Physic Project P6
STPI/P6/2021 – 038

Feasibility study for the installation of renewable energy technologies on the English Channel (Nearshore or offshore)

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Report submission date: ***12/06/2021***

Project reference: ***STPI/P6/2021 – 038***

Project title: ***Feasibility study for the installation of renewable energy technologies on the English Channel (Nearshore or offshore)***

Project type: ***Review Study, Feasibility study, Data Analysis***

Project aims:

Our project's main purpose is to look into the feasibility of establishing renewable energy facilities in the English Channel. Before we could reach this goal, we had smaller ones to help us achieve it. First, we wanted to study the advantages and limitations of different types of marine renewable energies that exist today. Then, we looked at the characteristics of the Channel and the existing projects in the area. Only then we could focus on our main goal: gathering wind data from various areas in order to choose the ideal location for a new wind farm.

Project keywords: ***Feasibility study, Renewable energies, English Channel, Wind farm***

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ACKNOWLEDGEMENTS

Before starting our report, all of the six members of our group would like to thank our two teachers/researchers, Mr SHADLOO and Mr ALAMIAN who helped us a lot during all this semester by leading us through several steps in order to progress rapidly and to work efficiently, in team.

1. INTRODUCTION

1.1. Abstract

Nowadays, protecting the environment has become at least as necessary as providing for the needs of the population. This is why we need to produce electricity in a way that limits the environmental impact, and the best way to do it is by developing renewable energies. Taking that into account, the main purpose of our project is to consider the possibilities of implementing renewable energy facilities in our region, and more precisely, at the English Channel.

To achieve this goal, we followed multiple steps, considering the little we knew about the subject at the beginning. First, we studied all the different types of marine renewable energies that exist today defining the advantages and drawbacks of each device. Given that, we were able to determine, whether they could be installed in the English Channel or not. Meanwhile, we were also looking at the different projects already underway in the English Channel. As a result of those primary research, having the most data for wind turbines, we decided to centre our project on this technology. Our final task was then to collect wind data on different locations to figure out which would be the best to install a new wind farm.

1.2. Introduction

In this world of innovation, we are constantly looking for the best performance. That is why there is a huge variety of renewable energy devices, each one with its own characteristics and limitations. We have divided them into four categories.

First, the wind energy. It is produced by wind turbines that capture the kinetic energy of the wind through their blades and drive a generator to produce renewable electricity. Then there are solar energies. The most common one uses photovoltaic panels to convert sunlight through semiconductor, photons hitting the electrons and releasing them, induce an electric current. The third category is water current energy extraction devices. This one includes devices such as underwater turbines or tidal power which uses the power of tides to produce electricity. Finally, the last subsection includes biomass or thermal energies as well as osmotic energy which we will discuss in further details.

As we can see, most of those technologies depends largely on the location and the seasons as they rely only on natural resources. Moreover, even though they produce greener energy, a lot of the installations can affect the ecosystem where they are placed. It is also very expensive to install such devices at sea. These are some reasons why the sea power is not fully exploited yet.

Because renewable energies depend so much on location, we must consider the reasons why the Channel Sea is ideal to implant them. The English Channel is located between northern France and England, a body of water that links the Atlantic Ocean to the North Sea. The English Channel covers an area of roughly 75 000 square kilometres and has an average depth of 63 meters.

In order to present our project in the most effective way, we will, in the first part, explain what kind of marine renewable energies devices exist in the world. In a second step, we are going to centre our focus on the English Channel, its characteristics and the projects of marine technologies that are already planned there. Finally, in the last part, we will present the results of the wind studies we made about different locations in the Channel and conclude about which place would fit the more for a wind farm implementation.

2. METHODOLOGY / WORK ORGANIZATION

First of all, at the beginning of the project, we did not know each other: we had to make a choice according to our favourite subject and not according to our friendship. Nevertheless, from the first session, our referent teacher asked us to create three groups of two people in order to begin some research. Our three groups were as follows: Emilien FOISSEY and Maëva VAUTRIN (group 1), Juliette LENGELE and Lucie GELLE (group 2) and the last one was Maureen MURER and Shani ARROUCH (group 3). As the girls of group 2 were living not so far, they used to see them in real conditions. Nevertheless, the two other groups used to talk by messages or even to create virtual reunions on zoom or other social media. We could also come once a week, the Tuesday from 4:30pm to 5:15pm in our referent teacher's office. This meeting has enabled us to make a point of our progress, our questions, and our organization for the following week. Generally, not all of us were able to come because we had to respect the sanitary measures so every Monday on the evening, we were talking on our Messenger conversation who wanted and were able to come the day after. We used to be three in presence and three behind our computers. On average, we came once every two weeks. There was a globally good communication because when one of us did not succeed in doing something or had a question, the other member of the group tried to help him/her as best as he/she can. We also did not hesitate to send some e-mails to our two teachers.

Even if globally, each of us worked on each part of the project, there were some parts for which we had to divide the work: at the beginning of the project, group 1 worked on Inshore energy facilities, group 2 on Offshore and the third one worked on Nearshore ones. At this time, we did not still have the reflex to communicate a lot and so some parts were done by two different groups. But we bounced in order not to do the same mistake and not to lose time either.

One important part where tasks have been divided were the redaction of the final project. Indeed, we wanted to write this document on Word, but everyone did not have this application. As a consequence, group 3 took the decision of centralizing every part in order to do a good and regular layout in addition to the writing part of the report assigned to them.

Our project is not finished yet because we still have our oral and poster to prepare but we continue moving forward in order to give back the best possible work.

Furthermore, before choosing this project, we did not know that we should do it entirely in English (report included) and therefore we were not all necessarily comfortable with that at the beginning because it is sometimes really difficult to understand and be understood in a foreign language. However, we did not give up and we gave our best to be up to this difficulty and it is also an aspect that brought us together, the 6 members of the group, since we helped each other in order to communicate correctly with our two teachers and in order to write properly our report.

Finally, it was an enjoyable experience because it enables us to work in team, to adapt each other and also to be either understandable or efficient so that everyone could go on at the same rhythm.

3. WORK CARRIED OUT AND RESULTS

3.1. Renewable energies

3.1.1. Wind energy

figure 1 : *Wind Turbine Park [2]*

3.1.1.1. Fixed wind turbines

Fixed wind turbines are anchored in the sea's underground meaning that it is fixed in nearshore areas because the depth must be low. As a consequence, this kind of turbine can be fixed about at 20 meters deep but not more than 50 meters.

The principle of these fixed wind turbines is that wind energy is caught in order to be converted into electricity which will be linked and driven to the ground by cables. This technology costs 1700 €/kW to 3000 €/kW depending on the depth of the water, the composition of the floor, the distance from the coast and the farm size. This technology is set up for 20 years. Their efficiency is higher than fixed turbines onshore: 3000 to 4000 hours/year instead of 2200 to 3000 hours/year. Finally, the electricity production is immediate.

3.1.1.2. Floating wind turbines

The main difference of floating wind turbines with the previously mentioned wind turbines is that these ones are directly attached to the ocean floor thanks to the mooring cables. Thus, they can be fixed further away from the coasts and so can be installed in offshore zones *[3]*.

3.1.2. Solar energy

This technique consists in recovering the sun's rays' energy and transforming it into electricity. A photovoltaic installation requires solar panels, an inverter, and a meter. This technology can be installed at the sea surface. First, photons from the sunlight strike the photovoltaic cells of the solar panel. These cells are made of silicon, a semiconductor material. Next, the electrons move around, producing a direct electric current. Finally, this current is turned into alternating current thanks to inverters so that it can be sent to the electricity grid. The current cost of large-scale photovoltaic energy reaches 0.085 €/kWh in 2020. A solar panel has an average lifespan of 25 years *[4]*.

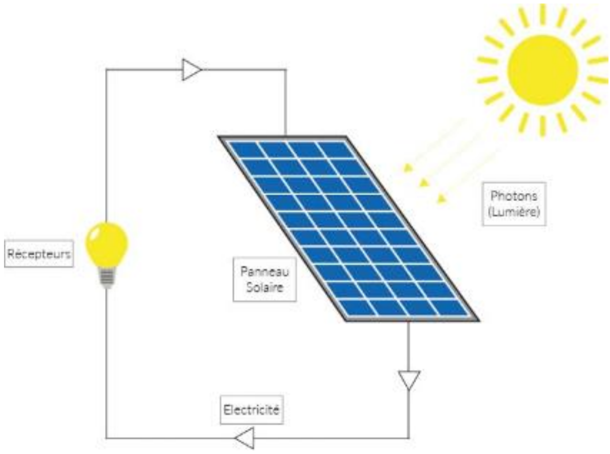

figure 2 : *Solar panel [5]*

3.1.3. Energy of current

3.1.3.1. Hydrokinetic turbines

Hydrokinetic turbines are installed on the ocean floor (or at least half-submerged) and fixed thanks to cables. They will capture the kinetic energy from the ocean current to transform it into electricity. More precisely, the rotation of the turbine blades generated by the waves will produce a mechanical movement. No matter the current, the water movement will be caught and will turn the turbine on. Then, the turbine rotation will bring about an electric generator that will convert this mechanical energy into electricity which will be linked to the sea floor either by fixing it or using mooring cables *[6]*.

figure 3 : *Hydrokinetic turbine [7]*

We can compare its functioning with the wind turbines however the energy is not provided by the wind, but by waves and sea currents. We can distinguish various types of stream turbines such as the ones that are placed on the water surface (floating), immersed or emerged. Ideally, concerning the immersed stream turbines, we may put them where the depth water is higher than 20mto be efficient considering that the minimum blade diameter is usually around 15m. Moreover, the area must have a speed current higher than 2m/s. There are less obligations for the other types of stream turbines (like the ones floating). In Europe, 20% of these resources are located in Brittany and in the Basse-Normandie region. For now, this installation is still expensive compared to the wind turbine. This technology would cost 2500 to 3500€/kW according to the depth, the consistency of the ground, the farm size… Stream turbines can be implanted for 20 to 25 years *[8]*.

3.1.3.2. Wave power plant

This device works thanks to the waves and the swell: as an example, that is also shown in Fig. 4, a long cylinder produces energy thanks to the swell of the sea, following the waves at the surface of the sea. This energy can be used offshore and nearshore.

figure 4 : *Wave power plant [9]*

While the cylinder oscillates with the waves, the piston of water aspirates and exhales both water and air. It is fixed to the floor by mooring cables. An artificial ramp concentrates the waves that arrive, and it propels water to an altitude higher than the level of the sea and this latest is caught in a big reservoir. Afterwards, other turbines with low pressure make use of this height when the device frees the caught water.

The installation cost is about 1000 to 3000 euros/kW and the production cost is about 60 euros/MWH. Plus, the cost of a farm with 3 machines is about 3,8M euros/kW. Its lifespan is around 20 years, but it is not exact as we do not have enough experience on this device yet *[10]*.

3.1.3.3. Tidal power

This technology actually uses the tide effects. During a rising tide, sea water is caught. When the sea level has fallen enough, the water reserved is released turning a turbine on which will produce electricity.

