WEC Development Project

Winter Semester 2025/2026

Final Design Report

Project Name: **Optimus Syria**

Sub Project: **Project Development**

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Abstract

This report presents the project development and pre-feasibility work for *Optimus Syria*, including site selection, constraint screening, energy yield modelling, and an initial economic assessment for a country-specific onshore wind turbine concept (OSyr160-5.0MW at 100 m hub height). A multi-criteria comparison of candidate regions (wind resource indicators, grid proximity, transport/logistics, geotechnical suitability and operational security) resulted in the selection of the tendered Qattinah area close to the City of Homs. Site screening was refined through GIS "white mapping" in QGIS, translating exclusion criteria (settlements, roads, water bodies, and powerline safety buffers) and terrain layers into usable siting zones, complemented by assessments of bird migration sensitivity, transport requirements from Tartous port, relevant noise and shadow-flicker benchmarks, seismic considerations, soil investigations, and the potential role of battery energy storage. Wind resource characterization combines met-mast measurements (10 m and 40 m, extrapolated to hub height) with ERA5 reanalysis via MCP in WindPro, yielding an average hub-height wind speed of 8.49 m/s and Weibull parameters supporting turbine sizing. The WindPro PARK simulations estimate 22.49 GWh/year AEP for a single turbine (21.91 GWh/year with curtailments) and 79.48 GWh/year for an optimized four-turbine layout with curtailments. The techno-economic model indicates a total CapEx of roughly €5.30 million, an LCOE of 4.917 ct€/kWh, an IRR of 16.61%, and a payback period of 11 years under an IPP/PPA framework, suggesting strong feasibility subject to on-site verification and stakeholder permitting.

List of abbreviations

Abbreviation	Meaning
WTG	*Wind Turbine*
MW	*Megawatt*
AEP	*Annual Energy Production*
LCOE	*Levelized Cost of Energy*
CapEx	*Capital Expenditures*
OpEx	*Operational Expenditures*
LiDAR	*Light Detection and Ranging*
FLH	*Full Load Hours*
MWh	*Megawatt Hours*
NPV	*Net Present Value*
MCP	*Measure Correlate Predict*
STATGEN	*Statistical Generation*
RESGEN	*Resource Generation*
OSyr160-5.0	*Optimus Syria Turbine 160m 5.0 MW*
NSA	*Noise Sensitive Area*
BImSchG	*Federal Immission Control Act ("Bundesimmissionsschutzgesetz")*
dB(A)	*Decibels A-weighted*
QGIS	*Quantum Geoinformaticssystem Software*
TIN	*Triangulated Irregular Network*
LMA	*London Metal Exchange*
PGA	*Peak Ground Acceleration*
BESS	*Battery Energy Storage Systems*
FS	*Feasibility Study*
IRR	*Internal Rate of Return*
P90	*Probability of Exceedance (90% confidence level)*
WHO	*World Health Organisation*
OSM	*Open Street Map*
DEM	*Digital Elevation Model*
OEM	*Original Equipment Manager*
IPP	*Independent Power Producer*
PPA	*Power Purchase Agreements*

List of symbols

Abbreviation	Definition	Unit
ρ *(rho)*	*Density*	*kg/m*^{3}
ω*(omega)*	*Angular Velocity*	*rad/s*
C_p	*Power Coefficient*	/
P	*Power*	*W*
v	*Windspeed /Windbin*	*m/s*
v_{ref}	*Windspeed at reference height*	*m/s*
h_{ref}	*Reference height*	*m*
h	*Height (hub height)*	*m*
z_0	*Roughness factor*	/
A	*Scale factor*	/
k	*Shape factor*	/
n	*Rated rotational speed*	*rpm*
λ	*Tip speed ratio*	/

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1 Introduction

Written by Luis Urhahn

As the global community accelerates its transition toward sustainable energy systems, the strategic deployment of renewable infrastructure has evolved from a climate necessity into a cornerstone of national security and economic recovery. For Syria, a nation currently navigating the challenges of extensive infrastructure reconstruction and energy shortages, wind energy represents a transformative opportunity. Beyond carbon reduction, it offers a decentralized and resilient solution to a power grid heavily strained by years of instability and a reliance on volatile fossil fuel markets.

Syria is geographically characterised with several high-potential wind corridors, most notably along the eastern side of the mountain ranges and across the central plains. These areas benefit from stable, high-velocity wind patterns that are ideally suited for wind energy production. However, this potential remains almost entirely untapped. The current state of wind energy in Syria reveals a significant gap between theoretical potential and actual implementation. To date, there are only two commercially operational wind turbines in the entire country. The present political situation creates difficulties in identifying a suitable and protected location for a wind farm.

The Optimus project has been designed to support this development. It is a pioneering effort to progress from ideas to a theoretical approach for developing a new turbine for the country. By presenting this turbine as the next development in Syria's renewable energy sector, the project aims to provide a decentralised, robust power solution. Serving as a demonstration project for future wind projects, it will show that sustainable energy is a viable option for an emerging country and the most effective way to achieve a modernised, independent energy future.

Project Objectives

The primary objective of the Optimus project is the development of a sustainable, efficient, and country-specific wind turbine for Syria. The sub-task assigned to the project development team is to define and analyse the location for the wind turbine and to research all the sub-conditions regarding the development of a wind turbine in Syria. The present study aims to address the discrepancy between theoretical wind potential and its practical implementation by addressing the multifaceted challenges of site selection, site potential and financial viability.

By employing advanced simulation tools and industry-standard methodologies, this report aims to:

- Identify and validate optimal locations through multi-criteria site analysis.
- Quantify the available wind resource and expected energy yield.
- Assess the environmental and logistical constraints inherent to the Syrian context.
- Determine the economic feasibility and long-term sustainability of the project.

Scope of Work

This report follows a standard project development cycle, moving from large-scale site assessments to small-scale technical details and financial planning. The analysis is divided into several crucial work packages:

- **Site Selection & Resource Assessment:** Performing a comprehensive spatial and meteorological evaluation across various regions in Syria to identify optimal development zones. This phase involves a multi-criteria decision-making process, comparing regional wind potential against infrastructure proximity and historical meteorological data.

- **Technical Design & Infrastructure Planning:** Defining turbine characteristics, formulating a transportation and grid connection plan tailored to the local infrastructure and designing an realistic windfarm area layout with the help of QGIS.
- **Energy Yield Assessment:** Performing advanced modelling with WindPRO to calculate the Annual Energy Production (AEP), considering not only the performance of a single wind turbine, but also the potential of a windfarm layout, taking into account its losses and uncertainties. This includes the application of the PARK module to account for wake effects, terrain-induced speed-ups, and the integration of long-term climate data through Measure-Correlate-Predict (MCP) methodologies.
- **Impact & Constraint Analysis:** Evaluating the project by studying the environment and conducting a curtailment analysis to account for the location and environmental limitations.
- **Project Economics:** A comprehensive financial evaluation encompassing CapEx, OpEx, and the Levelized Cost of Electricity (LCOE) to determine the financial viability of the project.

Through this integrated approach, the report provides a comprehensive design plan for wind energy development, serving as a technical reference for upcoming wind farm projects and a contribution to Syria’s sustainable energy future.

2 Site Comparison and Selection

Written by Luis Urhahn

The following site analysis describes the different approaches taken by the individual team members, as we each conducted independent analyses of the site selection during the semester break in the summer of 2025. During the interim period, the majority of the group participated in regular meetings to present and compare their respective results. Consequently, there may be some overlap in the results and descriptions presented in this analysis. The primary task before the official start of the project was to identify a suitable and feasible location for the OSyr160-5.0 (Optimus Syria Turbine) wind turbine, which subsequently had to be developed.

2.1 Site Analysis by Sohilbhai Mansuri

Written by Sohilbhai Mansuri

2.1.1 Introduction

This project evaluates and develops a wind farm concept in Syria using a pre-feasibility workflow that reflects typical early-stage wind project development. The study begins with the proposal and screening of candidate locations using wind resource indicators and practical development constraints. Candidate sites are compared based on mean wind speed and power density at hub height, grid connection feasibility, logistics and access, terrain suitability, and early environmental sensitivity.

We have selected the Qattinah site based on multi-criteria comparison. For further study we have used QGIS for special analysis and constraint mapping, including the preparation of base maps, exclusion buffers, and identification of suitable land for turbine siting. For Environmental point of view, we have also considered the bird migration pathways and permitting implications. In addition to that report includes preliminary transportation and crane capacity considerations, as wind turbine components need to require to unload and transport to the destination.

2.1.2 Data Sources and Methodology

Wind data Source

Wind resource data we have collected using the Global Wind Atlas (GWA) [29]. For each site wind parameters were obtained at 100m hub height using the "data for 10% windiest area" view. Crucial outputs from this stage includes mean wind speed (m/s), mean wind power density (W/m²), and the wind frequency rose.

Assessment (GWA) is suitable for early-stage comparison and inspection but does not replace on-site measurements such as a met mast or LiDAR. Consequently, the results in this chapter should be interpreted as pre-feasibility indicators rather than bankable yield estimates.

Development feasibility criteria

With the Wind resource data site selection is based on below mention criteria, which is also suggested by many study reports like "wind power plant site selection" [28]. Grid proximity and connection feasibility (voltage level, substation distance, likely connection cost)

- Transport and logistics (distance to ports, road access constraints for turbine components)
- Terrain and constructability (slope, earthworks effort, access road complexity)
- Land availability and scale potential (contiguous land for layout, settlement density)
- Environmental and permitting sensitivity (e.g., coastal protected landscapes and bird corridors)

Data Sources used in this chapter

Table 1 summarizes the main datasets used for the site selection and comparison stage.

Data type	Dataset / Provider	Purpose in this study
Wind speed, wind power density, wind rose	Global Wind Atlas (DTU Wind Energy; World Bank Group/ESMAP) [29]	Pre-feasibility wind resource screening at 100 m
Base maps, roads, settlements (visual context)	Google Earth; OpenStreetMap (where applicable) [30]	Initial logistics and access review
Site coordinates and local constraints (project inputs)	Google Earth [32]	Consistency in comparisons between sites

Table 2-1: Data sources used for site screening and comparison.

During the site selection task, we had proposed site individually, after comparison we had decided final site. From my side I have suggested two sites as mention below:

1. Latakia (coastal/ridge-influenced site)
2. Tareen (inland plateau site near Homs)
3. Qattinah (Homs Governorate; final selected site for further development work)

Latakia and Tareen were proposed and analyzed, which provides high wind source and both sites are near to costal area so easy for transportation. Qattinah was then selected as final site as it has balanced performance of wind resource, grid connection, and also this site is among the proposed site for their future project.

Table 2 provides a summary of the sites coordinates and key wind metrics (100 m).

Site	Governorate / context	Representative coordinate (Lat, Lon)	Wind speed at 100 m (m/s)	Power density at 100 m (W/m²)	Notes
Latakia	Coastal / ridge-influenced	35.586689°, 35.735779°	6.22	266	Strong port access; weaker wind resource
Tareen	Inland plateau (Homs region)	34.75882°, 36.509285°	9.2	858	Highest wind resource among screened points; inland logistics
Qattinah	Inland; near Qattinah Lake (Homs)	34°40′22″N, 36°35′59″E	8.64	824	Final selected site; strong grid access and buildability

Table 2-2: Shortlisted sites and wind resource indicators at 100 m (GWA, 10% windiest areas) [29][32]

2.1.3 Wind Resource Assessment (Global Wind Atlas)

Latakia,

Lattakia Governorate, Syria,

Center (Lat, Long): 35.586689°, 35.735779° [29].

The main reason to proposed this site is coastal site, which provides easy transportation. From Global Wind Atlas outputs at 100m, the mean wind speed is 6.22 m/s and the mean wind power density is 266 W/m² [29]. As shown in theFigure 2-1, it has been noted that wind source direction towards the southern sector, which is consistent with complex coastal influences.

While Latakia benefits from closeness to port and costal infrastructure, the lower wind energy provides lower annual energy production related to other proposed sites.

Wind condition:

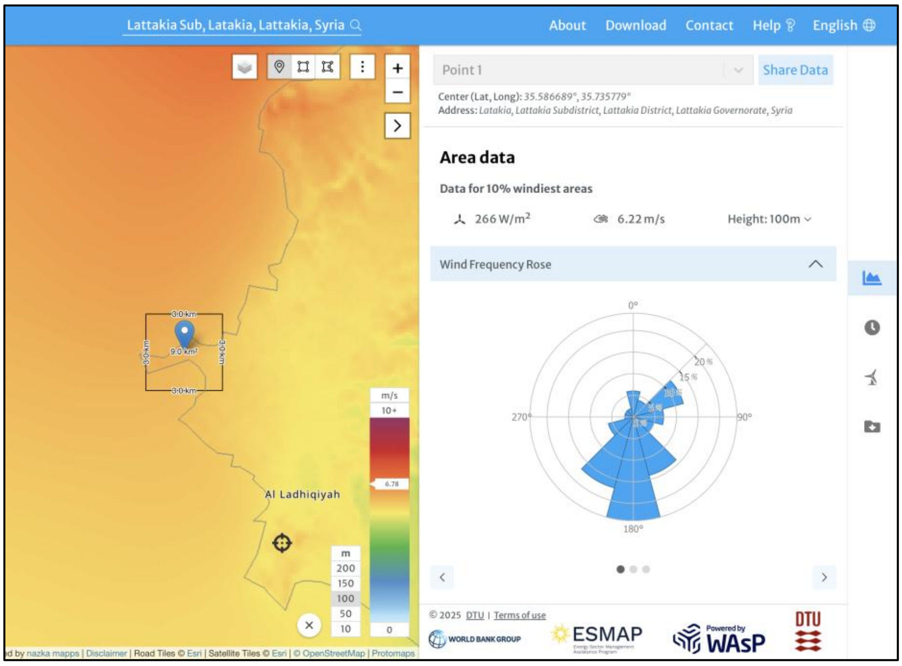


Figure 2-1: Latakia site [2]

Tareen

Khirbat Tin Nur Subdistrict, Homes District

Center (Lat, Long): 34.75882°, 35.509285° (google earth).

Tareen provides stronger wind source, which is the main reason behind one of the proposed sites. At 100 m hub height, Global Wind Atlas indicates a mean wind speed of 9.2 m/s and a mean wind power density of 858 W/m² (Global Wind Atlas). This wind power is significantly higher than another proposed site.

From Figure 2-2, most of the wind source from west (270°), which is favorable for early layout concepts. However, Inland Sites require detailed logistic planning from transporting large components of turbine from port and grid costs depend on distance and voltage level of nearby substation.

Wind condition:

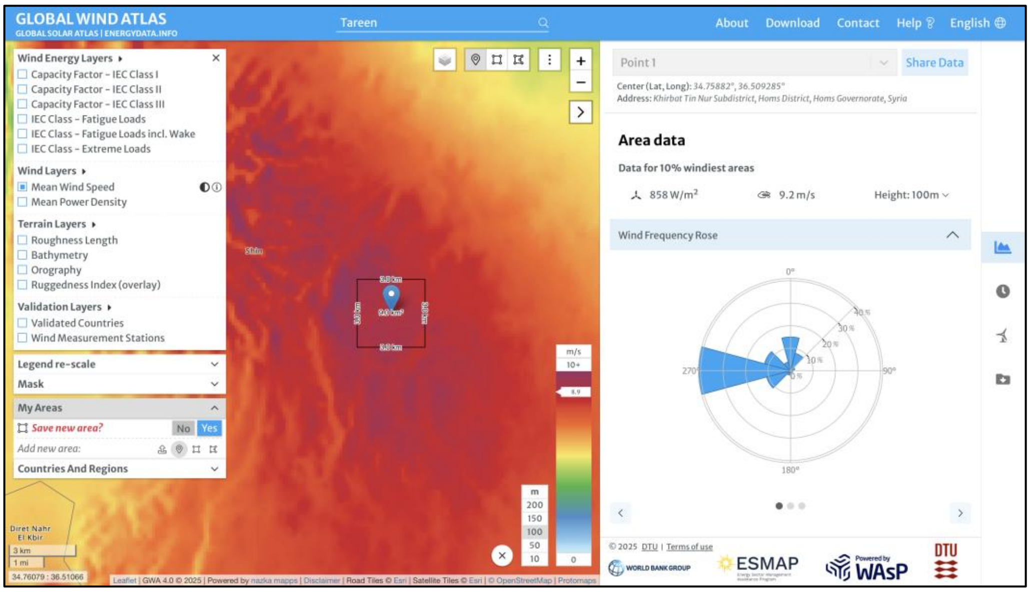


Figure 2-2: Tareen site [2]

Qattinah (Final selected site)

Qattinah (Homes Governorate) was selected as final site because it has strong wind resource, grid connection, and this site is among the proposed site of Syria for their upcoming project. At the project coordinate 34°40′22″N, 36°35′59″E the mean wind speed at 100 m is 8.64 m/s and the mean wind power density is 824 W/m² [29]. The major wind direction is 270° (west), denoting a highly stable main flow direction.

Overall, I have suggested Latakia and Tareen sites, as explained above, however for further study, with all group members we are agreed with Qattinah site. This site is among the future project proposed site of Syria, which is one of the main reasons among the pivotal factor for selection.

2.1.4 Development Probability comparison

Grid connection probability

Location of Grid connection plays vital role during the selection of site, as cost and schedule of the project also depend on that. From the data of Open infrastructure map, Latakia has an access to regional substations, but for specific location it may require additional high voltage lines depending on the final connection point. Tareen is located in Homes, which area has an advanced facility compare to previous site, like it has major transmission infrastructure; nevertheless, the selected site is located little far away from substation so again it boosts the cost for transmission line.

For Qattinah, it has a stronger grid connection compare to other sites. Around 2.5 km selected Qatinah site is located from substation, which provide 230kv power supply [30]. Overall, this reduced distance advantage for reduced cost of transmission line and also reduced the routing and permitting complexity for connection.

Port access and transport logistics

Port location is also important factor for selection of site, as it provides logistic handling capacity for long blades, heavy nacelles, and tower section. And to transport all of these heavy and big components to site we also need proper transportation route, for all of requirements fulfil by Latakia site, which is one of the pivotal reasons behind proposal site. Tartous port is located nearest to latakia site, so it also reduces transportation cost.

In contrast, the site which is located far away from port area require long distance transportation which may require detail route analysis because of sharp turning, narrow roads, and may be at some area require strong road construction. Like Tareen, which is located around 180 km from port (via Home corridor) making long distance travel and likely require route check.

For Qattinah, distance from Tartus port is 86 km. Which access through M1 road and 6 km earthen road, in which earthen road may require to improvement during construction planning.

Final Site selection: Qatinah

Overall, as explained previously that for site selection crucial factors are wind resources, grid connection, transportation, port location and soil. By analysing each of the factor we found that in grid connection and low constructability risk Qattinah achieves highest role among all. However, Tareen remains attractive in wind source, but in grid connection possibility and transport factors this site is power as compare to Qattinah. Latakia has good access for port but power in all other factors. So, by comparing all the sites with above mention factors Qattinah plays a major role among all, which leads to select as final site.

The key selection reasons are summarised as below [29] [32] :

- High wind source at 100m (8.64 m/s; 824 W/m²) with only one directional stability (270° west)
- Strong grid viability with 230 kv connection (substation at ~2.5 km).
- Good soil condition for construction (flat and dry land) so lower civil work complexity.
- Active transport road from Tartous port (M1 road ~86 km) within 6 km of earthen road.
- One of the proposed locations for national development priorities (as informed by Professor’s friend who is working in Syria).

Limitations

Site selection based on early-stage dataset, key limitation include:

- Wind source data collected from Global Wind Atlas, which require authentication by on site measurement.
- Grid connection and Substation distance data derived from Google Earth and Open infrastructure Map, which must be confirmed with authorities’ grid and site visit.
- For transportation (road suitability for heavy and big components), require detail analysis of route (bridge, turning radius and clearance)

2.2 Site Analysis by Sila Ceren Cetin

Written by Ceren Cetin

This part of the report outlines the progress made during the summer research phase for establishing a wind farm in Syria. The study covers the legal framework, regional screening of four primary locations (Al-Qanniye, Latakia, Ar-Raqqa, and Aqrab), and a detailed technical deep-dive into the most promising sites in Latakia and Tareen.

2.2.1 Legal Framework and Permitting

The project's foundation rests on a thorough understanding of the Syrian energy sector's regulations:

Legislation: The 2010 Electricity Law and its 2021 amendments permit private and foreign entities to generate power and sell it to the national grid.

Investment Incentives: Investment Law No. 18 of 2021 provides tax exemptions and customs benefits for renewable energy projects.

Permitting Process: Key milestones identified include obtaining an investment license from the Syria Investment Authority (SIA), a generation permit from the Ministry of Electricity, and Environmental Impact Assessment (EIA) approval [13].

2.2.2 Preliminary Regional Assessment

Four strategic points were analysed based on wind speed, grid connectivity, and logistics:

Al-Qanniye: Solid wind speeds (6.35 m/s) and proximity to a 230 kV line, though land use is competitive due to local farming.

Latakia: Strategic location near the harbor with wind speeds around 7.6 m/s.

Ar-Raqqa: Good infrastructure (near M1 motorway) and wind speeds of 7.29 m/s, offering potential for academic collaboration with nearby universities.

Aqrab: Exceptional wind resource (10.21 m/s at 100m) but requires significant investment in road infrastructure [10] [11].

2.2.3 Detailed Site Deep-Dive: Latakia and Tareen

Latakia Sites

Two specific points were analysed in the Latakia region. While Site 1 (Qastal Maaf) offers high power density (617 W/m^2), it is remote. Site 2 is closer to the 230 kV and 400 kV "Lattakia-2" stations, making grid integration more cost-effective, despite potential land-owner negotiations.

Tareen Site Analysis

Tareen emerged as a high-priority location. The technical data indicates:

Wind Profile: Average speeds reaching 9.69 m/s to 9.85 m/s at 100m height [10].

Logistics: Excellent transport links via the M1 motorway and Route 43, facilitating the movement of turbine components from Tartus port.

Geotechnical Suitability: Soil analysis shows stable pH levels (7.2-7.4) and increasing bulk density with depth, which is favourable for heavy turbine foundations [12].

