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EXPLORING AIRBORNE WIND ENERGY: A COMPARATIVE STUDY AND THE POTENTIAL FOR IMPLEMENTATION IN JORDAN

Rami S. Rzouq, Rua'a Abdel Mun'am Suboh and Nabela Bilal Tamimi
Department of Electrical Engineering, Al-Balqa Applied University, Salt, Jordan
E-Mail: drrami.rzouq@bau.edu.jo

ABSTRACT

Airborne Wind Energy (AWE) technologies are fundamentally new and different from traditional wind turbines which have a tower and blades, (AWE) has other unique features regarding cost, transportation, installation, and even the method of generation.(Weber *et al*., 2019.) Many companies across the globe are developing large kites and aircraft to capture wind energy high up in the sky, these kites and aircraft can reach an altitude up to half a mile above the ground, (Gordon 2023) The generating stations are either based on the ground or airborne, so what are the differences between all of them and which is better? Wind energy has emerged as a promising renewable energy source worldwide, and Jordan is no exception. With its vast potential for harnessing wind power, Jordan has been actively exploring the possibilities of integrating wind energy into its energy mix. For that providing a wind distribution map for all Jordan governorates, to know the possibility of implementing the airborne energy project in Jordan.

Keywords: airborne wind energy, renewable, ground generation, fly generation, Jordan governorates.

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1. INTRODUCTION

Airborne wind energy systems (AWES) and traditional wind Energy systems differ in their design and operation. While traditional wind turbines are fixed structures on the ground, airborne wind turbines capture the energy of strong winds at high altitudes using a turbine that is suspended in the air without the need for a traditional tower structure, typically tethered to the ground and flying in the air. (AZoCleantech.com, 2022) (A Report from EPRI's Innovation Scouts, 2012) (AWES) can go higher up in the sky where the wind is stronger and more consistent, allowing for more efficient power generation. Additionally,(AWES) use Materials 90% less than the Materials used in traditional wind Energy systems, have a High-capacity factor, low environmental impact, low cost, low noise pollution, are easy to maintain, and are easy to transport (Kitepower, 2021) (*Introduction to Airborne Wind Energy - Energypedia*, n.d.) Wind power P_w flowing through a specific cross-section (A) is expressed as:

$$P_w = \frac{1}{2}\rho A {v_W}^3 \qquad (1)$$

(AWE) devices aren't confined to a specific space but rather cover a larger area. That's why we consider wind power density (P_w), which is related to the unit area: (Wilhelm, n.d.)

$$P_w = \frac{P_w}{A} = \frac{1}{2}\rho {v_W}^3 \qquad (2)$$

2. CLASSIFICATION OF AWE

The (AWES) system distinguishes itself from traditional wind energy systems by deviating from the conventional tower and blade setup. Instead, (AWES) takes a unique classification approach, which can be described as follows:

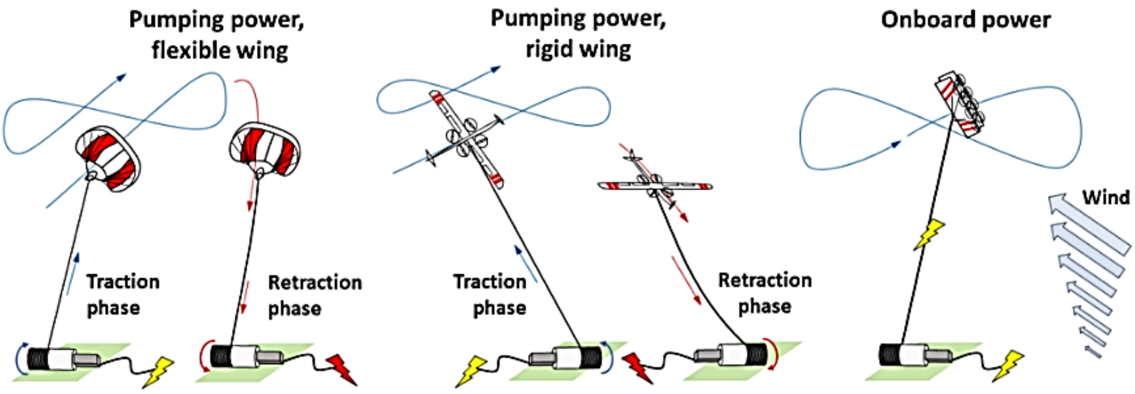
a) Depending on the generation location (Ground generation or Fly generation).
b) Depending on the wing nature (Rigid aircraft or flexible kite).

This distinct classification highlights the innovative nature of AWES and its potential to revolutionize the way we harness wind energy.

2.1 Classification According to the Generation Location

a) Ground-Generation AWES (GG-AWES): The mechanical work of a traction force generates electrical energy on the ground. This force is transferred from the aircraft to the ground system via ropes, which then drives an electrical generator. This setup allows to production of electricity from the motion generated by the airborne wind energy system.

b) Fly-Generation AWES (FG-AWES): Electrical energy is generated on the aircraft and transmitted to the ground via a specialized rope carrying electrical cables. Wind turbines are commonly used to convert the wind's energy into electrical power. This innovative approach allows for electricity generation to occur on board the aircraft itself. Figure-1 shows the difference between the (GG-AWES) and (FG-AWES).



a) GG-AWES using flexible kites b) GG-AWES using rigid aircraft C) FG-AWES using flexible kites.

Figure-1. (Ground-Generation and Fly-Generation).

2.2 Classification According to Wing Nature

a) Rigid aircraft: it has a hard structure. This type of aircraft is designed to maintain its shape and stability during flight, allowing it to effectively capture and convert wind energy into electricity. The use of a rigid wing offers certain advantages in terms of control, stability, and the ability to withstand various weather conditions. It's an exciting component of airborne wind energy systems. By using this type of aircraft, generation can be done either on the ground or on-board.

Figure-2. Kitemill's aircraft prototype.

b) Flexible kites: these kites are made of lightweight and flexible materials, such as fabric or inflatable structures, which allow them to adapt to changing wind conditions and generate lift. The soft kite design offers advantages such as ease of transportation, deployment, and maneuverability. It's an exciting technology that showcases the versatility of airborne wind energy systems. By using this type of kite, generation can be done only on the ground.

Figure-3. Skysails power kites harvest wind energy at altitudes of up to 400 meters.

3. APPLICATIONS OF AWE

"It is not just limited to electricity generation! AWES can also be used for various applications like powering remote areas, providing emergency power during natural disasters, and even supporting aerial surveillance. They can also be used for offshore wind farms, where they can harness stronger and more consistent winds. They can also be utilized for research purposes, such as collecting data on wind patterns and studying atmospheric conditions."

4. RIGID VS. FLEXIBLE

Over time, both types of wings have been developed simultaneously in the airborne wind energy (AWE) community. Initially, "rigid wings were considered the most promising concept for AWE". However, around 2015, more companies started shifting their focus from soft wing development to rigid wings. In recent years, there has been a resurgence of interest in soft wings(Van Der Burg *et al.* 2022). In continuation of the classification mentioned in section 2. We have studied the characteristics and advantages of each wing type as shown in Table-1.

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Table-1. Comparison between Rigid Aircraft and flexible kites.

Parameters	Rigid Aircrafts	Flexible kites
Aerodynamics and durability	Better (More energy generated for the same size kite)	Worse
Construction	Solid and heavy weight.	Soft and lightweight.
Generation	Fly Generation + Ground Generation.	Ground Generation.
Rated power	(Lower) 50-150 kW	(Higher) 60-200 kW
Potential power output	Directly proportional with speed.	Directly proportional with speed.
Material cost	Expensive	Cheap
Lifetime	More	Several hundred hours
Efficacy	High weight reduces efficiency.	Low weight increases efficiency.
Auto launch	Possible	Have problems
The importance of controllers on the wing	Need aerodynamic systems to control the wing.	Can be controlled by dual tethers.
Traction force	Reduced due to airfoil rigidity.	Increased due to light kite.
Effects of surrounding conditions	Low effect	High effect
CapEx[1]	Higher	Lower
Transport	Difficult and expensive	Easy and cheap
Prototype	Difficult	Easy
Wingspan (m)	Smaller	Larger
Wing surface area (m^2)	Smaller	Larger
Wing surface	Remains roughly fixed the entire flight.	It may be exposed to bends during the flight.
Operating altitude	(10-500) m	(70-400) m
Danger when crashing	The solid body breaks and turns into splinters that could cause significant damage.	The fabric shrinks together and does not cause danger to what is around it.
Reuse parts after the crash.	Most of the parts cannot be reused due to being broken and damaged.	At low, the wing is more likely to be used again.
Insurances	Higher	Lower

5. GROUND VS. FLY GENERATION

To clarify the classification mentioned in section 2 and to clarify which location is better for generation, we made the comparison shown in the following table.

