Evaluation of the environmental impacts due to floating offshore wind farms

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***Abstract*— Around the world, the utilization of technologies powered by so-called renewable energy sources is in progressive development, and this is a major factor in the move toward a cleaner and more efficient energy system. The move toward more sustainable alternative energy sources enables the possibility of producing electricity without emitting greenhouse gases, thanks to the reduced use of fossil. Wind and solar power are major players in the current energy transition. The limits of land availability for wind farm installation have led in recent times to focus more research on the study of different types of wind turbines for offshore applications. In this regard, the paper presents a case study in Mazara del Vallo (Trapani, Italy) for an offshore wind farm power generation with subsequent estimation of environmental impacts.**

***Keywords*— Wind turbine, RES, off-shore wind farm, environmental impact**

I. Introduction

Several studies show that our country is an ideal place for clean energy production through the use of floating wind turbines given its optimal location in the middle of the Mediterranean Sea [1], [2]. This technology can be a decisive approach to meet the decarbonization goals. Currently, in Italy there is only one offshore wind installation; it is Beleolico, a farm consisting of 10 turbines, each with a capacity of 3 MW, located in the Gulf of Taranto [3]. In recent years, installed wind power capacity has grown significantly worldwide to the extent that it has reached a total capacity of more than 1,000 GW, thanks in part to the 116 GW of wind power plants introduced in 2023 [4], [5]. Reports show 12.5 percent growth in the past year, which is higher than in 2022. So, wind power currently generates about 10 % of global electricity, and this percentage is expected to grow further in the coming years. In Italy, the beginnings of the exploitation of wind energy for power generation are around the 1980s. Italian wind farms are mainly concentrated in the South and the islands: Campania, Puglia, Sicily and Sardinia represent the regions with the highest number of installations and in which there is the greatest annual growth [6].

The article aims to evaluate a floating offshore wind farm located in the Mediterranean Sea, where the case study examined is the Mazara del Vallo Offshore Wind Project, which involves the construction of 74 wind turbines, each of 15 MW rated power, with a total installed capacity of 1110 MW, located off the coast of Mazara del Vallo. The entire life cycle of these facilities is considered in the analysis, from extraction of raw materials through operation and maintenance to decommissioning. The considerable difference in information currently available regarding LCA analysis is emphasized, accompanied by a significant lack of information regarding offshore farms.

II. Wind Turbines

A preliminary analysis of the type of turbine to be used was performed. Theoretically, the power that a wind turbine generates can be described by the following equation 1 [7]:

$$P = \frac{1}{2}\rho A v^3 C_p \quad (1)$$

Where:

- P is the power production [W]
- ρ is the air density [kg/m^3]
- A is the area swept by the blades [m^2]
- v is the wind speed [m/s]
- C_p is the power coefficient, which represents the aerodynamic efficiency of the turbine. The theoretical maximum value of C_p is 16/27≈0.5926 known as the Betz limit.

Among the different types of wind turbines on the market, the most popular model appears to be the three-bladed horizontal axis wind turbine, which has a lower rotational speed than the two-bladed model because increasing the number of blades results in a decrease in rotational speed but also has a number of advantages, including greater aerodynamic efficiency and limited noise problems. The following Figure 1 shows the comparison between different C_p [8]. The trend of the power factor C_p as a function of specific speed or TSR (Tip Speed Ratio) is shown, and it is precisely shown that the turbine with the highest efficiency turns out to be the three-bladed model. It is possible to define a fundamental parameter for evaluating the efficiency and reliability of wind power generation, namely Capacity Factor (CF).

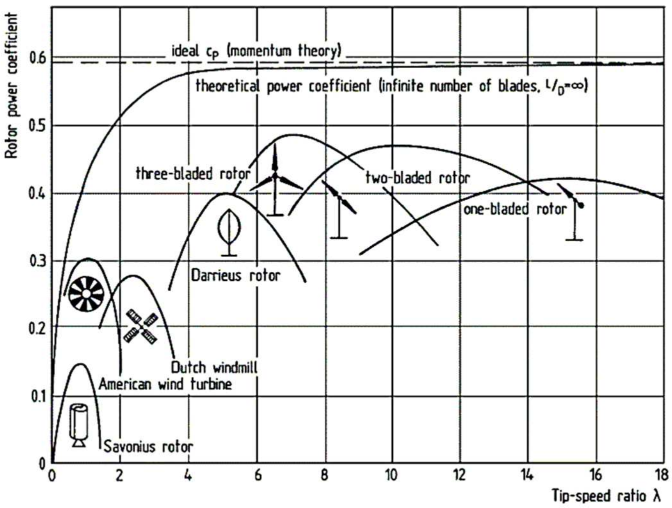

Fig. 1. C_p comparison between different wind turbines [9]

