CHARACTERIZATION OF TUGBOATS ACTIVITY WITHIN SPANISH PORTS

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Abstract

The maritime industry's vital role in global trade contrasts with its significant greenhouse gas emissions. Pollution emitted from ports comes from different sources, one of which is merchant ships constantly docking and undocking and other auxiliary port vessels working continuously throughout the year (e.g., pilotage vessels, bunkering barges, vessel-generated waste collection services, mooring and unmooring services and port tugs). Port tugboats sail between terminals and provide docking, undocking and removing merchant ship services. This leads to a high variability on tugs' manoeuvres. The first and most representative characteristic of a tug's manoeuvre is the vessel in need of the service (e.g., ship particulars, cargo carried or mooring zone, among others), which usually defines the type of manoeuvre and the number of tugs needed. This study presents the initial phase of the research project TUG-EMI (Optimizing in-port tugboats emissions) aiming at reducing in-port emissions by optimizing tug's manoeuvres. At this stage, the project focuses on characterizing tug manoeuvres within Spanish ports by combining a general overview of tug characteristics and prescriptions of port tugboat services in Spain, incorporating insights from stakeholder interviews. Tug shipmasters and chief engineers with a large experience are interviewed, aiming to obtain detailed information of how manoeuvres are performed and how to characterize them.

1 INTRODUCTION

Maritime transport is the pillar of economic growth as 80% of worldwide freight is carried by vessels (UNCTAD 2022). However, it is a substantial source of greenhouse gas emissions (GHG) causing a noticeable impact on air, water and biodiversity and generating a social alarm particularly in coastal communities. Greenhouse gas emissions from shipping increased worldwide by 9.6% from 2012 to 2018, amounting to some 1076 million tonnes, accounting for 2.9% of global GHG emissions (International Maritime Organization 2020). This figure is a small amount compared to the close to 3 trillion of CO_2 tones in the atmosphere that represents 27% more than in the industrial revolution period (OCEANA Europe 2022). In this regard, CO_2 is responsible for ocean acidification, temperature rise and sea level rise, contributing to climate change together with other greenhouse gases (GHG) such as methane or hydrofluorocarbons. In global terms, the quantified SO_x, NO_x and $PM_{2.5}$ emitted from shipping sector was 24%, 24% and 9% of worldwide emissions, respectively (European Maritime Safety Agency 2021). A growth in global seaborne trade is forecasted in the near future because of the world's growing population, which will translate into an increase in air pollution from maritime transport (International Maritime Organization 2020). In parallel, the growth of maritime transport and the pollutants emitted has created a social alarm in coastal communities that has to be addressed. Major concerns are related to the consequences of emissions on human health affecting respiratory systems among others (Sofiev et al. 2018; Viana et al. 2014). As a consequence of the exisiting and predicted paradigm, the International Maritime Organization (IMO) has developed and adopted over the years more stringent regulations aimed at dramatically abating emissions from vessels (Raza 2020).

Exhaust from large marine diesel engines contributes significantly to the anthropogenic burden, thereby affecting the chemical composition of the atmosphere, global climate, and air quality in coastal areas (Capaldo et al. 1999; Duce et al. 2008). Pollution emitted from ports comes from merchant ships constantly docking and undocking but also from other auxiliary port vessels working continuously throughout the year, like pilotage vessels, bunkering barges, vessel-generated waste collection services, mooring and unmooring services and port tugs.

The need to emission-control policies and regulations at ports is widely acknowledged as an active policy issued by maritime port authorities. It is also considered an answer of international and European regulations and depends on an accurate estimation of emission inventory in close-to-land and in-port (Yu et al. 2021). Port tugboats frequently sail between terminals (light-sailing) and provide docking, undocking and removing merchant ships services. Port tugboats have powerful engines but they are not prepared for speeding and in most ports, between 40% and 70% of all light-sailing is done at speeds where the fuel consumption is higher, often for no reason. Murcia González (2021) also reports that only 3.5% of the total time operation, tugs are required to give maximum power, and at only 0.5% of total manoeuvring time, the main engines have a maximum continuous rate of 81%, confirming that not as much propulsion power is needed during the manoeuvres of a tugboat, and smaller ones could be used. It would reduce emissions and fuel consumption.

Tugboats stand as indispensable assets within the maritime domain, assuming a pivotal role in the safe and efficient manoeuvring of vessels within ports. Their operations represent a cornerstone in ensuring the seamless management of port traffic across all maritime hubs. The main objective of this study is focused on characterizing tug manoeuvres within Spanish ports, the initial phase of the national research project TUG-EMI (optimizing in-port tugboats emissions).

In the following sections, this article presents the methodology and results, combining data from tugboats characteristics, prescriptions of port services in Spain, and incorporating insights from stakeholder interviews. Finally, the article concludes with some insights drawn from the findings and observations of this research. The data will provide a comprehensive understanding of the procedural and operational characterization of tugboat activities within Spanish ports.

2 METHODOLOGY

This section describes the methodology conducted to obtain a general overview of the tugboats activity in Spain (see Figure 1). The flowchart illustrates the methodological process followed to carry out the study of tugboat activity in Spanish ports, from the identification of relevant ports to the collection of data and analysis of results.

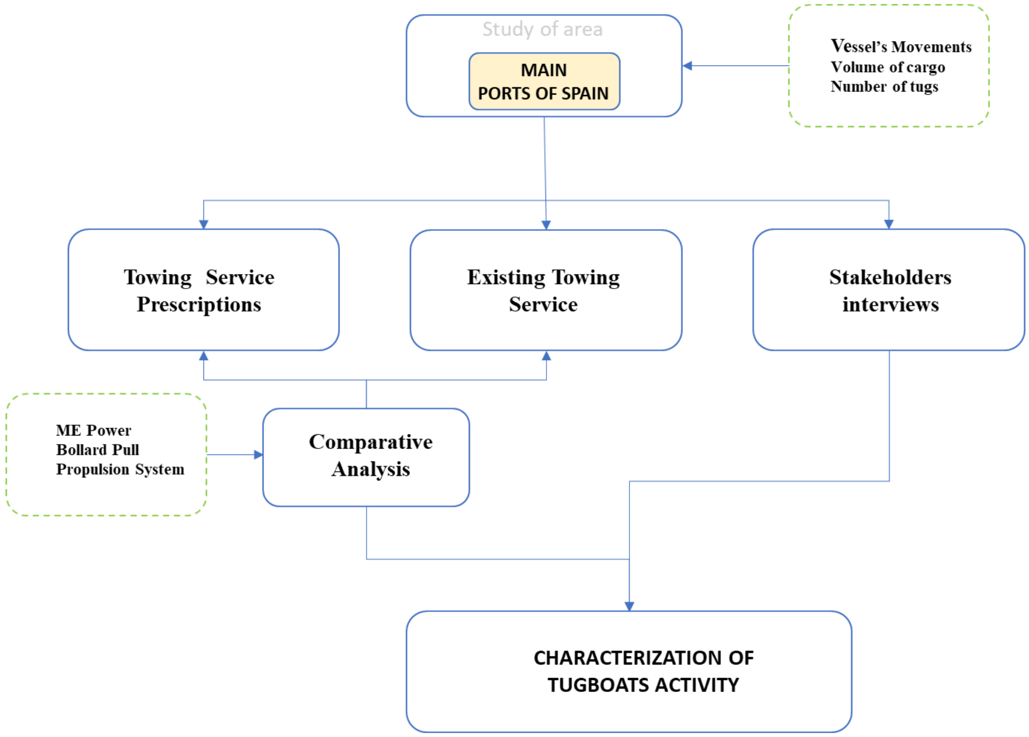

Fig. 1 Flowchart of characterization tugboat activity in Spain

The methodology used to characterise tugboat services in Spanish ports is divided into different steps. First, the definition of the area of study, identifying the relevant ports based in key parameters. Then, after defining the study area, detailed analysis of the port prescriptions related to tugboat services is conducted considering technical specifications required by each port for tugboat services. On the other hand, the main characteristics of the existing port tugboat services in the ports within the study area have been analysed, comparing them with the reference values derived from technical port prescriptions. Finally, a set of interviews are designed and conducted with relevant stakeholders such as tugboat captains and chief engineers to gather information about ship and tugboat manoeuvres in ports.

