Sustainable Harbor Towards Energetic Sustainability

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1. Introduction

Ports are key infrastructures for economic growth and development, since they act as trading gateways, which is important for a nation [1]. Even though they favor the economic development, they create a negative impact on the environment, due to the nature of the activities [1]. This impact can be found in water, soil, air and even the life quality of local communities [1].

Among the different types of impacts, air pollution is the one that possesses the greatest negative impact in this kind of infrastructures [1]. In seaports, NOx, SOx, CO_2 emissions take place, where the emission of carbon dioxide is the most relevant because of its direct relation with climate change [1,2].

According to the Paris Agreement 2015, which is related to the mitigation of the greenhouse gases (GHG) emissions, stated a common goal that is to limit the temperature increase to 1.5 °C above pre-industrial levels [3]. In an attempt to reduce the GHG emissions, the electrification of the seaports could be carried out [4]. Furthermore, the electricity market prices almost doubled in Spain, between December 2020 and June 2021, due to the rise in CO_2 prices as well as the gas price [5]. Aiming to reduce the dependence on fossil fuels, it is time to take a step towards the energetic sustainability by boosting the proportion of renewable energy [6].

1.1. Self-sufficiency

Self-sufficiency can be defined as the ability to maintain oneself or itself, if it is an organization, a family, a community, or a country; without outside aid [7]. In other words, these entities are capable of providing or fulfilling their own needs [7].

In fact, self-sufficiency helps to establish a better resilient economy practice that leads to communities development by ensuring sustainability and continuity, empowering communities to develop more independent models and business models [7].

For instance, this term leads to the energy self-sufficiency, which can be defined as the capability of self-satisfying its energy needs [8]. Taking advantage of the renewable energy sources, seaports could be energy partial or self-sufficient [8]. But this ambition is limited by the possible disruptions that may be caused by the marine environment [8].

1.2. Renewable energy sources

Because of this major impact on society, some harbors are moving forward in switching to a renewable energy source. There are some renewable energies that could be applied to harbors to reduce energy consumption, replacing this to new renewable sources such as solar, wind energy, tidal and wave power. These four renewable sources could be implemented in a seaport due to its location compatibility [9].

The conception of solar energy is to take profit of solar radiation and heat from the sun to generate electricity. This renewable energy source can be implemented in many places due its small dimensions. Its drawback is that for a cloudy day or at night, solar panels cannot generate energy. Therefore, its operation is in discontinuous [10].

To solve this problem, solar energy is combined with wind energy since it could be used the 24 hours each day of the year [10]. This energy can work at night or when weather conditions are not optimal for solar power. Moreover, in cloudy or rainy weather conditions the wind velocity tends to be higher. Wind power takes advantage of wind velocity and converts mechanical energy into electricity by a generator. As it mentioned before renewable sources do not work continuously, as an example if there is no wind, aerogenerators do not produce energy from the wind.

In addition, there are two types of hydropower that could be used in seaports [9]: tidal and wave power. On one hand, tidal power refers to the use of the difference in height generated by tides to drive turbines to produce energy. On the other hand, wave power collects the movement of waves created by wind and boats and converts them into energy. The disadvantage of wave power is that the speed at which boats enter the port is limited by legislation, therefore, the waves created by boats do not generate the same energy as if the boats were in the middle of the sea [11].

This project is based on the improvement of harbors energetic sustainability, focused on the harbor of Barcelona as an example of implementation.

1.2.1. Case study: the Port of Barcelona

To achieve this target, an evaluation is carried out to analyze strategic energetic consuming areas to implement sustainable and self-sufficient infrastructures. At a global scope, harbors have been identified as one of the consuming areas since there is a high energetic demand and level of pollution emissions.

In the first place, a study of the harbor of Barcelona in terms of energetic consumption and pollutant gases emissions has been carried out. Nowadays, the harbor in Barcelona is one of the areas where the energetic consumption is higher compared to other parts of the city [12]. According to the Red Eléctrica de España, the energetic production of the port's thermal central in 2019 was of 2679 GWh [13].

Secondly, the air quality is conditioned by different pollutant gases released from boats sailing into the harbor of Barcelona. According to the Ajuntament de Barcelona and the Generalitat de Catalunya, these emissions represent 7.6% of air contamination of Barcelona [14]. By harbor electrification, the idea is that boats consume energy from the electrical network instead of consuming fuel during their stay at the harbor to prevent part of these emissions.

2. State of the art

Nowadays, extensive electrification of maritime transportation has been viewed as a feasible route to mitigate the environmental issues [15]. In fact, many seaports have started to install fully electrified equipment to use electricity as a source of energy, instead of carbon-intensive energy sources, to fight against climate change [16].

