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for Science , Technology and Maritime Transport

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"MARLOG 13"

Towards Smart Green Blue Infrastructure

3-5 March 2024 - Alexandria, Egypt

Assessment of Renewable Energy Supply for Shore Side Electricity in Green Ports

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Table of Contents

I. Introduction

II. Aim and Objectives

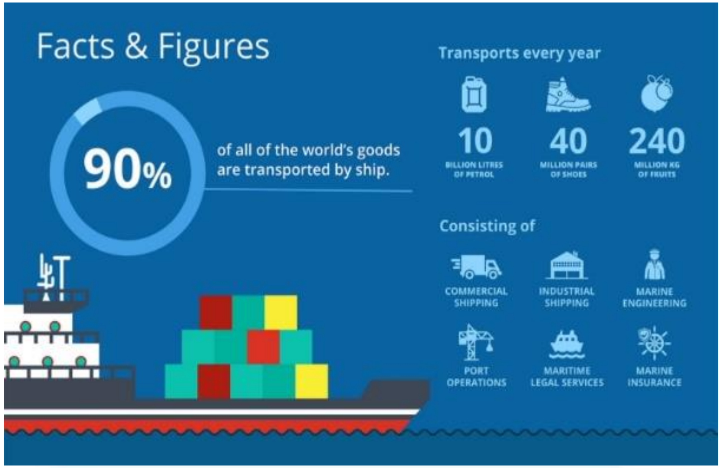
III. Methodology

IV. Results and Discussion

V. Conclusion and Future Work

Introduction

- Maritime transport is the backbone of the increasingly globalized economy and the international trade system.
- Greenhouse gases (GHGs) and other emissions from vessels and related activities in maritime trade have caused significant environmental impacts, especially in coastal areas [1].
- Ports have expanded significantly from just the handling of ships and cargo to the pursuit of a wide range of interests [3].

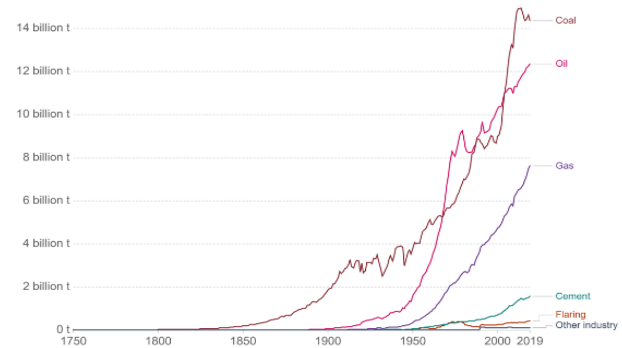


Maritime Economy, eBlue Economy [2]

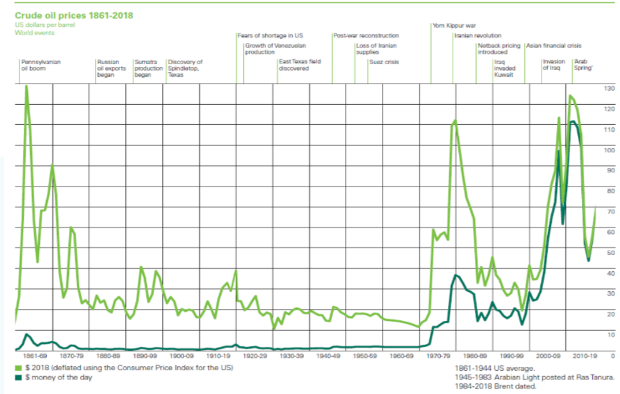
[1] A. M. Kotrikla, T. Lilas, and N. Nikitakos, "Abatement of air pollution at an aegean island port utilizing shore side electricity and renewable energy," *Marine Policy,* vol. 75, pp. 238-248, 02/01 2017, doi: 10.1016/j.marpol.2016.01.026.
[2] e. Economy. "The Maritime and Port Authority of Singapore to extend support measures under the maritimeSG Together Package." eBlue Economy.
[3] N. Kozarev, S. Stoyanov, and N. Ilieva, "AIR POLLUTION IN PORT AREAS," 11/30 2023.

