POLITECNICO DI TORINO

Master of science program in Energy and Nuclear Engineering

Course of Wind and Ocean Energy Plants - 01TVKND

PW.1 - PRE-FEASIBILITY STUDY OF A WIND FARM

PROVINCE OF Ascoli Piceno

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1. Scope

Italy will promote the further development of renewables while also protecting and enhancing pre-existing products, by exceeding, if possible, the 30% target set, which must, in any event, be assumed to be a contribution towards meeting the EU target.

The greatest contribution to the growth of renewables will come from the electricity sector, which will achieve 16 Mtoe generation from RES, equal to 187 TWh, by 2030. The significant penetration of technologies for renewable electricity production, primarily photovoltaics and wind power technology, will enable the sector to cover 55.0% of gross final electricity consumption with renewable energy, compared with 34.1% in 2017. Meanwhile, the renewable source that made the greatest contribution to actual electricity production in 2017 was hydropower (35% of overall electricity production from RES), followed by solar power (23%), bioenergy (19%), wind power (17%) and geothermal power (6%).

Nowadays, the significant technically and economically feasible growth potential of photovoltaic installations and wind parks, thanks also to the reduction in costs associated therewith, points to a major development of these technologies, the production of which should triple and more than double, respectively, by 2030.[4]

In this project, we will analysis the wind energy environment and scenarios for Ascoli Piceno, discussing the existing wind energy projects at first. Then design and model a wind farm located on this province by WAsP to satisfy the regional energy plan and the local carbonization plan. At last, we will try to connect this project to the national electric grid and analysis the economies, like WACC, LCOE, NPV and PBT to identify whether it's worth investment.

This project makes use of the following software and website:

WAsP

Google Earth

Microsoft Word & Excel

Global Wind Atlas

ATLAIMPIANTI GSE

Region Marche - Sitbiodiversita

IEA Website

Terna

2. Territorial context

2.1 Current wind energy exploitation

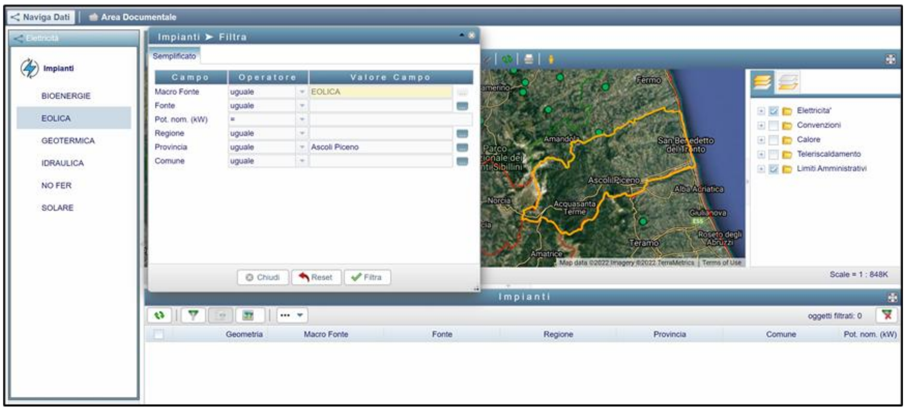

Figure 2.1 - wind turbines in Ascoli Piceno

From ATLAIMPIANTI GSE, we can find different energy plants established in Italy. But, for Ascoli Piceno, unfortunately, there is no wind energy plant built in this province. There is no possible project which is in the design, authorization, or realization phase, as well.

2.2 Local energy needs

Regarding the energy consumption and demand for Ascoli Piceno, we find some data from Terna[1], which is shown as below.

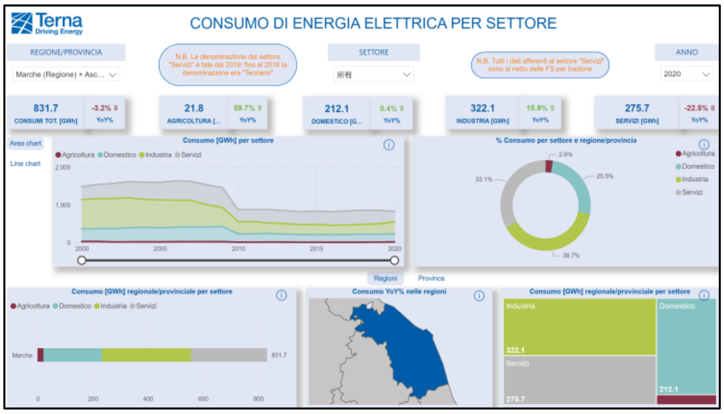

Figure 2.2 - electricity consumption in Ascoli Piceno in 2020

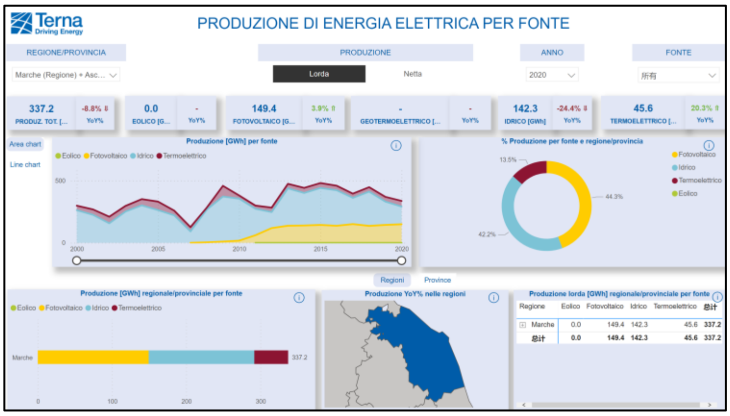

Figure 2.3 - electricity production in Ascoli Piceno in 2020

It can be noticed from figure 2.2 and figure 2.3 that, in 2020, the annual electricity consumption is about 831.7 GWh, while there are 337.2 GWh is produced from Ascoli Piceno itself, which means that approximately 59.5% of the electricity is imported to satisfy the energy need. Furthermore, we should pay attention that there are 44.3 % of electricity produced in Ascoli Piceno is from photovoltaic, 42.2% is from hydroelectric, and 13.5% is from thermoelectric, while wind energy occupies 0%.

2.3 Wind energy development

As mentioned before, there is no wind farm existing in Ascoli Piceno now. But, in 2006, Giunta regionale delle Marche had hold a meeting regarding individuazione aree idonee alla realizzazione di un parco eolico di 40 MW cooperating with università di Chieti[6] and had selected two preselected places in Ascoli Piceno (as below) which are rejected at last because of some environment protection acts.

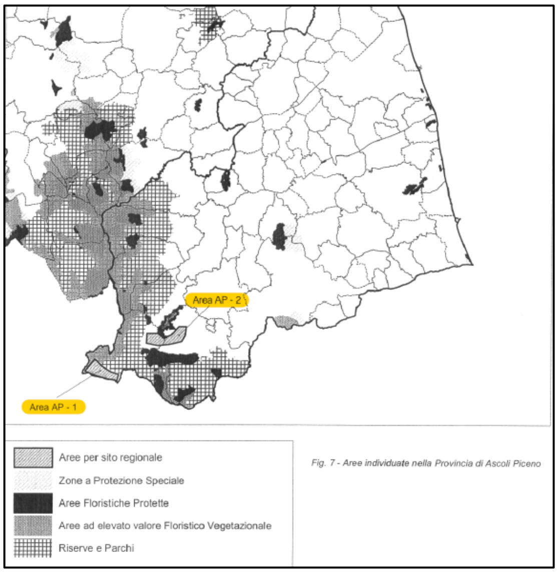

Figure 2.4 - preselected places for wind turbines from Giunta regionale delle Marche

2.3.1 Opportunities

To realize the Decarbonization Plan, more and more incentives are proposed to make the installations and operation of renewable or clean energy more economically feasible. e.g., D.M. 04/07/2019 has the aim of supplying economic support to the small, medium, and large-sized electricity production plants from renewable sources including onshore wind farm, photovoltaic power station, biogas system and so on.