Renewable sources play an important role towards the path of achieving a greener industry [16]. In fact, ports have a great potential of utilizing solar, wind, waves, and tidal power. For instance, there are some ports which have already applied renewable energies such as the Port of Hamburg that uses wind power, the Port of Singapore which uses solar or the use of waves and tidal power in Valencia [16].

However, renewable energy has a major concern: natural conditions lead to intermittent generation such as sunlight not being available at nights or the variability of the wind speed [16]. Energy consumption is among the top ten environmental priorities of the European port sector, and it has been increasing in recent years [17]. Because of this reason, the main goal is to minimize the electricity consumption [16] and improve energy efficiency [17].

3. Objectives

This project aims to go further in terms of sustainability since it aims for the partial self-sufficiency. Even though, different techniques to generate renewable energy at different spots have been implemented separately, the combination of two or more energy sources in the same port has not been assayed yet. Due its great potential, the present work will combine these techniques to make a more suitable port, since most of these infrastructures tend to have similar characteristics in terms of space and energy consumption.

3.1. General objectives

The main objectives of the project are the following ones:

- Study renewable energies and its feasibility to implements these technologies in the Port de Barcelona.
- Achieve partial energetic independence from fossil fuels.
- Reduce the emission of pollutant gases.

3.2. Specific objectives

Also, specific objectives of the project are described:

- A specific study of the port of Barcelona focusing on the energy consumption in the last years.
- Determinate the feasibility of each renewable energy taking into account the localization, optimal conditions, equipment needed, and energy saved.
- Estimate the cost of implementation considering staff and workers and equipment purchased. Also, the return period of the implementation needs to be considered.
- Finally, calculate the amount of contaminants gases saved when implementation is done.

4. Current projects

The European Commission has set objectives towards green energy that should be achieved before 2030. To this purpose, several projects are being developed:

- World Ports Climate Action Program which aims to reduce the fossil fuels utilization in ports all over the world [18]. Barcelona leads the work group that is focused into fuel consumption of ships that are docked at the port, which make use of fossil fuels in their auxiliar engines. To counter that consumption, it is planned to electrify the docks to connect the ships to electrical network of Barcelona. Besides that, there is no actual plan to reduce the use of fossil fuel consumption in ports, and that is where this project will be oriented.
- PIF building Energy Improvement [19]: This project aims to reduce the energy consumption of the PIF building (border inspection post). For this matter, a photovoltaic installation and a control and monitoring system will be implemented, in addition to the conversion of the lighting system to LED technology.

5. Study of the Port of Barcelona

As mentioned above, this project will focus on using the port of Barcelona as a model for the implementation of renewable sources due to the proximity and access of information by the authors (University of Barcelona). The port of Barcelona is one of the biggest ports in Spain and it is divided into 10 different parts [20,21]. In the following points the different renewable sources and its feasibility in the port of Barcelona are explained.

5.1. Wind power

Wind energy has been steadily increasing in the last decade [22]. In the past, aerogenerators were implemented in remote areas but nowadays, wind energy is moving towards urban and suburban areas, such as the subject of this work [22].

Wind power takes advantage of the wind velocity and converts mechanical energy into electricity via a generator.

5.1.1. Location and wind velocity data

To define the energy that could be achieved, it is important to study the wind velocity in the Port de Barcelona. The ideal wind velocity is 13 m/s but above 3 or 4 m/s the aerogenerator could work perfectly [23].

To determinate wind velocity, meteorological data from meteorological station of Aeroport de Barcelona could be taken. The document says that the most probable wind velocity is 6.92 m/s so installing a wind turbine is worthwhile for this part [24].

Next, it must be decided in which area in the Port of Barcelona could be implemented. The installation of wind turbines needs to be near the sea, without buildings that could slow down the wind and sometimes create turbulence around them [25] Therefore, the idea is to implement these aerogenerators in the most external part of the port, at the following locations mentioned below:

- L’escullera: this place is a large path next to the sea built to protect the port from waves. This road has a length of 1 km approximately, with an area of 2 hectares about.
- Moll Adosat: it is an area of about 17 hectares [26].
- Dic de l’Est: is a very long dam of approximately 4 km.

These three zones could be seen marked in green in the Figure 1 below.

Figure 1: Wind turbine deployment areas

In conclusion, about 7 km are available for the installation of wind turbines. However, wind turbines need to be separated to avoid the interference with each other. The space between them depends on the diameter of the rotor, which is seven times the rotor diameter [27].