CF can be calculated by the equation 2.

$$CF = \frac{Effective\ Energy\ production}{Theoretical\ energy\ production} \quad (2)$$

The term in the numerator is the amount of electricity produced by the turbine over a given period, usually one year, while the denominator indicates the amount of wind power the turbine could generate if it operated continuously at its rated power for the entire period under consideration. The Capacity Factor depends substantially on the regularity of the source, the location of the turbines, and the downtime periods required for maintenance. Globally, capacity factors for wind turbines vary between 20% and 40%; offshore installations tend to have higher values than onshore installations due to the presence of stronger and more consistent offshore winds [10]. In this regard, interest in offshore plants has been gradually growing over the years, also dictated by the fact that they involve less visual impact and are characterized by an annual producibility in the range of 3000-3500 MWh/MW, significantly higher than that of an onshore plant.

The technologies used for offshore applications currently turn out to be similar to those used for onshore installations [11], with the difference being the arrangements needed to cope with the different problems that can be encountered in water dictated by adverse sea conditions, the not always perfect characteristics of the seabed and the wear and tear caused by waves. In this sense, it is possible to distinguish different types of support structures for offshore wind turbines according to the depth of water in which they are installed [12], [13]. For water depths greater than 50 to 60 meters, where fixed structures are no longer functional, floating turbines are preferred, offering the possibility of possibly being able to move the wind turbine-floating system from one site to another, see Figure 2.

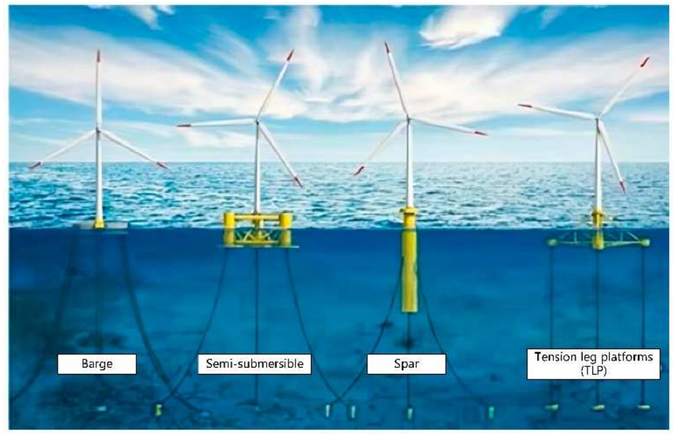

Fig. 2. Offshore wind support and anchorage [14]

However, offshore wind power plants involve a significantly higher investment than onshore technology resulting mainly from the need for more robust underwater foundations, as well as various costs related to offshore installation, maintenance and power transmission.

III. The Case Study

The offshore wind farm is assumed to be installed about 57 km off the west coast of Sicily (Italy) between the municipalities of Mazara del Vallo, Campobello di Mazara, Castelvetrano, Marsala and Petrosino, in the province of Trapani, see Figure 3.

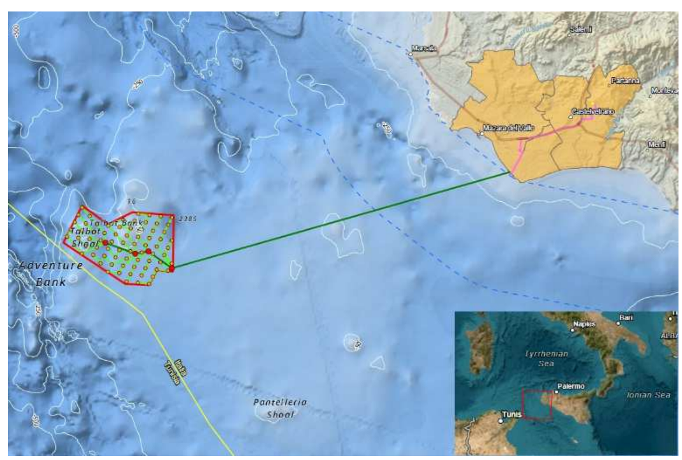

Fig. 3. Southern Italy offshore site installation [15]

The study area extends for a length of 11.4 km parallel to the coastline and covers an area of about 238.9 km^2 on a perimeter of 66.54 km. The preliminary project does not fall within protected natural areas or areas subject to airport constraints despite its proximity to Trapani airport.

Figure 4 shows the layout of the plant; the turbines are spread over 11 rows positioned parallel to the coastline and are all located beyond the 12-nautical-mile limit.

This design strategy considers both wind characteristics in the area and environmental and social peculiarity. This is commonly used to minimize the visual impact of the installations and optimize the energy production of the farm.

