	DC
	Lifetime	25 years
Battery	Initial state of charge	100%
	Minimum state of charge	20%
	Degradation limit	30%
	Nominal Voltage	3.7 V
	Electrical Bus	DC
Wind Turbine	Hub Height	25 m
	Electrical Bus	AC
	Lifetime	25 years
Converter	Efficiency	96%
	Electrical Bus	AC/DC
	Lifetime	15 years

2.2. HOMER optimization procedure

Once the input data is loaded into HOMER, as explained previously, the ideal sizes of the MGs systems are established in two processes. These steps include simulation and optimization, and sensitivity analysis.

2.2.1. Simulation and optimization

Optimization and simulation processes are conducted on each system. For the total NPC, the optimal solution is kept, defined as the present value of expenditures minus the sum of revenues. The costs include the cost of grid electricity, the initial investment, the cost of replacement, and the cost of operation and maintenance. Revenues are earned through the sale of electricity to the grid. Restrictions include power balance constraints, battery charging and discharging constraints, and constraints on energy transactions with the grid. A viable MG satisfies the power balance requirement at each time step. Finally, possible MG systems are sorted by minimum NPC, with the first design having the smallest NPC and thus being regarded as the best system.

The following formulas are used to determine the parameters necessary for conducting an economic analysis of hybrid systems. The net present cost (NPC ($)) of an investment can be calculated as follows [47]:

$$NPC = \frac{TAC}{CRF(i,n)} \tag{1}$$

where TAC stands for total annualized cost, CRF for capital recovery factor, n for project duration (years), and i for real annual interest rate (percentage) that can be computed using the nominal discount rate and the inflation rate. The (2) [48] is used to compute the CRF:

$$CRF\ (i,n) = \frac{i(1+i)^n}{(1+i)^n-1} \tag{2}$$

The levelized cost of electricity (LCOE) is calculated as (3) [48].

$$LCOE = \frac{TAC}{E_p+E_{ev}} \tag{3}$$

E_p is the electrical energy generated to meet the primary load, and E_{ev} is the amount of electricity generated to satisfy the EV load.

Another critical economic factor is the Net Present Worth for a given system Si (NPW_{Si}) which is an economic tool used to analyze the project's profitability. The general equation of a given project is defined as (4) [49]:

$$NPW_{Si} = NPC_{Si} - NPC_{Sr} \quad (4)$$

where NPC_{Si} is the NPC for a system Si, and NPC_{Sr} is the NPC for a referential system. A positive value indicates that the project is economically feasible, while a negative value shows that it is not. Thus, the CO_2 emissions have been estimated using (5) [50]:

$$EM_{CO2} = \frac{44}{12} Q_f * HV_f * CEF_f * OCF \quad (5)$$

where EM_{CO2} is the amount of CO_2 emissions, Q_f is fuel quantity (Liters), HV_f is the fuel heating value (MJ/L), CEF_f is carbon emission factor (ton carbon/TJ), and OCF is the oxidized carbon fraction.

2.2.2. Sensitivity analysis

A sensitivity analysis was conducted to determine the feasibility of the ideal scenario's results to be generalized to other parts of the MENA region other than large cities, considering the variations in climate, including sun and wind. Along with regional changes in meteorological data, the variety of the components continues to fluctuate from year to year. The simulation and optimization stages are repeated for these two uncertain parameters, resulting in the generation of new and improved systems. Appropriate data are provided to demonstrate how these uncertain parameters affect the output of the best systems.

3. RESULTS AND DISCUSSION

In this section, several MG systems are compared to a reference system based on their economic and environmental qualities, the variation of the most important NPC metrics, such as PV and WT capital, and variations in meteorological resources. The reference system assumes that the grid meets all of the electrical demand.

3.1. Economic analysis

In our review, we compare the economic viability of six MG configurations across 16 MENA countries, examining net present cost (NPC) and levelized cost of electricity (LCOE). The results show that, for regions with low electricity prices, such as Damascus, Kuwait, and Manama, the basic grid-only system is more economically viable due to the lower NPC compared to alternative renewable systems. In contrast, for regions with higher electricity prices, such as Sana’a, Beirut, and Tunis, hybrid configurations like Solar-Grid systems demonstrate a more favorable NPC.