5.1.2. Selection of wind turbine and electrical supplement achieved

The next step is to determine which wind turbine could be implemented. In this work, horizontal-axis are selected for its higher performance, low cost and ease to maintain [25]. Also, the number of blades must be selected. Usually, two or three blades are the most ubiquitous. The power obtained of each turbine is 34 883 kW·h considering the wind velocity of the port de Barcelona and 50% of windy days [28].

The selected rotor diameter of the turbines has 92.7 m [29]. Considering this rotor diameter, the distance between each turbine is about 648.6 m. So, in one hand, the part of l'Escullera, which has 1.5 km long it could be installed 2 wind turbines. On the other hand, the part of Moll Adossat and Dic de l'Est 5.5 km long are available, therefore 8 wind turbines could be implemented. Consequently, only 10 wind turbines could be installed in the port of Barcelona.

The electrical supplement achieved in one year with the 10 wind turbines is about 127.3 GW·h/year with all the considerations mentioned above. All the calculations are described in chapter 10.1.

The problem with this implementation is that near the port of Barcelona there is the Aeroport de Barcelona. The idea is to dialogue with the airport manager AENA to consider the feasibility of this implementation [30]. The other important issue is the bird migration routes, which would be studied by professionals on the matter.

5.1.3. Financial cost

Another important part to determine is the financial aspects of this implementation. The cost of one turbine of about 3MW is 2 M€ approximately [31]. The purchase of these wind turbines would cost up to 20 M € overall.

5.2. Solar power

Solar power is right now the most reliable and powerful source of green energy. Compared to most alternatives, it is more highly developed, gives the best results and is widely commercialized among society.

There is a huge quantity of successful applications and ongoing projects on this topic, which combined with the fact that the sun is not turning off anytime soon both confirm the previous statement [32,33].

5.2.1. Solar power in the Port of Barcelona

The sunlight hours in Barcelona are between 9 at winter and 15 at summer, are higher compared to the rest of the world which suits this source of energy perfectly [34,35].

To evaluate the viability numerically, it has been considered that all the official buildings in the port have at least 80% of its ceiling surface available to install solar panels.

For the energy generation a commercial model has been selected to have a realistic approach [36]. This model consists of an 11-panel pack of 2 square meters each which comes with all the required complements. The legalization and installation costs are included in the price of 6 833.40 €. According to the provider, each 11-panel pack can produce 15.02 kWh/day in winter and up to 35.04 kWh/day in summer after applying an efficiency of 20% [37]. The surface, estimated by the Visor SigPac [38], energy and install costs calculations are presented in Table 1 and Table 2 for each building.

Table 1: Available solar power in building surfaces.

Building	Building surface (m^2)	Available installing surface (m^2)	Available Power (kWh/day)	MWh per year	Solar Panels
Cruise Terminal A	6 100	4 880	5 552	2 027	2 440
Cruise Terminal B	6 100	4 880	5 552	2 027	2 440
Cruise Terminal C	5 100	4 080	4 642	1 694	2 040
Cruise Terminal D	7 300	5 840	6 644	2 425	2 920
Cruise Terminal E	7 100	5 680	6 462	2 359	2 840
Mare Magnum Shopping Centre	5 880	4 704	5 352	1 953	2 352
Agència Tributària	7 720	6 176	7 027	2 565	3 088
PIF Building	5 700	4 560	5 188	1 894	2 280
Terminal Grimaldi	1 900	1 520	1 729	631	760
Warehouse TCB	3 600	2 880	3 277	1 196	1 440
Warehouse Terminal Catalunya	7 920	6 336	7 209	2 631	3 168
Warehouse Port Nou	9 000	7 200	8 192	2 990	3 600
Warehouse BIT	4 670	3 736	4 251	1 551	1 868

Table 2: Available solar power in structures over parking lots.

Parking	Available Surface (m^2)	Installing surface (m^2)	Available Power (10^2 kWh/day)	10^2·MWh per year	Number of Solar Panels	Parking Spaces
1	28 900	23 120	263.04	96.01	11 560	690
2	99 600	79 680	906.54	330.89	39 840	2 379

Parking	Available Surface (m^2)	Installing surface (m^2)	Available Power (10^2 kWh/day)	10^2·MWh per year	Number of Solar Panels	Parking Spaces
3	10 500	8 400	95.57	34.88	4 200	251
4	6 068	4 854	55.23	20.16	2 427	145
5	4 353	3 483	39.62	14.46	1 741	104
6	3 394	2 716	30.90	11.28	1 358	81
7	4 323	3 459	39.35	14.36	1 729	103
8	1 027	821	9.34	3.41	411	25
9	2 494	1 995	22.70	8.28	997	60
10	1 872	1 497	17.04	6.22	749	45
11	6 577	5 262	59.87	21.85	2 631	157
12	2 396	1 916	21.80	7.96	958	57

In the parking, solar panels will be placed on top of solar canopies as it will be explained in section 5.6. The location of every parking is shown in Figure 2.

