Hochschule Flensburg
University of Applied Science

Wind Energy Technology Institute
Research on wind Energy

Advance Wind Farm Development, WiSe 2024/25

Master's degree in Wind Engineering, Flensburg, Germany

Submitted by

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1. Introduction and Motivation

This report presents general information on wind farm planning area. The project was developed as part of the exam "Advance Wind Farm Planning" module within the Wind Energy Engineering Master's Program at the University of Applied Sciences in Flensburg. Wind farm planning is increasing energy production and energy quality as well as reduce structural load. [1]

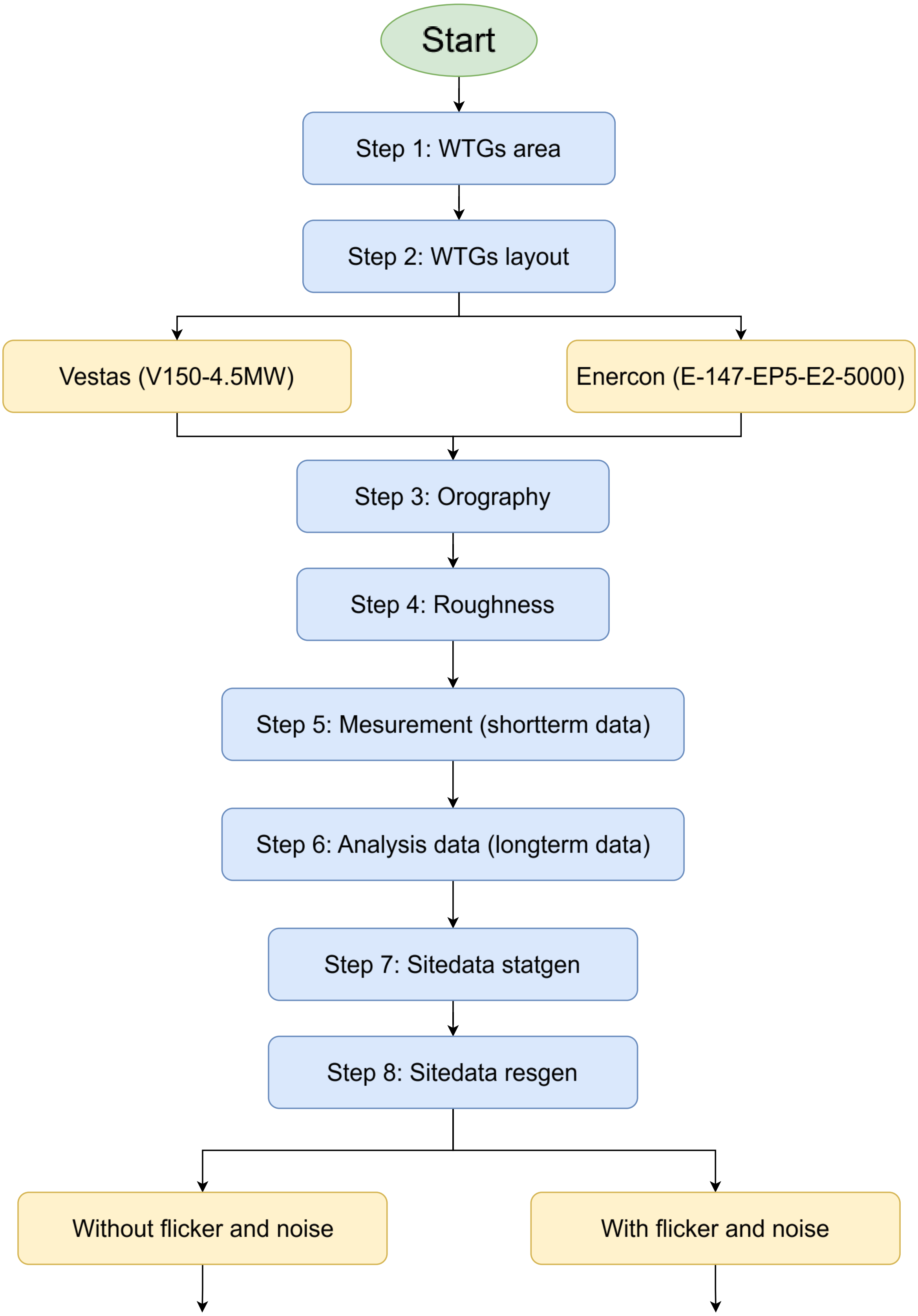
The shapefile already provided into exam, which shows the planned wind farm area, including all exclusion zones, so no need to consider distances to roads or boundaries. The tip height is limited to **200 meters**. Lidar measurements were taken at coordinates **548207 E, 6061864 N (UTM ETRS89 Z32).** This report presents wind farm layouts for **Vestas V150-4.5MW** and **Enercon E-147 EP5 E2 5000** turbines, considering maximum hub height limit. The layouts follow a minimum spacing of **5 RD** in the main wind direction and **3.5 RD** perpendicular.

