

# Techno-Economic Analysis of a Hybrid PV/Wind-Diesel Grid-Connected System for the Great Man-Made River Project's Wellfields, Libya

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DOI: <https://doi.org/10.30880/ijie.2025.17.08.018>

## Article Info

Received: 2 July 2025

Accepted: 9 December 2025

Available online: 31 December 2025

## Keywords

Wind and solar potential, great man-made river, hybrid renewable energy systems, optimization, HOMER software, energy-water nexus, large-scale grid-connected systems, Libya

## Abstract

The Great Man-Made River (GMMR) wellfields in southern Libya are critical to national water security but rely heavily on fossil-fuel electricity, resulting in high operational costs, grid instability, and elevated greenhouse-gas emissions. This paper presents a comprehensive techno-economic and environmental feasibility of integrating large-scale hybrid renewable energy systems (HRES) across five major GMMR wellfields, Sarir, Tazerbo, Al-Hasouna, Al-Kufra, and Ghadames, using HOMER Pro. Site-specific configurations were optimized and evaluated using key performance indicators, including Net Present Cost (NPC), and Levelized Cost of Electricity (LCOE). Environmental performance was estimated using HOMER's emissions model. Sensitivity analyses examined the influence of solar and wind variability on economic outcomes. Optimized HRES configurations resulted in significant cost savings, reducing NPC by over \$1 billion relative to grid-only scenarios. Al-Kufra achieved the lowest LCOE at \$0.095/kWh, while Tazerbo had the highest at \$0.139/kWh. CO<sub>2</sub> emissions were reduced by up to 69%, and payback periods ranged from 2.0 years (Al-Kufra) to 5.2 years (Sarir). These findings highlight the viability of large-scale HRES for sustainable water-pumping operations, offering a robust model for energy-water infrastructure in resource-scarce regions. Beyond technical and economic benefits, HRES adoption would reduce fossil fuel dependence, mitigate environmental impacts, and enhance operational resilience, supporting energy security and sustainable development in Libya and similar regions worldwide.

## 1. Introduction

Energy and water are crucial prerequisites and inputs for both national economic progress and sustainable development [1], [2]. They play a vital role in both the consumption and production of services and goods [3]. Although modern advancements have greatly improved quality of life, access to safe drinking water and nutritious

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food remains a major global challenge and a barrier to achieving the United Nations' Sustainable Development Goals (SDGs) outlined in Agenda 2030 [4]. Recent international climate agreements, including the Dubai Climate Pact adopted at COP28, underscore the urgent need to scale up clean energy technologies and accelerate the deployment of renewables [5]. The water-energy relationship is closely interconnected, as energy production relies on water and water services consume substantial energy. Worldwide, about 7% of total energy is used for water extraction, treatment, and distribution, highlighting the importance of diverse and reliable energy sources for water services [6]. Without secure access to both energy and water, economic expansion, job creation, and poverty reduction are severely constrained, and by 2050 many regions could experience up to a 6% reduction in gross domestic product due to insufficient clean water and rising energy requirements [7], [8].

Meeting basic water needs is therefore essential and non-negotiable for local communities yet supplying energy to dispersed and often remote pumping stations poses significant logistical and financial challenges. Water scarcity and energy shortages are pressing issues worldwide, particularly in the Middle East and Africa, where urbanization and population growth reduce freshwater availability while driving up energy demand [9]. Libya exemplifies this stress, with around 90% of its land classified as arid or hyper-arid and potable water scarce in coastal and desert regions [10]. Covering over 1.75 million km<sup>2</sup> with a 2,000 km coastline [9], its 7.5 million people are densely concentrated along the coast, where groundwater is limited and often of low quality, hindering agriculture and underscoring the urgent need for alternative water sources for domestic and agricultural demands [11], [12].

To address severe water scarcity and support development in the densely populated coastal regions, the Great Man-Made River (GMMR), the largest irrigation project in the world and a UNESCO-recognized engineering feat (1999), was launched in 1984, to transfer groundwater from deep transboundary aquifers in major basins (Al-Kufra, Sarir) to the north via extensive pre-stressed concrete cylinder pipelines (PCCP) [13]. The project comprises over a thousand wells and has operated for more than a quarter century in three of its four planned phases [10]. Deliveries are about 4 million m<sup>3</sup>/day, with a projected capacity of ~6.5 million m<sup>3</sup>/day when remaining phases commence [14]. Historic feasibility work found groundwater transfer to be markedly more economical than alternatives such as desalination ( $\leq$ \$0.35 versus \$3.75 per m<sup>3</sup> in early studies), motivating long-distance conveyance [15]. Although the GMMR has been the backbone of Libya's water supply for over 30 years, the process of extracting and transporting this water is highly energy intensive. The water collection system within the wellfield network comprises approximately 1,604 km of pipelines, while the water conveyance system spans about 4,071 km, linking the upper reservoirs at the southern wellfields to northern regions. Although water flows from these upper reservoirs to the coastal areas at an average velocity of 0.95 m/s in some sections without additional pumping, the overall process of lifting and pumping water within the wellfield network remains highly energy-intensive [10], [16]. Earlier reports estimate that wellfield operations alone consume roughly 3–4% of national electricity generation [17], [18]. Most GMMR wellfields and facilities are in remote, rural areas [15], making energy supply pivotal to potable-water cost effectiveness.

Reliability at these sites is limited because generation is concentrated along the coast and the sector remains dependent on unsustainable fossil fuels [19]. During peak periods, long transmission distances, efficiency losses, and weather-related disruptions constrain delivery, causing frequent, prolonged outages in remote regions [20]. According to the published data, in 2023, GECOL's available capacity was 7,300 MW against 8,900 MW, about 1,600 MW deficit, driving multi-hour power cuts across most of the country [18]. Systemic shortfalls, compounded by repeated grid collapses (16 times in 2020 and further events in 2021–2022) and heavier load shedding in the south where networks are sparse, undermine service continuity [19], [21]. These interruptions cascade across critical infrastructure, jeopardizing the GMMR's power-dependent pumping and long-distance delivery, and risking water shortages for households, hospitals, agriculture, and industry, with significant public-health and economic impacts [22]. Ensuring cost-effective potable water provision through the GMMR project requires energy sources that are locally available and sustainable.

Declining renewable costs and heightened environmental concerns make solar and wind credible substitutes for fossil fuels in Libya. Diesel reliance entails price volatility, difficult fuel logistics to remote wellfields, higher O&M, and high greenhouse-gas emissions [23], making renewable integration both environmentally necessary and economically advantageous for rural water infrastructure. Globally, diversification of the energy mix in line with SDG 7 has intensified, with particular urgency in sub-Saharan Africa [24]. Libya has likewise signalled an intent to meet part of rising demand with domestic renewables to restraint fossil dependence, reduce emissions, and advance sustainable development. Given current deficits and projected load growth, renewables can help satisfy demand, lessen outages, and mitigate environmental impacts. Libya's central location in North Africa, combined with its vast land area, long Mediterranean coastline, and largely uninhabited desert regions, makes it ideally suited for large-scale renewable energy development [25], [26]. Multiple studies confirm that Libya holds significant potential for both photovoltaic (PV) and wind energy, which are considered the most promising options for diversifying and strengthening the national energy mix [27]–[29].

Hybrid renewable energy systems (HRES) offer a practical response to widespread electricity shortages and reduce dependence on fossil fuels [30]. Overall, the literature finds that grid-connected hybrid renewable energy

systems (HRES), especially PV/wind, improve reliability and grid stability, reduce levelized cost of energy, and cut emissions compared with single-source or diesel options [31]. Evidence across diverse contexts supporting these overall findings for large-scale and remote applications include Egypt [32], West Bank/Jenin [33], Ethiopia [34], Chad [23], Saudi Arabia [35], and Indonesia [36]. Many of these analyses employ the HOMER software tool for resource assessment, optimal sizing, and LCOE analysis, with performance sensitive to local resource quality, component costs, and load profiles. Despite extensive studies on Libya's renewable energy potential and hybrid PV-wind systems in other regions, no previous research has conducted a detailed techno-economic and environmental assessment of grid-connected HRES for the GMMR wellfields using HOMER Pro.

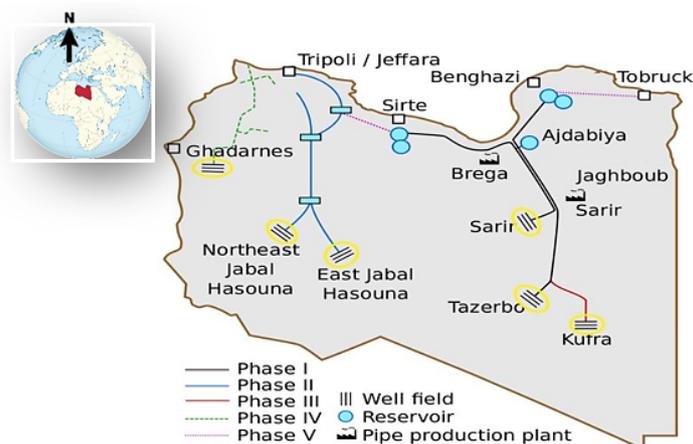
Existing studies often overlook the unique characteristics of large, continuous pumping loads in remote desert locations. The present study addresses this gap by evaluating the feasibility of grid-connected PV/wind systems for five key GMMR wellfields, Sarir, Tazerbo, Al-Kufra, Jabal Hasouna, and Ghadames. Using HOMER Pro, this research analyses site-specific resource potential, wellfield demand profiles, and various system configurations, comparing them against grid-only and diesel-supported alternatives. Key performance indicators, including Net Present Cost (NPC), Levelized Cost of Electricity (LCOE), renewable fraction, and CO<sub>2</sub> emissions, are used to identify cost-effective and sustainable solutions. The findings provide decision-relevant evidence for integrating renewable energy into the GMMR's power supply, establish a benchmark for designing hybrid systems in arid regions, and highlight optimal pathways for ensuring sustainable and reliable electricity for large-scale groundwater extraction and distribution.