Figure 2: Location of parking lots.

5.3. <u>Wave energy</u>

This kind of energy seems to be one of the most promising alternative to conventional fuels [39]. The use of wave energy is expected to increase over the next decades as wave energy converter (WEC) technology matures [39].

Three major groups of wave energy converters can be distinguished depending on the working principle [40]. These groups are namely the oscillating water column (OWC), oscillating body systems (OBS) and overtopping converters [40]. Since the OBS technology is usually employed in off-shore systems, and more complex systems, this technology will not be considered in the present work [40].

5.3.1. Oscillating water column (OWC)

The majority of designs used in the conversion of wave energy are oscillating water column [41]. Inside the OWC a fixed or floating hollow structure can be found under the water surface, which pits the air over the inner free zone [41]. The wave action alternately compresses and separates the air that is forced to flow into a turbine together with a generator [41].

In Naples, the implementation of 20 OWC could generate 2 500 MWh/year, which means around 150 MWh/year per converter, which was an ISWEC developed by the Politecnico di Torino. This converter consists of a floating converter that uses the inclination of the wave side to produce energy. The estimated investment cost, of 30 convertors, is 9 375 000 € [42].

5.3.2. Overtopping converters

Overtopping converters capture the water close to the wave crest and introduce it, by over spilling, into a reservoir where it is stored at a level higher than the average free-surface level of the surrounding sea [40]. The potential energy of the stored water is converted into useful energy through hydraulic turbines [40].

This kind of converters are usually embedded in a rubble mound breakwater to exploit wave energy potentials [43]. This option was, tested in Naples, able to produce 4 000 $MWh \cdot yr^{-1} \cdot km^{-1}$ [42]. The estimated investment for the appliance of this energy wave converter in Naples was up to 10 528 401 € [42].

In Norway, a 500 m of three levels full scale plant is expected to produce 320 MWh/year [44]. In this location, waves were larger than one meter of height [44].

5.3.3. Major drawbacks

Even though this kind of technology is easier to connect to the electric grid, the installation cost of marine energy is much higher than any other renewable energy [45]. In addition, the required maintenance is expected to be more regular and require highly skilled workers [45].

5.3.4. Wave energy converters in Barcelona

Nowadays, this kind of technology is not well-developed yet. Due to the following reasons the present project would not recommend the use of this technology:

- The waves in Barcelona are not as high, neither important, than other places in the Mediterranean. In fact, 80% of the waves don’t reach the meter of height [46].
- The installation cost is higher than other renewable technologies, namely solar and wind power, and require more maintenance.

- The visual impact that this technology would have.

5.4. Tidal energy

This energy takes advantage of the tides produced by the gravitational action of the sun and the moon [47]. In areas where the difference between the high and low tide is considerable, the appliance of this technology would be feasible [47].

Tidal energy is based on the water storage in a reservoir with gates. These plants need a lot of space to store water, and this space is not generally available in most of the seaports [47]. So tidal energy could be a proper way to obtain energy, but it would not be feasible in seaports.

This source of energy would be inappropriate in Barcelona for two main reasons: there is no relevant difference between the high-low tide and there is not enough space to use this technology.

5.5. Marine Current energy

From the kinetic energy involved in the marine currents, electricity can be produced [47]. By the use of turbines, analogous to wind turbines but under the water, energy can be captured and thus be transformed into electricity [47]. Marine currents in seaports are not big enough to run the marine turbines, therefore the implementation is not feasible [47].

5.6. Economic study

Solar panels have been proved to be the most economic option followed by wind power, while the other renewable energy technologies are not economically viable. Unlike wind turbines, solar panels can be implemented in specific spots which makes the solar power the better option a priori.

This project proposes to place the solar panels in solar canopies, such as the ones shown in Figure 3. The estimated cost for each parking lot is 2 500 € [48]. The total cost estimation and annual savings are shown in Table 3. The return period is of less than three years.

Figure 3: Solar canopies installed in parking lots [48].

Table 3: Economic summary for solar panels

11-panel pack (€)	6 833
Surface of a single panel (m^2)	2
Total number of panels	99 837
Total number of 11-panel packs	9 076
Total cost (€)	$6.30 \cdot 10^{7}$
Annual generated power (kWh/year)	$8.29 \cdot 10^{7}$
Annual generated power (GWh/year)	82.92
Annual savings (€)	$2.35 \cdot 10^{7}$
Return period (years)	2.68

Table 4 shows the economical summary for the implementation of the solar panels and wind turbines in the Port de Barcelona. Furthermore, it shows the carbon dioxide that would not be emitted due to the use of the renewable energy.

