Green Ports Analysis Using an End-to-End Tool Application in the Fishing Port of Vigo

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Abstract: Modern ports tend to focus on freight transport and cruise traffic. The fishing sector is often the forgotten sector in terms of sustainability and port planning, despite the fact that fishing is a sector of great importance and interest; though it is currently obsolete in many respects. Literature on sustainability and green ports in the context of fishing ports is practically non-existent; however, it is necessary in order to implement a sustainable fishing infrastructure. For this reason, the aim of this study is, within the green ports framework as outlined by the European Commission and using an innovative end-to-end tool methodology, to determine the reality of the conditions of the port environment in fishing ports. Furthermore, this study establishes a possible green ports scenario for Spanish fishing ports and carries out an analysis of a specific case study within the Spanish port system: the Port of Vigo. It is concluded that the key fishing features of the Port of Vigo should, in order to expand its sustainability strategies, are: growth expectations, closely related to the evolution of the goods unloaded in the Port of Vigo and the possible growth that this may have in the future; legislation and current trends in terms of sustainability; and diversification, the Port of Vigo has realistic options to diversify the business beyond the traditional fishing activities.

Keywords: end-to-end tool; green ports; Vigo fishing port; sustainability; fisheries

1. Introduction

Traditionally, throughout history, society has focused on developing the highest levels of wellbeing. It is this approach that has accounted for most of the advances and developments that have taken place throughout history [1]. The industrial revolution marked a turning point; from this point onwards, growth was exponential and pressure began to be exerted on the environment. Industrial processes, which were born during the first industrial revolution and continued into the second, generated a series of impacts that were not initially considered. However, as years went by, they became increasingly more important [2]. Since societies agglomerated in cities and left industrialization processes behind, new problems have arisen. Cities and their environments have high levels of pollution at all levels that affect the quality of human and animal life. The global society must become aware of these situations and the inherent pressures placed on the environment, as well as the need to improve quality of life, in order for these trends to change [3].

Europe is a developed region, and the European Union is one of the organizations that promotes sustainable considerations to a great extent. Throughout its history, it has developed countless projects and plans with sustainable objectives. The example that concerns this study is one of the more recent innovation projects launched by the European Commission: Horizon 2020 Green Deal Call [4]. It is an investment and project finance initiative with the main objective of combating the climate crisis. Specifically, the section that concerns the current study pertains to green ports; a concept located within the
framework of the Horizon 2020 Green Deal Call, which has direct implications for the European port sector and its future [5]. Within the port system, the area on which this study will focus is the fishing industry, including activities derived from it [6]. Fishing activities are no longer the epicenter of port activity as they had been throughout history. Today, focus is almost exclusively limited to freight transport and cruise ship traffic; despite this, fisheries are of high importance and interest, with a presence in most of the world’s ports, which are now obsolete in many respects [7].

Despite being a primary activity, fishing has been highly industrialized. Having benefitted from the same technological advances introduced by the Industrial Revolution, fishing has developed to a great extent and has moved away from exclusively traditional fishing equipment to operate using specialized modern fishing technology and practices; opening up new fishing grounds, increasing distances, and even allowing freezing and processing onboard [8].

Traditionally, Spain has been and remains a country in which the fisheries sector is of great importance, something reflected in the per capita consumption of fish and the total kilograms consumed by the country, especially along the Spanish coast [9]. Over the years, and with improvements in preservation, refrigeration, and transport, the commodities of fishing have made their way inland and consumption has continued to increase.

Since joining the European Union, catches have been limited due to fisheries legislation from Brussels [10]. The aim of this legislation has been to release the pressure that fishing exerted on the marine environment so that it would not be excessively affected and lead to the disappearance of species. This limitation in terms of catches significantly affected Spain, the largest fish consumer in the EU. Faced with this situation, aquaculture has made its way into the fishing industry with the aim of satisfying the deficit between demand and supply. This sector has boomed in recent years and has managed to reduce the cost of fish and make it accessible to a larger part of the population.

The aim of this article, using an end-to-end tool within the green ports framework as outlined by the European Commission, is to carry out an analysis of a specific case within the Spanish fishing port system: the Port of Vigo.

The aim of the study is to develop a methodology using an end-to-end tool that obtains a picture of the past, present, and future situations of a business; in this case, it is applied to fishing ports. The method is adapted to consider the active elements operating within model green ports, observing the environment and other representative factors. It will help to better understand the reality of conditions within the port environment; namely, the features where green port development is planned. Moreover, in the final phase, the study establishes possible green port scenarios within Spanish fishing; in this case, it is applied to the fishing elements of the Port of Vigo, in order to evolve these concepts further.

The Port of Vigo is the largest fishing port in Spain, and its commitment to sustainability and generating a green environment has been, thus far, outstanding. This is why it has been chosen as the focus in this study.

In order to take advantage of the mechanisms offered by the European Union in terms of port sustainability, the study is conducted in an area that still has a long way to go in terms of sustainability, namely fishing. The end-to-end tool methodology will be used to analyze companies operating within the specific context of the Port of Vigo, a leading institution in the fishing sector. This analysis will allow for an in-depth understanding of the context of the Port of Vigo and the development of a strategy within the green ports framework for its application in both the medium and long term.

This is followed by a description of the state of knowledge in the field, in order to focus on the subject of the study. Then, a description of the novel methodology applied through the end-to-end tool is outlined, followed by an exhaustive analysis of the results that allows the final conclusions to be drawn.
2. State of Knowledge

This section puts into context the current situation of ports, both on a national and international level, having evolved from their exclusive role as a mode-shifting element between sea and land for goods and people, to one of the most important elements in terms of logistics and distribution.

Likewise, the tool used for the analysis of the study ports will be described; this methodology is the so-called end-to-end tool.

2.1. Evolution from Ports 4.0 to Green Ports

The first of the concepts introduced is that of the Ports 4.0 project. This is associated with the so-called industrial revolution 4.0, which is based on the improvement of the different production processes, thanks to various collaborations between computer and physical systems [11].

