Evaluation of the potential environmental impacts from an offshore wind energy farm in the Mediterranean Sea

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***Abstract* — Following the desire to reduce the energy dependence from fossil fuels, plants supplied by renewable energy sources are spreading worldwide. Among the current technologies, a new frontier is represented by offshore wind energy, thanks to the possibility to increase the capacity factor, and consequently the income from the investment, and at the same time overcome the problem of finding places without environmental constrictions. In this context, some new projects are currently under investigation in Italy, proposing the installation of floating wind farms, due to the deep seabed. For this reason, this manuscript evaluates the potential impacts related to the construction of a new big offshore wind farm, located in the Mediterranean Sea. The LCA methodology is applied to the case study.**

Keywords—offshore wind turbines, environmental impacts, LCA.

I. INTRODUCTION

The offshore wind sector is attracting huge investments, thanks to the possibility to achieve a higher capacity factor, i.e. a statistic parameter, representing the ratio between the annual expected production and the product of the rated power and the hours per year (8760). In simple words: higher is this parameter, greater is the potential energy production from this technology and the consequently income for the selling of the electricity [1].

The exploitation of wind energy is continuously increasing, with a more than linear trend. In the end of 2022, the total installed capacity was close to 900 GW, of which 836.2 GW in in onshore areas and 62.6 GW in offshore context. In the end 2021, the corresponding annual electrical production was equal to 1700 TWh for onshore wind farms and 137.6 TWh for offshore sites [2].

Focusing on the bigger players on the wind energy sector, Fig. 1 reveals that in absolute terms Asia has almost half of the total installed power (47.34%) of the power capacity, followed by Europe (26.73%) and North America (18.19%). The other areas have a very marginal amount of wind power. If we consider only the offshore plants, it is possible to observe that they practically concentrated only in Asia and Europe [3].

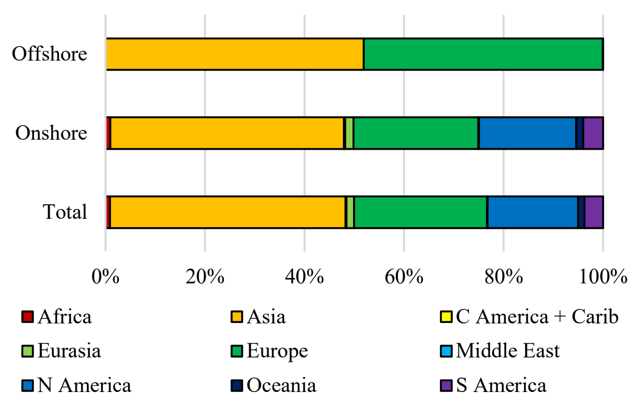

Fig. 1. Distribution of the installed power around the world by the end of 2022

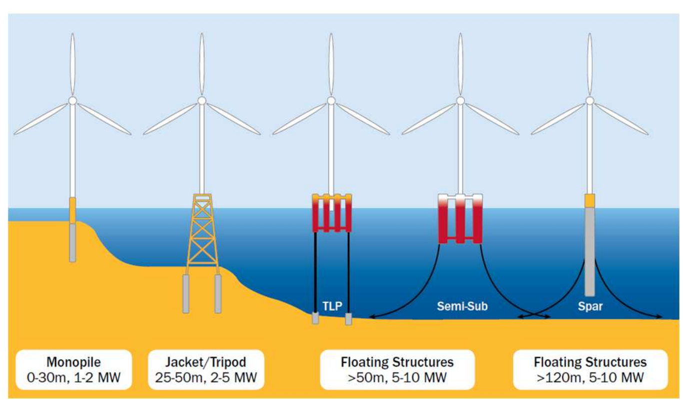

Fig. 2. Technique to install wind turbines in marine areas [4]

As introduced above, the offshore wind turbines are commonly installed in shallow water, where the seabed is not so deep (no more than 60 m), and the interactions with sea waves are limited [5], [6].

The installation techniques are progressively evolving, from the fixed structures (monopile, jacket and tripod) to the floating structures like tension leg platform (TLP), semisubmersible structures and spar buoy (see Fig. 2) [7]. Thence, the installation of wind turbines is now potentially realizable in ever deeper seabed.