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Table-2. Ground vs. Fly generation (Barnard 2019).

Parameters	Ground generation	Fly generation
Generation machine location	**Generation mechanics and electronics are on the ground.**	**On the ground and in the sky.**
Electricity generation	Generate electricity has a phase cycle: As the kite travels downwind, the first phase releases the drum's tether. The kite and tether are retrieved in the second phase using a few low-drag techniques.	Generate electricity has a phase cycle: As the aircraft travels downwind, the first phase releases the drum's tether. The aircraft and tether are retrieved in the second phase using a few low-drag techniques.
	*In comparison to the low-drag retrieve phase, the generation phase generates a lot more electricity.	
In-air aircraft and kites' complexity/ weight/ failure points	Less	More
System design	Simple and robustness	Complicated
Tether characteristics	Nonconductive tethers are: Much lighter weight. Slimmer. A more widely used high-strength cable. Cheaper.	Conductive tethers are: Heavier. Thicker. More expensive.
Danger when the aircraft/kite crashes	Less likely to cause significant damage.	More
1 Cycle duration	1-5 min	N/A
Maintenance	Easy to maintain	Difficult to maintain
Tether material	*Non-conductive braided polyethene fibers.*	Conductive *Ultra-High-Molecular-Weight Polyethylene (UHMWE).*

[1]CapEx: short for capital expenditure refers to the funds that an organization or company invests in purchasing, maintaining, or enhancing its fixed assets. (Wikipedia contributors, 2023)

6. GROUND-BASED GENERATION USING (RIGID VS. FLEXIBLE)

Currently, the most used method in airborne wind energy systems involves a ground-based generator connected to a tether cable winch. This setup generates power as the kite or aerofoil pulls out the cable, creating torque and velocity. The rotation of the winch drum then drives an electrical generator, producing electricity (Wikipedia contributors, 2023). To provide a comprehensive comparison, we have decided to analyze this type of generation alongside the cases of rigid and flexible wings.

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Table-3. Flexible vs rigid) Ground-based generation (Van Der Vlugt *et al*. 2013) (Licitra *et al*. 2019).

<table>
<tr><th>Parameters</th><th colspan="2">Flexible</th><th colspan="2">Rigid</th></tr>
<tr><td>Flight operation in a pumping cycle requirement</td><td colspan="2">Steering of the wing (remote-controlled wing), the kite control unit (KCU) steers and de-powers the kite.
Changing the angle of attack of the tether to alternate between reel-out and reel-in (single-line traction tether)</td><td colspan="2">Steering of the wing (remote-controlled wing), the kite control unit (KCU) steers and de-powers the Aircraft.
Changing the angle of attack of the tether to alternate between reel-out and reel-in (single-line traction tether)</td></tr>
<tr><td rowspan="2">Tether material</td><td colspan="2">High Modulus Polyethylene rope (HMP) (3-4) mm.
Characteristics:
-It has high failure resistance.
-Lightweight (the material weighs less than water).
-Extreme toughness (15 times stronger by weight than steel).</td><td colspan="2">Braided polyethylene fibers. Endurance abilities that are unrivaled. These, in turn, provide the tether with the smallest diameter, which is critical for extracting energy from kite turbines. The tether's material is durable and can withstand exposure to various environmental conditions such as moisture and UV light.</td></tr>
<tr><td colspan="4">-Upper bounded to keep mechanical stress on the aircraft structure and tether severance to a minimum.
-A lower bound is also required to avoid tether sag effects during the reel-in phase.</td></tr>
<tr><td>Efficient energy conversion</td><td colspan="4">-The wing's traction force must be high, approaching the maximum allowable loading of the tensile membrane structure.
-It may be beneficial to stay well below the maximum wing loading for material durability reasons.</td></tr>
<tr><td>The object velocity</td><td colspan="4">The velocity increases with increasing wind velocity.</td></tr>
<tr><td>Traction force into electricity conversion cost</td><td colspan="4">Low-cost solution.</td></tr>
<tr><td rowspan="3">Generator mode</td><td colspan="2">Reel-out (ascending)</td><td colspan="2">Reel-in (descending)</td></tr>
<tr><td>Flexible</td><td>Rigid</td><td>Flexible</td><td>Rigid</td></tr>
<tr><td colspan="2">Generator mode.
The generator is operated as a generator.</td><td colspan="2">Motor mode.
The generator is used as a motor to pull the kite back towards the ground station.</td></tr>
<tr><td>Phase of operation</td><td colspan="2">The traction force and the generated energy are maximized.</td><td colspan="2">The traction force and the consumed energy are minimized.</td></tr>
<tr><td>Tether</td><td colspan="2">The tether should be reeled out slowly.
Using a single-line traction tether to reduce system losses caused by aerodynamic drag.</td><td colspan="2">The reel-in should be fast.</td></tr>
<tr><td>* Angle of attack</td><td colspan="2">The kites have a high angle of attack, which results in a high traction force. As a result, the amount of energy required for the retraction phase is maximized.</td><td colspan="2">The kites have a low angle of attack, which results in a low traction force. As a result, the amount of energy required for the retraction phase is reduced.</td></tr>
<tr><td>Cycle duration</td><td>60-180s</td><td>60-90s</td><td colspan="2">N/A</td></tr>
</table>

7. THE LOCATION OF JORDAN

Jordan is located in the southern portion of the Levant and the center of the Arab Levant in southwest Asia. Additionally, it can be found in the northern section of the Arabian Peninsula. Geographically speaking, Jordan lies between longitudes 39 and 34 east and latitudes 33 and 29 north (الموقع والجغرافيا, n.d).

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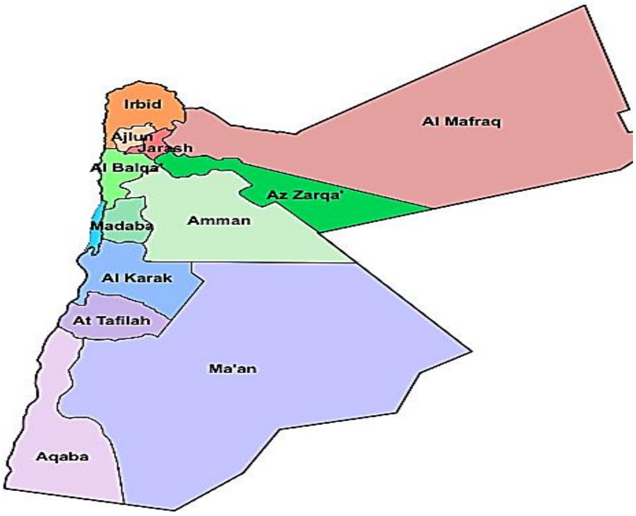


Figure-4. Jordan governorates.

The discovery of wind energy in Jordan comes from two factors: the first is the high demand for energy in Jordan, and the second is the availability of wind energy sources. (Ababneh, 2009).

8. WIND DISTRIBUTION AT JORDAN GOVERNORATES

This section shows results related to (mean power density [W/m^2], wind speed [m/s] and wind rose) at 200 meters above the ground taken from the GLOBAL WIND ATLAS website for all Jordan governments (Aţ Ţafīlah Climate, Weather by Month, Average Temperature (Jordan) - Weather Spark, n.d.).

