ENERGY MANAGEMENT OPTIMIZATION BASED ON FACILITIES LAYOUT PLANNING FOR PORT CONSTRUCTION: MEDITERRANEAN REGION CASE STUDY

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1. **ABSTRACT:** The construction industry is one of the largest sectors in the world economy, but it suffers from a lot of problems, most of them related to construction project management, like cost, productivity, safety, schedule, site layout, and environmental impact. Sustainable development and climate change are global challenges that must be protected from the impact of construction, especially ports. In this approach, this research has to focus on the ports, which contain all kinds of activities, buildings, and facilities. As a result, ports rank among the most environmentally impactful constructions. The emission of carbon dioxide (CO2), sulphur oxides (SO2), and nitrogen oxides (NO2) from ports has a key impact on climate change and the greenhouse effect; consequently, the solution to this problem is using clean energy through construction facility layout management in ports. The aim of this research is to convert an existing port to a green port through energy savings using solar and wind energy using Homer software to obtain an optimal port construction facility layout with minimum cost, area, and gas emissions. This case study takes place in the Mediterranean region using Homer software to obtain ten hybrid renewable energy systems, each producing 1000 kwh, and then calculate the area needed for each one. This case uses all the results of cost, area, and carbon emissions on SPSS to validate and get the optimal construction facility layout. The final selection indicates that PV, converter, or battery is the optimal HRES for the selected region, which provides the minimum cost of energy, which saves 70% more than the other scenarios and also saves around 85% of the area required by its alternatives. Since there are no carbon emissions in this scenario, the research concludes that it offers the best environmental protection.

2. INTRODUCTION

Rapid growth in construction projects has significantly contributed to economic growth and social requirements, including infrastructure and ports. However, these projects also generate significant construction waste, consuming resources excessively and negatively impacting the environment. The most neglected branch of construction management is site layout, which often overlooks environmental impacts. Ports are crucial institutions that provide effective services to facilitate the global economy, encompassing various construction types and activities. Seaports are thought to be accelerators for a region's social, economic, and geographic development. They include logistics, distribution, trade, industry, and transportation, and they are "city-genic" and "region-genic" in terms of spatial development was also conducted by Montwill *et al*., [1]. Port superstructure (cargo handling equipment, port rolling stock, warehouses, storage yards, and other equipment and auxiliary facilities) and port infrastructure (port water basins, port premises, transport system, networks, and nodes) are examples of the infrastructure and port services that are traditionally provided by seaports. Seaports undergo constant change as a result of worldwide trends and economic shifts. Another important factor is the way that environmental responsibility and comprehensive protection are being approached and how the social landscape is changing was also conducted by Żukowska *et al*., [2]. Despite their beneficial contribution to economic growth, seaports have a pronounced detrimental effect on the urban environment, the natural environment, and the operational grounds—both on land and in the water. The ecology will be further threatened by the ports' continued expansion. Because of these growth-related realities, ports ought to take sustainability into account when developing and expanding their policies. When a ship is in port, it releases dust and toxic gases into the air. They contaminate soil and water as well. The linkage of the port with the hinterland causes noise, vibrations, congestion, and potential collisions and transport accidents was also conducted by Klopott *et al*., [3]. Port emissions have a significant impact on climate change, altering both the environment and economic activity. Sustainable development is crucial to addressing this issue. Green ports can reduce CO2 and local emissions, creating a healthier environment, especially in cities where respiratory diseases cause thousands of deaths annually.

The green port is a comprehensive concept to preserve the environment, including port buildings, energy sources, ships inside the berths, and the movement inside the port, which supports the sustainability concept. The World Port Sustainability Programme (WPSP) is a global initiative aimed at promoting sustainability in ports. It focuses on reducing emissions and pollution by implementing energy-saving measures like cold ironing, which supplies ships with clean energy sources. The WPSP goals include reducing pollutants, promoting good health and wellbeing, and promoting economic growth. Ports like Hamburg, Helsinki, and Genoa are implementing these projects, achieving various goals in climate and energy. Hamburg's off-shore power supply project aims to reduce pollutants by 383 t, while Genoa's project aims to achieve six goals. Helsinki's port aims to become 100% carbon neutral by 2035, reducing CO2 emissions in the entire harbour area. These projects contribute to the achievement of international climate goals and contribute to the green port concept. The research case study aims to achieve these goals following WPSP through port facility layout management.

