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STM Validation Use Cases Results (final information report from test beds)
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1 *ABSTRACT*

The mission of the Analysis and Evaluation (A&E) Activity in the frame of the STM Validation project has been to facilitate the validation of the STM concept, through the quantification of the benefits associated with STM implementation.

Methods for evaluation as well as requirements for data collection have been defined during the project with the objective of contributing to demonstrate that some of the current shipping industry constraints could be mitigated by the use of STM, improving efficiency, safety and environmental sustainability of the stakeholders involved.

With the aim of turning the STM concept into tangible services for the improvement of the current maritime traffic management system, the project has developed large-scale test beds. In particular, the concepts of Port Collaborative Decision Making (Port CDM), Voyage Management (VM), Sea System Wide Information Management (SeaSWIM) have been tested. Moreover, the European Maritime Simulator Network (EMSN) has been refined and has allowed the use of simulators for testing complex situations that in real life could not be performed, thus facilitating valuable data.

The mentioned test-beds have provided with plenty of results that are developed in several deliverables and summarized in the final report. Additionally, as the berth to berth approach was pinpointed as the most interesting outlook in terms of efficiency and environmental sustainability during the process of hypotheses definition, an ad-hoc study has been performed, as described in this report, with the aim of forecasting the potential benefits for the shipping industry, including ports, if STM was implemented globally.

The reader will find in this document the methodologies used to extract information from AIS data from some of the ships included in STM test bed, the analyses performed and the results that permit to draw conclusions that may help the decision-makers of the potential STM adopters and the agents involved with GHG emissions regulation.

2 INITIAL PROJECT HYPOTHESES VALIDATION

A report describing the information environment created during the project has been delivered in which the ensemble of the different methodologies used for the organization of the information expected to be collected during the course of the test beds were defined. The steps followed in the construction of the Information Environment are depicted in Figure 1.

The first layer represents the review of **STM Concept** and the basis of the need to building up such a system, by defining the different STM concepts: Strategic Voyage Management, Dynamic Voyage Management, Flow Management, Port Collaborative Decision Making and Sea System Wide Information Management.

In the second layer, the different **STM services** were defined with proper specifications for service providers/manufacturers. During this process, A&E was indirectly involved in order to gain understanding of the services and to determine which were the most relevant objectives in order to define the hypotheses that could fulfil the inadequacies in the maritime sector. These results complete the third layer of the Information Environment Structure: **STM Validation Hypotheses Model.**

In the framework of the project, several working groups were created and conformed by experts in the different areas over which STM is expected to have positive impacts for the maritime industry: efficiency, safety and environmental sustainability. These working groups gathered participants with a deep knowledge both of the services that the project would develop and of the maritime transport sector. The goal of these working groups was defining a series of key performance objectives and how they could be reached through the STM development. This joint effort resulted on series of hypotheses describing potential changes that STM would introduce in the maritime industry.

Figure 1: Information Environment Architecture

The Milestone 21 Report: STM Information Environment enumerated and described these hypotheses as well the potential benefits that the implementation of STM would bring to the shipping industry in Europe. This document outlined the expected benefits jointly with the different STM services to be developed within the frame of the project and stated that further testing and validation was required.

According to the hypotheses deducted and considering the data that could be extracted from the test beds, the simulations, and the transversal issues such as legal, business, operational, safety and training aspects, the fourth layer of the information environment was defined as **Information Environment Sources**.

The fifth layer of the Information Environment Structure is titled **Collection, Processing and Analysis of Data,** which explains the methodology for collecting the data from different sources in order to make analyses with the support of different tools and show the results that can fulfil STM validation.

In the case of the present document, an ad-hoc study has been developed in order to obtain the potential benefits of port-call synchronization for the shipping industry by selecting some of the ships involved in STM testbed and analysing their AIS data during one year in order to have a picture of their current behaviour and some of the apparent inefficiencies that might be mitigated by the use of STM tools. Hence, a simulation of the future impact of STM implementation is developed and some results are obtained. The sources of data and the methodology for the procedure of AIS data processing is defined in section 3.

Finally, the results will be presented in a macro-level, using the results from the test beds and inserting them in a database created for this purpose, which is represented by the world map screen and the Valenciaport European Short Sea Shipping (VESSL) Database Logo and the methodology is described in section 4.

3 USE CASES STUDY METHODOLOGY

1.1 Selection of Use Cases

Performing a berth-to-berth analysis of the navigation of ships, as well as of their stay in port was selected by the working groups as the main scope for validation of STM benefits. This type of holistic analysis would best allow quantifying the potential benefits associated to the stated STM hypotheses or estimating the impact on fuel consumption, the largest operational cost in navigation.