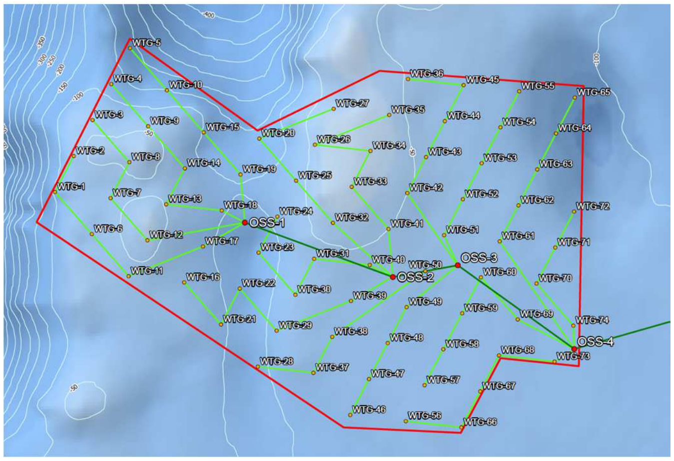

Fig. 4. Farm layout [15]

The connection of the Mazara del Vallo wind farm to the National Transmission Grid (NTG) requires an articulated infrastructure that includes several elevator substations and a cable network to transport the energy from offshore to onshore. Starting with offshore elevating substations, there are four 66 kV/150 kV ones that are responsible for collecting the energy produced by the wind turbines and increasing its voltage for more efficient transmission to the onshore. The technical farm parameters are resumed in the Table I.

TABLE I. WIND FARM TECHNICAL DATA

Wind turbine number	*74*
Power turbine [MW]	*15*
Farm power [MW]	*1100*
Diameter single rotor [m]	*236*
Number of blades	*3*
Rotation	*Upwind*
Voltage [kV]	*66*

IV. ENVIRONMENTAL IMPACT

The construction of the offshore wind farm under consideration reasonably involves impacts on the environment related particularly to the construction, installation and decommissioning phase of the plant [16], [17]. The most important evaluation impacts are listed:

- Noise pollution during site construction.
- Noise and vibration may disturb marine species, especially migratory species.
- Visual impact
- Seabed sedimentation and turbidity: cable laying can alter the seabed, increasing water turbidity and negatively affecting the fauna.

During the construction of the farm, the main activities for the construction of the wind turbines and floating foundations will be carried out at construction sites on land adjacent to port areas closer to the project area. The installation operations at sea will be coordinated with the relevant maritime authorities for temporary closure of the area. In addition, installation activities of the wind turbines and ancillary elements will take place with specific vessels that will transport the assembled turbine to the installation site. What is more, submarine cables will be laid by cable-laying ships. Thus, significant seabed changes may occur due to all these operations. In fact, the installation of the cable laying vessels must be planned in advance to minimize seabed alteration and subsequent turbidity of the water.

During the construction phase of the work, another aspect to watch out for is air quality, as it will be affected by emissions from the vessels used to transport the devices. The installation activities at sea will be carried out with a limited number of vehicles operating in compliance with applicable maritime regulations regarding atmospheric emissions and for a rather short period of time. Therefore, impacts related to air quality can be classified as minor. Regarding the noise impact, during the installation of the various offshore works, a contribution to noise generation will be attributable to the traffic of vessels supporting the operations, which will transport the components to be assembled to the chosen point. There is a possibility that these noise levels will create disturbance to marine mammals. Environmental impacts caused by the turbines can also be evidenced during the operation phase of the plant, although they are moderate compared to the installation phase.

In fact, noise generated by the rotation of the blades, gearboxes, and vibrations of the transformer and electrical equipment could disturb migratory marine species [18]. These potential effects of emitted noise, which usually affect public health, are greatly reduced by the considerable distance between the wind farm and the coast.

On the subject of visual impacts, it can be seen that the increase in turbine power rating leads to an increase in size, with turbines that can reach significant heights and impressive rotor diameters, as evidenced by the market trend. Therefore, selecting areas sufficiently far from the coast can significantly minimize this aspect.

The design strategy employed of arranging the wind turbines in rows perpendicular to the coastline can further help reduce the visual impact. Regarding impacts on flora and fauna, it is useful to point out how the project area enclosing the wind farm does not fall within any marine protected area.

A. *Visual impact estimation*

For an assessment of the visual impact of the offshore wind farm, several vantage points of scenic and tourist interest were selected along the affected stretch of the Sicilian Channel and simulations were made of the view that would be presented to a hypothetical observer. The relevant factors are listed below:

- Position.

- Distance from the coastline.
- Wind turbine height.
- Visual conditions.
- Height of the observer above sea level.