In 2016, Juanrehinzadeh *et al*., [4] worked on optimizing renewable energy sources and storage systems to meet load demands and lessen reliance on fossil fuels. In this case, wind turbines, PV, micro turbines, batteries, and fuel cells are the optimal size for the city demands in Nain, Iran. The main reason they chose the optimal system was cost, without taking into account any other aspect. In 2017, Lata-García *et al*., [5] worked on two scaling approaches for a standalone hybrid generation system that are being investigated using fundamental equations, Simulink design, and a homer optimizer. In order to construct two systems, the best systems include hydrokinetic, PV, diesel generator, battery, and ac load. In 2018, Ahamad *et al*., [6] use a grid-connected MG encompassing PV, wind, battery, ac load, grid, and power converter as the ideal energy planning system for Copenhagen seaport, according to a case study conducted in Copenhagen, Denmark. According to this professional, the prevailing tendency was financial and environmental aspects, and none of the prior studies concentrated on the relevance of site layout and facility management in all aspects.

Facility management plays a crucial role in various business sectors, including construction and facilities. Green ports are increasingly being considered as a sustainable solution to environmental pollution. The construction of these ports involves the use of renewable energy sources like solar and wind energy. The management of these facilities is essential for maintaining the health of residents and the environment. The port layout should consider the space and cost of the port while considering the minimum space and maximum energy required for the operation of these facilities. Homer software is being utilized by the National Renewable Energy Laboratory of the US Department of Energy to convert idle ports into renewable energy plants. The National Renewable Energy Laboratory developed the software., which offers advanced modelling and optimization for microgrid systems. The research aims to convert existing ports to green ones by optimizing port construction facilities with minimal cost, area, and gas emissions.

3. METHODOLOGY.

3.1 Describe the study area and its location.

The study takes place in a port in the Mediterranean. The Mediterranean region has a good climate, especially from the east to the south, where wind and sun are plentiful most days of the year, making it appropriate for the production of renewable energy. Due to ships and other operations inside the port, this location produces a lot of hazardous gas emissions that create pollution and considerably contribute to global warming because of its strategic importance in marine transit and huge role in worldwide trade.

3.2 overview of study models.

The proposed study model's flow is shown in Fig. 1 in order to accomplish the study's objective. Three phases make up the study model: Stage 1: Utilize the Homer software to optimize energy production scenarios for 1000 kwh utilizing only renewable energy sources; Stage 2: Calculate the area needed for each hybrid renewable energy scenario; and Stage 3: Use statistical methods through SPSS software to compare all the outputs of cost, area, and carbon emissions in order to select the optimal site layout for the research region that achieves minimum cost, area, and carbon emissions.