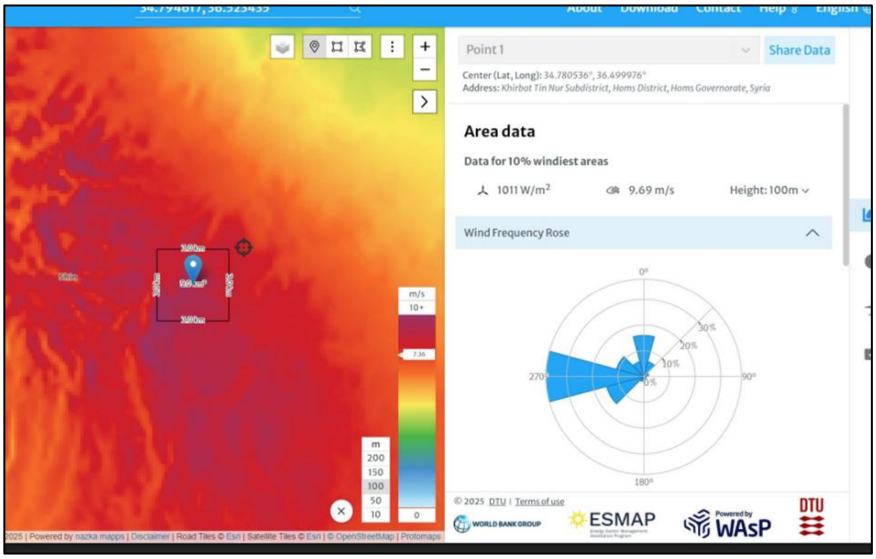


Figure 2-3: Wind Resources in Tareen [10]

2.2.4 Tareen Geotechnical & Soil Profile

The feasibility study for the Tareen site includes a preliminary soil analysis, which is vital for turbine foundation engineering:

Soil Composition & pH: Analysis conducted at coordinates 34.794617, 36.523435 shows a stable chemical environment with pH levels ranging between **7.20 and 7.40**. This alkalinity is favourable as it minimizes the risk of corrosion for reinforced concrete foundations.

Bulk Density: The data indicates a consistent increase in soil bulk density with depth, moving from approximately **1475 kg/m³** at the surface to over **1600 kg/m³** at lower strata (35cm and below). This trend suggests a stabilizing soil structure suitable for supporting heavy structural loads.

Physical Properties: The presence of **Silt (around 31-32%)** and organic carbon content has been mapped, providing a baseline for future deep-drilling geotechnical surveys.

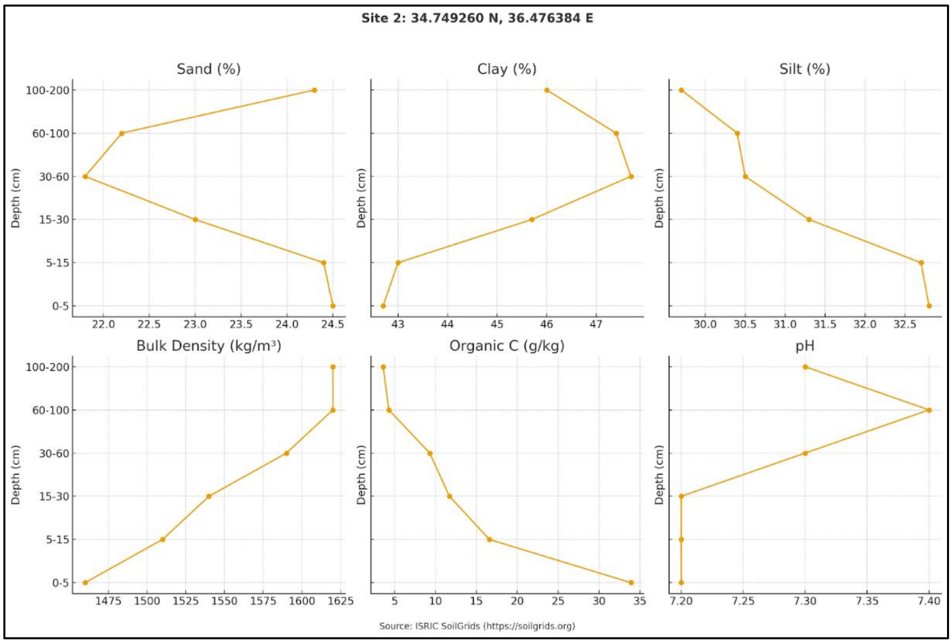


Figure 2-4: Soil condition in Tareen

2.2.5 Methodology & Site Selection Process

The site selection followed a multi-criteria decision-making process:

Technical Parameters: Evaluation of wind power density, average wind speeds at 100m, and seasonal stability.

Logistics & Infrastructure: Proximity to the **Port** for turbine transportation and accessibility via the **M1 motorways**.

Grid Integration: Analysis of distances to V substations to minimize transmission losses.

Data Validation: Initial focus was on the **Al Qanniye** region. However, following professional correspondence with **Dr. Alhrshy**, we identified a strategic area in the **Qattinah** region already designated for wind energy projects.

Comparative Analysis: To ensure accuracy, a comparative study was conducted between Al Qanniye and Qattinah using **NASA MERRA-2** and **ERA5** satellite datasets. The analysis confirmed that Qattinah not only offers high wind speeds but also provides superior data accessibility and alignment with existing energy planning.

2.3 Site Analysis by Luis Urhahn

Written by Luis Urhahn

In order to determine a suitable location for a wind turbine, it is necessary to define a number of key parameters regarding the turbine itself and the expectations of its use. However, given that the project will solely develop this wind turbine over the course of the semester, it is even more challenging to identify a suitable location. In this particular instance, it is assumed that a suitable location will first be identified, followed by the development of the wind turbine in accordance with the prevailing local conditions.

The following fundamental conditions and priorities were identified as the primary focus of the preliminary research:

1. wind resource viability
2. Strategic grid connection
3. Logistical accessibility
4. Geopolitical and operational security
5. Geotechnical suitability
6. Regulatory and legislative compliance

The development of wind turbines or wind farms is dependent on optimal wind conditions, proximity to the nearest substation, and a suitable grid connection. However, it is important to emphasise that the assessment of the development in a country such as Syria must be undertaken with a distinct perspective compared to Europe. In the context of the prevailing political situation in Syria, it is imperative to select a location that will maintain political stability and security for the duration of the 20-year turbine lifetime. It is essential to prioritise the safety of the turbine and the reliability of the constant feed into the power grid. Consequently, this factor must be given primacy over others. In this case, soil conditions are not a top priority, but they are of fundamental importance, as without solid soil conditions, it would be impossible to erect a turbine, or the implementation would involve high costs.

In contrast to developments in Germany or Europe, where legal requirements for the implementation of wind turbines are a top priority, it is assumed that these do not initially meet the highest requirements in Syria. There are currently no clear guidelines for the implementation of renewable energies in the country. Only a few restrictions have been defined, which must be taken into account in the detailed planning. This aspect must be considered in the further development of the project and will be included in the analysis of the site.

In this study, several locations were subject of the detailed analysis. Using a pros and cons list, they were evaluated and classified according to the given conditions. The study did not focus on a specific location, but rather on a specific area. The exact locations can be found in the Figure 2-5 and Table 2-3. The evaluations are also documented in Appendix AI.

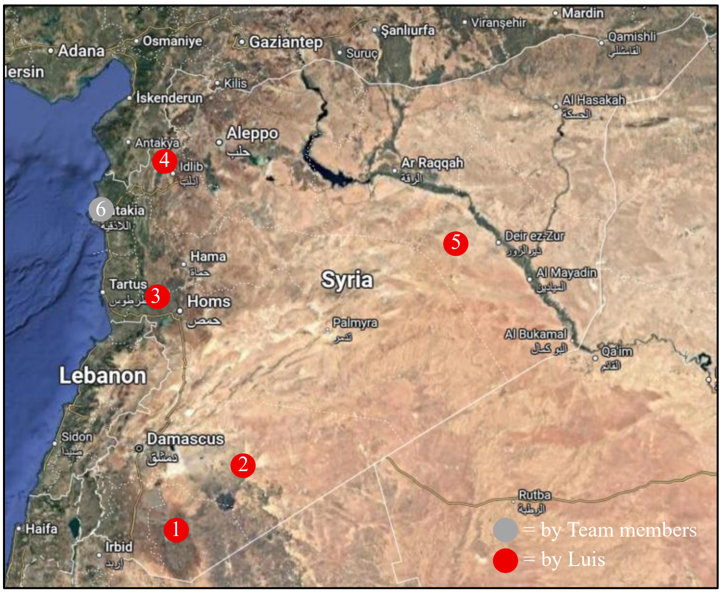


Figure 2-5: Overview of the different areas [GoogleMaps]

Area	Name
Area 1	As Suwayda
Area 2	Barek
Area 3	Tareen
Area 4	Maryamayn
Area 5	Ash Sholah
(Area 6)	(Latakia)

Table 2-3: Names of the areas

Due to the unstable political situation in the south of the country, the significant distance to the nearest ports and the partial damage to the infrastructure, Areas 1 and 2 south of Damascus were excluded from further analyses. Although the wind conditions in Area 5 are excellent and highly suitable for the implementation of a wind farm, there are significant challenges in terms of connection to the power grid, logistics, transport and electricity demand in this region. Implementation would therefore be highly complex, which is why this region is also not included in the analysis. Due to the favourable wind conditions, Area 4 is also well suited for wind energy generation. However, the transport infrastructure for a commercial wind turbine is quite challenging and would involve high costs for the construction of new roads. For this reason, this area is also excluded from the analysis.

For further investigation, only Area 5, the surrounding area of Tareen, remains. With very good wind conditions, good logistics and transport options, a relatively secure political environment and high energy demand with a nearby city such as Homs the area around Tareen suits best for the development of a wind turbine.

After consultation with the other team members, the decision was made to continue the investigation of the region around Latakia, a port city in northern Syria. A detailed analysis and comparison of these two regions have been carried out.

The region around Latakia also appears to be a very good location for wind energy. Wind conditions are good to excellent, there is a close connection to the nearest port, and there is also demand from the port city of Latakia. A detailed analysis of wind conditions shows that the main wind direction is from the east, which is contrary to expectations given the proximity to the sea. Due to the topographical conditions of the mountains, increased turbulence and inconsistent wind conditions are to be expected at this location. In addition, connection to the electricity grid would involve high costs, particularly due to the construction of a separate substation and connection to the main grid. In addition to the complex wind conditions and the costly grid connection, the region around Latakia is also characterised by a high population density, which makes it even more difficult to identify unused areas for wind energy. Appendix 1 and Appendix 2 contains a description of the wind conditions and the electricity grid connection.

Detailed investigations of the sites were also carried out in the region around Tareen. In this context, the focus was directed towards the grid connection and transport options in the region, as the wind conditions in this area are considered to be highly favourable, with only minor variations attributable to the low elevation variations of the terrain. The Figure 2-6 illustrates the potential sites in the Tareen region, which are listed in the Table 2-4. A comprehensive analysis of the different location is presented in appendix AII.

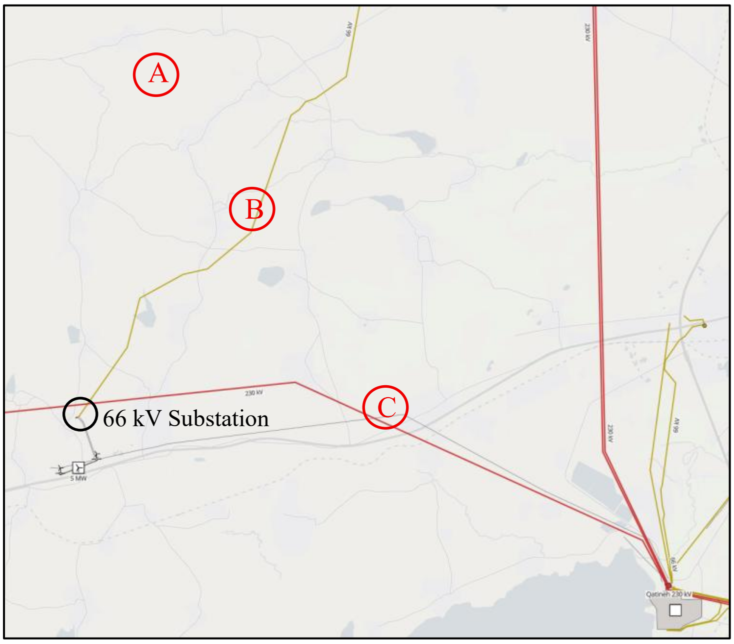


Figure 2-6: Detailed view on the area around Tareen [OpenInfrastructureMap]

Location	Name
Location A	Tareen West
Location B	Balqasah
Location C	Um Aledam

Table 2-4: Names of the locations

A relatively large, currently unused area is available at location A (west of Tareen). However, the distance to the nearest substation is simply too far (see Figure 2-6). In addition, the roads leading to the final location A create a significant challenge, as they pass through narrow villages. Although location B is in the immediate surroundings of the power line, it is still necessary to connect the turbine to the existing substation first. However, a corridor for the power line has already been constructed. As already mentioned in relation to location A, the transport options via the narrow roads and through the small villages are the limiting exclusion criteria for location B.

Overall, location C in Um Aledam is the most convincing due to the excellent transport options provided by the M1 highway. The location is in close proximity to the highway and has a significantly large area that is suitable for the installation of a wind turbine. The connection to the nearby substation is also along an already established corridor and is within the permissible tolerance limits. The 2 × 2.5 MW wind turbines already installed nearby support the assumption that the location is ideal for the construction of another wind turbine. The distance between the turbines would be great enough to prevent the wake effect from influencing the operation of the new turbine. The key data for the Um Aledam area are listed in the appendix AIII.

The location in Um Aledam offered the best conditions at the official kick-off of the project.

2.3.1 Tendered Windfarm Area: Qattinah

With the official start of the project at the beginning of the 2025/2026 winter semester, further details and data regarding wind energy developments in Syria were provided. Access to potential sites already designated for wind energy by the state was provided with the support of the University of Damascus [1]. The date of the tender is not known. The available tender listed five areas, which are shown in the Figure 2-7 below.

Figure 2-7: Tendered windfarm areas in Syria [1]

Two of the areas selected by the state are located close to the city of Homs and therefore also nearby the previously selected location in Um Aledam. A significant advantage of the areas advertised is the detailed data available on preliminary investigations that have already been carried out. For the location known as “Qattinah”, data on soil conditions and wind measurements at heights of 10 meters and 40 meters have already been collected.

Based on the new information, the project development team evaluated the options to reach a final decision on the site. In order to make an informed decision regarding the final location, the criteria listed above were re-examined and re-evaluated. Due to the relatively close proximity of the locations and the resulting strong similarity of the parameters, the environmental influences and the distance to the surrounding buildings were given more consideration. The pros and cons listed in the Table 2-5 below serve as a concise summary of the key factors for both locations. The different locations are shown in the Figure 2-8.

The distance analyses to the surrounding buildings are listed in Appendix 3 and Appendix 4. The results of the two distance analyses show that the minimum distance of 800 meters in the main wind direction is sufficiently covered. Consequently, no significant restrictions are to be expected. However, it should be noted that the distance in the other wind directions should be kept as wide as possible, as the turbine will cause noise in all directions due to the generator.

Um Aledam	Qattinah
Pros	
+ Excellent wind conditions, + Best transportation route, close to main highway M1, + Relatively close to 66kV substation, + Good soil conditions, + Safe area, + Demand for renewable energy in the area (City of Homs).	+ Excellent wind conditions, + Close to 66kV substation, + Safe area, + Demand for renewable energy in the area (City of Homs), + Available data for soil condition (proof) + Measured data for the wind resources for different hights, + Large area for the possibility of a windfarm, + Tendered area for wind energy.
Cons	
- Relatively small area, single turbine, - Close to the surrounding buildings, high probability for restrictions, - Uncertainty regarding the land lease / approval of the area, - No actual or measured values for soil and wind conditions.	- Sufficient soil conditions, plenty of water in the surrounding area, - Inaccurate information about surrounding buildings, barns, ruins.

Table 2-5: Comparison of the two final locations, Um Aledam vs. Qattinah

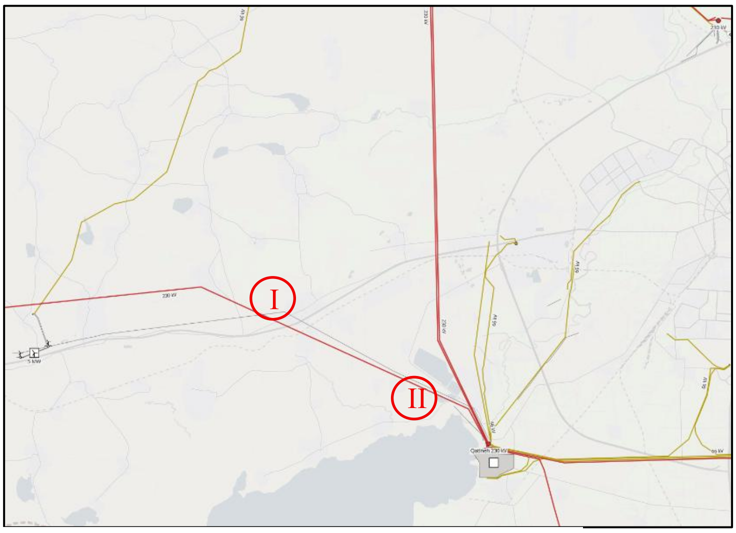


Figure 2-8: Locations of Um Aledam and Qattinah

Location	Name
Location I	Um Aldedam
Location II	Qattinah

Table 2-6: Location of Um Aledam and Qattinah

The presented advantages and disadvantages indicate that the benefits derived from the available data for soil and wind measurement, as well as the fact that the area is already designated for wind energy, favour the second location in Qattinah. The arguments against the site are not exclusion factors and can be disregarded for the time being. The already recorded wind data represent a significant database for calculating the wind energy yield potential. This ensures the reliability of the data, as it is based on realistically measured values and not on simulated or assumed data. It should be noted that the advantage is not limited to the energy yield calculation alone. In addition, meaningful and comprehensible information is also provided to the other teams developing the mechanical components of the turbine. For the reasons stated above, the location in Qattinah will be finalised.

Figure 2-9: View to the windfarm area in Qattinah [Pictures by Eng. Basem]

3 Detailed Site Analysis

Written by Luis Urhahn

The following chapter is dedicated to a detailed analysis of the site-specific conditions for the project location in Qattinah. The creation of a solid planning basis initially requires an evaluation of the logistical requirements and the existing transport infrastructure (transport routes). Another focus is on the geotechnical investigation of the soil conditions, which are of crucial importance for the foundations of the turbines, along with the meteorological evaluation of the wind characteristics.

In addition, the precise spatial boundaries of the wind farm are determined. Limiting factors such as ecological restrictions or distance regulations are taken into account when optimising the layout of the wind farm. At the same time, the technical specifications of the characteristic properties of the turbines are defined. The data obtained in the context of this site analysis serves as the basis for cooperation between the various project teams and is therefore of crucial importance for the successful realization of the overall project.

3.1 White Mapping

Written by Sohilbhai Mansuri

3.1.1 Objective and study context

This topic represent the GIS work process used for screen and map for wind turbine siting zones near Qattinah Lake, Syria by combining (i) constraints/ exclusion buffers (settlement, roads, water, powerlines etc.) with (ii)terrain layers (slope aspect, hill shade, DEM,). Result from that process were (a) “restricted areas” layers, (b) “usable wind siting zone” layer, and (c) exportable files (shape file/GeoPackage) for further use (WindPro). This GIS process follow site screening approach which describe in report, where number of special criteria are converted into exclusion layers and output layers is usable land for wind farm [28].

The study area is near the Qattinah Lack area in western Syria. The project site location was managed in WGS 84/UTM zone 36N (EPSG:32636) for data set and engineering measurements.

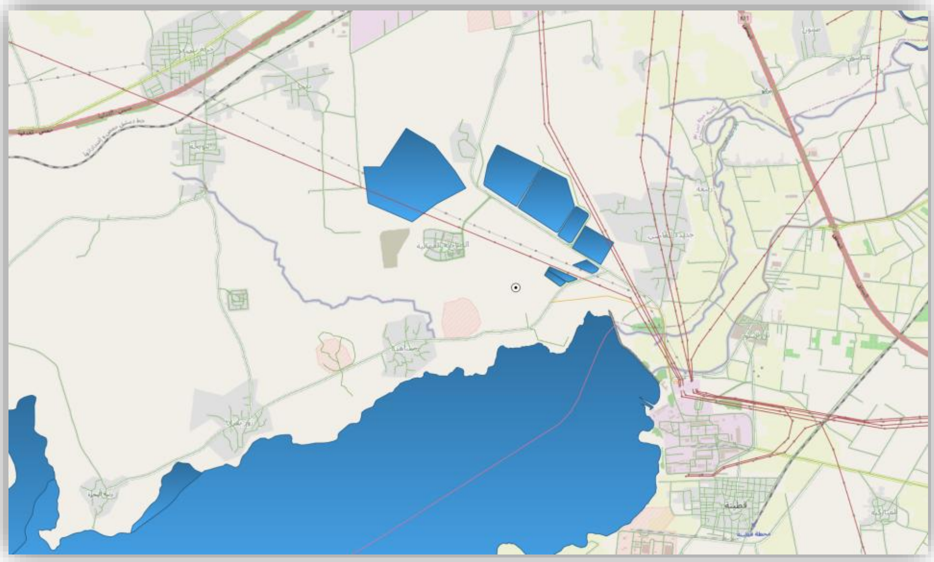


Figure 3-1: Study area overview and project reference point [4]

3.1.2 Data sources

During the primary stage as mention below data source used for screening:

1. OpenStreetMap (OSM) features:
   land use polygon, water bodies, roads, buildings, buildings and point of interests. This data used as base map as it provides the broad view of transport and land use context. Within the QGIS software, OSM is openly available [30][31].

2. Digital Elevation Model (DEM):
   DEM data helps to extract the topographic interpretation and to generate slop, aspect, hill shade layers for engineering context. Open data DEM source is SRTM

3. GIS result produced:
   Final usable wind farm zones produced through industrial/residential/water bodies /roads /power lines buffers and merged restricted areas.

The selected partition factors and the function of number of restricted layers follow established wind farm siting literature, which suggest that firstly, need to evaluate restrictive factors (exclusion mapping), then need to evaluate the applicable factors and optimization [28].

3.1.3 Methodological framework for site screening

The GIS screening was processed as follow:

Constraint Mapping (Exclusion Zones)

A vital step in wind farm site selection is to remove inappropriate areas first, such as protected or sensitive areas, infrastructure corridors, and safety buffers [28].

So, in this project, as mention below the constraint's layers were prepared and buffered to create exclusion zones.

(a) Residential and Industrial buffer:
   (to reduce noise, shadow and social impacts with selected site). Literature mention that there should be minimum distance from residential and industrial buildings as per local regulation and standard [28]. However, there are no any standard for this distance recorded for Syria country so those distance as per average range which is followed by most of the country standard, so 300m for industrial and 500m for residential building we had followed (Industrial_Buffer_300m and Residential_Buffer_500m).