Problem Statement

- Kyoto Protocol (adopted in 1997 and entering into force in 2005) introduced legally binding emissions targets, aviation and shipping were not included.
- In 2007 – 2012, shipping accounted for 2.8% of global GHGs or double that produced by air travel.
- Worldwide, shipping accounts for approximately 15% of NO_x and 5% - 8% of SO_x emissions, causing serious harm both to human health and the environment.
- Fuel prices increase should reduce the demand on fossil fuels, but oil prices have been low for several years, therefore the economic incentive to switch to alternative fuels has been reduced.



Global Carbon Project/ OurWorldInData.org/co2-and-other-greenhouse-gas-emissions.CC BY



BP Statistical Review of World Energy 2019

Survey

Greenport Concept

- It's the concept of managing and operating seaports with clean energy sources in order to reduce air and sea pollution and increase port's economic interests by decreasing the operation costs [4].

- Greenport concept can be summarized into the following points :
  - Reducing Shipping within the port.
  - Port activity and operations.
  - Inland transportation.
  - Using renewable and cheap energy sources.

- The Maritime and Port Authority of Singapore launched the "Maritime Singapore Green Initiative" in 2011 to reduce greenhouse gas emissions from maritime transportation with up to $100 million in funds throughout the next five years [4].

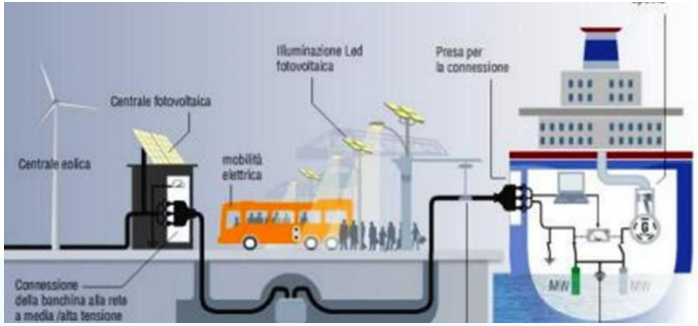
Source : Port of Venice

[4] B. Pavlic, F. Cepak, B. Sucic, M. Peckaj, and B. Kandus, "Sustainable port infrastructure, practical implementation of the green port concept," *Thermal Science,* vol. 18, pp. 935-948, 01/01 2014, doi: 10.2298/TSCI1403935P.
[5] Y.-C. Yang and W.-M. Chang, "Impacts of electric rubber-tired gantries on green port performance," *Research in Transportation Business & Management,* vol. 8, pp. 67–76, 10/01 2013, doi: 10.1016/j.rtbm.2013.04.002.

Survey

- There is a general conciseness on the use of various renewable energy sources to reduce the port's dependence on fossil fuels [6].
- The electricity coming from these renewable sources can be considered a source of income enabling ports to sell this cheap energy with acceptable profit margins .
- This energy is not only used to power the port's systems, trucks and machinery, but also to power the ships at berth(On-shore power supply), since ships are the main source of pollution in ports.
- Hamburg port owns half of the city's 52.75 MW of wind turbines. In addition, it has two 12 MW solar energy installations, which generate approximately 500 MWh of energy annually [7].

World Energy Outlook – International Energy Agency, 2019



Maritime Economy, Source : Singapore Maritime Officers Union (SMOU)

[6] Y.-C. Yang and W.-M. Chang, "Impacts of electric rubber-tired gantries on green port performance," *Research in Transportation Business & Management,* vol. 8, pp. 67–76, 10/01 2013, doi: 10.1016/j.rtbm.2013.04.002.
[7] D. Han, Y. G. Heo, N. J. Choi, S. H. Nam, K. H. Choi, and K. C. Kim, "Design, Fabrication, and Performance Test of a 100-W Helical-Blade Vertical-Axis Wind Turbine at Low Tip-Speed Ratio," *Energies*, vol. 11, no. 6, doi: 10.3390/en11061517.

Gap analysis

- To the best of this author's knowledge, to date **no** specific experimental study of hybrid Twisted Wind-Solar unit model has been performed for **Greenport**.

- To the best of this author's knowledge, to date **no** specific Techno-Economic study of hybrid Twisted Wind-Solar unit model has been performed for **Greenport**.

- To the best of this author's knowledge, to date **no** study of Greenport methodology has been performed for **Alexandria Port** in Egypt using hybrid Twisted Wind-Solar unit model .