Table 4: Economic summary for wind turbines and solar panels

	Wind Turbines	**Solar Panels**
Quantity	10	99 837
Install cost (€)	20 000 000	63 044 740
Annual energy generated (kWh/year)	122 230 035	82 919 085
Annual energy generated (GWh/year)	122.23	82.9
Savings/year (€)	34 713 330	23 549 020
Return period (years)	1	2.7
CO_2 kg-equivalent	31 657 579	21 476 043
CO_2 tn-equivalent	31 658	21 476
% CO_2 emissions 2020 [49]	18.69	12.68

Table 4 shows the economical summary for the implementation of the solar panels and wind turbines in the Port de Barcelona. Furthermore, it shows the carbon dioxide that would not be emitted due to the use of the renewable energy.

Table 4A total of 99 837 solar panels and 10 wind turbines could be implemented in the Port de Barcelona. The total cost would be of 83 million €, the annual energy generation would be of 205 GWh and it would save 58 million € and 53 million of CO_2 equivalent kilograms. Out of those 58 million €, 2.4 million € are destinated to maintenance purposes.

5.7. <u>SWOT analysis</u>

A general SWOT study has been done to determinate the internal and external threats and opportunities that the project can handle with. The analysis has been made at a global scope considering all the renewable energies presented above.

STRENGHTS	WEAKNESSES
- Work team with good intellectual property. - Low return period for each renewable energy implemented in Barcelona. - Strong marketing team to promote the project to other ports.	- In the port of Barcelona not all the renewable energies are feasible. - In other ports, one of these renewable energies can be already implemented or not feasible.
OPPORTUNITIES	**THREATS**
- Implementation of the project in some port where all, or at least two, renewable energy sources can be implemented. Therefore, a better result can be obtained. - Reduce the CO_2 emissions with self-producing energy - High social awareness about the importance and need to move to renewable energies.	- Concerns by AENA management due to the impact on the airspace. - The biodiversity cannot be altered. - Citizens in Barcelona may not like the project as it requires a lot of equipment and has a visual impact of the port.

6. Implementation

6.1. Milestones, deliverables and Gantt Chart

With all the implementations mentioned above, now it must be decided how many years are needed to carry out the implementation and which are going to be the work packages involved. The project is stablished for 4 years. The development of every task and its time is specified in Table 5.

This project considers different deliverables related to the milestones shown in Table 5, which are listed below:

Deliverables	Delivery phase of the project
Report of the current existing renewable energies and the feasibility to implement them in the port.	Phase 2
Safety and environmental study to verify compatibility with biodiversity.	Phase 3
Arrangement of the project with the study of implementation and economic saves and costs.	Phase 4
Technical memory of the civil work.	Phase 5
Certificate of the installation’s correct start up and functioning.	Phase 6
Performance and maintenance reports at 1,2,6 and 12 months of operation time.	Phase 7

Table 5: Phases of project

Phases		Description	Time
1	Study of existing technologies for renewable energies.	Bibliographic research is done to determinate the current situation of energy consumption in ports. Study of technologies in renewable energies available.	8 months
2	Case of study: Port of Barcelona	Report of the energy consumption and the feasibility to implement renewable sources of energy in the port of Barcelona.	6 months
3	Safety and environmental study	Study of the security of the implementation and environmental law compliance.	5 months
4	Arrangement of the project	Present the project to the Autoritat Portuària del Port de Barcelona for their approvement.	3 months
5	Project start-up	Hiring of staff and searching for suppliers.	9 months
6	Implementation	Purchasing and installing the equipment for solar and wind power.	33 months
7	Achievements review	Control of the energetic achievements proposed for the project.	12 months