The concept of the Ports 4.0 project is directly linked to that of the fourth industrial revolution, since the objective is to integrate information technology systems into port activities in order to improve the different processes [12]. Ports 4.0 is an investment element within the Spanish port system, under the Ministry of Transport, Mobility, and Urban Agenda, and has been adapted by “Puertos del Estado” (State Ports). It is a capital fund that aims to attract, support, and facilitate the application of talent and entrepreneurship to the Spanish public and private logistics-port sector in the context of the fourth industrial revolution. This fund has been used to finance a series of technological start-ups with the aim of developing innovative processes or services to improve competitiveness, efficiency, and sustainability, among other factors, in the logistics-port sector [13].

The Smart Ports concept is relatively recent, and is directly associated with Ports 4.0 and the fourth industrial revolution. In particular, the concept of Smart Ports is particularly related to digitalization and the use of new technologies in the port sector [14].

The main objective of Smart Ports is to carry out large-scale digital transformation and automation of port activities. To this end, technologies such as artificial intelligence, Big Data, the Internet of Things, and Blockchain have been applied [15].

Green ports are a vision of the port system on a European scale. The concept was introduced by the European Commission, within the Horizon 2020 Green Deal Call program, which aimed to foster European recovery from the pandemic by addressing sustainability issues through innovation [16].

The Horizon 2020 Green Deal Call program aims (Figure 1), through a total investment of €1 billion, to promote sustainable digital transition. In contrast to previous Horizon 2020 programs, results are expected in the short and medium term [17]. According to the European Commission, projects financed under this fund should deliver results in the following areas [18].

![Figure 1](image-url)  
**Figure 1.** Typology of projects funded by the Horizon 2020 Green Deal Call Program. Source: own elaboration.
The program was intended to also foster knowledge acquisition and the empowerment of citizens. The eight basic principles on which projects subject to funding should be focused on are very present factors within the activity of ports in the 21st Century [19].

Within the port sector, the various management bodies of European ports will have to submit projects in accordance with the pillars mentioned above in order to receive European funding, thus entering the so-called green ports program [18].

The main challenge facing European ports is the reduction of greenhouse gasses from maritime freight transport; representing 2.5% of total global emissions of pollutants [20]. The continued growth of port economic activities is expected in the future. Ports can play an important role not only in terms of transport mode shifts, but also as a multimodal node and economic activity zone that allows connections with the hinterland to be integrated within the city [21].

2.2. Green Ports: Fishing Ports

Maritime transport carries virtually all internationally traded goods. Major commercial ports are fully integrated into transnational production and distribution systems, enabling the circulation of massive flows of energy and materials in the global economy [22]. Port activity and development is often associated with positive socio-economic effects, such as increased GDP and employment, but the continued expansion of the industry has produced adverse results, such as air and water pollution, destruction of marine and coastal environments, dock congestion, health risks, and labor problems.

Currently, despite the importance of developing green ports, the literature on fishing ports associated with green port development is not overly extensive. The majority of literature is not focused on European ports.

Several references to Egyptian fishing ports can be found. For example, [23] outlines a methodology for converting Egyptian ports into sustainable green ports, incorporating a balance between environmental, social, and economic concerns. The port’s environmental sustainability objectives are achieved through six key areas: water, energy, air, waste management, sustainable development, and sustainable business practices. According to the study, the main objectives should be to: manage resources in an environmentally sensitive and responsible manner; minimize environmental impacts directly attributable to operations in the harbor bay and marshlands; prevent pollution and improve personal, community, and environmental health; and ensure a balance of environmental, social, and economic development. According to the authors, this methodology could be considered as a guideline for turning ports in the Middle East and Africa into sustainable green ports.

In addition, [24] addresses the waste generated. The study explored collaborative management of waste generated from different port activities, such as operators of the public seaport, fishing terminal, and a city authority in Bali–Indonesia using circular economy principles. It was discovered that the integration model has the potential to generate new energy by recycling waste from all related entities in the production of a few main fishing products, such as tuna, sardines, and squid, as well as vessel traffic, facilities, and cargo flow interactions, in addition to other port operations.

In essence, bridging the disconnect between natural environmental issues and port development requires taking the natural environment into account from the outset in port development, and recognizing the multi-use benefits of natural capital [25]. Furthermore, in the operation and maintenance phases, port environmental management systems should not only focus on environmental performance, but also on the multi-use valuation of the natural environment (ecosystem services) to make sense of the need to protect the environment. However, for the effective implementation of an Integrated Port Management (IPM) framework, its integration into organizational processes, supported by collaborative institutional structures, will be crucial. Only then will the environment take its place as an equal partner in port development.

Gulf ports face fierce market competition and severe environmental pollution while assuming major responsibility for oil transport [26]. The propagation of the concept of
sustainable development among the Gulf ports group will help to provide a new perspective for port governance in the Gulf region. In the above research, the network of port relationships in the Gulf region was constructed with the complex network method, which established the propagation model of the concept of sustainable ports and simulated the model. The results suggest that: optimizing and adjusting the relationship structure of Gulf region ports and reducing the recovery rate will promote the spread of sustainable development concepts in the region; improving the sustainable competitiveness of ports is the most effective way to promote the spread of sustainable development concepts; and the increasing pressure of international sustainable development regulations and regional consensus will make ports more receptive to sustainable development concepts.

In the work of [27], potential environmental problems associated with fishing port operations were identified and a multi-criteria evaluation structure for green fishing ports was established. A review of literature related to port environments, the modified Delphi technique, and the AHP method were used to establish an evaluation structure for high-use fishing ports in Taiwan. The results showed that vessel and port management, hygiene, waste, and energy management are considered relatively important criteria at the second level.

2.3. Situation Analysis of Outstanding Ports in the World and in Spain

The green port framework is directly linked to the European Union, as it is associated with the Horizon 2020 Green Deal Call. Despite this, there are numerous ports worldwide that have committed to self-generation systems for port operations and other aspects related to the nature of green ports [28].

As mentioned above, following the principles of the fourth industrial revolution, ports are committed to innovation and the use of technology in order to improve and modernize port activities. The ports of Antwerp, Rotterdam, and Hamburg are at the forefront of these developments, with a series of projects oriented towards the Smart Ports framework and sustainability.

The Port of Antwerp: This port has presented solutions to improve the flow of information in its facilities, using innovative technology through digital transformations, including digital twins, intelligent transport, and drone technology, which help port processes [29]. These technologies will help in areas such as measuring air quality, identification systems, and the safe and quick detection of chemical accidents [30].