## 2. Methodology

### 2.1 Site Description

The Great Man-Made River (GMMR) is a vast underground pipeline network that transports fossil groundwater from deep southern aquifers to densely populated northern cities. The system spans 4,071 km, linking over 1,300 wells, with depths exceeding 500 m, across four major basins: Kufra, Ghadames, Sirte, and Jabal Al-Hasouna. The water is conveyed via pre-stressed concrete cylinder pipes (PCCP), each 4 meters in diameter, through main five major phases established as Sarir-Sirt/Tazerbo-Benghazi; Al-Hasouna-Sahl Jefara; Ghardabiyah Assdada; Ghadames-Zwara; Al-Kufra-Tazerbo; and Ajdabiya-Tobruk. Despite its critical role in water supply, the system remains heavily reliant on fossil fuel-based electricity, with a total daily energy demand of 184.3 MWh for its facilities. For operational purposes, the GMMR wellfields are divided into five distinct zones, enabling tailored hybrid renewable energy systems (HRES) with optimized component sizing to ensure the reliable delivery of renewable electricity to all wellfield sites.

For this study, five wellfields were selected for a techno-economic and environmental analysis of hybrid renewable energy systems (HRES): Sarir, Tazerbo, Al-Kufra, Jabal Al-Hasouna, and Ghadames. These sites were chosen based on their strategic importance for water distribution, along with the availability of renewable energy resources (solar and wind) in the region. The selection also factored in the feasibility of integrating renewable energy based on local resource availability, aiming to optimize the Cost of Energy (COE) for each location and maximize the economic viability of the proposed systems. While the GMMR wellfields are located in remote desert regions, where access to localized environmental data is limited due to the absence of nearby meteorological stations, this study leverages satellite-derived datasets for solar and wind resources. These resources are critical for designing energy systems that can meet the wellfields' continuous operational demand. Fig. 1 illustrates the geographic distribution of the selected wellfields, while Table 1 provides their specific coordinates and elevations.



**Fig. 1** Location of the considered GMMR Project's wellfield areas in Libya

**Table 1** The geographical coordinates of the selected wellfields

Wellfield region	Latitude ( <sup>0</sup> N)	Longitude ( <sup>0</sup> E)	Elevation (m)
Sarir	27.30	21.6	121
Tazerbo	25.55	21.6	288
Jabal Al-Hasouna	28.51	16.07	607
Al-Kufra	23.33	22.08	392
Ghadames	30.12	9.53	589

## 2.2 System Design using HOMER

HOMER was selected for this study due to its robustness and versatility in renewable energy system analysis. It is widely used for optimizing system configurations to assess the potential for substituting conventional sources with renewables. Originally developed by NREL and now managed by UL Solutions, HOMER supports simulation, optimization, and sensitivity analysis [37]. Accurate simulations require input data such as meteorological parameters, renewable resource availability, electrical load profiles, and technical and economic specifications. Inputs can be monthly averages or time-series data, enabling realistic modeling. HOMER supports both AC and DC architectures and hybrid configurations integrating renewable and non-renewable sources. If renewable generation cannot fully meet demand, the grid is used to compensate [38]. In this study, the system includes PV arrays, wind turbines (WT), diesel generators (DG), the grid, and an inverter. HOMER processes daily energy demand, site resource characteristics, microgrid components, and economic metrics to simulate and screen feasible configurations. Results are ranked by net present cost (NPC), with sensitivity analyses examining how variations in key variables impact system cost-effectiveness.

## 2.3 Resource Assessment

Accurate resource assessment is crucial for designing and simulating hybrid renewable energy systems. This section outlines the methods and datasets used to assess solar and wind potential at the selected GMMR wellfields. In early-stage analysis, where detailed data is limited, HOMER provides reliable system estimates using data from trusted sources. Solar irradiance and wind speed data were sourced from the National Aeronautics and Space Administration (NASA) and the National Solar Radiation Database (NSRDB), providing robust inputs for techno-economic modeling. For the GMMR wellfields, HOMER requires data input on global horizontal irradiance (GHI), wind speed, and ambient temperature. Hourly solar radiation data and wind speeds were obtained from the NSRDB and NASA POWER database via HOMER Pro's resource interface. Precise geographical coordinates for each wellfield (latitude and longitude) were entered into HOMER Pro, which retrieved the corresponding hourly GHI, ambient temperature, and other meteorological parameters from satellite observations.

Figs. 2, 3, and 4 show the monthly average daily solar radiation (in kWh/m<sup>2</sup>) with clearness index, average wind speed (m/s), and average temperature across the GMMR wellfields. These figures enable a comparative analysis of resource availability and atmospheric transparency. Across the five wellfields, clearness indices range from 0.66 to 0.69, with GHI averaging 5.82-6.45 kWh/m<sup>2</sup>/day. GHI peaks in June–July and drops in December–January. Mean wind speeds range from 5.79 to 6.16 m/s, and mean temperatures are around 21-22°C, which minimizes thermal derating for PV. Solar resources show clear seasonal variation, with peaks in late spring and summer, while wind resources exhibit moderate annual variability but remain within an optimal range for small/medium-scale turbines. These conditions support the deployment of PV/wind hybrid renewable energy systems across all sites, with wind contributing to energy yield and variability smoothing, especially at Al-Kufra, Jabal Al-Hasouna, and Ghadames. Tazerbo and Sarir appear PV-dominant, with adequate wind contributions. The quantified resource profiles provide reliable inputs for component sizing, dispatch optimization, and leveled cost of energy analysis.

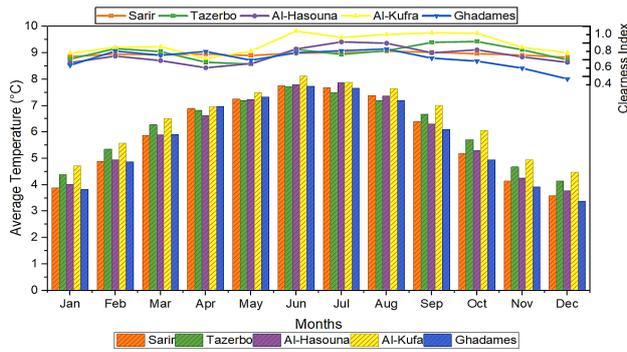


Fig. 2 Annual average GHI and clearness index

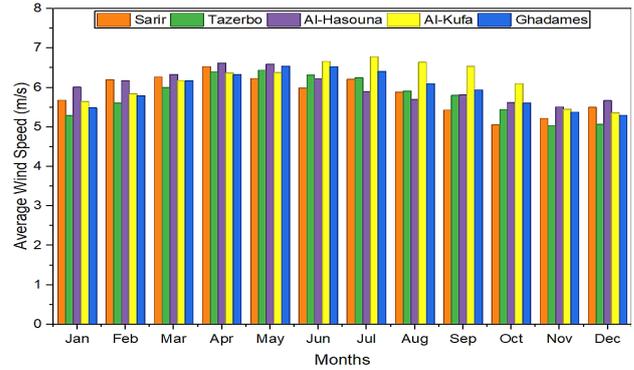


Fig. 3 Annual average wind speed

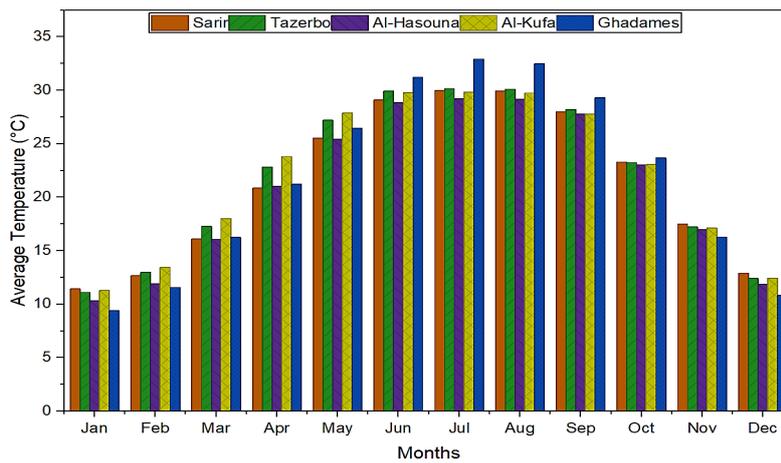


Fig. 4 Monthly average temperature for selected GMMR wellfields

### 2.4 Electrical Load Profile for GMMR Wellfield

An hourly load profile (8,760 points) is required in HOMER Energy. For the GMMR wellfields, an industrial, continuous-operation profile is used, as these facilities run without interruption. Annual load profiles were estimated by consulting the GMMR Authority and reviewing relevant energy consumption data for each system phase. Groundwater extraction relies on submersible pumps (UBWM310 Ulelectriglide) across all wellfields, with Al-Hasouna also using horizontal split-case centrifugal pumps for long-distance conveyance. The system is designed for 24-hour operations to ensure delivery reliability, and all wellfields depend on the national grid.

Hourly energy-use data from January 1, 2020, to December 31, 2024, were compiled from relevant datasets and processed in Excel to meet HOMER input requirements. Although the fourth and fifth phases remain incomplete, major transmission lines are operational, though further progress is stalled due to contractor withdrawal and financial issues. Energy consumption for the Al-Kufra wellfield was estimated by the GMMR Authority's Data, Studies, and Research Centre. Analysis shows relatively constant annual usage, with daily consumption averaging 4,423,967 kWh/day across all wellfields. Table 2 summarizes the average electrical load for each wellfield.

**Table 2** Electricity consumption of GMMR's wellfields

Wellfield	No of wells	Avg pump head (m)	Production target (m <sup>3</sup> /d)	Energy required in vertical lift (kW/day)	Wellfield's facilities demand (kW/day)	Total avg demand (kW/day)
Sarir	120	246	2,000,000	517,440	132.54	517,572
Tazerbo	102	312		496,944	39.72	496,983
Al- Hasouna	329	534	2,500,000	1,567,416	170.6	1,567,587
Al-Kufra*	286	254	1,650,000	1,393,392	124.4	1,393,516
Ghadames	92	280	250,000	448,224	85.7	448,309
Total	1152	-	6,400,000	-	-	4,423,967

\* Al-Kufra (Phase III) was estimated by the Data, Studies and Research Centre of GMMR Authority.

## 2.5 Component Modelling and Input Parameters

This section outlines the modelling approach and input parameters used in HOMER to simulate hybrid energy systems. The base case is validated against observed energy consumption, followed by alternative scenarios to identify the most cost-effective design. Simulations rely on site-specific meteorological data, hourly electrical load, and technical and economic component characteristics. Component sizes and costs are optimized, and system performance is assessed through NPC, ICoE, and reliability metrics, with sensitivity analyses.