(b) Road corridor buffer:
   (Transport safety and nuisance effects) M1 road (main road) is located around ~8km from selected site. As per the literature this distance should be minimum 5000m (from main road), for local road there are no illustration, however for selected site location there are earthen road, for that 70m buffer created to maintain safe distance (Road_Buffer_70m) [28]. In practise road buffer can be treated differently depending on the road used.

(c) Powerline Buffer/electrical corridor buffer:
(safety, clearness and construction constraints) This factor treated on both views, as it is better to have close distance from it so cost of electric line could be reduced, on the other view is should be on safe distance from turbine [28]. For this project 100m buffer created to maintain safe distance from powerline (Powerline_Buffer_100m).

(d) Watercourse / river buffer:
(environmental and construction risk) The report explain that selected area of wind turbine should be at safe distance from river / streams [28], for this project, Qattinah lake is located around ~2km, which comes under safe distance as per report [28]. Buffer used for water all water bodies for project was 300m (Water_Buffer_300m).

For this project, during the buffer creation all safe distance as per own illustration (based on standard followed by all countries, which within the safe range).
All constraint buffers were dissolved into a single layer (Restricted_Area_Merged), which provide a single area to be subtracted from the study area.

Figure 3-2: Restrictive area merged (Own illustration) [4]

Terrain Characterization (Engineering context)

Terrain significantly affects the turbine performers, constructability and cable routing. The literature number of times highlights slope/orography and elevation is vital factors [28].

In this GIS process four types of terrain visualization were used [31] [33]:

(a) DEM (Digital Elevation Model): Illustrate elevation distribution and is the base layer for the terrain metrics. SRTM-type DEMs are mostly used for primary stage [33].
(b) Hill shade: Provides the 3D visualization for hill, so it is easy to understand the valley, cut/fill complexity and ground level.
(c) Slope: Highlights steepness. The literature illustrated that the slopes greater than 25 degrees are mostly not recommended for wind farm construction [28].
(d) Aspect: Shows terrain facing direction, relevant for wind exposure interpretation and for understanding likely windward/leeward slope condition.
(all the above mention layer data from NASA, SRTM [33])

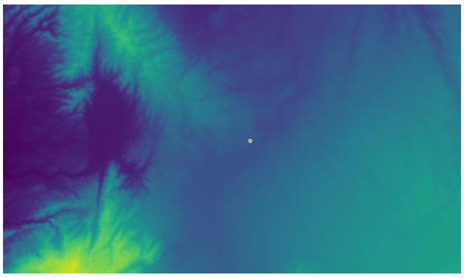


Figure 3-3:DEM (own illustration)

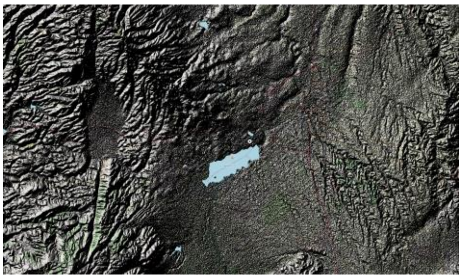


Figure 3-4: Hill Shade (own illustration)

Figure 3-5: Slope (own illustration)

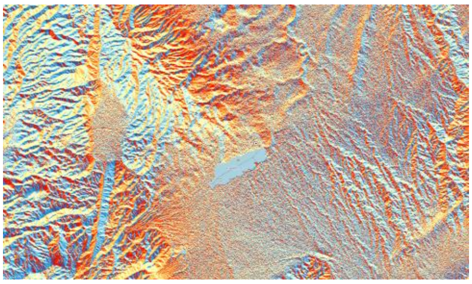


Figure 3-6: 8 Aspect (own illustration)

Usable land Mapping

After preparing the merged restricted layer, the usable wind siting zone was produced as mention below:

Usable area = Study area – Merged restricted area

This provides a defensible first pass map, which followed the “remove unsuitable area first” process describe in the wind siting literature [28].

Figure 3-7: Final usable wind siting area (own illustration [31])

3.2 Bird Migration and avifauna constraints

Written by Sohilbhai Mansuri

Syria serves as a pivotal geographical gateway for bird migration because of its location at the intersection of the three countries: Asia, Africa and Europe. Millions of birds cross this region twice a year, normally birds in the Northen hemisphere take a north-south path during the fall and the opposite direction during the spring.

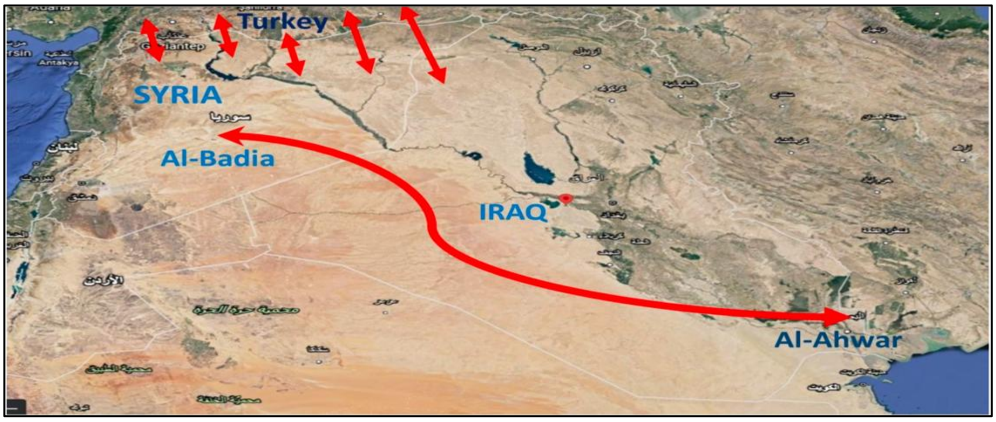


Figure 3-8: The main places of the relative convergence of biodiversity of migratory wild birds in Iraq, Syria, Turkey

Wind farm siting includes environmental restriction layers for example forest, rivers, lake, protected areas and bird migration route as that area are related to collision sensitivity. This is the vital part of during the first stage of screening, which is sited in literate [28]. Qattinah lake is located near (2km) to the final selected site, which is a wet land attract the birds.

It has been reported in the report "In Syria, 85 species were considered as winter visitors, 15species as summer visitors in an unlike statistic, 143 species of migratory birds stopped breeding in Syria. 71 species of migratory birds that do not breed. 83 species that live throughout the winter season. 15 species of birds that live throughout the summer. Also, 53 of these species of birds are considered endangered (Salloum, 2020)" [36].

The Crucial species of Syria:

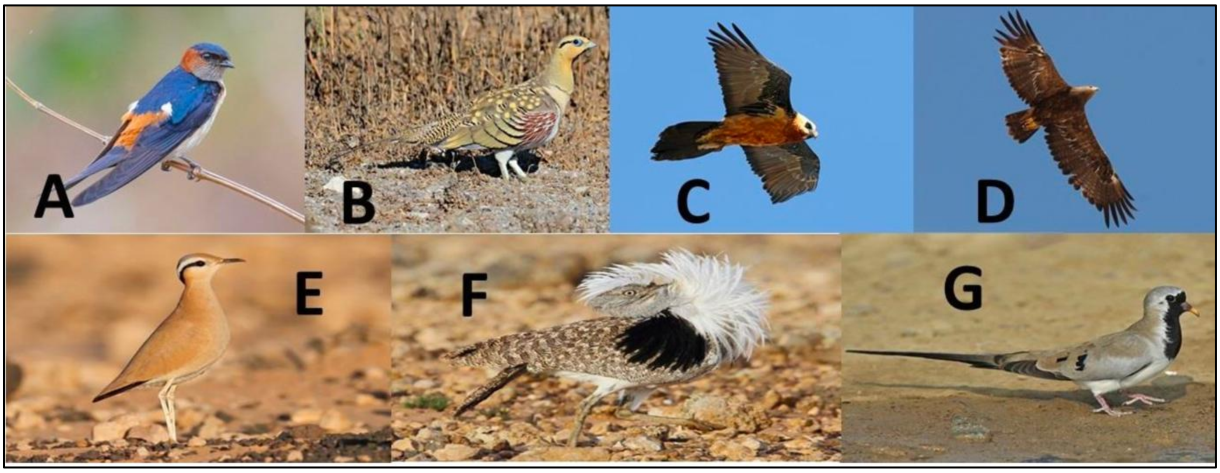


Figure 3-9: The most important species of migratory wild birds in Syria [36]

The most important species of migratory wild birds in Syria, which have been considered in the context of conservation concern and globally threatened with extinction.

A: Red-rumped Swallow (Hirundo daurica), B: Pin-tailed Sandgrouse (Pterocles alchata), C: Bearded Vulture (Gypaetus barbatus), D: Steppe Eagle (Aquila nipalensis), E: Cream-coloured Courser (Cursorius cursor), F: Houbara bustard(Otis tarda), G: Namaqua Dove (Oena Capensis) [36].

The Convention on Migratory Species (CMS) explained how flyways link breading and non-breading ranges across areas and sited that migratory species management must be consider across the connected routes [35].

Syria serves as a pivotal geographical gateway for bird migration because of its location at the intersection of the three countries: Asia, Africa and Europe. Millions of birds cross this region twice a year, normally birds in the Northen hemisphere take a north-south path during the fall and the opposite direction during the spring.

Because of the selected site is near to the wetlands-influenced landscape, internationally recognised AEWA priority waterbirds are treated as likely receptors during screening. Absence or presence and seasonal abundance must be confirmed by specific bodies [34].

International good practise wind projects require biodiversity issues, especially birds and bats be addressed through base line surveys and micro siting decision designed to reduce collision risk and habitat disturbance. The IFC environmental, Health and safety Guidelines for wind energy illustrate about biodiversity risk management.

3.3 Logistic and Transportation Assessment

Written by Sohilbhai Mansuri

Focus of this section is to evaluate the feasibility and risk of transporting wind turbine components through Port of Tartous to project area Qattinah. The objective is to (i)sum-up port handling capability (ii)identifying information gaps. Wind turbine logistic includes blade, tower section, nacelle, hubs, transformers and special transport frames.

Public reporting indicates that Tartous port is undergoing (or is on the planning for) a major modernization program. Public projects update's introduction of the port service assets such as a tugboat (~22m length) with 50-ton bollard pull, framed as part of operational and safety improvements [37].

Tartous port is best suited for project site Qattinah (Homes) wind turbine project because it is a primary coastal gate and this port is under the upgradation of performance and safety (as per publicly announced, there are no official data). However, publicly available open data is insufficient to certify that Tartous can handle the heaviest wind turbine components using port equipment alone. Therefore, project should process with verification plan requesting:

(i) Certified crane SWL charts and test certificates
(ii) Quay/yard bearing capacities
(iii) Berth/depth and laydown constraints

Once all of this mentioned information received, the project can select an import scenario (ship's gear vs. port cranes vs. mobilized heavy crane) and develop a safe, permitted transport corridor from Tartous to the wind farm site Qattinah.

3.4 Noise Regulation & Environmental Compliance

Written by Ceren Cetin

European and International Standards

To ensure the health and well-being of local communities, the following standards from Europe and the World Health Organization (WHO) serve as the primary benchmarks for the project:

Country / Organization	Day-time Limit (dB)	Night-time Limit (dB)	Context
Finland	45 dB	40 dB	Residential and holiday homes (Decree 1107/2015).
Sweden	40 dBA	40 dBA	Permanent and holiday homes. [16]
WHO (Global)	—	40 dB	Recommended night-time limit for health protection. [15]

Table 3-1: Noise regulation standards

Regional Context: Turkey and Syria

As Syria currently lacks specific, detailed legislation regarding wind power noise limits, a comparative study was conducted using the **Turkish Regulation on Management and Control of Environmental Noise** due to geographic and industrial proximity [14].

Turkey's Noise Limitations for Industrial Sources:

Area Type	Day-time (dB)	Evening (dB)	Night-time (dB)
Noise-sensitive areas (Education, Health, Cultural)	55	50	45
Residential areas (High density)	60	55	50
Commercial / Industrial areas	65	60	55
Industrial areas (High density)	70	65	60

3.5 Logistical Analysis and Infrastructure Requirements

Written by Ceren Cetin

Route Inspection: Tartus Port to Homs City

Based on the road inspection document previously provided by Dr. Alharsy (originally covering the route from **Tartus Port** to the **Ali Power Plant**), an extensive analysis was conducted for the extended route leading to the **Homs City** and **Qattinah** regions. The primary transport corridor identified is the **M1 Motorway**, which serves as the backbone for moving heavy turbine components.

Infrastructure Requirements and Necessary Actions

To ensure the successful transport of oversized wind turbine components (blades, nacelles, and tower sections), the following logistical actions have been identified:

- **Port Facilities:** Utilization of the **Tartus Harbor** as the primary entry point due to its capacity for heavy-lift cargo and proximity to the M1 motorway.
- **Road Widening:** Specific sections of the secondary roads, particularly near **Shin** and **Tareen**, will require widening to accommodate the turning radius of long-blade transporters.
- **Bridge Reinforcement:** Structural inspections and potential reinforcements are required for overpasses along the route to Homs to ensure they can withstand the concentrated weight of the nacelles.
- **Obstacle Removal:** Permanent or temporary removal of overhead power lines and telecommunication cables that do not meet the minimum vertical clearance for turbine towers.
- **Access Road Construction:** New heavy-duty access roads must be constructed from the main motorway exit directly to the **Qattinah** site coordinates to facilitate crane movement and component delivery [17].

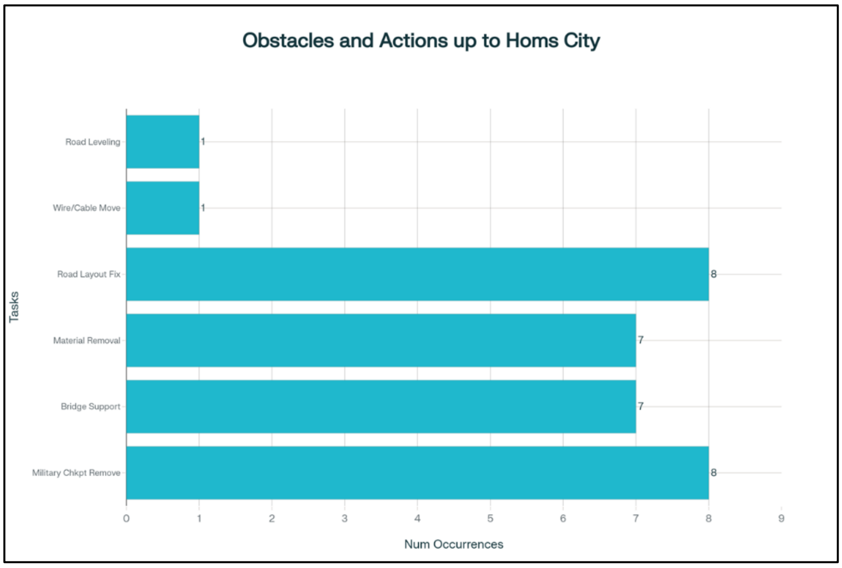


Figure 3-10: Number of obstacles on the route to Qattinah

3.6 Financial Estimation: Cost Distribution & Turbine Pricing

Written by Ceren Cetin

Since specific pricing data for the Syrian market is not publicly available, the following estimates are derived from **Turkish wind energy market** benchmarks.

Project Cost Distribution

The "distribution of portions" for a typical wind energy investment in Turkey estimates as follows [18].

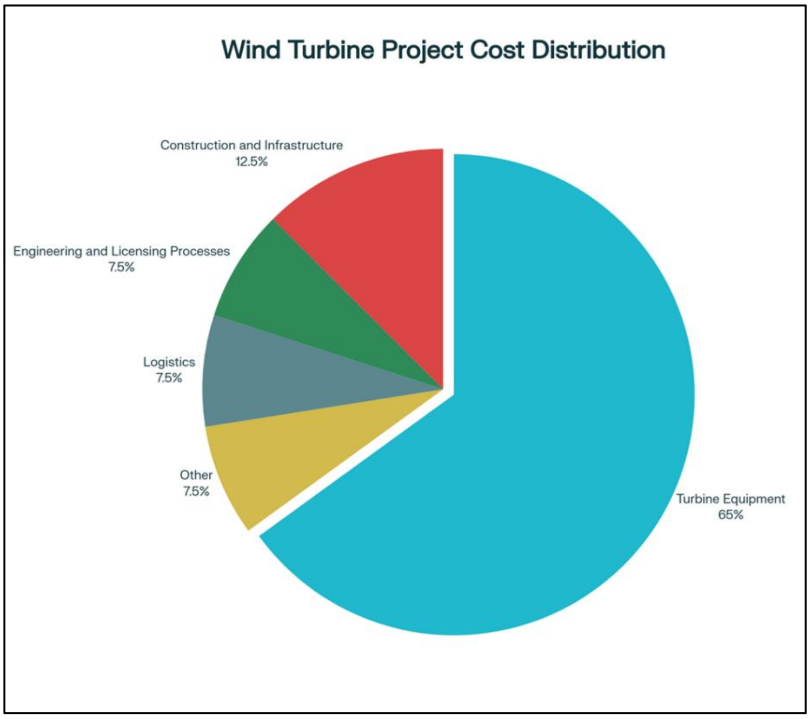


Figure 3-11: Wind turbine cost distribution in Turkey

Pricing for a 5 MW Turbine

To capitalize on the high wind speeds identified in the region, high-capacity **5 MW turbines** are recommended. Based on Turkish market benchmarks:

Estimated Unit Price: Approximately **$4 million to $50 million USD** per 5 MW turbine.

Cost per MW: Calculated at roughly **$1 M to per Megawatt** [18].

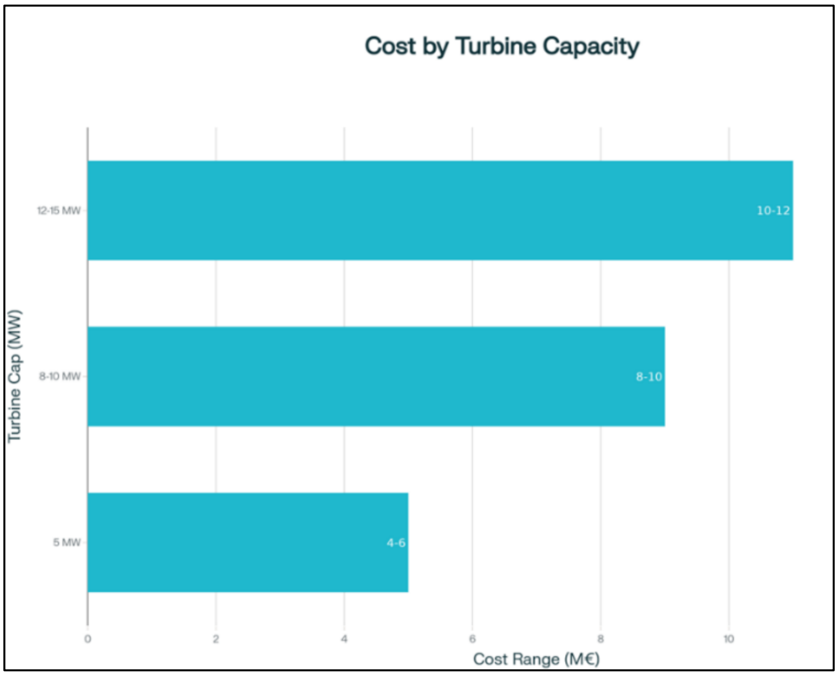


Figure 3-12: Cost by turbine capacity

3.7 Cabling Prices

Written by Ceren Cetin

An overview is found for the cabling process from Dr. Blohm´s lecture notes from Wind Farm Planning table and translated in English and shared to the grid group [19].

Cable Price Table and Price Calculation

Voltage Level	Type	Cross-section	Price per km (2014, €/km)	Alu Current (A)	Copper Current (A)	Current in Delta (A)
Medium Voltage 12/20 kV	NA2XS(FL)2Y	1x150 RM/25	2,500.00	435	283	352
Medium Voltage 12/20 kV	NA2XS(FL)2Y	1x185 RM/25	2,900.00	485	311	387
Medium Voltage 12/20 kV	NA2XS(FL)2Y	1x240 RM/25	3,000.00	545	355	442
Medium Voltage 12/20 kV	NA2XS(FL)2Y	1x300 RM/25	3,250.00	610	394	493
Medium Voltage 12/20 kV	NA2XS(FL)2Y	1x400 RM/35	3,650.00	710	448	561
Medium Voltage 12/20 kV	NA2XS(FL)2Y	1x500 RM/35	3,850.00	1450	394	634
Medium Voltage 12/20 kV	NA2XS(FL)2Y	1x630 RM/35	4,150.00	1827	394	752
Medium Voltage 12/20 kV	NA2XS(FL)2Y	1x800 RM/35	4,850.00	2230	394	934
Medium Voltage 12/20 kV	NA2XS(FL)2Y	1x1000 RM/35	5,300.00	2900	394	1152

- The total cable price consists of a base (metal-free) price and the market value of
- copper and aluminum contained in the cable.
- The metal content per kilometer for both copper and aluminum is determined for
- each cable type.
- Metal surcharges are calculated according to the daily official London Metal Exchange (LME) rates, converted to euros at the current exchange rate.

The price formula is:

Cable price = Base price + (Copper content × Copper market price) + (Aluminum content × Aluminum market price) + VAT [19].

3.8 Earthquake Analysis

Written by Ceren Cetin

Main Fault Lines

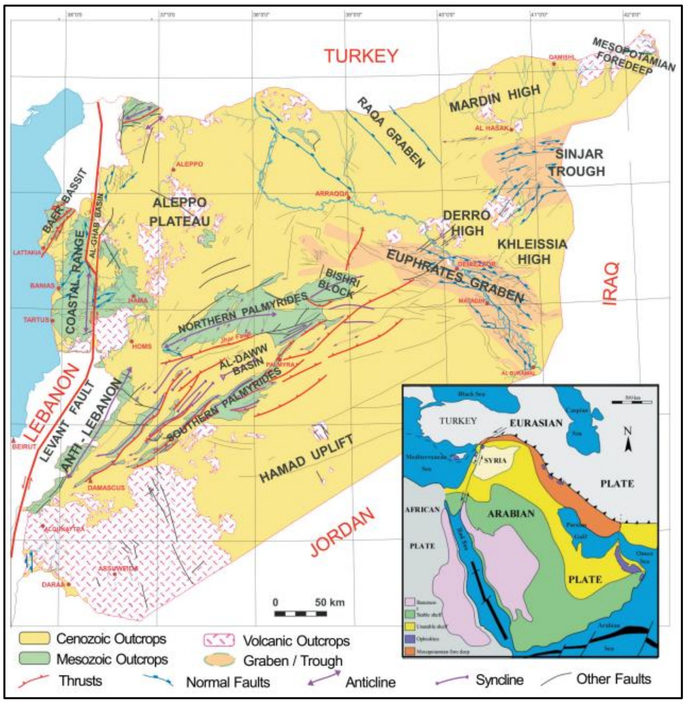


Figure 3-13: Earthquake main fault lines [20]

- The Qattinah region is close to the Dead Sea Transform Fault
- Local fault branches from this system pass near Lake Qattinah (Lake Homs), increasing the seismic risk in the area.
- The interaction of these faults with the regional geology makes Qattinah seismically significant within Syria. [21]

Guidelines

DNV-RP-0585 is an international engineering guideline for seismic design of wind power plants. It describes how to assess earthquake hazards and safely design wind turbines and foundations.