Appendix shows an economic comparison between six systems: base case, solar-grid, solar-storage: LI ASM-grid, solar-wind- grid, solar-wind-storage: LI ASM- grid, and wind-grid for 16 countries of the MENA region. To meet the load for the project's entire life (25 years), the system was found to need 47.3 MWh/year. The costs necessary to satisfy this need are estimated based on the energy cost of each country (Table 2). The energy charges for the base case can vary from 1850 to 58 600 $. The NPC is equal to the electricity charges for the reference system since all the energy is satisfied from the grid only.

Considering the basic scenario for each country, we notice that the lower the energy cost/kWh, the lower the NPC (the lowest NPC is associated with the city of DAMAS and the highest c for the city of Tunis). When the energy price is low, it is noticeable that the basic system (grid only) is the most advantageous compared to the other systems. For example, for Damascus, Kuwait, Manama, Baghdad, Riyadh, Tripoli, Doha, Muscat, and Cairo, the basic system's NPC is lower than the other alternative systems. Due to the relatively low energy costs compared to other countries, however, for the cities of Sana'a, Beirut, Alger, Abu Dhabi, Amman, Oujda and Tunis where the price of electricity is higher, the NPC of the basic system (grid only) is higher than that of other alternative renewable systems. It is noticeable that the higher the cost of electricity (Table 2) [1]-[3], [40], the more economically advantageous the other alternative systems are.

In comparison with studies by Khemariya *et al.* [27] and Razmjoo *et al.* [28], our findings align with their conclusions that solar-based systems provide the most cost-effective solutions for regions with abundant solar resources. However, our analysis highlights that wind systems, while environmentally beneficial, may not be as economically viable due to the high capital costs of wind turbines, as noted in studies by Qolipour *et al.* [30]. Comparing the alternative systems, the lowest NPC is for the solar-grid system for all cities considered. In terms of energy charges, the system that sells the most electricity through the grid is solar-wind-storage-grid. In other words, the system accumulates the most money from the authorities by selling them the excess, but despite this, the system remains less economically reliable given the high capital of the turbine (higher NPC). This is confirmed by comparing NPW systems. The greater the NPW, the more profitable the project. The wind-grid system is not recommended given the capital of WT and the wind deposit (NPW <0). The lowest energy cost corresponds to solar-grid systems (lowest LCOE). Considering these parameters, the most economically reliable system in this region is solar-grid. Other systems may be more financially profitable by considering component capital and meteorological resources, as discussed in more detail in the sensitivity analysis section.

Given the impact of the price of electricity on the profitability of the solar-grid system, we studied the impact of increasing the price of energy (removal of substitutions on the variation of NPC, NPW, and LCOE) for the case of Morocco. By increasing the electricity price from 20% to 100% for Morocco, Table 5 shows that as the electricity price increases, the NPC and LCOE decrease, making the system more economically profitable. This is confirmed by the NPW, which increases as the electricity price increases.

Table 5. Economic metrics of optimal design (PV-grid) as a function of the increased level of utility rates for Morocco

	0%	20%	40%	60%	80%	100%
NPC ($)	18529	16230	15682	15106	14509	13892
NPW ($)	38509	52215.6	64171.2	76154.8	88159.4	100184
LCOE ($/kWh)	0.015	0.014	0.013	0.013	0.012	0.012

3.2. Emission analysis

Morocco was chosen to test this hypothesis to confirm the positive impact of the adoption of the alternative renewable system on the environment. When considering carbon emissions, the Solar-Wind-Storage-Grid system stands out as the least polluting configuration, emitting only 6.4 metric tons of CO_2 per year, compared to the grid-only system's 11.7 metric tons (Figure 4). These findings are consistent with Debouza *et al.* [31], who emphasized the environmental benefits of high renewable energy integration in MGs. However, while our study confirms the low emission benefits of wind systems, it diverges from Wu *et al.* [32], who suggested that wind-dominated systems could achieve greater CO_2 reductions with optimized battery integration. Our analysis suggests that a combination of solar and wind, rather than wind alone, offers the best balance between cost efficiency and emissions reduction.