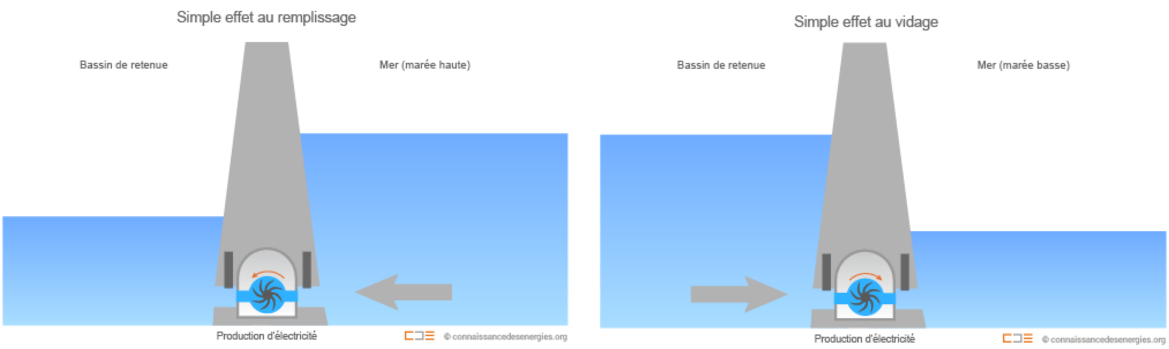

figure 5 : *Operation of a tidal barrage [11]*

There are 3 main types of tide power. The first one is called a tidal dam that will hold some water back when the sea level is high. In fact, this contained water has a lot of potential energy. Then, the dam will release it when the sea level has fallen enough, turning a turbine on. This turbine will convert the energy to mechanical energy and finally to electric power using the generators. The estimated cost is between 0.05 and 0.14 €/kWh. This type of technology can work about 120 years which is very impressive.

The second type looks similar to the first one, but the main difference is that the location of the installation called tidal lagoon is artificial and without a pre-existing ecosystem. Tidal lagoons can work by pumping or not according to their location and to the current.

The third type, named tidal power, is not a dam but a wall that does not enclose water as we can see on the following diagram because this wall creates a big difference in water sea level near the coasts. This installation uses a “water piston” to pull or push a jet of air that will activate a rotary air generator.

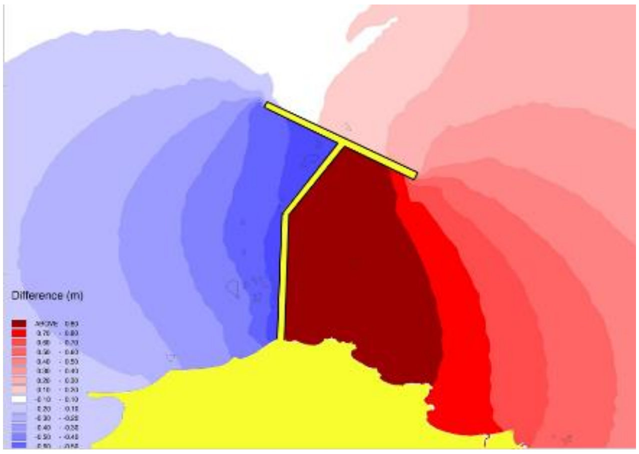

figure 6 : *Dynamic Tidal Power [12]*

3.1.4. Other types of energy

3.1.4.1. Marine biomass

Algae are photosynthetic organisms. There are between 200 000 and 1 million different algae species all around the world. This large diversity suggests that there must be some original molecules such as lipids. Thus, microalgae seem to be likely to produce fatty acid.

This fatty acid will be extracted from algae in the form of oil that could possibly be used to produce biofuel. For the moment, the use of algae’s oil is rather theoretical, but scientists are particularly interested in that rich potential. Today, the estimated price of this biofuel is about 2 €/L and this is not yet enough attractive *[13]*.

3.1.4.2. Thermal energy

It can be defined as the calorific potential of cold or warm water which can be used separately or together. 3 main functions exist:

- A supply of cold water directly for air conditioning.
- A mix between deep cold water and hot water near the surface for the production of mecano-electric energy.
- A mix between deep cold water and hot water near the surface for desalination of seawater.

This device pumps cold deep water and carries it into a distribution network that will cool down the place. The production of energy mecano-electric is ensured by thermodynamic cycles where the fluid is sprayed by hot water, then drives a turbine-alternator, and is condensed by cold water etc.

The cost linked to the electricity production is about 16 000 euros/kW for a power plant of 5 MW net. The cost linked to freshwater production is about 1.5M euros for a 500m^3/day module. The device which delivers cold air can last 30 years. The device that produces energy can work 25 years and the one which desalinates can operate for 15 years *[14]*.

3.1.4.3. Osmotic power

This technology uses the difference in salt concentration between freshwater (from rivers) and sea water which will produce some energy when the two waters mix up.

There are three main types of technologies that can be used: pressure-retarded osmosis, reversed electrodialysis and vapour pressure difference utilisation. With the first one, freshwater and saltwater are separated thanks to a semipermeable membrane where freshwater will migrate toward. This will create a flow which will turn a turbine on, and this will produce electricity (see appendix 1).

With the second one, freshwater and saltwater are separated thanks to a selective ionic membrane and saline ions will go through this last membrane and that will create electricity too (see appendix 2).

The last technology is the vapour pressure difference one, it consists in using freshwater vapour pressure which is different from the one of saltwater to produce electricity thanks to an electric turbine that will turn (see appendix 3) *[15]*.

The cost remains expensive, and the devices will have to be resistant because of strong flows. The cost related to this technology is about 36 000 $/kW because of the high price membrane. A membrane lasts about 3 to 5 years but if we take precautions (with water quality control for example), the membrane may last about 7 to 10 years *[16]*.

3.1.4.4. Combined energies

Another solution is to combine solar energy and wind energy. This involves the installation of a wind system coupled with a photovoltaic panel system, allowing the balance of electricity production.

The solar panels work exactly as in the system explained above. They are installed on the foundation of the fixed or floating wind turbines. On the one hand, kinetic energy of the wind is transformed into electricity and on the other hand the energy from the photons of the sun's rays is transformed into an alternating current. These two sources of electricity are joined together.

The combined energy enables having a system functioning on a relatively continuous basis. Moreover, this technique has a good efficiency. However, as this system requires the installation of both wind turbines and solar panels, it takes up a lot of space and is expensive to implement. The estimated cost would be approximately 40 €/MWh. The lifespan of this installation is about 20 years *[17]*.

Before going on with the study of the Channel and its characteristics, a table gathering the advantages and drawbacks for each type of energy is available in the appendix 4.

3.2. English Channel and its characteristics

3.2.1. Generalities

Located between the United Kingdom and the North of France, the English Channel is part of the Atlantic Ocean. This sea has a surface of 75,000 km². It is linked with the North Sea by the Detroit du Pas de Calais and with the Atlantic Ocean on the west. The English Channel is an epicontinental sea: it is the part of the ocean which covers the continental platform. Its depth average is about 63 meters (with a maximum depth of 180m) and its temperature varies between 5 to 20°C. This sea represents a real stake for fishers because of its marine wildlife diversity. This sea is described by a strong and constant wind and an important ocean current (that can exceed 7 knots). It also has a strong swell, and we can notice that there is an important tidal current. Indeed, this area is specifically suitable for marine technologies.

The Channel climate is very changeable with strong wind and thunderstorm in winter and clouds or sun in summer. This specific climate allows the exploitation of different types of energy such as wind and solar.

The “climate legislative package” makes it compulsory for European countries to use renewable energies up to 20% by 2020. This is why nowadays the wind turbines are studied very closely *[18]*.

figure 7 : *Channel Sea map Wind features [19]*

3.2.2. Depth features

The fixed wind turbines cannot be implanted anywhere in the sea. In fact, there are some criteria to respect. First, they cannot be implanted if the depth water is higher than 50 meters. Secondly, the VLIZ Maritime Boundaries Geodatabase defines precisely the EEZs which correspond to the Exclusive Economic Zones, that is to say, it allocates a certain part of the sea to a country. Indeed, the law claims that the water located up to 200 nautical miles (which is equivalent to 370 km) from the coasts belong to the country in question. Thus, we cannot put wind farms wherever in the sea.

Considering this parameter of 50 meters of maximum depth we obtain the following map:

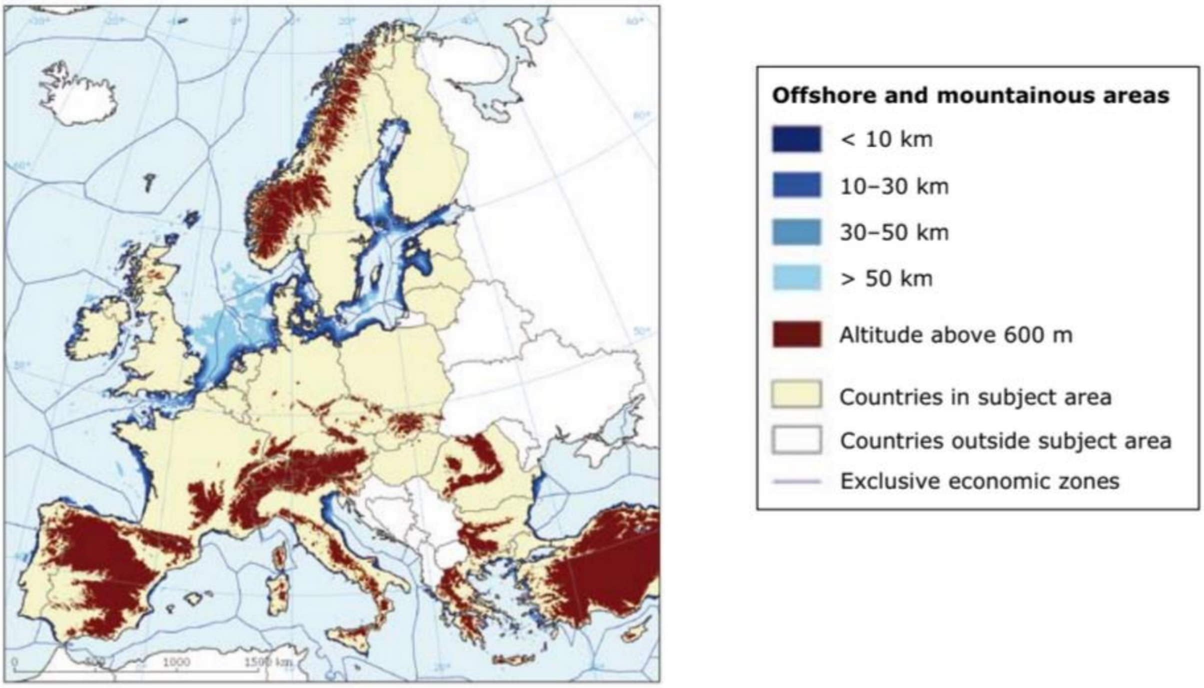

figure 8 : *Offshore locations with water depth of less than 50 meters [20]*

Therefore, we can see that the areas where wind turbines could potentially be implemented are located close to the English and French coasts concerning the Channel Sea. In fact, thanks to this other map bellow, which is a zoom on the depth water of the sea, we can see that, usually, the water depth is not very important near the coasts (about 30-40m on average).