For Qattinah wind project:

- Use the local seismic hazard (considering fault lines and historical earthquakes).
- Design for the 475-year return period event (Ultimate Limit State scenario).
- Perform response spectrum analysis using site-specific earthquake data.
- Ensure the wind turbine and foundation can safely withstand earthquake forces, including soil-structure interaction [22].

Seismic Parameters for 475-Year Return Period (Ultimate Limit State)

- Peak Ground Acceleration (PGA): Approximately 0.38–0.40g for western Syria (Homs, Hama, Latakia regions)
- Design Earthquake Magnitude: Expected in the range of M 7.2–7.5
- Richter Scale History: Over the last 50 years, earthquakes of M≥7.0 have occurred (2023 Turkey-Syria M7.7/7.6), with approximately 60 earthquakes in the M 5.0–6.0 range recorded [23]

3.9 Battery Energy Storage Systems (BESS)

Written by Ceren Cetin

The integration of a Battery Energy Storage System (BESS) is essential for the **Qattinah project** to manage the intermittency of the high wind speeds recorded and ensure a stable supply to the Syrian grid.

Location and Strategic Placement

To maximize efficiency, the BESS should be positioned in close proximity to the wind farm's **substation** or **collector station**. This strategic placement is designed to minimize cable length, reduce electrical transmission losses, and lower overall connection costs [24].

Site Selection and Environmental Safety

- The physical site must meet specific technical and safety criteria to protect the infrastructure and the surrounding environment:
- **Topography:** The storage units must be installed on flat, stable ground located strictly outside of flood zones.
- **Accessibility:** Direct road access is mandatory to allow for routine maintenance and the rapid entry of emergency vehicles.
- **Containment:** Spill containment systems are required to prevent any potential battery electrolyte leakage from contaminating the soil or local groundwater.
- **Security:** The site must include perimeter fencing, visible warning signs, and comprehensive lightning protection, ensuring full compliance with local zoning and safety regulations [25] [26].

Safety Codes and Setback Requirements

Adherence to strict setback distances is vital for fire safety and risk mitigation:

- **Roads and Infrastructure:** A setback of **5–10 m** from public roads must be maintained.
- **Structural Safety:** A minimum setback of **10–15 m** from existing buildings and infrastructure is required.
- **Fire Suppression:** The installation of advanced smoke detection, automated fire-suppression systems, and clearly marked emergency escape routes is mandatory [27].

Applicable Standards and Regulatory Compliance

While Syria currently lacks wind-specific BESS restrictions, the project will follow international best practices to ensure bankability and safety:

- **International Standards:** The project will adhere to **NFPA 855** for fire safety and **UL 9540A** for energy storage testing [27].

3.10 Soil Analysis

Written by Luis Urhahn

At the start of the project, online data based on simulations and measurements from a neighbouring area was used to examine the soil conditions. The data refers to the locality of Talbiseh (north of Homs), approximately 20 km from the selected site in Qattinah. The soil data for depths of up to -18 meters are listed in the following Table 3-2 [1].

Depth [m]	Dataset	Clay [%]	Sand [%]	Silt [%]
0 to -18	US-NCSS	58.4	17.3	24.3

Table 3-2: Soil condition in Talbiseh

However, due to its proximity to the Qattinah lake, the soil conditions in the available online data are not sufficiently reliable, as the water percentage would most likely cause the conditions to change. For this reason, the accuracy of this data should be considered low.

After consultation with the University of Damascus, soil samples in the area around the lake were taken in addition to the already measured wind data. The corresponding investigations are listed in Appendix AIV. The available data enable the determination of specific information regarding the soil conditions, which has been made available to the foundation team. The properties of the soil at the Qattinah site are listed in Table 3-3. The present study concludes that there is no groundwater in the subsoil at the investigated location, even though it is in the immediate vicinity of the lake. The largest proportion consists of ”fractured basalt rock”, a rock that is suitable for the construction of a wind turbine foundation due to its physical properties. However, it should be noted that the investigation involved drilling to a depth of up to seven metres. Despite its suitability, further preparations must be made for the construction of the foundation.

Depth [m]	Soil description
0 to -0.8	Red Brown Plastic Silty Clay with Boulders (Topsoil)
-0.8 to -1.2	Red Brown Plastic Silty Clay
-1.2 to -6.0	Fractured Basalt Rock (with Sand Lenses)
-6.0 to -7.0	Basalt Sound Rock

Table 3-3: Detailed investigations of soil conditions in Qattinah

3.11 Wind Resource Analysis

Written by Luis Urhahn

The wind resource analysis forms the basis for the energy yield calculation described in Chapter 4. It also serves as the guideline for the orientation of turbine components, particularly for aerodynamic properties, and consequently for all other components such as the generator, gearbox and other mechanical components. This assessment highlights the need for explicit accuracy when analysing wind resources. In the wind industry, measurement masts or LiDAR systems are used to collect wind data for the analysis, so that it is not necessary to rely exclusively on simulated wind data.

Figure 3-14: Met mast in Qattinah facing the south direction

For the location in Qattinah, measured data using a measuring mast was provided by the University of Damascus. The location can be seen in the figure. Considering that the installed met mast is a mobile device, the measurement height is limited to an upper limit of 40 metres. Overall, wind measurements were taken at heights of 10 meters and 40 meters over a period of several years, taking all wind directions into account. The measurements were taken between 2005 and 2009. The present analysis shows that the data was not always recorded or transmitted adequately, which consequently leads to errors in the results. For this reason, 2006 was used as the reference year, as all values for the entire year are available at 10-minute intervals for the height of 40 meters.

The measured values were used as a basis for calculating the wind conditions at a height of 100 meters. It should be noted that the hub height was set in advance at 100 meters. By taking the roughness factor into account, the wind data can be extrapolated to the hub height. The wind speed at hub height is calculated using the formula below. According to the available literature, a roughness factor of $z_0 = 0.002$ is assumed, which corresponds to open terrain with a smooth surface ([3] p.87).

$$v(h) = v_{ref} * \frac{ln\left(\frac{h}{z_0}\right)}{ln\left(\frac{h_{ref}}{z_0}\right)}$$

[3] p.90

$$with\ v_{ref} = wind\ speed\ at\ 40m,$$

$$h = 100m\ (hub\ height),$$

$$h_{ref} = 40m.$$

The Weibull distribution can then be calculated and visualised. First, it is necessary to determine the absolute frequency of all wind data measurements over the different wind speeds (windbins v) in order to determine the Weibull distribution. The cumulative distribution function, which represents the percentage distribution of wind speed, can be calculated using the absolute frequency. The probability density function, in this case the Weibull distribution, is calculated using the shape factor k and the scale factor A, as well as the following formula:

$$f(v) = \frac{k}{A} * \left(\frac{v}{A}\right)^{k-1} * e^{-\left(\frac{v}{A}\right)^k}$$

[3] p.105

After extrapolating the wind data to a hub height of 100 metres, the average speed at the site can be determined by dividing the sum of the measured wind data by the sum of the measurements. The average speed determined serves as a guide value for further calculations carried out by the project teams. The Qattinah site has an average wind speed of **8.49 m/s**.

$$v_{average} = \frac{\sum v_{extrapolated}}{\sum measurements} = \frac{446234.4}{52560} = \mathbf{8.49\frac{m}{s}}$$

The calculated Weibull distribution curve and the percentage distribution of wind speeds are shown in the following Figure 3-15. The table of the Weibull distribution can be found in Appendix 6.

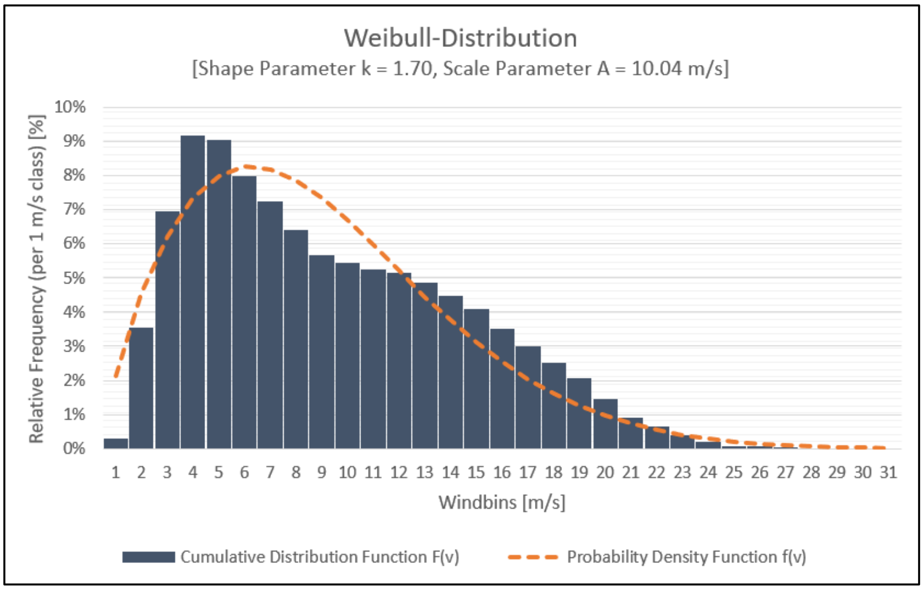


Figure 3-15: Weibull-Distribution for the hub height of 100m

The Scale Parameter of 9.52 meter per second indicates a very strong wind resource at the location. This high value shows that the average wind speed is high, which results in high energy potential. These values are typical for exposed sites, such as coastal areas, mountain ridges or offshore locations. The Shape Parameter of 1.72 suggests that the wind conditions are quite variable. This is common for onshore locations. A low k-value indicates a wide distribution of wind speeds, meaning the site experiences frequent periods of both low and very high wind speeds. In comparison, offshore locations have more stable wind, with k-values typically ranging from 2.5 to 3.0 [3].

The extrapolated wind data, presented in the form of a Weibull distribution, serves as the basis for determining the key data for the turbine's power curve and other turbine characteristics. The long-term analysis of the wind data also refers to simulated data from the publicly available ERA5 data. A detailed analysis of this data is provided in Chapter 4.

3.12 Turbine characteristics

Written by Luis Urhahn

The main characteristics of the wind turbine are determined with the help of the wind data and the specified average wind speed. The hub height of 100 meters and the rotor diameter of 160 meters with a blade length of 77.75 meters were determined by the Aerodynamics and Blade Structure team. The management team set the rated tip speed to 85 meters per second. The rated tip speed controls the ratio of wind speed to rotational speed. The aerodynamics team also provided the power coefficient, while the controller team determined the rated tip speed ratio. The specific input data for the turbine is compiled in the Table 3-4.

Parameter	Unit	Value
Hub height	m	100
Rotor diameter	m	160
Rated tip speed $\boldsymbol{v_{tip}}$	m/s	85.0
Rated tip speed ratio $\boldsymbol{\lambda}$	/	9.15
Power coefficient $\boldsymbol{c_{p,opt}}$	/	0.474

Table 3-4: Specified input parameters of the turbine

The additional key figures are now calculated using the input parameters. It is from high important to determine the value of the rated wind speed. For this calculation, the formula for power is transformed to account for the wind speed, as shown in the following formula [3]. The resulting wind speed is calculated to **10.86 meters per second**.

$$v_{rated} = \sqrt[3]{\frac{2 * P_{rated}}{\rho * A * c_{p,max}}} \quad with\ A = \frac{\pi D^2}{4} \tag{[3]}$$

Afterwards, the rated rotational speed is calculated. Using the specified formula, a value of 10,146 rpm is obtained [3]. It is essential not to exceed this value, as this would lead to increased loads on the components. In addition, the generator is not designed for higher rotational speeds. Exceeding this value may result in material damage.

$$n_{rated} = \frac{v_{tip} * 60}{D * \pi} \tag{[3]}$$

Furthermore, the optimal conditions for the turbine were calculated. The alignment was carried out taking into account the optimal wind speed, which is based on the average wind speed of 8.49 meter per second. The following Table 3-5 summarises all key figures.

Parameter	Unit	Value
Rated tip speed $\boldsymbol{v_{tip}}$	m/s	85.0
Rated tip speed ratio $\boldsymbol{\lambda}$	/	9.15
Rated wind speed $\boldsymbol{v_{rated}}$	m/s	10.86
Rated rotational speed $\boldsymbol{n_{rated}}$	rpm	10.15
Power coefficient $\boldsymbol{c_{p,opt}}$	/	0.474
Optimal wind speed $\boldsymbol{v_{opt}}$	m/s	8.49
Optimal rotational speed $\boldsymbol{n_{opt}}$	rpm	8.61
Optimal tip speed ratio $\boldsymbol{\lambda_{opt}}$	/	8.5

Table 3-5: Turbine characteristics of the OSyr160-5.0

The values for cut-in wind speed at 3 meter per second and cut-out wind speed at 25 meter per second are determined based on standard values commonly used in the industry. The power curve of the wind turbine is then plotted taking all the specified values into account and is shown in the Figure 3-16. The corresponding values for the power curve are listed in Appendix 7. It should be noted that the shown power curve refers to the output power. This implies that the total efficiency has already been taken into account in the calculation. For this reason, the maximum achievable power is lower than 5 000 kW.

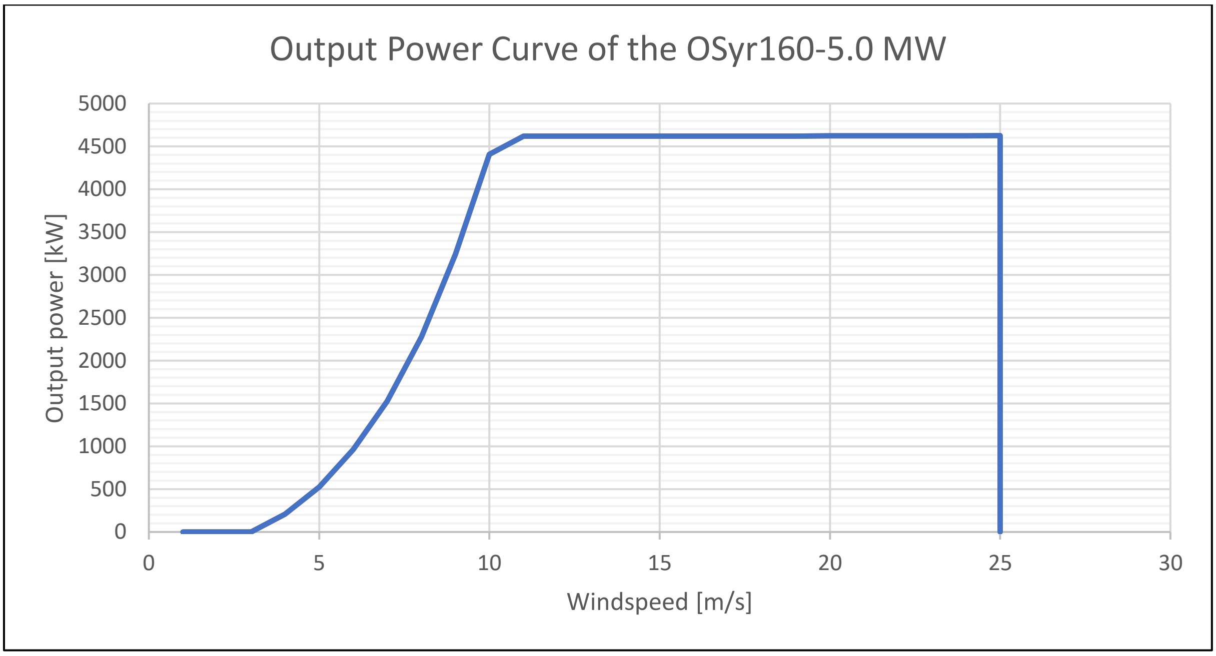


Figure 3-16: Output power curve of the OSyr160-5.0

4 Energy Yield Assessment with WindPro

Written by Luis Urhahn

The core of the following technical evaluation lies in the energy yield assessment, where theoretical potential is translated into quantifiable production data. To achieve a high degree of precision, this project utilizes WindPro, the industry-standard software for wind farm design and simulation. This assessment is crucial for understanding the site's productivity and forms the technical foundation for the subsequent economic analysis.

The primary objective of this chapter is to determine the annual energy production (AEP) for both the single Optimus turbine and the possible wind farm layout. This AEP value is the most critical technical variable in this study, as it serves as the direct input for the following chapter on Project Economics. By accurately quantifying the expected kilowatt-hours produced, we can calculate the LCOE and determine if the project is financially viable compared to local and international benchmarks.

The modelling workflow is structured as follows:

1. Including the defined wind farm area
2. Defining the orography and roughness class
3. Wind Resource implementation
    - Long Term Data (ERA5 Gaussian Grid & ERA5 Rectangular Grid)
    - Short Term Data (measured data)
    - Performing an MCP (Measure Correlate Predict)
4. Including the Moduls STATGEN and RESGEN
5. Set up the 5 MW Optimus Syria turbine (OSyr160-5.0)
    - Developing the turbine layout
    - Considering the environmental curtailments (noise & shadow)
    - Energy Yield Calculation for 1 x OSyr160-5.0
6. Development of a wind farm layout (3 or 4 WTGs)
    - Including the curtailments for the wind farm
    - Energy Yield Calculation for the wind farm

4.1 Simulation Basics

Written by Luis Urhahn

The first part of the technical assessment is to set up the basic simulation parameters in the WindPro environment. This is the foundation for all the other modelling steps and makes sure that the virtual environment accurately reflects the physical characteristics of the site. These academic foundations provided the necessary proficiency in the software's core functionalities, enabling a rigorous and systematic approach to the wind farm's design and the validation of its projected energy output.

Project Setup

As a first step, we set the location for our site centre and defined the base of our area. Therefore, the identified location from the distance analysis is used. It is important to change the coordinate system accordingly so that the coordinates can be entered correctly. Next, the supplied "wind farm planning area" file was uploaded into WindPro and added as a WTG area.

Planning Area

Next up, the supplied “wind farm planning area” file was uploaded into WindPro and added as a WTG area. With the help of QGIS it was possible to create the so called “White Map” which was uploaded as a background layer in WindPro. It is important that both systems use the same coordinate system as they need to be overlayed correctly. The map from QGIS also needs to be exported as a file-type WindPro can read. Therefore, a shapefile is recommended. To get the same area in WindPro you simply draw the area in WindPro accordingly to the white map with the help of the area layout object. Particular care must be taken to ensure that roads and buildings are not neglected in the process. The final windfarm area can be seen in the Figure 4-1 below.

Figure 4-1: Wind farm area in WindPro

Orography and Roughness

Following the creation of the wind farm area, the next step involves integrating orography and roughness data. This is achieved by adding a Line Data object for both categories.

For the orography, the object's purpose is defined as “Height Contour Lines”. As manual input values are not available, the Online Data option is utilized. The NASADEM dataset serves as the reference source. It is particularly suitable for this application as it includes comprehensive data-sets for the environment, which aligns with the requirements of the project area. When configuring the orography settings, it is essential to select Method 2 within the TIN (Triangulated Irregular Network) grid settings. This ensures the TIN is calculated for the entire file. Furthermore, in topographically complex regions, for example as hilly or mountainous terrain, the application of additional line colours facilitates a clearer visualization of elevation gradients. The final location in Qattinah is relatively flat so no coloured lines are shown.

A second Line-Data object was added for the roughness lines. This time the purpose is “Roughness Lines”. Again, online data is used for this purpose. We use the “Corline land cover 2018 - 100m grid” data as a reference, as this is the most recent data. The data is produced by visual interpretation of high-resolution satellite images. It consists of an inventory of land cover in 44 classes which has been mapped into roughness lengths for use in WindPro. No further settings need to be made for the roughness lines.

4.2 Wind Resource Data

Written by Luis Urhahn

A crucial part of this simulation is the wind resource implementation. In order to carry out a good, realistic and meaningful analysis of the wind conditions measured data from our location, at least over one year, as well as long-term data that reflects the changes over several decades is needed. By performing a MCP analysis, the short-term local data is correlated with long-term trends to provide a statistically robust wind climate for the project's entire lifetime.

Measured Data (Met Mast Data)

As already mentioned in Chapter 3.11, the measurement data originates from a meteorological mast with a total height of 40 meters. The calendar year 2006 serves as the reference period, as it provides a complete dataset with ten-minute intervals throughout the entire year. Furthermore, the data has already been extrapolated to the designated hub height of 100 meters.

Reanalysis Data (Long Term Data)

Wind statistics are important for energy forecasting. We used two different data sets for the reanalysis data and compared which one was more suitable for the project. In both cases we use online data for the datasets. The online data is stored directly in WindPro and can be accessed via the “Meteo Object”. When the online data is opened in the object, the possible locations of the reference points for different wind statistics are displayed. The following Figure 4-2 shows the available data in our area.