The Port of Rotterdam has committed to becoming a connected and Smart Port [17]. Its goal is to become an ideal port without delays, and, to this end, it proposed four digital solutions: Pronto (an application designed to allow shipping companies to optimize port entries), Portinsider (a new generation port community system that brings together all parties present in a port on a single platform), Portmaster (a management system to plan, monitor, and manage port calls and operations to increase port performance at all levels), and finally, they launched a digital twin that allows them to enhance their model. These initiatives, together with supply chain solutions (with its application, Navigate) and API-driven vessel tracking, ensure that the port of Rotterdam continues in achieving its goal of becoming a connected port [31].

The Port of Hamburg has been moving away from air quality challenges and focusing on mobility by working on testing the optimization of cruise passenger land transport through agent-based modeling (ABM), thus reducing the complexity of port flow. This was achieved through virtual reality and interactive port city modeling [32]. With the model fully developed, there is hope to take it even further by optimizing the tool in terms of user experience, implementing it in a second use case, and even including geo-fencing [33].

In Spain, the vast majority of ports of general state interest have or are planning a series of objectives or projects related to the Horizon 2020 Green Deal Call; thus, applying the green port framework to their operations and governance.
The most advanced port in this respect is the outer harbor of La Coruña (Arteixo) [34]. The port authority launched the “A Coruña Green Port” project with the aim of decarbonizing industrial activity, thus qualifying for the European Union’s Next Generation fund [35]. The project has a number of main objectives [36]:

- Projects for the digitalization and modernization of the activities located in the port with the aim of achieving greater sustainability of the activities.
- Development of energy storage systems and self-sufficiency of the port through green and clean energies.
- Development of the green hydrogen value chain and its integration into industrial and logistics activity (ships, trucks, auxiliary vehicles, cranes, warehouses, forklifts, etc.).
- Transformation and decarbonization of industrial activity and biofuel production.
- Development, manufacturing, and deployment of offshore wind renewable energies at industrial level for export, mainly to Northern Europe, and the development of experimental prototypes.

The Port of Valencia is another of the Spanish ports which has strongly committed to its transformation into a green port. The port authority, in collaboration with other European ports, is currently carrying out the “Green C Ports” project. Within this program, the main areas of action in the Port of Valencia consist of the digitalization and integration of information systems to improve the levels of road traffic in the entrances and exits of the port [37]. The second main objective of this project is the reduction and monitoring of noise and air pollution arising from port activities. Finally, a real-time measurement system will be developed in collaboration with the ports of Barcelona and Mallorca regarding the emissions derived from logistical operations between the three ports with the aim of reducing the impact of these operations on the cities [38].

2.4. New Planning Tools

The whole process of improving the quality of port operations through technology has led to a progressive liberalization of the activities carried out in the ports of the Spanish state-owned Port System. In order to ensure that these activities are carried out in a way that respects free competition and avoids the formation of monopolies, the Port Authorities have been given the capacity to act on these issues. Furthermore, they have the responsibility of promoting innovation and the development of strategies aimed at improving port competitiveness [39].

Ports have always played a key role in the development of society, being a fundamental element in the economic development of different countries and being placed in a strategic position worldwide. The current changes at global level, motivated by new forms of communication, behavioral patterns, innovative technologies, etc., have meant that ports cannot remain on the sidelines of these new trends; they have to take an active role in this global change and a key element in the transformation [40].

When talking about strategic management, strategic marketing is responsible for the analysis phase, i.e., analysis of the organization’s resources and capabilities, as well as defining the reference market in which it works [12].

Describing the current and future environment based on variables is a reflection exercise that can provide very good clues as to how the market will behave in the near future. These analysis tools are used in strategic marketing, and are strategic analysis techniques to define the context of an organization through the analysis of different factors [41].

Some of the best-known strategic analysis instruments in the literature are: SWOT, Porter’s competitive forces, the BCG Matrix, McKinsey’s GE Matrix, Kotler’s 4P and 4C models, McKinsey’s 7S Model, business plans, the blue ocean strategy, and the strategy map impact matrix [41].

Management tools make it possible to establish the tasks and the path that organisations must follow in order to achieve the goals set, taking into account the changes and demands imposed by their environment. In the current study, this corresponds to the path that ports must follow in order to become green ports [12].
In terms of previous research applied to the Spanish port system, the work of [12] included an analysis of the Spanish port system in order to evaluate ports and consider the new concept of “Smart Ports”. Some indicators and measurement variables were defined, which enabled technical elements to be quantified. These items, both quantitative and qualitative, reflected, in the most objective and complete ways possible, the adequacy and achievement of the characteristics and objectives associated with the Smart Port framework in all ports. The results obtained a Smart Ports index that allows us to calculate the ranking of the Spanish Smart Ports. This study concludes that the development of a port must be based on digitalization, the use of ICT, and the automation of port processes.

In [35], in order to understand the current state of digitalization in which the Spanish ports find themselves and the current scenario in which they develop their activity, a SWOT analysis (Strengths-Weaknesses-Opportunities-Threats Analysis) was proposed. The main conclusion of the analysis was that the Spanish ports were currently at a medium-high level of digitalization, and that they continued to update and innovate in order to become increasingly competitive in this market, despite the fact that there is still a long way to go in terms of digitalization.

In [42], a series of proposals were put forward to serve as a framework for the development of the port system, so that companies, port administrations, workers, and society as a whole could benefit from the application of policies aimed at the competitive development of ports in an international context. The proposed methodology was a SWOT analysis based on the definition of strategic objectives for the new strategic framework. The main conclusion was that the Port Authorities must continue to make progress using the Landlord model; however, they must change their approach, avoiding becoming only a passive owner of port infrastructure. It was suggested that they rather become the facilitator of activities and services through more proactive management, encouraging intra-port competition, and with a view to achieving the strategic objectives set out.

Regarding sustainability, ref. [43] presented a detailed analysis of the sustainability of the Spanish port system using a pioneering graphical tool: the business observation tool (BOT). The aim of this study was to identify the minimum elements to be taken into account when formulating the concept of sustainability linked to Spanish ports, making it possible to understand the reality of the conditions of the port environment and establishing possible scenarios to evolve beyond the current situation towards harmonious and balanced growth by means of an observation model through the BOT. The work concluded with the fundamental idea of the need to promote the implementation of increasing measures towards Smart Ports.

