is a significant step. Figure4 shows the contribution of different forms of energy to the National Energy System. It is observed that the components of coal and hydrocarbs are still very large.

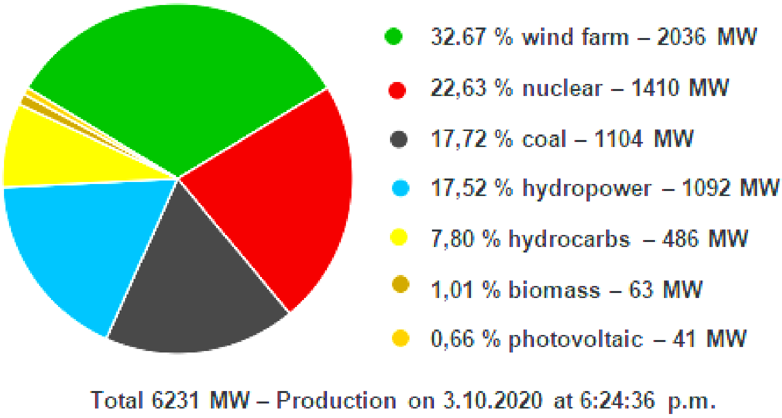

Figure 4. The contribution of energy sources in SEN (National Energy System) **[12]**

RES (Renewable Energy Fact Sheet) must also realize the potential of the Black Sea for Romania. If we analyze the map of Romania's wind sources, we find that in the Black Sea coastal area, the average wind speed is higher than 8.5 m/s, and the energy potential is over 700 W/m^2. In the high open sea area, the values are 9 m/s and respectively 800 W/m^2. These values of the wind speed and power density are maximum values.

Romania is not currently harnessing the area with the greatest potential. The decision to install offshore wind farms cannot be left at the level of the state-owned company „Hidroelectrica“ due to the difficulties to carry out such projects. First, we need to build on the studies that have been carried out so far and to hold debates and conferences on this issue. Both feasibility studies and the actual installation of wind farms can be carried out with the help of European funds.

The decision to exploit the offshore potential of the Black Sea is of economic and geostrategic importance that is part of the European target to combat climate change and reduce carbon emissions.

In the paper *A study on the wind energy potential in the Romanian Coastal environment* **[14]** it is mentioned that there are many locations with potential in the installation of an offshore wind farm, the first of which is in the north of Romania's exclusive economic zone on the Black Sea, next to Sf. Gheorghe is about 40 km from shore. The second location with potential would be near the city of Mangalia, 20 km from shore.

The conclusions on these areas are based on an analysis of factors such as wind speed and persistence, water depth, distance from shore, and turbine performance. Romania's entire coastal area can support offshore wind farms, using local and European experience in major wind energy recovery projects.

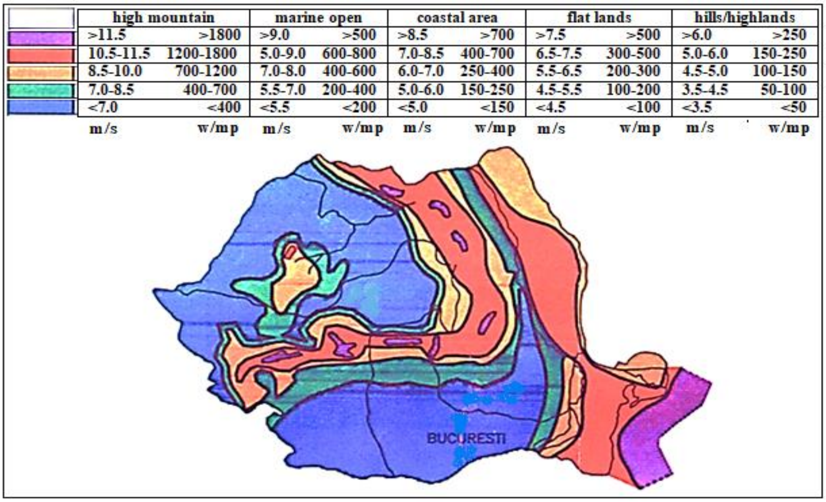

Figure 5. Romania’s wind resources at 50 m height for different topographic conditions **[13]**

Currently, offshore installation models are close to technological maturity and can be used as models for future Romanian wind farms. In *Studies on the evaluation of renewable energy resources in the area of the Romanian Black Sea coast* **[15]** both opportunities and limitations regarding the installation of future parks are analyzed.