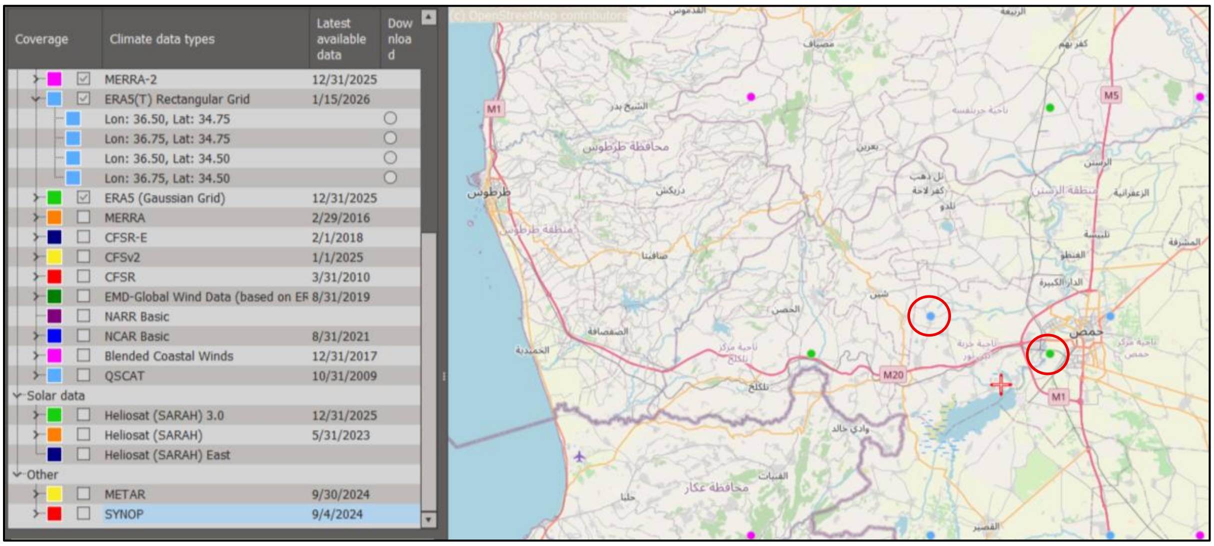


Figure 4-2: Overview of the available reanalysis data around the location

The red cross marks the site center, while the green and blue dots represent data provided by ERA5(T), and the pink dots indicate data provided by MERRA-2. The red circles highlight the chosen data points for the analysis. Although the MERRA-2 data point within the rectangular area (bottom right, top left) is in some cases the more accurate data set, the distance to our location is too far away for a realistic analysis. Consequently, the circled green and blue dots were selected as the most appropriate data point for the analysis from the ERA5(T) dataset.

“ERA5(T) Rectangular Grid” was selected for the first reanalysis data. ERA5(T) Rectangular Grid is a high-resolution reanalysis dataset provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) and is widely used in WindPro for wind resource assessment. This dataset integrates final ERA5 data with preliminary ERA5(T) data, ensuring both high accuracy and almost real-time availability. Unlike finalised ERA5 data, which can have a 2-3 month delay, ERA5(T) is updated twice a month and provides access to atmospheric conditions with a delay of only five days, making it highly valuable for applications requiring up-to-date information. With a spatial resolution of approximately 31 km and hourly time resolution, ERA5(T) provides detailed wind speed and direction data at multiple heights. In addition, ERA5(T) incorporates advanced data assimilation techniques that integrate satellite measurements, ground-based observations and radiosonde data, resulting in more accurate and consistent wind estimates. Reference studies have shown that ERA5(T) correlates well with high quality wind measurements from meteorological masts, increasing its reliability for wind energy applications. Compared to other reanalysis datasets such as MERRA-2 or CFSR, ERA5(T) provides better height coverage and better representation of local meteorological conditions, making it an ideal choice for long-term wind resource assessments, site suitability studies and energy yield forecasts. Its frequent updates and proven accuracy ensure that wind farm developers and analysts can make informed decisions based on the most up-to-date and reliable atmospheric data available [5].

The second reanalysis dataset utilized is the "ERA5(T) Gaussian Grid". Similar to the Rectangular Grid, this dataset is provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) and represents the latest generation of atmospheric reanalysis. However, the Gaussian Grid is unique because it provides data in the native horizontal resolution used by the ECMWF's Integrated Forecasting System (IFS). In WindPro, this is typically implemented as a Reduced Gaussian Grid (N320). By accessing the data in its native format rather than a standard latitude-longitude interpolation, analysts can minimize potential interpolation errors and artifacts, ensuring a more physically consistent representation of atmospheric dynamics.

Like the Rectangular version, the ERA5(T) Gaussian Grid seamlessly integrates finalized ERA5 data with preliminary ERA5(T) updates. This hybrid approach offers the best of both worlds: the rigorous quality control of the final ERA5 archives and the near real-time availability of the "T" (test/timely) version, which is updated twice monthly with only a five-day delay. This makes it an invaluable tool for operational monitoring and projects requiring the most current data available. The dataset features a spatial resolution of approximately 31 km and provides hourly temporal resolution, capturing the nuances of diurnal wind patterns and rapid weather transitions with high precision [6].

Due to the recommendation to ERA5(T) Rectangular Grid in the lecture of "Advanced Wind Farm Planning" this reanalysis data was chosen for the final analysis. It is also the preferred industry standard due to its optimal balance between high spatial resolution and user accessibility for wind energy modelling.

MCP Analysis

MCP stands for Measure, Correlate, Predict. With the data provided by the measurement campaign, the first step, Measure, has been successfully completed. The downloaded reanalysis data, while not site-specific and not accounting for local orography and topography, provides long-term wind data over a period exceeding 20 years, making it representative from a meteorological perspective. The longer the reanalysis period, the better natural fluctuations can be smoothed, resulting in a more representative mean.

This long-term data is then used for the second step, Correlate. The site-specific data collected over a relatively short period is correlated with the long-term reanalysis data. This correlation process bridges the gap between short-term site measurements and the long-term wind data.

Finally, in the last step, Predict, the result of the correlation is the ability to make long-term projections about the wind climate at the site. It becomes possible to derive accurate and reliable long-term wind resource assessments for the planned wind farm and henceforth the energy yield calculation.

For the calculation of the long-term wind statistics via the MCP, the MCP Tool provided by WindPro is used. The on-site measured data is correlated with the previously mentioned data sets of ERA5. The utilisation of two distinct data sets enables a comparative analysis of results and thereby identifying the most suitable model for the long-term wind statistics on site. The description for the methodology for the ERA5(T) MCP is described in the following.

Initially, the appropriate wind data for correlation is selected. Subsequently, models are integrated to define the training parameters for the data. There are five available options for this selection [7]:

- Regression
  - Performs regression analysis for each wind direction to scale long-term wind speeds and directions.
- Matrix
  - Simultaneously models and adjusts wind speed and direction for long-term correction.
- Neural network
  - Machine learning method that trains a neural network to identify patterns between local measurements and reference data.
- Solver based
  - Uses linear regression to determine scaling and offset parameters for each sector, season, and day, which can be applied for further calibration.
- Simple speed scaling
  - Uses the ratio of mean wind speeds between site data and long-term reference as a scaling factor. Adjusts only wind speed.

After comparing the values and the different graphs between the models, it was decided to select either the regression model or the neural network model. A close examination of the key parameters indicated that the regression model appeared to demonstrate a slightly better fit compared to the neural network model. A more detailed comparison of the regression model and the neural network model revealed that the neural network is more effective in capturing the variability of wind speed and wind speed frequency distribution over time. Finally, the neural network model has been chosen as the best model for the long-term prediction on site. For additional calculations, the selected model is saved as a meteorological object.

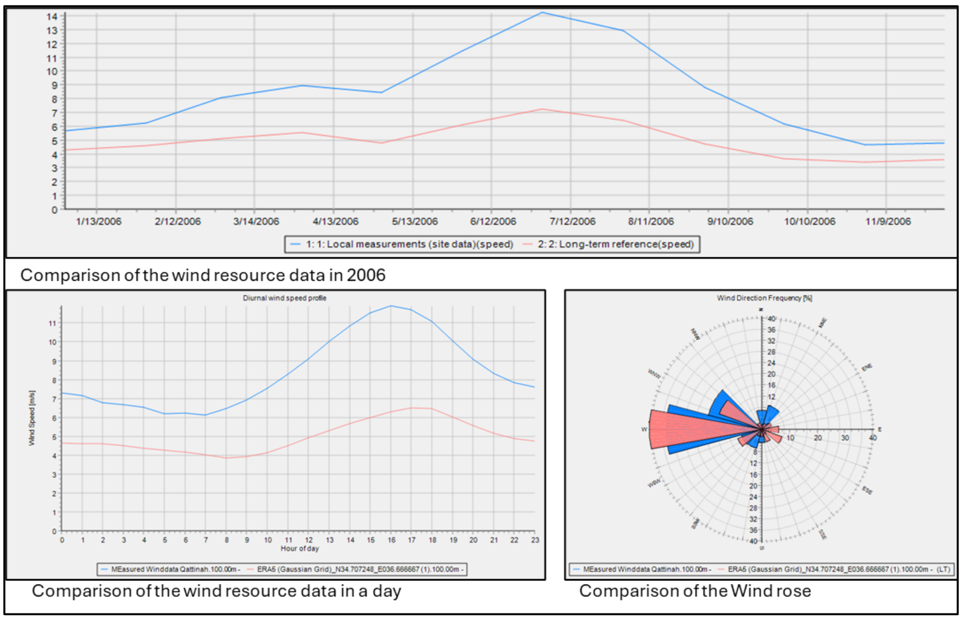


Figure 4-3: MCP Analysis comparing measured data and long-term data

The graphs above clearly show that the measured data deviates significantly from the simulated data of the ERA5 model. However, the distribution of meteorological variables shows a high degree of consistency. The maxima are displayed at the same time and the distribution of wind direction is also comparable. It is assumed that the simulated data is simply insufficiently accurate due to the fact that the locations of the measuring points differ from each other. Therefore, the measurement data from the measuring mast located closer to the defined location will continue to be relied on.

4.3 Layout Design

Written by Luis Urhahn

Usually, the layout for the turbine is initially just roughly sketched. For this project the final location was already decided due to the previous distance analysis. Although the position is "fixed", a position adjustment due to the noise or shadow impact is still considered. Before the energy yield calculation can be performed, the resource generation is required.

Turbine set up

As the Optimus Syria is a fictive project, a new turbine will be developed and is therefore not listed in the WindPro wind turbine catalogues. The key figures determined in Chapter 3.12 as well as the power curve are required for the analysis. In the present context, all key data of the turbine are integrated into the settings of the turbine. Since no noise impact data is available for the developed fictitious turbine, the reference turbine SG 5.0-145 from Siemens Gamesa with a hub height of 102 metres is used for the noise calculation.

For the so-called "distance circle", an ellipse is set in the main wind direction to illustrate the possible wake effect. Due to the fact that more than 90 percent of the wind speed blows from the west (270°), a distance of 1.8 times the rotor diameter perpendicular to the main wind direction is selected. Although the value is considered low (usually 2.5 to 3.5 is chosen as a guideline), the choice of distance is justified because the wind comes from one specific direction to a significant extent. In the main wind direction, a distance of 4.0 times the rotor diameter is selected. This value is also at the lower end of the tolerance range, but it should be noted that the area of the wind farm does not allow for the installation of turbines in a direct sequence anyway. For this reason, this value is sufficient for the requirements of our project. For illustrative purposes, the simple rotor diameter has also been represented as a circle to provide a better overview of the size of the turbine. The positioning is shown in the following Figure 4-4.

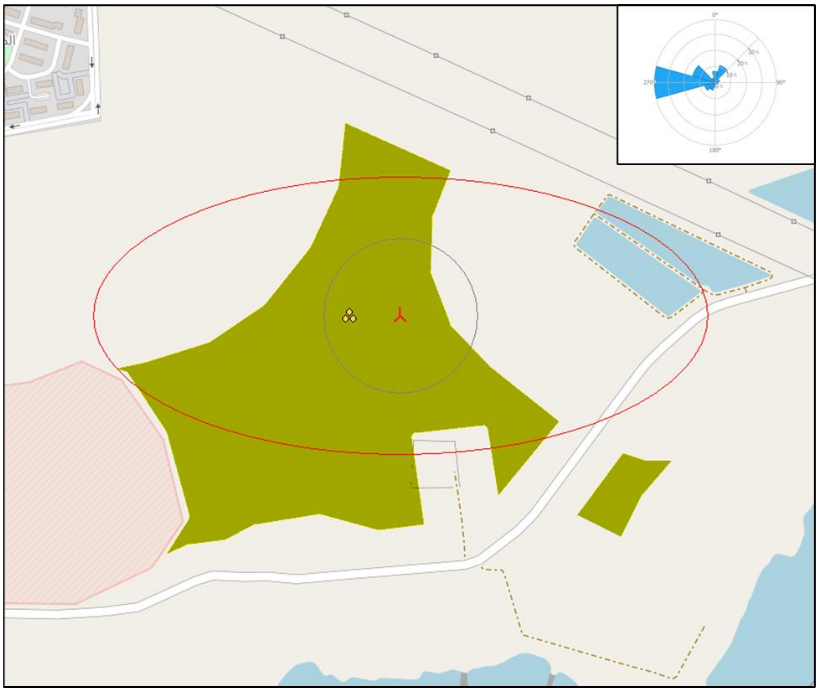


Figure 4-4: Illustration of the turbine position including the distance circles

Resource Mapping

Before the initial energy yield calculation can be performed, both Statistics (STATGEN) and Resource (RESGEN) generation data must be established. This is accomplished by adding a Site Data object to the project area and defining its purpose as STATGEN (generation of wind statistics). Within the Terrain tab, the data must be verified for accuracy and to ensure it encompasses the specified spatial dimensions. If the coverage is insufficient, the parameters for roughness and orography must be extended. For this specific case, the existing parameters are sufficient, allowing the STATGEN process to be implemented.

In addition to wind statistics, the RESGEN (Wind Energy Resource) option is required for certain calculations. RESGEN can be implemented either by modifying the designated use of an existing Site Data object or by adding a new one; in this instance, a separate Site Data object is created specifically for RESGEN. Within the interface, these objects are distinguished by colour, with green representing RESGEN and orange representing STATGEN. Selecting the RESGEN option enables additional configuration tabs, including the Wind Statistics tab, where the previously generated MCP data is selected. Similar to the STATGEN process, the Terrain tab values must be verified for accuracy. Finally, the Resource/CFD area tab is used to define the spatial extent of the resource map, which is accomplished by entering specific coordinates or by defining a rectangular area. Once these parameters are correctly established, the RESGEN calculation can be performed.

Following the configuration of the Site Data objects, the initial calculation is performed using the RESOURCE module. This module is designed to calculate and calibrate wind resource maps, which are essential for assessing wind conditions across a defined area.

These maps are generated using various data sources, such as local measurements, online datasets, or, as implemented in this case, an MCP analysis. The RESOURCE module enables detailed visualization of wind quality throughout a region, providing comprehensive data for each grid point. This includes sector-wise Weibull distributions at multiple target heights. Such detailed information supports several critical applications, including the identification of optimal wind energy sites, the evaluation of wind potential for planning purposes, and the precise micro-siting of turbines within a selected area [8].

The following Figure 4-5 shows the resource map for the wind farm area.

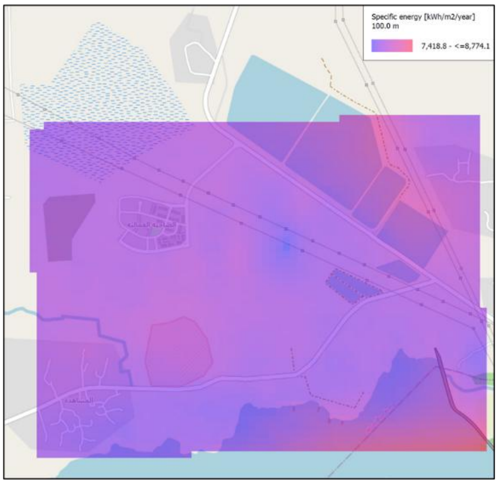


Figure 4-5: Illustration of the wind resource map (RESGEN)

As illustrated in the above figure, there is no significant discrepancy in wind resource availability for the selected location. Because of the flat terrain of the area there is not an outstanding difference and therefore no need to change the layout of the site. It is evident that the discrepancy would be more pronounced if the location were situated in a mountainous region.

Energy Yield Calculation (w/o curtailments)

The PARK module enables the calculation of AEP and overall energy yield. For this analysis, a time-based approach is utilized by selecting the "time-varying based on measured data" calculation method. Within the WTGs tab, the appropriate layout must be selected. This core calculation setup remains consistent throughout the project, with adjustments made only to the layout configurations and specific curtailment parameters. In the Scaling tab, the previously defined MCP wind analysis, specifically the MCP-ERA5-Neural Network Analysis, is applied. For the wake loss assessment, the "N.O. Jensen (Riso/EMD) Park 2 2018" model is employed. This model represents the current industry standard and is widely utilized for modern wind farm modelling. The wake decay constant for the site is set to z_0 = 0,002, reflecting the site's location in flat, open terrain. Once these wake parameters are established, the PARK calculation can be executed.

The results for the optimized basic layout, excluding curtailments, are summarized in the Table 4-1 below. The full calculation reports are available in the Appendix.

Parameter	Unit	Value
Result PARK (AEP)	MWh/year	22 491.8
Capacity factor	%	51.3
Full Load Hours (FLH)	Hours/year	4 498
Average wind speed	m/s	8.5

Table 4-1: Results for the 1xOSyr160-5.0 w/o curtailments

Compliance Optimization (Curtailments)

Curtailment compliance and optimisation are essential to ensure that wind farms meet regulatory and environmental requirements while providing maximum energy production. Noise and shadow flicker curtailments are particularly important as they meet regulatory requirements, minimise environmental impact and increase community acceptance. Noise curtailment ensures that turbine operation is within permitted noise levels, particularly near residential areas, by adjusting turbine speeds or shutting them down at certain times. Shadow flicker curtailment prevents excessive flicker effects on nearby buildings by strategically pausing turbine operation when shadow flicker limits are exceeded. Optimising these curtailments in WindPro helps to balance regulatory compliance with the energy yield, ensuring that wind farms operate efficiently while respecting environmental and social constraints. Although there are no regulations in Syria it is still recommended to consider the noise and shadow as a respect to the local citizens. Therefore, conventional values for the noise impact from neighbouring countries such as Turkey were used. For the shadow impact, the values of the German regulations were taken as a benchmark.

Noise

The accepted noise levels, measured in decibels A-weighted [dB(A)], vary depending on the type of area and the time of day. For the noise compliance requirements, the guidelines for rural village and mixed-use areas with a maximum noise level of 45 dB (A) during the nighttime should apply to the wind farm. For industry a maximum noise level of 55 dB (A) during the nighttime should be considered. Those values were defined by the Management Team. Turbines above this level must be regulated or switched off. The following Figure 4-6 shows the Noise Sensitive Areas (NSA) and the noise impact. The Table 4-2 shows the corresponding values.

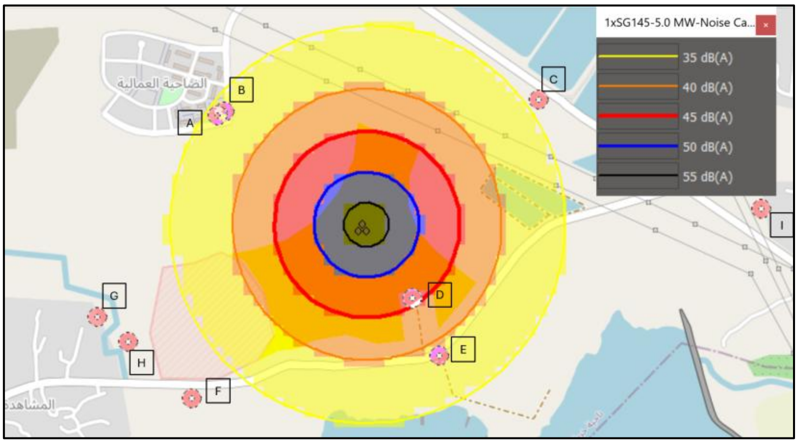


Figure 4-6: Noise impact of the OSyr160-5.0

Location	Sound level [dB(A)]
A	38.8
B	36.0
C	34.2
D	**45.7**
E	38.6
F	32.2
G	30.3
H	31.2
I	26.2

Table 4-2: Noise levels

It is evident that the value of NSA Point D exceeds the threshold, but due to the assumption that it is a industry building it id below the limit of the threshold for industry.

Shadow

Shadow flicker is an important consideration in wind farm development, particularly in mixed-use areas where residential, commercial and agricultural zones coexist. Due to the relatively flat terrain and dispersed settlements, wind turbines can cast moving shadows on neighbouring properties, particularly during low sun angles in the morning and evening. German regulations, including the Federal Immission Control Act (BImSchG) and specific planning guidelines for Schleswig-Holstein, limit shadow flicker exposure to 30 hours per year or 30 minutes per day to minimise disturbance to residents [9]. In mixed areas where both homes and workplaces are affected, excessive flicker can lead to complaints, legal challenges and reduced public acceptance of wind projects. To comply with regulations and maintain community support, it is likely that simulation tools, such as WindPro, will be used to model and optimise turbine placement and to implement automated curtailment strategies that temporarily shut down turbines when shadow flicker thresholds are exceeded.

For the windfarm the worst-case scenario needs to be consider, which is a maximum shadow flicker of 30 hours per year and/or 30 minutes per day. For the 1xOSyr160-5.0 layout the shadow impact without curtailment is shown in Figure 4-7. The shutdown for some time during the day will be mandatory.

The following Table 4-3 shows the worst-case results for shadow hours per year. The aim is to keep the hours per year below 30 h/year and below 30 min/day.

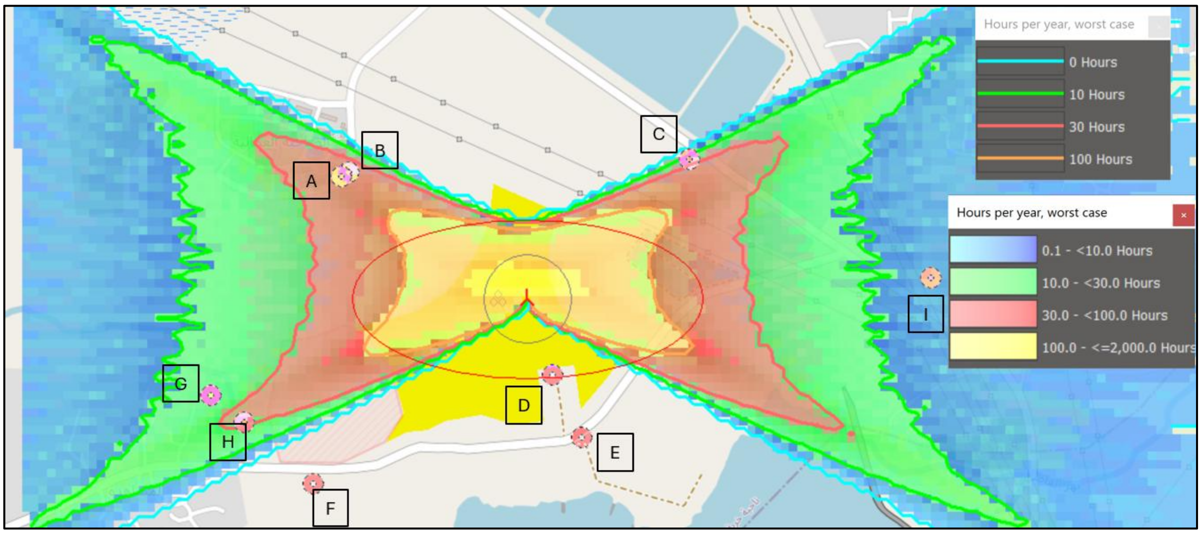


Figure 4-7: Shadow impact at the location

Location	Shadow [h/year]	Shadow [h/day]	Critical?
A	55:42	0:47	**Yes**
B	50:56	0:49	**Yes**
C	20:54	0:37	**Yes**
D	0:00	0:00	No
E	0:00	0:00	No
F	0:00	0:00	No
G	16:51	0:26	No
H	32:03	0:30	**Yes**
I	6:33	0:19	No

Table 4-3: Shadow impact during the year or day

The table shows that, as a result of the impact on buildings A, B, C and H, the turbine must be shut down, particularly in the early morning hours or at sunrise. The turbine will be completely shut down for 30 minutes after sunrise, which brings the times within the tolerance range of 30 minutes per day or 30 hours per year.