### 2.5.1 PV Panel

A market analysis identified the most suitable PV modules, with polycrystalline, monocrystalline, and thin-film technologies being the most common. Module performance depends on climate, ambient temperature, lifespan, and humidity. In HOMER, system design uses solar radiation, clearness index, and temperature data, which can be manually entered or imported. The PV array output is calculated using Equation 1, and the rated PV capacity is optimized in HOMER to reflect site-specific conditions for accurate performance estimation. The technical characteristics of the PV modules are shown in Table 3.

**Table 3** Summary of technical and economic aspects for the design system

Component	Parameter	Value	Component	Parameter	Value
PV module	Model	Canadian solar 330CS6X-330P (multi-c-Si)	Wind turbine	Model	Vestas V136-3.45 MW
	Capacity (W)	330		IEC Class	IIIA
	Capital cost (\$/kW)	375		Nominal output (kW)	3,500
	Replacement Cost (\$/kW)	110		Capital cost (\$/unit)	5,700,000
	O&M (\$/year)	5		Replacement cost (\$/unit)	3,700,000
	Derating factor (%)	88		O&M Cost (\$/year)	128,000
	T. coefficient (%/°C)	-0.41		Cut-in wind speed (m/s)	3
	NOCT (°C)	45		Rated wind speed (m/s)	10
	Rated electrical eff. (%)	17		Cut-out wind speed (m/s)	20
	Lifetime (years)	25		Hub height (m)	112
Diesel generator	Model	Wärtsilä	Converter	Capacity (kW)	1
	Rated capacity (kW)	20,700		Lifetime (years)	15

Component	Parameter	Value	Component	Parameter	Value
	Capital cost (\$/unit)	2,000,000		Efficiency (%)	95
	Replacement Cost (\$/unit)	1,900,000		Capital cost (\$/kW)	300
	O&M (\$/kW/hr)	30		Replacement cost (\$/kW)	300
	Fuel Price (\$/L)	0.71			
	F <sub>0</sub> (L/kWh)	0.014	Grid rate	Rate 1 (\$/kWh)	0.0301
	F <sub>1</sub> (L/kWh)	0.21		Rate 2 (\$/kWh)	0.22
	Min. load ratio (%)	25		Rate 1 months	Feb, Mar, Apr, May, Sep, Oct
	Min. runtime (min)	15		Rate 2 months	Jun, Jul, Aug, Nov, Dec, Jan
	Lifetime (hrs)	20,000		Currency rate (LYD/USD)	4.48

$$P_{PV} = Y_{PV} \times f_{PV} \left( \frac{G_T}{G_{T,SC}} \right) \times [1 + \alpha_f (T_C - T_{CS,C})] \quad (1)$$

where:

$Y_{PV}$ : is the rated output of the PV panels under standard test conditions (kW)

$f_{PV}$ : PV represents the PV derating factor, accounting for real-world losses (%)

$G_T$ : denotes the actual solar irradiance incident on the PV modules (kWh/m<sup>2</sup>)

$G_{T,SC}$ : is the standard irradiance value (1 kW h/m<sup>2</sup>)

$\alpha_f$ : is the temperature coefficient of the PV module (% °C)

$T_C$ : indicates the actual cell temperature (°C)

$T_{CS,C}$ : refers to the standard cell temperature (25 °C)

## 2.5.2 Wind Turbine (WT)

Optimizing wind turbine performance requires selecting a turbine with rated power and cut-in wind speed suitable for local wind conditions. Site-specific wind speed is the primary factor in determining rated capacity. In HOMER, wind speeds recorded at a reference height are adjusted to the turbine hub height using the logarithmic wind profile law, and the turbine's power curve and local air density are applied to estimate power output. Generation occurs only when wind speeds fall within the operational range. Hourly wind datasets are synthesized from monthly averages, and parameters such as variability, a correlation coefficient of 0.85, periodic pattern intensity of 0.25, site-specific mean monthly wind speeds, and Weibull shape factors are included to improve accuracy. Table 3 also presents the cost and technical characteristics of the turbines used.

$$V_H = V_{AN} \times \left( \frac{\left( \ln \frac{H_H}{H_O} \right)}{\left( \ln \frac{H_{AN}}{H_O} \right)} \right) \quad (2)$$

where  $V_H$  is Average wind speed at the hub height (m/s),  $V_{AN}$  is Wind speed value at anemometer height (m/s),  $H_H$  is turbine hub height (m),  $H_{AN}$  is height of turbine anemometer (m) and  $H_O$  is height of surface roughness (m).

## 2.5.3 Diesel Generator

Diesel generators are incorporated into hybrid systems to ensure stable electricity supply by mitigating solar and wind intermittency. In wellfields, they serve as backups during grid failures. Their role depends on the system configuration: off-grid systems run alongside renewables, while grid-connected systems operate during outages or critical events. Generators are sized to meet peak electrical demand, with fuel consumption modeled as a linear function of output in HOMER.

$$F = F_0 Y + F_1 P_{gen} \quad (3)$$

where  $F$  is the total fuel consumption (L/kwh),  $F_0$  is the fuel of the fuel curve (L/kwh),  $F_1$  is the slope of the fuel curve (L/kwh),  $Y_{gen}$  is the rated generator capacity (kW)  $P_{gen}$  is the actual power produced (kw).

### 2.5.4 Converter

The converter is essential for managing energy flow within the hybrid system, directing surplus energy from wind turbines and enabling bidirectional AC-to-DC and DC-to-AC conversion. It converts DC from PV panels to AC power for the wellfield's electrical loads, ensuring optimal use of renewable resources. HOMER evaluates the converter's efficiency, lifespan, and cost, with the total AC load not exceeding the inverter's rated capacity. The required inverter capacity and efficiency are calculated based on the PV array's rated power using Eqs. (4) and (5). The converter selected has a capital cost of \$300 per kW, 95% efficiency, and a 15-year lifespan, as recommended by [39].

$$C_{conv}(KW) = P_{array} \times (100 \div 85) \quad (4)$$

$$\eta_{conv}(\%) = \frac{OUTPUT_{conv}}{INPUT_{CONV}} \times 100 \quad (5)$$

### 2.5.5 Power Grid

Connecting hybrid systems to the national grid enhances reliability by exporting surplus electricity and importing power during shortfalls. HOMER models both purchase costs and revenue from excess generation. In the grid-connected scenario, standalone energy storage is unnecessary, as the grid serves as a large-scale energy buffer. In Libya, electricity prices are subsidized, with the National Strategy for Renewable Energy and Energy Efficiency (NSREEE) reporting a main tariff of 0.135 LYD/kWh (approx. 0.0301 USD/kWh). For the GMMR wellfields, a peak period tariff of 1.0 LYD/kWh (approx. 0.22 USD/kWh) is used, reflecting the actual cost environment for large-scale energy consumers in Libya, as shown in Table 3.

## 2.6 Economical Assessment

Economic analysis establishes the financial viability and long-term sustainability of the proposed hybrid system. In HOMER, the assessment uses user-defined financial inputs, discount rate 8%, inflation 2%, debt structure and costs, over a 25-year project life with 0% annual capacity shortage. HOMER performs time-series simulations to test technical feasibility (meeting load, renewable contribution, capacity-shortage limits) and to run optimization/sensitivity analyses. HOMER then computes Net Present Cost (NPC), Levelized Cost of Energy (LCOE), Simple Payback and system capital and salvage cost, to compare different configurations and inform investment and policy decisions. The NPC represents the total lifetime expenditures, including capital, O&M, replacement, and salvage, and is computed as following equations.

$$NPC = \frac{AnnC}{CRF}, \quad RF(i, n) = \left( \frac{i(1+i)^n}{(1+i)^n - 1} \right), \quad i = \frac{i-f}{1+f} \quad (6)$$

where  $AC$  denotes the annualized cost, and  $CRF$  is the capital recovery factor, which is derived from the real discount rate ( $i$ ) and the project lifespan ( $n$ ) and  $f$  represents the inflation rate. The  $CoE$  and  $LCoE$  quantify the annualized cost per unit of electricity determined using Eq. (7).

$$COE \left( \frac{\$}{kWh} \right) = \frac{C_{ann.tot}}{E_{served}}, \quad LCOE (\$/kWh) = \frac{TAC (\$/years)}{E_{load\ served}} \quad (7)$$

The Payback Period (PBP) measures the time to recover initial investment from annual revenue and savings. These metrics enable a comprehensive techno-economic evaluation of the optimized system configuration.

$$Payback\ Period = \frac{I}{R + E} \quad (8)$$

## 2.7 System Configuration

A hybrid renewable energy system combines renewable technologies like photovoltaic (PV) panels and wind turbines with non-renewable systems, such as the national utility grid and diesel generators. Fig. 5 illustrates the proposed grid-connected, AC-coupled configuration, consisting of a PV array, wind turbine (WT), diesel generator (DG), and converter. The grid, DG, and WT are connected to the AC bus, while the PV array is linked to the DC bus

via a unidirectional inverter that converts DC to AC for the load or grid export. The utility grid serves as the primary supply, operating alongside fluctuations from renewable integration, while renewable sources supplement the load during peak hours or grid outages.