2.1 Area of study

In order to carry out the characterization of the towing service in Spain, a comparative analysis has been conducted among the ports that are relevant in maritime traffic to some extent. To fulfil this purpose, three factors have been considered: i) the number of vessels' movements of each port, by means of the information published in the annual reports by different port authorities; ii) the total volume of cargo in different ports, and iii) the number of tugs per port, sourced from statistics published by Spanish Puertos del Estado (www.puertos.es).

To restrict the study area of this analysis, the following reference values have been taken into account for each of the parameters: a minimum of 1,000 vessel entries, a minimum of 3,500,000 metric tons, and maintain a minimum fleet of 4 tugboats. Accordingly, the result obtained provides a list of the main ports in Spain subject to this study, both by the number of manoeuvres performed and by the total volume of cargo handled.

2.2 Towing service prescriptions

Once the most relevant ports are identified, it is possible to proceed with the study of the different technical prescriptions required by the various port authorities for their own ports. These prescriptions take into account the level of operability, the characteristics of the ports and the climate, among other factors. Through this analysis, a series of reference values are obtained for all selected Spanish ports, taking into account, their main engine power, bollard pull and propulsion system. These reference values will serve to position the existing technical prescriptions situation in Spanish ports.

2.3 Existing towing services in Spanish ports

For the characterization of the current situation in the main Spanish ports, it is necessary to understand the resources they have available, starting with the knowledge of each tugboat operating in these ports. To compare the actual values of port services with the reference values of technical prescriptions, the same data has been collected regarding the main engine power, bollard pull and propulsion system.

2.4 Stakeholders interviews

To characterize ship-tug manoeuvres within ports, the last step of the applied methodology involved designing interviews with relevant stakeholders, including tug shipmasters and chief engineers with a large experience. A total of 17 interviews were conducted with stakeholders from different Spanish ports, including Barcelona, A Coruña, Valencia, Castellón, Algeciras, La Rápita, Tarragon, Gijón, Las Palmas de Gran Canaria, Sagunto and Carboneras. To achieve this, the interview has been divided into 4 sections: Personal data related to the job position; Specific data about the tugboat; Specific data about the characterization of tugboat manoeuvres; and Personal experience questions about optimizing tugboat operations and manoeuvres.

3 RESULTS

This section describes the main outcomes of the different subsections outlined previously. By collating reference values from the technical prescriptions, identifying operational data of tugboats within the selected ports, and integrating insights from stakeholder's interviews, it facilitates the characterization of the tugboats activity in Spain.

3.1 Area of study

In Spain, ports of general interest are those managed by the "Dirección General de la Marina Mercante" through Puertos del Estado, and they have a strategic relevance for foreign trade and the country's economy. From the last update in January 2022, there are 48 ports of general interest in Spain divided in 28 port authorities. These port authorities sometimes have more than one port available, and their cargo volumes are accounted for under the same port authority. For this reason, in Figure 2, the 28 port authorities are shown rather than the ports.

These ports include some of the most important in the country, such as the Port of Algeciras, the Port of Barcelona, the Port of Valencia, the Port of Bilbao, among others.

From the information of all Spanish ports, an analysis, which includes the total cargo volume, the number of tugboats available at each port and the number of vessels' movements of each port, is conducted. Results are shown in Figure 2. This figure illustrates the correlation between the total cargo volume handled at each port and the corresponding availability of tugboats, as well as the relationship between the number of tugboats and the overall number of vessels that have entered each port. The boundary reference values have also been represented in this figure for the subsequent analysis, taking into account:

- Total cargo volume per port ≥3,500,000 metric tons
- Total number of vessels that have entered the port ≥ 1000
- Total number of tugboats per port ≥ 4

Fig. 2 Volume of cargo and number of tugs (left) and number of entered ships and number of tugs (right)

The aforementioned criteria are selected based on their significant representation of the maritime industry's operational landscape. First, ports handling 3,500,000 metric tons or more of cargo are strategically prioritized, as they collectively contribute to 95% of the total cargo volume within Spanish ports, underscoring their pivotal role in national trade dynamics. Second, regarding tugboat availability, the threshold of 4 or more tugboats is established following thorough assessments. Reflecting the standard towing infrastructure prevalent across 85% of Spanish ports, thus ensuring operational readiness and efficiency. Lastly, the stipulation that 90% of ports have hosted 1000 or more vessels underscores the extensive maritime traffic and navigational activity within Spanish waters.

After the application of the above criteria, the final study area is established. A total of 18 Spanish ports have been selected for characterizing port tugs based on threshold values of cargo volume, tugboat availability, and vessel movements Figure 3 shows the selected ports.

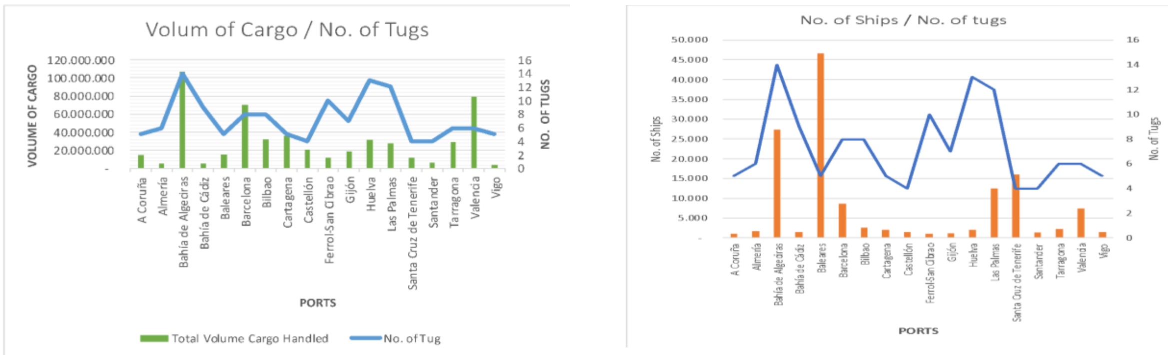

Fig. 3 Volume of cargo and number of tugs (left) and number of entered ships and number of tugs (right) of the study of area

In some cases, there is no straightforward correlation between the total cargo volume and the number of tugboats, nor is there a direct link between the number of visiting vessels and the available tugboat count at each port. This phenomenon arises from a set of specific conditions. For instance, in the case of the Balearic Islands, a significant portion of their cargo volume is transported via ferries and passenger vessels. This particular traffic seldom necessitates tugboat services, thereby creating a disparity between the overall cargo volume and the requisite tugboat count at the port.

Therefore, the definitive compilation of ports forming the study area is based on criteria such as total cargo volume (figure 4 left), the number of tugboats (Figure 4 right), and the total number of vessels (Table 1). Accordingly, Table 1 provides the list of main ports and the number of tugs subject to this study.

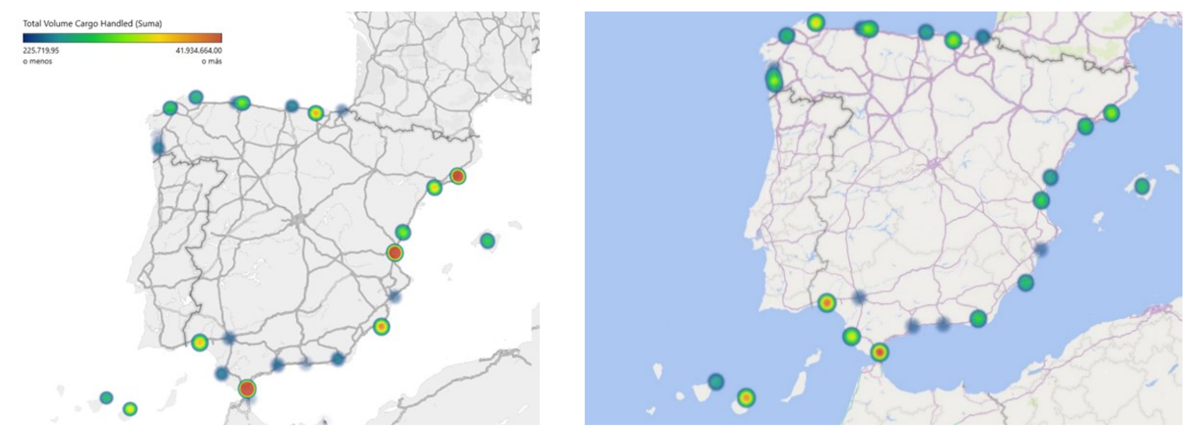

Fig. 4 Distribution volume cargo (left) and distribution number of tugs (right) for each selected