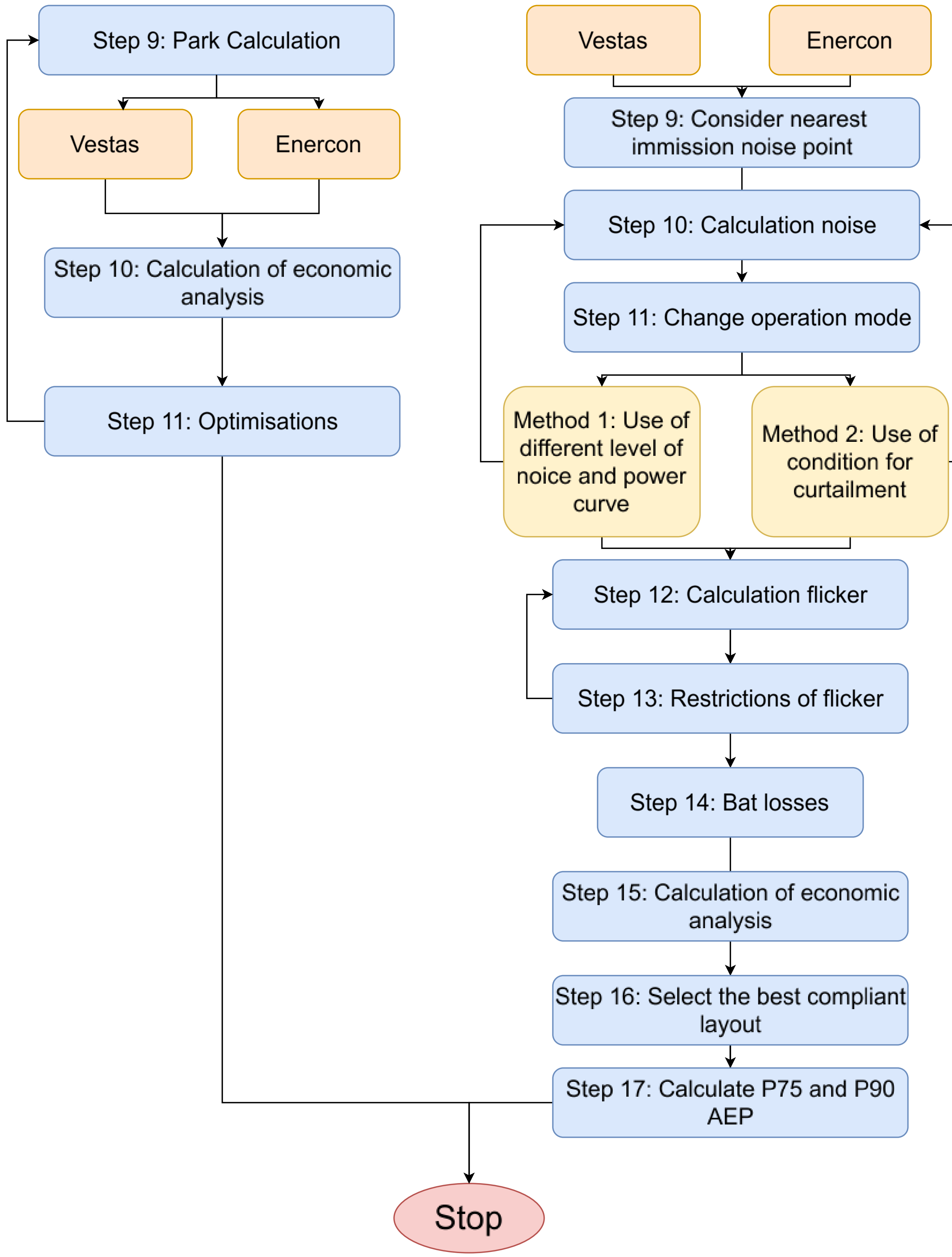
The Objective of this report is to estimate the energy yield for the baseline layout of two turbines, considering losses, without accounting for flicker and noise. The calculations will include the Levelized Cost of Energy (LCOE), Net Present Value (NPV), and Internal Rate of Return (IRR) for each turbine layout. The same calculations will be repeated, this time including flicker, noise, and bat losses. Based on the NPV, the report will identify the best compliant layout. Finally, the **P75** and **P90** Annual Energy Production (AEP) will be calculated for the selected best compliant layout.