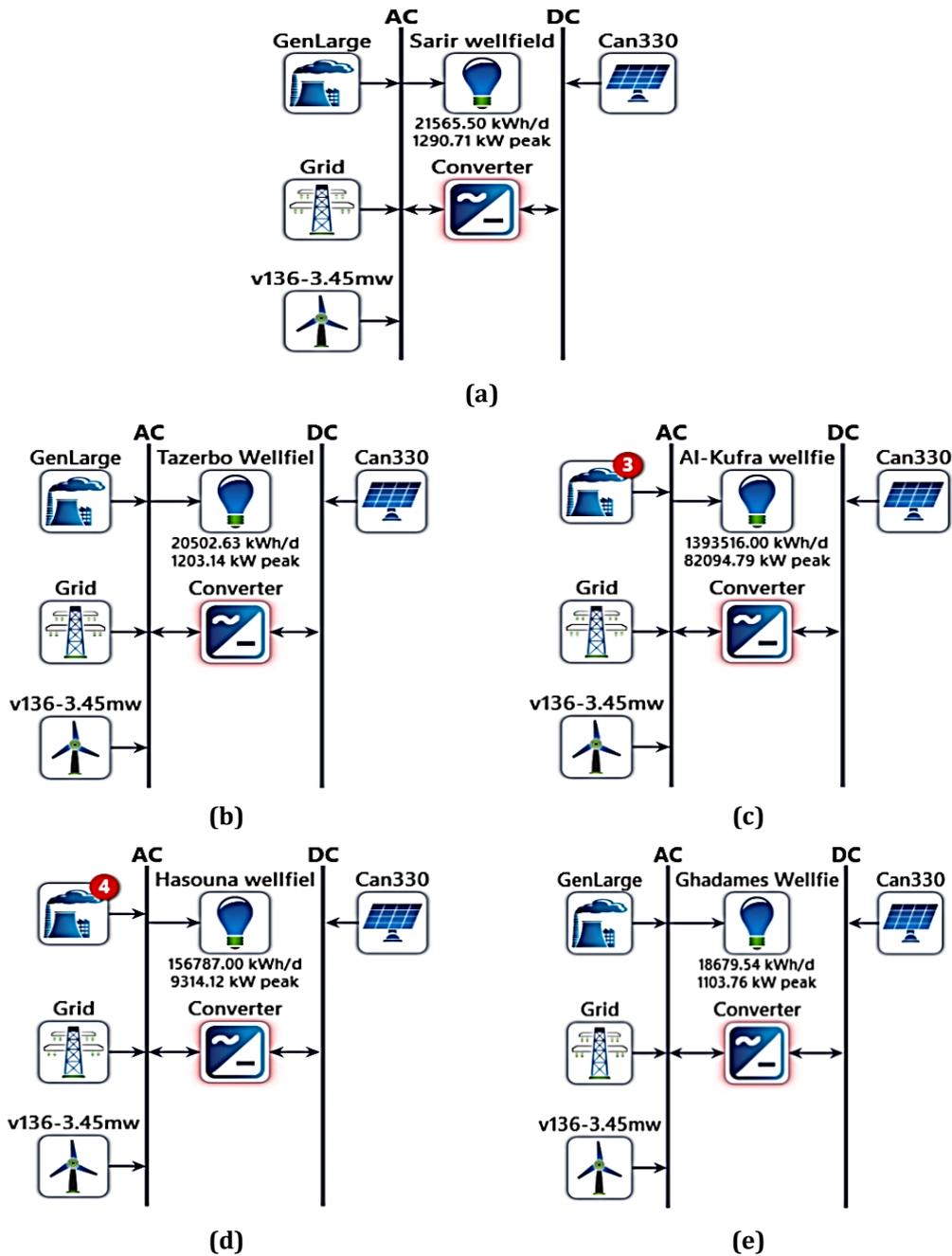


Fig. 5 The schematic diagram of the proposed hybrid grid-connected system

### 3. Simulation Results

#### 3.1 Production of Electricity in the GMMR Wellfield Systems

Annual electricity generation profiles for the GMMR wellfields, shown in Tables 4-8 and Fig. 6, highlight the significant role of hybrid renewable energy systems (HRES) in meeting energy demands efficiently while reducing reliance on the national grid. The monthly production profile shows seasonal consistency, with wind energy being the dominant source throughout the year. Solar PV output is stable, with minor seasonal fluctuations. The grid's contribution is minimal, reinforcing the system's reliability and autonomy. At Sarir, wind provides 82.4% (29,275 MWh/yr) and PV 13.6% (4,813 MWh/yr), with grid contribution at 4.03%. Total generation exceeds the 7,871

MWh/yr load, with 27,628 MWh/yr excess and a renewable fraction of 81.8%, highlighting export potential. At Tazerbo, PV supplies 72.9% (11,563 MWh/yr), with no wind in the base profile. The grid provides 27.1% (4,306 MWh/yr). The renewable fraction is 42.5%, with excess generation of 8,219 MWh/yr. A PV+wind layout increases the renewable fraction to 82.6%, though at higher COE and NPC. At Al-Hasouna, wind contributes 51.3% (60,301 MWh/yr), PV 34.4% (40,469 MWh/yr), and the grid 14.3% (16,771 MWh/yr).

Excess generation totals 13,448 MWh/yr, with a renewable fraction of 83.7%, indicating strong export potential. At Al-Kufra, wind supplies 45.0% (436,567 MWh/yr), PV 38.9% (377,705 MWh/yr), and the grid 16.1% (156,417 MWh/yr). With a 508,633 MWh/yr load, excess generation is 459,040 MWh/yr, resulting in a renewable fraction of 69.2%, with opportunities for export, storage, or hydrogen production. At Ghadames, wind provides 95.5% (30,199 MWh/yr), and the grid 4.03% (1,435 MWh/yr), matching the 31,634 MWh/yr load exactly. The renewable fraction is 95.5%, indicating optimal sizing and minimal grid dependency. These findings demonstrate the technical feasibility and economic viability of HRES deployment at GMMR wellfields. Performance variations reflect site-specific factors, such as renewable resource availability, system capacity, and load demand, highlighting the importance of optimization for reliable, cost-effective energy delivery and reduced emissions.

**Table 4 Sarir wellfield annual load profile**

Sarir wellfield								
Production			Consumption			Quantity		
Systems	KWh/yr	(%)	Load	KWh/yr	(%)		KWh/yr	(%)
PV	4,813,280	13.6	AC	7,871,408	100	E. E	27,627,596	77.8
WT	29,275,137	82.4				R. F		
Grid	1,430,878	4.03				Max. R. P	1,560	81.8
Total				7,871,408	100			

**Table 5 Tazerbo wellfield annual load evolutions**

Tazerbo wellfield								
Production			Consumption			Quantity		
Systems	KWh/yr	(%)	Load	KWh/yr	(%)		KWh/yr	(%)
PV	11,562,932	72.9	AC	7,483,460	100	E. E	8,218,694	51.8
WT	-	-				R. F		42.5
Grid	4,306,433	27.1	Grid	26,443,176	77.9	Max. R. P		830
Total	15,869,365	100		7,483,460	100			

**Table 6 Al-Hasouna wellfield annual load evolutions**

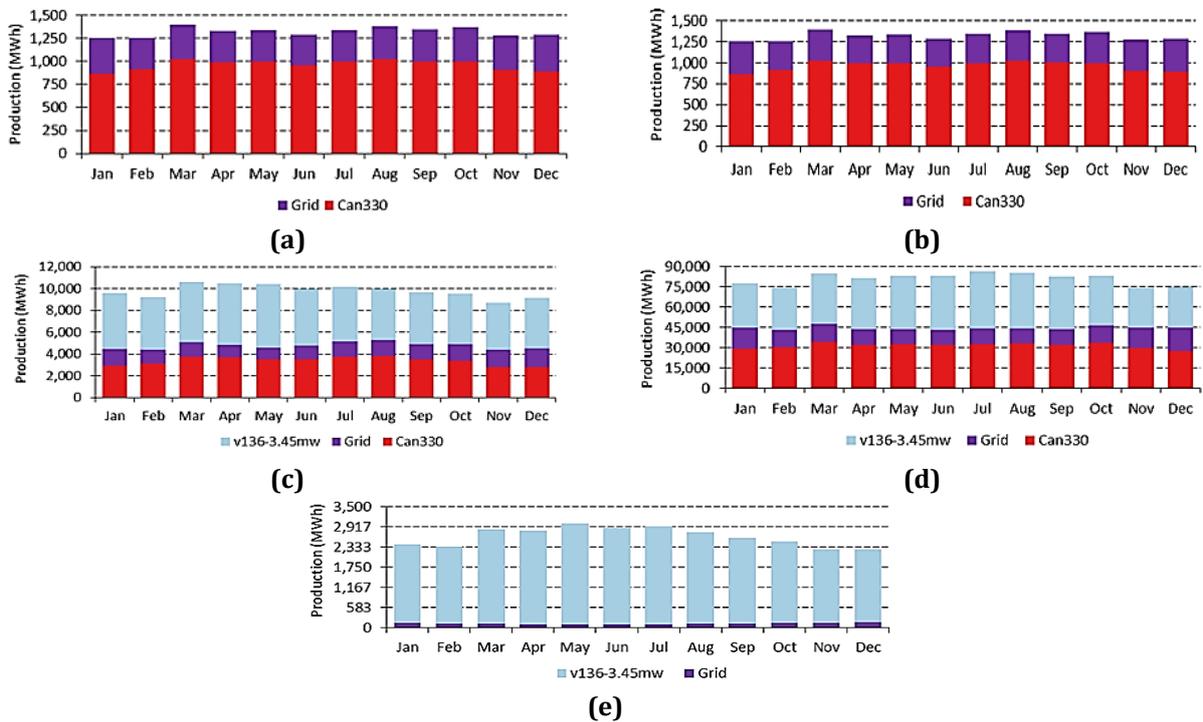
Al-Hasouna wellfield								
Production			Consumption			Quantity		
Systems	KWh/yr	(%)	Load	KWh/yr	(%)		KWh/yr	(%)
PV	40,468,531	34.4	AC	7,871,408	23	E. E	13,448,33	11.4
WT	60,301,161	51.3				R. F	95.8	83.7
Grid	16,770,926	14.3	Grid	45,514,015	44	Max. R. P		250
Total	117,540,617	100		102,741,270	100			

**Table 7** Al-Kufra wellfield annual load evolutions

Al-Kufra wellfield								
Systems	Production		Load	Consumption			Quantity	
	KWh/yr	(%)		KWh/yr	(%)		KWh/yr	(%)
PV	377,705,007	38.9	AC	508,633,340	100	E. E	459,040,231	47.3
WT	436,566,937	45.0	Grid	-	-	R. F		69.2
Grid	156,416,946	16.1				Max. R. P		674
Total	970,688,890	100		508,633,340	100			