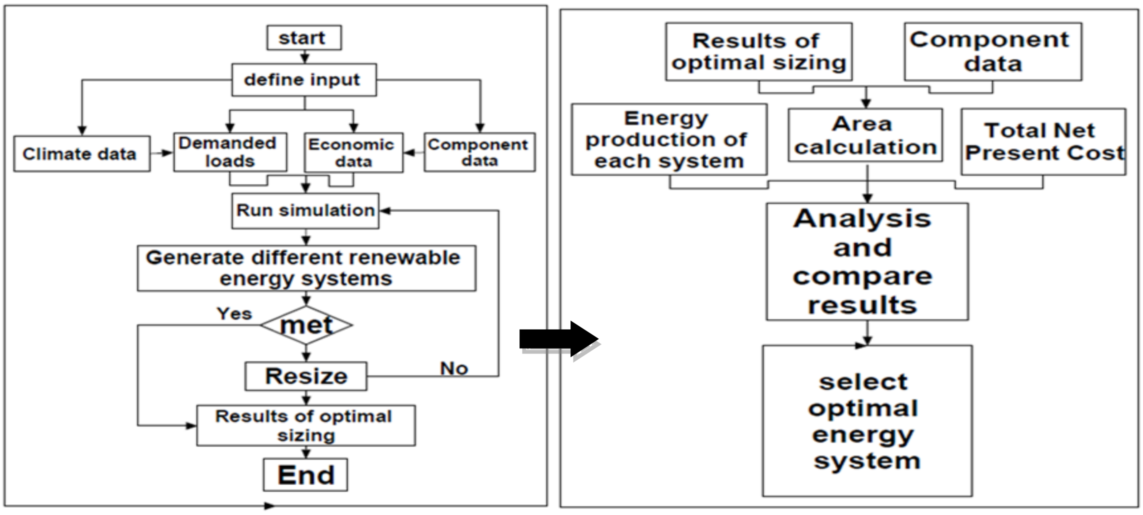

Figure 1: Flowchart showing the steps of the suggested study model.

3.3 Resources evaluation and load profile.

In this study's simulation, the load profile is depicted in Figure 2. This research is designed to produce a fixed amount of energy, so the load used is a uniform load with a scaled annual average of 1000 kwh. All of the meteorological information utilized in this simulation, including statistics on temperature, wind resources, and global horizontal irradiance (GHI), is from the NASA Worldwide Energy Resources Prediction (POWER) Database. Figures 3 (a), (b), (c), and (d) show the daily radiation readings. Most of the year is sunny with a long daylight period, especially in June and July. The annual average temperature of the study region is 21 C, and the annual average of radiation and clearness is 5.87 kwh/m2/day. the monthly average wind speed, which increases in January and February. The scaled annual average wind speed is 5.84 m/s.

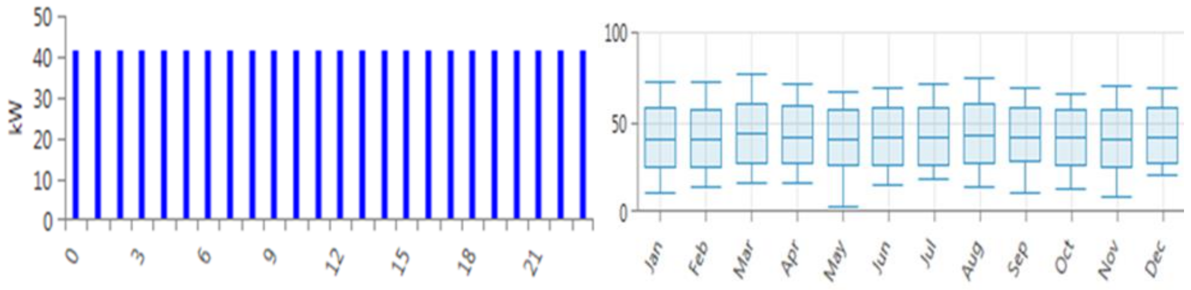

Figure 2: Load profile for the city (a) hourly AC load, (b) average for each month.