Aim and Objectives

Aim:

Examine the Alexandria port case study and the applicability of Green Port concepts by studying the possibility of supplying ships at port with renewable shore side electricity.

Objectives:

- ❑ Experimental investigation of a Twisted Wind-Solar hybrid power system to assess its capability of meeting all the ships' energy needs while they are in port.
- ❑ Modelling the system using HOMER with the data available for the port of Alexandria.

Methodology

PHASE 1	PHASE 2	PHASE 3	PHASE 4
Collecting data for the Case Study	Mathematical Formulations	Experimental Setup	Modelling Software

Methodology Tools:

Experimental Model + Homer Software

Methodology

Case Study (Alexandria Port)

- With history dating back to the founding of the city itself, the port of Alexandria is one of the most important ports of Egypt.

- Unfortunately it is also one of the most polluted areas with even more environmental impact due to the fact that it is located within city limits and well within urban areas.

- The port's coordinates are 31°12′16″ N 29°52′48″ E / 31.2045796° N 29.8800659° E. Its land area is 22.8 square kilometers

Global Carbon Project/ OurWorldInData.org/co2-and-other-greenhouse-gas-emissions.CC BY

Methodology

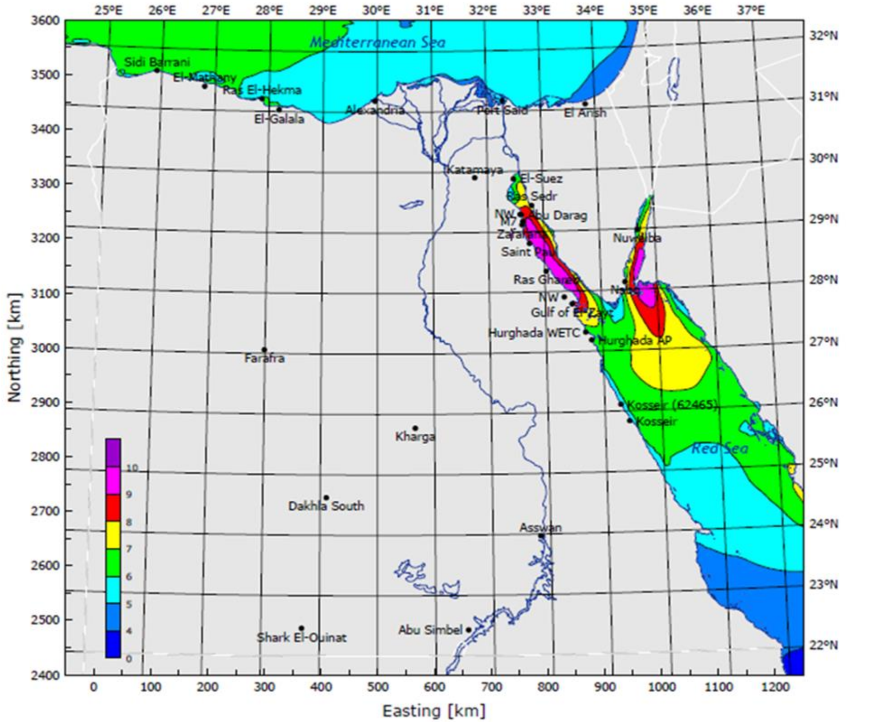
Mathematical Formulations

 # Wind Power

$$P_w = \frac{1}{2}\rho_a A_s C_p V_w{}^3 \qquad P_w = 2\pi N60T$$

$$\eta_w = \frac{P_{actual}}{P_{theoretical}} = \frac{2\pi N60T}{\frac{1}{2}\rho_a A_s C_p V_w{}^3}$$

- ❑ Wind speed at the shore line of the Mediterranean Sea is well within the range of 5 to 6 (m/s).



Mortensen, N.G., U.S. Said, and J. Badger, Wind Atlas for Egypt. In Proceedings of the Third Middle East-North Africa Renewable Energy Conference, 2006.