Furthermore, the province of Ascoli Piceno, is a relatively scarcely populated zone, with many mountain areas in the west and south of the province where there is rich wind resource, which means that there is some free space where an installation of a new wind farm is possible.

2.3.2 Limitations

Even though there are some suitable places to install wind turbine in the west and south of Ascoli Piceno, most are located in the national park or plants protection areas, where is illegal to build wind farm. Moreover, Ascoli Piceno is a historic city, where there are lot of monuments and places of interest located. To avoid and reduce the negetive effects it is better to avoid making wind farm site near them.

Even though there are some suitable places to install wind turbine in the west and south of Ascoli Piceno, most are located in the national park or plants protection areas, where is illegal to build wind farm. Moreover, Ascoli Piceno is a historic city, where there are lot of monuments and places of interest located. To avoid and reduce the negetive effects it is better to avoid making wind farm site near them.

3.1 Preliminary site selection

For the site selection, a collection of maps has been used to select the best position for the wind farm. To do that, the software Google Earth and Global Wind Atlas were used to superimpose maps and see the best places.

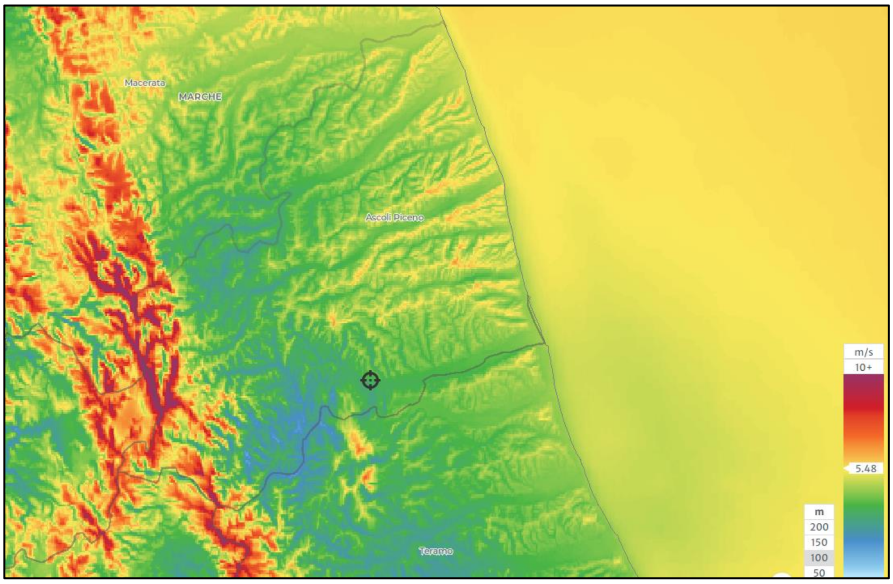

Figure 3.1 - Wind speed data from Global Wind Atlas

From Atlas, it can be noticed that mostly rich wind source places are in the north-west of Ascoli Piceno where have steep terrain because of Parco Nazionale del Gran Sasso e Monti della Laga and Parco Nazionale dei Monti Sibillini.

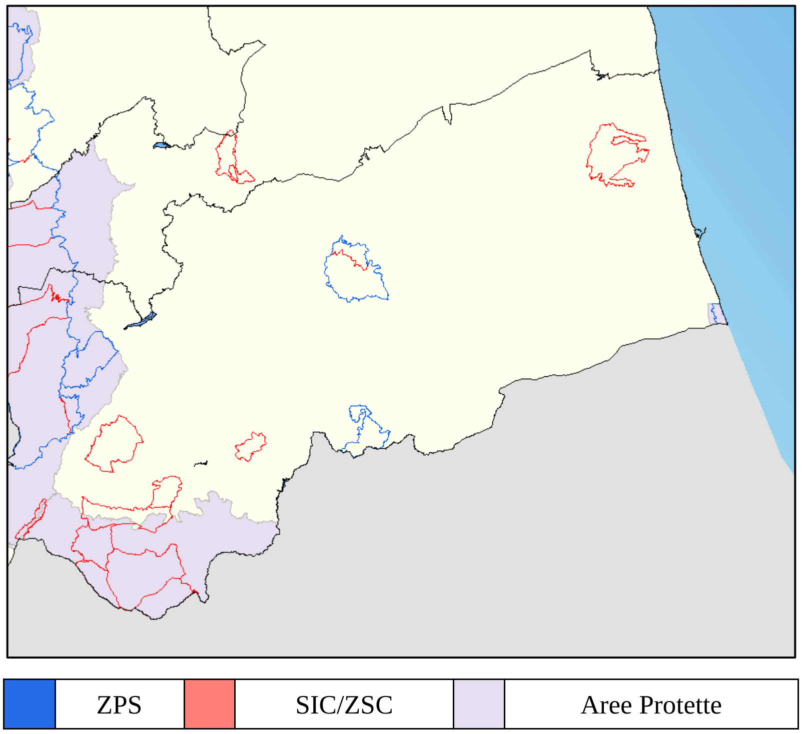

Figure 3.2 - Wind turbine prohibited area in Ascoli Piceno

The second thing needed to be considered for site selection is the area that are illegal to build a wind farm, like National Park, SIC, ZPS or where there are restrictions. For our province, unfortunately, most of the richest wind resource areas are in these forbidden regions, which is the reason that there is no wind farm built in Ascoli Piceno currently, as mentioned before. So, in this project, we need be careful about the wind farm site selection in case touching with this area and for ecological conservation.

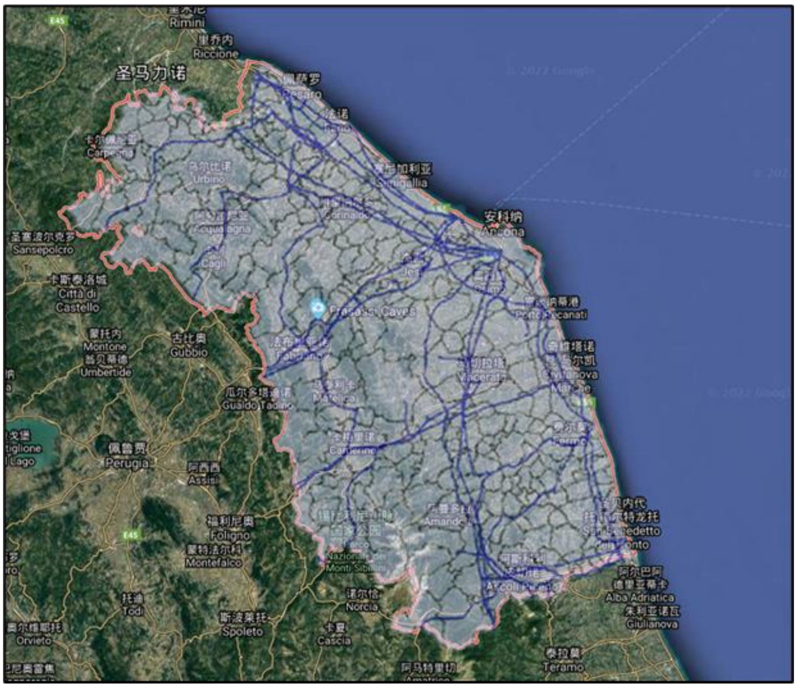

Figure 3.3 - HV line network of Marche region

The last thing which was checked was the distance of wind turbine site from the national electric HV line, which must be lower than 15 km. A network map provided by the Marche region was used on google earth together with the province borders. Here the blue lines are the HV lines, and they already make some zones not feasible for the wind farm because of the long distance.