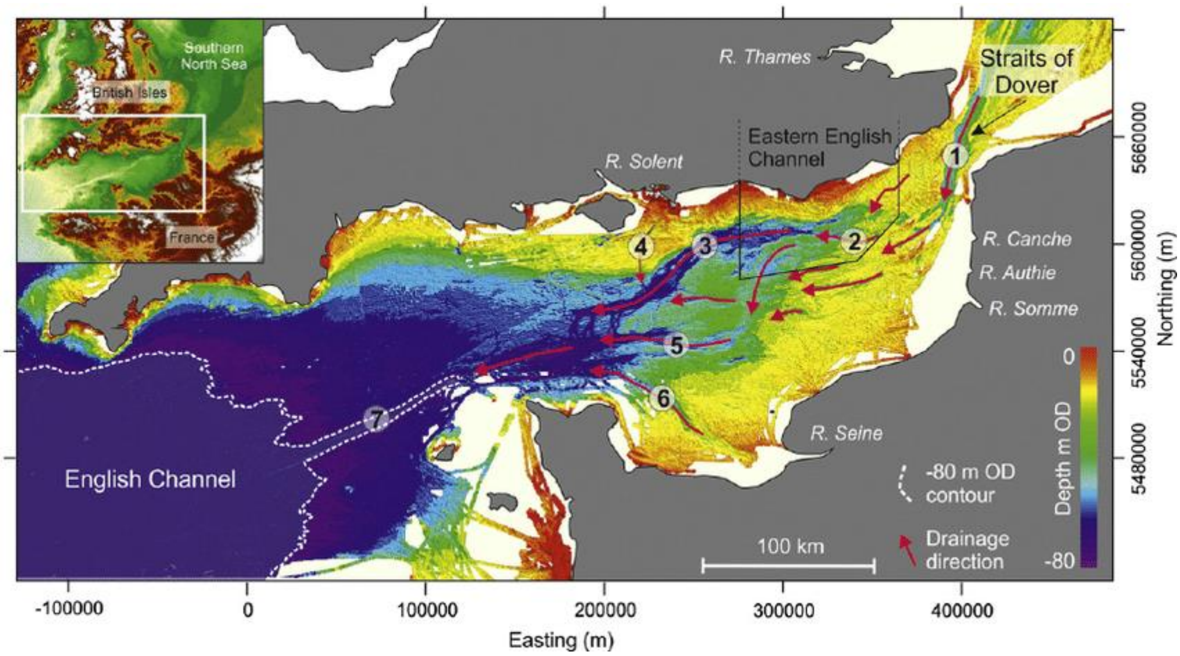

figure 9 : *Water depth in the English Channel [21]*

3.2.3. *Allocation of wind potential*

Regarding to the location of the distribution of wind potential, we can observe, thanks to the following figure, that the English Channel is the place with the strongest winds that makes it a potential important zone of renewable energies exploitation.

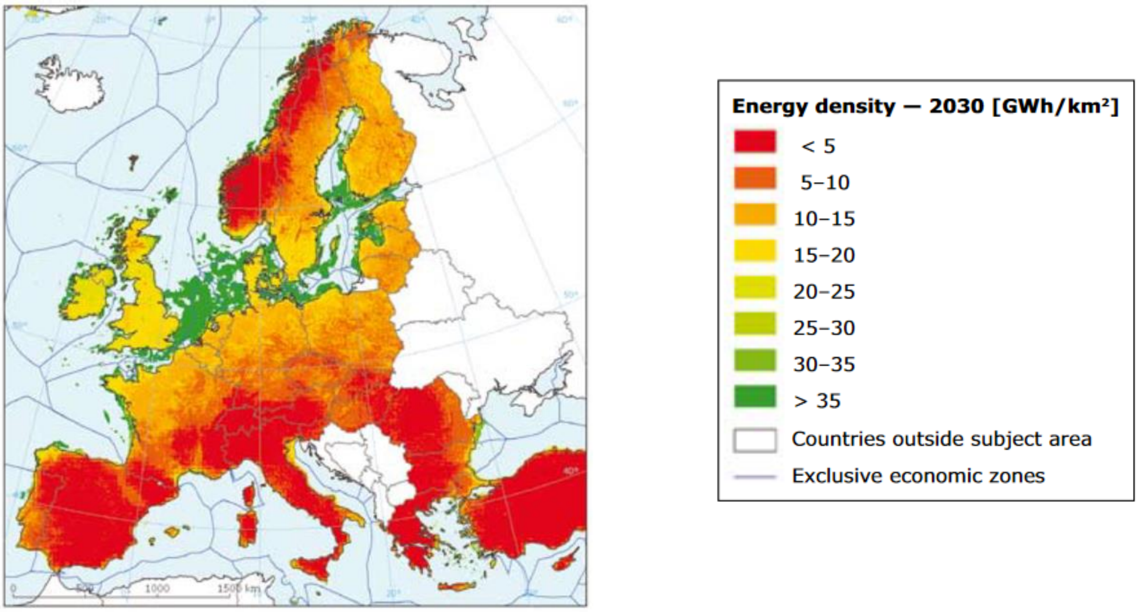

figure 10 : *Allocation of wind energy density in Europe [22]*

Indeed, the map shows a dark green colour in all the Channel Sea which reflects an energy density higher than 35 GWh/km². Thus, the Channel Sea seems to be the place where this energy density is the highest! That is why it is interesting to study what kind of device could be installed in order to get a maximum of wind energy. Moreover, we can also notice that there is more wind potential near the coasts than inside the continent. The idea of nearshore facilities can also come from this kind of study which shows that there is a lot of wind potential in the sea and on the coasts. Indeed, there is more wind in the Channel Sea with more than 35GWh/km² (green colour) instead of 17GWh/km² for the onshore coasts (yellow colour). Finally, the more we come through the land, the less important is the velocity (colour turning progressively to the red). Therefore, in terms of optimisation, the Channel Sea is a really strategic place.

3.2.4. *Channel Sea weather*

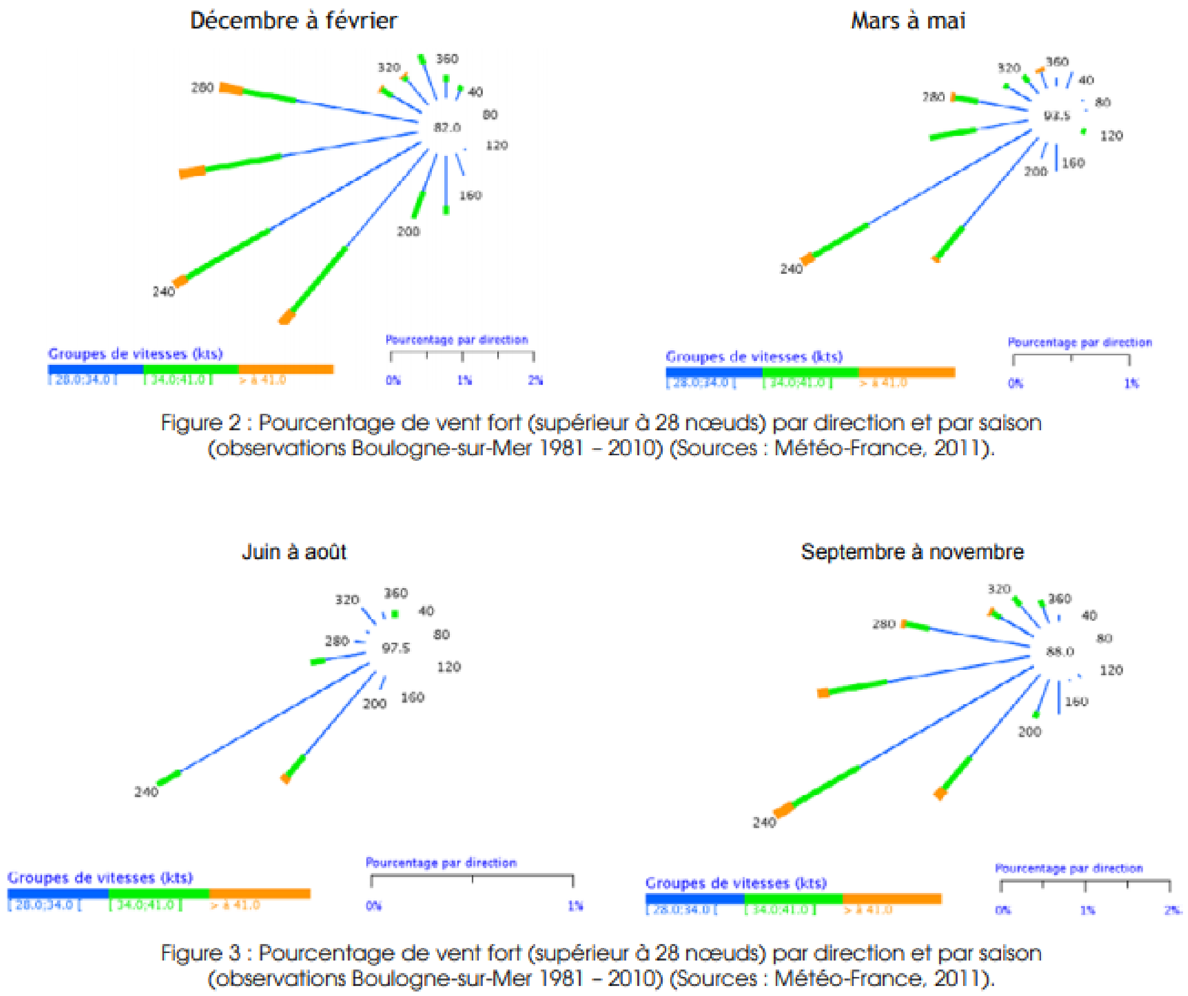

figure 11 : *Strong wind percentage by season [23]*

We will see later that our study will concern the wind velocity in the Channel Sea but nevertheless, we can already notice that the wind is particularly strong because of the weather. Indeed, in the north of our country, it is not rare that rain and wind are the usual previsions of the day, especially in cold seasons. Carefully observing the graphs above, we can analyse that the main directions of the wind in this sea are south-west and north-east. They correspond to particular points which are the depression of the Island, the anticyclone of the Azores and the anticyclone of Siberia.

The south-west wind blows all the year with a presence of 26% in winter and 48% in summer. Nevertheless, the north-east wind is less present: 14% in autumn and 18% in summer.

It is worth noted that the climate can also be really local in the English Channel and it can change in a really short laps of time. Indeed, if there is some rain on a place, it is really possible that at 500 meters away, there is still a blue sky. On top of that, rain can be very strong sometimes. Indeed, it can cause problems when a company proposes to study where to install potential facilities because of strong rains or strong winds, ingenues must anticipate this oceanic climate. They need to put stronger pillars and use material which easily resists to sever weathers (see appendix 5).

3.3. Projects in English Channel

In France there are already some projects of marine technologies, mostly planned in the Atlantic Ocean and in the Channel Sea. However, in this section we will especially focus on the last one. Concerning the types of technologies that are planned in the Channel, most of them are wind farms but there are also some hydrokinetic turbines or some EEL tidal energy converter (where the energy is converted thanks to an undulating membrane).

3.3.1. Wind farm near Courseulles-Sur-Mer

In Courseulles-Sur-Mer, the installation of a farm of 75 wind turbines of 6 MW each (which means a total of 450 MW) is planned. The energy produced would supply approximately 630 000 households with electricity. This wind farm project is expected to be operational between 2022 and 2024. The turbines' diameter will be about 150 meters, and the wind turbines will cover a zone of 17 860 m². This area is really strategic because there are strong winds, and the water depth is not too important. In theory, this wind farm will work for 25 years *[24]*.

figure 12 : *Wind farm project in Courseulles-Sur-Mer [25]*

3.3.2. Wind farm near Cotentin

In 2022, the fourth wind farm of Normandie will start working near Cotentin as decided officially the 5th of December 2020. The power capacity is about 1 000 MW which will produce enough electricity for about 800 000 households. These wind turbines will be located at a distance of more than 32 km from the coasts. But for now, some studies concerning the environment and the final area that will be used will be realised in the next few months. *[26]*

figure 13 : *Project of wind farm in Cotentin [27]*

3.3.3. Wind farm of Dieppe - Le Tréport

This wind farm is expected to work in 2021 and it will produce about 496 MW thanks to 62 offshore wind turbines. These turbines will produce enough electricity to supply approximately 850 000 people. Moreover, 2 GW/h per year are expected to be produced *[28]*. This wind farm is expected to produce electricity for approximately 20 years *[29]*.

A map representing the precise location of this future wind farm between Dieppe and Le Tréport in Normandie is available in the appendix 6.