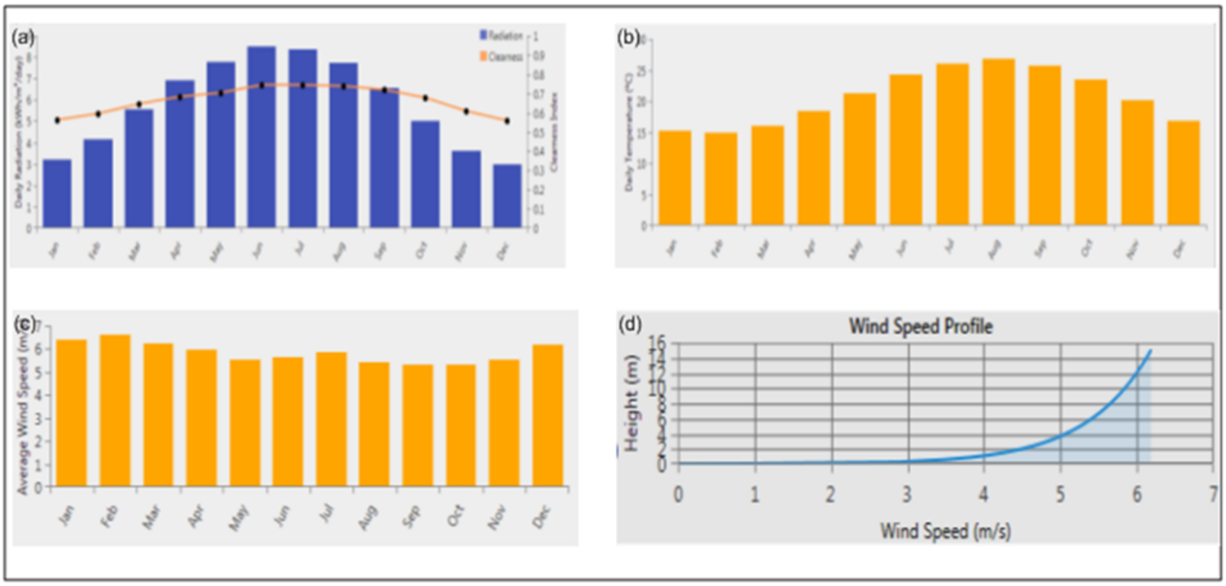

Figure 3: a) Average monthly daily clearance index and radiation, b) Average monthly daily temperature, c) Average monthly wind speed, d) wind speed profile

3.4 HOMER optimization and simulation.

Based on a reliable algorithm, the Hybrid Optimization of Multiple Energy Resources (HOMER) program supports the design of hybrid renewable energy systems for distributed, standalone, and distant generation and evaluates their techno-economic feasibility (Odoi-Yorke *et al*.,2022) [7]. By identifying the optimal equipment size and configuration, a simulation-based program known as HOMER is utilized to maximize the net present cost (NPC) of any integrated system was also conducted by Anida *et al.*, [8]. Equation (1) is used by the HOMER software to ascertain a PV array's output power.

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G}_T}{\overline{G}_{T,STC}} \right) \left[1 + \alpha_P \left(T_c - T_{c,STC} \right) \right] \qquad (1)$$

Where PV is the component of the system and YPV is the rated capacity of the PV array in kWh. The solar irradiation is expressed as GT (W/m2), the irradiation under standard testing circumstances is expressed as GT, ST C (W/m2), the coefficient of temperature is expressed as p (%) / ◦C, the cell temperature is expressed as Tc (◦C), and the PV cell temperature at standard conditions is expressed as Tc, ST C (◦C) was also conducted by Elnajjar *et al.*, [9].

HOMER uses a three-step process to determine the wind turbine's power output at each time step. Initially, HOMER measures the wind speed at the wind turbine hub height. The amount of electricity the wind turbine generates at that wind speed and standard air density is then calculated. Equations then illustrate how HOMER alters the power output value according to the real air density. (2) as well as (3):

$$U_{hub} = U_{anem} \cdot \left(\frac{Z_{hub}}{Z_{anem}} \right)^{\alpha} \qquad (2)$$

In this case, Zhub and Zanem represent the height of the anemometer and the wind turbine hub, respectively, in meters, Z0 represents the surface roughness; and Uanem is the average wind velocity as determined by the station anemometer in meters per second.

$$P_{WTG} = \left(\frac{\rho}{\rho_0} \right) \cdot P_{WTG,STP} \qquad (3)$$

In this case, ρ represents the real air density (kg/m3). The power output of a wind turbine at standard temperature and pressure (kWh) (1.225 kg/m3) is denoted by PWTG and STP, respectively.