4.1 Predicted wind climate

Once we have confirmed our wind turbine farm position in Ascoli Piceno, identified a macro area as the operation area in WAsP for our simulation.

At first, the Generalized Wind Climate (GWC) file should be download from Global Wind Atlas, and then generate the orography and roughness length map of this 20*20 km^2 area, which is show below:

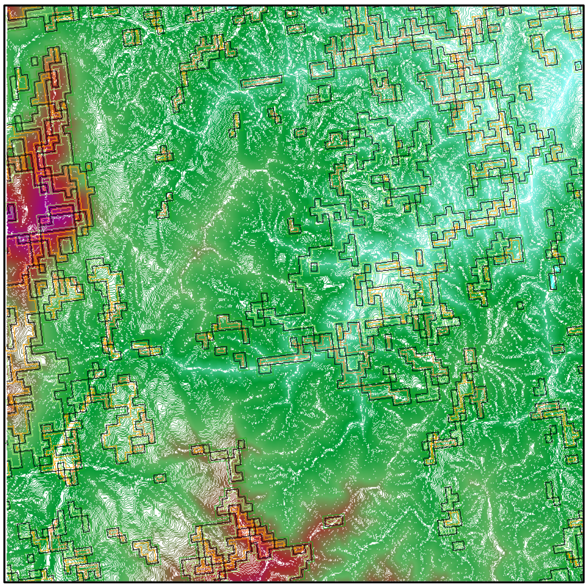

Figure 4.1 - orography and roughness length map

From figure 4.1, it's easy to be noticed that the high terrain areas all are distributed in the west and south of this area, where all these places are located on the environment protection area, although the wind speed of which is much higher than the area we choose. On the up and right corner of this map, there is a relatively large roughness while they are low terrain areas, since production activities of human being society.

Before we try to site our turbine to the vector map in next section, the resource grid of the wind turbine farm is generated to simulate the power density and mean speed at 75m height, from which we can identify the suitable site for wind turbines. The photo below is the about power density plot and the mean wind speed plot are below:

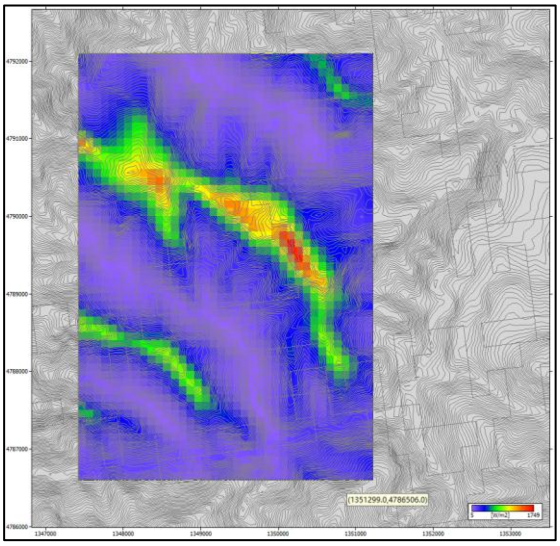

Figure 4.2 - power density plot

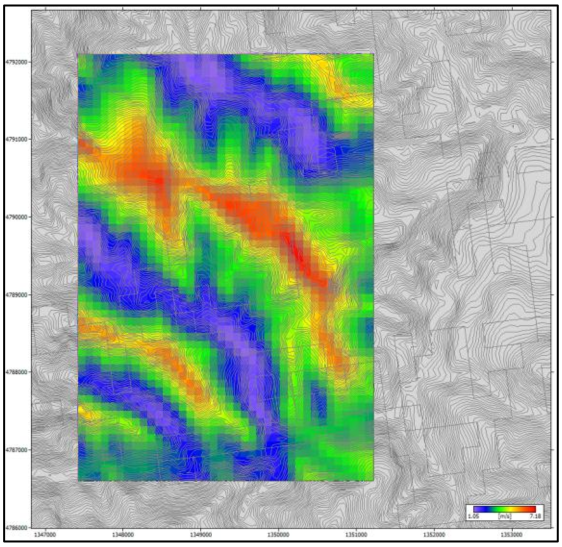

Figure 4. 3 - mean wind speed plot

5.1 Single turbine productivity estimation

At this section, we are going to analysis three turbines at different IEC class:

① Vestas V100-1.8 MW (IEC class: IIIA)

② Vestas V90-1.8 MW (IEC class: IIA)

③ Vestas V80-2 MW (IEC class: IA)

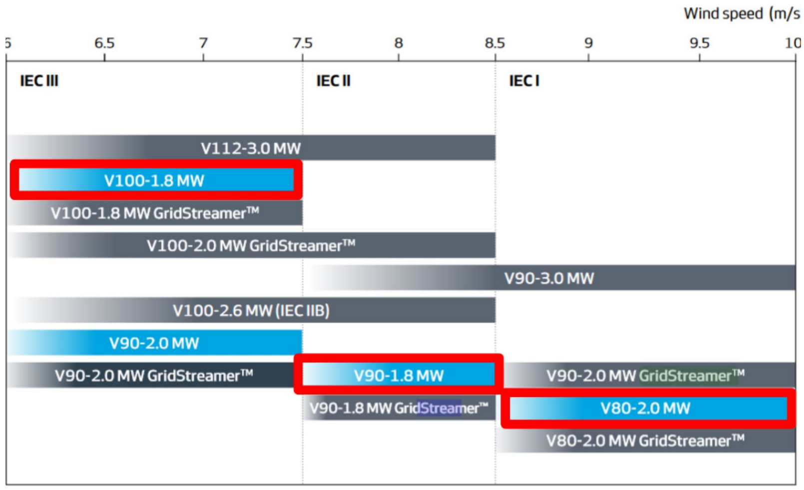

Figure 5.1 - wind turbines at different IEC class

Based on the data of resource grid generated before, we know the maximum wind speed in this area is 7.11 m/s, so we suppose that the first type of wind turbine (Vestas V100-1.8 MW (IEC class: IIIA)) will produce the most power.

In the next part, the data of three turbines will be shown separately.