Chapter 2 discusses the method used to achieve the objective. Chapter 3 covers our wind farm layout with two types of wind turbines, both with and without requirements. Chapter 4 investigate into the optimization process we followed during the exam time **(4 hours)**. Chapter 5 presents the results of the report. Chapter 6 discusses how the optimization of the wind farm could be improved if more time was available during the exam.

For the achieved of these tasks, we used lecture notes and the WindPro software, which we learned during class.

2. Methodology




Step 9: Park Calculation
Vestas
Enercon
Step 10: Calculation of economic analysis
Step 11: Optimisations
Vestas
Enercon
Step 9: Consider nearest immission noise point
Step 10: Calculation noise
Step 11: Change operation mode
Method 1: Use of different level of noice and power curve
Method 2: Use of condition for curtailment
Step 12: Calculation flicker
Step 13: Restrictions of flicker
Step 14: Bat losses
Step 15: Calculation of economic analysis
Step 16: Select the best compliant layout
Step 17: Calculate P75 and P90 AEP
Stop

3. Wind Farm Development

The wind area was already provided in the exam, so we did not create it (see figure 3.1).

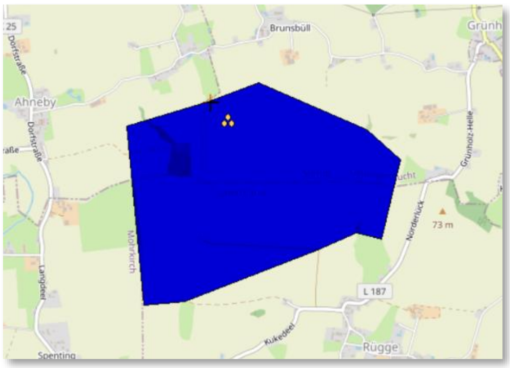


Figure 3. 1: WTGs area

In our calculations, we considered both orography and roughness, as they are crucial factors. Orography refers to the shape of the terrain, such as mountains and valleys, as well as elevation, which impact wind speed and direction. Roughness relates to the surface texture, including forests, buildings, and water bodies, which affect the wind profile near the ground. These factors play a significant role in accurately assessing wind conditions [2].

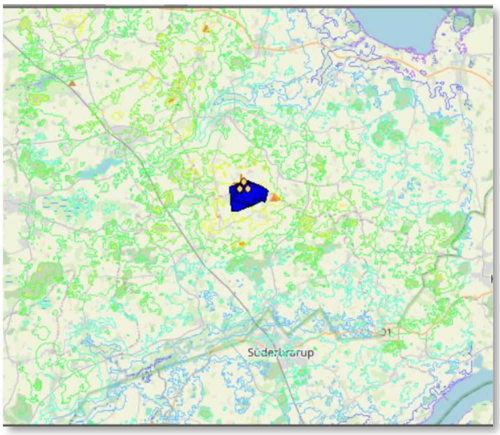


Figure 3. 2: Orography

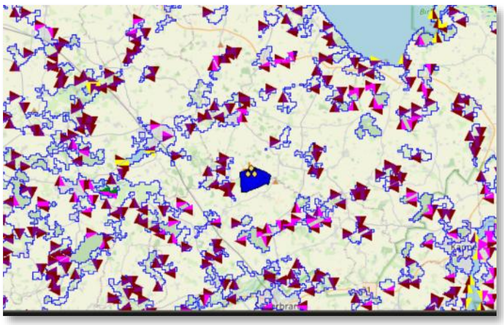


Figure 3. 3: Roughness

The short-term LiDAR data was already provided in the exam, so we imported it into WindPro for further analysis. The long-term wind data was sourced online and also imported into WindPro, which is ERA5(T) (See figure 3.4).