The limitations relate to port areas, oil and gas offshore platform areas, shipping lines, protected areas, and reservations. Analyzing these limitations results the maps in fig. 6.

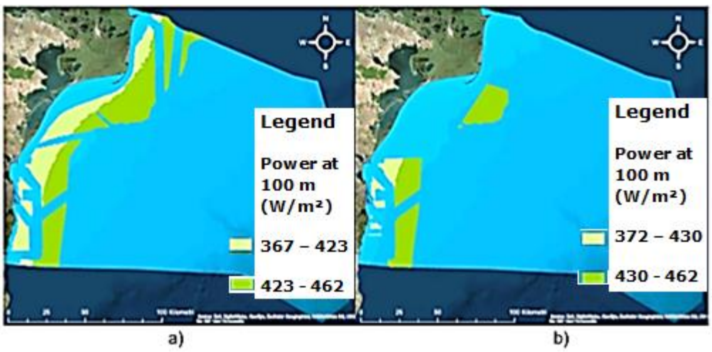

Figure 6. Optimal location areas (a); free location areas (b). **[15]**

Figure7 shows the range of wind speeds in the Black Sea area.

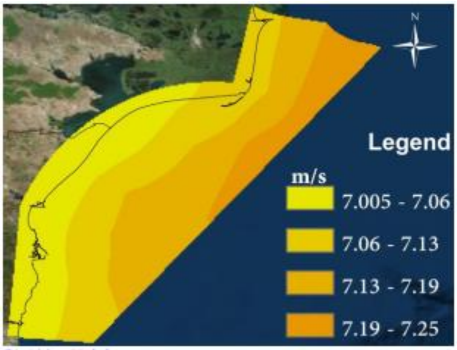

Figure 7. Speed 100m at Height **[16]**

Figure 8 shows the range of power densities in the Black Sea area.

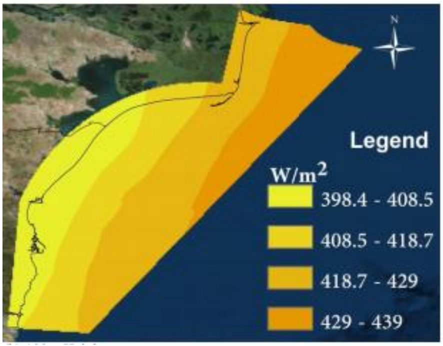

Figure 8. Power Density 100m at Height **[16]**

Sufficient areas for the location of several offshore parks can be found in areas marked in green. In the case of an offshore park, the distance between two turbines shall be approximately 1 km given the rotor diameter dimension of 154 m. An offshore park can consist of 40 to 70 turbines and a converter station for power acquisition. The installed power of such a park can be 500 MW.

The analysis of the Black Sea wind energy potential involves considering several parameters which represents „*data analysis*“ in the section „*Material and method*“: depth of sea according to distance from shore, WDP parameter meaning wind power density (W/m^2), rated turbine power (MW), rated turbine speed (rpm), height to rotor (m), minimum disconnection speed (m/s), maximum disconnection speed (m/s), AEP annual electricity production (MWh).

In the analysis we have to start at the nominal turbine speed. If we consider three producers: SIEMENS, General Electric and AREVA, we notice that the nominal wind speed for a rated projected power is around 13 m/s. At wind speeds between 13 m/s and 25 m/s, the turbine operates at rated power.

This wind speed is nowhere on the Black Sea coast. On the area from 10 km to 40 km from shore, the average wind speed is around 6 m/s, with a minimum of 4 m/s and a maximum of 9 m/s.