The maximum power that the storage bank can discharge is calculated by HOMER. When assessing whether the storage component is capable of supporting the load independently, it takes into account the "maximum discharge power." Equation (4) gives the maximum power that the storage bank can release over a given period of time:

$$P_{batt,dmax,kbm} = \frac{-kcQ_{\max} + kQ_1 e^{-k\Delta t} + Qkc\left(1 - e^{-k\Delta t}\right)}{1 - e^{-k\Delta t} + c\left(k\Delta t - 1 + e^{-k\Delta t}\right)} \tag{4}$$

In this case, Qmax represents the total capacity [kWh] of the storage bank, c denotes the storage capacity ratio, t is the duration of the time step [h], k is the storage rate constant [h-1], and Q1 is the amount of power (in kWh) that was available in the storage component at the start of the time step.

HOMER calculates the maximum amount of power that the storage bank is capable of storing. It uses the maximum charge power provided by Equation (5) to determine things like whether the storage bank can take in all of the excess renewable energy available or how much extra power a cycle charging generator should output:

$$P_{batt,cmax,kbm} = \frac{kQ_1 e^{-k\Delta t} + Qkc\left(1 - e^{-k\Delta t}\right)}{1 - e^{-k\Delta t} + c\left(k\Delta t - 1 + e^{-k\Delta t}\right)} \tag{5}$$

Table 1. Hybrid renewable energy scenarios

scenario (s)	*hybrid renewable energy system*
s1	PV/converter/grid
s2	PV/converter/battery
s3	wind/converter/battery
s4	wind/grid
s5	50 % PV/50 % wind/battery/converter
s6	50 % PV/50 % wind/grid/converter
s7	25 % PV/ 75 % wind/battery/converter
s8	25 % PV/ 75 % wind/grid/converter
s9	75 % PV/ 25 % wind/battery/converter
s10	75 % PV/ 25 % wind/grid/converter

Table 2. Essential information for HOMER simulation and optimization summarized also conducted by Odoi-Yorke et al., [7].

Component	*Input parameters*	`
PV module	Rated capacity Footprint Capacity search space Temperature effect on power Operating temperature Module efficiency Derating factor Capital cost Replacement cost Operation and maintenance cost Life time	1 kw 1.627 m2 1 – 500 kw -0.42 %/◦c 25◦ 17.8% 80% 2540 USD/ kW 0 USD/ kW 10 USD/ kW/yr. 30 years
Wind Turbine	Rated capacity Rotor diameter Capacity search space Cut in speed Cut out speed Life time Capital cost Replacement cost Operation and maintenance cost Life time	3.3 kw 4.65 m 1-2 3 m/s 20 m/s 20 years 5000 USD 5000 USD 90 USD/year
Converter	Inverter and rectifier efficiency Capacity search space Lifetime Capital cost Replacement cost Operation and maintenance cost	95 % 0-2000 kw 15 years 300 USD/ kW 300 USD/ kW 5 USD/year
Battery	Nominal voltage Nominal capacity Capacity ratio Roundtrip efficiency Search space Lifetime Minimum state of charge Capital cost Replacement cost Operation and maintenance cost	12 V 1 kWh 0.403 80% 1-2000 10 years 40% 110 USD/ kW 110 USD/ kW 10 USD/ kW
Economics	Discount rate Expected inflation Project lifetime	16.75 % 25.80 % 20 ears

3.5 area calculations.

3.5.1 PV.

In each scenario, the research uses different amounts of PV units, but they are the same type from the same manufacturer with the same specification. From this specification, the footprint is measured in m^2, which means the area of land needed to produce 1 kwh.

3.5.2 Wind turbines.

In each scenario, the research uses different amounts of wind turbine units, but they are the same type from the same manufacturer with the same specification. From this specification, the rotor diameter (m) is used to calculate the area of a single wind turbine. This research arrays the wind turbines in each scenario. The distance between wind turbines is defined as 10 times the diameter along the wind direction and 3 times the diameter perpendicular to it, it was also conducted by Wu *et al*.,[10] and Bakeer *et al*.,[11].

4. RESULTS AND DISCUSSIONS.

The hybrid renewable energy systems' sizes were determined using the HOMER modelling program, which can handle the electrical load that was identified in this study, which is 1000 kwh. After that, the research calculates the area of each scenario, and then the research lists all the results to recognize the optimal scenario, which includes the lowest cost, minimum emissions, and area.