Port	No. of Tugs
A Coruña	5
Almería	6
Bahía de Algeciras	14
Bahía de Cádiz	9
Baleares	5
Barcelona	8
Bilbao	8
Cartagena	5
Castellón	4
Ferrol-San Cibrao	10
Gijón	7
Huelva	13
Las Palmas	12
Santa Cruz de Tenerife	4
Santander	4
Tarragona	6
Valencia	10
Vigo	5

Table 1 Final selection of the area of study considering the number of tugs

3.2 Towing service prescriptions

In this section, the results of the analysis of the technical specifications required by each port for the towing service are presented. The 'tug prescriptions of a port' refer to the regulations or guidelines set by a port for the use of tugboat services. These prescriptions may include specific requirements regarding the number and technical capabilities of tugboats required, as well as operational procedures during towing operations in the port. They are designed to ensure the safety and efficiency of vessel manoeuvres within the port.

Upon examining the prescriptions for all Spanish ports, a similar analysis is conducted, focusing exclusively on ports within the study area. It is pertinent to note that the dataset is incomplete due to the unavailability of technical prescriptions from certain ports for towing services. Hence, out of the 131 tugboats constituting the study area, a subset of 23 tugboats is excluded from analysis, leaving a sample size of 108 tugboats for examination.

For the characterization of the Spanish towing service prescriptions, following parameters have been taken into account: (1) Bollard pull; (2) Propulsion system; and (3) Main Engine (ME) power.

3.2.1 Bollard pull

Following the analysis of the data from the ports within the study area, Figure 5 shows the distribution of the different bollard pull values across the ports. The distribution was constructed solely based on the diverse bollard pull values without consideration for the number of tugboats present in each port within the study area.

After reviewing the distribution of the bollard pull, the analysis shifts to the number of tugboats present in the ports relative to the bollard pull (see Figure 5). Figure 6 illustrates the correlation between bollard pull and the quantity of vessels required to adhere to these technical specifications. It is observed that 48.14% of the prescribed vessels fall within the range from 50 MT to 70 MT, totalling 52 vessels. It is important to note that not all ports have bollard pull prescriptions for all tugboats.

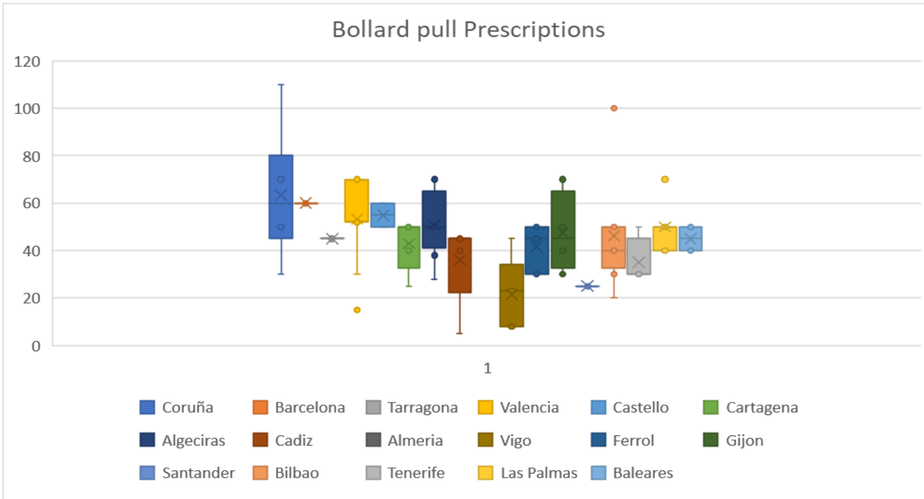

Fig. 5 Distribution of bollard pull technical prescriptions

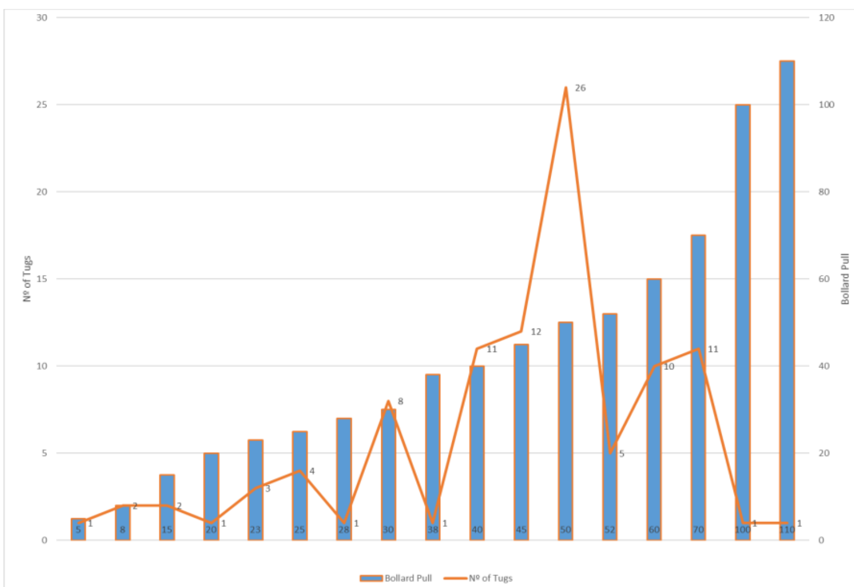

Fig. 6 Distribution of bollard and number of tugs technical prescriptions

3.2.2 Propulsion system

Regarding the prescriptions, the type of propulsion that ports require for the tugboats that will operate their ports is also reviewed. Out of the 108 vessels analysed (see Figure 7), only 11 tugboats employ conventional propulsion, representing 10.18% of the total. Additionally, 20 vessels lack specifications regarding propulsion type, making up 18.51% of the reviewed vessels.

Conclusively, upon assessing the remaining vessels, which encompass 71.29% of the total analysed in this section, all are equipped with omnidirectional propulsion (Azimuthal (ASD) or Voith propulsion). A more detailed analysis reveals: 17 vessels use Azimuthal propulsion, accounting the 15.74% and 28 vessels use Voith propulsion, comprising 25.92 % of vessels with omnidirectional propulsion. The remaining 32 vessels, which constitute 29.62% of the total tugboats with omnidirectional propulsion, lack specifications regarding propulsion type (Omnidirectional).

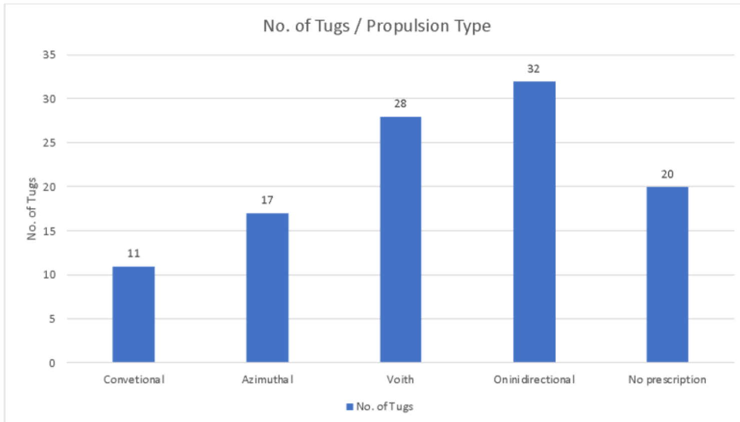

Fig. 7 Distribution of type of propulsion of technical prescriptions

3.2.3 Engine power

Finally, this section examines the engine power specifications of the tugboats within the ports of the study area. After reviewing the power ratings, an average power value is derived, yielding a mean of 2897 kW (Figure 8).