Consequently, if we install turbines of the type mentioned above, they will operate at half the rated power. Due to climate change there may also be changes in wind speed. The result of this situation could be an increase in the rest window (the time the turbine stops). This parameter may be approximated by values between 15 and 25 %. At the average wind speed of 8,5 m/s, the generated power is about 50 % of the rated value.

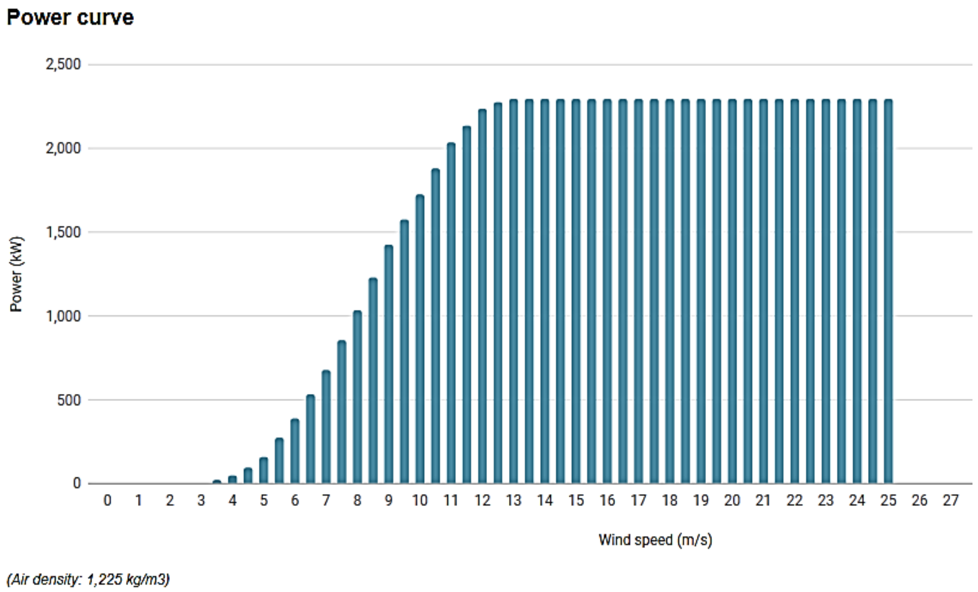

Figure 9. Dependence of power on wind speed **[17]**

Where studies are validated by reality, the capacity factor indicating a percentage of the rated capacity of the turbine may also be taken into account. For the winter season, for turbines mounted in the most favorable area, namely Sf. Gheorghe results in a capacity of approximately 50 %.

In the summer season, this coefficient may fall to an average value of 25 %, which would call into question the justification for the investment.

According to international renewable energy organizations, the cost of installing a wind farm has fallen in the last 10 years.

Figure 10 highlights the years when the production exceeds the other categories of classical energy.

In terms of achieving the electrical connections, one of the most commonly used solutions is to place an HVDC converter station in the vicinity of the wind farm, which also transforms the alternating voltage into continuous voltage and the energy will be sent ashore through special continuous current cables. Figure 11differentiates the two types of AC and DC connections with the use of HVDC converters.

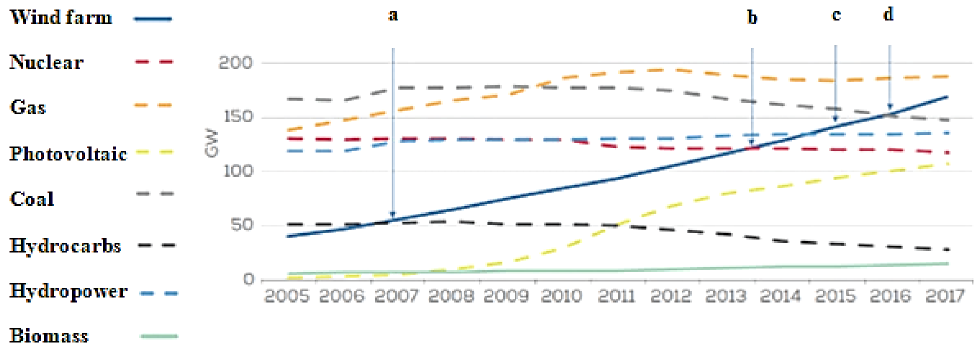

Figure 10. The level of wind production compared to classical production: a) 2007 wind farm exceeds hydrocarbs;b) 2013 wind farm exceeds nuclear ; c) 2015 wind farm exceeds hydropower; d) 2016 wind farm exceeds coal. **[19].**