3.3.4. Wind farm near Saint Brieuc

This wind farm project will normally be operational in 2023. It consists of 62 offshore wind turbines located at 16,3 km from the coasts. These wind turbines will be 207 meters high, spread on a surface of 75km². The capacity of this wind farm is estimated about 496 MW exactly the same as the wind farm project near Dieppe - Le Tréport. Therefore, this installation will also supply around 850 000 people with electricity and will produce 1.8 GW/h per year. The wind turbines are currently under construction. This is the precise location of the project:

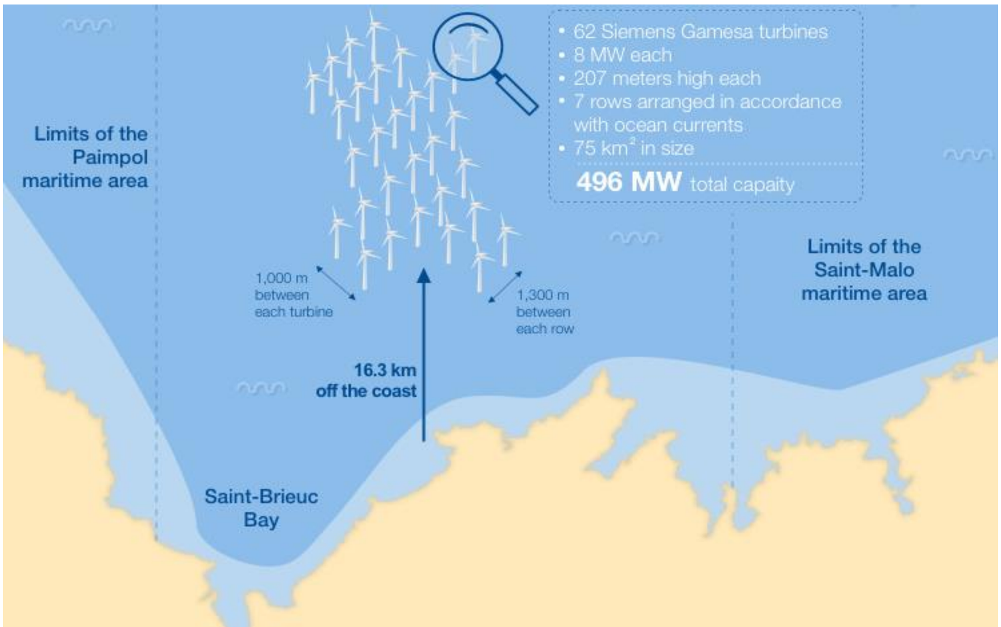

figure 14 : *Map of the wind farm Saint Brieuc [*30*]*

3.3.5. Wind farm of Fécamp

The future wind farm of Fécamp will start working in 2023 with a power capacity of 500 MW. Thus, this wind farm will supply about 770 000 people with electricity. Actually, there will be 71 offshore wind turbines all located between 13km to 22km from the coasts, at about 30 meters depth. For now, the wind turbines of this wind farm are in construction at Le Havre. This wind farm is expected to work for 25 years.

3.3.6. TIGER Project in Normandie

The TIGER project will demonstrate that tidal energy is a maturing industry, capable of achieving an accelerated cost reduction pathway. The project aims to stimulate the growth of tidal energy by installing up to 8 MW of new tidal capacity in the Channel area, essentially with submerged turbines off the coast that will harness the energy of tidal currents and will be converted into electricity. The aim is to make a stronger and cost-effective case for Tidal Stream Energy as part of the FR/UK energy mix *[31]*.

TIGER will:

- Switch back on the dormant site in the Celtic Sea.
- Create a new operational community energy scheme at Isle of Wight with up to 1.2 MW of new turbine capacity.
- Repurpose the Paimpol-Bréhat site (Brittany, FR) and install 100KW of capacity.
- Complete the authorisations for two new sites in Morbihan (Brittany, FR) and another at Le Raz Blanchard (Normandie, FR) that we will discuss further a bit later.

The project will install up to 8 MW of additional energy capacity, ultimately leading to a reduction in greenhouse gas emissions of approximately 11,000 tons per year and a reduction in the cost of tidal energy to around 150 euros/MWh.

figure 15 : *Tidal Turbine [32]*

Near La Hague in Normandie, at Le Raz Blanchard, a new project of hydrokinetic turbine pilot has been approved by the government leaving the opportunity to Atlantis to launch its project. This last one consists in building 7 submerged tidal turbines. These ones could produce a total of 12 MW. This location is very interesting because, “Raz Blanchard, Lower Normandie, is France’s strongest tidal current and holds 50% of the national tidal power potential” according to a Britannic press release: *Normandy Prefecture approves transfer of 12 MW tidal power development lease from Engie to Normandie Hydroliennes* (published in June 2020). These hydrokinetic turbines are a sort of pilot that will allow scientists to study more precisely this type of power in order to be exploited it in a few years with larger farms. This farm would have a power capacity of 14 MW. According to the DCNS (Direction des Constructions Navales) that is the equivalent of the annual electricity consumption of 10 000 to 13 000 people. Indeed, the turbines’ diameter would be about 16 meters, and they would be located at 3.5 km from Goury. Plus, the total of the surface that would be used for the park would reach about 28 hectares at about 30 meters depth.

3.3.7. Rance Tidal Power

The Rance Tidal, near Saint-Malo power plant was commissioned in 1966. EDF is one of the forerunners in this type of technology with Sihwa in South Korea. It was built at the mouth of the Rance River in Brittany, and it cost 817 M€. The installed power is 240MW, spread over 24 turbines of 10 MW but the annual electricity production is about 500 GWh. Indeed, the equivalent of this consumption is 225 000 inhabitants. *[33]*

To generate this power, the tidal plant uses the variation in sea level that occurs on a daily basis. This creates a difference in the height of the water on either side of the dam and generates a sufficient flow to turn the turbines on. The main advantages of this type of plant are its zero-CO2 emission, its low environmental impact and above all the very precise predictability of tidal phenomenon *[34]*.

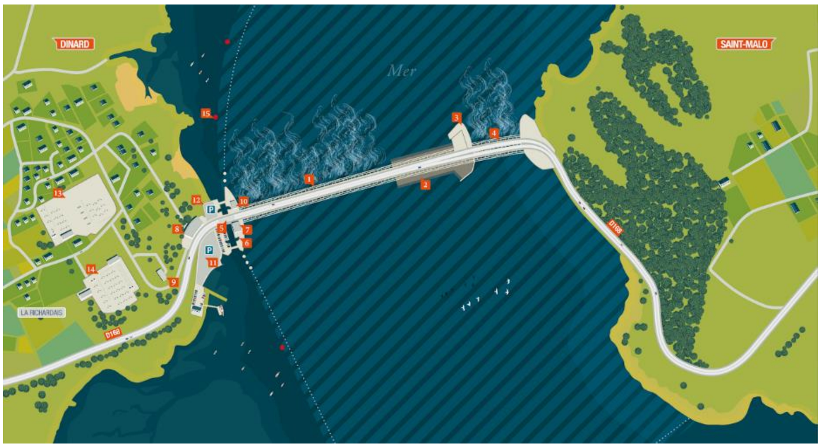

figure 16 : *Rance Tidal Power Plant [35]*

3.3.8. EEL tidal turbine

Here is the process of an EEL tidal turbine: the EEL energy technology works on the basis of a membrane that undulates under the pressure of the currents. The deformations of the membrane are converted into electricity. This system is currently available in prototype stage. It has the advantage of being non-polluting, underwater, and less bulky than wind turbines. It is operational for about 20 hours a day.

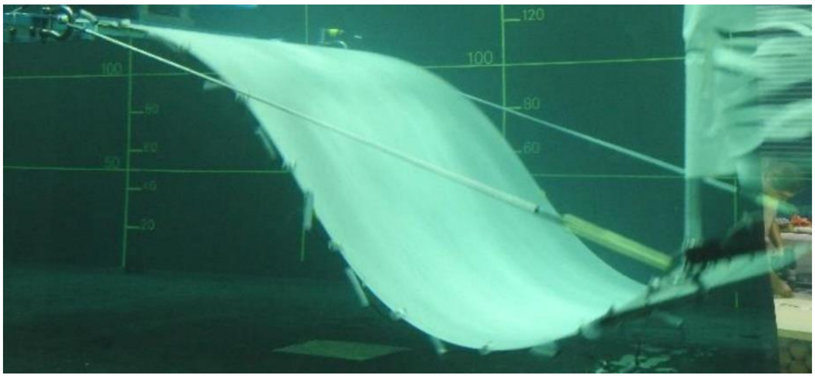

figure 17 : *EEL Tidal Turbine [36]*

The EEL tidal turbine in the Channel Sea: the English Channel is an ideal place to install this type of system. There are tides and many currents. This source of energy will therefore be launched by a French start-up. The "Opal' EEL" project has received a 950 000€ grant from the European ERDF funds, which should cover the assembly and testing on a test site of a prototype wave membrane tidal turbine with a power of 30 KW. The implementation is planned on the Channel coast in Boulogne sur Mer allowing the project to be close to the IFREMER test basin, where all the tests are carried out *[37]*.

Some figures about the EEL tidal turbine: there is a possibility of high power (5 MW). The tidal turbine starts producing energy even when the current is low (0.7 m/s). Moreover, its operation is very predictable because the currents are continuous. The potential of this prototype has already been evaluated. It is estimated that 450 TWh/year could be produced worldwide, 10 TWh/year for France and 16 TWh/year for the UK.

To resume this part, there is a table that summarize the different projects with their features (appendix 7 and 8). Based on this table, we can see that most of the projects that are planned in Channel Sea are wind farms and this can be explained by their important yield and because this type of technology is the most widespread all around the world. Thus, for the next part, we will concentrate on the wind farms.

3.4. Wind potential in the English Channel

3.4.1. Location and characteristics of the wind farm

We chose to focus on the installation of a wind farm in the Channel Sea. In order to know the optimal location to take advantage of wind farms, we have to take into account several characteristics. We need to find the windiest zone on average in a year, but we also have to take into account the wind direction at different spot. Actually, each person of the group worked on one particular area on the Channel Sea to study the wind's data to determine which location would fit the best to implement our wind farm. These are the coordinates for which we studied the wind data (see appendix 9):

- Shani Arrouch: 49.005 (N), -3.414 (E) → Offshore area
- Emilien Foissey: 50.875 (N), 1.57 (E) → Nearshore area
- Lucie Gellé: 49.339 (N), 0 (E) → Nearshore area
- Juliette Lengelé: 49.935 (N), 0.22 (E) → Offshore area
- Maureen Murer: 48.7 (N), -4.14499 (E) → Nearshore area
- Maëva Vautrin: 49.732 (N), -1.95 (E) → Nearshore area

Thus, we studied the wind data of 2 offshore zones, and 4 nearshore zones. To do this, we downloaded the wind data of each area from the website ECMWF *[38]*. Then we used Matlab (a maths software) to organize these data for each month (from 2014 to 2019) in Excel files by separating the vertical wind directions (v) from the horizontal ones (u). Then, we gathered these Excel files to determine the velocity using the formula $V = \sqrt{v^2 + u^2}$ of the wind for each area. These results allowed us to draw some graphs according to the year, the season, the month, the hour (12:00AM, 6:00AM, 12:00PM and 6:00PM). Thanks to all the graphs we made regarding the wind velocity in different areas of the Channel Sea, we are now able to compare the data that we collected. Indeed, we used these graphs to compare the wind velocity for each zone and for each parameter. Here are the different types of graphs we studied: 6 hours period graphs, monthly graphs, seasonally graphs, yearly graphs, and wind roses graphs.