It was assumed that the analysis does not consider potential obstacles such as trees, buildings, or other structures that might prevent or limit the visibility of wind turbines. Therefore, the resulting view will be idealized, showing what would be visible if the landscape were completely free of man-made or natural barriers. Meteorological factors (rain, fog, cloudiness, snow, or haze) that can drastically affect what is visible to the naked eye and thus could reduce visibility were not considered. All these considerations allow you to carry out a conservative study and obtain results of overestimated visibility compared to reality. To calculate the visibility distance of an offshore turbine (evaluated in km), an important factor for planning and evaluating the visual impact of offshore wind farms, it was possible to refer to the following equation 3.

$$D=\sqrt{(r_e+h_t)^2-r_e^2}+\sqrt{(r_e+h_0)^2-r_e^2} \quad (3)$$

Where:

- r_e is the radius of the earth (6371 km).
- h_t is the height of the turbine above the sea level.
- h_0 is the height of the observer above the sea level.

Equation 3 can be approximated, by considering that h_t and h_0 are negligible compared to the Earth's radius, with equation 4.

$$D= 3.57(\sqrt{h_t}+\sqrt{h_0}) \quad (4)$$

The dimensions of the turbines are as follows:

- Total height turbine 270 m
- Rotor diameter 240 m
- Hub height 150 m

In the first case, an observer was considered located at a point on the coast of Mazara del Vallo, at an altitude of 13 m above sea level.

By applying the simplified formula, it was possible to calculate the distance to the horizon visible to an observer positioned at that altitude. This formula considers the curvature of the Earth and gives the maximum distance an observer can see before the Earth's surface disappears behind the horizon. The distance result is 12.8 km.

Subsequently, the various distances at which it is possible to see different parts of the wind turbine were evaluated, obviously considering the dimensions (lengths and heights) of these components. Below, Figure 5 shows the graphic representation of the view of an observer positioned at a point on the coast of Mazara del Vallo at an elevation of 13 m above sea level. Considering this distance visibility:

- **Red area**: Distance from which the tip of the vertical blade of one or more turbines is visible.
- **Orange area**: distance from which half of the rotor is visible, i.e. the length of the blade, of one or more turbines.
- **Green area**: distance from which the entire diameter of the rotor of one or more turbines is visible.
- **Purple area**: distance from which one or more turbines is entirely visible

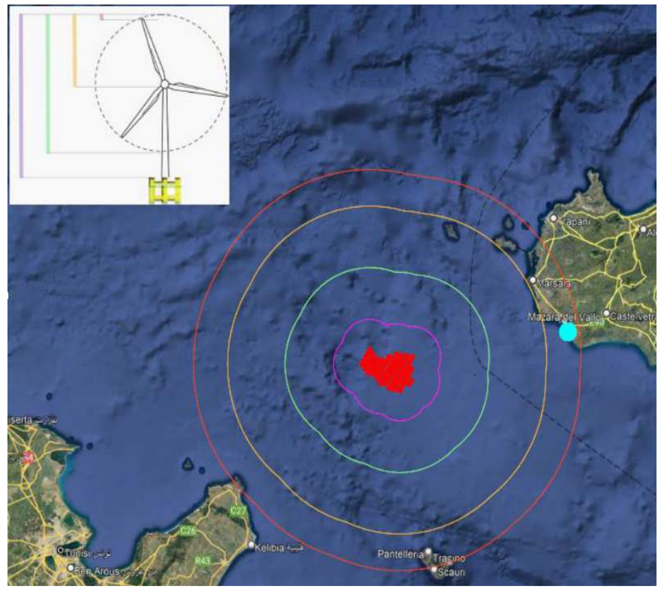

Fig. 5. Wind farm visibility from Mazara del Vallo at 13 m above sea level

The simulation results of the respective areas are listed below.

- **Red area**: Distance equal to 71.5 km
- **Orange area**: 56.6
- **Green area**: 32.4 km
- **Purple area**: 12.8 km

It is possible to note that the visual impacts are very limited generally in areas such as Pantelleria, Favignana and the south-western coast of Sicily.

Ultimately, these representations act as a key element in the overall assessment of the environmental impact of the wind farm, allowing to concretely visualize the possible changes expected following the construction of the plant, so as to adopt any corrective measures to minimize the negative effects on the landscape.

V. CONCLUSION

The article showed that offshore wind can have a promising future in the renewable energy sector. A large portion of production could help the energy transition by reducing impacts. As shown, it is possible to reduce them with design choices that respect the flora and fauna. From the point of view of visual impact, it is possible to choose unprotected areas that are well suited to reducing this impact.

In the future, a preliminary LCA study will be carried out to estimate the environmental impact linked to the construction of an offshore farm, which considers the materials and energy used.

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