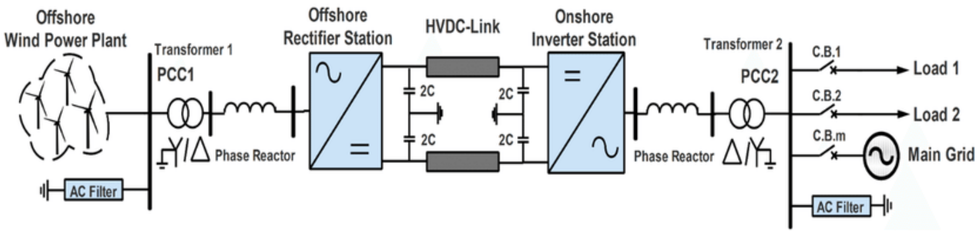

Figure 11. LCC HVDC solution for offshore wind farm connection **[21]**

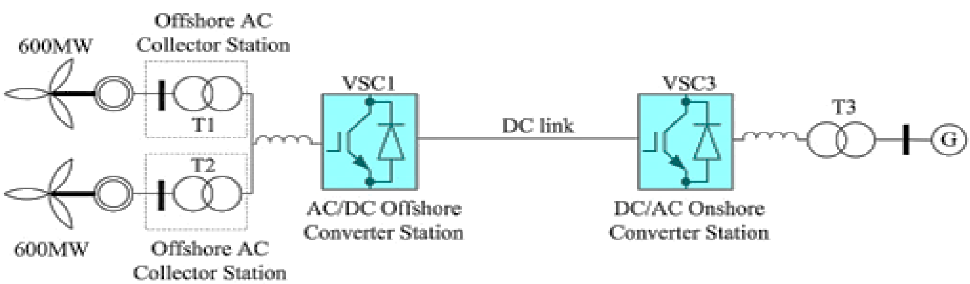

Figure 12.VSC HVDC solutions for offshore wind connections **[22]**

First HVDC solution is LCC HVDC (Line Commutated Converters) used for high power.

The VSC HVDC solution (Voltage Source Converters) use IGBT instead the thyristors.

It should be noted that the transmission of energy through AC cables is carried out with extremely high losses, which are proportional to the voltage, power and length of the cable.

HVDC cables do not entail power transmission losses but require high costs for converters.

5. Economic aspects

Technological developments over the last 10 years in offshore platforms, especially floating ones, will lead to a new trend and implicitly a new market in this area.

There are very few major players in this market. The European Union is one of them, with contributions from countries such as France, the United Kingdom, Portugal, and Norway. Installation prices in these areas are still high also due to a lack of competition but are also driven by technologies and production patterns.

For fixed-foundation offshore solutions, the technology has reached maturity and the production mode is serial, which should lead to a faster fall in prices. This is not because of very expensive installation technologies. Maintenance of fixed installations is difficult and extremely dangerous, as they work in open sea with special equipment and special safety measures.

Floating offshore solutions once technologically and functionally validated, will replicate at an exponential pace. A new line of business is practically born. Prices for this solution should also fall with the turn to serial production. This is not happening yet, because some models are in the testing and certification stage.

It should be pointed out that as an entirely special area, the launch of large-scale activities cannot take place without investment support from governments. An especially important aspect is. Finally, the resulting tariff in Euro/MWh of energy produced.

In France, for example, the resulting tariff is higher than 210 Euro/MWh, while in the UK the tariff is lower than 125 Euro/MWh.

There is a cost indication, found in the studies, called LCOE (Levelized Cost of Electricity).

There are projects supported by European programs, such as the Windfloat model in Portugal through the EUROPEAN NER 300 program.