Methodology

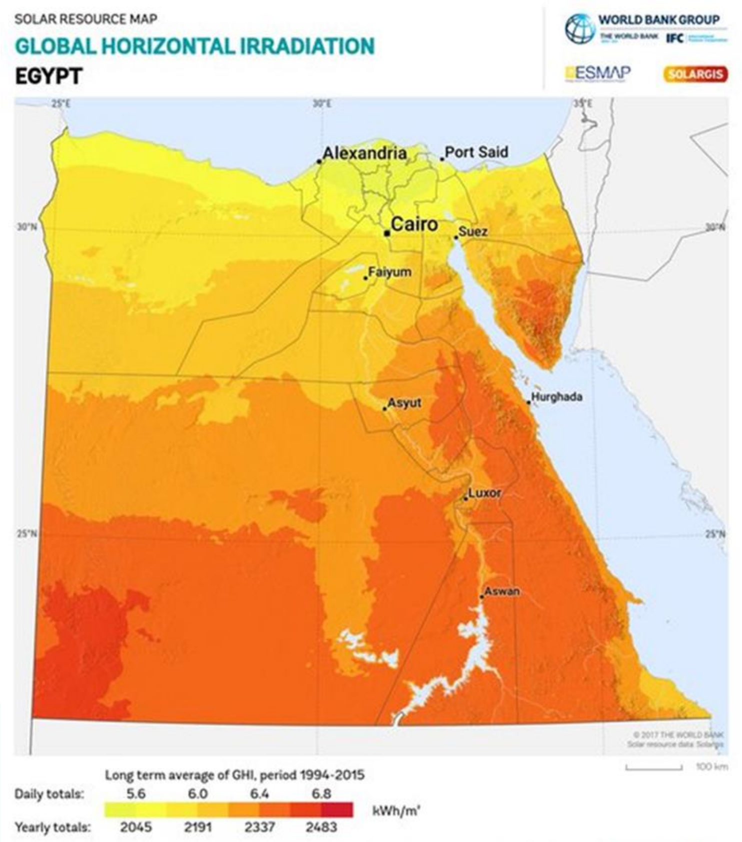
Mathematical Formulations

 # Solar Power

$$E = ArHP_r \qquad E = 365P_k r_p H_h$$

$$E_{out} = A_e E_e G \qquad P_{electrical} = VI$$

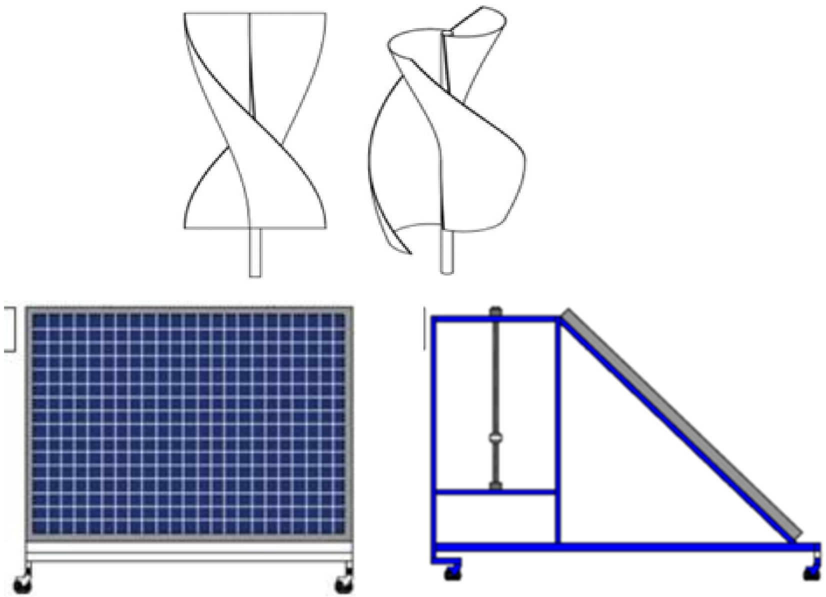
- Egypt receives annually 2,400 (hrs.) of solar operation with high intensity of solar radiation equivalent to 2,600 (KWh/m²).



© 2024 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis.