Unlike the fossil fuel utilization, plants supplied by renewable energy sources are responsible of environmental impacts mainly during the construction and installation of these technologies. Limited impacts could also occur in case of wind power, in particular if big turbines are installed [8]:

- Acoustic noise, due to the blades and gearbox rotation
- Visual occlusion, due to the even bigger rotor (one of the last proposed turbines has a rotor with a diameter of 222 m for a rated power equal to 14 MW) [9]
- Obstacles to the migration routes of birds and changes in the local ecosystem.

It is important to remind that the offshore condition could limit these impacts (at least to the population), thanks to the high distance between the machines and the potential people exposed. Indeed, noise propagated as sphere or hemisphere (according to the position of the noise emitter) in open spaces, thus the noise level is reduced by 6 dB per doubling of distance [10].

However, the emission of noise could disturb the migration of marine animals [11]. Indeed, some noise frequencies emitted under sea level can run for more miles in comparison to the air [12].

During the lifespan of wind turbines, the installation and the decommissioning activities are certainly the most impacting phases. However, noise is also emitted by turbines during their operation, due to the rotation of blades and gearbox, the movement of actuators to control the system, the vibrations of transformer [13] and electrical equipment [14], [15]. This is more relevant especially in case of stall regulated turbines [16].

The development wind turbines introduced new solutions to increase the energy performance [17]. At the same time, they help the restraint of the noise of wind turbines [14]:

- New turbines are designed to change the rotation speed according to wind speed, in order to maintain the tip speed ratio almost stable. Despite this is done to maximize the power production, indeed, the low speed of blades allows the wind to mask the noise of the machines, when the wind blows with a lower intensity.
- Pole and hub are shielded, with insulating materials to reduce the emission of noise outside [18].

However, builders are continuously proposing even bigger wind turbines with the aim to collect as much power as possible, maximizing the capacity factor and consequently minimizing the LCOE (Levelized Cost of Energy) [19].

The diameter of the rotor and the height of the tower are continuously increasing. Just to have the idea of the sizes, a 15 MW turbine could require a tower 150 m high and a rotor with a diameter of 235 m.

In this scenario, to limit the visibility from mainland the only practicable technique is the installation in offshore areas, far away from the coastline. Areas subjected to tourism should be avoided [20], [21].

The Earth's curvature and the presence of humidity in the atmosphere can limit the identification of obstacles (including wind turbines) at high distances.

Finally, the evaluation of potential impacts on flora and fauna is a complex topic. As an examples, research assessed the potential influence between the electromagnetic field due to the high with the migration routes of mammals and birds [14], [22]. Some studies also emphasize the risk of impacts between birds and rotating blades [22].

Flora and fauna are exposed to a relevant stress during the installation of the wind farm, in particular the laying of the basement (in case of fixed machine) or the installation of moorings (like the last solution for the offshore areas) [23], [24]. Furthermore, local electrical substations and the electrical link to the mainland must be installed. These infrastructures could modify the deposition of detritus. However, the basement could become home for crustaceans and mollusks [22].

The realization of a wind farm could limit the navigation of boats, and in particular the fishing activities.

In Italy, the Legislative Decree n. 152/2006 is applied to limit the environmental impacts due to anthropic activities. According to this, an Environmental Impact Assessment is mandatory for the authorization of this kind of plants.

II. THE CASE STUDY

An Italian company (Renexia) is planning to realize a huge floating wind farm in the western area of Sicily.

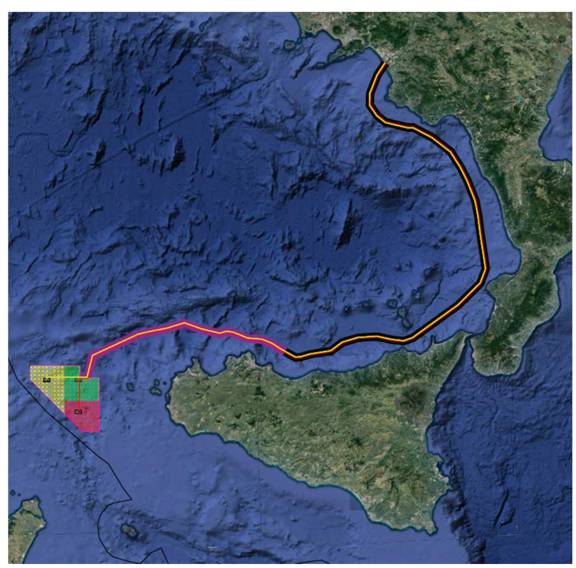

Fig. 3. Position of the proposed wind farm.