3.4.2. Yearly graphs

Concerning the yearly graphs (see appendix 10), we can clearly see that 2015 was for most of us the windiest year between 2014 and 2019, with velocity data reaching from 5.8 m/s (Lucie's graph) to 7.9 m/s (Maëva's graph). Nevertheless, the velocity tends to decrease the following years and reaches its lowest data in 2019, with a minimum of 5 m/s (Lucie's graph) and a maximum of 6.3 m/s (Maureen's graph). It can be assumed that the velocity has decreased in the following years (2020, 2021).

If we give a general look to the wind velocity over the 6 years studied (2014-2019), we can notice that the graph that has the yearly highest velocity data is the one of Maëva. Therefore, it means that we can find the strongest winds around Cherbourg en Cotentin, at the following coordinates of 49.732 (N), -1.95 (E) (Nearshore area).

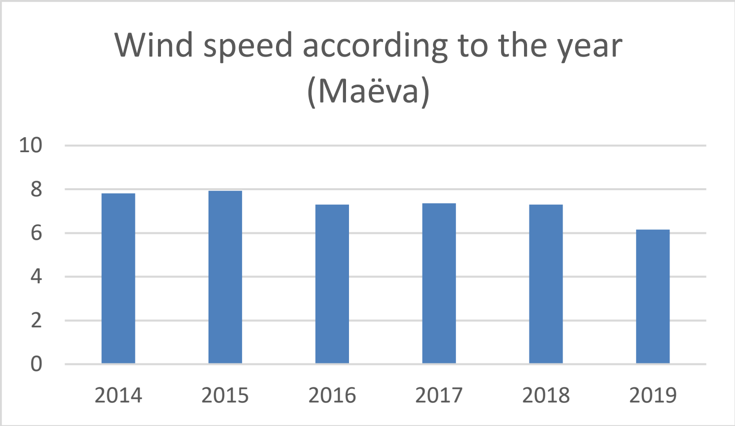

figure 18 : *Yearly graph based on the average velocity of the wind for each year (for Maëva's area)*

3.4.3. Seasonally graphs

If we take a closer look at the seasonal graphs (see appendix 11), the lowest velocity data is reached in summer and its value is 4.6 m/s according to Lucie's graph. On the contrary, the highest velocity data is reached in winter and its value is 8.9 m/s (Maëva's graph). Moreover, we can see from our graphs that the windiest season in the Channel Sea remains the winter, data varies between 6.6 m/s and 8.9 m/s. Summer is the season with the lowest velocity. It varies between 4.6 m/s and 5.8 m/s (Shani's graph). In general, the data in autumn are also quite important, varying between 5.7 m/s (Emilien's graph) and 8.2 m/s (Maëva's graph). Spring such as summer has the lowest data, from 4.6 m/s (Lucie's graph) to 6.0 m/s (Maëva's graph).

Again, we can see that if we take into account all the seasons, it is also the graph of Maëva which has the seasonally highest velocity data.

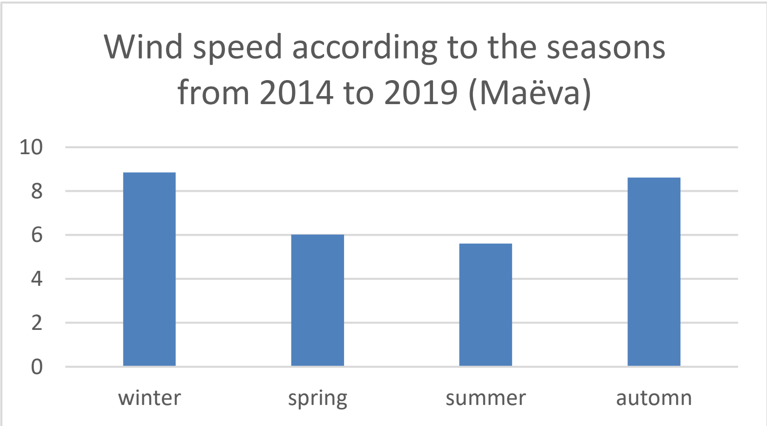

figure 19 : *Seasonally graph based on the average velocity of the wind for each season (for Maëva's area)*

3.4.4. Wind roses graphs

In this section, we will study in detail the wind directions in the areas assigned to each of us. To do this, we used so-called "wind roses". They consist in calculating for each graph of each month during a year (2018) the angle of the wind in order to know its direction. The wind roses will therefore make it possible to highlight the most frequent directions. This type of graph is very interesting because it allows to see a lot of information on one graph for each location area. Indeed, it shows the wind velocity (in m/s) according to the direction and to the hour. To draw this graph, we used the website *[39]*. If we look at the 6 wind roses (see appendix 12), it is clear that two directions dominate. Indeed, the north-east and south-west directions are the most frequent in each zone and reach 1500 hours in all graphs. On the contrary, the south-east and north-west directions are the least frequent, which seems logical since they are opposite to the prevailing wind directions.

Here is an example of a wind rose, this one is from Maëva's data since, as we saw earlier, this is the area where the wind is the strongest.

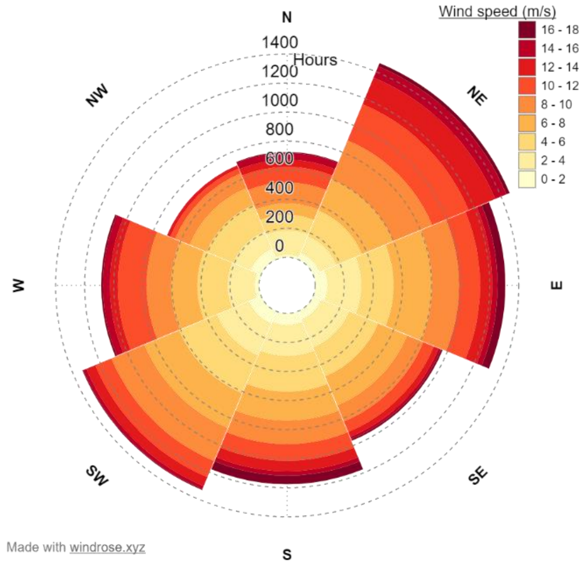

figure 20 : *Wind rose graph based on the number of hours of each direction of the wind (for Maëva's area)*

3.4.5. Analysis by location

3.4.5.1. Shani Arrouch – 49.005 (N), -3.414 (E)

For this offshore location, we can see that the year with the strongest wind was 2014 with an average velocity of 7.3 m/s. However, we do not have data for all months of that year. In second place comes 2015 with an average velocity of 6.5 m/s. As far as seasons are concerned, the one where the wind clearly dominates is autumn (7.6 m/s) followed by winter (6.5 m/s). Now if we compare the different months of each year, we see that December is dominant (8.7 m/s) and November follows closely (8.0 m/s). Moreover, if we now take into consideration the data per hour, we can clearly notice that in autumn, 12:00pm is the time when the wind is the strongest (8,0m/s), whereas in every other season, it is at 18:00pm that we have the main wind velocity with data above 6m/s. Finally, if we take a look at the wind rose, we can notice that the wind is the strongest in the direction South-west and North-east.

3.4.5.2. Emilien Foissey – 50.875 (N), 1.57 (E)

Focusing on my graphs regarding the position of the probable wind turbine site, the year with the highest wind speed is 2015 with an average speed of almost 6m/s. Overall, the period of the year with the highest wind speed is winter. If we look more precisely at the monthly graph, it is from November to March. During this period the wind speed will not fall below 6.4 m/s (November) and will not exceed 7.1 m/s (December). According to the data of these 5 years, we can see that it is at noon that the wind is the strongest on the whole of these years. It is at this time that the wind speed does not go below 6m/s while for the other 3 hours, the wind speed will not exceed 6m/s. If we now focus on the wind rose for 2018, we can see that the wind is predominantly in the North-east direction. In this direction, the wind speed will even reach 18m/s.

3.4.5.3. Lucie Gelle – 49.339 (N), 0 (E)

By taking a global look at the graphs concerning my area, we can clearly notice that 2015 was the year with the highest wind intensity. Moreover, there is a huge difference between the velocities over the seasons. In winter and autumn, it is relatively intense with data reaching 6m/s, whereas in summer and spring, it stays under 4.6m/s. Now looking between the different months, the wind intensity is the highest in November, December, and January (around 6.5m/s) and the lowest in July and August (below 4.5m/s). By analysing the wind velocity data per hour, we mainly notice that the highest ones are at 12:00:00 regardless of the month and the season. Finally, the wind rose of my area makes it clear that the wind speed is the highest in the North-east direction, reaching 12-14m/s, but stays quite intense in the South-west where it reaches 10-12m/s. The lowest one is in the North-west with wind speed below 4-6m/s.

3.4.5.4. Juliette Lengelé – 49.935 (N), 0.22 (E)

If we look globally at the graphs in my assigned area, we can see that the wind intensity is higher in winter (the speed reaches 7.9 m/s on average) followed by autumn (the speed is about 7.7 m/s). The month with the highest average wind speed is December (8.4 m/s). In terms of year, 2015 was the year with the highest wind speed (7.1 m/s). From the graphs plotted against the hours, we can see that the wind is mostly present in the middle of the day around noon every year. The dominant wind direction is SW with 1404 hours followed by NE with 1392 hours.

3.4.5.5. Maureen Murer – 48.7 (N), -4.14499 (E)

First of all, if we analyse the different graphs that are related to the area I was assigned to, we can see that globally, from 2014 to 2019, the strongest wind year was 2015 with a wind speed average of 7.3m/s and with an average of approximately 6.8m/s for all this period. Regarding the monthly graphs, we can notice that the wind is stronger from November to March with a speed higher than 8m/s. Therefore, this is also proved by my seasonally graph where we can notice a wind speed peak for the autumn and the winter. Besides, if we look more precisely at wind speed variations, thanks to the hourly graph, we can remark that for one month, the wind is quite constant all day with a wind speed average of 8-9m/s from November to March all day long and of 5-6m/s from April to October all day during those months. Finally, regarding the wind rose for the year 2018, we can notice that the main directions of the wind for my area are South-west and North-west with a wind speed maximum higher than 18m/s.

3.4.5.6. Maëva Vautrin – 49.732 (N), -1.95 (E)

As we can see from the monthly and seasonally graphs, the wind has much more intensity in autumn and winter, e.g., from October to March, with a speed around 9m/s against a speed around 6m/s the remaining six months. Regarding the yearly graph, the speed is almost always above 7m/s with the maximum of 7.8m/s in 2015. The only exception is 2019 with a speed only slightly above 6m/s that is due to the fact that we do not have data for the last four months of the year. If we look at the wind rose graph for the year 2018, we can see that the wind has the following main directions: north-east and east, south-west, and west. However, the direction north-east is the most frequent with 1400 hours.

4. CONCLUSION AND PERSPECTIVE

At the beginning of our project, we studied the different renewable energy solutions that could potentially be installed on the Channel coast. As a result, we looked at which systems would be most suitable for nearshore and offshore locations. After an analysis of the costs and yield of each system, the wind turbines seemed to be the most relevant technology and the most efficient one.

Thus, the aim of this science project was to use velocity data analysis to find the most suitable location in the Channel Sea for a wind farm. The numerous data analysis, including comparative graphs and wind roses that we were able to produce throughout this project, allowed us to conclude that a wind farm would be the technology the most profitable in terms of energy production at a location of 49.732°N, -1.95°E, i.e., near Cherbourg en Cotentin.

Therefore, this project enabled us to analyse what happened in the Channel Sea, we hoped that our project could help people to either understand the potential there.