Methodology

Experimental Setup



Different views of the hybrid wind-solar unit model

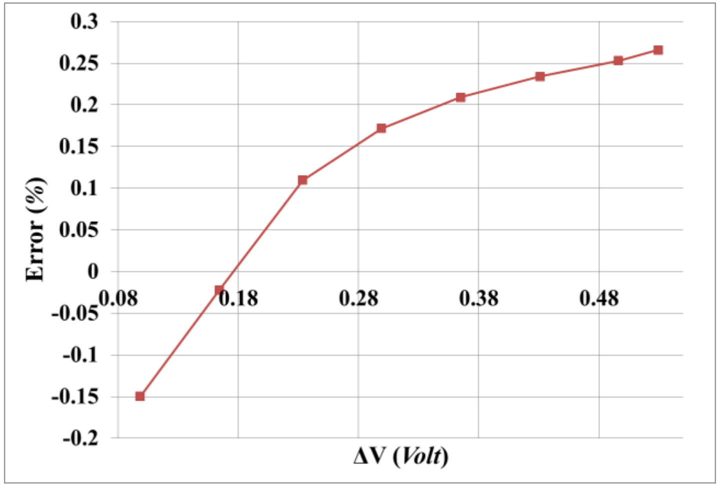
A dynamic torque sensor with its power convertor

Multimeter device for the voltage and amperage measurements

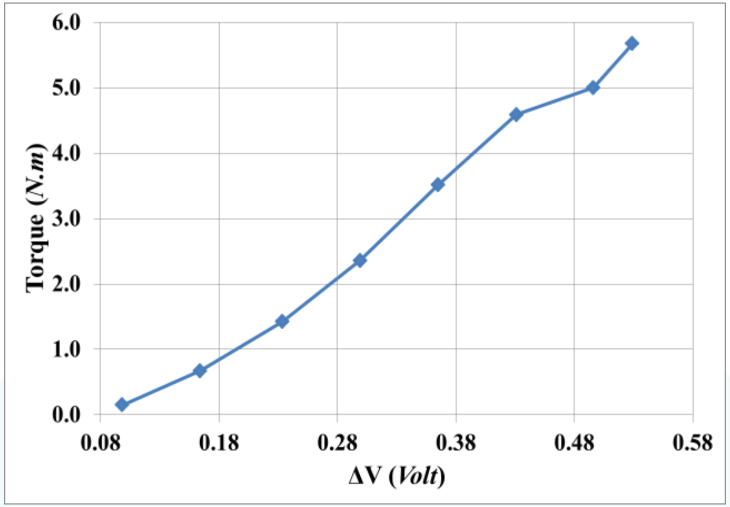
Methodology

Instrumentation Calibration

- Error deviation less than 0.5% of the output signal, with a sensitivity of 1±0.2mv/Volt.



- The resulting torques is corresponding to a wind speed of 1.5 to 9.0 m/s.



A dynamic torque sensor calibration, the error relative to the voltage variation in transduction electronics circuit

Methodology

Experimental Setup

Wind Tunnel Unit

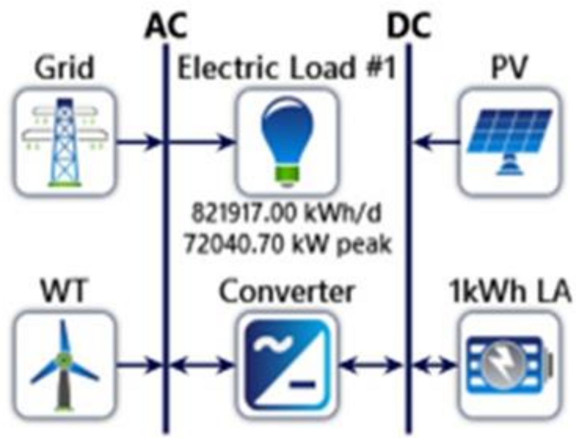
Twist vertical axis turbine

An isometric final view of the hybrid wind-solar unit prototype

Methodology

HOMER Setup (Hybrid Optimization of Multiple Electric Renewables)

- **HOMER** modeling software facilitates decision making on the optimal mix of resources, system configuration, and capital and operating costs of micro grids and distributed energy resources.
- An electric model was developed in the simulation program using combinations of 200 kW to 1000 kW solar systems and 100 to 800 kW wind turbines.
- The simulation was set to provide the needs of a constant load of 1 MW, making it a dimensionless reference for the port of Alexandria.
- HOMER Energy uses an Emission Factor of 680 g/kWh, while the ships use an EF of 700 g/kWh.
- The software used to determine the decrease of PM used an energy factor of 0.3 g/kWh for the ships and 0.091 g/kWh for the port of Alexandria.
- The standard utilized in the software was 1 kWh, which is equivalent to 3.6 MJ of energy.