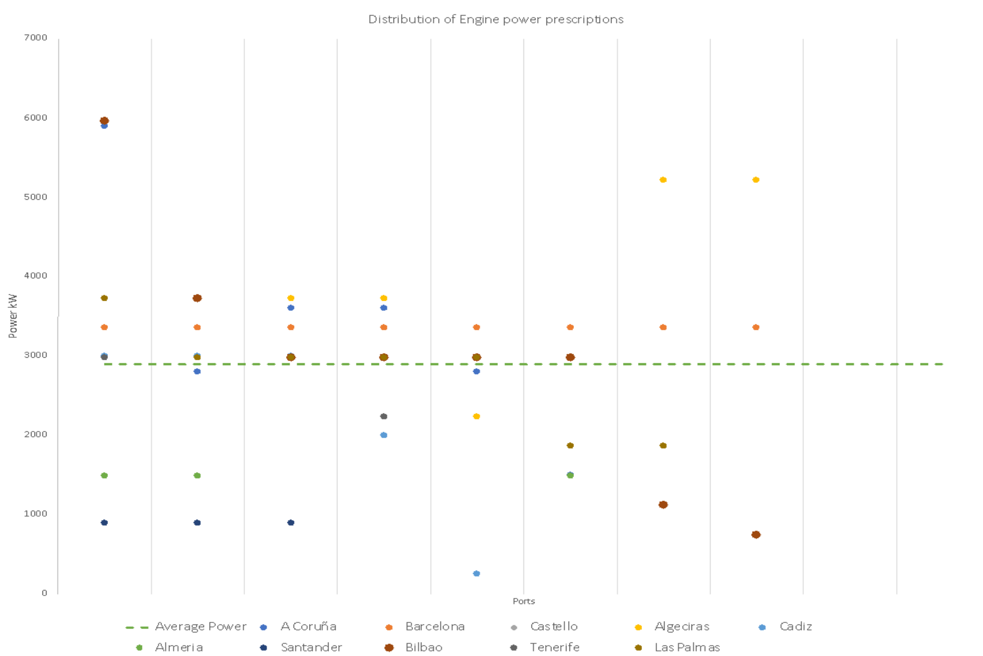

Fig. 8 Distribution of engine power each tugboat from prescriptions

Out of the total of 108 ships listed in the towing technical specifications, the power criterion appears only 59 times as a requirement for the ships that will provide service in the ports of the study area, constituting 54.6% of the total prescribed ships. Of the 59 tugs for which power data are available, 41 have a power higher than the average value obtained from the technical specifications, i.e. 69.49% of the total number of tugs appearing in the power specifications.

3.3 Existing Towing services

In this section, the existing situation of the towing service in the 18 selected ports is analysed. Firstly, it is worth noting that the total number of tugboats providing service in all Spanish ports (as considered by Puertos del Estado) is 159 vessels, of which 125, data on bollard pull has been obtained. Therefore, these 125 tugboats represent 78.61% of the total vessels providing service in the ports of the study area, distributed as shown in figure 9.

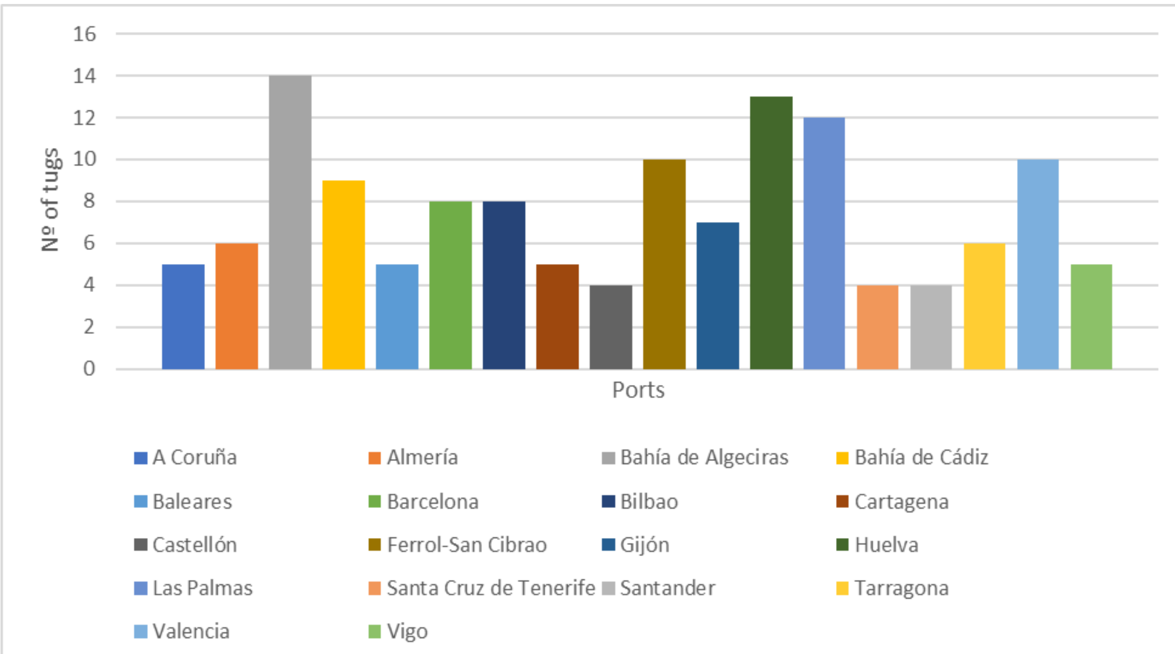

Fig. 9 Number of tugs for each port within the area of study

3.3.1 Bollard Pull

As depicted in the histogram of Figure 5, the predominant concentration of bollard pull prescriptions is located within the range spanning from 50 to 75 metric tons. This comprises a total of 70 tugboats, representing 56% of the vessels operational within the designated study area (Figure 10).

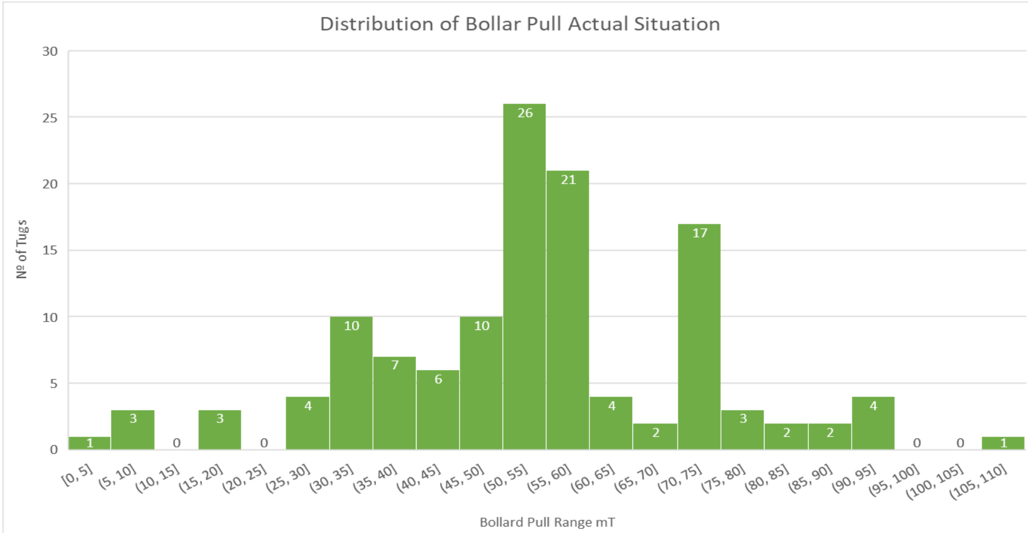

Fig. 10 Distribution of bollard pull and number of tugs of the area of study

Upon reviewing the overarching distribution of bollard pull relative to the total fleet, the next step involves scrutinizing the bollard pull distribution of tugboats within the ports of the study area vis-à-vis the predetermined benchmark of 50 tonnes bollard pull, established subsequent to a comprehensive analysis of technical specifications as observed in Figure 11.