5.1 Vestas V100 - 1.8 MW (IEC class: IIIA)

The third class of wind turbines operates best at low wind speed (around 7.11 m/s). the AEP for this turbine configuration stands at 4.072 GWh per year. With a capacity of 1.8 MW the Capacity Factor for this turbine is

$$\frac{4.072 * 10^{\wedge}6}{1.8 * 10^3 * 8760} = 25.82\%$$

Sector		Wind climate				Power (at 1.095 kg/m³)		
number	angle [°]	frequency [%]	Weibull-A [m/s]	Weibull-k	mean speed [m/s]	power density [W/m²]	annual prod. [GWh]	wake losses [%]
1	0	3.2	2.9	0.79	3.26	221	0.062	-
2	30	16.6	4.4	1.02	4.35	258	0.491	-
3	60	21.0	4.4	1.24	4.12	145	0.563	-
4	90	4.0	3.1	1.34	2.81	39	0.039	-
5	120	1.8	2.1	1.25	1.92	14	0.006	-
6	150	1.5	2.2	1.19	2.03	19	0.007	-
7	180	2.3	2.6	1.16	2.43	33	0.018	-
8	210	9.7	9.7	0.90	10.18	4581	0.480	-
9	240	33.2	12.9	1.26	11.96	3408	2.265	-
10	270	4.1	4.4	1.07	4.31	222	0.121	-
11	300	1.1	1.0	0.77	1.15	11	0.002	-
12	330	1.5	1.8	0.72	2.26	104	0.017	-
All (emergent)					7.11	1669	4.072	-

Figure 5.2 - power data for Vestas V100 - 1.8 MW (IEC class: IIIA) in simulation

5.2 Vestas V90 - 1.8 MW (IEC class: IIA)

The second class of wind turbines operates best at low wind speed (around 7.11 m/s). the AEP for this turbine configuration stands at 4.185 GWh per year. With a capacity of 1.8 MW the Capacity Factor for this turbine is

$$\frac{4.185 * 10^{\wedge}6}{1.8 * 10^3 * 8760} = 26.54\%$$

Sector		Wind climate				Power (at 1.095 kg/m³)		
number	angle [°]	frequency [%]	Weibull-A [m/s]	Weibull-k	mean speed [m/s]	power density [W/m²]	annual prod. [GWh]	wake losses [%]
1	0	3.2	2.9	0.79	3.26	221	0.057	
2	30	16.6	4.4	1.02	4.35	258	0.446	
3	60	21.0	4.4	1.24	4.12	145	0.483	
4	90	4.0	3.1	1.34	2.81	39	0.031	
5	120	1.8	2.1	1.25	1.92	14	0.004	
6	150	1.5	2.2	1.19	2.03	19	0.005	
7	180	2.3	2.6	1.16	2.43	33	0.014	
8	210	9.7	9.7	0.90	10.18	4581	0.519	
9	240	33.2	12.9	1.26	11.96	3408	2.501	
10	270	4.1	4.4	1.07	4.31	222	0.108	
11	300	1.1	1.0	0.77	1.15	11	0.002	
12	330	1.5	1.8	0.72	2.26	104	0.015	
All (emergent)					7.11	1669	4.185	

Figure 5.3 - power data for Vestas V90 - 1.8 MW (IEC class: IIA) in simulation

5.3 Vestas V80 - 2 MW (IEC class: IA)

The first class of wind turbines operates best at low wind speed (around 7.11 m/s). the AEP for this turbine configuration stands at 4.115 GWh per year. With a capacity of 2.0 MW the Capacity Factor for this turbine is

$$\frac{4.115 * 10^6}{2.0 * 10^3 * 8760} = 23.49\%$$

Sector		Wind climate				Power (at 1.096 kg/m³)		
number	angle [°]	frequency [%]	Weibull-A [m/s]	Weibull-k	mean speed [m/s]	power density [W/m²]	annual prod. [GWh]	wake losses [%]
1	0	3.1	2.8	0.77	3.25	243	0.050	-
2	30	16.5	4.4	0.98	4.41	298	0.417	-
3	60	21.4	4.4	1.18	4.20	167	0.463	-
4	90	3.9	3.0	1.28	2.81	43	0.026	-
5	120	1.8	2.0	1.21	1.90	15	0.004	-
6	150	1.5	2.1	1.15	1.97	18	0.004	-
7	180	2.2	2.5	1.12	2.42	36	0.012	-
8	210	9.4	9.8	0.88	10.45	5291	0.496	-
9	240	33.8	13.1	1.24	12.23	3754	2.535	-
10	270	3.9	4.4	1.03	4.31	248	0.094	-
11	300	1.1	1.0	0.74	1.15	13	0.002	-
12	330	1.5	1.8	0.71	2.21	103	0.013	-
All (emergent)					7.29	1877	4.115	-

Figure 5.4 - power data for Vestas V80 - 2 MW (IEC class: IA) in simulation

5.4 Discussion

Table 5.1 - simulation data for three class turbines

Paraments	Wind turbine		
	Vestas V100-1.8 MW (IEC class: IIIA)	Vestas V90-1.8 MW (IEC class: IIA)	Vestas V80-2 MW (IEC class: IA)
Power density (W/m^2)	1669	1669	1877
Annual energy production (GWh)	4.072	4.185	4.115
CF=AEP/(Capacity*8760)	25.82%	26.54%	23.49%

From the table, we can see that the most suitable wind turbine is Vestas V90-1.8 MW (IEC class: IIA) which can produce 4.185 GWh yearly, and the capacity factor ups to 26.54%.

Figure 5.5 is the AEP net rose of the wind turbine (Vestas V90-1.8 MW) located in best site in our wind farm in Ascoli Piceno. It shows that 59.8% of the energy produced from the south-west wind, while the north-east wind produces about 20% energy in all (sector2 plus sector3).

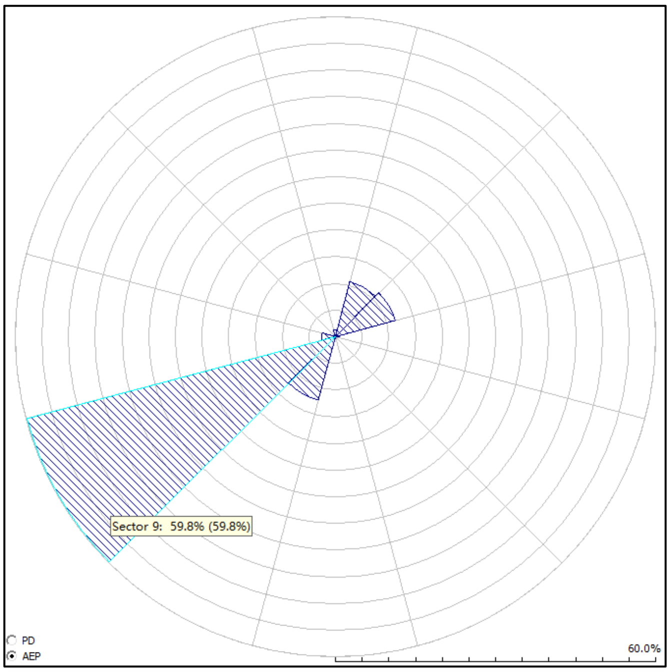

Figure 5.5 - AEP net rose of the most suitable wind turbine (Vestas V90-1.8 MW)

So, in wind-farm configuration, we should be careful about the turbine spacing to minimize the aerodynamic losses between turbines under prevailing wind conditions.

6. Wind farm

In this section, we build a wind farm with 9 turbines (Vestas V90-1.8 MW (IEC class: IIA)), keeping 8 to 10 D spaces between each turbine to avoid wake loss.