Schematic Diagram of the Relations Between Grid and Renewable Application

Results and Analysis

Experimental Results

Wind Turbine Configuration:

- At each velocity, the turbine was tested under several loads ranging from 5% to 30%.
- The highest power results were achieved with the 10% load.

V (m/s)	Load (%)	Rotational Speed (rpm)	Torque (N.m)	Power (W)
3	5	9	0.08	0.11
3.5	5	26	0.06	0.12
	10	16	0.07	0.16
4	5	51	0.06	0.15
	10	18	0.08	0.32
5	5	115	0.05	0.15
	10	18	0.08	0.6
6	5	255	0.05	1.34
	10	150	0.1	1.57
	20	100	0.12	1.26
	30	35	0.1	0.37
7	5	305	0.04	1.28
	10	160	0.08	1.34
	20	80	0.1	0.84
	30	60	0.12	0.75
8	10	160	0.09	1.51
	20	105	0.12	1.32
	30	95	0.13	1.29

Results and Analysis

Experimental Results

Wind Turbine Configuration:

- The results at various speeds with a 10% load condition show a tendency towards better performance at air speeds close to the 6 m/s mark.

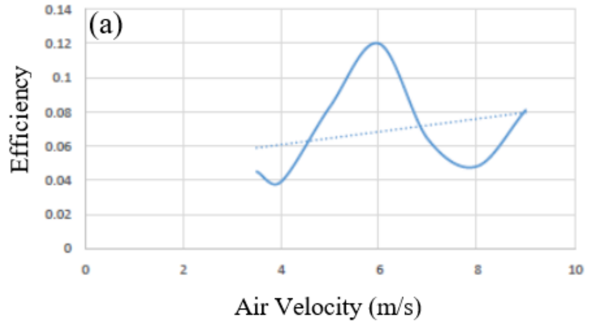
V (m/s)	Rotational Speed (rpm)	Torque (N.m)	Power (W)	Efficiency (%)
3.5	16	0.07	0.16	4.5
4	18	0.08	0.32	3.9
5	75	0.08	0.6	8.3
6	150	0.1	1.57	12
7	160	0.08	1.34	6.4
8	105	0.09	1.508	4.8

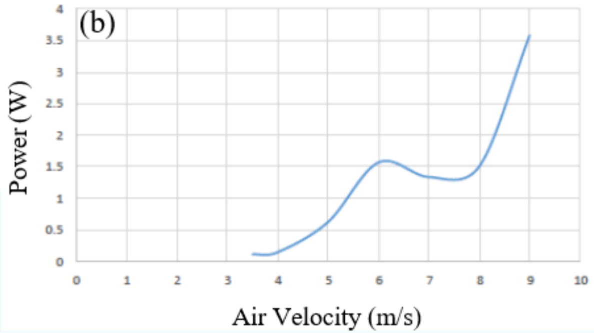
Results and Analysis

Experimental Results

Wind Turbine Configuration:

- ❑ Efficiency decreases at air speeds greater than 6 m/s.
- ❑ Further speeds were deemed unnecessary for testing, as such wind velocities are rarely reported in this region.





Results and Analysis

Experimental Results

PV Solar Panel System:

- The power did not fall much below the rated power of 80 W, with the minimum reading of 72 W.
- This gives the unit an average power generation of about 80 W during the day. This indicates an average of 138.5 W per 1 m^2 of area for this type of solar panel.

Time of Day	Temperature (°C)	Humidity (%)	Voltage (V)	Current (A)	Power (W)
09:00	14	68	20.75	3.48	72.13
10:00	17	60	21.37	3.63	77.64
11:00	19	60	21.66	3.94	85.36
12:00	21	50	21.7	3.96	86
13:00	22	52	21.55	3.88	83.72
14:00	19	55	21.5	3.5	75.25
15:00	19	58	21.63	3.85	83.26

Results and Analysis

Simulation Results

Emissions Reduction:

- The system can provide 29% of the demand, reducing the dependence on the grid down to only 71% of the demand.
- Slightly less than 3000 metric tons carbon dioxide emissions are produced per year with sulfur dioxide reduced by 12 tons each year and just shy of 6 tons less nitrogen oxides every year.