The new park calculation can then be performed, taking into account the curtailments for shadow. The results are summarised in the Table 4-4.

Parameter	Unit	Value
Result Park (AEP)	MWh/year	**21 909**
Capacity factor	%	**50**
Full Load Hours (FLH)	Hours/year	**4 382**
Average wind speed	m/s	8.5
Curtailment loss	%	2.6

Table 4-4: Results for the 1xOSyr160-5.0 with curtailments

4.4 Windfarm Layout

Written by Luis Urhahn

The analysis of the wind farm site in Syria examines not only the technical feasibility of a single turbine, but also the possibility of a potential wind farm. The use of WindPro enables a relatively simple process for comparing different layout concepts. Due to the limited area available for the construction of a wind farm, a number of three to four turbines was selected and compared. In this regard, the influence of the wake effect must be taken into account.

Layout Optimization

With the help of the resource map, it is possible to optimise the roughly created layouts using the optimisation module. The optimize module in WindPro provides a comprehensive and efficient solution for wind farm layout optimisation. Iti s possible to specify objectives such as maximising AEP, minimising LCOE or optimising Net Present Value (NPV). The module takes into account a wide range of constraints, including turbine siting areas, exclusion zones, minimum turbine spacing, noise restrictions and component lifetime considerations. By integrating these factors, the module ensures that the resulting wind farm layout is both efficient and compliant with the provided restrictions. In the Optimization the NSA/Shadow receptors will be considered, so that turbines will not be placed directly besides the receptors. The main objective is to maximise the AEP. For the project, the layouts for 3xOSyr160-5.0 and 4xOsyr160-5.0 were optimized. In the end of the optimization, the realized final layouts were saved in the according layers. The following figure shows the two different optimized layouts.

3 x OSY160-5.0 MW 4 x OSY160-5.0 MW

Figure 4-8: Comparison of the windfarm layouts

Energy Yield Calculation (w/o curtailments)

The same calculation as described in Chapter 4.3 is used to calculate the AEP of the two wind farm layouts. For this reason, a detailed description is not provided in this chapter. The following tables show the results of the calculation for the different layouts.

Parameter	Unit	3 x OSyr160-5.0	4 x OSyr160-5.0
Result Park (AEP)	MWh/year	66 109	87 468
Capacity factor	%	50.3	49.9
Full Load Hours (FLH)	Hours/year	4 407	4 373
Wake loss	%	1.7	2.6

Table 4-5: AEP results for the different windfarm layouts

Final Energy Yield Calculation (with curtailments)

Despite the slightly lower efficiency, the layout with four turbines was chosen for the final calculation of the energy yield and AEP, taking into account the shadow and noise impacts. As the layout with four turbines still represents an excellent solution, a decision has been made in favour of a sustainable solution that generates the highest amount of renewable electricity. The final calculation requires the shadow and noise impact for the wind farm layout to be recalculated. The impact can be seen in Figure 4-9 (Noise) and Figure 4-10 (Shadow). As illustrated in the figures, it is necessary to shut down the turbines in the early hours of the morning at sunrise.

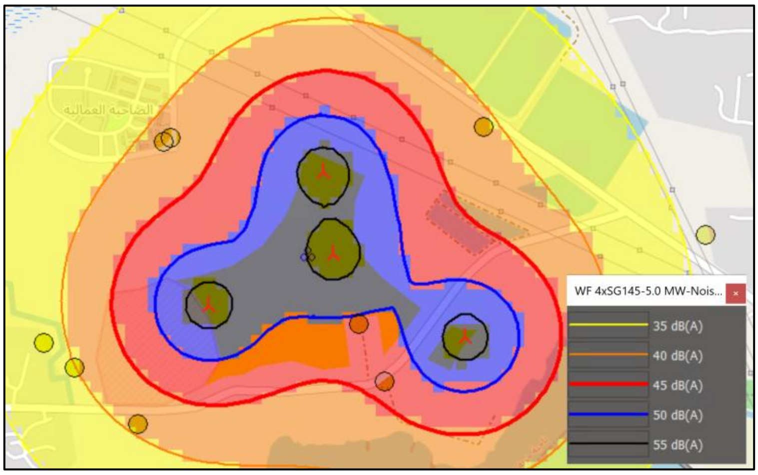


Figure 4-9: Noise impact for the 4xOSyr160-5.0 layout

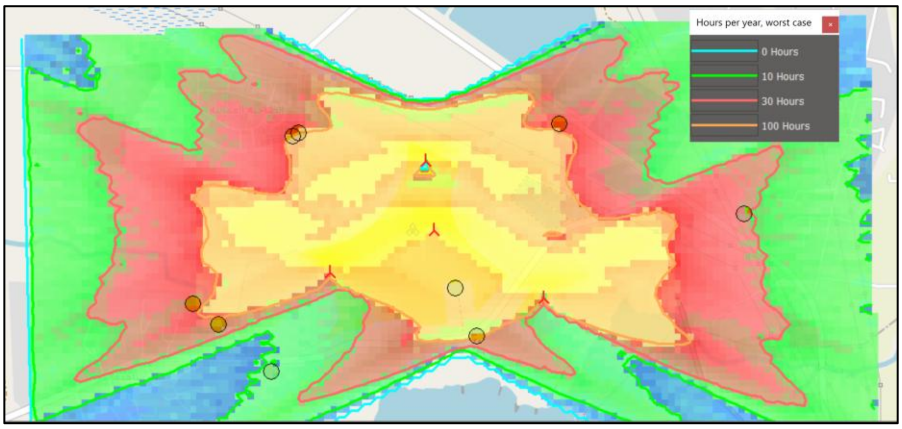


Figure 4-10: Shadow impact for the 4xOSyr160-5.0 layout

The final calculation for AEP is taking the shadow impact into account. The results are summarised in the table below. All calculations made within WindPro are attached in the appendix.

Parameter	Unit	3 x OSyr160-5.0	4 x OSyr160-5.0
Result Park (AEP)	MWh/year	60 933	**79 481**
Capacity factor	%	46.3	**45.3**
Full Load Hours (FLH)	Hours/year	4 062	**3 974**
Wake loss	%	1.7	2.4
Curtailment loss	%	7.8	9.0

Table 4-6: Final AEP results for the different windfarm layouts with all curtailments

5 Project Economics

Written by Luis Urhahn

The financial viability of this project is assessed through a comprehensive modelling of Capital Expenditures (CapEx) and Operational Expenditures (OpEx). A significant portion of the initial investment is driven by the material costs of the turbine, which include the main high-performance components of the turbine. These costs, alongside installation and infrastructure expenses, form the basis of the CapEx, while the OpEx accounts for ongoing maintenance, site management and insurance throughout the turbine's lifecycle.

Central to this economic framework is the LCOE, which serves as the primary metric for comparing the cost-effectiveness of this installation against other energy sources. In the Syrian context, the project must be evaluated against a local electricity price of approximately 6 ct/kWh. The electricity price estimation was derived from internal sources at the University of Damascus.

To ensure the project meets international standards of efficiency, the financial targets are oriented toward the current worldwide LCOE for onshore wind turbines, which, according to the Fraunhofer Institute (2024), typically ranges between 4.3 and 9.2 ct/kWh [4]. By benchmarking against these global figures, this analysis seeks to determine the degree of subsidies or market adjustments required to bridge the gap between production costs and the domestic tariff, ensuring a sustainable and bankable energy solution for the region.

5.1 Wind Turbine Transport Cost

Written by Ceren Cetin

This section presents a logical estimation of transport costs for a 5 MW wind turbine, produced near Tartus Port, Syria, and moved approximately 80 km to the installation site in Qattinah. Costs are derived from a reference European transport in 2022 from Spain to Sweeden case and adjusted using scaling factors based on volume, mass, and logistics complexity.

5.1.1 Blades Transport

Reference Case: European long-distance transport of 3 large blades in 2022 from Spain to Sweden.

Scaling Factors Applied:

1.15× – Larger rotor: The new blades are of higher class and larger overall transport envelope, increasing handling and logistical complexity.

0.65× – Short domestic route: The short inland distance significantly reduces transport time, fuel, and associated variable costs compared to the long European route.

1.10× – Handling, permits & escort services: Oversized blades still require specialized equipment, permits, and escort vehicles even for domestic transport.

Calculation:

$$\text{Reference Cost} \times 1.15 \times 0.65 \times 1.10$$

$$150{,}000 \times 1.15 \times 0.65 \times 1.10 \approx 125{,}000\ €$$

Rationale:
Despite larger blades, the reduced distance lowers overall cost, while regulatory and geometric requirements maintain a moderate cost increase.

5.1.2 Nacelle, Hub & Drivetrain

Reference: Blade transport in Syria

Scaling Factors (Mass + Volume Based):

0.55× – Volume factor: The nacelle occupies less transport space than blades, reducing the relative logistical footprint.

0.80× – Geometry & manoeuvring advantage: Compact shape simplifies routing and handling.

1.10× – Structural risk / axle load factor: High concentrated mass requires specialized multi-axle transporters, increasing complexity.

Calculation:

$$\text{Blade Reference Cost} \times 0.55 \times 0.80 \times 1.10$$

$$125{,}000 \times 0.55 \times 0.80 \times 1.10 \approx 95{,}000\ €$$

Rationale:
Transport cost is largely determined by the combination of volume and concentrated mass rather than simple linear scaling. Compact geometry reduces transport difficulty, but high weight increases logistical requirements.

5.1.3 Tower Sections

Reference: Blade transport in Syria

Scaling Factors (Mass + Volume Based):

0.85× – Volume ratio: Tower sections occupy less space than blades, decreasing envelope constraints.

1.30× – Mass / axle load factor: The high total mass increases transport complexity, requiring heavy-haul equipment and careful load distribution.

Calculation:

$$\text{Blade Reference Cost} \times 0.85 \times 1.30$$

$$125{,}000 \times 0.85 \times 1.30 \approx 105{,}000\ €$$

Rationale:
Tower transport is primarily influenced by mass rather than volume. Compact sections reduce volume-related challenges, but axle load considerations drive cost upward.

5.2 Detailed Cost Analysis

Written by Ahmed Salam

While the technical potential of the Qattinah site is dictated by the winds of the Homs Gap, its commercial reality is governed by the Feasibility Study. In the lifecycle of large-scale energy infrastructure, this phase represents the critical transition from a "visionary concept" to a "bankable asset." For a project of this magnitude, requiring immense upfront CapEx no financial institution or private investor will commit resources without a rigorous, data-driven validation of the project's long-term survival.

In the current Syrian context, the importance of this study is magnified tenfold. Syria's ongoing economic crisis, characterized by extreme currency volatility and restricted access to international liquid markets, has naturally made investors hyper-cautious. The "risk premium" for any project in the region is high; therefore, the feasibility study must act as the ultimate de-risking tool. It is the bridge that takes "theoretical knowledge", the fact that the wind blows at Qattinah, and converts it into "operational reality", a plan for how to import turbines, connect to a fragile grid, and generate a stable LCOE that ensures profitability despite the surrounding instability.

To provide the transparency required by modern financers, this study focuses on four critical indicators to prove the project's resilience:

- **LCOE:** Ensuring our localized design produces power at a lower cost than imported alternatives.
- **IRR (Internal Rate of Return):** Demonstrating a profit margin that justifies the regional risk premium.
- **Payback Period:** Determining a rapid timeline for capital recovery to minimize long-term economic exposure.
- **Sensitivity Analysis:** Stress-testing the project against currency fluctuations and wind variability to ensure viability in "worst-case" scenarios.

Ultimately, this study proves that through technical innovation and rigorous financial modeling, the Qattinah Wind Farm can overcome economic instability to become a profitable reality.

In the following parts we will go through how we conducted the FB from the beginning and all the process we pass through to evaluate the finical structure through the updates from each team, as their task was to find the balance between the new technology and the cost wise for innovation which we always consider as the aim of any engineering innovation, the "perfect wind turbine " with guarantee of 30 years life team and no losses with optimal efficiency couldn't be afforded.

5.2.1 Investment Framework: Independent Power Producer (IPP) & Feed-in Tariff

A pivotal update in the final phase of this feasibility study is the definition of the commercial model for the Optimus Syria project. Following consultations with academic and technical advisors, the project has been structured as an Independent Power Producer model. Under this framework, our team will bid for a long-term Power Purchase Agreement (PPA) with a proposed Feed-in Tariff of 6 cent€/kWh.

Competitive Pricing and Negotiation Strategy

The proposed tariff of 6 cent€/kWh was selected as a strategic balance between project profitability and national grid affordability.

- Profit Margin: Since our calculated LCOE is 4.917 cent€/kWh, this tariff provides a secure margin that covers operational risks and ensures a robust IRR of 16.61%.
- Negotiable Bidding: As an IPP, we recognize that this price is a starting point for negotiations with the Syrian Ministry of Electricity. The flexibility in pricing allows the project to remain competitive in national energy auctions while still guaranteeing a payback period of roughly 11 years.

Impact of the IPP Model on Bankability

Moving to an IPP model changes the risk profile for investors in several ways:

- Revenue Certainty: A fixed (or inflation-indexed) price of 6 cents provides the clear revenue forecast needed to justify the €5.29 million CapEx.
- Market Integration: This model aligns with Syria's Law No. 32, which encourages private sector participation to alleviate the current energy crisis.

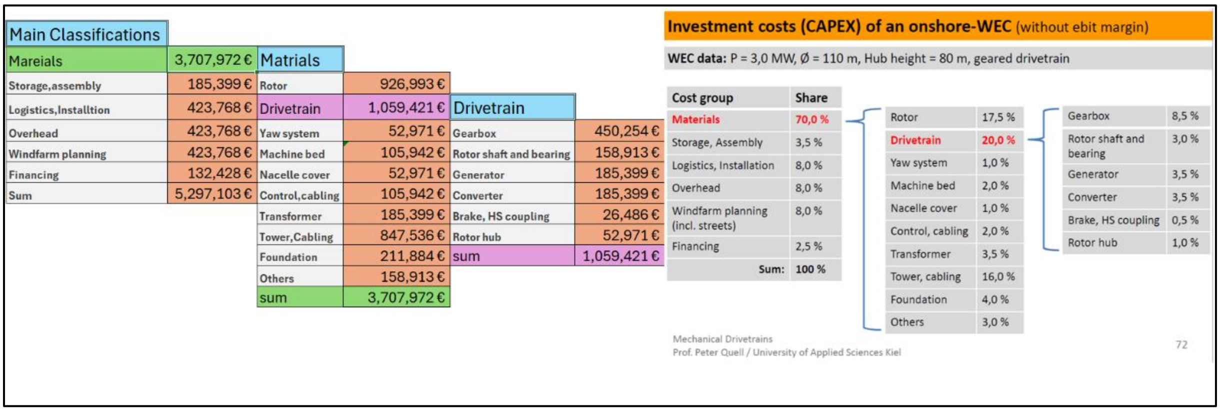
Strategic Alignment

By bidding at 6 cent€/kWh, Optimus Syria positions itself as a low-cost, high-efficiency provider compared to the cost of importing fuel for traditional thermal plants. This price point, combined with our bespoke turbine design, demonstrates that engineering innovation can drive down the cost of sustainable energy even in high-risk environments.

5.3 Initialization of the Feasibility Study Structure

Written by Ahmed Salam

As it was difficult to find sources how to start the feasibility study (FS) but for your designed wind turbine, I used the professor slides to make the initial estimation of the cost quotation for the whole project team as show in Figure 5-1 I used the same percentages form the slide to start calculating the percentage for each component in the total capex so that each team can have an indication on the available budget for their team.



Main Classifications	
Mareials	3,707,972 €
Storage,assembly	185,399 €
Logistics,Installtion	423,768 €
Overhead	423,768 €
Windfarm planning	423,768 €
Financing	132,428 €
Sum	5,297,103 €

Matrials	
Rotor	926,993 €
Drivetrain	1,059,421 €
Yaw system	52,971 €
Machine bed	105,942 €
Nacelle cover	52,971 €
Control,cabling	105,942 €
Transformer	185,399 €
Tower,Cabling	847,536 €
Foundation	211,884 €
Others	158,913 €
sum	3,707,972 €

Drivetrain	
Gearbox	450,254 €
Rotor shaft and bearing	158,913 €
Generator	185,399 €
Converter	185,399 €
Brake, HS coupling	26,486 €
Rotor hub	52,971 €
sum	1,059,421 €

Investment costs (CAPEX) of an onshore-WEC (without ebit margin)

WEC data: P = 3,0 MW, Ø = 110 m, Hub height = 80 m, geared drivetrain

Cost group	Share
Materials	70,0 %
Storage, Assembly	3,5 %
Logistics, Installation	8,0 %
Overhead	8,0 %
Windfarm planning (incl. streets)	8,0 %
Financing	2,5 %
Sum:	100 %

Rotor	17,5 %
Drivetrain	20,0 %
Yaw system	1,0 %
Machine bed	2,0 %
Nacelle cover	1,0 %
Control, cabling	2,0 %
Transformer	3,5 %
Tower, cabling	16,0 %
Foundation	4,0 %
Others	3,0 %

Gearbox	8,5 %
Rotor shaft and bearing	3,0 %
Generator	3,5 %
Converter	3,5 %
Brake, HS coupling	0,5 %
Rotor hub	1,0 %

Mechanical Drivetrains
Prof. Peter Quell / University of Applied Sciences Kiel
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Figure 5-1: Excel Optimus F.S and Mechanical drive trains

Now I have percentage for the material which helped me to do this evaluation according to the Figure 5-2 we could indicate a rough estimate for the total cost of a wind turbine around 1 M€/MW.

Then this helped us to determine the main target as developer for new wind turbine design.

The total materials cost which represents 70 % from the whole CapEx equal **3,707,972 €** then we continued with our research to find the side costs which might be neglected in the slide to have accurate cost estimation as possible.

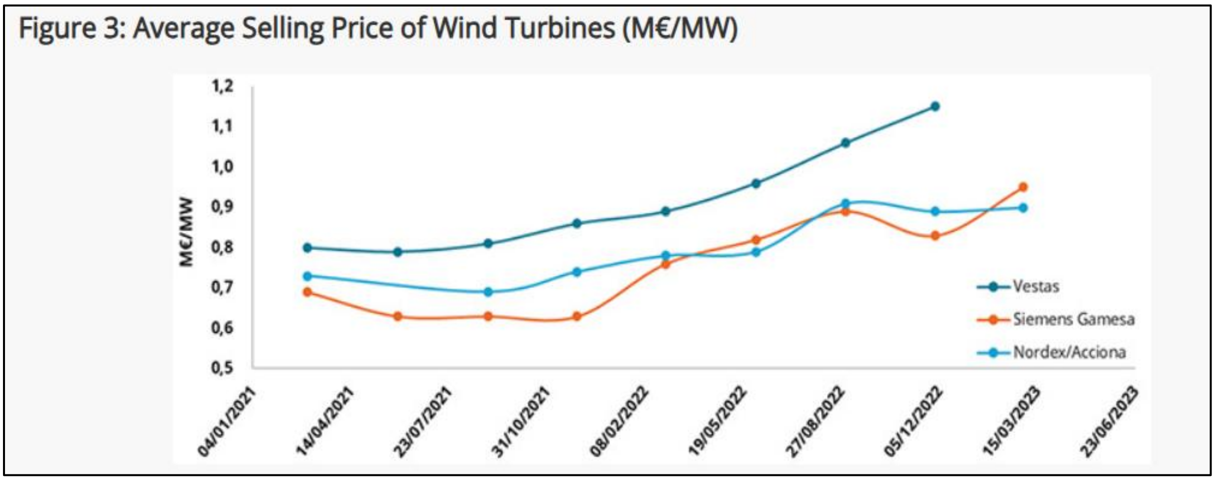


Figure 5-2: Average Selling Price of Wind Turbines (M€/MW)

5.4 Detailed components prices

Written by Ahmed Salam

In the part we worked together with different teams in our project to be able to conduct one sheet representing the whole project, the share of cost was divided into 9 teams with following names:

1. Electrical Drive Train
2. Tower structure
3. Foundation
4. Energy Storage
5. Rotor hub
6. Rotor blade structure
7. Gear box
8. Rotor bearing
9. Machine bed

As we divided the percentage of each team, we contacted each of them to have a continuous update for the components and their prices, some of the prices wasn't available online so we had to evaluate its price according to specific price for a material as it sold in the market in kg or in m^3.

Finally, we were able to reach the final updated components with their price estimation, which was in the acceptable range and matches our goals.