6.1 Optimal configuration, wake effect and productivity

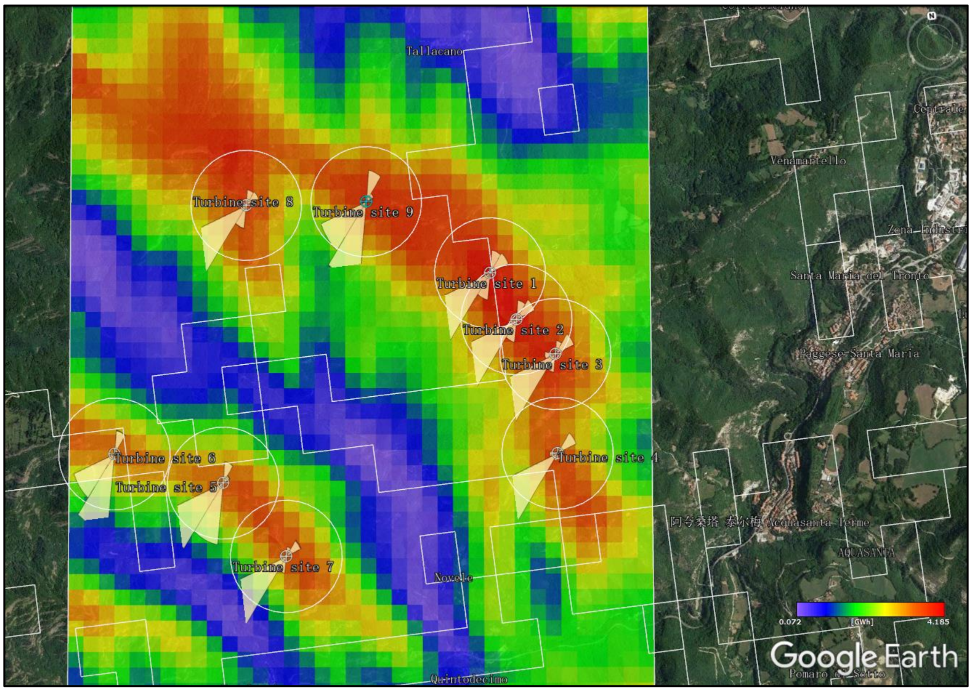

Figure 6.1 - distribution of wind turbines based on AEP map

From this figure, it is known that most wind turbine positions we sited obey the 8 to 9D rule, except for turbine site 1, turbine site 2 and turbine site 3 that we only keep a 4D distance from each other. When it terms to the top-right corner of this area where there is rich wind resource, it is not allowed to build wind turbines for the environment protection acts. Moreover, we had notice that there is only one prevailing wind condition for energy production in our wind farm, which is south-west, and so we make assumption that a narrower distance for our wind farm will not lead to a heavy effect of wake losses, trying to produce more energy at limited area that surrounded with environment protection area.

Table 6.1 - simulation data for wind farm

Turbine site	Height (m)	Speed (m/s)	Gross AEP (GWh)	Net AEP (GWh)	Wake loss (%)	Capacity fact..or (%)
1	80	7.11	4.185	4.162	0.53	26.4
2	80	6.83	4.084	4.052	0.78	25.7
3	80	6.41	3.947	3.916	0.80	24.8
4	80	5.69	3.564	3.540	0.69	22.4
5	80	5.49	3.379	3.357	0.65	21.3
6	80	5.40	3.262	3.245	0.53	20.6
7	80	5.54	3.481	3.455	0.75	21.9
8	80	6.03	3.682	3.674	0.22	23.3
9	80	6.42	3.828	3.804	0.64	24.1
All	/	/	33.412	33.205	/	/

6.2 Discussion

From the calculated data by WAsP, we can check the wake losses to verify our assumption that the effect of wake loss for these three turbines are neglectable. The gross annual energy production is 33.412 GWh, while the net annual energy production is 33.205 GWh. And the mean capacity factor of wind farm is 23.31%.

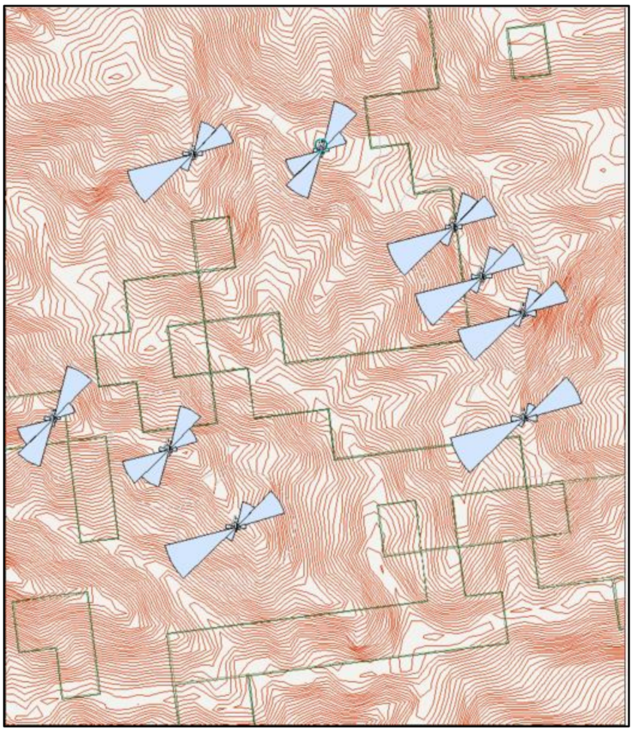

Figure 6.2 - predicted wind frequency map

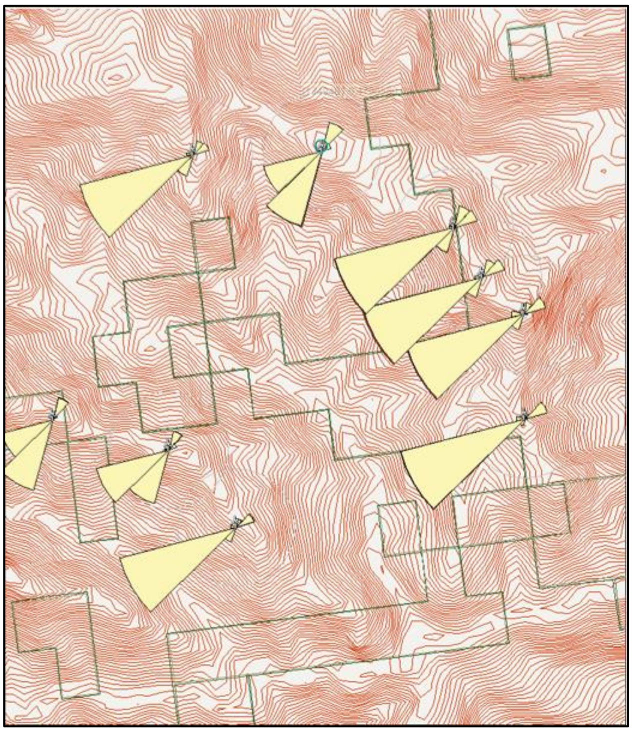

Figure 6.3 - predicted wind frequency map

The wind frequency picture shows that prevailing wind direction at our wind farm is south-west and north-east, but the south-west wind occupies the most energy production. And all our wind turbines are installed orthogonally in relation to the wind predominant. The effect of wake loss for this wind farm on the overall production is small.