With regard to the end-to-end tool, a study was developed to obtain an image of the past, present, and future situations regarding the digitization of Spanish ports, which is a model for observing the environment and the most representative factors. It allows us to understand the reality of the conditions of the port environment where digitization is planned to be developed, in addition to its final phase, which allows us to establish the possible scenarios of the digitization of Spanish ports. The main conclusion was that there is still a long way to go in terms of digitization, such as making an immediate conversion to digital, intelligent, and green ports, which optimize the existing infrastructures through the intelligent management of spaces [11].

As can be seen in the research areas of Smart Ports, green ports, Ports 4.0, and the sustainability of the Spanish Port system, previous studies with strategic tools have been very limited.

3. Methodology

With regard to the methodology, an end-to-end tool is used, which allows a picture to be obtained of the past, present, and future situations of a system; in this case, the green port in the Spanish port system. It is a model for observing the environment and the most representative factors pertaining to the business system. It allows for an understanding of the reality of the conditions of the port environment in which green ports are planned.
to be developed, and, in its final phase, it also allows for the establishment of possible scenarios for Spanish ports, specifically for the proposed case study, to evolve beyond the current situation.

The application of this tool, being an analysis technique, consists of identifying and reflecting, in a systematic way, on the different study factors in order to analyze the environment in which the port sector operates, and subsequently, to be able to strategically act on them. In other words, the tool allows for an understanding of what is going to happen in the near future and uses these projected situations as an advantage.

The methodological scheme is represented in Figure 2.

![Figure 2. General methodological scheme. Source: own elaboration.](image)

The case study is the Port of Vigo, and the specific data and relevant information of this macro environment will influence perspectives of its current context and projected future scenarios. Once this information has been collected and processed, it will be possible to define a tailor-made strategy for the Port of Vigo to develop into a green port.

Once this information has been obtained, a study will be carried out in accordance with the situation of the Port of Vigo pertaining to its past history, the present situation, and the plans and objectives set for its future development. Based on the information collected, a series of indicators (both quantitative and qualitative) are proposed that will help to identify the context of the Port of Vigo and a strategy for its development into a sustainable port.

3.1. Determination of the Working Scenario

The working scenario consists of identifying the state of the Port of Vigo and then, based on the information obtained, determining a series of indicators that allow for effective analysis to be carried out in the context of green ports.

3.2. End-to-End Tool

An end-to-end tool has been designed that allows for the tasks and the path that organisations must follow in order to reach their planned goals, taking into account the changes and demands imposed by their environment. In this way, starting with the environment in which the study is based, past methods of operation can be determined, and the present methods can be studied in terms of the motivations and capacities necessary to advance the same methods. It is necessary to determine the factors and conditioning factors that alter or intervene within the operating environment; starting from the macro environment and then studying the micro environment.
It is also necessary to understand the environment in which the project has been designed, as well as the elements external to the project that may alter future decisions and strategies formulated in order to plan for the future (Figure 3).

3.2.1. Selection of Study Variables

In this project, the end-to-end tool methodology is applied to the particular fishing elements of the Port of Vigo. This is a specific case within a micro environment in the Spanish port system. The Port of Vigo fish market is one of the most important fish markets in Spain for both inshore and offshore fishing. Recently, the Port of Vigo has carried out a series of actions to modernize the fishing port; the Ports 4.0 project aims to improve both the loading and unloading operations and the energy efficiency of the buildings.

Galicia has been, and continues to be, closely linked to fishing and the sea, which is why, in cities like Vigo, this is a representative economic activity that directly and indirectly employs a substantial percentage of the population. As such, the Vigo Port Authority is clearly committed to this sector and its modernisation in order to affect change and reach objectives in terms of sustainability.

In order to preset a series of objectives or roadmap to be followed by the Port Authority of Vigo within the framework of a green port, the Port of Vigo is analyzed using an end-to-end tool methodology. Analysis focuses on identifying the conditioning factors and...
variables that have influenced and continue to influence the development of port activities. This process not only exclusively focuses on the factors that currently affect the fish market, but it will also be necessary to understand the historical context, evolution, events, and factors that have resulted in what the Port of Vigo is today.

The study variables are closely related to the green port framework and under the umbrella of the end-to-end methodology.

In line with the selected analysis tool, the study variables are grouped into a series of categories (Figure 4).

![Figure 4. Elements of the end-to-end tool. Source: own elaboration.](image)

In terms of initial analysis and the compilation of information, all elements directly related to the Port of Vigo and the green ports framework are identified. Subsequently, this information is categorized according to its relationship with each of the concepts that define the study variables and the indicators that represent the current state of the Port of Vigo, as faithfully as possible, are identified.

The variables of the study are based on an exhaustive study of the Port of Vigo. The work scenario consists of identifying the state of the Port of Vigo as it was in the past, its present state, and potential future states; and subsequently, from the information obtained, a series of indicators are identified that allow for an effective analysis within the context of the green port framework. The variables included in the study were selected using the delphi panel method after the information had been collected. Twenty experts from public and private entities participated in the delphi panel in a 60/40 ratio; the delphi panel was carried out over the course of one day.

Variable: Past

This first group of variables was obtained by observing the historical situation and the events that have influenced what the Port of Vigo is today. In order to properly identify these variables, we needed to identify what elements had been historically inherited. That is to say, which elements, both material and personal, have been the result of the Port’s history. The green port framework was born from the European Union’s Horizon 2020 Green Deal Call. Despite being a novel concept and addressing the issue of sustainability (something that was not historically in the minds of the population), there have been relevant factors in the history of the Port of Vigo that have a direct influence on it today.

Variable: Present

As a key feature of the methodology, the present situation of the Port of Vigo is what most directly determines the steps to be taken and future strategies within the context of the green port framework.

This section addresses the current state of the Port of Vigo. The variables in this section are attained by asking questions most relevant to the current situation of the Port of Vigo in order to determine the means available to meet the challenges of adhering to a strategy for the Port of Vigo based on sustainability.

Variable: Future

These variables refer to the end goal scenarios to be reached through the defined strategy. Evidently, this strategy revolves around the green port framework; therefore, the plans and projects that can help to achieve this final objective must be identified. The
variables determined in this section are the most difficult to obtain, as these are new concepts. Similarly, their relationship with the green ports framework must be found.