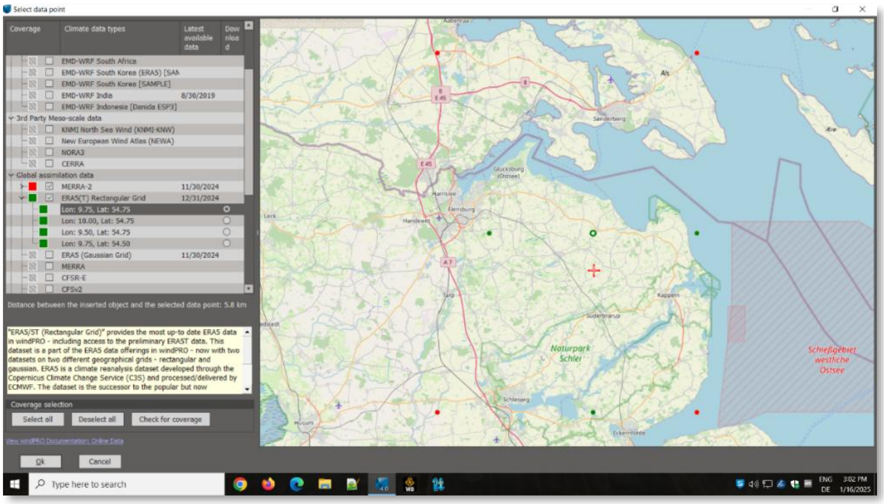


Figure 3. 4: Long term data ERA5(T)

To process and analyze the data, we used SiteData STRAGEN to generate site-specific wind statistics and SiteData RESGEN to create resource grids based on the available data. These steps allowed us to evaluate the wind resource distribution across the study area.

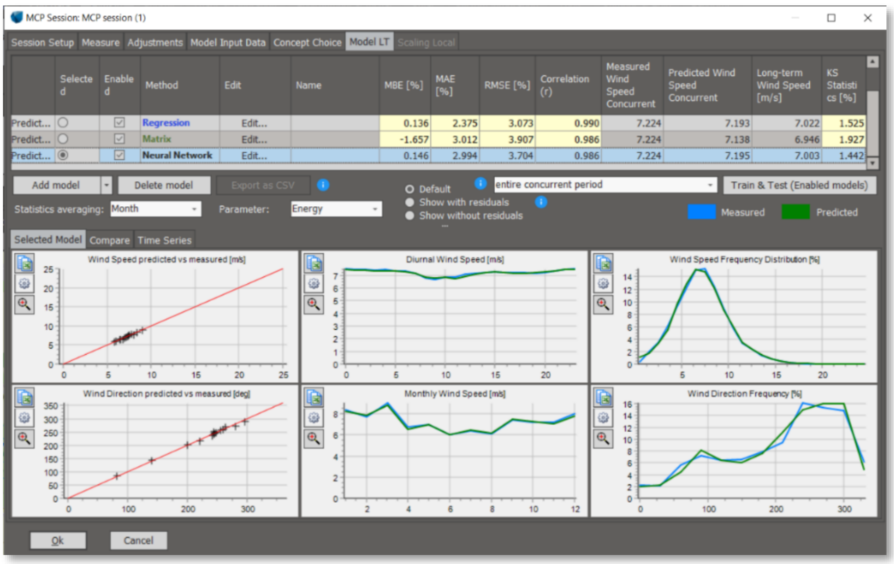


Figure 3. 5: Long term and short term data comparisons

After processing the data, we performed a comparative analysis using MCP (Measure-Correlate-Predict). This method helped in correlating the short-term LiDAR data with the long-term dataset, ensuring accurate long-term wind predictions. The MCP process enhances the reliability of wind resource assessments by adjusting for variations and filling gaps in the data, ultimately improving the accuracy of energy yield estimations. We applied four different models for comparison, but the neural network model showed the closest resemblance to the long-term data (see figure 3.5). Therefore, we selected this model as the most reliable for our analysis.(see figure 3.6)