The project includes the installation of 190 wind turbines, in order to achieve the total rated power of 2.8 GW.

Wind turbines should have a rated power of 14.7 MW each. The rotor should be installed at 150 m above sea level, in order to allow the installation of blades up to 125 m long.

According to this project ("Med Wind"), the expected production is about 9 TWh/y, about 2.8% of the annual energy demand in Italy. This amount of energy could avoid the emission of 2.7 million of CO_2 per year.

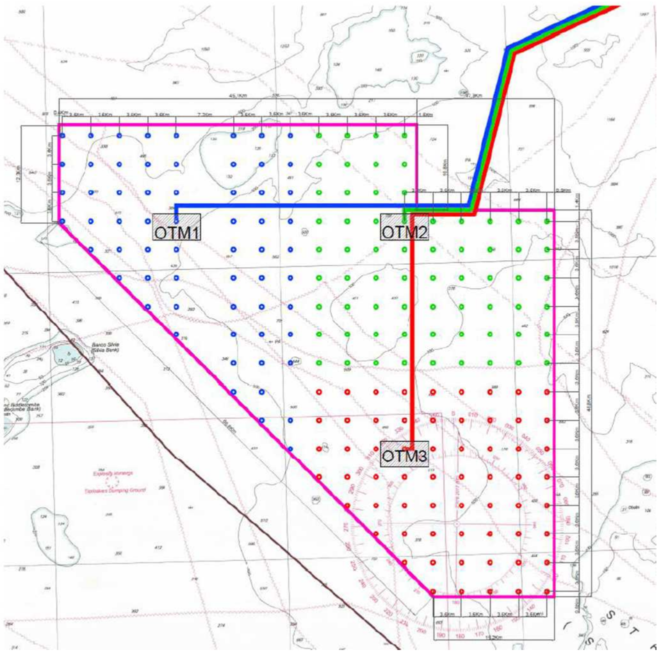

Fig. 4. Configuration of the proposed wind farm.

As shown in Fig. 4, the wind farm requires the installation of 3 floating substation. A HVDC link is proposed in order to connect directly the wind farm to Campania, avoiding the overload of the Sicilian electrical grid.

In this step, the project has not yet approved, and it is possible a significant downsizing in order to limit the interference to other activities. Indeed, many other wind farms could be installed in the next few years in surrounding areas [25].

Neglecting the refraction of light and assuming the condition of clean air, it is possible to evaluate the visibility of a wind turbine with the following relation:

$$d = \sqrt{(r_e + h_t)^2 - r_e^2} + \sqrt{(r_e + h_o)^2 - r_e^2}$$

where $r_e = 6730\ km$ is the radius of Earth, h_t is the height of the object and h_o is the quote of the observer above the sea level. Since the radius of the Earth is few orders of magnitude bigger than the other amounts, a simplified formula can be used:

$$d \approx 3.57\left(\sqrt{h_t} + \sqrt{h_o}\right)$$

by considering h_t and h_o expressed in meters and d in kilometers.

Considering the proposed sites, it is possible to evaluate the extension of the following areas: red – the entire rotor is visible from the sea level; purple – from the hub to the tip of the blade is visible; green – only the tip of the blade at the highest point is visible from the sea level. According to this map, the wind farm would be visible from the Egadi (a small archipelago located in the western area of Sicily), in particular from Marettimo. From Favignana, the visibility is limited to the upper part of the rotor.

From the Sicilian coastline, the wind farm would not be visible, expect from high places, like Erice (a famous touristic destination).

Fig. 5. Visibility of the wind farm

A. Estimation of the energy production

The authors verified the estimation of potential energy production, by consulting data reported in the SIAS (Italian acronym of "Servizio Informativo Agrometeorologico Siciliano", i.e. a Sicilian weather measuring network used to collect data useful for farming) [26]. In particular, the weather station of Trapani Fulgatore was considered.