Then, researchers could use our project to have a clearer view on the situation. Our wind roses can finally help to have an efficient conclusion of wind potential so scientists will be able to use them without doing them anymore.

In addition, the extensive bibliographical research that we carried out prior to this analysis enabled us to learn a great deal about the various renewable energy systems, their functioning, and their current state of development. We also had the opportunity to learn about the various projects underway for the installation of different types of technologies and the issues involved.

Working alongside Mr ALAMIAN, a researcher, has also been a very rewarding experience and we felt very lucky. Thanks to him, we were not only able to deepen our research, but also to see a concrete example of a job that we could do in a few years' time, and in which some of us see ourselves.

Despite the fact that wind turbines are both a non-polluting renewable energy device and visually unobtrusive because they are located in the open sea at a distance from the coast, they are still a man-made system located in the middle of nature, and as such can have consequences on the environment. To be clear, wind turbines have a first impact on local fauna as far as birds are concerned, as they can be disturbed by the blades of the turbines. Similarly, marine fauna and flora can be impacted by the installation of wind turbines on the seabed. In addition, it is essential to choose materials that are resistant to the sea water and wind will accelerate the wear of the wind turbine.

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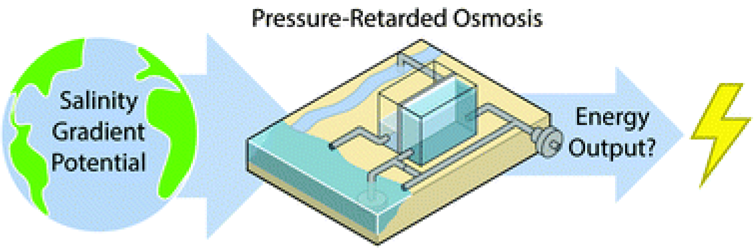
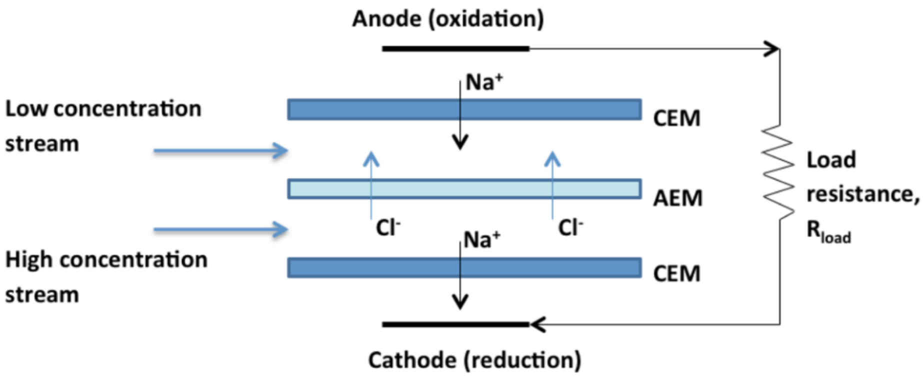
6. APPENDICES (TECHNICAL DOCUMENTATION, GRAPHS, MAPS, TABLES…)

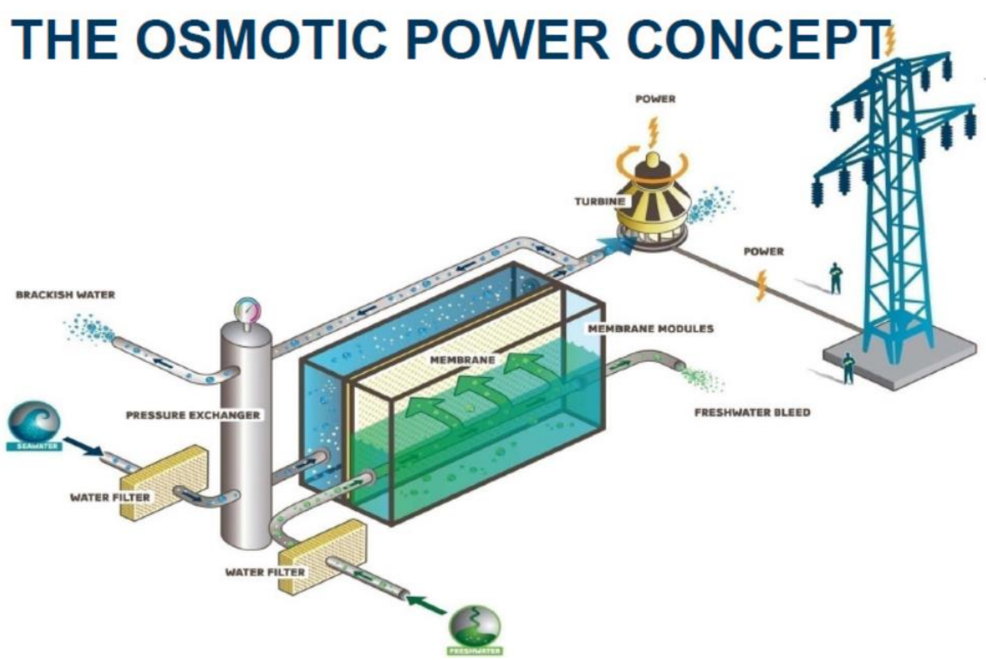
Appendix 1: Pressure-retarded osmosis [40]



Appendix 2: Membrane-based salinity gradient power [41]



Appendix 3: Vapour pressure difference technology [42]



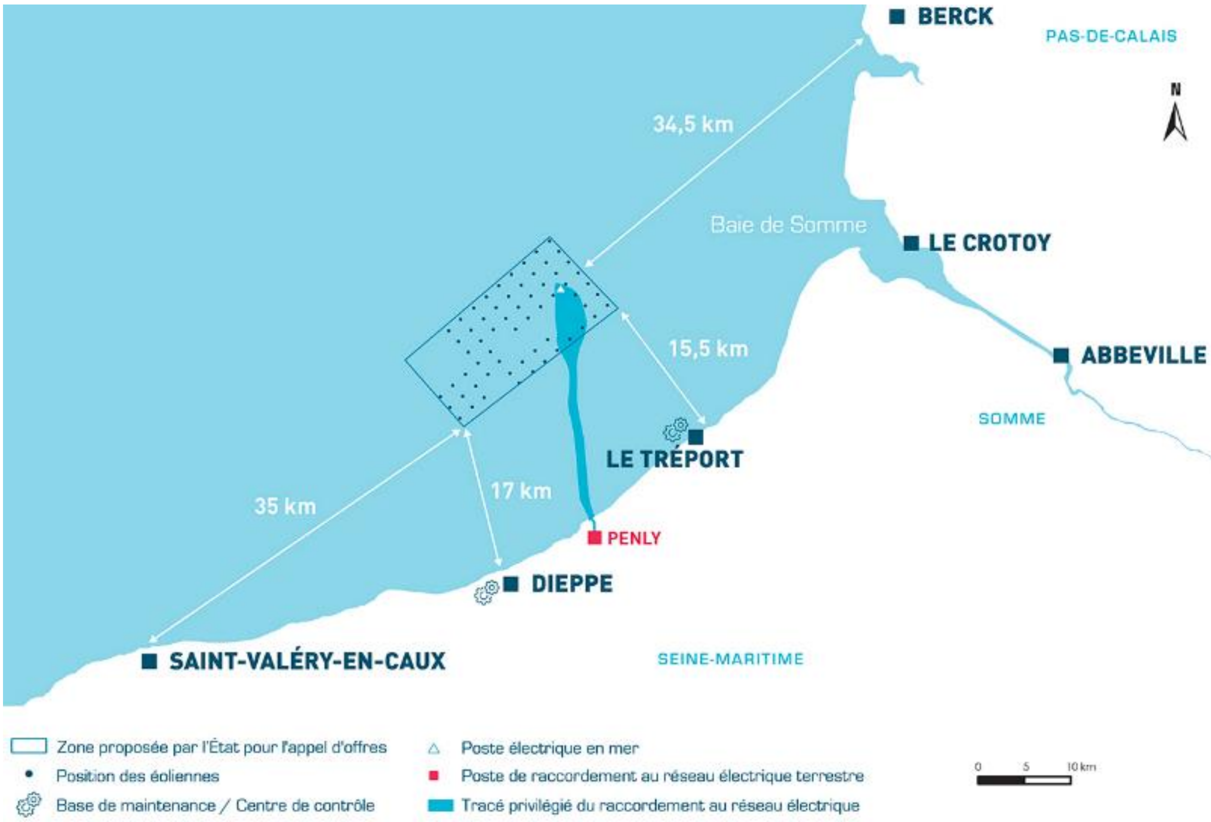
Appendix 4: Advantages and drawbacks for each type of energy

Types of energy	Advantages	Drawbacks
Wind turbines	- far from civilization - immediate production of energy	- landscape damage - special boat to install
Hydrokinetic turbines	- current predictable - discreet, invisible	- expensive - impact of the fauna
Wave power plant	- can be placed anywhere - productive	- huge and costly maintenance - season dependency
Tidal power	- efficiency - considerable lifespan	- impacts ecosystems - initial high cost
Marine biomass	- tremendous energy yield - season independent	- high cost of extraction - impact on ecosystems
Thermal energy of the sea	- no seasonality issues - can be used for a long time	- difference of 20 degrees necessary - needs a huge volume of water
Osmotic power	- works continuously - low environmental impact	- expensive cost - must be resistant to high flows
Solar energy	- highly resistant to sea storms - low costs	- daylight dependent - exposed to many environmental pressures (salt, currents…)
Combined energy	- good efficiency - system functioning on a relative continuous basis	- expensive to implement - needs a lot of space

(made by ourselves)

Appendix 5: Installation of a wind turbine [43]

Appendix 6: Map of the wind farm project near Dieppe and Le Tréport [44]



Appendix 7: Locations of the different project technologies in the English Channel

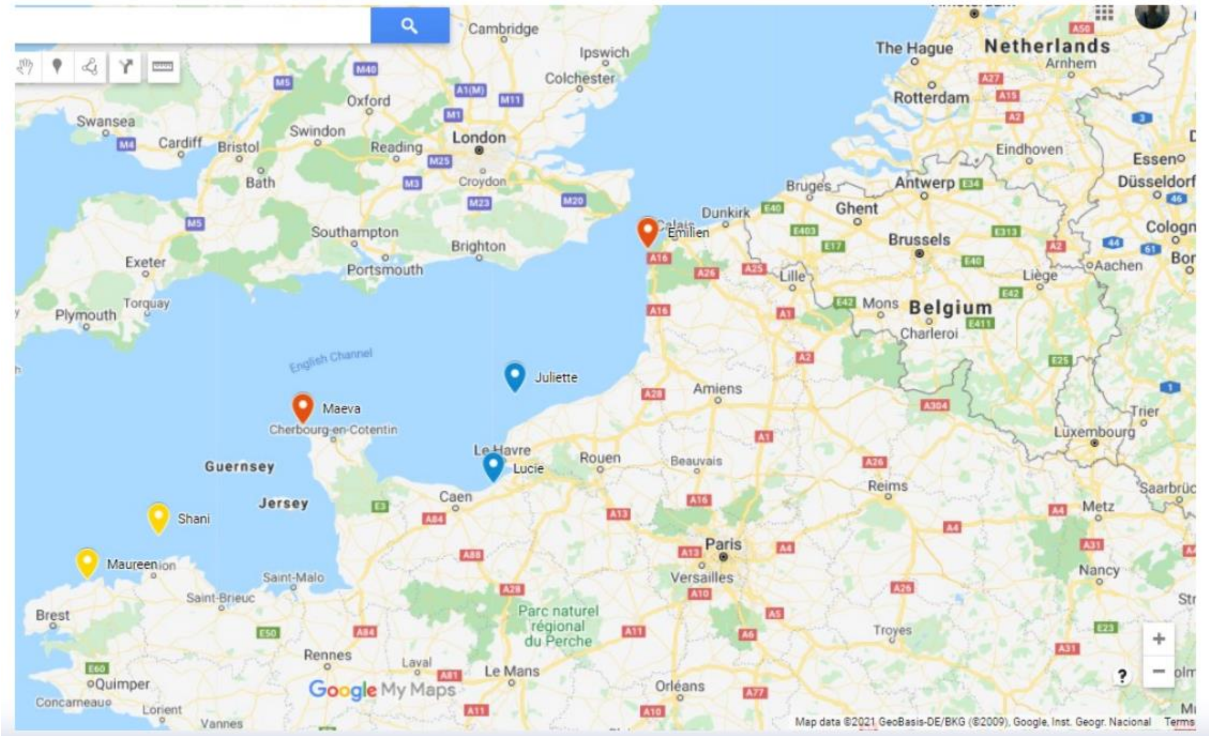
(made by ourselves)