**Table 8** Ghadames wellfield annual Load evolutions

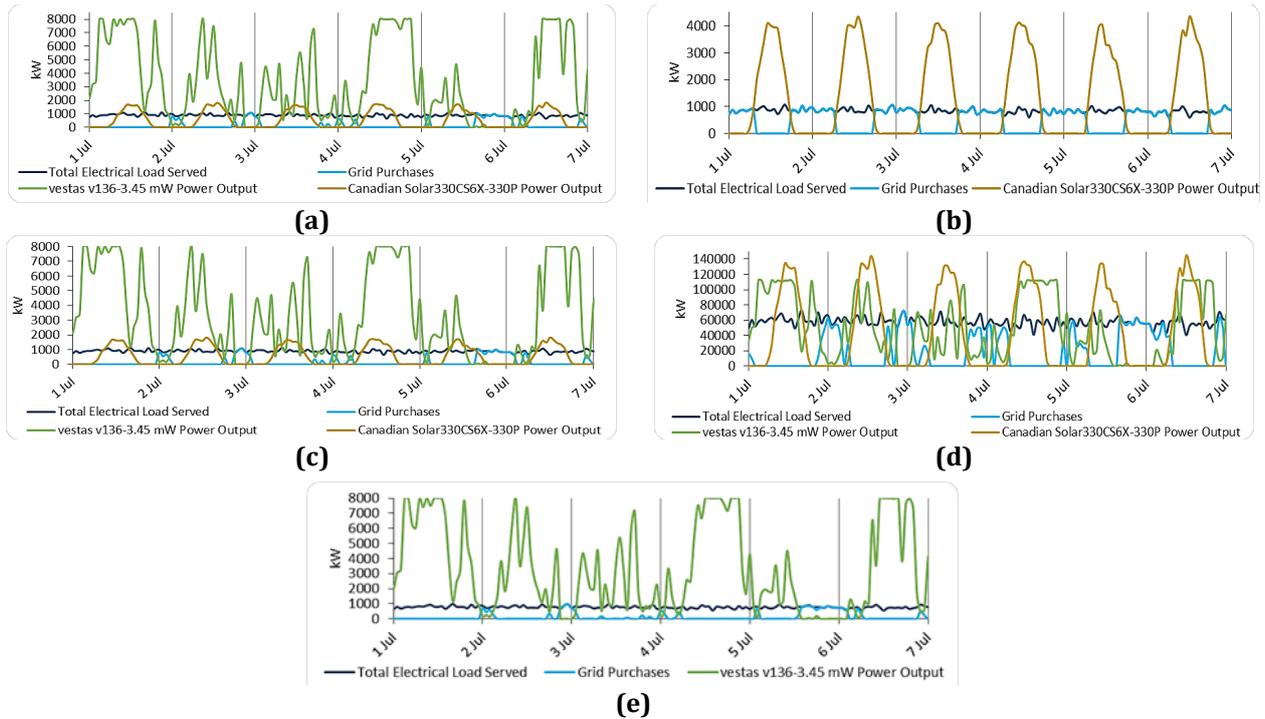
Ghadames wellfield								
Systems	Production		Load	Consumption			Quantity	
	KWh/yr	(%)		KWh/yr	(%)		KWh/yr	(%)
PV	-	-	AC	6,818,032	21.6	E. E	0	0
WT	30,199,041	95				R. F	95.8	95.5
Grid	1,435,007	4	Grid	24,816,016	78.4	Max. R. P		100
Total	31,634,048	100		31,634,048	100			



**Fig. 6** Monthly electricity production of the optimal HRES configuration for the GMMR wellfields (a) Sarir; (b)Tazerbo; (c) Al-Hasouna; (d) Al-Kufra; (e) Ghadames

### 3.2 Temporal Dispatch and Load Matching Across Wellfields

Electric power systems must handle rapid demand fluctuations due to weather and time variations. Fig. 7 shows a one-week July time-series for all GMMR wellfields, illustrating the dynamic interaction of wind turbines (Vestas V136-3.45 MW), PV (Canadian Solar 330CS6X-330P), and the grid in meeting total load. As renewable output increases, particularly from wind and PV, grid reliance decreases, demonstrating effective prioritization of renewables. At every timestep, the combined wind, solar, and grid supply matches the load, ensuring zero unmet power. This balance, observed across all sites, highlights the system’s technical robustness and operational flexibility, providing reliable energy year-round to support uninterrupted GMMR water delivery.



**Fig. 7** One-week time series analysis of proposed systems across GMMR wellfields (a) Sarir; (b) Tazerbo; (c) Al-Hasouna; (d) Al-Kufra; (e) Ghadames

### 3.3 Economic Assessment

The techno-economic evaluation identified the most feasible configurations for each wellfield, considering both technical and economic factors. Using HOMER Pro, grid-connected PV/wind hybrids were modeled with hourly simulations and ranked by Net Present Cost (NPC). The analysis also considered Levelized Cost of Energy (LCOE), operating costs, renewable fraction, and emissions. Two grid price schedules were applied: \$0.0301/kWh (off-peak) and \$0.22/kWh (peak), with no revenue from exporting surplus electricity, in line with current policy. The study prioritized supply security during shutdowns and blackouts, evaluating hybrid systems with firm grid interconnection. Optimal configurations and metrics (NPC, OPEX, LCOE) for all wellfields are shown in Table 9.

The results demonstrate clear benefits for hybrids over grid-only options. At Al-Kufra, the optimized hybrid achieves an LCOE of \$0.095/kWh and NPC of \$687 million, compared to \$0.220/kWh and \$1.58 billion for the grid-only case. Similar trends are observed at Al-Hasouna, Sarir, and Ghadames, with significant reductions in both capital and operating costs under hybrid designs. Tazerbo’s LCOE is \$0.139/kWh, significantly lower than the grid-only scenario. Overall, PV/wind-grid hybrids consistently lower energy costs, lifecycle expenditures, and improve economic sustainability for GMMR water-supply operations.

**Table 9** Economic evaluation for optimized systems in GMMR wellfields

GMMR Wellfield	R.F (%)	System configuration (Ideal Solution)					System component			Economic parameters		
							PV (kw)	WT (kw)	Conv (kw)	NPC (\$)	LCOE (\$/kwh)	O&M (\$/yr)
Sarir	81.8					2,519	1	1,154	\$13.7M	\$0.123	\$501,464	
	0					-	-	-	\$24.4	0.22	\$1.73M	
Tazerbo	42.5					5,894	-	1,161	\$15.7	\$0.139	\$982,197	
	0					-	-	-	\$23.2M	\$0.220	\$1.65M	
Al-Hasouna	70.7					23,641	2	8,804	\$88.5M	\$0.110	\$4.89M	
	0					-	-	-	\$177M	\$0.22	\$12.6M	
Al-Kufra	69.2					198,400	14	73,585	\$687M	\$0.095	\$34.6M	
	0					-	-	-	1.58B	\$0.220	\$112M	
Ghadames	79.0					-	1	-	\$12.5M	\$0.120	\$484,501	
	0					-	-	-	\$21.1M	\$0.220	\$1.50M	
Total cost		Base							817 M	0.11	41.5 M	
		HRES							1.83 B	0.22	129 M	
Overall Saving									1.013 B	0.12	87.5 M	

### 3.4 Cash Flow Analysis and NPC Structure of Optimized HRES Across Wellfields

The integrated cost analysis provides insight into the economic structure of the hybrid renewable energy systems (HRES) for the GMMR wellfields. Cost components vary significantly across sites, driven by differences in energy demand, system sizing, and contributions from solar PV, wind, and grid connectivity. The cash flow analysis reveals distinct investment and operating patterns. Al-Kufra has the highest financial burden, with large initial capital and significant replacement costs around year 20, partly offset by salvage recovery. Ghadames has moderate capital expenditure and limited replacement needs, making it the most stable site. Sarir and Jabal Al-Hasouna require about \$6.6 million in capital investment and annual O&M costs of \$456,000, with mid-term replacements and salvage of ~\$2.8 million at year 25, making them moderately attractive financially. Tazerbo shows high volatility, with a \$35.7 million replacement cost in year 20, partially offset by a \$26.8 million salvage value, indicating long-term viability despite mid-life expenditures. These results align with optimization outcomes based on NPC and LCOE. Ghadames, Sarir, and Al-Hasouna are more favourable due to balanced replacement schedules and salvage recovery, while Al-Kufra and Tazerbo rank lower due to higher volatility and replacement costs. Overall, hybrid system viability depends on renewable resource potential and effective life-cycle cost management, especially replacement planning and salvage optimization. The cumulative discounted cash flow patterns in Figs. 8 to 12 highlight these differences and provide a visual confirmation of the comparative economic performance.

Fig. 13 illustrates the cumulative discounted cash flow (CDF) profiles for all five GMMR wellfields, comparing the Base and Proposed Systems over the 25-year project horizon. Ghadames, Sarir, and Al-Hasouna show moderate, stable cumulative losses, reflecting balanced capital investment, predictable O&M costs, and manageable mid-life replacements. Tazerbo experiences a pronounced mid-life spike in replacement costs around year 20, partially offset by end-of-life salvage, while Al-Kufra exhibits the highest cumulative losses due to very large initial investments and heavy replacement requirements. Overall, the proposed hybrid system reduces cumulative losses compared to the base system across all wellfields. This highlights the improved economic performance and more efficient life-cycle cost management achieved through the integration of renewable energy, confirming the economic viability of hybrid systems for the GMMR wellfields.

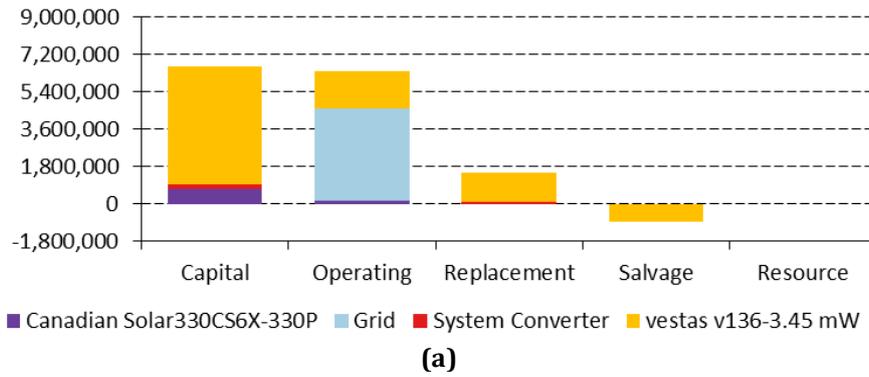


Fig. 8 (a) NPC of the proposed HRES by cost type; (b) Corresponding cash flow summary for Sarir