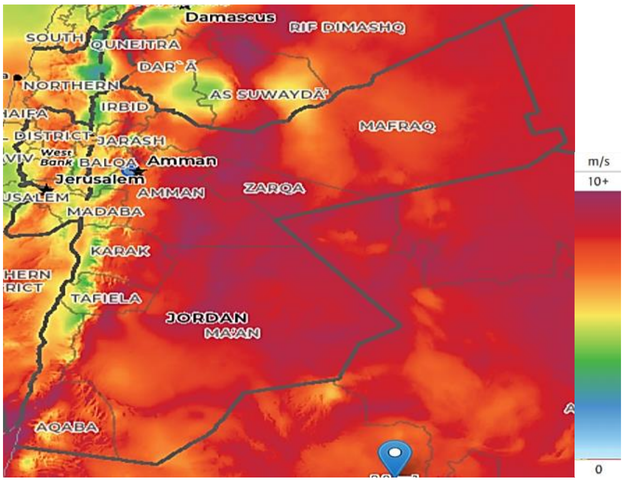
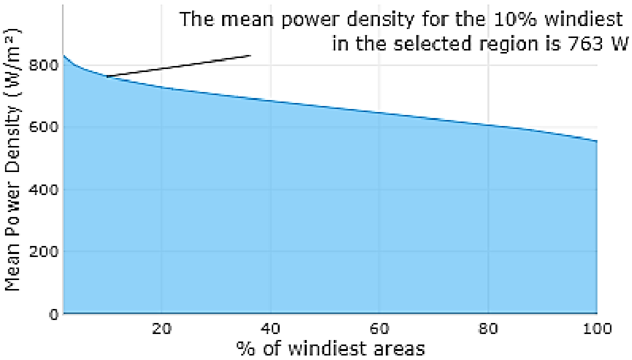
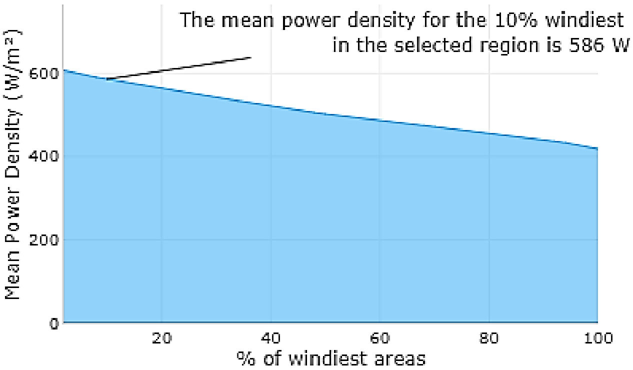


Figure-5. Geothermal gradient map at 200m high for Jordan according to GLOBAL WIND ATLAS website.

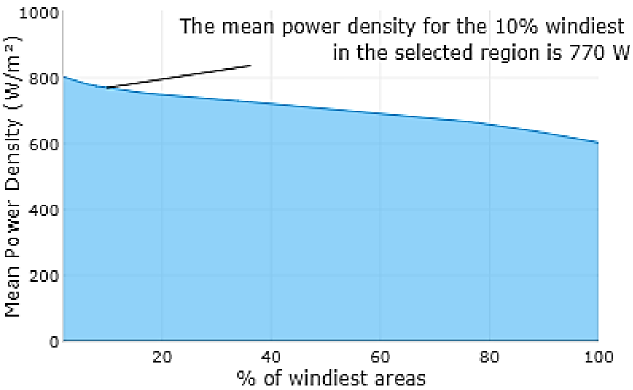
Selecting the optimal governorate to maximize the use of the available resources requires careful consideration of the wind mean power density of Jordan's governorates. Consequently, the investment cost is reduced. Figures show that the Aqaba governorate has the maximum mean power density and the lowest wind mean power density is found in Madaba (Alrwashdeh & Alrwashdeh, 2018).



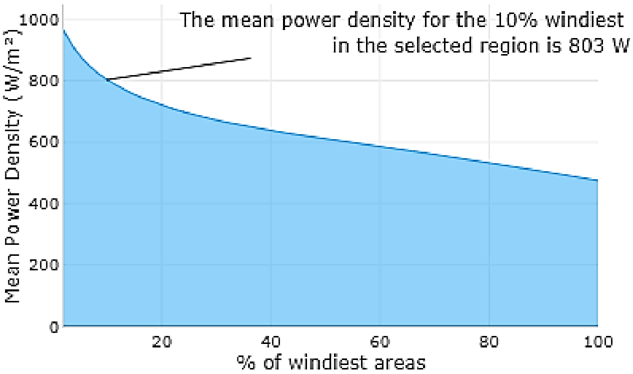
a) Power density in Jordan



b) Power density in Ajlun



c) Power density in Amman



d) Power density in Aqaba

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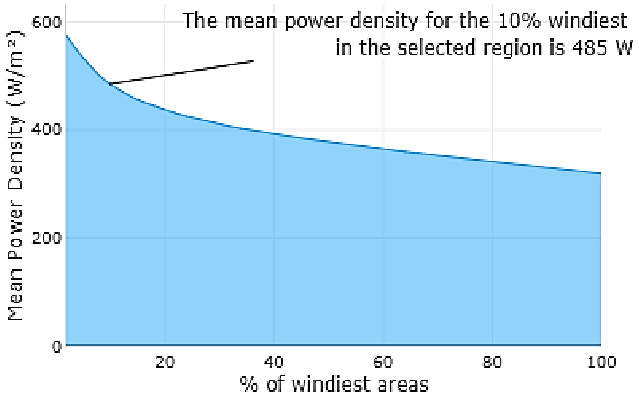
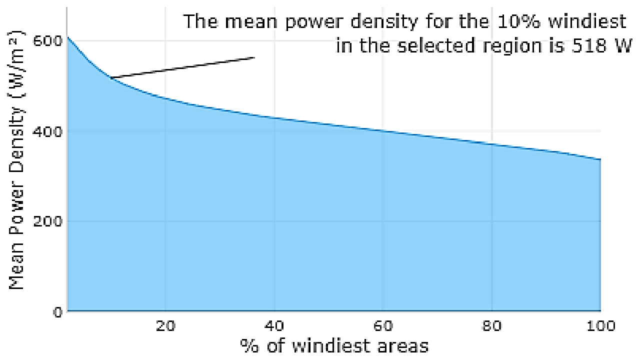
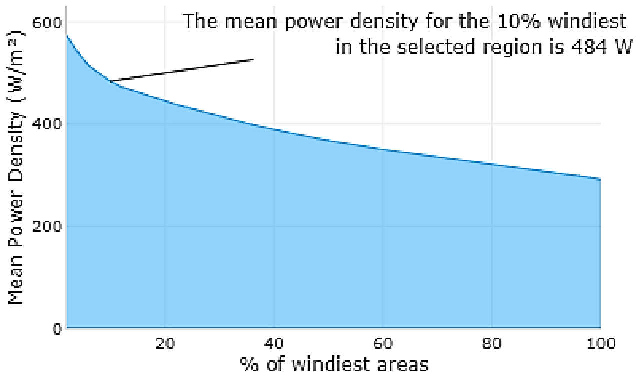