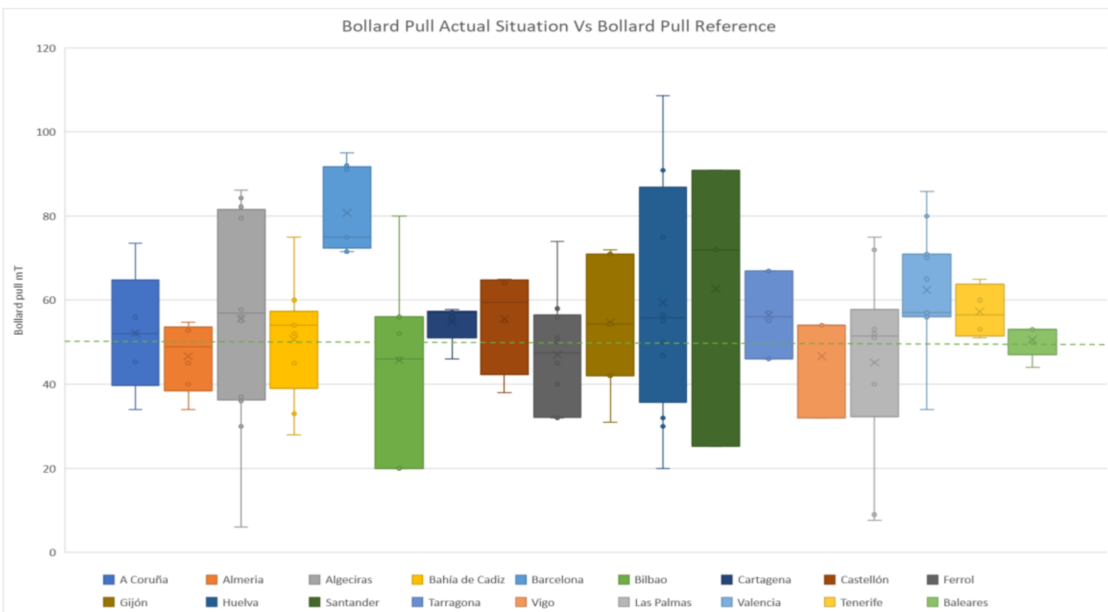

Fig. 11 Distribution of bollard pull for each port in relation average bollard pull

Figure 11 shows that many of the tugboats surpassing the 50 mT bollard pull criterion. Notably, Barcelona stands out with the highest average bollard pull in the study area, surpassing 80 mT. Furthermore, Huelva distinguishes itself by hosting the tugboat with the highest towing capacity among all entities within the study area, boasting a bollard pull exceeding 108 mT.

After scrutinizing the bollard pull data, it becomes evident that among the 125 tugboats for which pulling capacity data is available, the following findings emerge:

- 84 tugboats, constituting 67.2% of the total, surpass the reference value of 50 mT for bollard pull.
- 38 tugboats fall within the range of 20 mT to below 50 mT, representing 30.4% of the tugboat cohort within the study area.
- 3 tugboats exhibit a pulling capacity below 20 mT, amounting to 2.4% of the overall tug fleet.

3.3.2. Type propulsion

This section shows the distribution of tugboats in the ports of the study area in relation to the propulsion system installed on each tugboat. As shown in Figure 12, out of the 125 tugboats within the study area:

- 58 tugboats are equipped with an azimuthal propulsion system, constituting 46.4% of the total vessels in the study area.
- 41 vessels are fitted with the Voith Schneider propulsion configuration, representing 32.8% of the tugboats in the study area.
- 20 tugboats utilize a conventional propeller and rudder system, comprising 16% of the total tugboat fleet in the study area.

Finally, the two less common propulsion systems are:

- 5 vessels employ an Asymetric Tractor Tug (ATT) propulsion configuration, making up 4% of the total tugboats in the study area.
- 1 tugboat is configured as a rotor tug, accounting for 0.8% of the total study area.

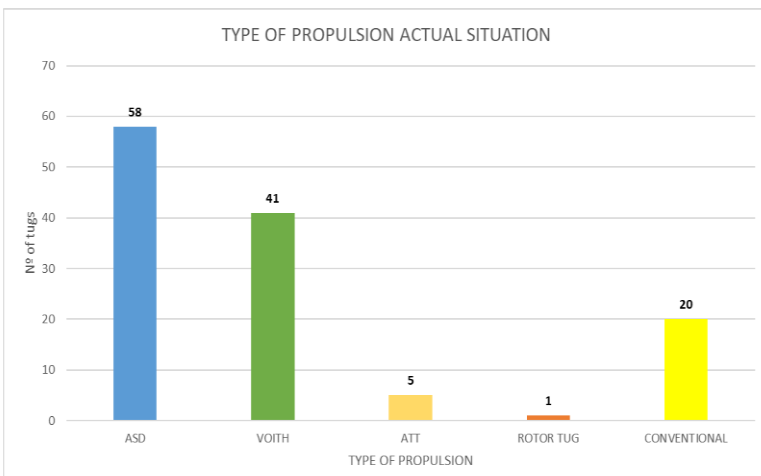

Fig. 12 Distribution of type of propulsion system within the study port area.

Despite the widespread use of omnidirectional propulsion, including both azimuthal and Voith propulsion methods, azimuthal propulsion remains the predominant choice. However, in this context, vessels equipped with Voith propulsion experience deficiencies compared to those with azimuthal propulsion, as the latter demonstrate superior compliance with prescribed standards.

3.3.3. Engine Power

Finally, the existing situation of the towing services in the ports of the study area is analysed in relation to the installed ME power. Upon thorough examination of the data concerning the installed power within the tugboats, and utilising the mean power value obtained from the technical towing specifications (2897 kW) as a reference value, the distribution of the tugboats in relation to their power is delineated. In this context, the data used is obtained from 136 tugboats out of the total 159 comprising the towing service within the study area.

Upon analysing the power data as shown in figure 12, the distribution is observed in relation to the mean power value obtained from the technical towing prescriptions of the ports in the study area.

- Among the 136 vessels for which data has been obtained, 84 of the tugboats in the study area's fleet, comprising 61.76%of the total, exhibit a power output surpassing the mean value derived from technical specifications (2897kW).
- Eighteen tugboats are situated within the power range spanning from 2,000 kW up to the mean power value, constituting 13.24% of the total tugboat fleet.
- Thirty-four tugboats within the study area exhibit powers below 2,000 kW, representing a cumulative 25% of the tugboat fleet.

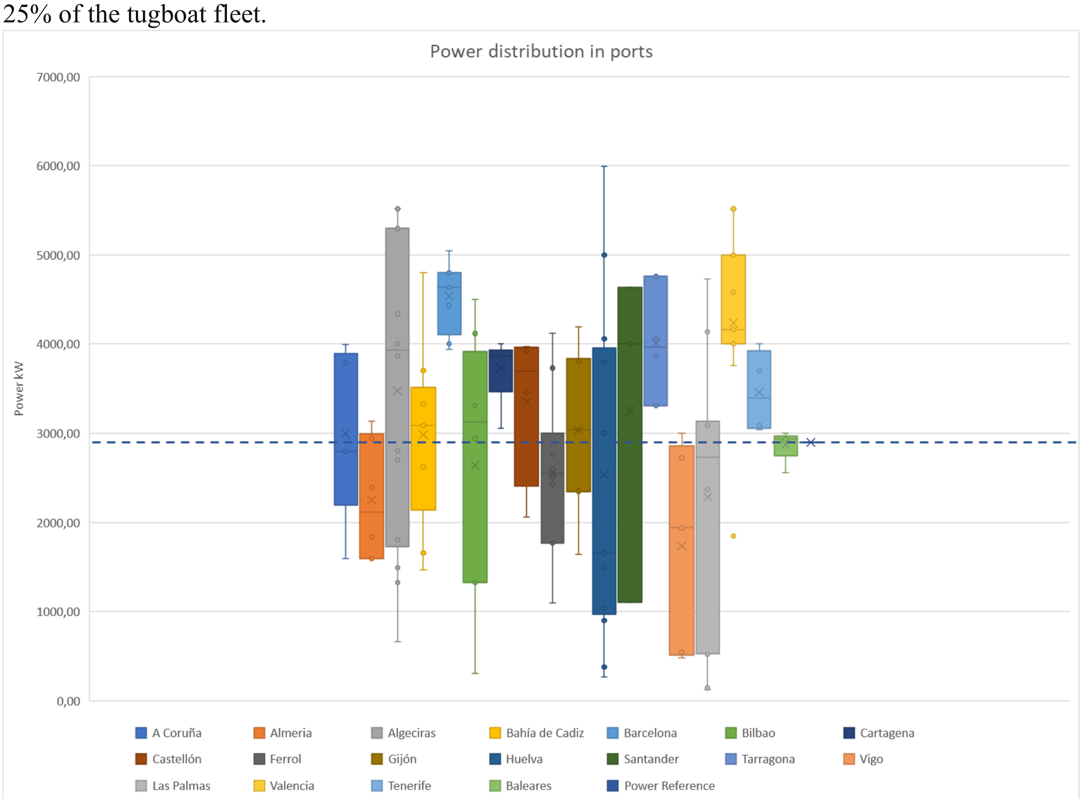

Fig. 13 Distribution of each tugboat for ports in relation average engine power

3.4 Interviews

To characterize ship-tug manoeuvres within ports, the third step of the applied methodology involved designing interviews with relevant stakeholders, including tug shipmasters and chief engineers with a large experience. A total of 17 interviews were conducted with stakeholders from different Spanish ports. The main objective of these interviews is to gather information regarding the characterization of manoeuvres based on the experience of key stakeholders of tugboats within Spanish ports. To achieve this, the survey has been divided into 4 sections:

- Section 1. Personal data related to the job position.
- Section 2. Specific data about the tugboat.
- Section 3. Specific data about the characterization of tugboat manoeuvres.
- Section 4. Personal experience questions about optimizing tugboat operations and manoeuvres.

Open fields, multiple and close questions totalling 29 questions, were asked. This interview can be found in Appendix 1.

Section 1. Personal data related to the job position

A total of 17 interviews were conducted to tug shipmasters and chief engineers from various Spanish ports, including Barcelona, A Coruña, Valencia, Castellón, Algeciras, La Rápita, Tarragona, Gijón, Las Palmas de Gran Canaria, Sagunto, and Carboneras. These ports represent 72.7% of the study area. Eighty-six percent were from the deck department (masters or first mates), while the remainder were from the engine department (chief engineers), being the 88.2% men.

Section 2. Specific data about the tugboat

This section gather information of specific data about the tugboats as dimensions, ME power, bollard pull, type of fuel and type of propulsion, with the aim of being able to compare these parameters with the same parameters than the previous sections.

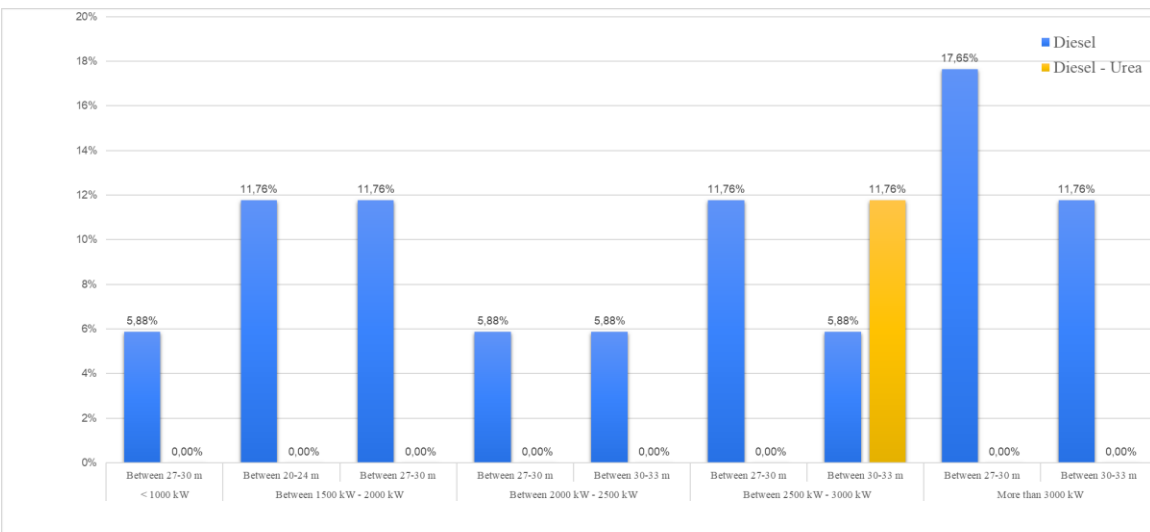

Fig. 14 ME power in function of the length and type of fuel used of tugboats of the interviewed stakeholders.

Figure 14 reveals that a significant portion of interviewees are employed on tugboats spanning lengths between 27 and 33 meters, equipped with power systems exceeding 3000 kW.

If we consider whether any emission mitigation measures is currently being undertaken to reduce emissions on-board, more than half of the surveyed respondents have answered affirmatively, including the incorporation of urea blended with diesel fuel, while the remainder persist in operating with diesel, as observed in Figure 15.

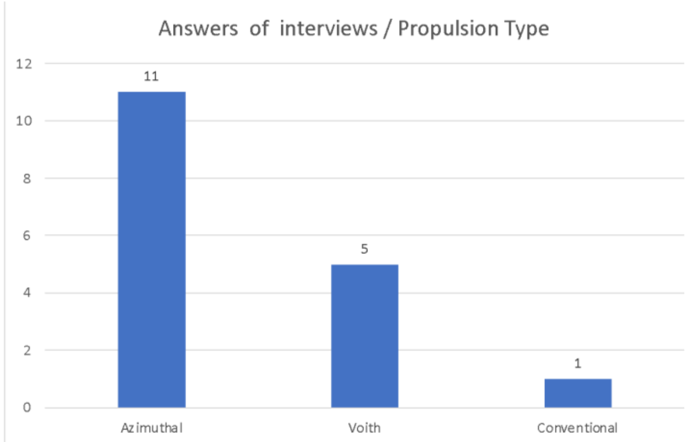

Fig. 15 Answers of stakeholders in relation with propulsion type.

Except for one of the interviewees, the rest have highlighted the significant advantage of using omnidirectional tugboats (Voith and ASD) due to their great capabilities, with the azimuthal propulsion system being deemed more practical. Of these, 11 are azimuthal, representing 64.7% Of those, 5 are Voith, which equates to 29.4%. The last one represents 5.8%, which corresponds to 1 tugboat.

<u>Section 3. Specific data about the characterization of tugboat manoeuvres</u>

The main objective of this section is to characterize the tugboat manoeuvres, considering the different operational phases within manoeuvres, types of available manoeuvres, and dependence on port plan design. The manoeuvring stages of a tugboat are divided into the following parts:

- Push: involves applying force to push a vessel in a specific direction, facilitating its movement.
- Pull: in a tugboat refers to the action of using the tugboat's force to tug or move a vessel in a specific direction. This involves the use of ropes, towlines, or other devices to apply the necessary force to move the vessel forward.
- Escort: Escort" in a tugboat refers to the action of accompanying and assisting another vessel, providing guidance, security, and support during its navigation. This can involve navigating alongside the escorted vessel to aid in navigation through congested areas, adverse conditions, or to provide additional protection as needed
- Free Sailing: means a tugboat that is sailing without towing or being involved in a towing operation at that time. In other words, the tugboat is sailing freely on the water without being engaged in assisting other vessels at that moment.

Figure 16 shows the time that tugboats operate at maximum power with the main propulsion system during the manoeuvre. As observed, the tugboats operate at maximum power less than 10% or between 10%-20% of the time during the manoeuvre.

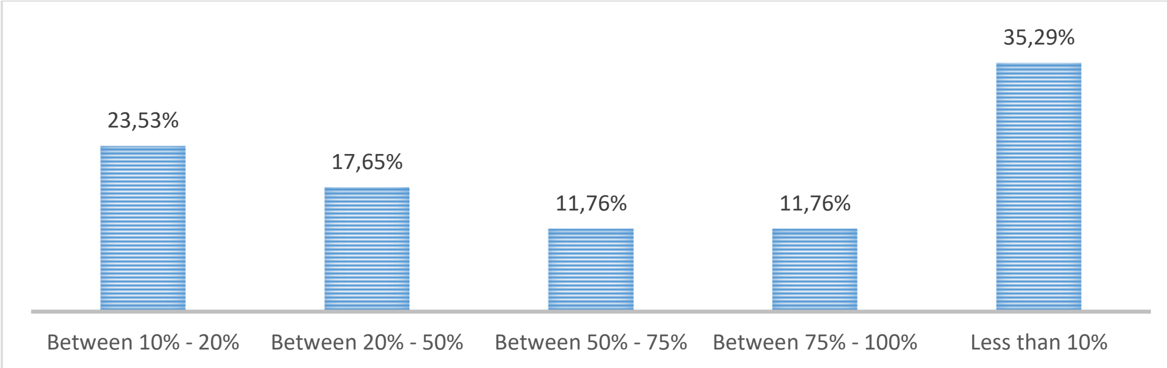

Fig. 16 Answers of stakeholders in relation with the time that tugboats operate at maximum power with the main propulsion system during the manoeuvre.