Data were extrapolated for the quote of the hub (150 m above the sea level), considering the wind shear profile of this area.

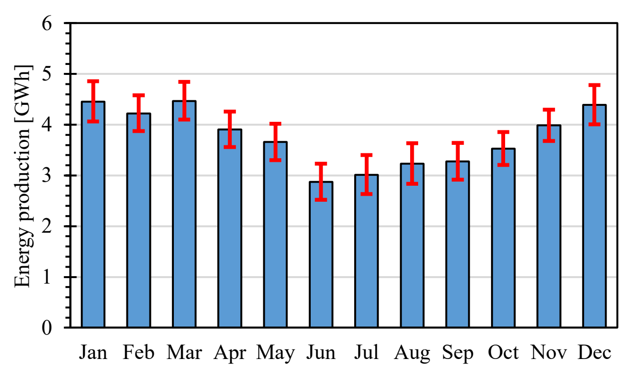

Fig. 6. Potential energy production of a single wind turbine

Considering the datasheet of the wind turbine, reported in the Annex of the project Wind Med, the authors estimated the annual producibility of a single turbine, equal to 45 GWh/y (from 41 to 49 GWh each). Thus, the wind farm could produce annually between 7780 GWh/y to 9320 GWh/y (roughly 2.7% of the annual Italian energy demand), corresponding to 3.4 million tons of avoided CO_2 emissions (emission factor 397 t CO_2/GWh) [27].

III. Life Cycle Assessment methodology

The Life Cycle Assessment (LCA) was performed to the MED Wind farm, according to the procedure described in the UNI EN ISO 14040 and 14044 [28], [29].

A. Goal and scope

The study aims to evaluate the energy and environmental impacts connected to the production of electricity generated by a wind farm, described in the previous section. Furthermore, a comparison of these impacts to the corresponding energy production from the Italian energy mix was carried out.

Annual electricity productivity was chosen as the functional unit (equal to 8550 GWh/year). The selected system boundaries include the stages of raw material procurement, material and component production, device assembly, transportation, and infrastructure. The following impact categories are examined:

- Acidification (fate not incl.) [kg $SO_{2\ eq}$]
- Eutrophication [kg $PO^{4-}{}_{eq}$]
- Global warming (GWP100a) [kg $CO_{2\ eq}$]
- Photochemical oxidation [kg NMVOC]
- Abiotic depletion, elements [kg $Sb_{\ eq}$]
- Abiotic depletion, fossil fuels [MJ]
- Water scarcity [$m^3{}_{eq}$]
- Ozone layer depletion (ODP) (optional) [kg CFC-11 $_{eq}$]
- Global energy requirement [MJ]
- Non renewable energy [MJ]
- Renewable energy [MJ]

B. Life Cycle Inventory and Life Cycle Impact Assessment

The inventory analysis considers the amounts of inputs and outputs in order to obtain the functional unit.

The Simapro software [30] was used to model the ecoprofiles of electricity from wind sources and electricity from the Italian grid, using the Ecoinvent database for secondary data [31].

The required wind turbine has a rated power of 14.7 MW. At this moment, only a 30 MW wind farm (10 turbines, 3 MW each, close to the coastline in Taranto, Puglia) was recently completed [32]. Due to the limited data, the authors preferred to use data from the German context, where many offshore wind farms are available.

The authors used the dataset "Electricity, high voltage electricity production, wind, 1-3MW turbine, offshore", that includes the energy production at high voltage in offshore area and the infrastructure for the connection to the electrical grid [31].

The dataset "Electricity, low voltage market" was used to consider the electrical energy production in Italy [31].

By using the climatic data and the estimation of the electrical energy production from the wind farm, the authors compared the environmental impacts due to the same amount of energy production. Fig. 7 shows the impacts of the electrical energy production from the wind farm on the left, and the impacts due to the same amount of energy produced by the Italian energy mix.