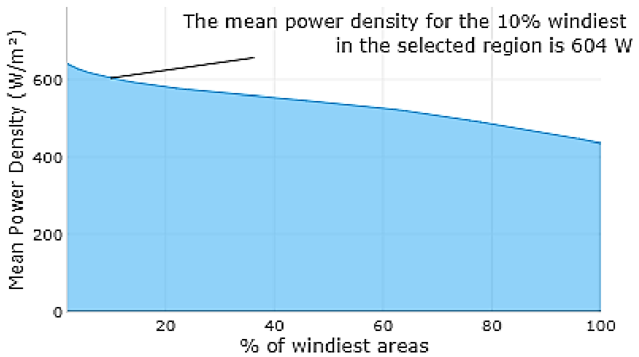
e) Power density in Balqa



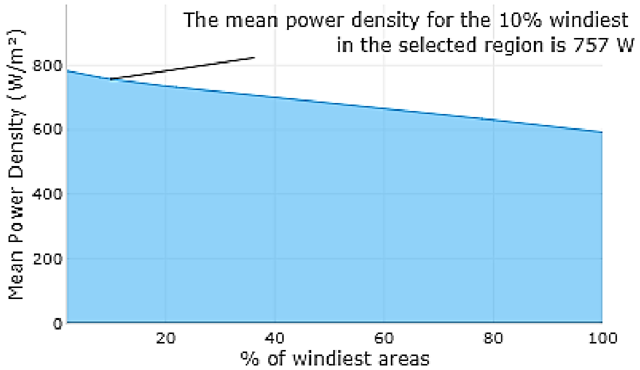
f) Power density in Irbid



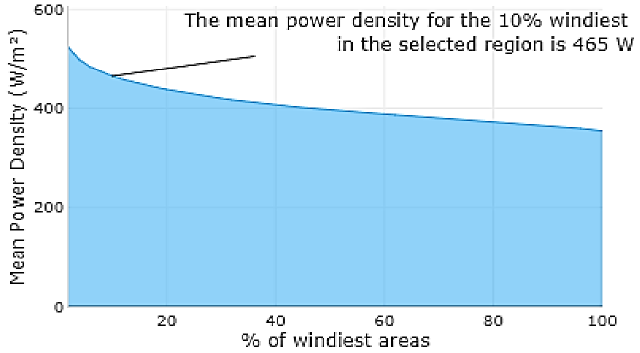
g) Power density in Jarash



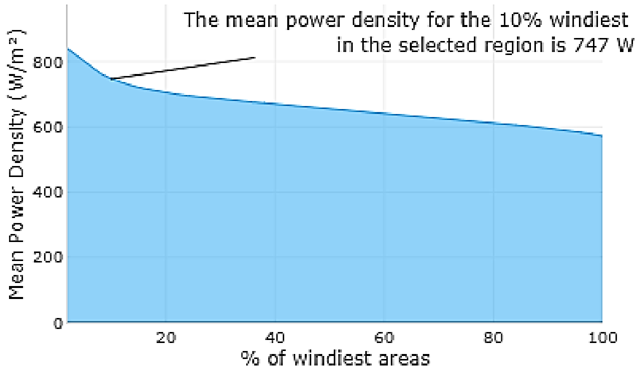
h) Power density in Karak



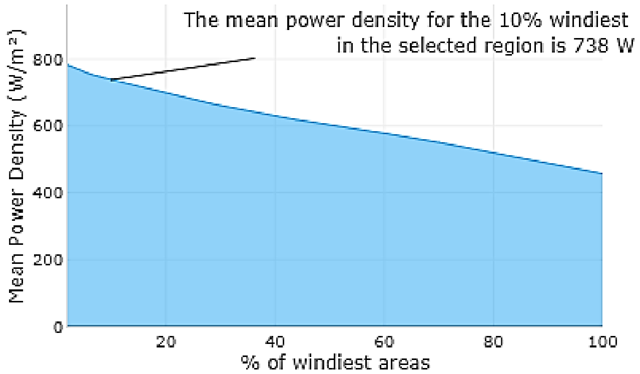
i) Power density in Ma'an



j) Power density in Madaba



k) Power density in Mafraq



l) Power density in Tafilah

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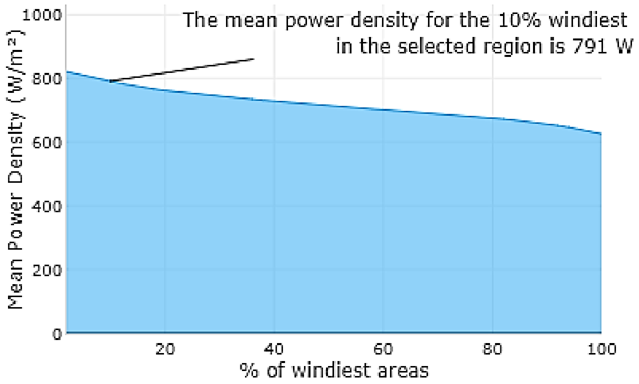
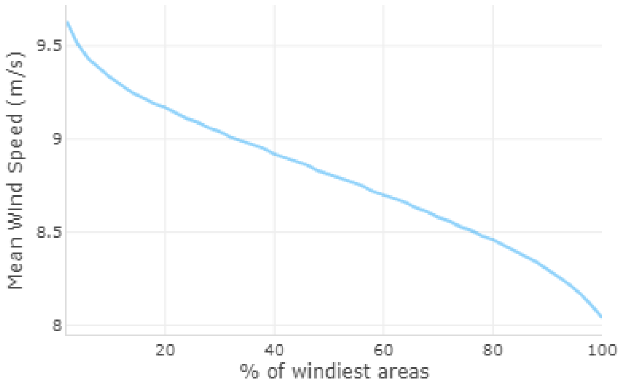


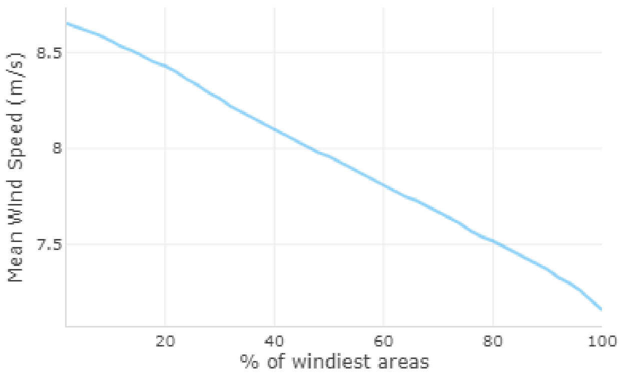
m) Power density in Zarqa

Figure-6. The mean power density in Jordan governorates (Ajlun, Amman, Aqaba, Balqa, Irbid, Jarash, Karak, Ma'an, Madaba, Mafraq, Tafilah, Zarqa).

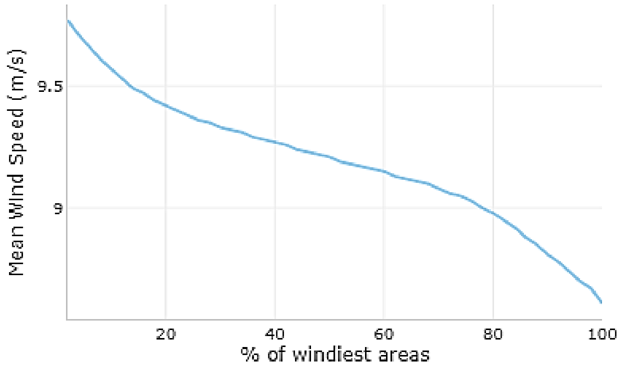
Additionally, the wind parameters were examined about the years, days of the week, and wind speed. The study yields the wind speed distribution and identifies the best locations for wind farms. The governorates of Aqaba and Madaba are responsible for setting the maximum and minimum wind speed values, respectively.