Another interesting result is that during manoeuvres, 47% of the time is spent alongside the vessel being assisted, without actively pushing or pulling the merchant ship.

Section 4. Personal experience questions about optimising tugboat operations and manoeuvres.

In this section, interviewees were asked about the activities currently being undertaken to reduce emissions on board and the actions they believe could be developed to decrease them. Approximately half of the respondents (52.9%) reported that activities are being conducted on the tugboat with the purpose of reducing emissions within the port.

Finally, from the interviewers' point of view, port tugboats could reduce emissions in the following ways:

1. Optimizing manoeuvre planning to minimize the time spent with engines running at high power.
2. Enhancing traffic control to reduce unnecessary waiting times.
3. Reducing manoeuvring time.
4. Limiting the power of main engines.
5. Utilizing shore power connections whenever possible to avoid running engines while docked and sailing at low speed.
6. Adequate tugboats dimensions and engines.
7. Utilizing hybrid technology and maximizing the use of shore power connections whenever available to minimize engine usage and emissions.
8. Implementing emission-reducing technologies on-board.

4 DISCUSSION AND CONCLUSIONS

This study focuses on characterizing tug manoeuvres within Spanish ports by combining a general overview of tug characteristics and prescriptions of port tugboat services in Spain, incorporating insights from stakeholder interviews. A total of 18 Spanish ports have been selected for characterizing port tugs based on threshold values of cargo volume, tugboat availability, and vessel movements. For the characterization of the Spanish towing service prescriptions, following parameters Bollard pull, Propulsion system; and Main Engine power has been taken into account as a reference parameters. The concentration of bollard pull value in the prescriptions range from 50 to 75 metric tons, with the 56% of the current tugboats within the study area falling in this range. The 67.2% surpass the reference value of 50mT for bollard pull and only 2.4% exhibit a pulling capacity below 20mTm. Barcelona, Valencia, and Tenerife ports stand out for having all their tugboats surpassing the 50 metric tons average across all vessels. According to the port prescriptions, 71.29% of tugboats should be equipped with omnidirectional propulsion systems such as ASD or Voith propulsion. However, the actual proportion of tugboats equipped with ASD or Voith propulsion systems within the study area is slightly higher, standing at

79.2%. Finally, the reference value, considering technical specifications, is around 2900 kW, with 61.76% of the analysed tugboats surpassing this value. Ports such as Barcelona, Cartagena, Tarragona, Valencia, and Tenerife have main engine power higher than the reference value across all vessels, while only Vigo port operates with main engine power lower than this value. It can be concluded that according to the analysed technical specifications, only the propulsion system meets the requirements. Both the bollard pull and the main engine power exceed the average established by the prescriptions, with Barcelona, Valencia, and Vigo ports standing out. A series of interviews was conducted with the aim of gathering information regarding the characterization of maneuvers based on the experience of key stakeholders of tugboats within Spanish ports. The majority of the interviewees were employed on tugboats with power systems exceeding 3000 kW. Voith and ASD are the preferred propulsion systems due to their great maneuvering capabilities, with ASD being more practical. More than half of the surveyed respondents undertake emission mitigation measures on-board. Figures also shows that tugboats operate at maximum power with the main propulsion system during the manoeuvre less than 10 % or between 10%-20% of the time during the manoeuvre. This data is particularly relevant, as it has been observed that the maximum power of the tugboats currently in use exceeds that specified by the regulations. Additionally, it was found that half of the time is spent alongside the vessel being assisted, without actively pushing or pulling.

On the other, this study confirms a direct relationship between bollard pull and power, emphasizing the importance of understanding the capabilities of tugboats in relation to their operational requirements. Interviews with stakeholders from various Spanish ports highlighted key strategies to reduce emissions from port tugboats, including optimizing manoeuvre planning, enhancing traffic control, utilizing shore power connections, and implementing emission-reducing technologies on-board. The study emphasized the importance of these measures in improving operational efficiency and environmental sustainability. Through the analysis of tugboat bollard pull capacities in different ports, variability in these capacities is observed, which may be attributed to varying operational demands and individual port characteristics. This variability highlights the importance of adapting tugboat bollard pull capacity to the specific needs of each port. The clustering of tugboats exhibiting distinct bollard pull capacities, as evidenced by the distribution across ports, underscores the critical necessity of deploying tugboats equipped to meet the requisite towing demands. This imperative aligns with ensuring the utmost safety and operational efficiency within port environments.

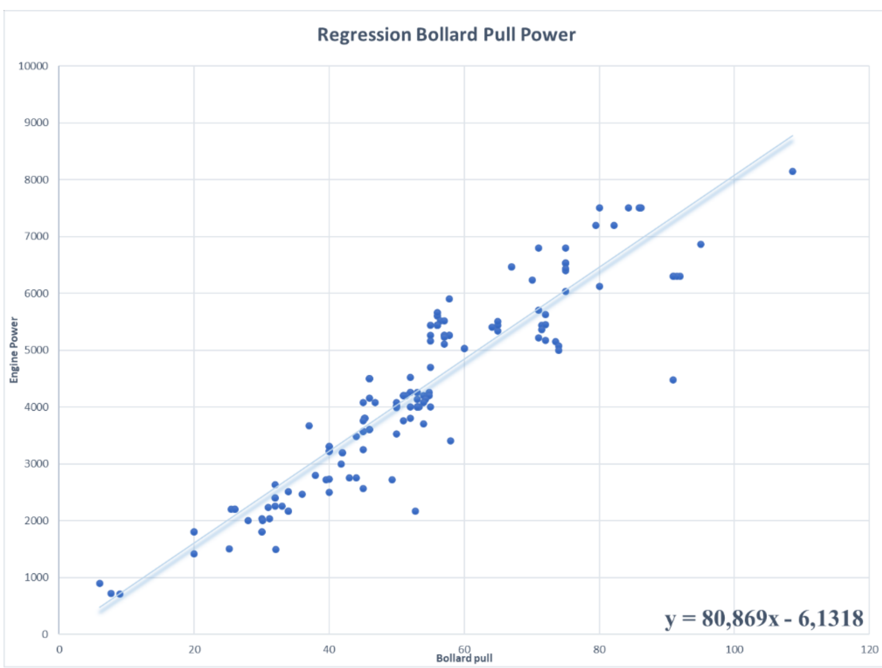

Fig. 17 Regression of each tugboat bollard pull for each port in relation with the average engine power

The predominant configuration entails a propulsion system comprised of symmetrically arranged azimuth thrusters, notably exemplified by the Azimuthal propulsion system. This corroborates their remarkable manoeuvring capability, which implies a reduction in manoeuvring times compared to the use of tugboats with conventional propulsion. Regarding the engine power of the 136 vessels for which data has been obtained, 84 of them have engine power exceeding the average reference value of 2897 kW, increasing up to an average of 3967 kW, which implies a nominal increase of 1070 kW, equivalent to a 37% higher demanded power.