Variable: Macro-Environment

This section analyzes factors that affect the Port of Vigo on a more general level, especially focusing on the industry context. In turn, these variables are subdivided into the following environments:

- Economic environment
- Institutional environment
- Social and cultural Environment
- Technology environment
- Legal environment
- Sustainability environment

Variable: Micro-Environment

These types of variables determine those factors and conditioning factors specific to the Port of Vigo; conditioning factors that do not necessarily have to be similar to other fishing ports in Spain or worldwide. These conditioning factors are grouped into:

- Customers
- Competition
- Suppliers

3.2.2. Development of the Database

The database is the link between the available information and the analysis of the results obtained. In order to analyze and understand the study variables more effectively, a series of representative indicators in the context of green ports are proposed. In this section, the indicators used for the analysis are defined and subsequently measured.

The values assigned to the measurements, as well as the selection of the variables, were carried out by a panel of experts. A total of 20 experts in the area of ports and sustainability from the public sector, such as representatives of the Public Entity Puertos del Estado, Spanish Port Authorities, or universities and research centers, and experts from the private sector and companies associated with ports. All of them had received extensive training in the field and had recognizable experience. The experts had collaborated on previous occasions on other studies in this subject area. Two working sessions were held. In the first session, the study variables were selected, and in the second session, the values of the measurements were assigned by consensus. The final result is shown in Table 1.

The assignment of weightings and values below was also conducted by a panel of experts.

Measurement of Indicators 1. Allocation of Weights

In this first phase, weightings were assigned to each of the indicators according to their importance for the development of the Port of Vigo within the framework of green ports and the definition of future strategies.

The assignment of weightings was made by an expert panel once all the variables that play an important role in the application of the end-to-end tool methodology to the selected case study had been identified, as well as the degree of importance of these factors and determining factors in relation to the concepts of green ports and sustainability.

There were three priority ratings: low, medium, and high; represented on a scale of 1 to 3, respectively. This subsequently allowed for variables to be weighted together with the values of the indicators to obtain a precise determination of the situation of the Port of Vigo in relation to green ports.

Measuring Indicators 2. Assigning Values

A value was assigned according to the measurement variables for each of the indicators proposed. The database contained qualitative and quantitative indicators. Similarly, there were indicators of a negative nature, i.e., the impact of having a large number may be
negative; indicated by those indicators that met this requirement. The assignment of values was determined according to a scale from 1 to 3; as shown in Figure 5.

Table 1. IDIndicators database and measurement weights.

<table>
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<th>Category</th>
<th>Subcategory</th>
<th>ID</th>
<th>Indicator</th>
<th>Weight</th>
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<td></td>
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Additionally, in cases where nothing had been implemented or no progress had been made regarding a given indicator, they were allocated “Warning”, which was equivalent to 0 in terms of weighting.

Based on this assignment of values, a weighting was then made according to the weightings assigned to each of the indicators, and the final situation regarding the state of the Port of Vigo was obtained according to the green ports framework.

3.3. Analysis and Interpretation of Results

The analysis of results consisted of answering the objectives or hypotheses set out from the measurements made and the resulting data. It consisted of dividing compact information into different elements that were individually reviewed and analyzed.

4. Main Results and Discussion

The database generated corresponds to 48 indicators that are shown in Table 1. Measurements 1 and 2 were carried out, along with the assignment of weightings and values, and the results obtained are represented in Figure 6. These present a quick and effective visualization of the state of the Port of Vigo in regard to the green ports framework by applying the end-to-end tool methodology.

Indepedently analyzing each of the variables and weightings of each indicator by its value, the following graph is obtained.

The graph reflects the percentage of each variable compared to the theoretically perfect situation. As can be seen, the Port of Vigo obtains the following scores according to the variables under study:

- Past: 86%
- Present: 69%
- Future: 36%
- Macro-Environment: 58%
- Micro-Environment: 76%

Regarding macro and micro environments, the partial elements obtained the following percentages of scores (Figure 7).
Vigo, its population and society have understood fishing as something necessary and to perfect which framework of the city of Vigo, the social programs carried out in the fishing port to raise awareness of to reflect the impact that the fishing port has on the city of Vigo at present. Factors such as its value reaches the maximum possible. Port of Vigo in terms of merchandise, the number of vessels, employees, etc. In this context, continue to lead the way in terms of annual product tonnage, the aquaculture industry is the fishing industry is at a “relatively” low ebb. As the fish markets in Vigo’s fishing port employment trends in the city. Indeed, this same population is now in favor of abandoning European Union, the sector suffered a hard blow, together with changes in population and advances and the development of aquaculture. Throughout the history of the Port of Vigo, the social programs carried out in the fishing port to raise awareness of the port environment and justified the actions to be carried out in the Port of Vigo. The lowest scoring indicators that should be given attention are the following:

- Growth expectations: This indicator, being of a qualitative nature, is closely related to the evolution of the goods unloaded in the Port of Vigo and the possible growth that this may have in the future; it also considers current legislation and trends in terms of sustainability. Exclusively guided by the recent evolution of the tonnage of goods entering the fish markets of the Port of Vigo each year, there are no expectations of growth in this area due to the catch limits imposed by the European Union. Despite this, the Port of Vigo could address new business models and exploit opportunities that are currently not being exploited in any other fishing port in the world.

- Diversification: Being immersed in the fourth industrial revolution, the Port of Vigo has realistic options by which to diversify business beyond traditional fishing activities through the use of Big Data. The arrival of the fourth industrial revolution, and with it the concept of Smart Ports, opens up a range of opportunities in the port sector worldwide. In the case of the fishing port of Vigo, beyond the traditional fishing activities, a range of data is generated that, with proper treatment and processing, generates added value and could be used as a new source of income. Despite this, this path has yet to be exploited by the Port of Vigo.

Historically, the Port of Vigo has been one of the main fishing ports in Spain, not only in terms of the amount of goods unloaded at its docks, but also in relation to technological advances and the development of aquaculture. Throughout the history of the Port of Vigo, its population and society have understood fishing as something necessary and an important economic activity. Despite this historical boom, following entry into the European Union, the sector suffered a hard blow, together with changes in population and employment trends in the city. Indeed, this same population is now in favor of abandoning an industrialized past in favor of a service-sector-oriented society, and this has meant that the fishing industry is at a “relatively” low ebb. As the fish markets in Vigo’s fishing port continue to lead the way in terms of annual product tonnage, the aquaculture industry is growing to a large extent.