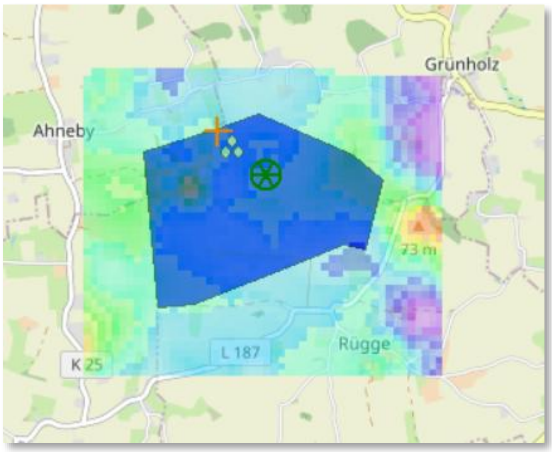


Figure 3. 6 MCP output

3.1 Baseline layout without flicker and noise requirements

Before placing the wind turbines, we considered the wind direction, which is crucial for minimizing wake effects and optimizing energy production. This approach helps increase the Annual Energy Production (AEP) and enhances the overall profitability of the project by ensuring an efficient wind farm layout. As shown in Figure 3.7, the wind rose illustrates the predominant wind directions, and we specifically considered a **240-degree** wind direction for our analysis.

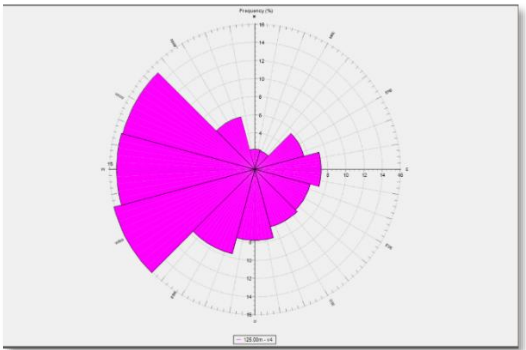


Figure 3. 7: Wind rose

For the wind turbine layout, we considered both wake direction and wake distance to minimize energy losses and optimize efficiency. The wake direction was analyzed using an elliptical shape, where the major direction was set to **5R** and the minor direction to **3.5R** (see Figure 3.8). This approach ensures better spacing between turbines, reducing wake effects and improving overall energy output.

Figure 3. 8: Distance circle for wind turbine

3.1.1 Layouts of Vestas V150-4.5MW HH125

As shown in Figure 3.9, the wind turbine layout features Vestas V150-4.5MW HH125 turbines. In our initial approach, we designed the wind farm layout with a total of six turbines, carefully considering wind direction and wake effects to maximize efficiency.

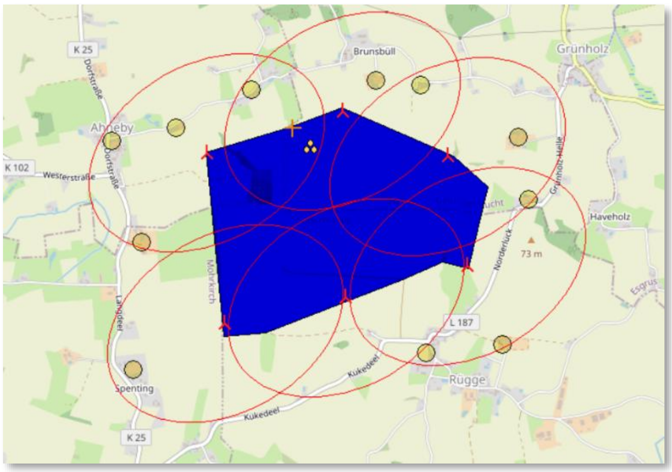


Figure 3. 9: Six wind turbine of Vestas V150 – 4.5MW HH125

As shown in Figure 3.10, the wind turbine layout features Vestas V150-4.5MW HH125 turbines. In our second approach, we designed the wind farm layout with a total of five turbines, carefully considering wind direction and wake effects to maximize efficiency. The wind turbine layout features Vestas V150-4.5MW HH125 turbines. In our third approach, we designed the wind farm layout with a total of seven turbines.