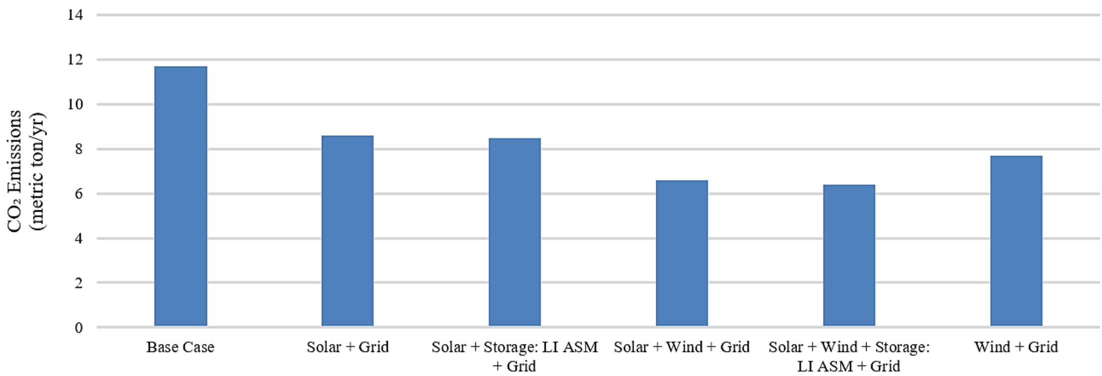

Figure 4. Environmental impact for each MG system

3.3. Technical analysis

Morocco was chosen to test the technical feasibility of alternative renewable systems to test this hypothesis. Figure 5 illustrates the monthly average of the various systems' electricity to meet total electricity demand (56.8 per cent primary load, 43.2 per cent EV load). The grid meets the reference system's entire load of 18549 KWh/year (Figure 5(a)). Given that the grid-PV system Figure 5(b) is dependent on the monthly solar radiation, the PV production was estimated at 40003 KWh/year. 73.6 per cent of PV production (renewable fraction) was used to meet demand; the grid satisfied the remaining demand. The surplus electricity was expected to be 14,417 kWh per year and was sold to the grid. The most cost-effective approach found that the system that considers batteries (PV-battery-grid) implies a single battery; nevertheless, this limited storage capacity has done not affect the monthly average significantly (Figure 5(c)). As illustrated in Figure 5(d), the PV-Wind-Grid system enables a higher renewable energy fraction to be used to meet the load than the two prior systems (81.7 per cent). Solar PV met 67.1 percent of demand on an annual average, while wind turbines met 14.6%. By integrating the batteries as an option, the optimal solution was to incorporate a single battery, which is not visible in (Figure 5(e)). However, the renewable fraction increased to 82.1 per cent, which is explained by the storage of energy generated by renewable energy sources to meet a small amount of demand rather than sourcing from the grid. The monthly energy production of the Wind-Grid system is depicted in

Figure 5(f). While 9195 KWh/year was produced by the turbine, 43.1 per cent was used to fulfil demand (renewable fraction), and the remainder was sold to the grid. The system with the highest renewable fraction is the PV-battery-wind-grid system; this result explains why the preceding section's CO_2 emissions were lower.