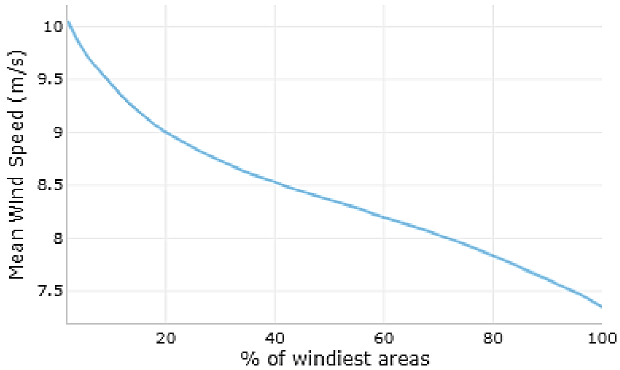
a) Wind speed in Jordan



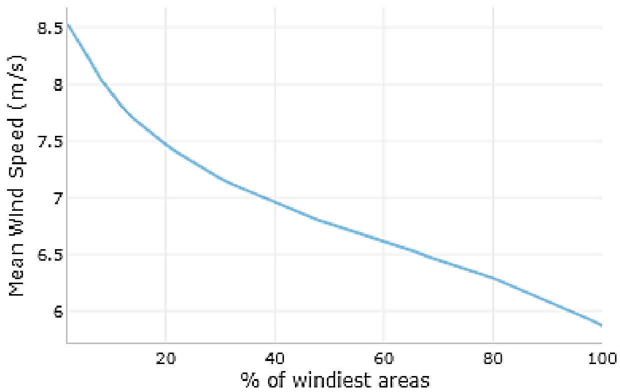
b) Wind speed in Ajlun



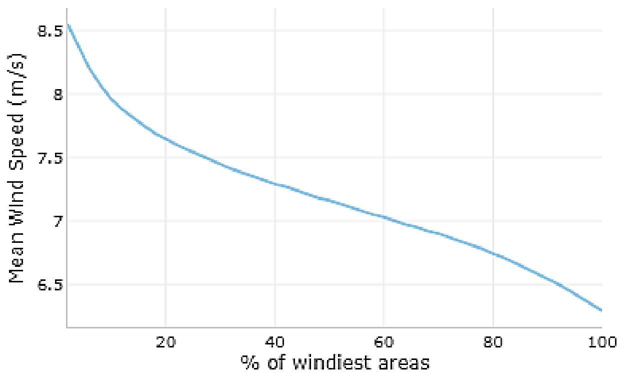
c) Wind speed in Amman



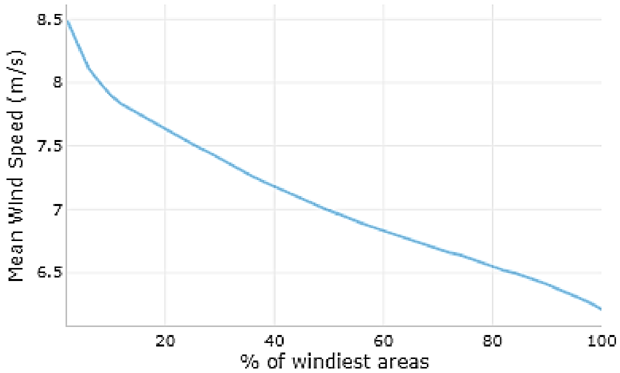
d) Wind speed in Aqaba



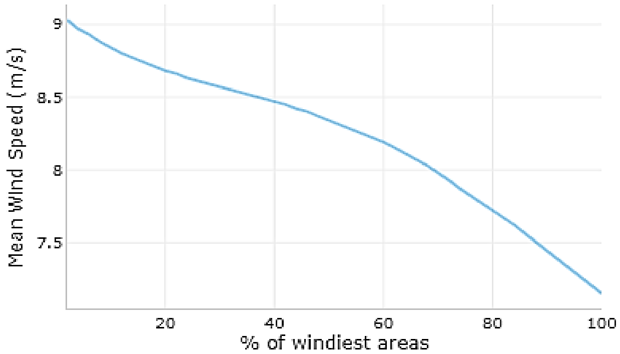
e) Wind speed in Balqa



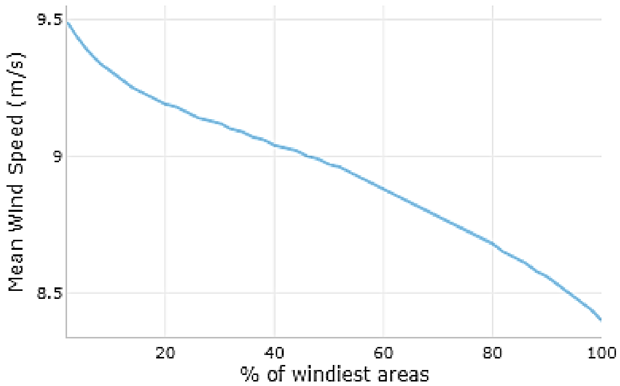
f) Wind speed in Irbid



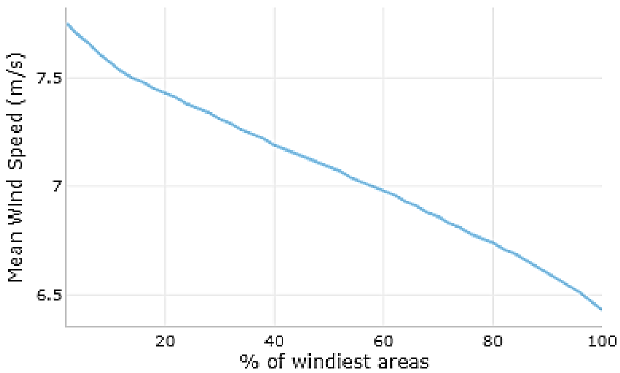
g) Wind speed in Jarash



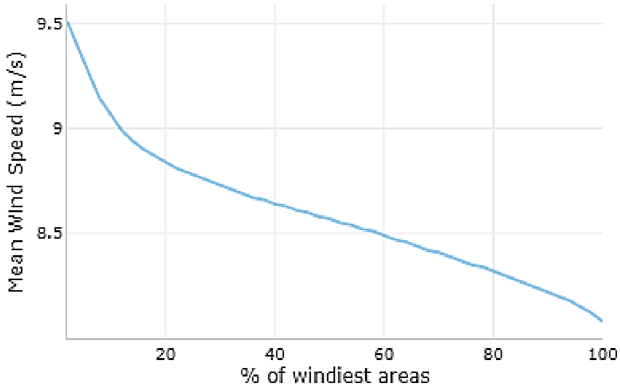
h) Wind speed in Karak



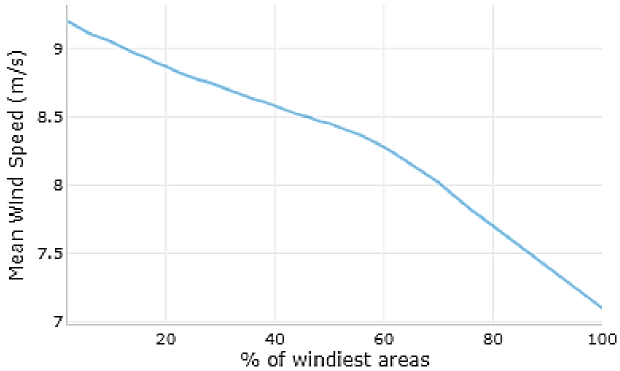
i) Wind speed in Ma'an



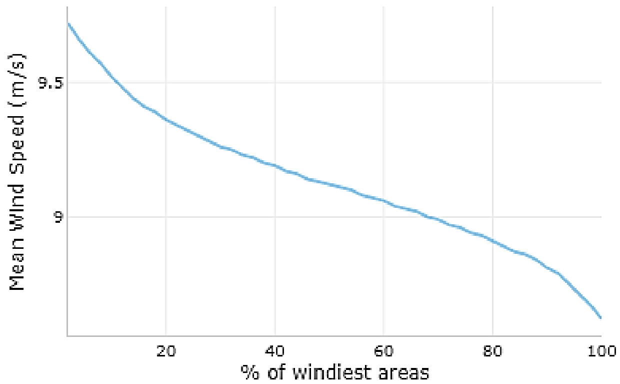
j) Wind speed in Madaba



k) Wind speed in Mafraq



l) Wind speed in Tafilah



m) Wind speed in Zarqa

Figure-7. The mean wind speed in Jordan governorates (Ajlun, Amman, Aqaba, Balqa, Irbid, Jarash, Karak, Ma'an, Madaba, Mafraq, Tafilah, Zarqa))

The wind rose displays the number of hours the wind blows from the given direction annually. An example is the wind's direction, which is blowing from South-West (SW) to North-East (NE). Figure-8 represents the wind roses for the governorates in Jordan.

1. Wind frequency rise indicates how frequently winds blow in a given direction. The frequency of the wind blowing from a specific direction is correlated with the length of every "spoke" around the circle.

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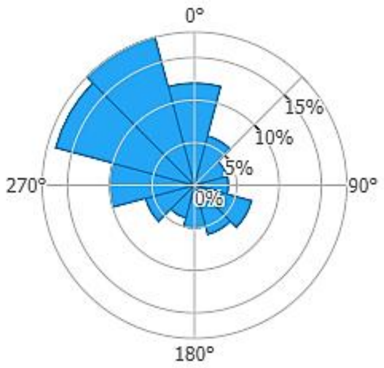
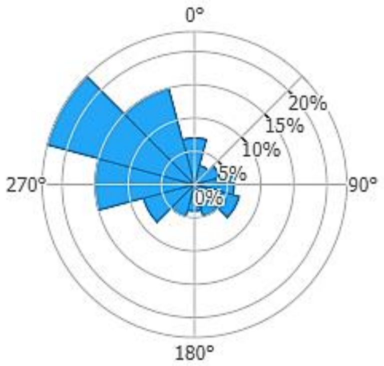
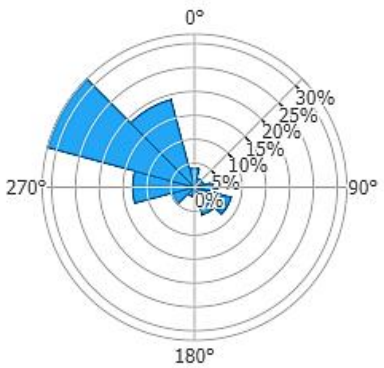