The historical impact indicator refers to the historical impact and importance of the Port of Vigo throughout history; from its beginning to its current situation. This is a qualitative indicator that takes into account factors such as the historical ranking of the Port of Vigo in terms of merchandise, the number of vessels, employees, etc. In this context, its value reaches the maximum possible.

The current repercussion indicator: This indicator, being of a qualitative nature, tries to reflect the impact that the fishing port has on the city of Vigo at present. Factors such as the image of fishing in Galicia, the employability of the sector, the consumption of fish in the city of Vigo, the social programs carried out in the fishing port to raise awareness of

![Figure 7](image-url)  
**Figure 7.** Scoring of macro and micro environment sub elements. Source: own elaboration.
the sector, etc., are considered. Today, and since the second industrial revolution passed, fishing activities have been decreasing due to improvements in processes and the sacrifices involved in working in the sector. Today, fishing activities do not have the relevance they had a century ago, and with each passing year it becomes a less attractive profession. This fact, coupled with the low visibility given to the sector, means that there is little or no impact today.

It is clear that society today is environmentally aware and demands action from authorities in order to improve the quality of life in cities and to protect the planet. As mentioned in previous sections, the green ports framework aims to bring about a transformation in the European port sector; a clear vision in favor of a circular economy and achieving zero net carbon emissions. In this respect, indicators were not poorly scored, but still had room for improvement, as represented by:

- Environmental impact: This indicator measures, in a qualitative way, the impact of the activities carried out in the Port of Vigo on the environment. For this purpose, factors such as the consumption of buildings and vessels, waste management, discards, etc., are analyzed. Compared to other port activities carried out in the Port of Vigo, fishing activities do not generate such a significant environmental impact. In terms of visual impact, the fishing port has a reduced space when compared to the transport of goods (especially vehicles). Similarly, it generates a visual impact due to the existence of the fishing rafts. Another important aspect is the emissions generated, which, in comparison with those produced by other activities carried out in the port, are not attributed the same degree of importance.

- The indicator of environmental actions refers to the plans and projects currently implemented in environmental matters related to the green port framework; not to those planned or yet implemented. Considering the current situation, the last few years have seen a change in sustainability trends. This has been even more noticeable in the industrial sectors, and fishing has also suffered. The Port Authority of Vigo has proposed a series of environmental programs and projects with the aim of reducing the impact generated on the environment by these types of fishing activity. Despite this, many of these projects have not yet been implemented and there is plenty of scope for developing and implementing new projects with these objectives.

- Environmental actions in the future: This indicator is similar to the present variable. In this case, reference is made to those actions within the framework of green ports that may be carried out in the future by the Port of Vigo. As in the section on modernization programs, the Port Authority of Vigo has proposed a series of projects and programs that have not yet been implemented, which, together with those that will be proposed in the near future, provide the basis for transforming the Port of Vigo into a green port.

Conversely, the fishing sector is still an industrial activity, which is perceived to be harmful to the environment. It is necessary to change this perspective of the population and modernize the entire sector. To this end, the Port of Vigo, as a historical reference point in Spain and the world, must be at the forefront of this transition. In this study, this was measured by the current impact indicator, being of a qualitative nature, which tries to reflect the impact that the Port of Vigo has on the city of Vigo at present. Factors such as the image of fishing in Galicia, the employability of the sector, the consumption of fish in the city of Vigo, the social programs carried out by the Port of Vigo to raise awareness of the sector, etc., are considered. This indicator had a value well below the expected value.

In order to achieve green port status, a main focus should be on sustainable energy use and self-consumption. For this, the framework of the Ports 4.0 project represents a good starting point, although it will not achieve all of the objectives. It will be necessary to improve the efficiency of equipment and lighting, especially in the case of refrigeration equipment, which currently has a high consumption rate. In order to encourage self-consumption and the use of renewable energies, it is proposed that the roof surface of the successive auction houses be used for the installation of solar panels. Similarly, it is proposed to create spaces in which to place a series of batteries that will enable part of the
buildings’ consumption to be met before dawn breaks. Due to the nature of the auction
days, it is necessary to have another method of energy generation for when there is no solar
lighting and the photovoltaic panels do not generate electricity. To this end, and similar to
the Port of La Coruña, a series of wind turbines should be installed to absorb part of the
Port’s consumption. Finally, in order to reduce electricity consumption in the fish markets,
it will be necessary to carry out a study of the energy consumption of the buildings and
to analyze whether losses can be mitigated by using more insulating materials than those
currently used. With these sustainability approaches in mind, the following initiatives
are outlined:

Smart Energy Ports and Harbors—Self-Sufficient Port

This project was created with the aim of achieving a self-sufficient port model, improving
energy efficiency and sustainability in port environments, by adopting innovative
energy technologies. The objective is to reduce the Port’s energy consumption by 25% and
to achieve 20% self-consumption in all the buildings owned by the Port Authority. The
project is structured in various “service units” linked to terminals and port services, which
allow its replicability and adaptation to other port environments, in which the different
innovative energy technologies are integrated.

Fish Market 4.0—Self-Sufficient

The aim of the project is to improve the energy efficiency of the Port of Vigo, including
the renovation of the air conditioning installations that condition the building’s auction
room, as well as further actions on the building to reduce the energy. Work will also
be carried out on the lighting system, and the project will be complemented with the
implementation of a solar photovoltaic installation for self-consumption, which will make
it possible to generate a large part of the energy consumed in the building itself.

In view of the changing trends in society in relation to sustainability and the use
of renewable energies, the Port of Vigo has proposed a series of initiatives to modernize
activities and infrastructures that will enable the port to be at the forefront. The most recent
program proposed was Blue Growth Vigo.

Within the macro environment, the sustainability variable includes:

- Use of Renewable Energies: This indicator measures the percentage of sustainable
  self-generation produced in Spanish ports and the existing plans and programs in this
  area. Following European directives and measures proposed in terms of sustainability
  and the use of renewable energies, an increasing number of ports are now contemplating
  self-generation. This technology is currently available, although efficiency
  improvements are expected, and some ports are already implementing it.