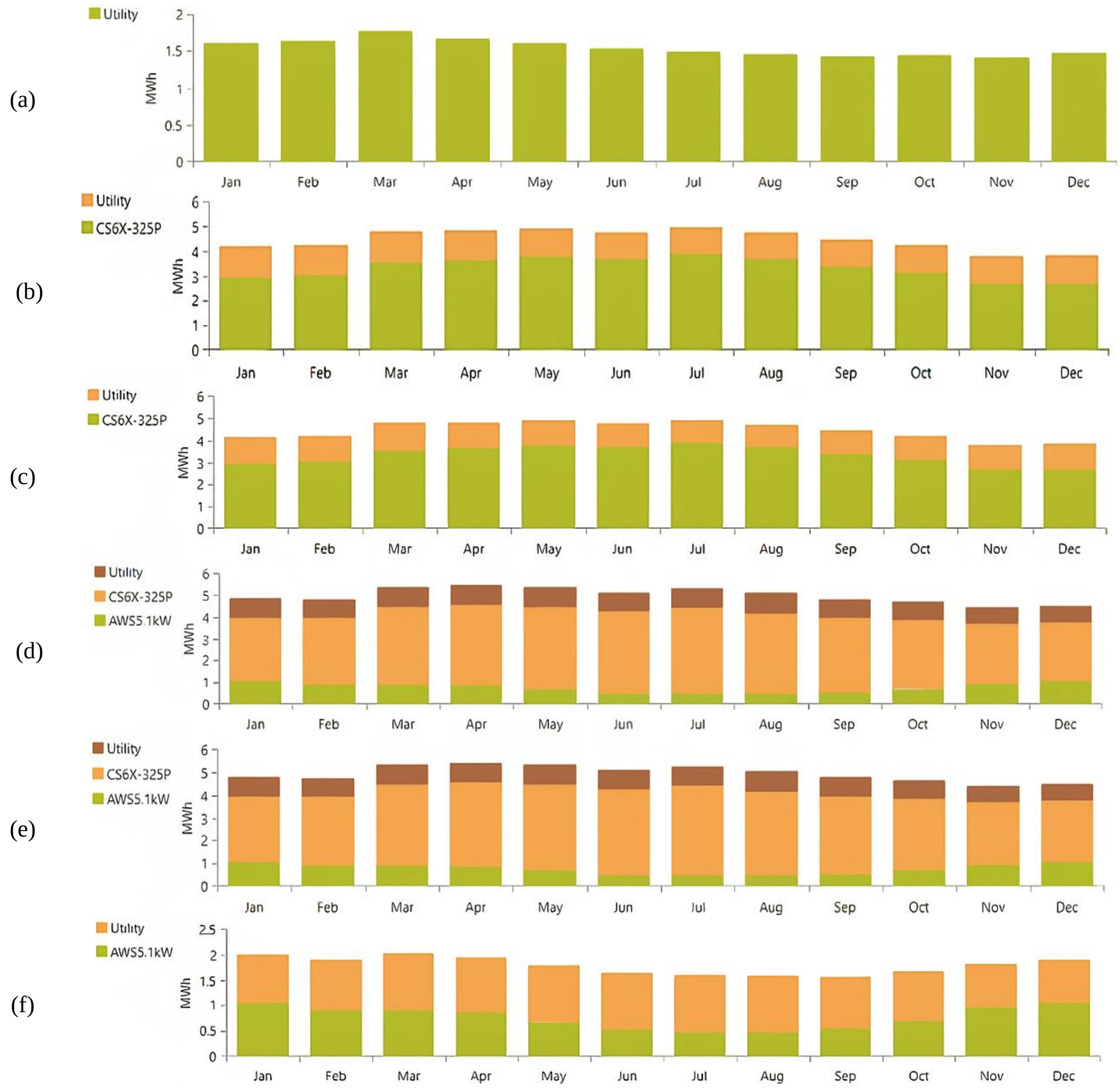

Figure 5. Monthly electric production of the (a) base case (b) solar-grid, (c) solar-storage-grid, (d) solar-wind-grid, (e) solar-wind-storage-grid, and (f) wind-grid

The performance of MG systems in responding to the heuristic request is depicted in Figure 6. Figures 6(a) and 6(b) shows that the grid and PV met the entire demand; unfortunately, during the hours when the solar radiation is most significant, demand is relatively low, whereas the load is greatest when recharging the EVs. It is plain to see that the amount of electricity generated by the PV is entirely absorbed by the load, with the remainder sold to the grid. The modest quantity of energy stored during certain excess hours may be seen by adding a battery to the system, shown in Figure 6(c). The battery is discharged in the absence of solar radiation. Evaluating the WT-PV-Grid system's heuristic response (Figure 6(d)) shows that the electricity absorbed from the grid is entirely consistent with the RE generation. Any electricity excess is sold to the grid, whereas purchases are made only when renewable energy sources are unavailable at a given time. Figure 6(e) illustrates that the MG's reaction is also accurate when adding a battery to the system. Finally, when analyzing the Grid-WT system, the micro-grid is still capable of supplying electricity to the load first from renewable sources and subsequently from the grid; the excess electricity is injected into the grid.