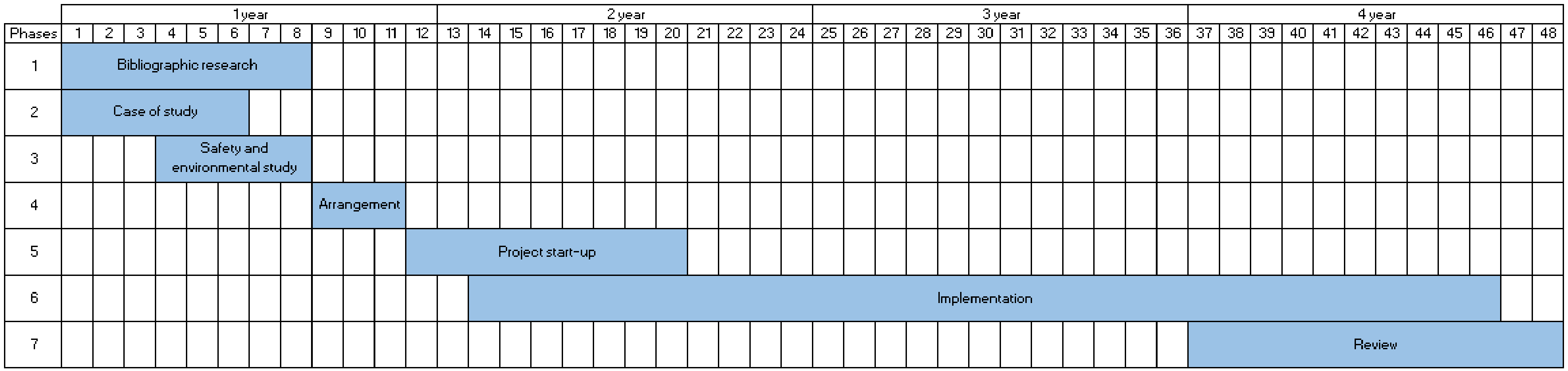

Figure 4: Gantt Chart of the project

6.2. Work packages

In the following table the work packages are described, showing their main tasks and the economical expenses.

Table 6: Description of work packages

Work package		Description	Main tasks	Economical contribution
1	Project management	The project management oversees and controls the strategy	- Organize meetings with the other committees - Make sure that the targets of the project are being achieved - Organize and control the times established for each task. - Stablish and guarantee the core values of sustainability, equality, and labor responsibility during all the project in all the teams. All people must be respected without regarding to their gender, race, origin, or sexual orientation.	657 000 €
2	Exploitation and dissemination	It is important to have a good communication strategy to improve the reputation of the port of Barcelona by implementing a more sustainable exploitation.	- Create a website where people could find the main target of the project. - Make a conference to raise awareness of energy consumption of the port of Barcelona and explain the solution presented in the project. - Search sponsors who want to join and be part of a more sustainable future with this project.	317 485 €
3	Environmental regulations	The different renewable sources implemented in the port of Barcelona must follow regulations to avoid any damage on the biodiversity of the port, both marine and aerial.	- Make sure that the project compliance two important laws: ○ *Law 41/2021* on the protection of marine environment requires the management of good state of marine waters in order to maintain the biodiversity and preserve the diversity and dynamism of the sea by having a clean and healthy sea which also is sustainable [54]. ○ *Orden AAA/1260/2014,* which stablishes the port of Barcelona as a bird preservation area [55].	186 302 €

Work package		Description	Main tasks	Economical contribution
4	Implementation and control	The team has the responsibility of the installing and control all the facilities of the project.	- The engineers must design the implementation of all the equipment needed and control the energetic achievement, considering the balance between the cost of the equipment and the energetic savings. - Technical workforces who carry out the installing of the equipment.	29 350 026 €
5	Purchasing team	Must evaluate, approve, and homologate suppliers to ensure that they have all the requirements to guarantee that the project is sustainable and follow the values of the project.	- Compare and choose the best option within all the suppliers in other to obtain material an equipment with a good relation between price and quality. - Guarantee all the materials of the supply chain according to project. - Develop the communication with the suppliers during the implementation of the project.	55 896 833 €
6	Security	In charge of the security of all the people and equipment involved on the plan.	- Make a study of the final installation’s security on the port of Barcelona, considering the usual workers and tourists. - Provide and supervise the correct use of personal protection equipment (PPE). - In case of accident the department of safety has to design action plans and form an intervention team to carry them out.	212 917 €

These work packages have a relation between them, so without the information of one of them the others could not follow their tasks correctly. The relations are shown in Figure 5:

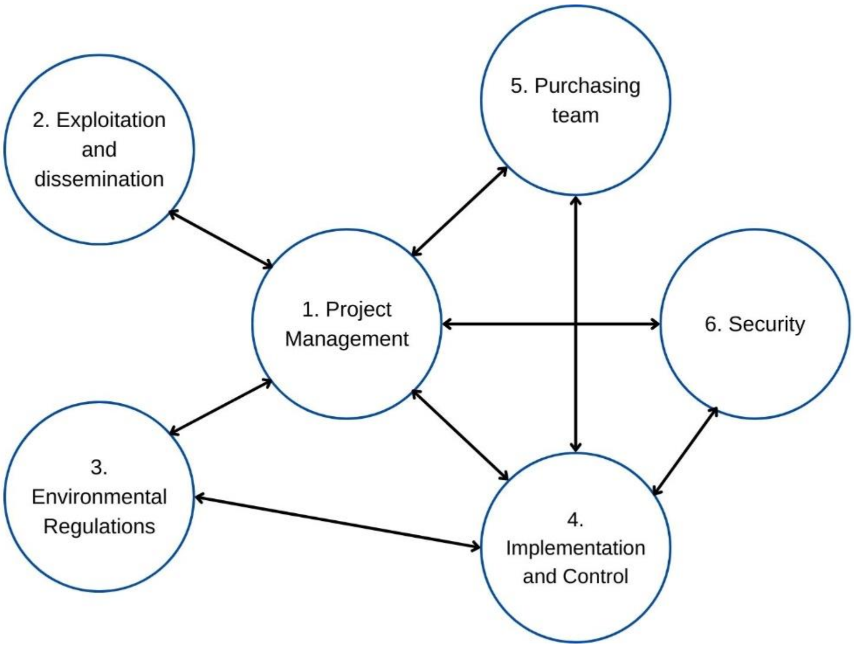

Figure 5: Relation between work packages

6.3. Business model canvas

The Business model canvas of the project is shown on Figure 6. The project is planned for public or private entities who operate port facilities, supplying the energetic needs with a high valued project of implementation based on the importance of self-sufficiency, sustainability, and social responsibility. As this project is on a public area, citizens must be informed. Information about the project is provided through a web page, social media and conferences.

The business capital assets come from the sales of the project, public funding, and any investors or sponsors who want to join the project. Key activities of the business are the appropriate selection of equipment and its installing to implement a project based on sustainability and self-sufficiency. To carry out these key activities, high qualified staff, technical equipment, and the facilities to install it, as well as intellectual property are needed as key resources. The participation of technological companies to provide the equipment and knowledge required and all the entities from the port involved is also a key for the project. The costs of the project come from taxes, equipment, personnel, marketing, supply chain and safety.

Key partners:

- Equipment suppliers
- Authorities from the Port de Barcelona
- Sponsors
- Council of Barcelona
- Generalitat de Catalunya
- Consorci de la Zona Franca
- Technological companies related to renewable energies
- AENA (Aeropuertos Españoles y Navegación Áerea)

Key activities:

- Implementation of a project to take advantage on renewable energies
- Bring sustainable self-sufficiency to an area with a high demand of energy
- Correct equipment selection and installing

Key resources:

- Intellectual property
- Facilities (location)
- Staff
- Equipment

Value proposition (VP):

- Use new technologies from renewable energies to reduce the emissions on the Port of Barcelona.
- Project based on sustainability and social responsibility.

Costumer relationships:

- Direct and honest communication with the Autoritat del Port de Barcelona during the sales and implementation of the project.
- Communication with public entities (Council of Barcelona and Generalitat de Catalunya) about land use planning and urbanism.

Channels:

- Website
- Publicity in social media
- Conference

Costumer segments:

- Port authorities
- State government
- City council
- Regional government
- Private companies based on the port

Cost structure

- Personnel
- Supply chain
- Taxes
- Legal
- Marketing
- Safety
- Equipment

Revenue streams

- Public funding
- Sponsors
- Sales of the project
- Business services

Figure 6: Business model canvas of the project.

6.4. Risk Management

One important point is to be aware of the possible risks that may occur meanwhile the project is being carried out. These risks may cause the failure of the project or avoid reaching the final planned results. The objective of these Risk Management is to analyze these risks and associate a probability, an impact, and a mitigation strategy for each one. In Table 7, the risks can be ordered according to its priority, which is the product of probability for impact.

Table 7: Possible risk during the project and its analysis

Risk		Description	Probability	Impact	Priority	Mitigation strategies
1	Visual impact	There may be complaints because of the visual impact of the project, as a lot of new equipment is installed on the port of Barcelona.	50%	4	2	A communication plan has been planned on the marketing work package to make people conscious about the benefits of the project and to inform that it is going to affect and already industrialized area.
2	Noise	The wind turbines exceed the maximum decibels allowed in urban zone.	50%	4	2	The structures of wind power are installed far away from residential areas, even though on the environmental study it is included a decibel analysis on urban areas next to the port to avoid a negative effect on residents.
3	Problems with aviation	There may be some troubles with the airport manager AENA because wind turbines could interfere the aviation of the port of Barcelona.	50%	4	2	• Wind turbines are installed far enough from the airport to mitigate the rejection of the airport authorities. • Reach an agreement with AENA.