- Environmental plans: This considers environmental action plans and programs imple-
  mented at port and fishing levels in a macro environment. In a macro environment,
  there are environmental plans at global, European, and Spanish levels. Precisely for the
  purpose of this project, the green port framework focuses port activities on a sustain-
  able scenario and the use of renewable energies. Despite the existence of these plans
  and guidelines, they are sometimes not applied due to funding or other difficulties.

Another factor that will allow the Port of Vigo to reduce its environmental impact and,
at the same time, reduce the impact of the fishing fleet is the modernization of the fleet.
As we have seen, the Vigo fleet is one of the oldest in Spain and Europe. It is necessary
to reduce the impact of oil flaring from fishing vessels. In order to do so, a thorough
study of the design and modernization of the vessels needs to be carried out. For this
measure to be more effective, incentives should be provided to owners, through subsidies
or other instruments.

The next important step that can place the Port of Vigo at the forefront of technological
and economic matters is the diversification of its income. Being immersed in the fourth
industrial revolution, a whole sector derived from the processing of information and data
has been born, which, if properly exploited, has considerable economic value. The Smart
Port concept is no longer as new as it was a few years ago, but the fishing sector seems to
have been excluded in this section; taking advantage of this lack of competition can place
the Port of Vigo in a privileged position worldwide, separated from its traditional activity. In order to enter this market, there are two fundamental pillars. The first of these is the adequate training of port personnel in new technologies and the recruitment of talent and professionals with experience in the sector:

- Qualified personnel: Faced with the challenges of the future, the Port of Vigo must have personnel with a profile oriented towards sustainable development and new technologies. This indicator refers to the Port Authority of Vigo’s commitment to this type of development. Despite the fact that the Port Authority of Vigo has set up programs such as Blue Careers with the aim of training its employees from the point of view of new technologies and sustainability, there is still a long way to go and the current training of the employees of the Fishing Port and the crews of the vessels assigned to it still have to make progress in this respect. The “History and Training” section also has projects that refer to the Fishing Port of Vigo: In a complex and diverse environment, such as the one surrounding the port sector, it is important to have specialized professionals. The acquisition and updating of knowledge by its workers is vital to remain within the appropriate parameters of competence. Blue Growth Port of Vigo is a suitable tool for analyzing the availability and existing qualifications in the trades of the Port of Vigo, as it includes the business vision and the needs of the different agents. It is also committed to adapting the educational plans to the professional needs of the Blue Economy operators, for the implementation of training programs. Priority has been given to learning aimed at improving skills in port logistics, knowledge of the fishing product and its marketing, and alternative energies and their supply to vessels. This indicator has very low values and needs to be improved.

The second fundamental principle is the adequacy of infrastructure and IT systems. Goods must be digitally recorded and digitally controlled at all times from the moment they are unloaded until they leave the port for first or second sale. At present, goods are digitally registered, which serves as a starting point for this area of the Port of Vigo’s development:

- Digitalization: This section measures the degree of digitization of fishing ports at a macro level, and compared to ports dedicated to other activities. Within the framework of the Ports 4.0 program at state level, a series of measures and support for the financing of this type of project have been introduced in different ports. Despite this, fishing activities have been left aside as other sectors are firmly committed to. This indicator, despite not having a low value, should be considered significant given the current importance of these elements. In general terms, the area of technology in the macro environment has a value of 65%, which places this area at a fairly advanced level.

On the other hand, it is important and necessary to take advantage of the activities and features in which the Port of Vigo is a pioneer and executes in a correct and environmentally responsible way. The aquaculture sector, thanks to developments and innovations of recent years, is growing to a great extent and it is necessary to continue along this path in order to relieve the pressure exerted on many species in many fishing grounds worldwide.

- Hatcheries and aquaculture: This indicator only takes into account the fish obtained from floating harbour hatcheries and from aquaculture.

Currently, along the Vigo estuary, there are 500 mussel cultivation rafts, which represent an annual quantity of 37 million kilograms. In addition, along the Port of Vigo, there are a series of hatcheries dedicated to the production of high-value shellfish, such as crabs, spider crabs, and lobsters.

- Innovation in aquaculture: This indicator takes into consideration those developments that have been carried out in the Fishing Port of Vigo to improve aquaculture; increasing the volume produced and reducing the environmental impact.

Between the universities of Vigo and the Spanish Institute of Oceanography (IEO), there have been various training programs set up within this sector that makes both the
estuary and the Port of Vigo areas at the forefront of the aquaculture industry. So much so that the first aquaculture method for effectively cultivating octopus has been developed and implemented in Vigo.

Historically, the Port of Vigo has been one of the key fishing ports in Spain, not only in terms of the quantity of goods unloaded at its docks, but also in terms of technological advances and the development of aquaculture.

5. Conclusions

The end-to-end tool makes it possible to establish the necessary tasks and the path to be followed by the Port of Vigo in order to become a green port, while also considering the changes and demands imposed by its environment. In this way, the Port’s past can be examined, the present can be studied, and the motivations and capacities necessary to move forward into a sustainable future can be determined and plotted.

This study utilized a novel end-to-end tool methodology that can help to outline scenarios for fishing ports where green port development is planned. The literature on fishing ports and the sustainability issues associated with green ports has been very limited, so the contribution of this research is a further step forward.

The case study, the Port of Vigo, is one of the most important fishing ports in Spain, in Europe, and worldwide. For this reason, it must be placed at the forefront of the industry and commit itself to modernization and sustainable development. Despite the fact that fishing does not economically contribute as much as other port activities, it is still an essential activity. The next important step that could place the Port of Vigo at the forefront of technological and economic matters is the diversification of its income, highlighted by the indicators of growth expectations and diversification, indicators that obtained the lowest scores, so effort must be focused on advancing along these lines.

This specific pathway was determined by the application of the end-to-end methodology in the context of the green port framework. It will enable the financing of specific projects that will allow the Port of Vigo to grow in a sustainable way and remain focused on the use of clean energies. The renewable energies indicator scored reasonably well, given the efforts made by the Port of Vigo in this area, but it must continue to evolve, being a key feature of green ports.

A selection of the most important elements for developing a green port in the Port of Vigo are listed in Figure 8.