Team	Electreical_Drive_train	intial cost assum.	Tower_struc.	intial cost assum.	Foundation	unit	intial cost assum.
comp.1	Generator	500,000 €	steel tower	(wight based (ton))	Reinforcing steel (rebar)(euro/ton)	49.5	595
comp.2	Power_converter	120,000 €	weight	433.4	Concrete + labour + formwork(euro/m^2)	491	182
comp.3	Transformer	85,000 €	price(euro/ton)	1800	Anchor bolts (M48)(euro/ton)	4	2273
comp.4	switch_gear and protection	70,000 €			Grout (euro/m^3)	0.54	727
total cost		775,000 €	total cost	780,120 €	total cost		192,449 €

Team	Rotor_Hub	Quantity	Cost per unit (€)	intial cost assum.	R_Blade_struc.	mass in (kg)	specific price (€/kg)	intial cost assum.
comp.1	Hub	1	70,000 €	70,000 €	E-glass fiber	15,480	1.8	27,864 €
comp.2	Additional Stiff.Ring	3	5,400 €	16,200 €	Carbon fiber	928	25.011	23,210 €
comp.3	Pitch Drive	3	6,333 €	18,999 €	Core (PET/PVC/Balsa)	1,795	4.000	7,180 €
comp.4	Battery	3	2,000 €	6,000 €	Epoxy resin	6,071	4.000	24,285 €
comp.5	Invertor	3	1,900 €	5,700 €	Adhesive & gel coat	160	10.000	1,600 €
comp.6	Blade Bearing	3	33,000 €	99,000 €	matrial percentage of total cost	55.00%		84,139 €
comp.7	Blade Bearing Cover	3	2,000 €	6,000 €	Manufacturing percentage of total cost	35.00%		53,543 €
comp.8	Spinner	1	4,000 €	4,000 €	Quality & Process of total cost	10.00%		15,298 €
comp.9	Fastening components and cable			10,000 €	total cost per blade			152,980 €
total cost				235,899 €	total cost			458,940 €

Team	Gear_Box	mass in (kg)	specific price (€/kg)	intial cost assum.	R_Bearing	mass in (kg)	specific price (€/kg)	intial cost assum.
comp.1	Gearbox	11600.58	43.96	510,000 €	Main Bearing Housing	9,815	2	19,631 €
comp.2	Brake	62	4.84	300 €	Shaft	31,184	2.5	77,959 €
comp.3	Coupling	170	4.71	800 €	Bearing	6,701	6	40,206 €
comp.4	Shaft	3000	3.33	10,000 €	Lock nut	333.2	2	666.40 €
comp.5	Bearing	1100	18.18	20,000 €	lock pin	183	4	732.80 €
comp.6	Labyrinth seals	30	23.33	700 €	labyrinth seal fixed	743	12	8,916.00 €
comp.7					labyrinth seal rotating	377	12	4,524.00 €
comp.8					V_ Ring	153.20	4	612.80 €
comp.9					additional costs			9,376.98 €
total cost				541,800 €	total cost			162,625 €

Figure 5-3: Excel sheet FS Optimus Syria (component prices)

Machine_bed	mass in (kg)	specific price (€/kg)	intial cost assum.		
Yaw Driver	1,070	37.85046729	40,500 €	6*6750	num.*cost of unit
Brake Calipers	210	133.3333333	28,000 €	14*2000	num.*cost of unit
Brake Disk	1,751	0.890286513	3,822 €		
Yaw bearing	4,293	5.708828325	24,508 €		
Machine bed casted	36,731	2	73,462 €		
Machine bed welded	16,339	2.5	40,848 €		
total cost			211,140 €		
Energy_stroage	intial cost assum.	foundation			
ST5015UX	350,000 €	391.95	Euro/m^2		
total cost	350,000 €				

Figure 5-4: Excel sheet feasibility study Optimus Syria

According to Figure 5-3 and Figure 5-4 we have the total cost for the pure material then we conducted the following Table 5-1 that enable us to use the 30% of additional as it was already mentioned in Figure 5-1 for side costs including the following:

- Installation and transportation
- Project development
- Financing
- Assembly
- Overhead

		increase10%	Decrease 10%
Electreical_Drive_train	775,000 €	852,500 €	697,500 €
Rotor_Hub	235,899 €	259,489 €	212,309 €
Machine_bed	211,140 €	232,253 €	190,026 €
Gear_Box	541,800 €	595,980 €	487,620 €
R_Blade_struc.	458,940 €	504,834 €	413,046 €
R_Bearing	162,625 €	178,887 €	146,362 €
Tower_struc.	780,120 €	858,132 €	702,108 €
Foundation	192,449 €	211,693 €	173,204 €
Energy_stroage	350,000 €	385,000 €	315,000 €
Total capx (optimus)	**3,707,972 €**	**4,078,769 €**	**3,337,175 €**
total matrial cost	3,707,972 €		
matrial represent	70%		
total capx	**5,297,102.79**		

Table 5-1: Summary of cost contributions

5.5 The detailed calculation of financial indicators

Written by Ahmed Salam

At this part we are interested in calculating the financial indicators which helps any investor to determine easily the project profitability.

For the calculations we need to initialize the main inputs like the wind turbine capacity and number of possible wind turbines according to the available land area we used the most normal evaluation for number of years and discount rate of return.

We used to evaluate the CapEx:

1. OpEx according to AEP
2. OpEx as a percentage from the whole lifetime

As mentioned in Figure 5-1 if the CapEx represents 55% so the OpEx represents 45% from the total cost.

In the Figure 5-4 you can see the cash flow of the project each year as the net revenue equals total money get from selling the electricity subtract from the annual operation expenditure. The equation used in the calculations will be mentioned in the appendix all at once.

As finial results from our calculations:

1. LCOE equals **4.917 cent€/kWh**
2. Payback period **11.016 years**
3. AEP **19.9164 GWh**

Typical range for new onshore wind (including a 5 MW turbine at a good site) about **4–9 eurocents per kWh**.

- Fraunhofer ISE's 2024 Germany study gives 4.3–9.2 €cent/kWh for onshore wind, depending on capex and full-load hours.
- Similar earlier Fraunhofer analyses and industry summaries report onshore wind LCOE mostly in the 4–8 €cent/kWh band at favourable sites, with higher values for weaker wind or higher costs.

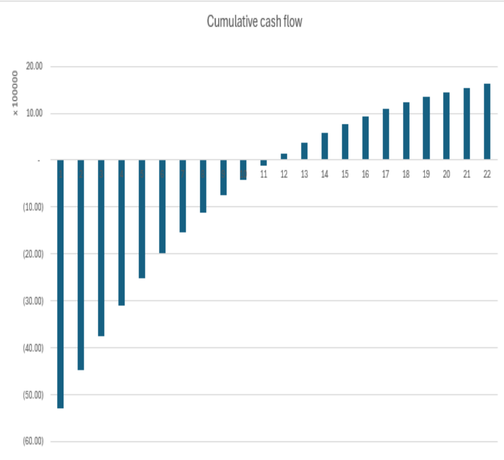
As we researched, we could find that for a modern 5 MW wind turbine, a typical AEP is roughly 15–20 GWh in a good site, corresponding to a capacity factor of about 35–45%.

Our AEP with calculated using WindPro software for more details have a look on Chapter 4 and we added the uncertainty in a separate table which as a summation equals 12 % from the AEP you can see the details of the losses in the Figure 5-5 below.

Main inputs			
Rated power	5	Mw	
CAPX_price_estimation	1	M€/Mw	
Intial price assumption	5,297,103 €		
CAPX	55%	equals	5,297,103 €
Opex	45%	equals	4,333,993 €
Life time	20	years	
Dicount rate	12%		
Full load hours	4498	h	
AEP	19.9164	GWH	
Electricity price	6	cent €/Kwh	
Annual revenue	1,194,985 €		
Annual O&M cost	216,700 €		
Annual O&M cost	1.4	cent €/Kwh	
Annual cost of O&M	278,830 €		
NPV	1,630,865 €		
IRR (internal rate of retuen)	16.32%		
Simplified LCOE	1.859	cent €/Kwh	
Advanced LCOE	4.917	cent €/Kwh	
Payback period	11.016	years	

losses and uncertainity	percentage
turbine availbilty	3%
grid availabilty	2%
electrical losses	2%
environmental losses	3%
other	2%

year	AEP TWH	Revenue	O&m	Net_Revenue	Cumulative cash flow
2030	0	0	0	0	(5,297,102.79)
2031	17.7825127	1,066,950.76	248,955.18	817,995.59	(4,479,107.20)
2032	15.8772435	952,634.61	222,281.41	730,353.20	(3,748,754.00)
2033	14.1761103	850,566.62	198,465.54	652,101.07	(3,096,652.93)
2034	12.6572413	759,434.48	177,201.38	582,233.10	(2,514,419.82)
2035	11.3011083	678,066.50	158,215.52	519,850.98	(1,994,568.84)
2036	10.0902753	605,416.52	141,263.85	464,152.66	(1,530,416.18)
2037	9.00917436	540,550.46	126,128.44	414,422.02	(1,115,994.16)
2038	8.04390568	482,634.34	112,614.68	370,019.66	(745,974.50)
2039	7.18205864	430,923.52	100,548.82	330,374.70	(415,599.80)
2040	6.41255236	384,753.14	89,775.73	294,977.41	(120,622.39)
2041	5.72549318	343,529.59	80,156.90	263,372.69	142,750.30
2042	5.11204748	306,722.85	71,568.66	235,154.18	377,904.48
2043	4.56432811	273,859.69	63,900.59	209,959.09	587,863.57
2044	4.07529295	244,517.58	57,054.10	187,463.48	775,327.05
2045	3.63865442	218,319.27	50,941.16	167,378.10	942,705.15
2046	3.24879859	194,927.92	45,483.18	149,444.74	1,092,149.89
2047	2.90071303	174,042.78	40,609.98	133,432.80	1,225,582.69
2048	2.58992235	155,395.34	36,258.91	119,136.43	1,344,719.12
2049	2.31243067	138,745.84	32,374.03	106,371.81	1,451,090.93
2050	2.06467024	123,880.21	28,905.38	94,974.83	1,546,065.76
2051	1.84345557	110,607.33	25,808.38	84,798.96	1,630,864.71



IRR is the Discount rate at which the NPV equal zero

Figure 5-5: Excel sheet Optimus Syria (Detailed Cal_)

5.6 Comprehensive overview of the feasibility study

Written by Ahmed Salam

In this part we were interested in establishing the IRR (internal rate on return) as this percentage has a weighted value from any investor looking to participate in an energy project.

From the definition of IRR you can understand how we calculated it , it represents the interest rate on your money when the NPV of the whole project equal Zero , then you can compare this percentage with the interest rate you can get from the bank on your money so our target is to set IRR higher than the interest rate from the bank on any deposited money which would attract the investors to participate then you can quickly have the finance you need for such a project.

As you can realize in the Figure 5-6 we could calculate the IRR using the function what if analysis in the excel by setting the value of NPV to zero through changing the interest rate and then , the interest rate then equal the IRR.

Then resultant IRR of our project is **16.61 %.**

To understand the value of how profitable our project is typical IRR ranges:

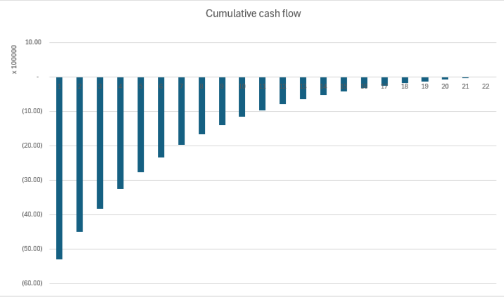
- Policy and academic work for Europe often assume “normal” or target project IRRs for onshore wind of about 4.5–7% in mature markets with low risk.
- Industry and investor sources report that many onshore wind projects now target around 5-10% IRR, reflecting higher interest rates and construction risk.

Some large utilities quote hurdle rates for renewables investments in the 8–12% range depending on region and risk profile, which is consistent with the upper end of that band.

Main inputs			
Rated power	5	Mw	
CAPX_price_estimation	1	M€/Mw	
Intial price assumption	5,297,103 €		
CAPX	55%	equals	5,297,103 €
Opex	45%	equals	4,333,993 €
Life time	20	years	
Dicount rate	17%		
Full load hours	4498	h	
AEP	19.9164	GWH	
Electricity price	6	cent €/Kwh	
Annual revenue	1,194,985 €		
Annual O&M cost	216,700 €		
Annual O&M cost	1.4	cent €/Kwh	
Annual cost of O&M	278,830 €		
NPV	0 €		
IRR (internal rate of retuen)	16.61%		
Simplified LCOE	1.735	cent €/Kwh	
Advanced LCOE	6.000	cent €/Kwh	
Payback period	14.204	years	

losses and uncertainity	percentage
turbine availbilty	3%
grid availabilty	2%
electrical losses	2%
environmental losses	3%
other	2%

year	AEP TWH	Revenue	O&m	Net_Revenue	Cumulative cash flow
2030	0	0	0	0	(5,297,102.79)
2031	17.0796493	1,024,778.96	239,115.09	785,663.87	(4,511,438.92)
2032	14.6469348	878,816.09	205,057.09	673,759.00	(3,837,679.92)
2033	12.5607203	753,643.22	175,850.08	577,793.13	(3,259,886.78)
2034	10.7716527	646,299.16	150,803.14	495,496.03	(2,764,390.76)
2035	9.23740834	554,244.50	129,323.72	424,920.78	(2,339,469.97)
2036	7.92169177	475,301.51	110,903.68	364,397.82	(1,975,072.15)
2037	6.79337734	407,602.64	95,107.28	312,495.36	(1,662,576.80)
2038	5.82577271	349,546.36	81,560.82	267,985.54	(1,394,591.25)
2039	4.9959874	299,759.24	69,943.82	229,815.42	(1,164,775.83)
2040	4.28439134	257,063.48	59,981.48	197,082.00	(967,693.83)
2041	3.67415041	220,449.02	51,438.11	169,010.92	(798,682.91)
2042	3.15082824	189,049.69	44,111.60	144,938.10	(653,744.81)
2043	2.70204469	162,122.68	37,828.63	124,294.06	(529,450.75)
2044	2.31718296	139,030.98	32,440.56	106,590.42	(422,860.34)
2045	1.98713844	119,228.31	27,819.94	91,408.37	(331,451.97)
2046	1.70410332	102,246.20	23,857.45	78,388.75	(253,063.22)
2047	1.46138189	87,682.91	20,459.35	67,223.57	(185,839.65)
2048	1.25323212	75,193.93	17,545.25	57,648.68	(128,190.97)
2049	1.07472986	64,483.79	15,046.22	49,437.57	(78,753.40)
2050	0.92165231	55,299.14	12,903.13	42,396.01	(36,357.39)
2051	0.79037813	47,422.69	11,065.29	36,357.39	0.00



IRR is the Discount rate at which the NPV equal zero

Figure 5-6: Excel sheet Optimus Syria (IRR)

As a summary of our work, we conducted a sensitivity analysis to determine which components (teams) have the biggest influence on the whole FS and how then we can consider optimizing this part with a lower cost match with our targets as project developers.

5.7 Cost Breakdown and Component Evaluation

Written by Ahmed Salam

The preliminary cost evaluation for our custom wind turbine design reveals a strategic distribution of expenses, focused heavily on the core energy-conversion systems. By acting as the OEM (Original Equipment Manufacturer), we have achieved a granular understanding of the cost drivers that impact our LCOE.

Key insights from the distribution cost include:

- Primary Cost Drivers: The Electrical Drive Train and Tower Structure represent the largest individual investments, each accounting for 21% of the total system cost. These components are critical for maximizing energy capture and structural longevity in the Homs Gap environment.
- Mechanical Core: The Gearbox (15%) and Rotor Blade Structure (12%) follow as significant capital outlays. Our design focuses on balancing high-performance materials in these areas with the economic necessity of the Syrian market.
- Infrastructure & Storage: Notably, the inclusion of Energy Storage (10%) and Foundation (5%) ensures that the project accounts for grid stability, a common problem in the local energy landscape, while keeping civil engineering costs optimized.

- Precision Components: Secondary components such as the Rotor Hub (6%), Machine Bed (6%), and Bearings (4%) have been streamlined to reduce mechanical complexity without compromising the turbine’s "P90" reliability.

Strategic Importance for Investors

This detailed breakdown is essential for the Sensitivity Analysis. By identifying that nearly 42% of the turbine cost is concentrated in the drive train and tower, we can focus our risk-mitigation strategies on these specific supply chain areas. For investors, this chart proves that the project’s CapEx is transparent, well-allocated, and geared toward high-efficiency energy production.

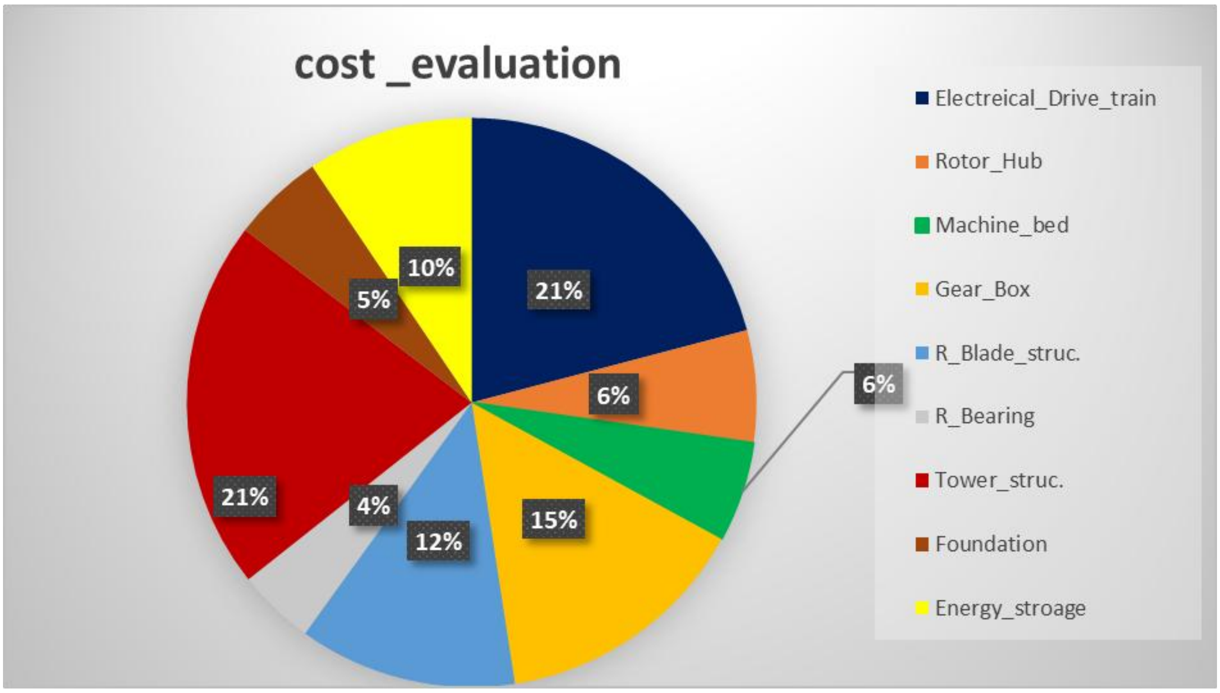


Figure 5-7: Pia Chart (teams Quotations)

5.8 Sensitivity Analysis: Risk and Resilience Modelling

Written by Ahmed Salam

The financial viability of a wind project is highly sensitive to the CapEx of its primary components. To ensure the Qattinah Wind Farm remains profitable despite Syria's economic volatility, we conducted a two-tier sensitivity analysis. This allows us to identify which "levers" have the greatest impact on our IRR and Payback Period.

Component Cost Sensitivity (Tornado Chart)

The first analysis (upper right chart) Figure 5-8 identifies the total financial exposure of each major turbine system.

- **High-Impact Components:** The Tower Structure (€780,120) and the Electrical Drive Train (€775,000) are the most significant cost drivers. Because these two areas represent the highest expenditure, our procurement and design strategy focuses on these components to prevent budget overruns.
- **Moderate Variables:** The Gearbox (€541,800) and Rotor Blade Structure (€458,940) also show significant weight. By designing these in-house, we can better control these costs compared to purchasing at fluctuating market prices from global OEMs.

10% Variance Stress Test (Impact Chart)

The second analysis (lower right chart) simulates a +/- 10% change in costs to see the immediate effect on the project budget.

- **Volatility Analysis:** The chart reveals that a 10% increase in the price of the Tower Structure or Electrical Drive Train creates the largest negative swing (indicated by the orange bars).
- **Strategic Mitigation:** This data justifies why we have prioritized localizing certain parts of the manufacturing process. By reducing reliance on imported "Electrical Drive Train" components, we shield the project from the 10% cost spikes often seen in international markets due to supply chain instability.
- **Result:** Even with a 10% unfavourable swing across all major components, the project's LCOE remains within a competitive range, proving that the custom design offers a "buffer" against economic shocks that standard imported models might not survive.

For a project in a high-risk economy, this analysis is the "Stress Test." It proves to financiers that we have not only identified the most expensive parts of the project but have also calculated exactly how much the project's profitability can "bend" before it breaks. This transparency is what builds the Bankability of the Qattinah site.

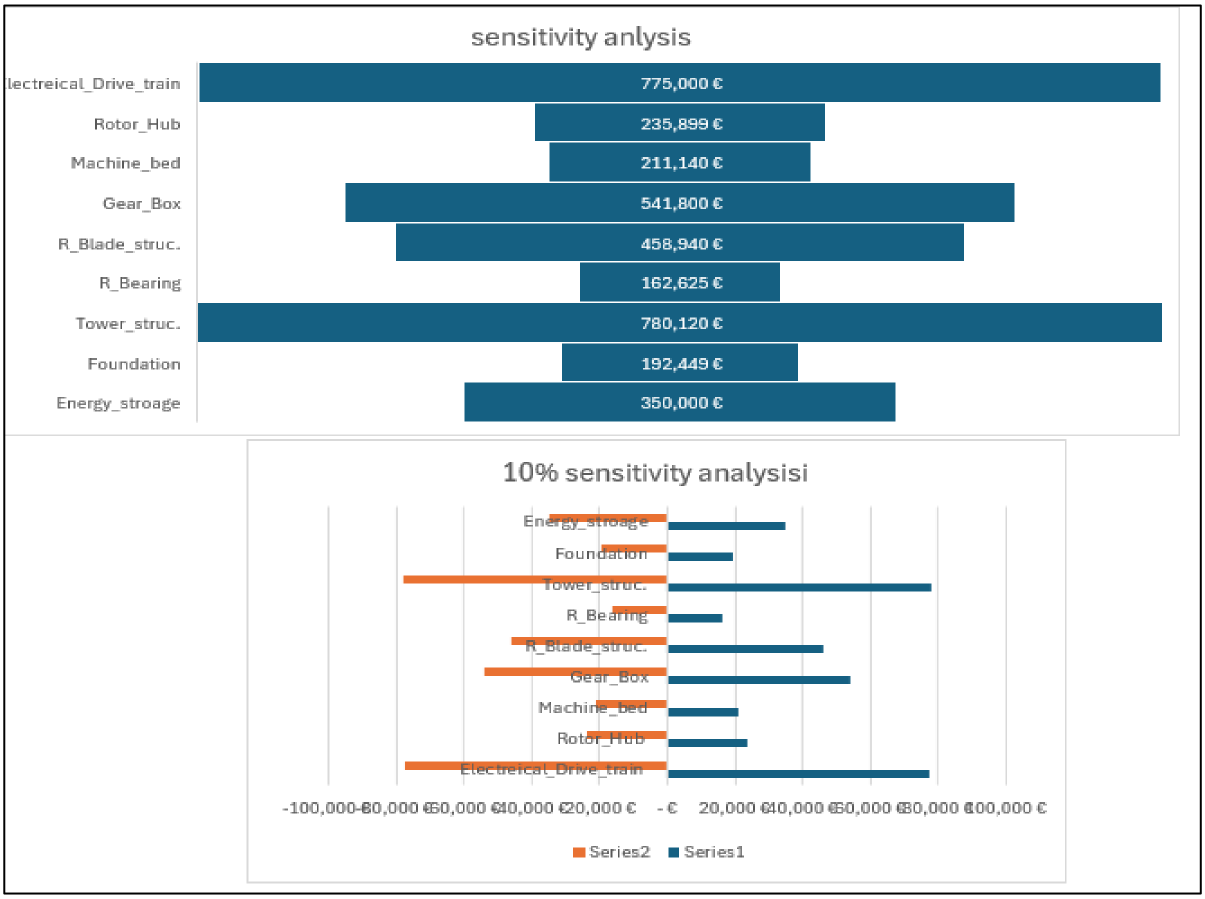


Figure 5-8: Excel sheet Optimus Syria (Sensitivity Analysis)

5.9 Strategic Feasibility of Optimus Syria

Written by Ahmed Salam

The feasibility study for the **Optimus Syria** wind farm demonstrates that technical sovereignty, acting as both developer and manufacturer, is a viable pathway to energy independence in high-risk economic environments. By designing a bespoke 5 MW turbine tailored for the Homs Gap, the project achieves an **LCOE of 4.917 cent€/kWh**, placing it at the highly competitive lower end of global onshore wind benchmarks.