Risk		Description	Probability	Impact	Priority	Mitigation strategies
4	Location problems	There may be land ownership problems with the companies that are already in the port of Barcelona.	40%	4	1.6	Private companies who operate on the port are included as Customers and Key partners on the business model canvas to convince them on joining the project.
5	Damage to biodiversity	Regulators, as well as environmental entities, can reject the installing of some equipment.	30%	5	1.5	The environmental study and the communication plan will inform people and regulators of the environmental safety of the project.
6	Delay in delivery of equipment	The equipment that needs to be installed can be delayed. In this case, the deadlines established change.	60%	2	1.2	Direct and honest communication with suppliers and strict supplying contracts carried out by the purchasing team are important to assure the delivery of equipment on time.
7	COVID-19	There is the possibility that COVID-19 affects to the workers of the project. In this case, the programming has to be delayed until they are recovered, even though then installing can continue.	50%	2	1.0	The HSE team will deliver covid-19 tests to all workers weekly to avoid a massive leave of workers due to a covid-19 outbreak.

7. Impact of the implementation

As a result of the implementation of the idea proposed in the present work, seaports could take a step towards the sustainability, having economical and feasible options.

In the present work, Port de Barcelona has been the target of the project to implement this idea. It has been proven that self-producing energy by solar and wind power is a feasible option for three main reasons:

1) Being able to save almost 55 000 tons of carbon dioxide.
2) Having a return period of less than 3 years.
3) Cover 7.7% of the actual energy generation in the port.

Even though the Port de Barcelona has been the only seaport studied it has shown great numbers in sustainable and economic terms. Due to these benefits, this project could be implemented in every seaport around the world. Nevertheless, the location of the seaport has a great impact on the economic viability because the use of the different technologies, but in any case, the carbon dioxide emissions would be reduced.

8. Conclusions

The main objective of this project was to make an intensive study of the Port de Barcelona to take a step towards the self-sufficiency by using different renewable energies. It has been observed that:

- Solar and wind power are viable both technically and economically.
- Wave, tidal and current powers are not viable in any way as the Port de Barcelona does not meet the requirements for those power sources to be efficient.
- If this project was carried out it would achieve the partial energetic self-sufficiency in the port.

Since it has shown great numbers, this project could be applied in other seaports from different parts of the world.

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10. Annex

10.1. Calculation of energy production with wind turbines

To calculate the energy produced by wind turbines it must be considered the wind velocity in the port of Barcelona. The equation used is the following one [28],

$$P = k \cdot \rho \cdot r^2 \cdot v^3 \quad (1)$$

where v is the wind velocity, k is a factor that depends on the turbine and r, the density of air and r the distance between two extremes of two blades. These values are shown in Table 8:

Table 8: Wind power parameters

Wind velocity	6.92	m/s
k	0.8	
r	92.7	m
Air density	1.225	kg/m^3

The results for 1 and 10 turbines are shown in Table 9 considering that 50% of the days in a year there is no wind.

Table 9: Energy generation of 10 wind turbines in one year

Power	2 790.6	kW	for 1 turbine
Energy generation	33 487.6	kW·h	
	12 223 003.5	kW·h/year	
	122 230 035.5	kW·h/year	for 10 turbines
	122.2	GW·h/year	

10.2. Costs of the project

10.2.1. Direct Costs

Wages

Table 10: Wages for every work packages

Position	Number of professionals	Wage (€/h)	1st year	2nd year	3rd year	4th year	Total wage (€)
			Hours/Day				
Project Manager	2	28.13	8	8	8	8	657 000
Marketing Manager	3	17.19	8	4	2	0	263 484
Environmental Engineer	2	18.23	8	4	2	0	186 302
Engineers	8	20.83	8	8	8	8	1 946 667
Purchasing expert	2	12.50	8	8	8	4	255 500

Position	Number of professionals	Wage (€/h)	1st year	2nd year	3rd year	4th year	Total wage (€)
			Hours/Day				
Financial Manager	2	11.98	8	8	8	8	279 833
Safety	1	18.23	8	8	8	8	212 917
Recruiting Expert	2	12.50	8	8	8	8	292 000

Other direct costs

Table 11: Other direct costs.

		Wind Power	Solar Power
Inventoriable	**Equipment (€)**	13 333 333	42 308 048
Outsourced services	**Install cost (€)**	6 666 667	20 736 692

10.2.2. Indirect Costs

Marketing

Table 12: Costs regarding to the communication campaign.

Type of cost	Cost (€)
Communication campaign	13 500
Website	1 500
Conference	2 000
Advertising	10 000

10.2.3. Total costs

Table 13: total costs of the work packages.

Work package		Costs (€)
1	Project management	657 000
2	Exploitation and dissemination	317 484
3	Environmental regulations	186 302
4	Implementation and control	29 350 026
5	Purchasing team	55 896 833
6	Finance	279 833
7	Security	212 917
8	Human resources	292 000