Quantity	Value (kg/year)
Carbon Dioxide	2,991,444
Carbon Monoxide	0
Unburned Hydrocarbons	0
Particulate Matter	396
Sulfur Dioxide	12,054
Nitrogen Oxides	5,895

Results and Analysis

Techno-Economic Analysis:

- Various combinations of energy sources that were previously used, and their cost compared to the cost of the proposed system:

Reference	System	Cost of Energy ($/kWh)
Baneshi, M. and F. Hadianfard [1] in Iran	PV/Wind Turbine/Battery	0.093 – 0.126
	PV/Wind Turbine/Grid	0.057 – 0.084
Shahzad, M. K., et al. [2] in Pakistan	PV/Biogas-Fuelled Generator/Batteries	0.036
Alwaeli, A. [3] in Oman	PV/Batteries	0.467
	Wind Turbine/Batteries	5.184
	Diesel Generator	0.567
	PV/Wind Turbine/Batteries	0.38
Proposed System in Egypt	Grid	0.14
	Grid/PV	0.095
	Grid/Wind Turbine	0.087
	Grid/ Wind Turbine/PV	0.08

[1] M. Baneshi and F. Hadianfard, "Techno-economic feasibility of hybrid diesel/PV/wind/battery electricity generation systems for non-residential large electricity consumers under southern Iran climate conditions," *Energy Conversion and Management,* vol. 127, pp. 233-244, 2016/11/01/ 2016, doi: https://doi.org/10.1016/j.enconman.2016.09.008.

[2] M. K. Shahzad, A. Zahid, T. ur Rashid, M. A. Rehan, M. Ali, and M. Ahmad, "Techno-economic feasibility analysis of a solar-biomass off grid system for the electrification of remote rural areas in Pakistan using HOMER software," *Renewable Energy,* vol. 106, pp. 264-273, 2017/06/01/ 2017, doi: https://doi.org/10.1016/j.renene.2017.01.033.

[3] A. Alwaeli, "Optimal Sizing of a Hybrid System of Renewable Energy for Lighting Street in Salalah-Oman using Homer software," *International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-2, Issue-5,May 2016,* vol. ISSN:, pp. 157-164, 05/05 2016.

Conclusion and Future Works

- **<u>In conclusion</u>**, the data from the experimental prototype and the simulation both support the viability of incorporating renewable energy sources into the Alexandria port's power supply system.

- As the simulation results suggest, the use of solar panels of 210 kW rating, which is about 1000 square meter footprint. While the use of wind turbines provide 80 kW. the simulation's small-scale components were able to consistently and profitably supply a continuous power rating of roughly 29% of a megawatt load

- In addition, this is done using a basic solar panel of about one square meter with a rating of 355 watts. The hybrid design similar to that of the prototype can save a lot of space since both power systems occupy the same space.

Conclusion and Future Works

- **For future work**, a model can be implemented using Computational Fluid Dynamics software to simulate the behaviors of the wind turbine as well as those of the solar PV system to enhance the performance of the new design at the Port of Alexandria.
- Moreover, an experimental model can be used as the same exact unit with a full scale structure to measure the output power.

Arab Organization for Industrialization

Within the framework of cooperation between **AASTMT** and **AOI**, and within the framework of the cooperation protocol that was signed during the activities of the Industrial ***Engineering Consultation Day***, according to the following:

1- Vertical-axis wind turbines (**Twist Turbine**) for a renewable energy source using artificial intelligence was selected to represent the college by AOI on Tuesday, 11/07/2023. (**Department of Marine and Offshore Engineering**).

2- A **field visit** was carried out from the Department of Marine and Offshore Engineering, on Saturday, 30/09/2023.

3- The final designs have been sent to implement the **first model**, on Sunday, 12/15/2023.

4- AOI will deliver the first model to the Department of Marine and Offshore Engineering to conduct experiments on it and ensure its **efficiency** during the beginning of **April** 2024.

5- AOI will transform them into a **production line** to market them locally and regionally on **June** 2024.

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Thank You