7. Grid connection

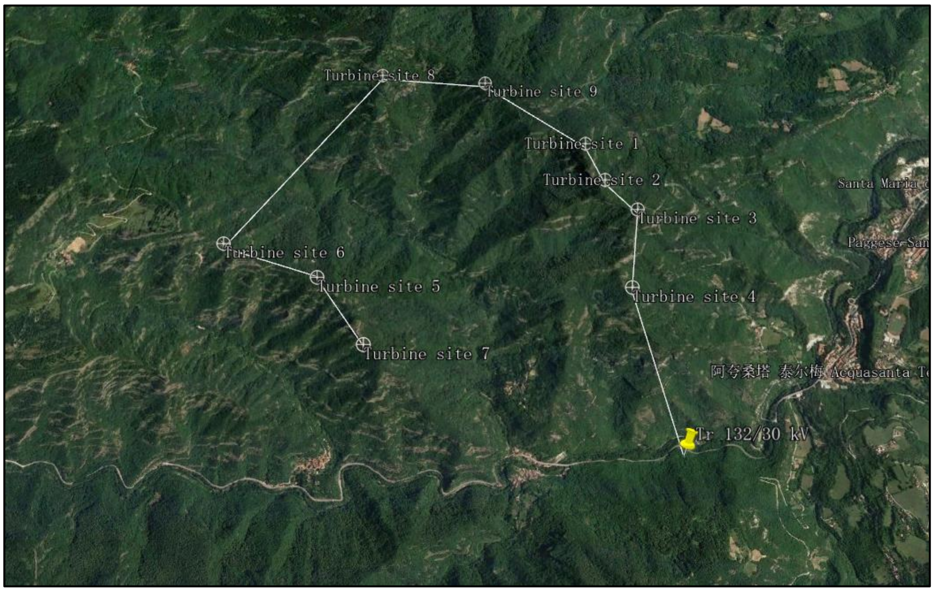

Figure 7.1 - wind farm on google earth

Before this section the wind farm building and operating simulation has most done, and we need to transfer the clean power from wind turbine to national electricity grid. Based on the HV grid route in Ascoli Piceno introduced before, we design this grid connection. The figure 7.1 is the visualization of our wind farm - grid connection on google earth, and the yellow thumbtack is where the HV/MV transformer located.

7.1 Grid connection scheme

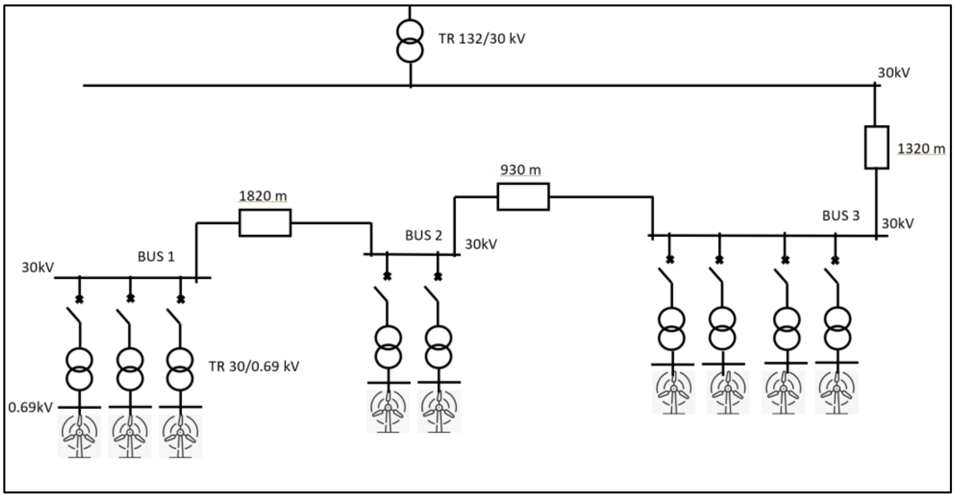

Figure 7.2 - Grid connection scheme

For this wind farm, we design three BUS that the BUS1 connect three turbines at first, then it comes to BUS2 in which two more turbines are connected and in BUS3 the last four turbines will be connected finally.

7.2 Resistive losses in the line, line reactive power and voltage regulation

To calculate related paraments, we need to choose the cable material for our wind turbine connecting to the national grid. After getting active power, reactive power, and phase current, we decide to choose aluminum cables for MV BUS1, BUS2 and BUS3, of which cross section Area is 1 x 70 mm^2, 1 x 95 mm^2 and 1 x 240 mm^2, respectively. And here is the technical data for our cable:

Table 7.1 - Technical data of BUS cables

	Section	R @20°C	X @50Hz	C	Imax
	n x mm2	Ω/km	Ω/km	μF/km	A
BUS1	1 x 70	0.443	0.133	0.166	187
BUS2	1 x 95	0.320	0.124	0.193	222
BUS3	1 x 240	0.125	0.105	0.294	370

After the calculation, paraments including resistive losses in the line, line reactive power and voltage regulation are below：

Table 7.2 - MV cable paraments

From	To	d	P_{in}	Q_{in}	S_{in}	cos (φ)	I_{phase}	A_{cable}	I_z	R_{cable}	X_{cable}	P_{cable}	Q_{cable}	$\frac{\Delta V}{V}$
		m	MW	MVAR	MVAR		A	mm^2	A	Ω	Ω	kW	kVAR	%
BUS1	BUS2	1820	5.40	1.21	5.53	0.976	106	70	187	0.806	0.242	27.42	8.23	0.52
BUS2	BUS3	930	8.97	2.00	9.19	0.976	177	95	222	0.298	0.115	27.95	10.83	0.32
BUS3	HV/MV TR	1320	16.14	3.60	16.54	0.976	318	240	370	0.165	0.139	50.16	42.14	0.35

From the table, we know that all the voltage regulation is less than 3%, which is acceptable. The total active power ($P_{cable,tot}$) is 105.53 kW, and the total reactive power ($Q_{cable,tot}$) is 61.2 kVAR.

7.3 Grid connection efficiency

For the HV/MV transformer, we choose the one that rated power (S_N) is 20 MVA.

Table 7.3 - Technical data of HV/MV transformers

Rated voltage ratio	kV	132/30
Rated power (S^N)	MVA	20
No-load losses (P_0)	kW	15.4
No-load current ($I_{0\%}$)	%	0.50
Short-circuit losses (P_{sc})	kW	100.0
Short-circuit voltage ($V_{sc\%}$)	%	12

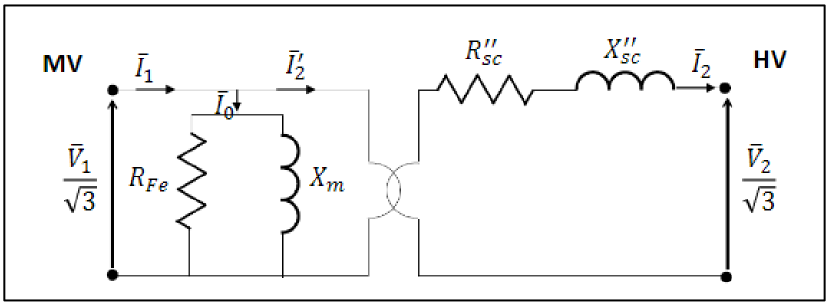

Figure 7.3 - equivalent circuit of the transformer

R_{Fe} = 58442 Ω $\qquad$ X_m = 9109 Ω

R''_{sc} = 4.36 Ω $\qquad$ X''_{sc} = 104.45 Ω

$$P_2 = P_{gen,tot} - P_{cable,tot} - P_0 = 16.08 \text{ MW}$$

$$Q_2 = Q_{gen,tot} - Q_{cable,tot} - Q_0 = 3.46 \text{ MVAR}$$

$$\cos(\varphi) = \cos\left(\arctan\left(\frac{Q_2}{P_2}\right)\right) = 0.978$$

$$I_2 = \frac{P_2}{\sqrt{3} * \cos(\varphi) * V_{2N}} = 71.93\text{A}$$

$$\eta_{\text{grid}-\text{con}} = \frac{P_2 - 3R''_{sc} * I_2^2}{P_{gen,tot}} = 98.84\%$$

With the equivalent circuit of the transformer above, we can get the grid efficiency is approximately 98.84%.