4.1 Economic results from Homer

The HOMER modelling program was used to calculate the sizes of the hybrid renewable energy systems using 10 scenarios with various components. Fig. 4 summarizes the total net present cost (NPC) results of the hybrid renewable energy scenarios and shows that the minimum total NPC of scenario number 4 (S4), which represents 1%, as it contains grid in its hybrid renewable energy system, is lower than the minimum total NPC of scenario number 2 (S2), which represents 7.5%, of those that contain batteries in their hybrid renewable energy system. And from this approach, this research can also look at Fig. 5: this research will find that the cost of energy refers to the same result as the previous figure, which refers to scenario number 4 (S4), Scenario number 2 (S2), representing 9%, has the lowest energy cost ($/kwh) when utilizing batteries, while scenario number 1, representing 0.1%, has the lowest energy cost ($/kwh) while using the grid.

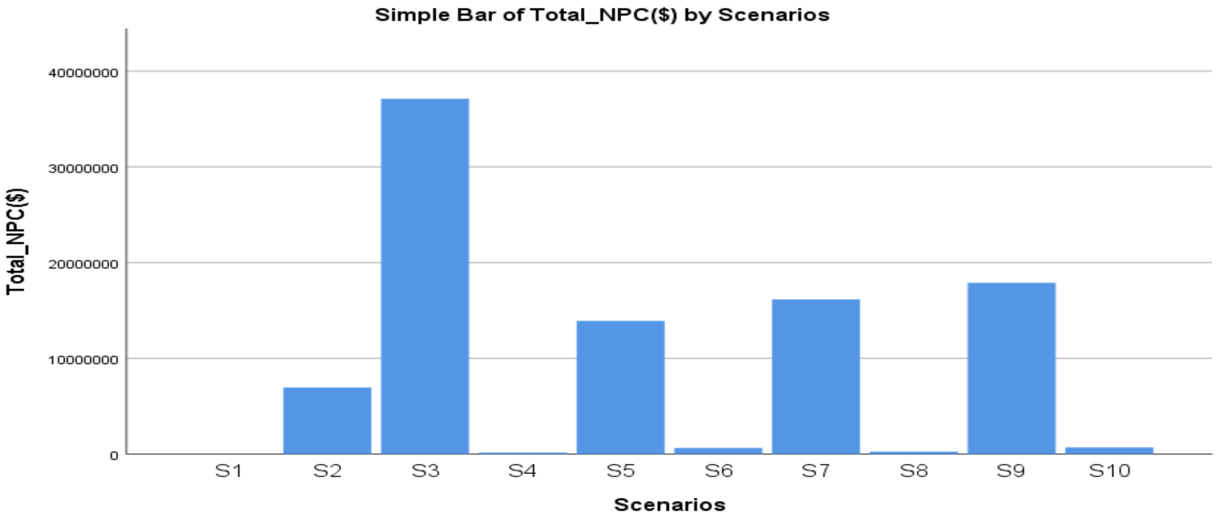