Our financial modeling confirms a robust **IRR of 16.61%**, which significantly exceeds the 5–10% target typically seen in mature European markets. This higher return profile is critical for attracting investment amid Syria's currency volatility and economic crisis, providing the necessary "risk premium" to secure financing. Furthermore, the **Payback Period of 11.016** years ensures capital recovery within the first half of the turbine's expected 30-year operational life.

The sensitivity analysis highlights that while the project is mostly exposed to cost fluctuations in the **Tower Structure and Electrical Drive Train** (comprising 42% of CapEx), our in-house design strategy provides a buffer against global supply chain shocks. Ultimately, Optimus Syria transitions from a theoretical concept to a bankable reality, proving that engineering innovation can effectively mitigate economic instability to deliver sustainable, profitable power.

6 Lesson Learned

Written by Luis Urhahn

The development of a wind turbine or wind farm in an environment like Syria provided the team with valuable insights into the transition from theoretical ideas to practical project development challenges. The following sections outline the key technical and organizational lessons learned.

6.1 Technical Lessons Learned

Site Selection and Data Integrity

One of the primary challenges was identifying a suitable site without predefined regulatory frameworks. The collaboration with the University of Damascus proved to be a critical factor leveraging their localized expertise and access to existing measured wind data significantly reduced the initial uncertainty in site analysis. Furthermore, the team learned that interpreting satellite imagery in a rural context is highly subjective. Distinguishing between inhabited housings, agricultural barns, and ruins required making conservative assumptions, highlighting the need for ground-truth data or local verification in the siting process.

Dynamic Modelling and Software Integration

The project utilized an iterative design approach, which presented unique challenges in data management. As various sub-teams worked in parallel, the turbine characteristics and technical parameters were subject to frequent updates. This required constant synchronization within WindPro to ensure that the energy yield assessments remained accurate. Additionally, the team discovered that processing measured wind data is a complex, non-intuitive task. Ensuring the data meets the specific software formats is a time-intensive process that must be accounted for in the early stages of the project timeline.

Spatial Planning and Scalability

A significant takeaway regarding spatial requirements was the difficulty in estimating the total area required for a wind farm. Initial assumptions focused on present needs, but it became clear later in the process that the selected area lacked the flexibility for future expansion for a wind farm. This taught the team the importance of “planning ahead” and considering maximum-scale scenarios during the initial land-lease planning phase.

Logistics in Developing Infrastructure

The planning of transport routes showed the differences between European infrastructure and that of a developing nation. The team had to account for variables often taken for granted in more developed markets, such as the structural load capacity of bridges and the specific geometry of rural roads. Designing an optimal route that balances the shortest distance with the physical limitations of transporting oversized components, e.g. avoiding sharp turns, is a critical logistical aspect that requires early-stage technical consideration.

Cost Analysis Boundaries

Close to the end, the sensitivity of the financial cost analysis became a key factor. In project development, the level of detail can range from broad estimations to specific line-item cost breakdowns. The team learned that establishing a clear "system boundary" for the cost analysis is essential. Without a predefined scope of needs to be included and what not, it is easy to lose focus or produce inconsistent financial projections.

6.2 Organizational and Team Lessons Learned

Communication challenges

The project highlighted that communication is the foundation of successful project development. Maintaining a cohesive workflow was significantly challenged by varying individual schedules and geographic dispersion during the semester and in the semester break. The team learned that in a remote or hybrid environment, "passive" communication is insufficient. Instead, regular and active communication is essential. To ensure all members remain aligned regardless of their physical location, future projects should implement mandatory synchronised meetings and centralised communication platforms from day one.

Alignment of Quality Standards and Priorities

One key takeaway was the impact of conflicting internal priorities. At the start of the project, the expected level of quality and the level of detail required for the final output were not clearly defined. This forced individual teams to establish their own standards, occasionally causing conflict. It is vital to establish a shared “Definition of Quality” from the start of the project and align on quality expectations during the kick-off phase to avoid inconsistent outputs and ensure a professional standard across all work packages.

Teams Synergy and Dependency Management

As this project involved multiple teams working toward a singular end result, the interdependencies between work packages were high. The importance of cross-team cooperation was realized relatively late in the process, which led to avoidable technical bottlenecks. This experience demonstrated that in large-scale developments, teams cannot operate in isolation. For future iterations, it is recommended that students are briefed on the necessity of cooperation to synchronize data before conflicts arise.

Decisions and Responsibilities

Perhaps the most significant challenge was the final decision making or taking responsibility. In a university environment, where all members hold equal status, exercising authority or demanding accountability is difficult. The absence of clearly defined decision-making protocols led to "decision paralysis" regarding critical project directions. Even in flat hierarchies, a project requires a defined governance structure. Assigning specific roles, such as a "Final Decision Maker" for specific modules and establishing clear escalation paths for disagreements is crucial to maintaining project momentum.

Overall, this project was a valuable learning experience for everyone involved. As well as providing an invaluable insight into the professional world, the process offered an invaluable preview of the technical complexities of wind energy development in a challenging context like Syria. Managing the interdependencies between specialised teams and navigating the challenges of collaborative decision-making offered insights that went far beyond theoretical knowledge. By overcoming these organisational and technical hurdles, the team gained a realistic understanding of how large-scale projects operate in practice, preparing each member for the complexities of their future professional careers.

7 Conclusion

Written by Luis Urhahn

The "Optimus Syria" project has successfully established a comprehensive and feasible framework for a fictive 5.0 MW wind turbine development tailored to the unique environmental and logistical demands of the Syrian energy sector. This report demonstrates that despite the country's current limited renewable infrastructure, high-performance wind energy is a feasible reality.

The technical foundation of the project was the identification of Qattinah as the optimal site for the OSyr160-5.0 turbine. Located in the Homs region, the site benefits from an average wind speed of 8.49 m/s at hub height and is strategically positioned just 2.5 km from a 230 kV substation, significantly minimizing grid connection complexities. WindPro PARK simulations show that a single turbine can achieve on the order of 22.5 GWh/year total AEP and about 21.9 GWh/year once curtailments are applied, scaling to an optimized four-turbine layout yields roughly 79.5 GWh/year with wake and curtailment losses included.

Logistically, the project confirmed that while infrastructure in a reconstruction context presents challenges, the 86 km transport route from Tartus Port to the site via the M1 highway is feasible. However, the analysis highlighted that success depends on early-stage infrastructure upgrades, including bridge reinforcements and road widening to accommodate the roughly 80 meter blades and heavy nacelles.

Financially, the Optimus Syria project shows high resilience against regional economic volatility. The project achieved a LCOE of 4.917 cent€/kWh, placing it at the competitive lower end of global onshore wind benchmarks. With a robust Internal IRR of 16.61% and an estimated payback period of 11 years, the development provides the necessary risk premium to attract private investment in the current Syrian context.

This report serves as a pioneering technical reference for Syria’s sustainable energy future and its broader economic growth.

Acknowledgements

Initially, appreciation is given to the members of this project development team for their dedicated cooperation and shared commitment, which formed the basis of this report. The collaborative efforts of all participating teams in the Optimus project played the fundamental part in its successful completion. Thank you to all the teams. Particular credit is given to the Management Team, especially the System Integrator, whose coordination and technical expertise were essential for the seamless integration of the various project components. Their contribution ensured an effective exchange of information and a consistent final result. Sincere appreciation is also expressed to the supervisor, Dr Marina Blohm, for her professional guidance and for investing significant time in reviewing and supporting this work. The academic expertise and constructive feedback provided invaluable direction throughout the project. The opportunity to benefit from the professional support is gratefully acknowledged.

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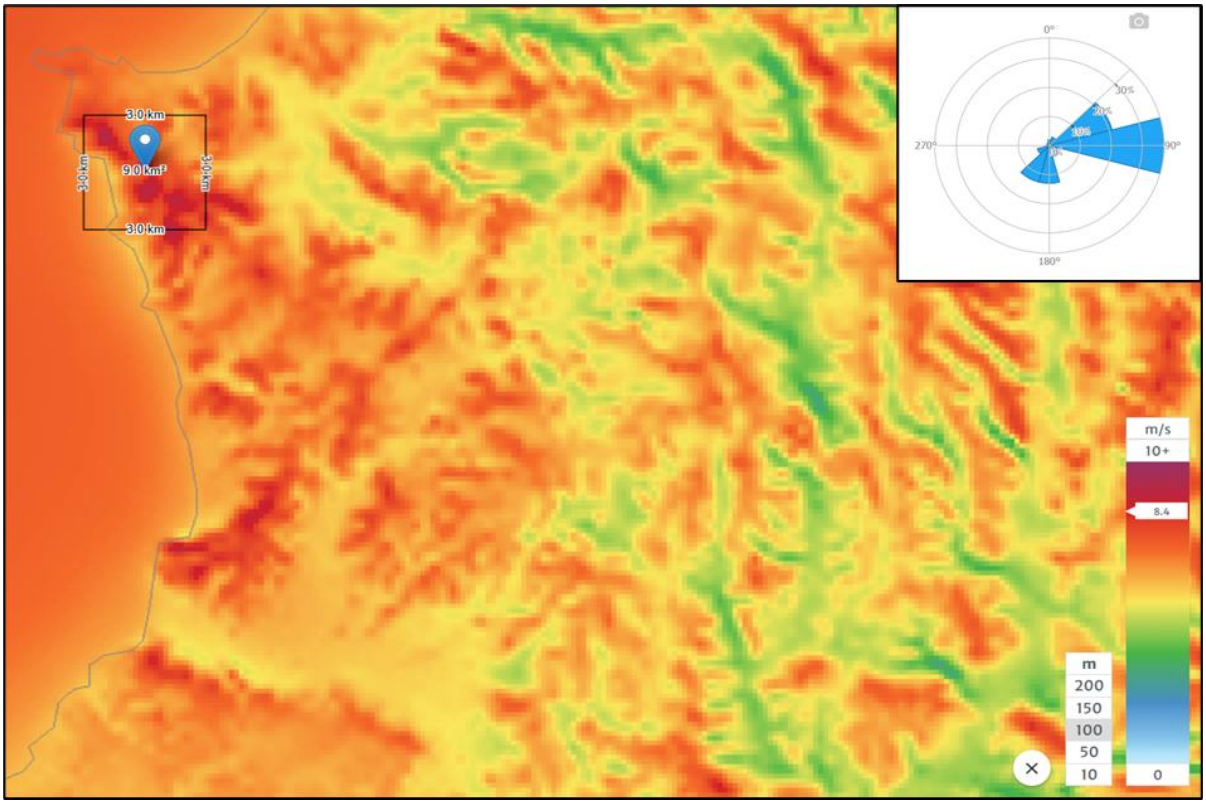
Appendix

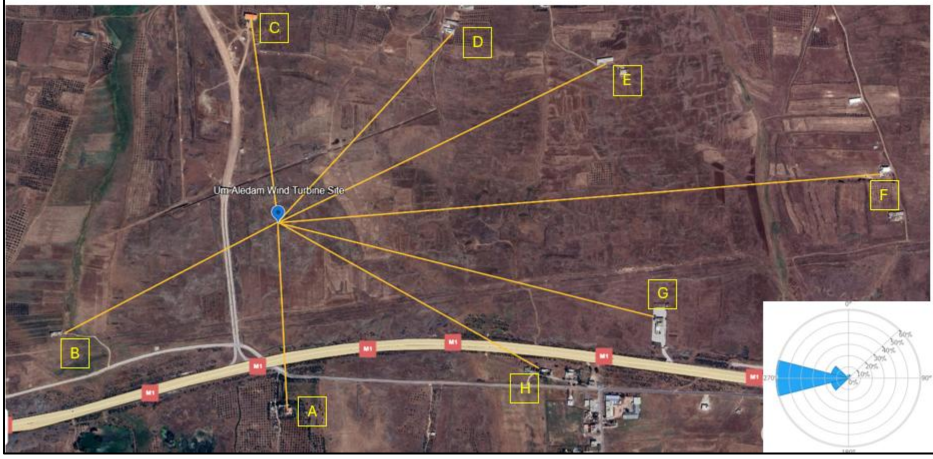
Appendix	Name
AI	Report for Site Analysis (Luis) – Optimus Syria
AII	Report for Site Analysis, detailed (Luis) – Optimus Syria
AIII	Final Report for Site Analysis, District Homs (Luis) – Optimus Syria
AIV	“Preliminary Geotechnical Survey at the Wind Turbines Project Kattina – Homs Presented to Ministry of Electricity National Energy Research Center” – Doctor Engineer Moh.AYHAM Toutoungi [Report], April 2010
AV	WindPro, Resource Calculation
AVI	WindPro, Decibel, 1xOSyr160-5.0
AVII	WindPro, Shadow, 1xOSyr160-5.0
AVIII	WindPro, Park, 1xOSyr160-5.0 (AEP) w/o curtailments
AIX	WindPro, Park, 1xOSyr160-5.0 (AEP) with curtailments
AX	WindPro, Park, 3xOSyr160-5.0 (AEP) w/o curtailments
AXI	WindPro, Park, 3xOSyr160-5.0 (AEP) with curtailments
AXII	WindPro, Park, 4xOSyr160-5.0 (AEP) w/o curtailments
AXIII	WindPro, Park, 4xOSyr160-5.0 (AEP) with curtailments
AXIV	WindPro, Decibel, 4xOSyr160-5.0
AXV	WindPro, Shadow, 4xOSyr160-5.0
AXVI	Project Wind Farm Development Contract

Appendix "2. Site Comparison and Selection"



Appendix 1: Wind resource at the location Latakia

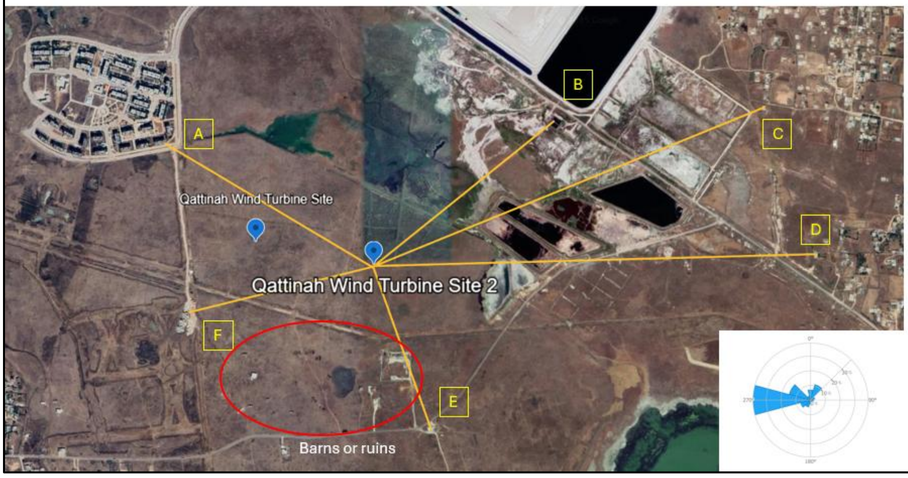
Appendix 2: Grid connection at the location Latakia



Final Turbine Location:
34°41'49.6"N
36°30'30.0"E

Building	Distance [m]
Building A	515 m
Building B	671 m
Building C	567 m
Building D	704 m
Building E	1 002 m
Building F	1 671 m
Building G	1 083 m
Building H	837 m

Appendix 3: Distance Analysis - Um Aledam



Final Turbine Location:
34°40'22"N
36°35'59"E

Building	Distance [m]
Building A	800 m
Building B	767 m
Building C	1 396 m
Building D	1 469 m
Building E	577 m
Building F	629 m

Appendix 4: Distance Analysis Qattinah

Appendix "3. Detailed Site Analysis"

Wind range [m/s]	Windbins [m/s]	Absolute Frequency (n_i)	Cumulative Distribution Function F(v)	Probability Density Function f(v)
0 - 1	0.5	154	0.00293	0.022910994
1 - 2	1.5	1863	0.03544	0.047745282
2 - 3	2.5	3652	0.06948	0.06430642
3 - 4	3.5	4805	0.09142	0.075101365
4 - 5	4.5	4736	0.09010	0.081127619
5 - 6	5.5	4180	0.07953	0.08316111
6 - 7	6.5	3796	0.07222	0.08194524
7 - 8	7.5	3353	0.06379	0.078210087
8 - 9	8.5	2975	0.05660	0.072651867
9 - 10	9.5	2856	0.05434	0.065906216
10 - 11	10.5	2746	0.05224	0.0585264
11 - 12	11.5	2691	0.05120	0.050970001
12 - 13	12.5	2550	0.04852	0.043594435
13 - 14	13.5	2343	0.04458	0.036660096
14 - 15	14.5	2134	0.04060	0.030339248
15 - 16	15.5	1831	0.03484	0.024728617
16 - 17	16.5	1566	0.02979	0.019863793
17 - 18	17.5	1319	0.02509	0.015733853
18 - 19	18.5	1078	0.02051	0.012295033
19 - 20	19.5	753	0.01433	0.009482683
20 - 21	20.5	477	0.00908	0.007221106
21 - 22	21.5	332	0.00632	0.005431172
22 - 23	22.5	204	0.00388	0.004035826
23 - 24	23.5	96	0.00183	0.002963737
24 - 25	24.5	35	0.00067	0.002151412
25 - 26	25.5	28	0.00053	0.00154413
26 - 27	26.5	8	0.00015	0.001096003
27 - 28	27.5	0	0.00000	0.00076947
28 - 29	28.5	0	0.00000	0.000534444
29 - 30	29.5	0	0.00000	0.000367296
30 - 31	30.5	0	0.00000	0.000249806

Appendix 5: Weibull-Distribution for 100m hub height

Parameter	Unit	Number
Number of Measurements	/	52560
Mean value (v_bar)	m/s	**8.49**
standard deviation (sigma_v)	m/s	5.1399
Ratio	/	0.6054
Form Parameter (k)	/	**1.7246**
Gamma-Argument	/	1.5798
Gamma-Value	/	0.8914
Scale Parameter (A)	m/s	**9.52**

Appendix 6: Basic parameters for the Weibull Distribution

Power Curve Optimus Syria							
	Output Power [kW]	c_p	Generator Power [kW]	Power Rotor [kW]	Power Wind [kW]	Rotational speed [rpm]	Tip speed ratio
1	0	0	0	0	10	1.4553	0
2	0	0	0	0	82	4.1979	0
3	0.00	0.474	0	131	276	6.6398	8.5
4	208.40	0.474	226	310	654	6.6667	8.5
5	526.50	0.474	570	606	1,278	6.6667	8.5
6	961.02	0.474	1,040	1,047	2,208	6.6667	8.5
7	1,526.16	0.474	1,652	1,662	3,507	7.6543	8.5
8	2,276.69	0.474	2,464	2,481	5,235	8.7460	8.5
9	3,239.27	0.474	3,506	3,533	7,453	9.8369	8.5
10	4,407.56	0.474	4,770	4,846	10,224	9.9999	8.5
11	4,619.98	0.37	5,000	5,000	13,608	10.0001	7.6
12	4,620.01	0.28	5,000	5,000	17,667	10.0001	7.0
13	4,620.07	0.22	5,000	5,000	22,462	10.0003	6.4
14	4,620.16	0.18	5,000	5,000	28,055	10.0005	6.0
15	4,620.29	0.14	5,000	5,000	34,506	10.0008	5.6
16	4,620.47	0.12	5,001	5,000	41,878	10.0011	5.2
17	4,620.67	0.10	5,001	5,000	50,231	10.0016	4.9
18	4,620.99	0.08	5,001	5,000	59,626	10.0023	4.7
19	4,621.38	0.07	5,001	5,000	70,126	10.0031	4.4
20	4,621.87	0.06	5,002	5,000	81,792	10.0042	4.2
21	4,622.48	0.05	5,003	5,000	94,684	10.0055	4.0
22	4,623.17	0.05	5,003	5,000	108,865	10.0070	3.8
23	4,623.98	0.04	5,004	5,000	124,395	10.0087	3.6
24	4,624.92	0.04	5,005	5,000	141,337	10.0108	3.5
25	4,626.05	0.03	5,007	5,000	159,750	10.0132	3.4
> 25	0.00	0.00	0	0	179,697	10.0158	3.2

Appendix 7: Table for the power curve of the Optimus turbine

Appendix "5. Project Economics"

The following equations were utilized to calculate the financial indicators presented in this Feasibility Study:

1. **Levelized Cost of Energy (LCOE)**

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:
I_t= Investment expenditures in year t,
M_t= O&M expenditures in year t,
E_t= Electricity generation in year t,
r= Discount rate,
n= Life of the system.

2. **Net Present Value (NPV)**

$$NPV = \sum_{t=1}^{n} \frac{R_t - C_t}{(1+r)^t} - CAPEX$$

Where:
R_t= Revenue in year t,
C_t= Annual Opex in year t.

3. **Internal Rate of Return (IRR)** The IRR is the discount rate r that satisfies

$$\sum_{t=1}^{n} \frac{CF_t}{(1+IRR)^t} = 0$$

Where:
$CF_t$is the Net Cash Flow at time t.

4. **Annual Energy Production (AEP) with Uncertainty**

$$AEP_{net} = AEP_{gross} \times (1 - Losses_{total})$$

Calculated using a **12% total uncertainty factor** in this study according to the table explained in Figure 5-6.