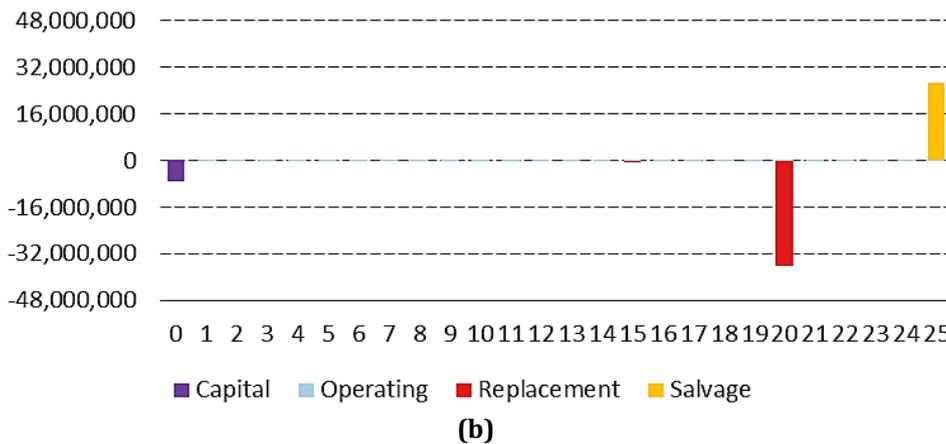
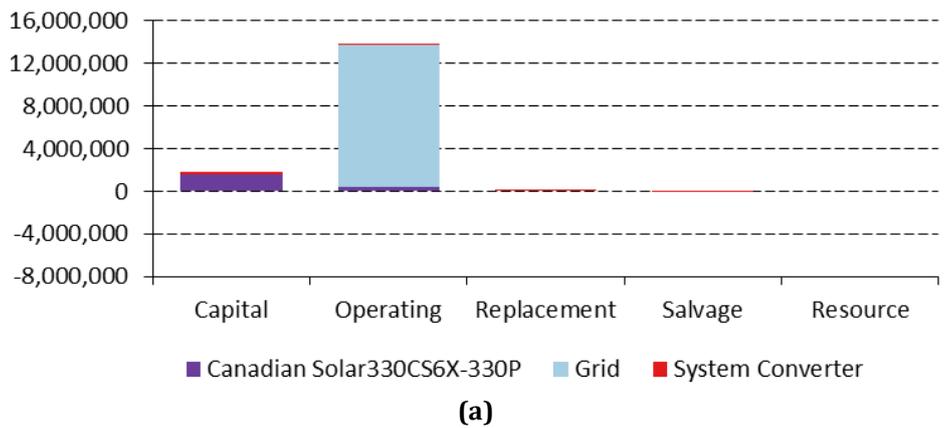


Fig. 9 (a) NPC of the proposed HRES by cost type; (b) Corresponding cash flow summary for Tazerbo

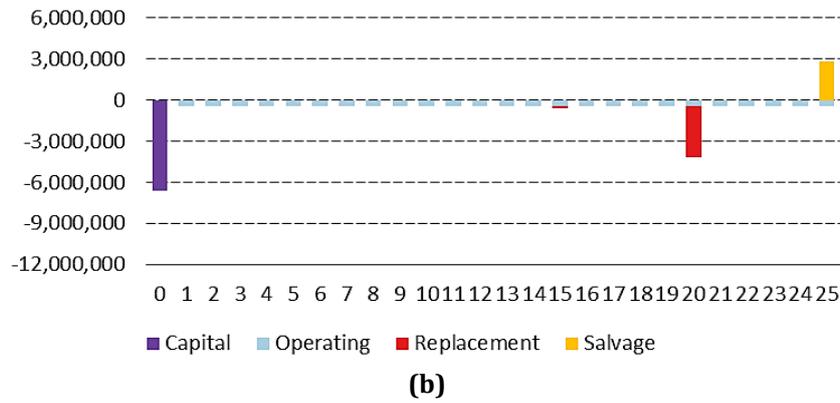
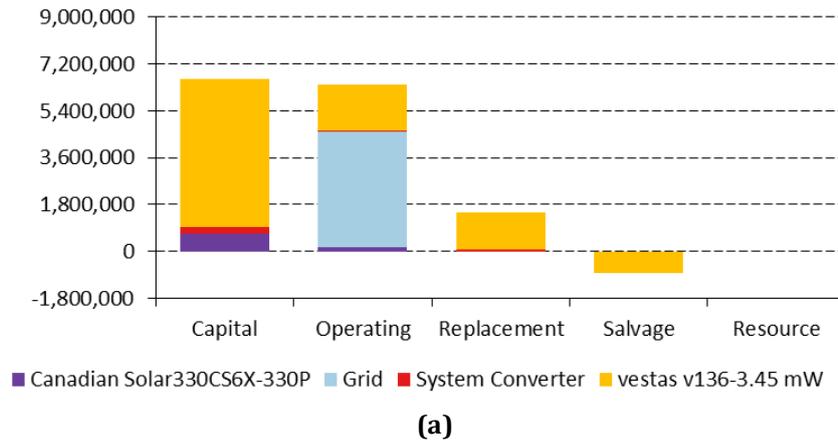


Fig. 10 (a) NPC of the proposed HRES by cost type; (b) Corresponding cash flow summary for Al-Hasouna

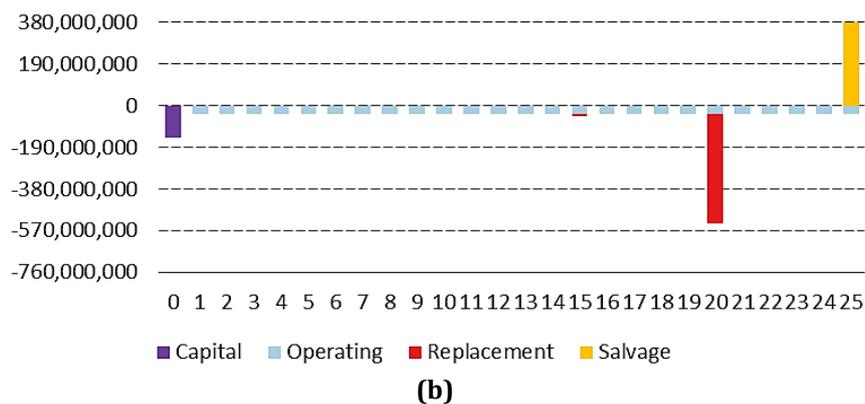
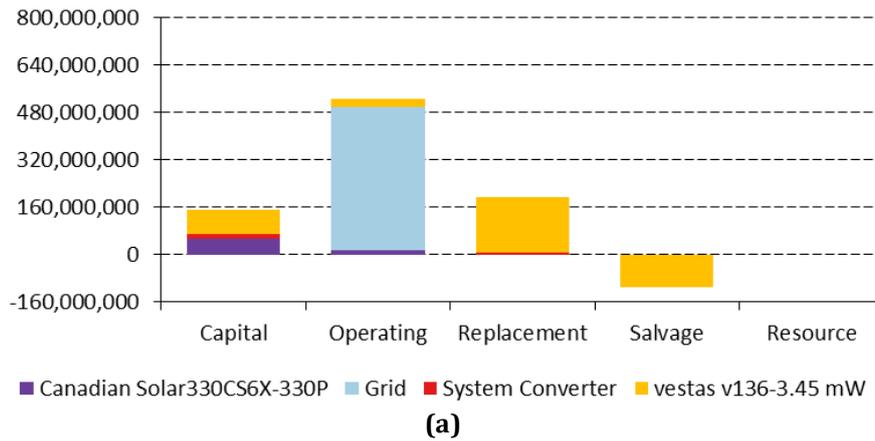


Fig. 11 (a) NPC of the proposed HRES by cost type; (b) Corresponding cash flow summary for Al-Kufra

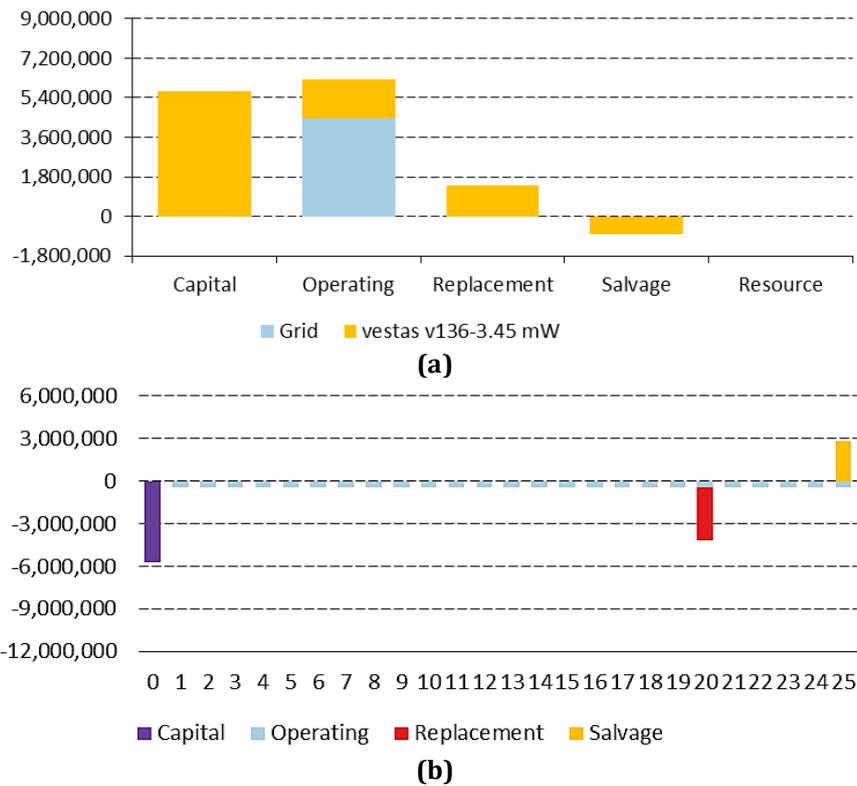


Fig. 12 (a) NPC structure of the proposed HRES by cost type; (b) Corresponding cash flow summary for Ghadames