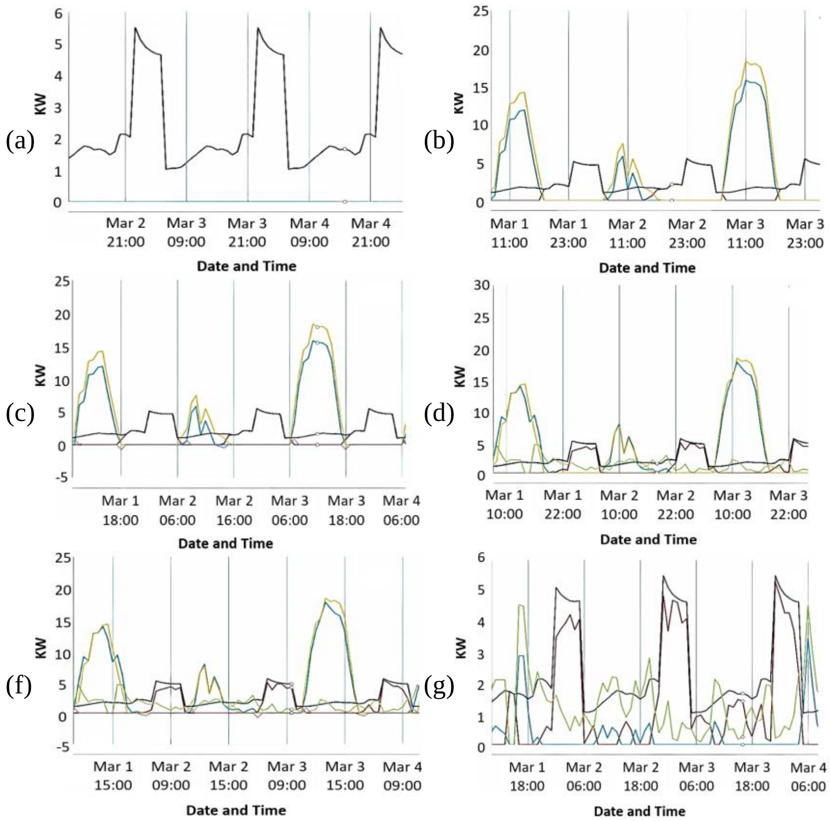

Figure 6. Hourly performance summary of the (a) base case, (b) solar-grid, (c) solar, storage, and grid, (d) solar, wind, and grid, (e) solar, wind, storage, and grid, and (f) wind, grid

3.4. Technical analysis

A sensitivity analysis was made for other geographical coordinates and other tolerance on component prices. Figure 7(a) shows how the NPC changes by varying the PV and turbine costs. By keeping the turbine's cost lower than the current value (capital cost multiplier <1), the NPC of the system seems to be more affected by the variation in the PV panels' cost. Indeed, the more the cost of PV decreases, the more the NPC tends to decrease. Moreover, by keeping the capital of the PV lower than the current value (capital cost multiplier PV <1), the NPC seems unchanged if the turbine's cost increases. On the other hand, it decreases as soon as the turbine's cost tends to decrease. By analyzing the impact of the solar and wind potential variation on the NPC Figure 7(b), the NPC depends strongly on these two natural resources. Indeed, above a wind speed of 4.9m/s, the NPC depends on the two parameters, wind speed and solar bearing, whereas below 4.9m/s, the NPC does not seem to be affected by the wind speed. Wind but only from the variation of the solar radiation. Figure 7(c) examines the impact of component cost variation on CO_2 emissions. The figure shows that CO_2 emissions are insensitive to PV cost.

Even if PV panels cost increases or decreases by 50%, the MG system will always recommend a maximum installation of PV (relatively low price compared to WT). In contrast, emissions are strongly linked to the capital of PV (capital cost multiplier <1). Finally, Figure 7(d) shows that CO_2 emissions are only affected by significant wind speed (the more the average annual wind speed increases, the more CO_2 emissions decrease). This result can be explained by the fact that the higher the wind speed, the more autonomous the MG system is relative to the grid.

Hence, our technical analysis shows that the inclusion of storage systems, particularly in solar-storage-grid configurations, increases the renewable fraction to over 80%, with surplus energy stored for later use. This finding echoes the results of Kumar *et al.* [20], who demonstrated that integrating battery storage into MGs enhances their ability to manage variable renewable energy sources. Moreover, when comparing PV-based systems to wind-based systems, our study highlights the sensitivity of system performance to meteorological conditions, particularly solar radiation and wind speeds. Andoni *et al.* [37] similarly found that wind speeds above 4.9m/s significantly enhance system performance, though our findings emphasize that solar energy remains the more reliable and cost-effective resource across the MENA region. The economic comparison between six systems namely base case, solar-grid, solar-storage: LI ASM-grid, solar-wind-grid, solar-wind-storage: LI ASM-grid, and wind-grid for 16 countries of the MENA region is presented in Figure 8 (see Appendix).