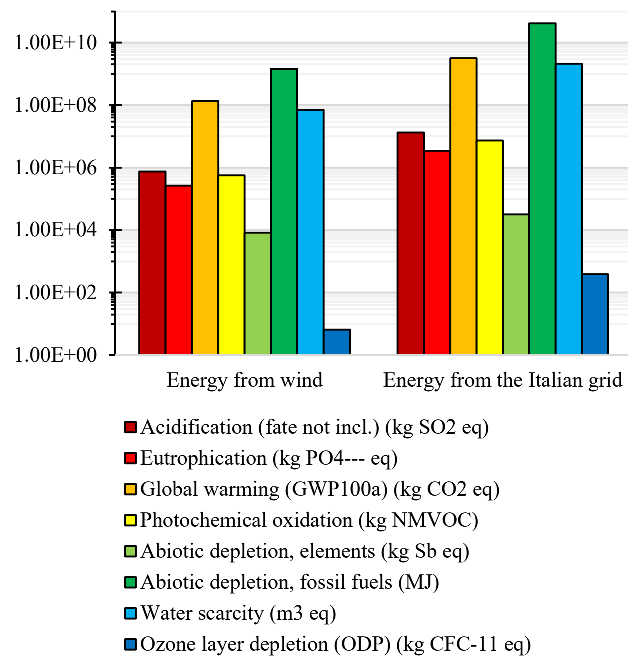

Fig. 7. Impacts comparison between the electrical energy production from the wind farm and the current Italian energy mix.

In detail, impacts related to Acidification, Eutrophication and Photochemical oxidation decrease by about 92-94%. With reference to the Global Warming, Abiotic depletion (fossil fuels) and Water scarcity decrease by about 95-97%.

With reference to the energy from wind, all the impacts are significantly lower than those attributable by energy from the Italian grid. The reduction ranges from 74.2% in the case of "Abiotic Depletion – Element", until 98.3% in the case of "Ozone Layer Depletion". .

Finally, Fig. 8 compare the global energy requirement for the electrical energy production connected with the functional unit.

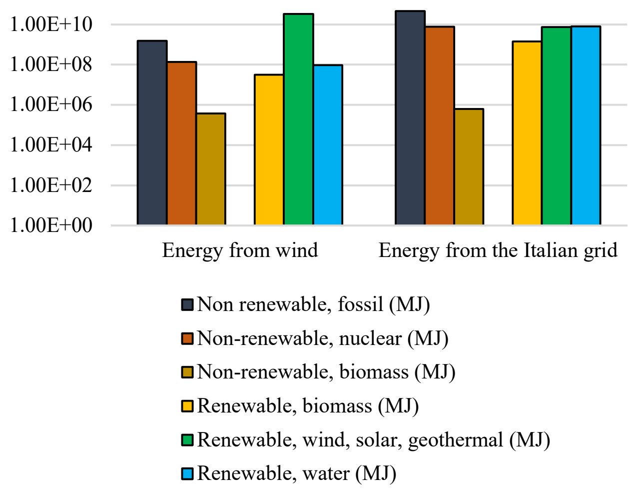

Fig. 8. The energy impacts: different energy sources

On the left, the graph reports the case of wind turbines. On the right, the current Italian energy mix is considered. It is interesting to observe the huge variations: in the case of wind turbines there are also consumption of fossil fuels, but these amounts are only related to the construction and installation phases, while during the entire life of the machine, only renewable energy is produced (wind). On the contrary, by using the Italian energy mix, all the sources are necessary according to the current share. Thus, in the second case, the relevance of fossil fuels is well higher than in the case of wind energy.

IV. Conclusions

This manuscript reported the case study of an innovative floating wind farm, that could be installed in the next years close to Sicily. The rated power could achieve the value 2.8 GW, thanks to the installation of 190 wind turbines.

The plant could produce annually 8.5 TWh of electrical energy representing the 2.7 % of the Italian energy demand and avoiding 3.4 million of CO_2 emissions per year.

The results of this evaluation confirm the lower environmental impacts for electrical energy generation in comparison to the current Italian energy mix.

Future research could be more focused on the specific solution for the exploitation of wind energy in the offshore area in the Mediterranean Sea. In detail, the creation of even bigger wind turbines and the floating platform could be considered. Furthermore, the potential integration with other renewable sources could be another interesting research area.

Acknowledgment

The presented work is carried out thanks the technical and operational support of Engcosys Enterprise. The authors thank the SIAS (Servizio Informativo Agrometeorologico Siciliano) for sharing meteorological databases.

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