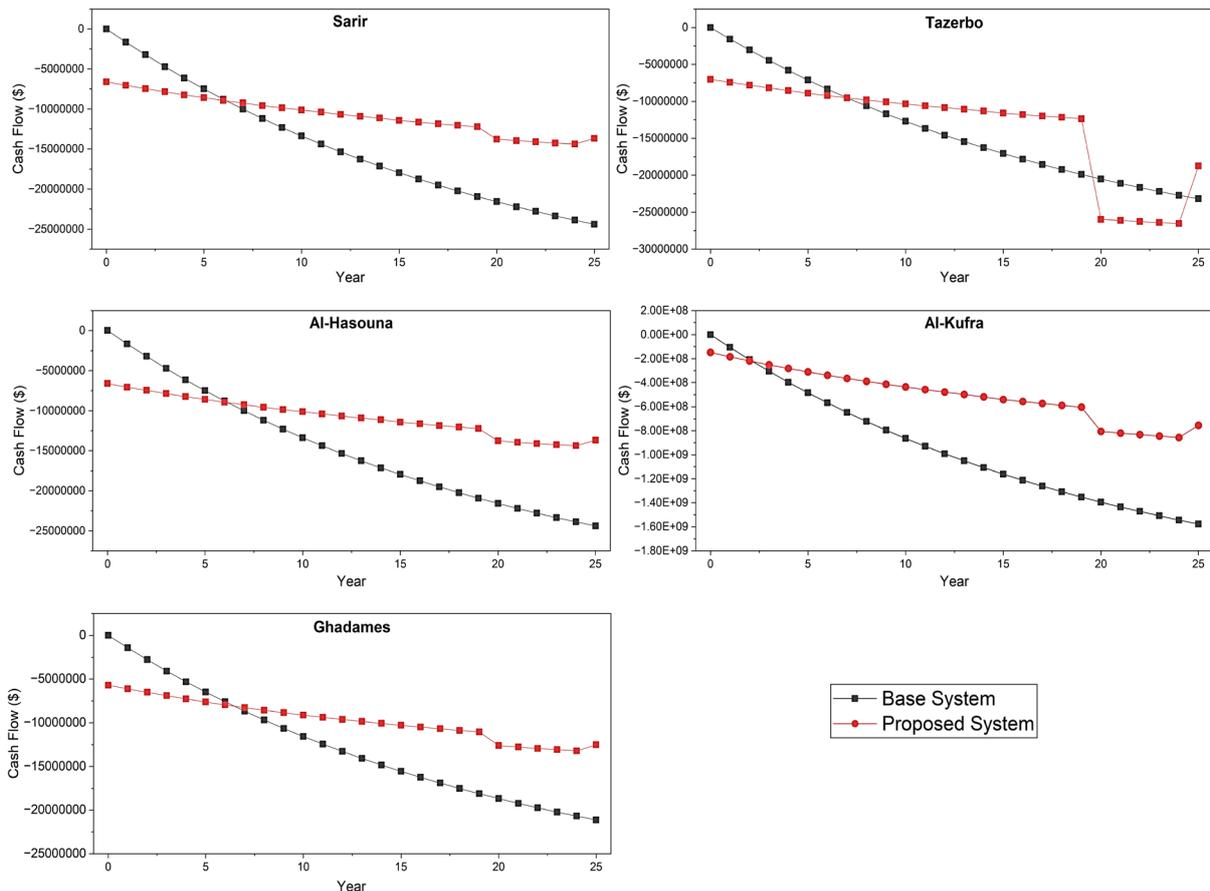


Fig. 13 Cumulative discounted cash flow profiles for GMMR wellfields over project lifetime

### 3.5 Environmental Assessment

Implementing hybrid renewable energy systems in the GMMR wellfields leads to significant reductions in environmental pollutants, as shown in Table 10. Emissions of CO<sub>2</sub>, SO<sub>2</sub>, and NO<sub>x</sub> are notably high in the conventional scenario, where electricity is supplied solely by fossil fuel plants. With the proposed hybrid configurations, annual CO<sub>2</sub> emissions decrease substantially at every wellfield. Total CO<sub>2</sub> emissions across all wellfields are reduced from 372,303,903 kg in the base case to 115,248,296 kg, a reduction of nearly 69%. These estimates, derived using HOMER's emissions model, highlight the environmental benefits of integrating PV and wind power with the grid, leading to lower greenhouse gas emissions and improved air quality. This supports the GMMR project's sustainability goals and demonstrates the broader potential of renewable energy in water and energy infrastructure.

**Table 10** Annual emissions comparison (Base vs. proposed systems)

		Wellfield system				
		Sarir	Tazerbo	Al-Hasouna	Al-Kufra	Ghadames
Carbon	Base	4,974,730	4,729,547	36,167,625	321,456,271	4,974,730
Dioxide	Proposed	904,315	2,721,666	10,599,225	98,855,510	2,167,580
Sulphur	Base	20,505	20,505	156,803	1,393,655	21,568
Dioxide	Proposed	3,921	11,800	45,952	428,582	9,397
Nitrogen	Base	10,028	10,028	76,685	681,569	10,548
Oxides	Proposed	1,917	5,771	22,473	209,599	4,596

### 3.6 Optimization Results

This section presents the optimization results for hybrid renewable energy systems (HRES) across five major GMMR wellfields. The analysis identifies configurations that meet energy demands while minimizing cost and environmental impact. HOMER was used for optimization, with Net Present Cost (NPC) as the primary ranking criterion, alongside Levelized Cost of Energy (LCOE), Renewable Fraction (RF), and carbon emissions. Results are ranked by NPC, with a baseline grid-only scenario for comparison. The findings, summarized in Tables 11 to 15, demonstrate the technical and economic potential of hybrid PV/wind-grid systems, with significant cost savings, reduced emissions, and improved sustainability. For Sarir, the optimized configuration includes a 2,519-kW PV array, one wind turbine, and a 1,154-kW converter. This setup achieves a low COE of \$0.0283/kWh, a high RF of 95.8%, and a reduction of approximately -15.78 million kg CO<sub>2</sub>/year. The total NPC is \$13.7 million, with a short payback period of 5.2 years. A secondary configuration (Rank 2) with diesel shows slightly higher COE and emissions but maintains an RF above 94%. A less favorable scenario (Rank 6) with diesel shows a reduced RF of 49.6%, higher COE of \$0.143/kWh, and positive CO<sub>2</sub> emissions (~2.17 million kg/year). For Tazerbo, the configuration includes a 3,952-kW PV array and one wind turbine. The COE is \$0.0392/kWh, RF is 96.2%, and the system offers a good balance between sustainability and cost. Ghadames has the lowest NPC (\$12.5 million) and COE (\$0.0281/kWh), relying on a single wind turbine and grid connection, achieving 95.5% RF and significant emission reductions.

**Table 11** Optimization result for Sarir wellfield

Scenario	Architecture					Cost			System	
	PV (kW)	Wt	DG (KW)	Grid (kW)	Conv (kW)	NPC (\$)	LCOE (\$/kWh)	O&M (\$/yr)	R. F (%)	(PBP) (yr)
	2,519	1		999,9	1,154	13.7M	0.123	501,464	81.8	5.2
	-	1	20,700	999,9	-	13.7M	0.124	568,414	76.9	4.7
	2,519	1	20,700	999,9	1,154	15.1M	0.137	462,649	81.8	6.8
	-	1	20,700	999,9	-	15.2M	0.137	529,599	76.9	6.4
	6,540		20,700	999,9	1,218	16.6M	0.149	1.03M	42.6	2.9
	-	-	-	999,9	-	24.4M	\$0.22	\$1.73M	0	-

By contrast, the wellfields of Al-Hasouna and Al-Kufra require larger systems. Al-Hasouna's top configuration includes 23,641 kW of PV and two wind turbines, achieving an RF of 83.7%, with the highest financial returns (IRR 43%, ROI 36%) and a short payback of 2.3 years, despite a higher NPC of \$88.5 million. Al-Kufra uses 196,400 kW

of PV and 14 wind turbines, achieving an RF of 81.2%, CO<sub>2</sub> reduction of 104 million kg/year, and the shortest payback period (2.0 years) despite an NPC of \$687 million. Importantly, diesel generators were excluded from all optimal configurations, indicating that hybrid PV/wind-grid systems provide a more cost-effective and sustainable solution. This supports the transition to cleaner, renewable-based energy infrastructure for the GMMR wellfields.

**Table 12 Optimization result for Tazerbo wellfield**

Scenario	Architecture					Cost			System	
	PV (kW)	Wt	DG (KW)	Grid (kW)	Conv (kW)	NPC (\$)	LCOE (\$/kWh)	O&M (\$/yr)	R. F (%)	(PBP) (yr)
   	5,894		-	999,9	1,161	15.7M	0.139	982,197	42.5	2.8
 		1	-	999,9	-	18.5M	0.175	908,237	76.5	5.0
   	3,952	1	-	999,9	1,190	15.7M	0.178	832,522	82.6	5.8
	-	-	-	999,9	-	23.2M	0.220	1.65M	0	-

**Table 13 Optimization result for Al-Hasouna wellfield**

Scenario	Architecture					Cost			System	
	PV (kW)	Wt	DG (KW)	Grid (kW)	Conv (kW)	NPC (\$)	LCOE (\$/kWh)	O&M (\$/yr)	R. F (%)	(PBP) (yr)
   	23,641	2	-	999,9	8,404	88.5M	0.11	4.89M	70.7	2.3
 	-	2	-	999,9	-	95.2M	0.118	5.94M	61.1	1.5
   	23,538	2	20,700	999,9	8,258	102M	0.127	4.27M	70.6	4.8
 	-	2	20,700	999,9	-	108M	0.134	5.26M	61.1	4.4
	-	-	-	999,9	-	177M	0.22	12.6M	0	-

**Table 14 Optimization result for Al-Kufra wellfield**

Scenario	Architecture					Cost			System	
	PV (kW)	Wt	DG (KW)	Grid (kW)	Conv (kW)	NPC (\$)	LCOE (\$/kWh)	O&M (\$/yr)	R. F (%)	(PBP) (yr)
   	198,400	14	-	999,9	73,585	687M	0.095	34.6M	69.2	1.8
   	196,345	12	20,700 x3	999,9	68,984	691M	0.096	35.7M	68.2	2.4
   	196,542	13	20,700	999,9	69,705	718M	0.073	46.3M	71.8	2.3
 	196,542	13	20,700	999,9	73,577	829M	0.075	51.1M	76.0	2.3
	-	-	-	999,9	-	1.58B	0.22	112M	0	-

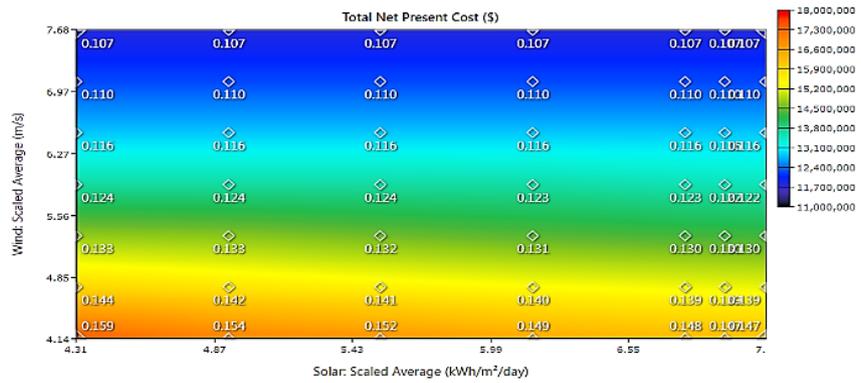
**Table 15 Optimization result for Ghadames wellfield**