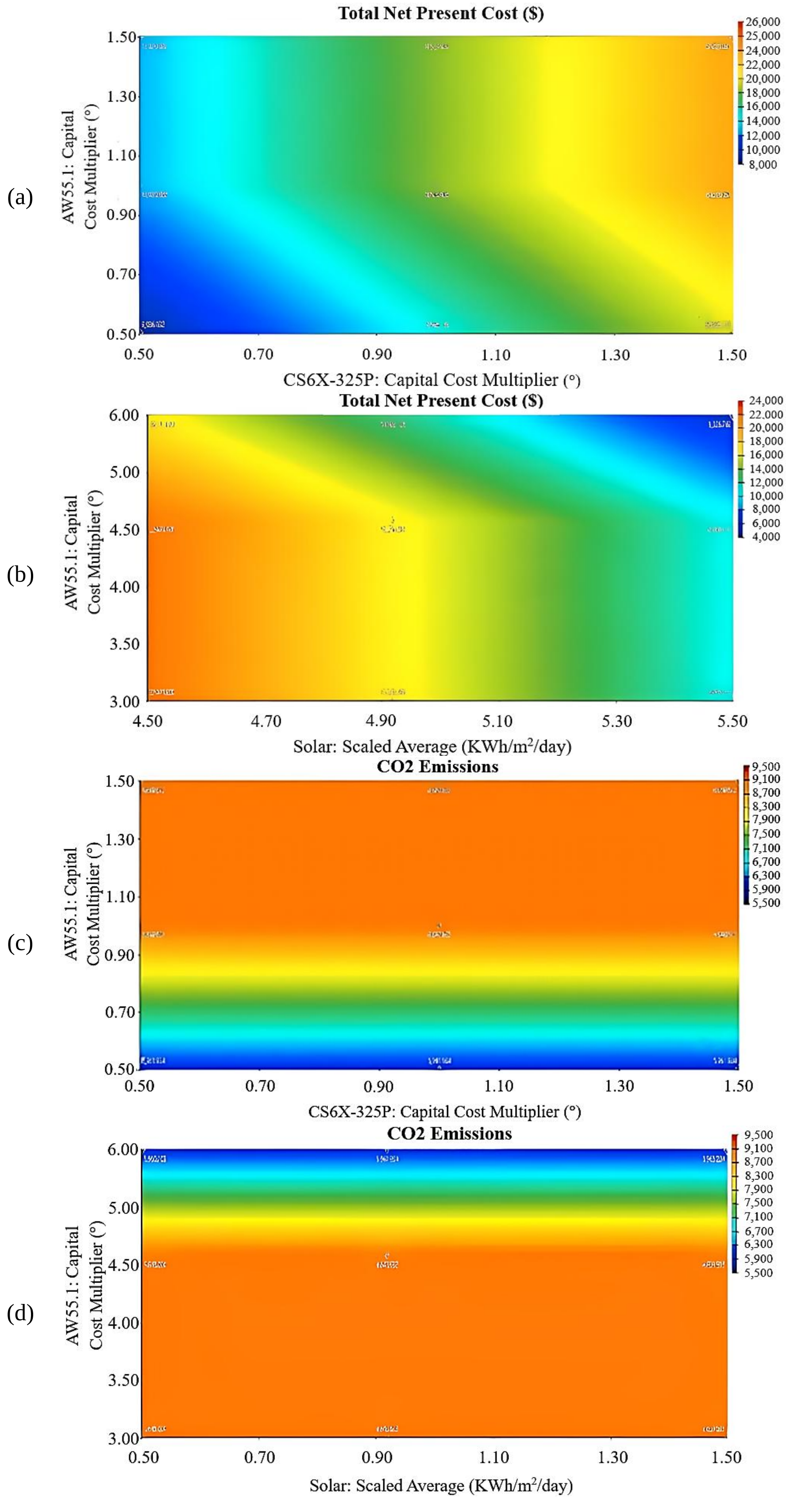

Figure 7. Effect of changes in the (a) NPC based on PV panels and WT capital cost, (b) NPC based on solar GHI and wind speed, (c) CO_2 based on PV panels and WT capital cost, and (d) CO_2 based on solar GHI and wind speed

4. CONCLUSION

This study highlights the technical and economic benefits of hybrid renewable energy systems in the MENA region, particularly solar-grid configurations, which demonstrated the highest economic viability. Sensitivity analyses underscore the critical role of regional electricity prices and subsidy policies in system performance. While wind systems offer environmental benefits, their high capital costs make them less attractive compared to solar-based systems. The findings suggest that phasing out energy subsidies and adjusting electricity prices can promote hybrid renewable energy systems adoption, especially in regions with high electricity costs. The study also emphasizes the potential of hybrid renewable energy systems for powering electric vehicles (EVs) with lower emissions than grid-powered alternatives. Future research should focus on advanced storage systems and expanding these configurations to similar climatic regions, addressing limitations in storage cost analysis to enhance understanding of hybrid renewable energy systems potential. These insights contribute to the literature and provide actionable recommendations for policymakers.