Figure 4 : chart of the total net present cost in the 10 scenarios

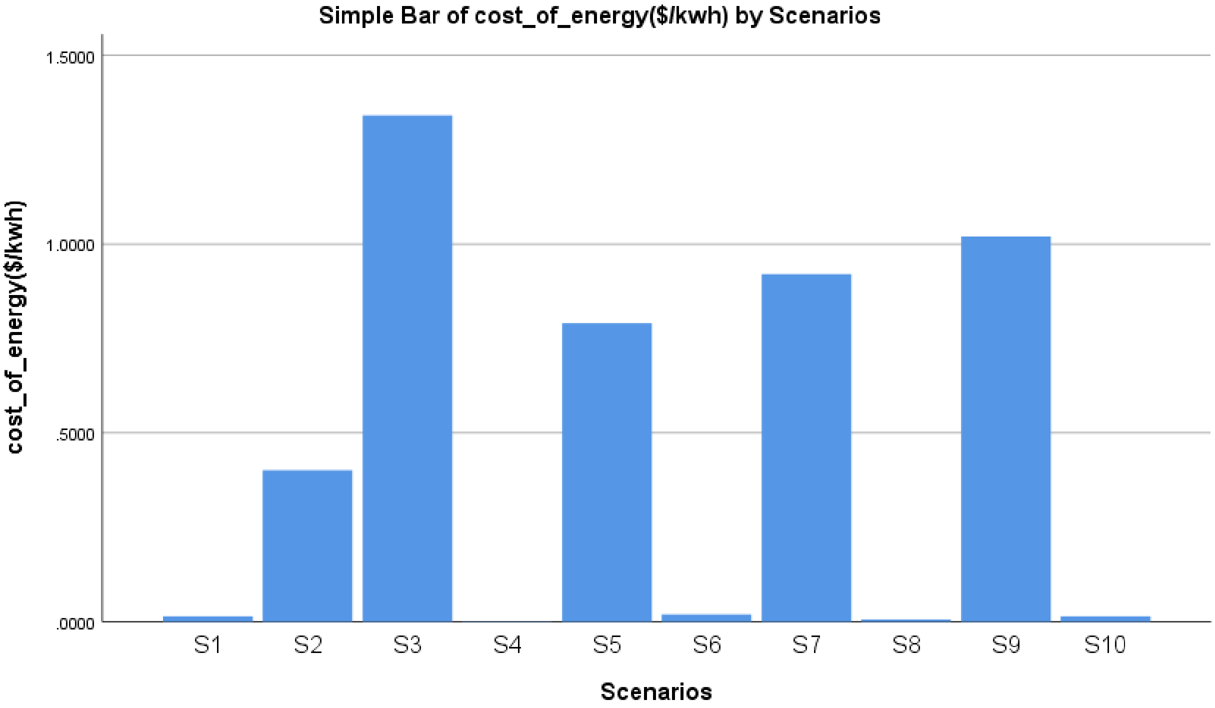

Figure 5 : chart of the cost of energy in the 10 scenarios

4.2 Environmental results from Homer

In this research, all scenarios use renewable energy sources as the region of the study has good weather most of the year, which gives the chance to use PV and wind turbines, which are the optimum solutions for carbon dioxide emissions, but in each scenario, the study uses a grid or battery system, which makes a difference in carbon emission percentage. Figure 6 depicts the annual carbon dioxide emissions for each scenario. Renewable energy scenarios that use batteries record zero emissions, but scenarios that use grids cause carbon dioxide emissions. In the shown figure, scenario no. 1 (S1) causes the minimum emissions to be 16% per year. The recent climatic conditions and the occurrence of many natural disasters around the world make the environment the first priority and of utmost importance for reducing carbon emissions.