Scenario	Architecture					Cost			System	
	PV (kW)	Wt	DG (KW)	Grid (kW)	Conv (kW)	NPC (\$)	LCOE (\$/kWh)	O&M (\$/yr)	R. F (%)	(PBP) (yr)
 		1	-	999,9		12.5M	0.120	0.48M	79.0	5.4
   	1,574	1	-	999,9	859	12.7M	0.133	0.45M	81.6	5.8
  	5,838	-	-	999,9	1,052	14.8M	0.154	0.92M	40.9	3.1
	-	-	-	999,9		21.1M	0.220	1.50M	0	-

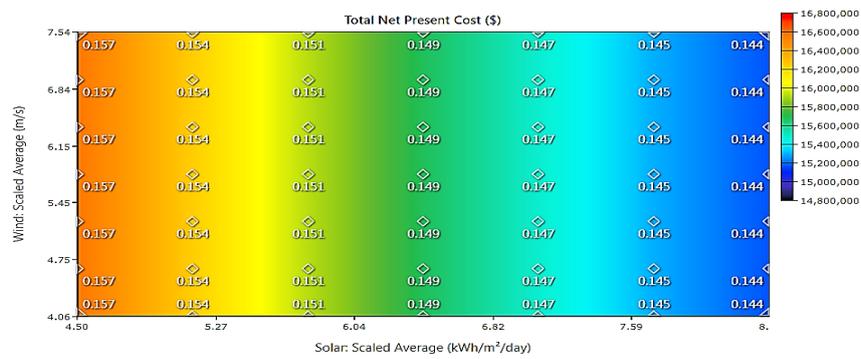
### 3.7 Sensitivity Analysis

Sensitivity analysis was conducted across all wellfields, varying solar irradiance, wind speed, and diesel prices by ±30% from baseline. This analysis quantified impacts on NPC, LCOE, and feasibility, aiding in risk-aware planning.

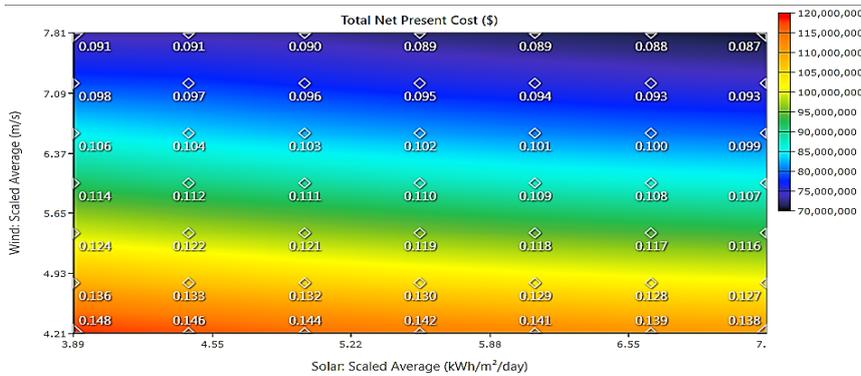
Diesel generators were never selected in optimal solutions, even with diesel price variations, confirming the cost-robustness of PV/wind-grid hybrids. As shown in Fig. 14, higher solar irradiance and wind speed reduce NPC and LCOE by increasing renewable yield and reducing grid dependence. Sensitivities are configuration-specific: Tazerbo (PV-only) shows NPC and LCOE sensitivity to irradiance but minimal sensitivity to wind, while Ghadames (wind-dominant) responds mainly to wind. At Sarir, Al-Hasouna, and Al-Kufra, both solar and wind reduce costs, with the greatest gains from increases in both resources. These results highlight the importance of site-specific resource assessment and hybrid sizing. However, the increase in solar irradiance or wind speed raises annual electricity production and renewable fraction, reducing grid reliance and improving sustainability. In locations like Al-Hasouna and Sarir (high irradiance, moderate winds), the renewable fraction approaches its maximum, reducing dependence on conventional power. Lower solar or wind availability reduces production and increases operating costs. Sensitivities align with optimized configurations: solar-only systems (e.g., Tazerbo) are sensitive to irradiance, wind-dominant systems (e.g., Ghadames) respond to wind speed, and mixed systems (e.g., Sarir, Al-Hasouna, Al-Kufra) benefit from both resources. These findings underscore the need for tailored hybrid sizing to maximize renewable energy use, stabilize the renewable fraction, and control energy costs.



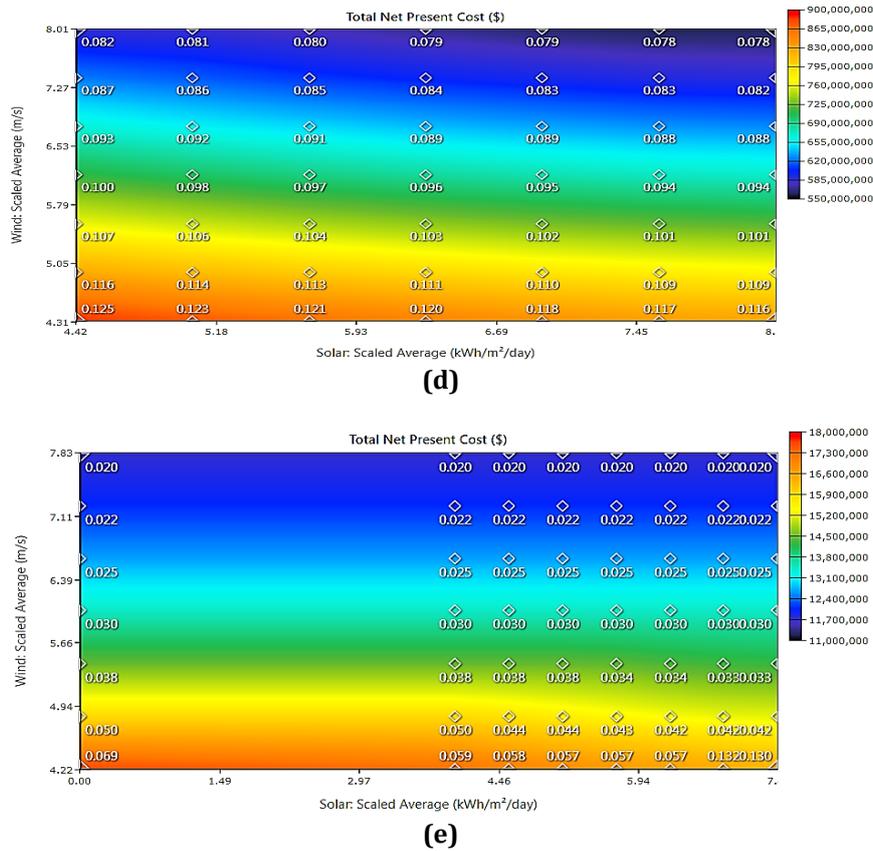
(a)



(b)



(c)



**Fig. 14** Solar radiation and wind speed variations versus the NPC And LCOE, For GMMR wellfields (a) Sarir; (b) Tarzebo; (c) Al-Hasouna; (d) Al-Kufra; (e) Ghadames

#### 4. Conclusions

This study assessed the techno-economic and environmental feasibility of hybrid PV/wind/grid-connected systems for Libya’s Great Man-Made River (GMMR) wellfields using HOMER Pro. Results show that large-scale renewable integration is technically viable and delivers substantial economic and environmental gains for critical water infrastructure amid grid instability and fossil-fuel dependence. Across Sarir, Tazerbo, Al-Hasouna, Al-Kufra, and Ghadames, abundant solar and/or wind resources enable high renewable penetration. HOMER optimizations consistently excluded diesel generation because of higher costs and emissions. The best-performing systems combine PV, wind, and grid interconnection, tailored to local resources. Net Present Cost (NPC) falls markedly under hybrid designs (e.g., large reductions at Al-Kufra and Al-Hasouna), Levelized Cost of Energy (LCOE) is well below the grid-only tariff (\$0.22/kWh), and payback periods are short (2.0-5.2 years). Renewable fractions range from about 70% to 94%, with large CO<sub>2</sub> reductions (up to ~70%) and lower SO<sub>2</sub>/NO<sub>x</sub>, and sensitivity analyses confirm further NPC/LCOE improvements with higher irradiance or wind speeds. Optimal architectures are site-specific, PV-dominant at Tazerbo (no wind), wind-dominant at Ghadames (no PV), and mixed PV/wind at Sarir, Al-Hasouna, and Al-Kufra.

In addition to these techno-economic indicators, the energy production analysis confirms that hybrid configurations reliably meet wellfield electricity demand with stable seasonal generation and high renewable fractions. Several sites also produce significant surplus electricity, creating opportunities for grid export, storage, or hydrogen production, thereby reinforcing both energy security and long-term sustainability. Meeting loads with PV/wind–grid hybrids also create the prospect of exporting surplus electricity to the national grid, contingent on future feed-in tariffs or sell-back rates. In this analysis, no revenue from exports is assumed (reflecting current Libyan policy), so neither NPC nor energy-cost results include potential income from grid sales. While NPC and LCOE will rise with higher demand, future sell-back mechanisms indexed to utility prices could partially offset these increases when loads are stable, highlighting the role of tariff design in maximizing the economic benefits of hybrid renewable systems.

Overall, the GMMR wellfields possess excellent solar and wind resources. Incorporating site-resolved wind and irradiance profiles strengthens the case for hybrid PV/wind–grid systems as cost-effective, sustainable, and technically robust power solutions for essential water infrastructure. Clear policies, feed-in tariffs, grid-access rules, and bankable interconnection standards, are needed to unlock full value, enhance energy and water

security, and de-risk investment. The evidence supports immediate, strategic adoption of hybrid renewables for Libya's water sector, positioning the Great Man-Made River Project as a model for sustainable energy-water integration in arid regions worldwide.

## Acknowledgment

Communication of this research is made possible through monetary assistance by Universiti Tun Hussein Onn Malaysia and the UTHM Publisher's Office via Publication Fund E15216.

## Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

## Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Mohammed Ogab, Djamel Hissein Didane; **data collection:** Mohammed Ogab; **analysis and interpretation of results:** Sofian Mohd, Djamel Hissein Didane; **draft manuscript preparation:** Faisal A. Mohamed, Djamel Hissein Didane. All authors reviewed the results and approved the final version of the manuscript.

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