Appendix 8: Summary table of the different projects in English Channel

	Wind turbine	Tidal barrage	Tidal turbine	Hydrokinetic turbine	Power (MW)	Electric production (GW/h per year)	Number of households supplied	Launching
Saint Brieuc	x				496	1.8	850 000	2023
Saint Malo (Rance Tidal Power)		x			240	500	225 000	already launched
La Hague (Raz Blanchard)				x	14	-	10 000 to 13 000	2019
Cotentin	x				1000	-	800 000	between 2022 and 2028
Courseulles-Sur-Mer	x				450	-	630 000	between 2022 and 2024
Fécamp	x				500	-	770 000	2023
Dieppe - Le Tréport	x				496	2	850 000	2021
Boulogne-Sur-Mer (EEL Tidal Power)			x (pilot)		0,005	-	-	prototype currently in test phase

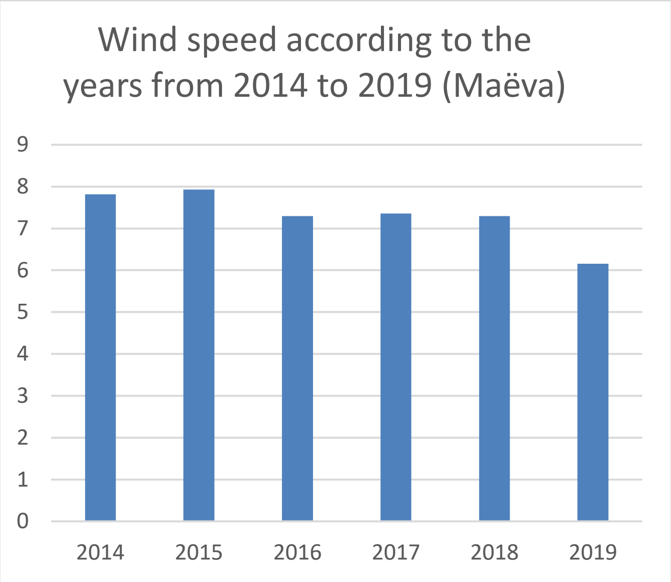
(made by ourselves)

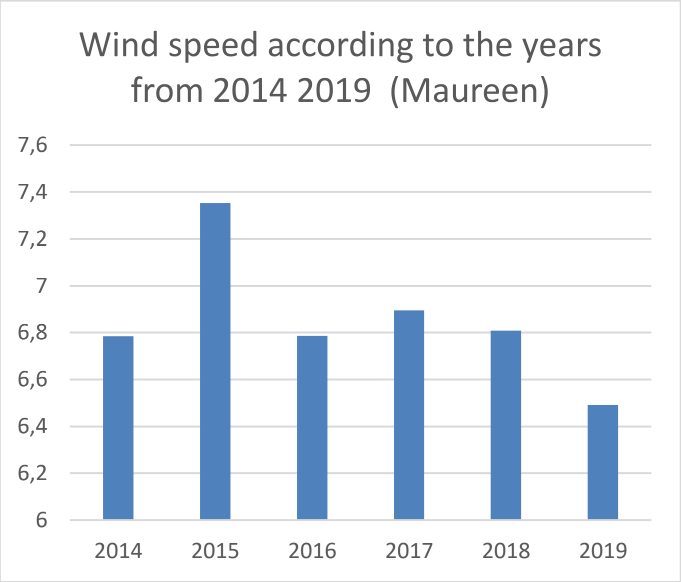
Appendix 9: Location of each site we studied

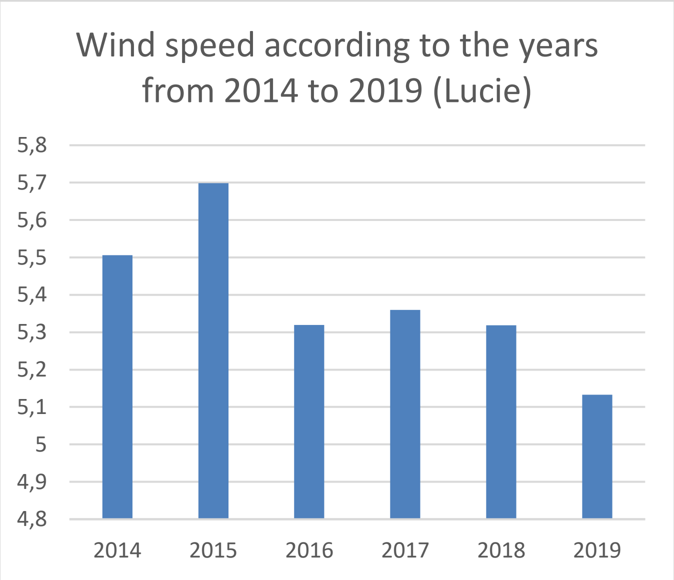


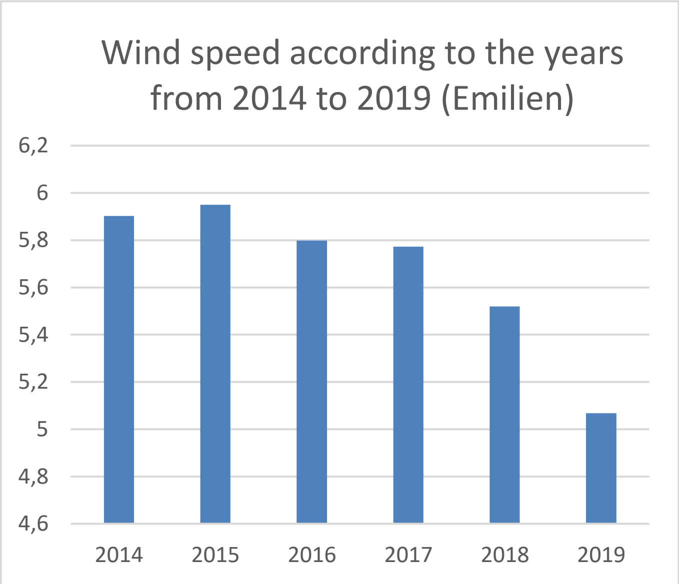
(made by Mr ALAMIAN)

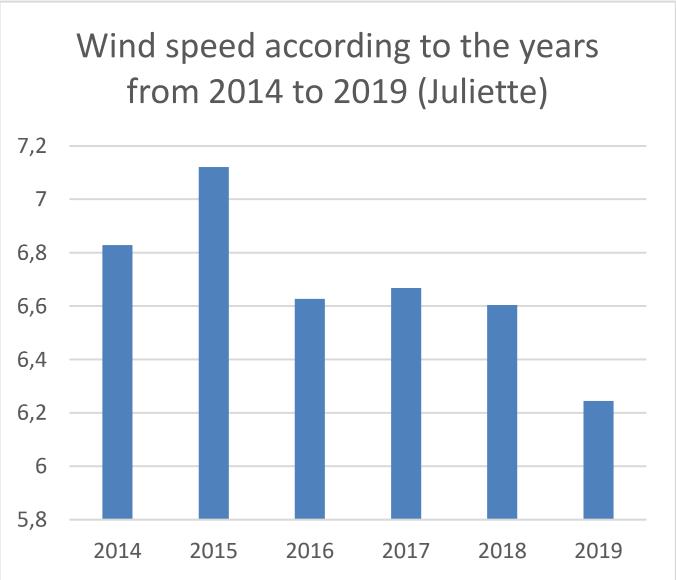
Appendix 10: Yearly graphs for each area