Floating offshore solutions still have high prices because they require collaborations between the floating company itself and the turbine delivery company. Figure 14 highlights the components cost contribution.

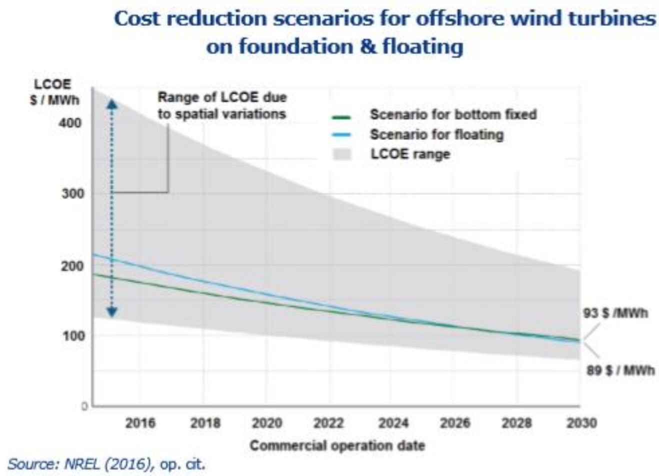

Figure 13. Levelized Cost of Electricity (LCOE) **[1]**

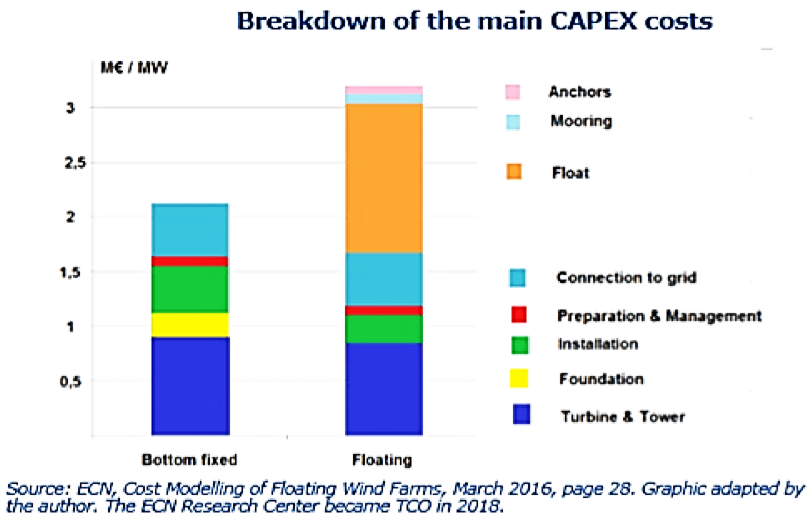

Figure 14. Cost modelling of floating wind farms **[1]**

Floating offshore solutions also serve to power offshore oil and gas platforms.

6. Environmental aspects

The impact of offshore wind turbines on birds does not differ greatly from the impact of onshore installations. For marine life, the installation of a foundation disrupts their entire habitat, but at floating offshore installations it is a less intrusive influence.

There are major restrictions on fishing for floating solutions due to cables and anchoring chains. A security zone of approximately 1 km diameter around the platforms is therefore required.

On-site studies are recommended on a case-by-case basis to reduce the impact on the marine environment. Obviously, port areas, tanker supply areas, oil, and gas exploitation areas, as well as tourist areas will be bypassed.

7. Conclusions

- The Black Sea offshore area shows wind speed variations from 4 m/s to 9 m/s.
- For harnessing wind potential, the best solution would be to develop pilot projects or test areas with a limited number of turbines.
- It is also appropriate to consider the emergence of a new generation of turbines suitable for wind speeds from 4 to 9 m/s.
- The success of the exploitation of wind energy at sea is also related to the sustained involvement of Romanian research in this field.
- The expertise accumulated in the offshore parks already operating in the Dobrogea area and in the Braila – Galati area must be capitalized.
- Given that this technology is quite new in the world, setting up a Romanian Institute for Wind Technologies would be a solution to consider.
- Given that offshore technologies are usually associated with HVDC technologies, it would be desirable for Romanian research to be able to successfully take over this area as well.

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