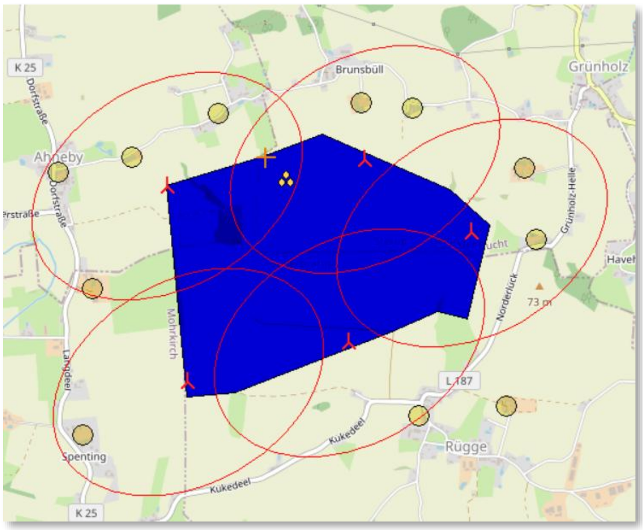
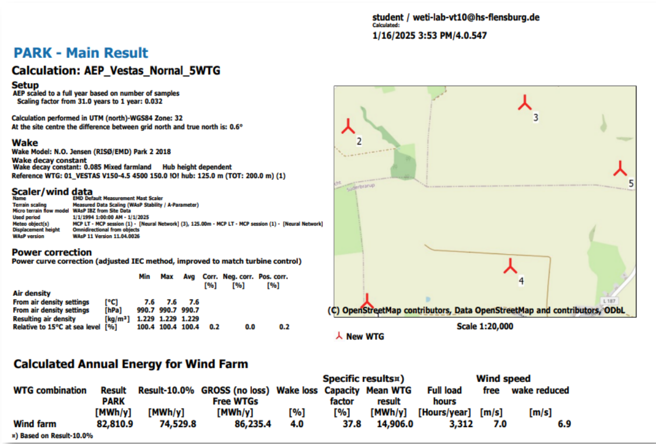


Figure 3. 10: Five wind turbine of Vestas V150 – 4.5MW HH 125

3.1.2 Comparison of different Layout of Vestas V150-4.5MW HH125

The AEP for the wind farm layout with **five** Vestas V150-4.5MW HH125 turbines is **82,810 MWh/year**, considering **4%** wake losses (see Figure 3.11). The calculated Net Present Value (NPV) is **9,354,499 euros**, and the Internal Rate of Return (IRR) is **14.52%**.



student / weti-lab-vt10@hs-flensburg.de
Calculated:
1/16/2025 3:53 PM/4.0.547

PARK - Main Result

Calculation: AEP_Vestas_Nornal_5WTG

Setup
AEP scaled to a full year based on number of samples
Scaling factor from 31.0 years to 1 year: 0.032

Calculation performed in UTM (north)-WGS84 Zone: 32
At the site centre the difference between grid north and true north is: 0.6°

Wake
Wake Model: N.O. Jensen (RISØ/EMD) Park 2 2018
Wake decay constant
Wake decay constant: 0.085 Mixed farmland Hub height dependent
Reference WTG: 01_VESTAS V150-4.5 4500 150.0 !O! hub: 125.0 m (TOT: 200.0 m) (1)

Scaler/wind data

Name	EMD Default Measurement Mast Scaler
Terrain scaling	Measured Data Scaling (WAsP Stability / A-Parameter)
Micro terrain flow model	WAsP IBZ from Site Data
Used period	1/1/1994 1:00:00 AM - 1/1/2025
Meteo object(s)	MCP LT - MCP session (1) - [Neural Network] (3), 125.00m - MCP LT - MCP session (1) - [Neural Network]
Displacement height	Omnidirectional from objects
WAsP version	WAsP 11 Version 11.04.0026

Power correction
Power curve correction (adjusted IEC method, improved to match turbine control)

		Min	Max	Avg	Corr. [%]	Neg. corr. [%]	Pos. corr. [%]
Air density							
From air density settings	[°C]	7.6	7.6	7.6			
From air density settings	[hPa]	990.7	990.7	990.7			
Resulting air density	[kg/m³]	1.229	1.229	1.229			
Relative to 15°C at sea level	[%]	100.4	100.4	100.4	0.2	0.0	0.2

(C) OpenStreetMap contributors, Data OpenStreetMap and contributors, ODbL
Scale 1:20,000
New WTG

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	Result-10.0% [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Wake loss [%]	Specific results¤) Capacity factor [%]	Specific results¤) Mean WTG result [MWh/y]	Specific results¤) Full load hours [Hours/year]	Wind speed free [m/s]	Wind speed wake reduced [m/s]
Wind farm	82,810.9	74,529.8	86,235.4	4.0	37.8	14,906.0	3,312	7.0	6.9

¤) Based on Result-10.0%

Figure 3. 11: Wind park result for five Vestas wind turbines

The AEP for the wind farm layout with **six** Vestas V150-4.5MW HH 125 turbines is **98,137.1 MWh/year**, considering **5.1%** wake losses (see Figure 3.12). The calculated Net Present Value (NPV) is **10,573,478 euros**, and the Internal Rate of Return (IRR) is **14.32%**.