APPENDIX

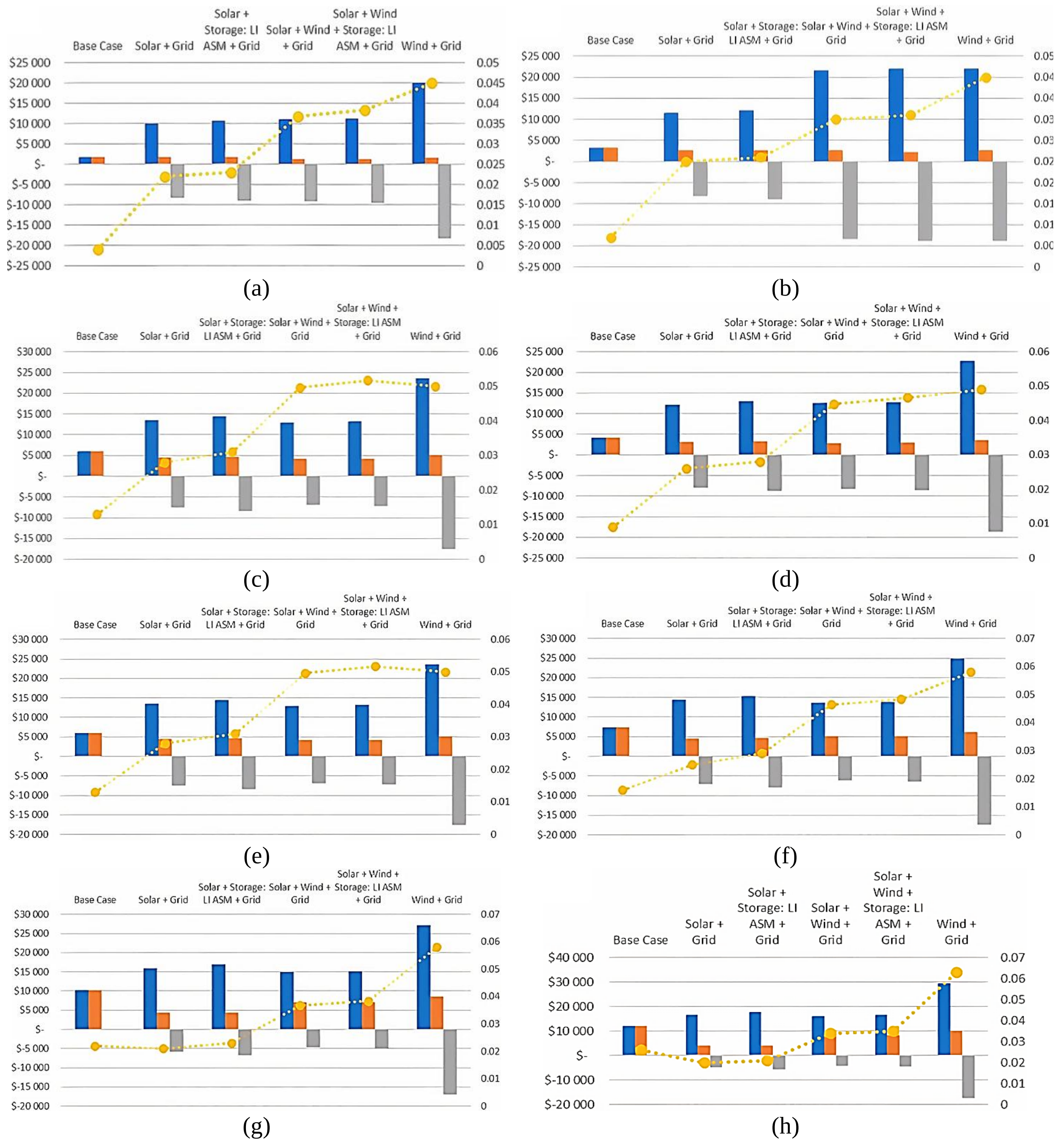

Figure 8. Economic metrics for each MG system: (a) Damas, (b) Koweit, (c) Manama, (d) Bagdad, (e) Riad, (f) Tripoli, (g) Doha, and (h) Mascate