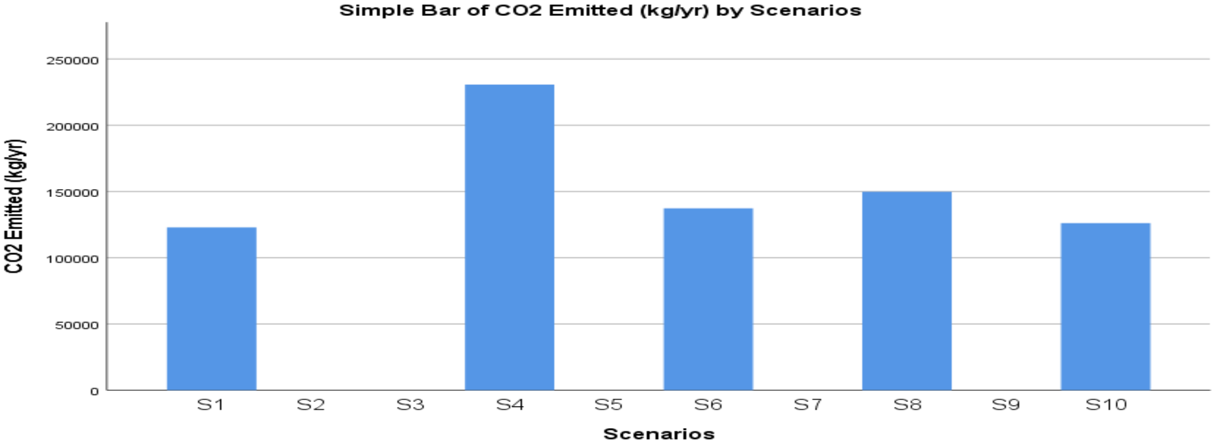

Figure 6 : chart of CO2 emitted in the 10 scenarios

4.3 Area results

One of the aims of this study is to obtain the optimum facility layout, taking into consideration the area of each scenario as one of the criteria for identifying the optimal renewable energy system that can be installed in the study region. Fig. 7 shows the slight difference between S1 and S2 in the area used to implement these systems; therefore, in comparison to the worst case, they both save about 90%. So this research will consider these two systems as needing the minimum area.

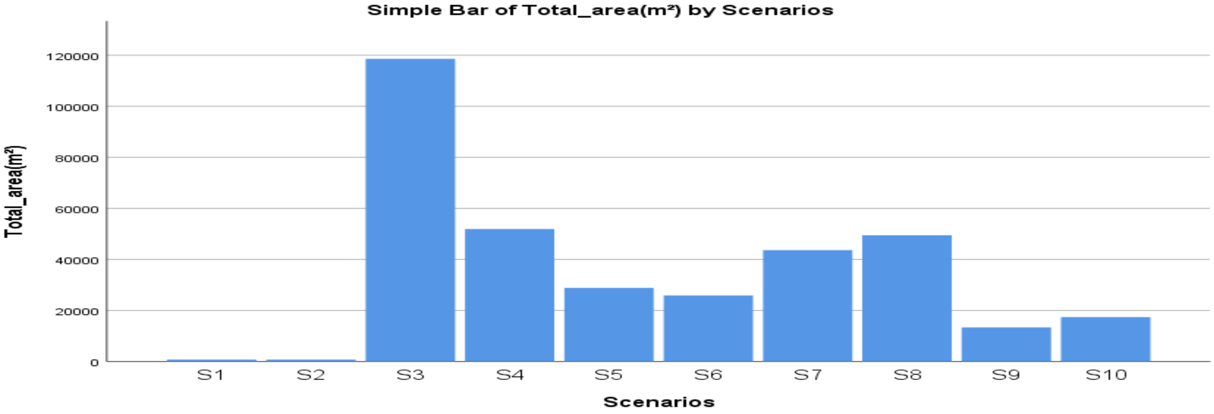

Figure 7 : chart of area in the 10 scenarios

5. CONCLUSIONS

The aim of this research is to convert an existing port to a green port through energy savings using solar and wind energy using Homer software to obtain an optimal port construction facility layout with minimum cost, area, and greenhouse gas emissions. This study takes place in the Mediterranean region, and the methodology of this study applies the concept of construction facility layout management through three stages: stage no. 1: utilizing the Homer software to optimize energy production scenarios for 1000 kwh using only renewable energy sources; stage no. 2: calculating the area needed for each scenario; and stage no. 3: comparing all outputs of cost, area, and carbon emissions. The research found that out of 10 hybrid renewable energy systems, each system produces 1000 kwh. The results of this study include cost, area, and carbon emissions. The results of the cost analysis show that scenarios no. 4 and no. 2 offer the most economical net present costs (NPC) and energy costs. The area calculation of each scenario shows that scenarios no. 1 and no. 2 differ slightly from one another. All the scenarios that use batteries have zero carbon emissions. And after the study showed these results, it proved that the area, when exploited appropriately and compatible with the climatic conditions of the region, will provide the energy needed with the minimum area, and by giving priority to the environment, the research found the optimal scenario is No. 2, which provides the minimum cost of energy, which saves 70% more than the other scenarios and also saves around 85% of the area required by its alternatives. This scenario depends on solar energy and batteries and requires the minimum area. The research shows that the relationship between area and energy production can be inversely proportional in the case of optimal construction facility site layout management.

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