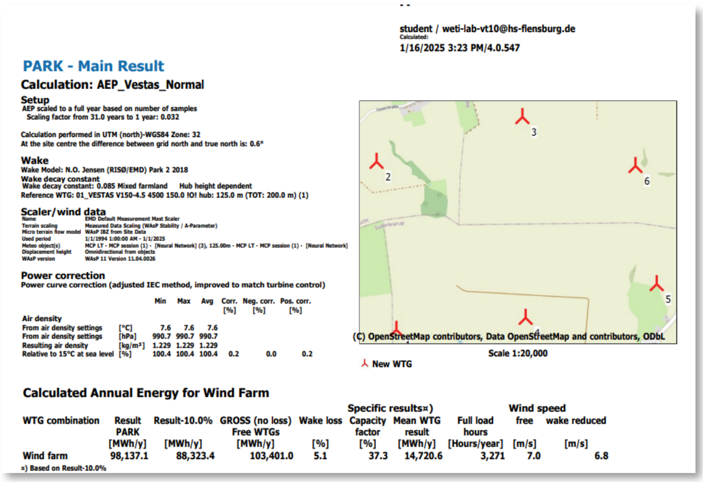


Figure 3. 12: Wind park result for six Vestas wind turbines

The AEP for the wind farm layout with **seven** Vestas V150-4.5MW HH 125 turbines is **112,331.2 MWh/year**, considering **6.8%** wake losses (see Figure 3.13). The calculated Net Present Value (NPV) is **11,187,243 euros**, and the Internal Rate of Return (IRR) is **14.01%**.

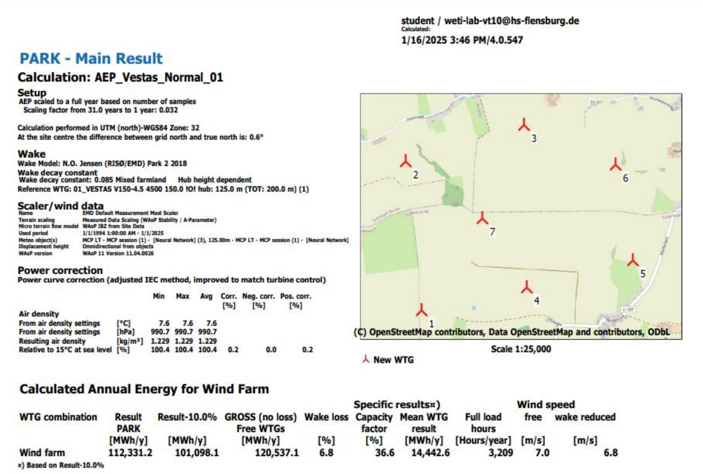


Figure 3. 13: Wind park result for seven Vestas wind turbines

The **seven-turbine** layout has the highest AEP **(112,331.2 MWh/year)** and NPV **(11,187,243 euros)**, but it also has the highest wake losses **(6.8%)** and a lower IRR **(14.01%)**, indicating a reducing over time return on investment.

The **five-turbine** layout has the highest IRR **(14.52%)**, but its NPV **(9,354,499 euros)** and AEP **(82,810 MWh/year)** are the lowest, meaning it generates less revenue overall.

The **six-turbine** layout provides a well-balanced solution, with a high AEP **(98,137.1 MWh/year)**, a competitive NPV **(10,573,478 euros)**, and a solid IRR **(14.32%)**, making it the most financially and technically viable choice. the **six-turbine layout** is the best option because it provides a strong balance between **energy production, wake losses, and financial performance**.

3.1.3 Layout of Enercon E-147 EP5 E2 5000 HH 127

As shown in Figure 3.14, the wind turbine layout features Enercon E-147 EP5 E2 5000 HH 127 turbines. However, as discussed in the previous chapter, the layout with six wind turbines proved to be the most optimal for maximizing both the NPV and Internal Rate of Return IRR of the project.