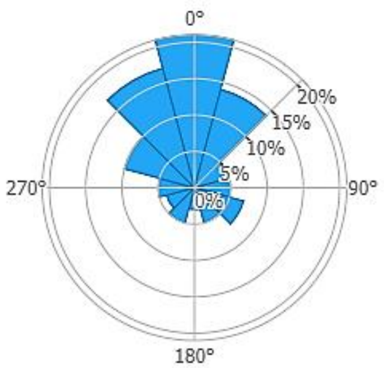
a) Wind freq. rose in Jordan



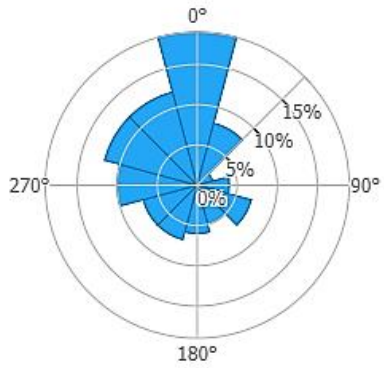
b) Wind freq. rose in Ajlun



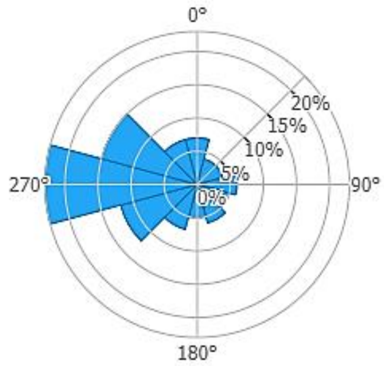
c) Wind freq. rose in Amman



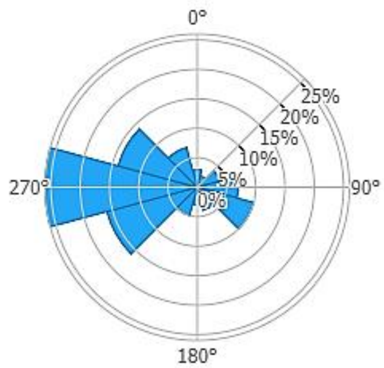
d) Wind freq. rose in Aqaba



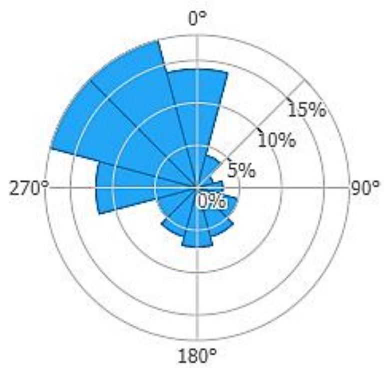
e) Wind freq. rose in Balqa



f) Wind freq. rose in Irbid



g) Wind freq. rose in Jarash



h) Wind freq. rose in Karak

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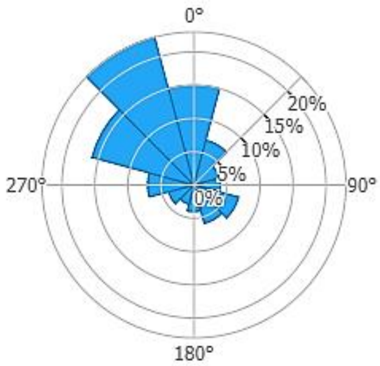
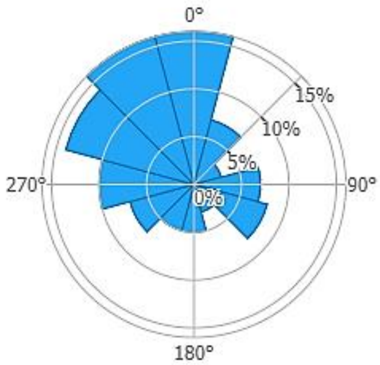
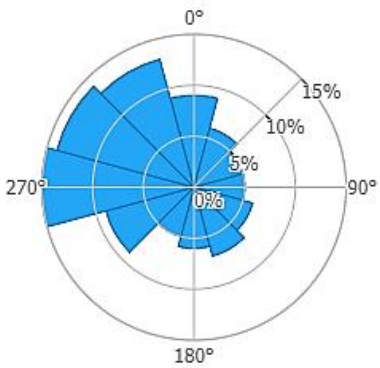


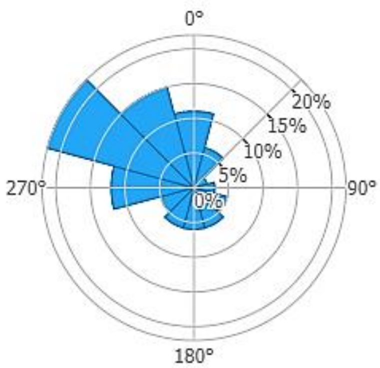
i) Wind freq. rose in Ma’an



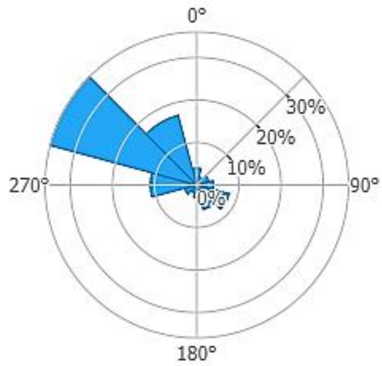
j) Wind freq. rose in Madaba



k) Wind freq. rose in Mafraq



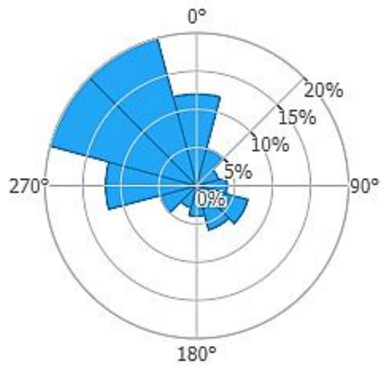
l) Wind freq. rose in Tafilah



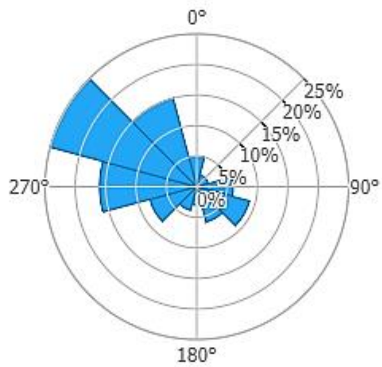
m) Wind freq. rose in Zarqa

Figure-8. The wind frequency rose in Jordan governorates (Ajlun, Amman, Aqaba, Balqa, Irbid, Jarash, Karak, Ma’an, Madaba, Mafraq, Tafilah, Zarqa)).

2. Wind speed rose:



a) Wind speed rose in Jordan



b) Wind speed rose in Ajlun

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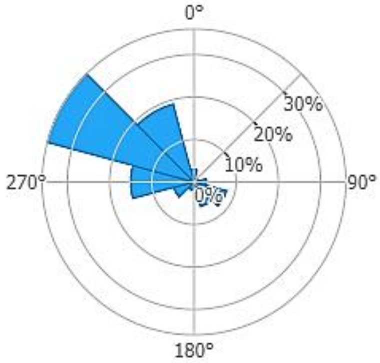
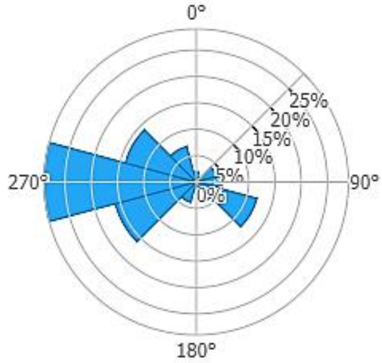
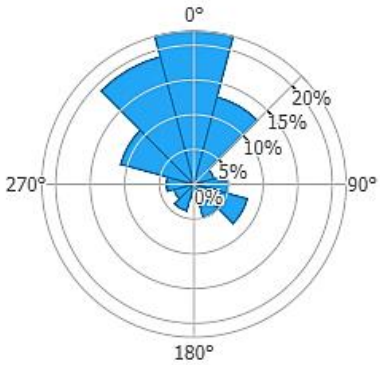