7.4 Grid connection cost estimation

Regarding the cost for grid connection, we assume that there are four kinds of expenditure: cable cost, design cost, underground cabling cost and transformer cost.

Table 7.4 - Cost estimation for grid connection

Cable cost: (aluminum)	BUS1 (1820 m)	3.9 €/m	21,294 €
	BUS2 (930 m)	4.4 €/m	12,276 €
	BUS3 (1320 m)	7.0 €/m	27,720 €
Design cost	4,070 km	5,000 €/km	20,350 €
Underground cabling cost	Agricultural land (4058m)	40 €/m	162,360 €
	Road crossing (12m)	150 €/m	1800 €
Transformer cost	< 25/30 MVA	1,527,000 €	1,527,000 €
Total cost			1,772,760 €

Note: Each section of the MV line requires 3 cables of equal length. Therefore, each cable cost has been multiplied by 3 from the initial cost. Our cable almost is laid in agricultural land, and only BUS3 will cross a road.

8. Economic evaluation

The aim of this part is to evaluate an economic analysis, to understand the feasibility and profitability of the plant. The economic indices used to perform the analysis are:

• Levelized cost of energy (LCOE)

• Net Present Value (NPV)

• Pay-Back time (PBT)

• Internal Rate of Return (IRR).

To carry out the study, Availability, Capital Expenditure (CAPEX) and Operating Expenditure (OPEX) are calculated, where availability is the probability that an item will operate satisfactorily at a given point in time when used under stated conditions in an ideal support environment, and CAPEX is the investment cost that the plant owner pays at the beginning, while OPEX is constituted by the operating costs that the plant owner pays every year for the whole plant lifetime.

8.1 Assumptions

8.1.2 Availability

Regarding the availability, there are three types of models: time-based, technical, and energetic availability.

Time-based availability provides information on the share of time where a WT is operating or able to operate in comparison to the total time. [2]

$$A_t = \frac{t_{available}}{t_{available} - t_{unavailable}}$$

Where:

A_t Time-based Availability

$t_{available}$ Time of Full & Partial Performance and Low Wind

$t_{unavailable}$ Time of Other Cases Except for Data Gaps

Technical availability is a variation of the time-based availability and provides information on the share of time where a WT is available from a technical perspective. For this purpose, e.g., down time with external causes like grid failures or lightning is considered as available. Further cases like scheduled maintenance or force majeure are excluded from the calculation. [2]

$$A_{tech} = \frac{t_{available}}{t_{available} - t_{unavailable}}$$

Where:

A_{tech} Technical Availability

$t_{available}$ Time of Full and Partial Performance, Technical Standby, Requested Shutdown, Downtime due to Environment and Grid

$t_{unavailable}$ Time of Corrective Actions and Forced Outage, excludes Data Gaps and Scheduled Maintenance

Energetic availability, also known as production, based availability, gives an indication about the turbine's energy yield compared to the potential output and thereby highlights long down time during high wind speed phases and derated operation. All differences between potential and actual production are assumed to be losses.[2]

$$A_w = \frac{\overline{w}_{actual}}{\overline{w}_{potential}}$$

Where:

A_w Energetic Availability

$\overline{w}_{actual}$ Average Actual Power Output

$\overline{w}_{potential}$ Average Potential Power Output, Data Gaps are Excluded

In our projection, the mean capacity factor of wind farm is about 23.31% and assume that availability is technical availability and equals to 94% which is a reference rate from the Muppandal Wind Farm of which capacity factor is 24.9%. As a result, the AEP, considering wind farm availability, is equal to 31.2127GWh.

When it comes the failure rate, we still choose Muppandal Wind Farm as the reference.

Table 8.1 - failure rate of wind farm in assumption

System	Failure Rate
Rotor System	0.187
Drive Train System	0.28
Speed Conversion System	0.173
Brake System Drive Train	0.107
Yaw System	0.16
Central Hydraulic System	0.173
Control System	0.12
Power Generation System	0.067
Meteorological Measurement	0.027

8.1.2 Capex and Opex

CAPEX cost considers WT cost, connection to the grid, transformer, and number of WTs, while OPEX is calculated considering Operation and Maintenance costs (O&M) and decommissioning costs.

From professor's slide, the installation cost (capital expenditure of the investment C_0 of wind turbines is within 1200−1400 €/kW, the O&M costs $C_{o\&m}$ ≈3% of this initial cost. Regarding the decommissioning costs, they are included as a percentage of capital cost, e.g., 5%.

For our wind fam:

C_0 = 1300 * 1.8 * 10^3 = 2,340,000 € for each WT

$C_{0,\ tot}$ = 2,340,000 * 9 =21,060,000 €

$C_{grid,con}$ = 1,772,760 €

$C = C_{0,\ tot} + C_{grid,con}$ = 22,832,760 €

O&M = 684982.8 €

Decommissioning costs = 114164 €

The value of discount rate may be the Weighted Average Cost of Capital (WACC) incorporating equity (E) and debt (D) as weights of their respective discount rates r_E and r_D.

$$WACC = E \times R_E + D \times R_D \times (1 - \tau)$$

Based on the "cashflow model Denmark 2009 v3", we define that the rate of return on debt (R_d) equals to 5%, the rate of required return on equity (R_e) equals to 11%, equity share (excluding EIA benefit) (E) equals to 20%, and debt share (including EIA benefit) (D) equals to 80%, with the corporate tax rate (τ) equals to 25%. With these parameters, the value of WACC is equal to 5.2%.

8.2 Outcomes

8.2.1 LCOE

With the WACC value, it is possible to calculate the LCOE now, following the formula:

$$LCOE = \frac{CAPEX + \sum_{k=1}^{N} \frac{OPEX_k}{(1+r)^k}}{\sum_{k=1}^{N} \frac{E_{G,k}}{(1+r)^k}}$$

There are no fuel expenditures (C_f) in our project.

Where:

N Project lifetime (20 years).

E_G Output of power plant asset, which is the sum of the generated electricity over the project lifetime.

r Discount rate, analogous to WACC.

$LCOE = \frac{CAPEX + \sum_{k=1}^{N} \frac{OPEX_k}{(1+r)^k}}{\sum_{k=1}^{N} \frac{E_{G,k}}{(1+r)^k}}$			year k	discount rate	$OPEX_k$	$E_{G,k}$
			0	1.000		
			1	0.951	651,124.33	29.67
			2	0.904	618,939.48	28.20
			3	0.859	588,345.51	26.81
CAPEX	22,832,760.00	€	4	0.816	559,263.80	25.48
N	20	y	5	0.776	531,619.58	24.22
E_G	31.2127	GWh	6	0.738	505,341.81	23.03
r	5.20%		7	0.701	480,362.93	21.89
OPEX	684,982.80	€	8	0.667	456,618.76	20.81
			9	0.634	434,048.25	19.78
			10	0.602	412,593.39	18.80
			11	0.573	392,199.04	17.87
LCOE	81644.34	€/GWh	12	0.544	372,812.78	16.99
	81.64	€/MWh	13	0.517	354,384.77	16.15
			14	0.492	336,867.65	15.35
			15	0.467	320,216.40	14.59
			16	0.444	304,388.21	13.87
			17	0.422	289,342.41	13.18
			18	0.402	275,040.31	12.53
			19	0.382	261,445.16	11.91
			20	0.363	248,522.02	11.32