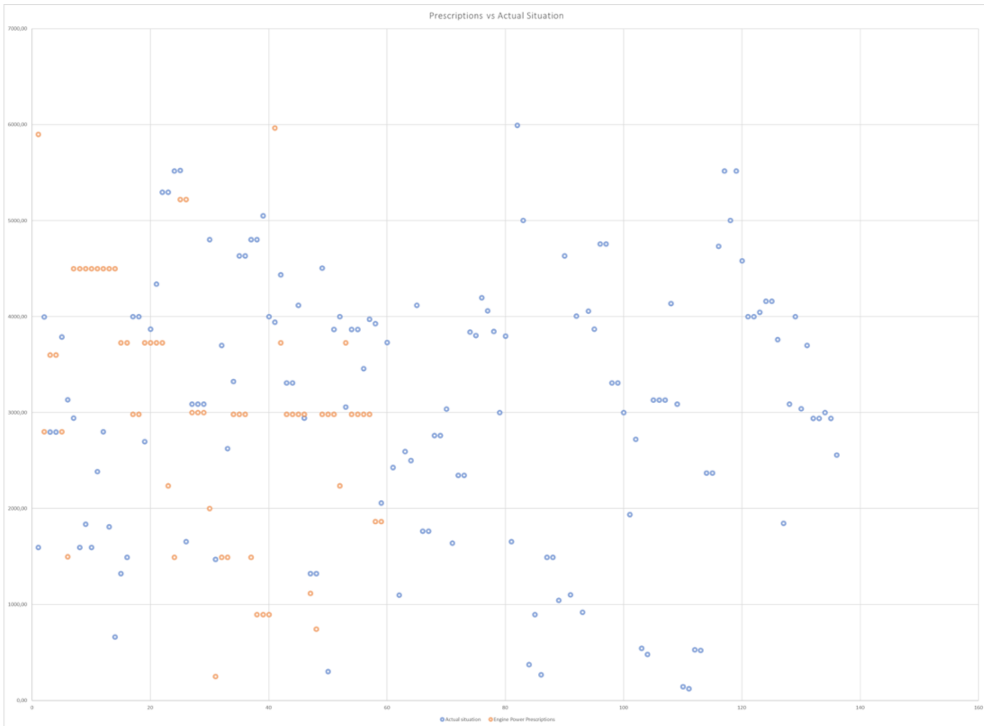

Fig. 18 Distribution of each tugboat pull for each port in relation average engine power

Based from the technical data and from the interviewers point of view, port tugboats could reduce emissions in the following ways: (1) Optimizing manoeuvre planning to minimize the time spent with engines running at high power, (2) Enhancing traffic control to reduce unnecessary waiting times and (3) Reducing manoeuvring time.

The approach used in this study involved carefully examining tugboat services in Spanish ports. We collected detailed data on engine power, bollard pull, and propulsion systems. This information was then compared to existing technical standards to evaluate how efficiently tugboats operate and whether they meet regulatory requirements. These findings emphasize the crucial importance of examining tugboat specifications, propulsion methods, and emission reduction strategies. This scrutiny not only helps to improve operational efficiency but also strengthens environmental sustainability in the maritime transport sector operating within Spanish port areas.

ASD tugs: Thrust and azimuth: learning

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Appendix I. Interview: Strategies for Emission Reduction in Tugboats at Spanish Ports"

<u>Section 1. Personal data related to the job position</u>

1. How do you identify yourself?
    - Man
    - Woman
    - Other
2. On-board position
3. In which port do you currently work or have you worked?

<u>Section 2. Specific data about the tugboat</u>

4. What is the length of the tugboat?
    - Less than 20 m
    - Between 20-24 m
    - Between 24-27 m
    - Between 30-33 m
    - More than 30 m
5. What is the beam of the tugboat?
    - Less than 10 m
    - Between 10-11 m
    - Between 11-12 m
    - Between 12-13 m
    - Between 13-14 m
    - More than 14 m
6. How many MMPP does the tugboat have?
    - 1
    - 2
    - More than 2
7. What is the MMPP engine power?
    - < 1000 kW
    - Between 1000 kW - 1500 kW
    - Between 1500 kW - 2000 kW
    - Between 2000 kW - 3000 kW
    - > 3000 kW
8. How many AAPP does the tugboat have?
    - 1
    - 2
    - More than 2
9. What is the AAPP engine power?
    - < 100 kW
    - Between 100 kW - 150 kW
    - Between 150 kW - 200 kW
    - Between 200 kW - 300 kW
    - Between 300 kW - 400 kW
    - > 400 kW
10. What type of fuel do you use on-board?
    - Diesel
    - Diesel - Urea
    - Metanol
    - LNG
    - Other:
11. What is the propulsion system of the tugboat
    - Conventional
    - Conventional Variable Pitch Propulsion
    - Azimuth Stern Drive (ASD)
    - Voith Schneider
    - Asymmetrical Azimuthal
    - Tractor Azimuthal
    - Other:
12. Does any activity take place on the tugboat with the purpose of reducing emissions within the port?
    - Yes
    - No

<u>Section 3. Specific data about the characterization of tugboat manoeuvres</u>

13. How often do you refuel?
    - Once a week

- Twice a week
- Three times a week
- Once a month
- Twice a month
- Three times a month
- Once every two months
- Once every three months

14. How much fuel do you take each time?
    - Between 0 - 25,000 litres
    - Between 25,000 – 50,000 litres
    - Between 50,000 – 75,000 litres
    - More than 75,000 litres
15. On average, how many manoeuvres can it perform in a month of work?
    - Less than 10
    - Between 10 and 50
    - Between 50 and 75
    - Between 75 and 100
    - Between 100 and 150
    - More than 150
16. During the manoeuvre, how much time do you operate at maximum power with the main propulsion system?
    - Less than 10%
    - Between 10% - 20%
    - Between 20% - 50%
    - Between 50% - 75%
    - Between 75% - 100%
17. During the manoeuvre, how much time do you operate the main propulsion system between 50% and 75% of its power?
    - Less than 10%
    - Between 10% - 20%
    - Between 20% - 50%
    - Between 50% - 75%
    - Between 75% - 100%
18. During the manoeuvre, how much time do you operate the main propulsion system between 25% and 50% of its power?
    - Less than 10%
    - Between 10% - 20%
    - Between 20% - 50%
    - Between 50% - 75%
    - Between 75% - 100%
19. During the manoeuvre, how much time do you operate the main propulsion system below 25% of its power?
    - Less than 10%
    - Between 10% - 20%
    - Between 20% - 50%
    - Between 50% - 75%
    - Between 75% - 100%
20. Of the time spent in manoeuvre, how much time is spent pushing the vessel being assisted?
    - Less than 10%
    - Between 10% - 20%
    - Between 20% - 50%
    - Between 50% - 75%
    - Between 75% - 100%
21. Of the time spent in manoeuvre, how much time is spent pulling the vessel being assisted?
    - Less than 10%
    - Between 10% - 20%
    - Between 20% - 50%
    - Between 50% - 75%
    - Between 75% - 100%
22. Of the time spent in manoeuvre, how much time is spent alongside the vessel being assisted?
    - Less than 10%
    - Between 10% - 20%
    - Between 20% - 50%
    - Between 50% - 75%
    - Between 75% - 100%

Section 4. Personal experience questions about optimising tugboat operations and manoeuvres.

23. Do you consider the length of the tug adequate for the development of its activity from the perspective of pollutant emissions?
    - Yes
    - No
    - I don't know

    If the answer is No, Why? [open question]

24. Do you consider the beam of the tug adequate for the development of its activity from the perspective of pollutant emissions?
    - Yes
    - No
    - I don't know

    If the answer is No, Why? [open question]
25. In your opinion, and considering the maneuver, what do you consider to be the best propulsion system for carrying out your activity?
    - Conventional
    - Conventional Variable Pitch Propulsion
    - Azimuth Stern Drive (ASD)
    - Voith Schneider
    - Asymmetrical Azimuthal
    - Tractor Azimuthal
    - Other:

    Why? [Open question]

    In your opinion, and considering pollutant emissions, what do you consider to be the best propulsion system for carrying out your activity?
    - Conventional
    - Conventional Variable Pitch Propulsion
    - Azimuth Stern Drive (ASD)
    - Voith Schneider
    - Asymmetrical Azimuthal
    - Tractor Azimuthal
    - Other:

    Why? [Open question]
26. Regarding the propulsion system and from the perspective of pollutant emissions, when it comes to working with constant revolutions or combined (working on revolutions and pitch), which do you prefer?
    - Constant revolution
    - Combined

    Why? [Open question]
27. Do you think the main power of the tugboat is adequate, insufficient, or overpowered?
    - Adequate
    - Insufficient
    - Overpowered

    Why? [Open question]
28. Based on your experience, how do you think emissions within the port could be reduced through tugboat operations? [Open question]