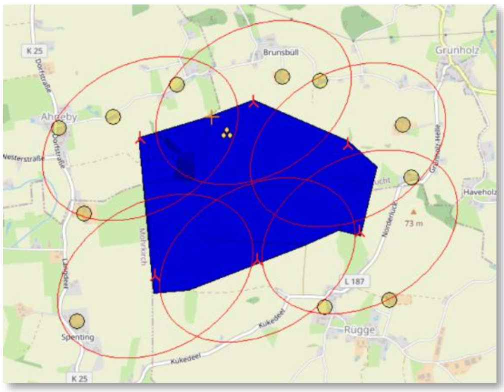


Figure 3. 14: Six wind turbine of Enercon E147 EP5 E2 5000 HH 127

3.2 Noise and Flicker considering for Wind Farm Layout

Before evaluating noise and flicker impacts, we identified key areas, such as residential zones, schools, and other critical locations that could be affected by noise. These areas are highlighted as red-colored boxes in Figure 3.15. Defining these zones beforehand allowed us to accurately assess and mitigate potential noise and flicker effects during the planning process.

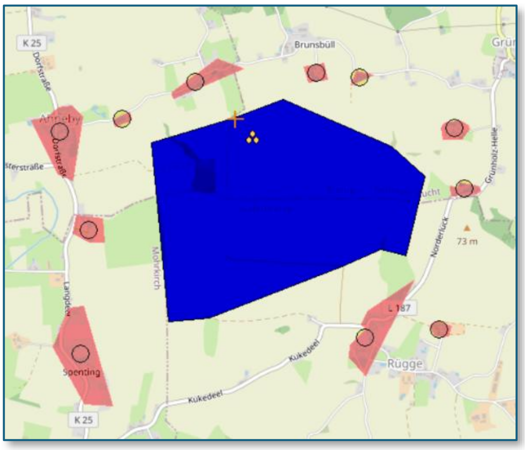


Figure 3. 15: Residencial and other area near to wind farm area

3.2.1 Noise

4. Results

4.1 Commercial Evaluation of Vestas V150-4.5MW HH125 Wind Farm without Flicker and Noice Requirements

	Value	Unit
Wind farm installed capacity	27	MW
No. of WTGs	6	
Lifetime	35	Years
Opportunity cost of capital	11	%
Remuneration rate	65	EUR/MWh
CAPEX		
WTG Capex per MW	1.05	MEUR/MW
Other Capex per MW	0.35	MEUR/MW
Total CAPEX	1.4	MEUR/MW
OPEX		
O&M	80,000	EUR/WTG/y
Gross AEP	103,401	MWh/y
Total Loss	11.6	%
Cashflows	37,800,000	EUR
NPV	10,573,478	EUR
IRR	14.32	%
LCOE Calculation		
PV CAPEX	37,800,000	EUR
PV OPEX	4,718,072	EUR
PV AEP	898,656	MWh
LCOE	47.3	EUR/MWh
NET P50 AEP	91,426	MWh/y
NET P75 AEP	85,301	MWh/y
NET P90 AEP	79,724	MWh/y

Table 4. 1: Commercial Evaluation of six Vestas V150-4.5MW HH125 Wind Turbines

4.2 Commercial Evaluation of Enercon E-147 EP5 E2 5000 HH 127 Wind Farm without Flicker and Noice Requirements

	Value	Unit
Wind farm installed capacity	30	MW
No. of WTGs	6	
Lifetime	35	Years
Opportunity cost of capital	11	%
Remuneration rate	65	EUR/MWh
CAPEX		
WTG Capex per MW	1.05	MEUR/MW
Other Capex per MW	0.35	MEUR/MW

Total CAPEX	1.4	MEUR/MW
OPEX		
O&M	80,000	EUR/WTG/y
Gross AEP	87246.7	MWh/y
Total Loss	11.1	%
Cashflows	42,000,000	EUR
NPV	1,614,005	EUR
IRR	10.53	%
LCOE Calculation		
PV CAPEX	42,000,000	EUR
PV OPEX	4,718,072	EUR
PV AEP	762,254	MWh
LCOE	61.3	EUR/MWh
NET P50 AEP	77,549	MWh/y
NET P75 AEP	72,353	MWh/y
NET P90 AEP	67,623	MWh/y

Table 4. 2: Commercial Evaluation of six Enercon E-147 EP5 E2 5000 HH 127 Wind Turbines

5. Recommendations for Future Work

6. Conclusion

7. References

8. Appendix