![Figure 8](image_url)

Figure 8. Key features for the Port of Vigo to address in order to become a green port. Source: own elaboration.

Historically, the Port of Vigo has not had a close relationship with the city of Vigo in terms of planning. The fishing port was developed separately from the city itself. The areas closest to the coast were exclusively used for port uses, with a high presence of industries and shipyards; this generated a division between the city and the port. In the past, a detrimental component in terms of sustainable development has been the port-city relationship; the port must improve this element in order to be able to achieve its green port ambition.

In terms of the present situation of the Port of Vigo, the current repercussion indicator reflected the impact that the Port of Vigo has on the city of Vigo at present. Factors such as perceptions of fishing in Galicia, the employability of the sector, the consumption of fish in
the city of Vigo, the social programs carried out in the port to raise awareness of the sector, etc., were considered. This indicator obtained a very low value and must be improved in order to ensure the status of a green port. The port authorities should work towards ensuring a more institutional approach, as well as promoting actions of a sustainable and environmental nature, which registered relatively lower values.

With regard to the short-term future of the Port of Vigo, based solely on the recent evolution of the tonnage of goods entering Vigo’s fishing port fish markets each year, there are no expectations of growth in this area due to the catch limits imposed by the European Union. Despite this, the Port of Vigo could tackle new business models and exploit opportunities that are not currently being exploited in any other fishing port in the world.

With regard to the macro environment, which corresponds to the port in which the fishing port of Vigo is integrated, the features that need to be improved are the economic, social, cultural, and legal features. Institutional and sustainable environments are key features of the green port framework, along with technological components.

In terms of economic features, both in the Port of Vigo and in other Spanish fishing ports, income has remained constant over the last decade due to the fact that quotas have limited the tonnage of fish entering Spanish ports. Taking this into account, and the fact that prices have not undergone excessive changes, the income received by the Spanish fishing ports has remained relatively consistent.

In terms of social and cultural influences, the perception of fishing at a national level is conditioned by the nature of the industry. Fishing is a primary activity, with scarce resources and very difficult working conditions. This, together with the social perception of intensive fishing and the impact on ecosystems, makes fishing a sector that is not well regarded by a large part of the population. This element must be improved in order to advance the green port development of the Port of Vigo.

Employability, both at the level of extraction activities as well as food processing (canneries) and ship services, is decreasing year by year. The various technological advances in the sector have led to a reduction in the total number of employees. This, together with the EU quota system, makes the fishing sector in Spain a minority industry that needs to be expanded.

The legal environment is determined by the European Union’s system of quotas and Total Allowable Catches (TAC), which have represented the hardest blow to Spanish fisheries in recent history.

The limitation of catches has meant that fishing in Spain has remained consistent over the last 30 years (with the exception of extractions from aquaculture).

In order to achieve the objective of becoming a green port, the port of Vigo must integrate technologies such as the Cloud, Big Data, and sensorization. In this way, and working together with the port community, the creation of more efficient logistics platforms should be promoted. To do so, the encouragement of coordination and communication between the different actors in the port-logistics field must be encouraged. However, the mere application of these technologies does not in itself guarantee that a community becomes “smarter”.

In line with European guidelines and measures regarding sustainability, as well as the use of renewable energies, an increasing number of ports are now considering self-generation. This is a technology that is currently available, although efficiency improvements are expected, and some ports are already implementing it.

In order to achieve green port status, the main focus of the Port of Vigo should be on sustainable energy use and self-consumption. For this, the framework of the Ports 4.0 project is a good starting point, although it will not achieve all the of the objectives necessary. It will be essential to improve the efficiency of equipment and lighting, especially in the case of refrigeration equipment, which currently has a high consumption rate. In order to promote self-consumption and the use of renewable energies, it is proposed that the roof surfaces of the auction houses be used for the installation of solar panels. Similarly,
it is proposed to create spaces in which to place a series of batteries that will enable part of the buildings’ consumption requirements to be met. Due to the nature of the auction days, it is necessary to have another method of energy generation for when there is no solar lighting and the photovoltaic panels do not generate electricity. To this end, similar to the Port of La Coruña, a series of wind turbines could be installed to meet part of the Port’s energy consumption requirements. Finally, in order to reduce electricity consumption in the fish markets, it will be necessary to carry out a study of the energy consumption of the buildings and to analyze whether losses can be mitigated by using more insulating materials than those currently used.

In view of the changing trends in society in relation to sustainability and the use of renewable energies, the Port of Vigo has proposed a series of initiatives to modernize activities and infrastructures that will enable the port to be at the forefront of sustainability efforts.

While it is clear that digitization can lead to greater efficiency, help reduce costs, and provide numerous environmental benefits, ports and the maritime industry in general have been slower to adopt digitization than other industries. The main problem facing the Spanish port sector is the fear of creating a competitive disadvantage if data is shared. Secondly, it would be necessary to move towards a new port community paradigm, so that the flow of information between the participants of a port community is achieved in a reliable, efficient, paper-free way. Thanks to technologies such as blockchain, this can be achieved in a secure way. The third key element is the development of new profiles. This commitment to technology is not only changing the way of working in port facilities, but also the profiles of the workers themselves, who see how the competences related to digitalization are becoming more important in order to be able to perform their tasks properly. Thus, digital knowledge and information management, understood as the ability to professionally develop by efficiently using digital resources and tools, and then integrating all of this into their day-to-day work, is essential in this environment.

With little effort from the Port of Vigo in implementing these suggestions for development, the short-term future scenario (taking 5 years) could reach 50% compared to the theoretically perfect situation; it could also be estimated to reach 80% for a long-term scenario of 10 years.

One of the most notable limitations in this field is how little progress has been made on the issue of green ports implemented in the context of fishing ports, which could serve as a guide for the development of a diagnostic and planning tool that would allow future scenarios to be proposed. Public and private port agents are well aware of the need for this commitment, and there has been complete collaboration when it comes to developing these study initiatives, but it would be necessary to determine who should lead these initiatives.

Research should be conducted to determine how other fishing ports in the Spanish port system are developing, in order to obtain a picture of how the whole system is developing overall, especially given that the Spanish port system tends to present numerous asymmetries between the so-called large and small ports.

Considerations could also be given to studying fishing ports in other countries to serve as points of comparison.

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