Figure 8.1 - LCOE data of wind farm

8.2.2 NPV

It is the algebraic sum of the investment cost with the net cash flows over the whole lifetime the projects that are discounted at a certain nominal rate.

$$NPV = -C_0 + \sum_{k=1}^{N} \frac{F_k}{(1+r)^k}$$

To get the NPV value, a cash flow analysis has been performed. The lifetime of WTs is 20 years, and the depreciation time equals to 9 years. The electricity price is 9 c€/kWh, while IRES tax and IRAP tax, which is 24% and 3.9%, respectively[5], for wind power companies. Moreover, Italy government offers incentives if RES plants are installed, which are equal to 70 €/MWh.[3] What should be cared about is the debt which is 80% of the Capex, the loan duration we assumed is 13 years, with a Loan - market interest rate: 3%.

year k	Opex	Depreciation costs	Loan costs	Revenue	Revenue after Taxes	Incentives	Cash flow	Discount rate	Present cash flow	Capex	Summation
1	-684,982.80	2,536,973.33	-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.951	1,896,578.44		-20,936,181.56
2	-684,982.80	2,536,973.33	-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.904	1,802,831.22		-19,133,350.34
3	-684,982.80	2,536,973.33	-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.859	1,713,717.89		-17,419,632.45
4	-684,982.80	2,536,973.33	-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.816	1,629,009.40		-15,790,623.05
5	-684,982.80	2,536,973.33	-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.776	1,548,488.02		-14,242,135.03
6	-684,982.80	2,536,973.33	-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.738	1,471,946.79		-12,770,188.24
7	-684,982.80	2,536,973.33	-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.701	1,399,188.96		-11,370,999.28
8	-684,982.80	2,536,973.33	-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.667	1,330,027.53		-10,040,971.75
9	-684,982.80	2,536,973.33	-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.634	1,264,284.73		-8,776,687.02
10	-684,982.80		-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.602	1,201,791.56	-22,832,760.00	-7,574,895.46
11	-684,982.80		-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.573	1,142,387.42		-6,432,508.04
12	-684,982.80		-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.544	1,085,919.60		-5,346,588.44
13	-684,982.80		-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.517	1,032,242.97		-4,314,345.47
14	-684,982.80		-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.492	981,219.55		-3,333,125.92
15	-684,982.80		-1,530,097.78	2,809,143.00	2,025,392.10	2,184,889.00	1,995,200.52	0.467	932,718.20		-2,400,407.72
16	-684,982.80		-	2,809,143.00	2,025,392.10	2,184,889.00	3,525,298.30	0.444	1,566,549.18		-833,858.54
17	-684,982.80		-	2,809,143.00	2,025,392.10	2,184,889.00	3,525,298.30	0.422	1,489,115.19		655,256.66
18	-684,982.80		-	2,809,143.00	2,025,392.10	2,184,889.00	3,525,298.30	0.402	1,415,508.74		2,070,765.40
19	-684,982.80		-	2,809,143.00	2,025,392.10	2,184,889.00	3,525,298.30	0.382	1,345,540.63		3,416,306.03
20	-684,982.80		-	2,809,143.00	2,025,392.10	2,184,889.00	3,525,298.30	0.363	1,279,031.01		4,695,337.04

Figure 8.2 - Cash flow for wind farm in lifetime

The cumulate summation that gives the net present value, is equal to 4,695,337.04 €.

8.2.3 IRR

It is a metric used in financial analysis to estimate the profitability of potential investments. The internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis.

$$NPV = -C_0 + \sum_{k=1}^{k} \frac{F_k}{(1+r)^k} = 0$$

From the excel function, the value equals 1.99%.

8.2.4 PBT

It describes the opportunity to choose the investment with the shortest period of return of the invested capital.

$$NPV = -C_0 + \sum_{k=1}^{PBT} \frac{F_k}{(1+r)^k} = 0$$

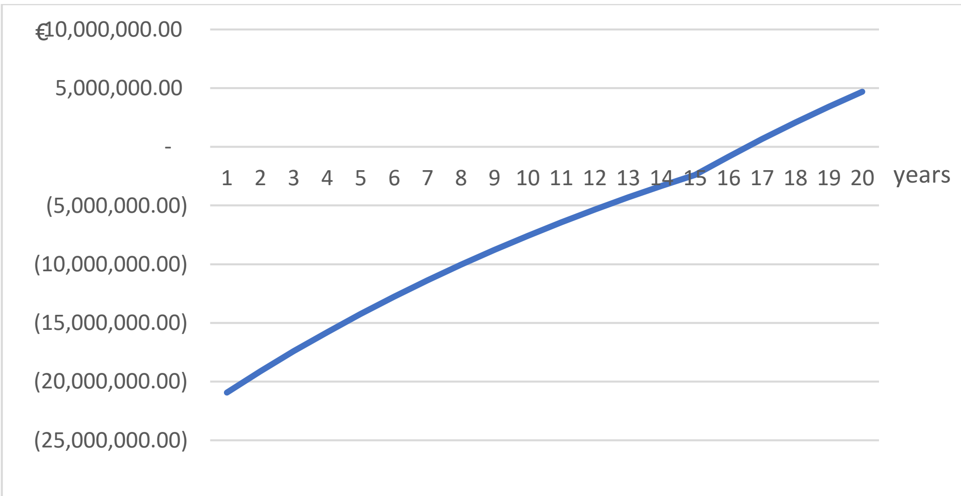

Figure 8.3 - Payback time for wind farm in lifetime

For our wind farm, PBT occurs exactly at the 16th years.

9. Conclusion

The aim of this study was the feasibility of a wind farm installation in the province of Ascoli Piceno, Marche, Italy. This site, according to the Global Wind Atlas, is installed on the south-west of Ascoli Piceno, where there is relatively rich wind resource and legislative and local environmental constraints are fully respected.

Through WAsP software, a wind analysis was performed, considering three different classes of wind turbines. As expected, the best solution is represented by the IEC Class: IIA. For the whole wind farm having considered an optimal layout, a nice result can be seen in the value of mean capacity factor, which is around 23.31%. and the distances between WTs had been considered as well to avoid wave loss. For our wind farm, all the wake loss is less than 1%, which can be seen as a good value. regarding the grid connection section, we design three BUS of which the cable material is aluminum to connect wind farm to a HV/MV transformer, then to the national grid.

When it comes to economical side, the availability of the project can be assumed up to 94% based on a reference wind farm "Muppandal Wind Farm". the LCOE result is 81.64 €/MWh, which is in internal of current LCOE range (3.94 to 8.29 €cent/kWh). Moreover, according to the cash flow analysis, the Net Present Value assumes a positive value. So, it indicates that the projected earnings generated by the investment exceeds the anticipated costs, also in present euros. The payback time is at the 16th year

As a conclusion, considering an increasing electricity price with more and more positive renewable energy incentives, possible investors can expect a higher profit, but should consider moving forward with the investment carefully, because of the strict environment protection acts and the very limited areas with rich wind resource in Ascoli Piceno.

Overall, to attain the targets on renewables identified for 2030, it will not only be necessary to stimulate new production, but also to preserve existing production and, if possible, increase it, by promoting the revamping and repowering of installations. In particular, the opportunity to promote investments in the revamping and repowering of existing wind power plants with more developed and efficient machines, by exploiting the excellent wind conditions at well-known sites that are already being used, will also help to limit the impact on soil consumption.

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