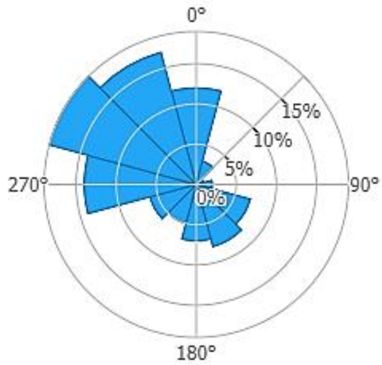
c) Wind speed rose in Amman



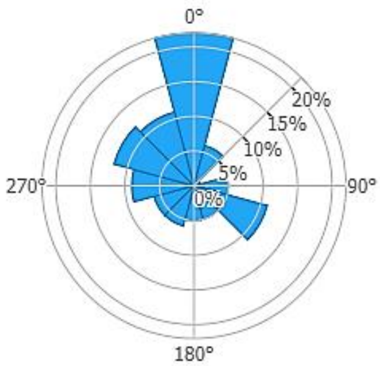
g) Wind speed rose in Jarash



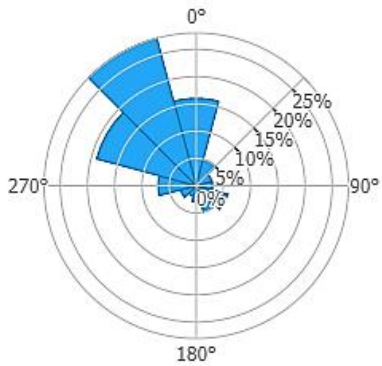
d) Wind speed rose in Aqaba



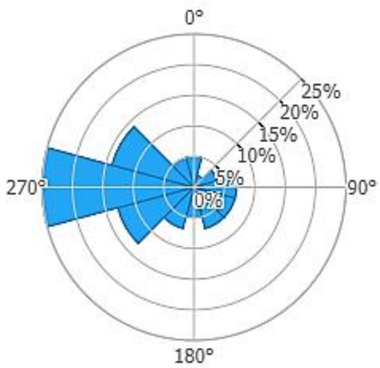
h) Wind speed rose in Karak



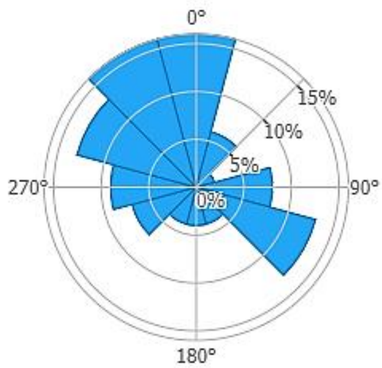
e) Wind speed rose in Balqa



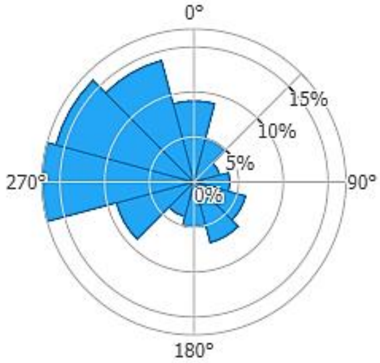
i) Wind speed rose in Ma'an



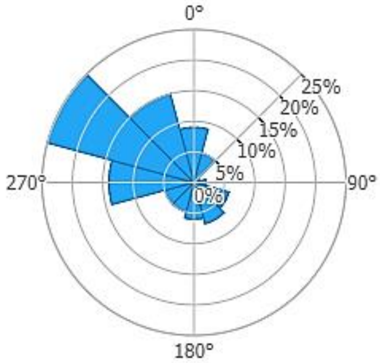
f) Wind speed rose in Irbid



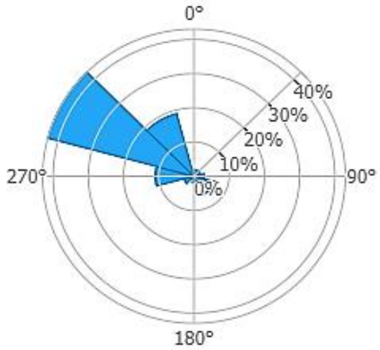
j) Wind speed rose in Madaba



k) Wind speed rose in Mafraq

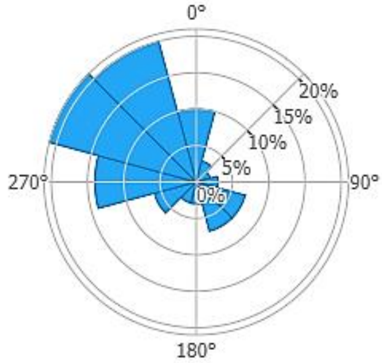


l) Wind speed rose in Tafilah

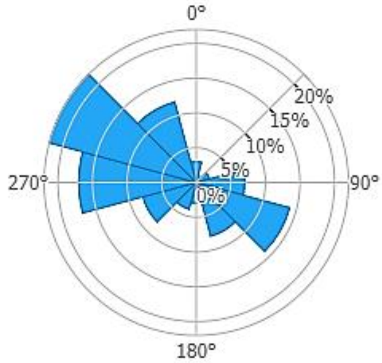


m) Wind speed rose in Zarqa

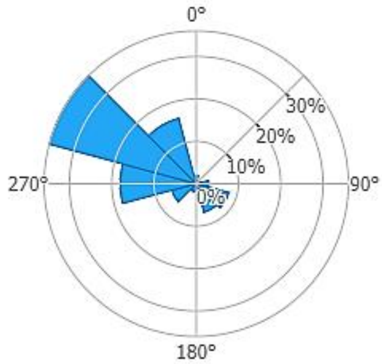
Figure-9. The wind speed rose in Jordan governorates (Ajlun, Amman, Aqaba, Balqa, Irbid, Jarash, Karak, Ma'an, Madaba, Mafraq, Tafilah, Zarqa)).



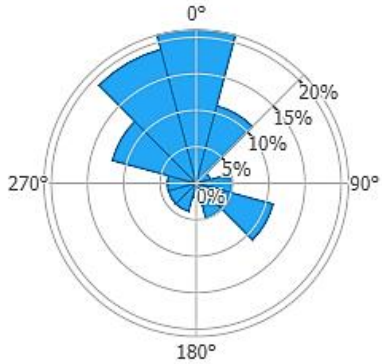
a) Wind power rose in Jordan



b) Wind power rose in Ajlun



c) Wind power rose in Amman



d) Wind power rose in Aqaba

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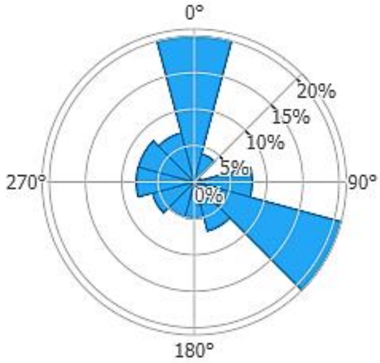
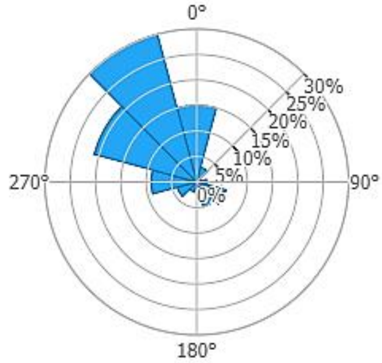
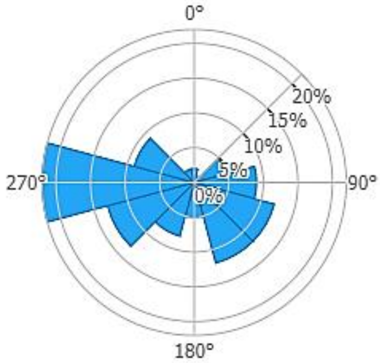