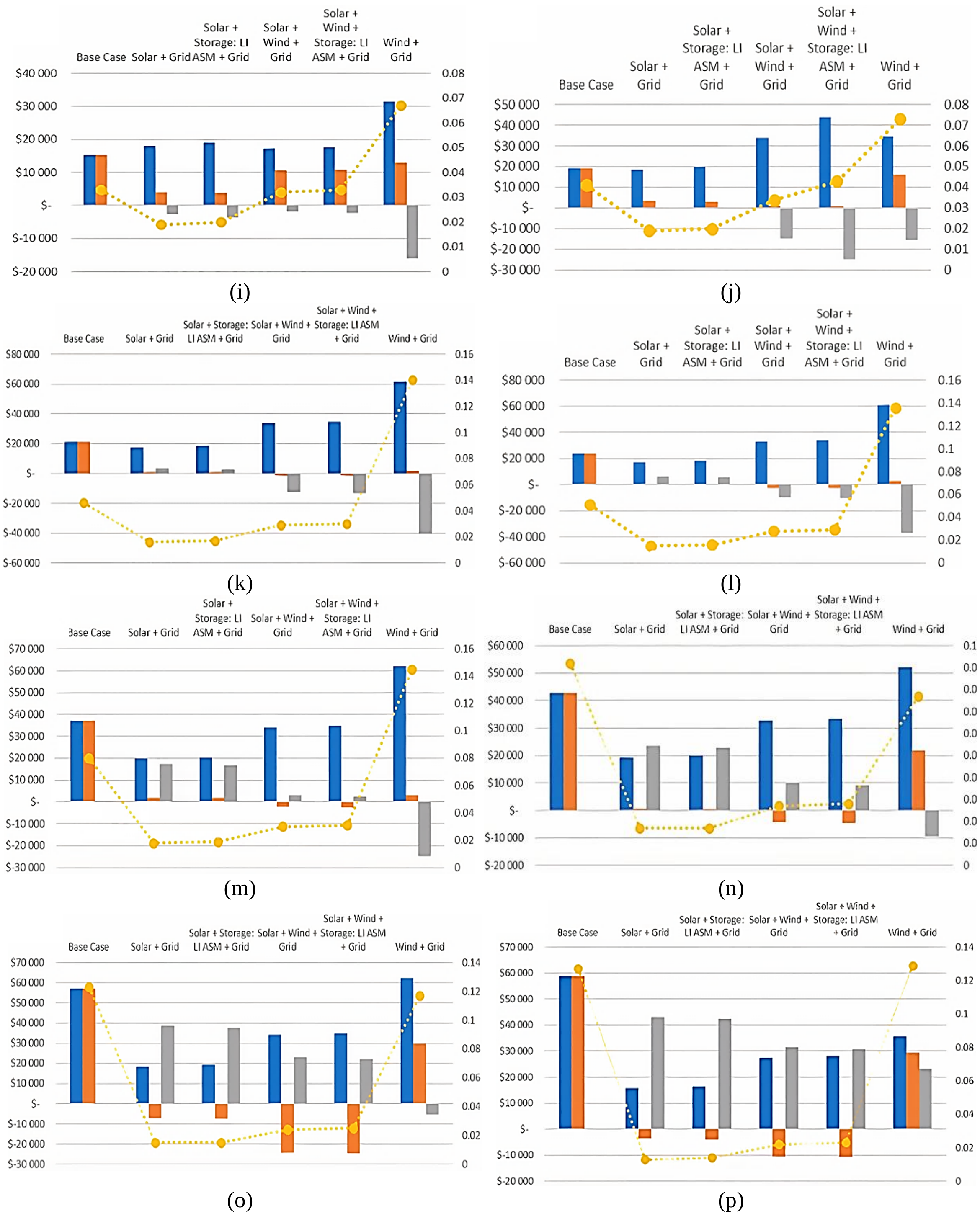

Figure 8. Economic metrics for each MG system: (i) Cairo, (j) Sanaa, (k) Beyrouth, (l) Algeia, (m) Abu Dhabi, (n) Amman, (o) Oudja-Morocco, and (p) Tunis *(continued)*

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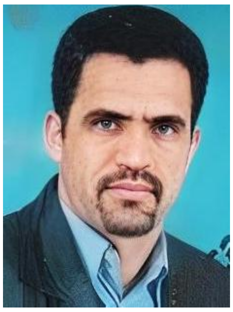

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