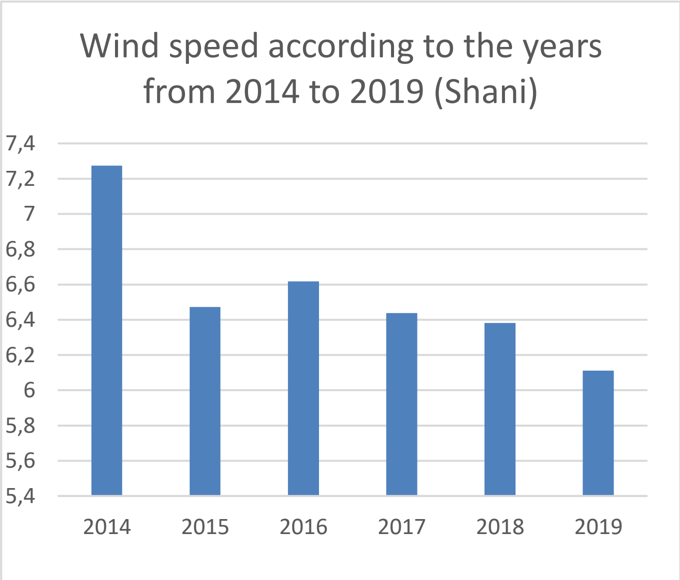




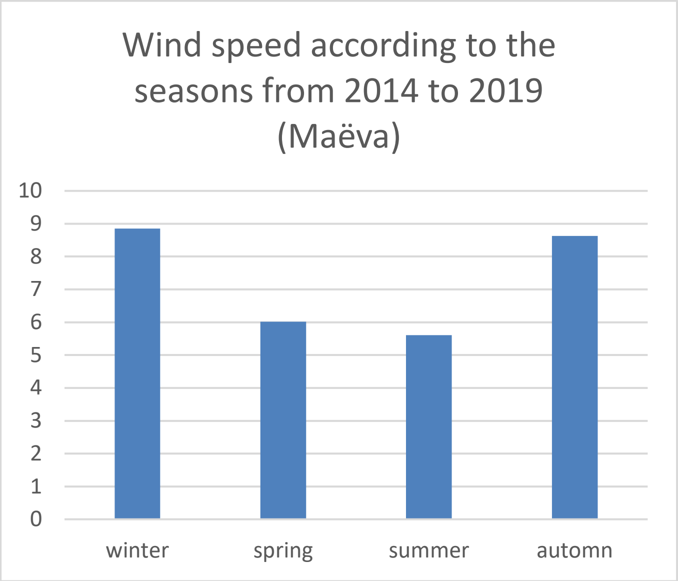


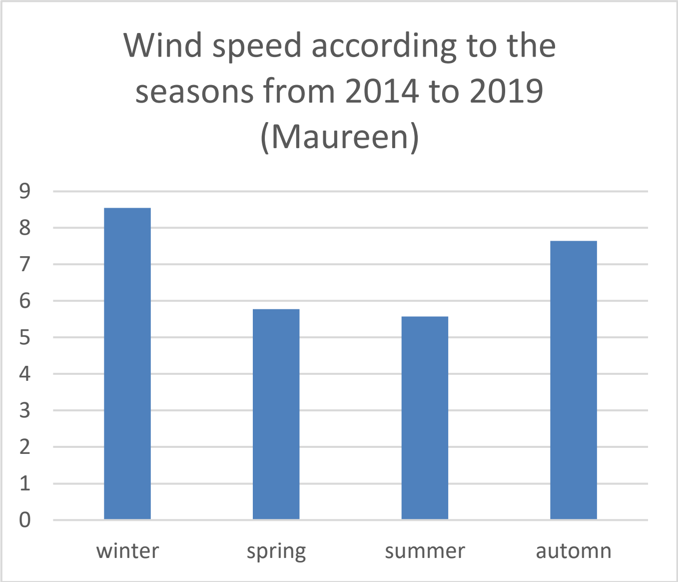


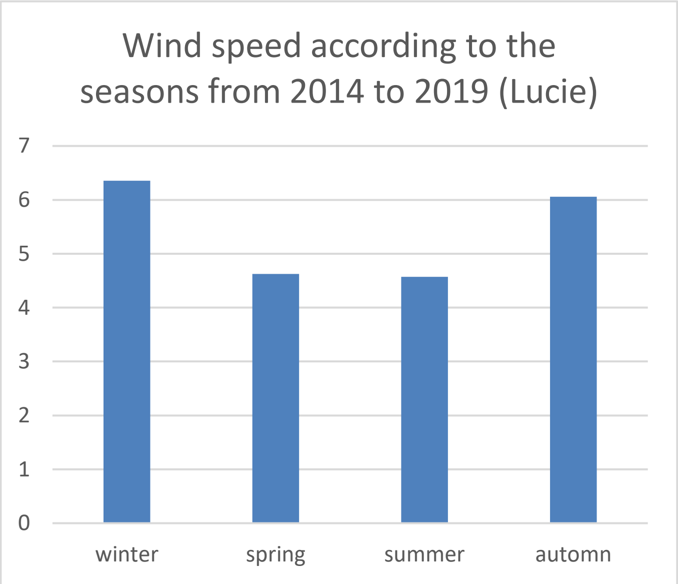


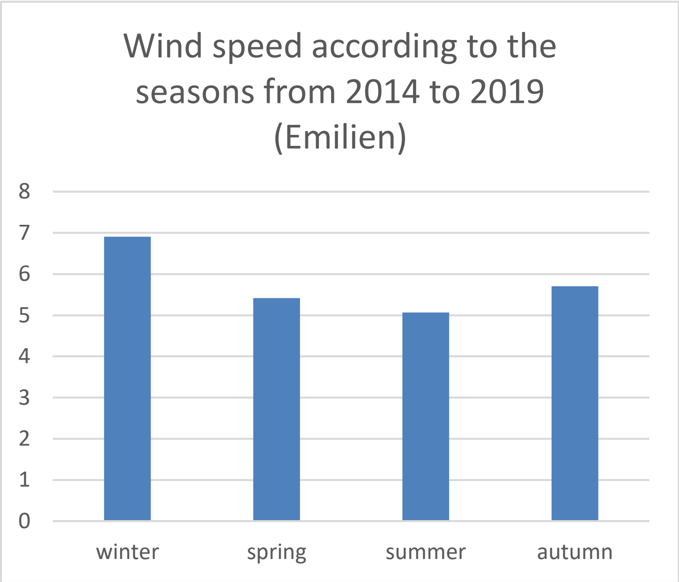


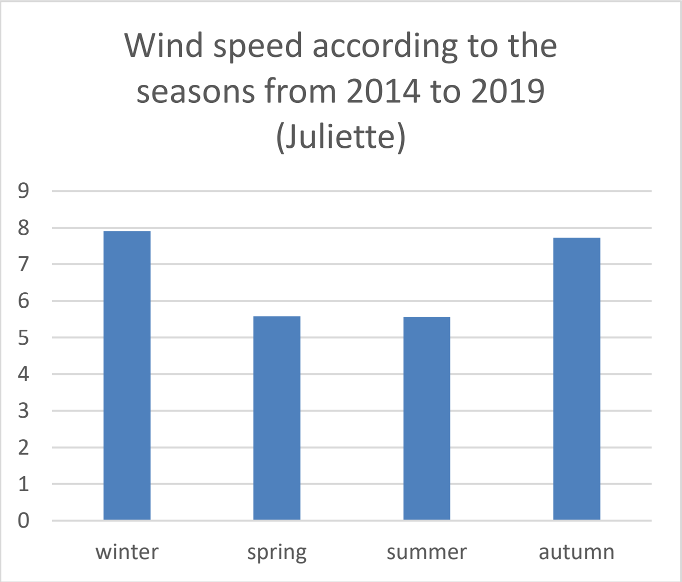
Appendix 11: Seasonally graphs for each area

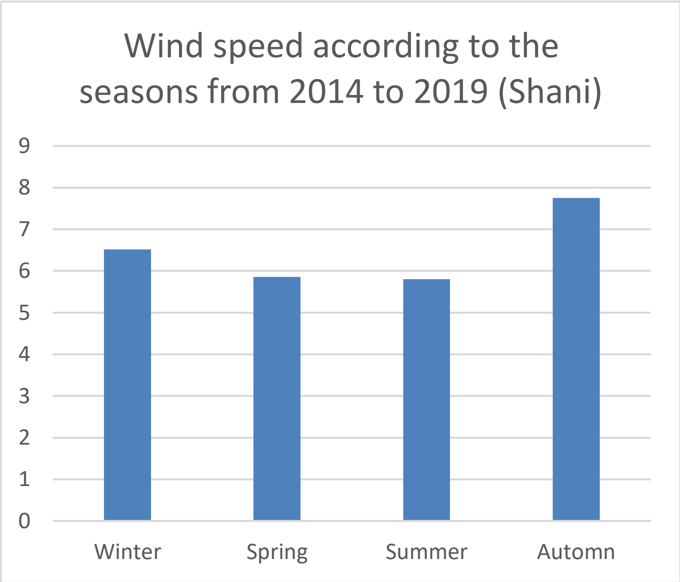




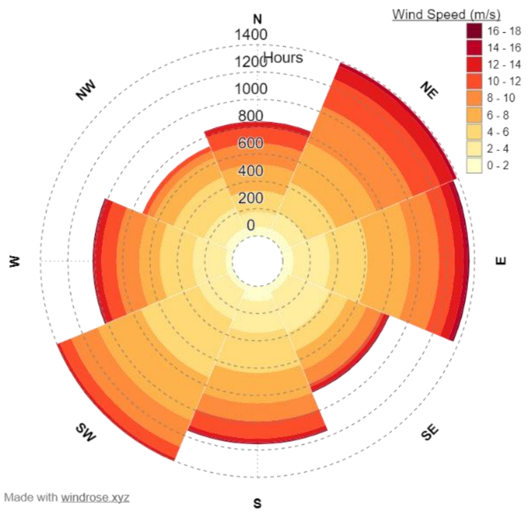




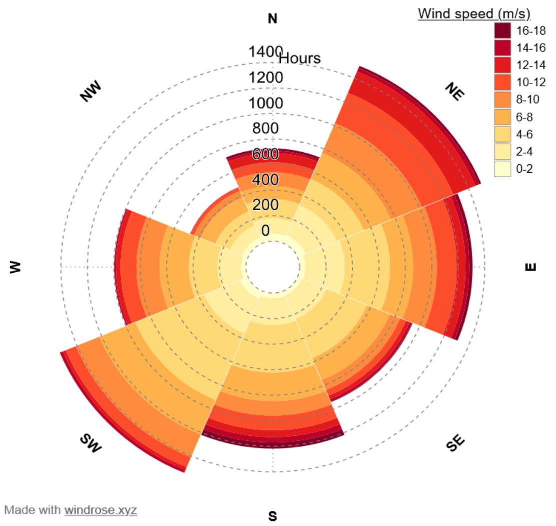




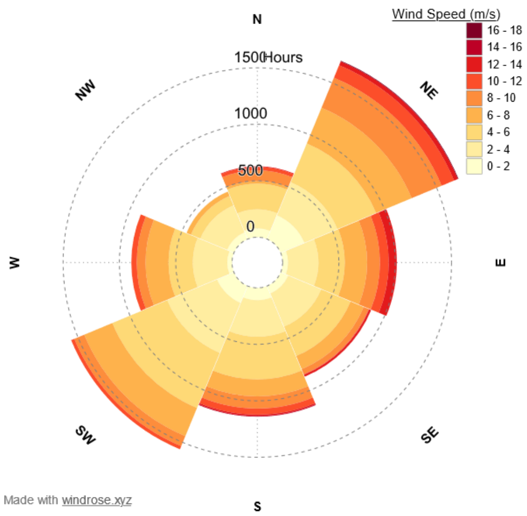
Appendix 12: Wind Roses for each area



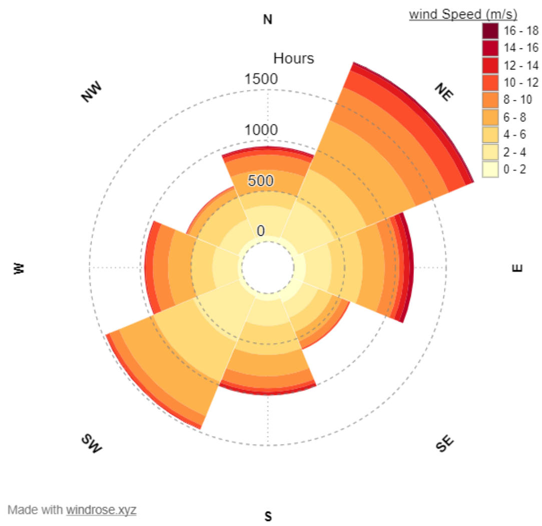
Maëva's wind rose



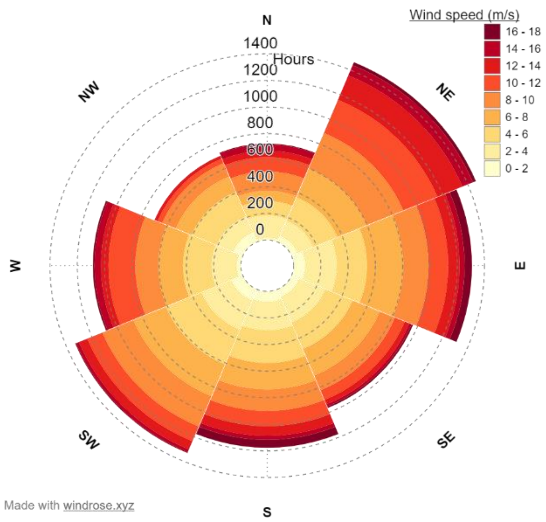
Maureen's wind rose



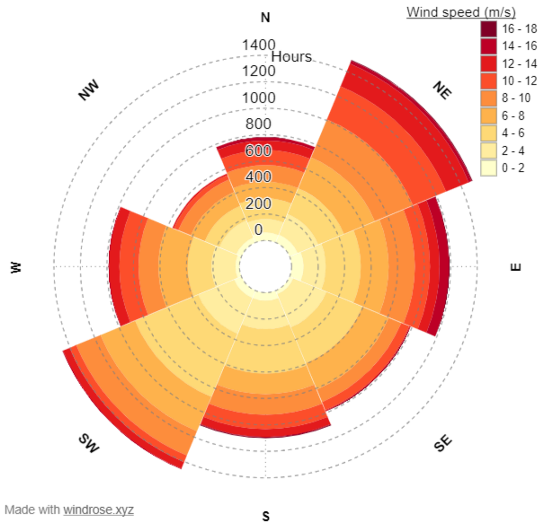
Lucie's wind rose



Emilien's wind rose



Juliette's wind rose



Shani's wind rose