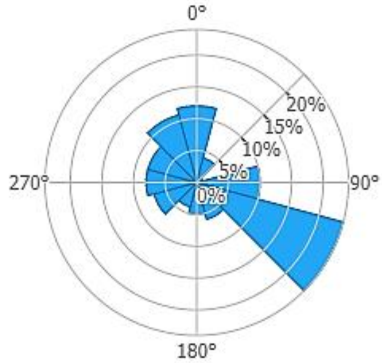
e) Wind power rose in Balqa



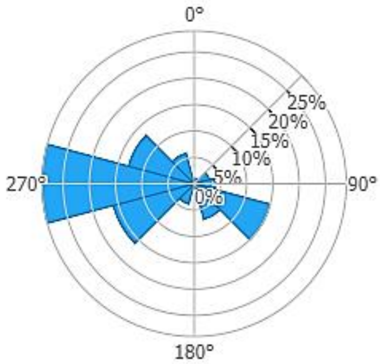
i) Wind power rose in Ma'an



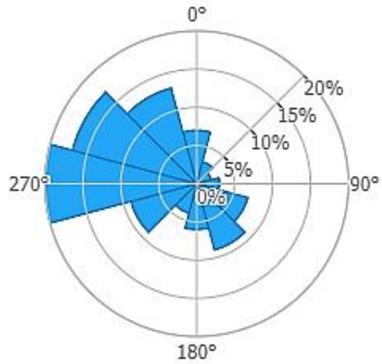
f) Wind power rose in Irbid



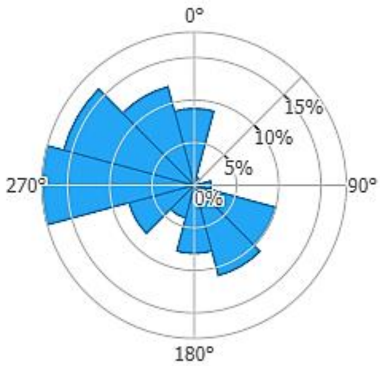
j) Wind power rose in Madaba



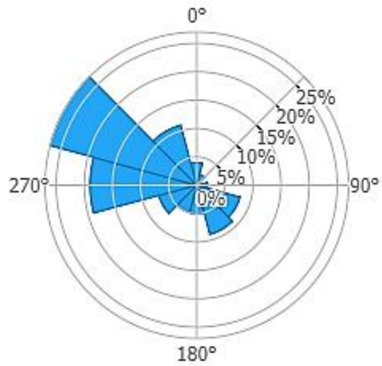
g) Wind power rose in Jarash



k) Wind power rose in Mafraq



h) Wind power rose in Karak



l) Wind power rose in Tafilah

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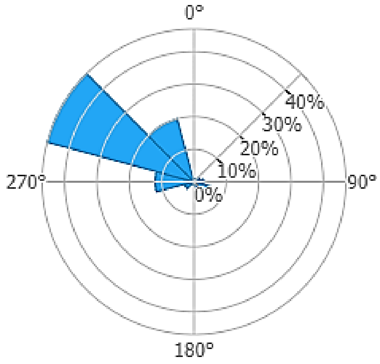


m) Wind power rose in Zarqa

Figure-10. The wind power rose in Jordan governorates (Ajlun, Amman, Aqaba, Balqa, Irbid, Jarash, Karak, Ma'an, Madaba, Mafraq, Tafilah, Zarqa).

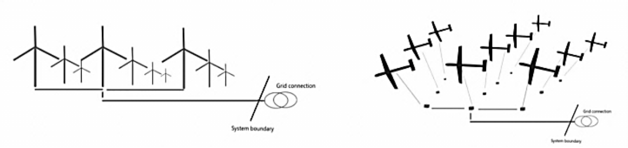
It is noted that:

- Nearly all of the wind in the governorates of Aqaba and Ma'an produces the most mean power density in a northwesterly direction.
- The direction of the wind distribution in Ajloun, Jarash, Mafraq, Amman, Zarqa, Karak, Balqa, Madaba, and Tafilah is toward the west.
- Wind distribution in the WSW in the Irbid governorate.

Implementing an airborne wind energy system project in Jordan has promising potential. With its geographical location and ample wind resources, Jordan could benefit from harnessing wind energy using AWES. It would contribute to the country's renewable energy goals and help reduce reliance on traditional energy sources. It's an exciting opportunity for sustainable development.

9. PAYBACK PERIOD

Because this type of energy system is still under development the model for the airborne wind energy (AWE) system primarily relies on information provided by Ampyx Power. However, it's important to note that the data provided isn't based on an actual large-scale system design but, it's calculated using scaling estimations from previous designs and predictions for future systems. In comparing the (AWE) and Horizontal Axis Wind Turbine (HAWT) technologies, we consider a hypothetical farm with a capacity of 50 MW, Each individual (AWE) & (HAWT) system has a power rating of 5 MW each. And situated at a distance of 15 km from the grid. Both the (AWE) & (HAWT) systems are modeled to operate at the same specific location. However, it's important to note that environmental conditions can vary with height from the ground. As a result, AWE systems are likely to experience higher average wind speeds compared to HAWT systems in the same locations (Van Hagen, 2021).



a) HAWT farm b) AWE farm

Figure-11. Visualizing 50 MW Farms and System Boundaries.

Table-4. Main AWE specification.

Topic	Value/Description
Location	Onshore
Rated power	5 MW
Capacity factor	52.8% at 11 m/s
Lifetime	20 years
AWE type	Ground generation, Rigid wing
Wing span	53.7 m
Average flight height	250 m
Tether length	1200 m
Tethering:	Two sections on a single tether
Drivetrain	Hydraulic

Table-5. Main HAWT specifications.

Topic	Value/Description
Location	Onshore
Rated power	5 MW
Capacity factor	46.9% at 10 m/s
Lifetime	20 years
Rotor diameter	126 m
Hub height	117 m
Generator type	DFIG
Tower type	Steel cylinder

Table-6. Farm Specifications.

Topic	Value/Description
Farm size	50 MW
No of System	10
Service Life	20 years
Location	Onshore
Distance to Grid	15 km
System Distance AWE	1* Tether Length (1200 m)
System Distance HAWT	7* Rotor diameter (882 m)

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Table-7. Energy Production Summary.

Parameter	Unit	AWE	HAWT
Full energy input (farm)	MWh	163772.9	222579.5
Rated power farm	MW	50	50
Average wind speed	m/s	11	10
AEP* farm	MWh/year	231264.0	205442.8

*AEP: Annual Energy Production.

The Energy Payback Time (EPBT) refers to the amount of time it takes the system to recover the energy used in its production and operation. It includes all energy consumed throughout the system's entire lifespan.

$$EPBT = 12\frac{Life\ Cycle\ Input\ Energy}{AEP}$$

(AWE) systems have a faster payback time which is equal to 8.5 months, while (HAWT) systems take 13 months to recover all input energy.

The Energy Return on Investment (EROI) quantifies how much energy is obtained as output compared to the energy invested as input over the system's lifespan.

$$\text{EROI} = \frac{\text{Total Lifetime energy Produced}}{\text{Total Lifetime energy Required}} = \frac{\text{AEP. Service life}}{\text{time Cycle Input Energy}}$$

(AWE) the system has a higher (EROI) which is equal to 28.2 times its input energy while the (HAWT) system will generate only 18.5 times its input energy.

Table-8. EPBT & EROI.

Parameter	Unit	AWE	HAWT
EPBT	Months	8.5	13
EROI	-	28.2	18.5

These findings are derived from the research conducted by Luuk van Hagen in 2021, titled "Life Cycle Assessment of Multi-Megawatt Airborne Wind Energy." The study aimed to find the Energy Payback Time and Energy Return on Investment for (AWE) and (HAWE) systems.

10. CONCLUSIONS

Is the AWE system the superior and reliable replacement for the traditional wind turbine system? A thorough study was made to knowledge that, including the generation categories, the wing nature, and the variation of AWE against HAWT. As a sequel, we inferred that the ground generation system is the best option in many aspects. But looking at the conflict of whether the rigid aircraft or the flexible kite is the best choice. After all the aim here is to produce more efficient power, and that will be achieved by using the flexible kites whose aerodynamic performance is strongly coupled to the deformation of the wing. Though there are some limitations to this study, the field of AWE aims to tackle these limitations by producing wind energy at higher altitudes and with a much lower environmental footprint. However it is still at an early stage of development, and better models are needed to make the system more robust. Jordan possesses abundant wind energy potential that can be effectively harnessed for power generation, particularly in regions where the yearly average wind velocity surpasses 7 m/s (at a height of 10 m). As we ascend, the wind speed further amplifies, opening up even greater opportunities. Implementing the AWE system would have a positive effect due to the speed and direction of the wind in most governorates. There is no doubt that this type of renewable energy is interesting and calls for increased research and development, especially after studies have shown that it has a lower cost, shorter payback time, and other interesting features.

ACKNOWLEDGEMENTS

Doctor Rami S. Rzouq provided valuable and constructive suggestions to the authors during the planning and development of this research work. His generosity in donating his time has been greatly appreciated.

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