Additionally, it was decided that these analyses should be performed on different key types of traffic services separately, namely regular, tramp, cruise or other services, as the expected impact would be different depending on each type of traffic.

This section describes the STM testbed fleet and the criteria used to select, from this fleet, the ships that took part in the analysis.

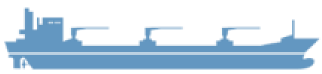
1.1.1 STM Fleet

The STM testbed fleet consists of 300 ships. These ships can be classified in four different groups according to their business models or type of service:

Regular services: short-sea or deep-sea services that are stable in terms of frequency, itinerary and transit times. The type of ships performing these services depends on the type of cargo transported and the characteristics of the ships used.

1. **Tramp services:** flexible shipping services influenced by three operational elements: the shipment modality, the contractual modality and the sailing modalities. The type of ships depends on the type cargo transported (raw materials, foodstuffs such as grain, non-container general cargo, etc.) and are related to a specific market.
2. **Cruise services:** the ships that carry passengers with a leisure purpose and that call in different ports of interest.
3. **Other services:** include ships offering other services such as navigational aids, port services, inspection services, icebreakers, etc.

In addition to the type of service, ships are classified at a detailed grain level, according to the type of ship and segment. The literature on ship types is varied and depending on the taxonomy, ships may belong to one segment or another. In this case, regular shipping has been classified using a cargo/passenger and size criteria, while only size has been used for tramp shipping. The segmentation offered by Fairplay and by prestigious publications from the maritime world has been taken into account. The following tables show the taxonomy used and quantifies the number of ships of each type included in the STM fleet.

BULK CARRIER	***Segmentation (DWT)***	***No. of ships***	***Name of the segment***
	<= 9,999	-	Very small Handy
	10,000 – 24,999	-	Small Handy
	25,000 – 39,999	2	Large Handy
	40,000 – 49,999	-	Handymax
	50,000 – 64,999	-	Supra/Ultramax
	65,000 – 84,999	-	Pmax/Kamsarmax
	85,000 – 99,999	-	Post Panamax
	100,000 – 119,999	-	Mini Capesize
	>= 120,000	-	Capesize

GENERAL CARGO	***Segmentation (DWT)***	***No. of ships***	***Name of the segment***
	<= 4,999	5	-
	5,000 – 9,999	17	-
	10,000 – 14,999	9	-
	15,000 – 19,999	1	-
	20,000 – 29,999	-	-
	> = 30,000	-	-

CHEMICAL/PRODUCT S TANKER	***Segmentation (DWT)***	***No. of ships***	***Name of the segment***
	<=9,999	39	Very Small Handy
	10,000 – 26,999	28	Handy
	27,000 – 39,999	5	MR2
	40,000 – 54,999	7	MR1
	55,000 – 79,999	1	Panamax
	80,000 – 124,999	-	Aframax
	125,000 – 199,999	1	Suezmax
	200,000 – 324,999	-	VLCC
	>=325,000	-	ULCC

CEMENT CARRIER	Segmentation (DWT)	No. of ships	Name of the segment
	<= 4,999	2	-
	5,000 – 9,999	3	-
	10,000 – 14,999	-	-
	15,000 – 19,999	-	-
	20,000 – 29,999	-	-
	> = 30,000	-	-

LPG TANKER	Segmentation (m3)	No. of ships	Name of the segment
	<=4,999	5	Very Small Gas Carrier
	5,000 – 19,999	6	Small Gas Carrier
	20,000 – 39,999	-	Medium Gas Carrier
	40,000 – 59,999	-	Large Gas Carrier
	>= 60,000	-	Very Large Gas Carrier

Figure 2: Taxonomy of STM fleet performing tramp services (131 ships)

CAR CARRIER	Segmentation (cars)	No of ships	Name of the segment
	< 500 cars	-	-
	500 - 999 cars	-	-
	1,000 – 1,499 cars	-	-
	1,500 – 1,999 cars	-	-
	2,000 – 2,999 cars	-	-
	3,000 – 3,999 cars	-	-
	>= 4,000 cars	23	-

CONTAINERSHIP	Segmentation (TEU)	No of ships	Name of the segment
	<=999	2	Small Feeder
	1,000 – 1,999	13	Regional Feeder
	2,000 – 2,999	8	Feedermax
	3,000 – 5,399	17	Baby Post Panamax
	5,400 – 9,999	10	Post Panamax
	> 10,000	-	ULCS

PAX	Segmentation (Passengers)	No of ships	Name of the segment
	< 200	-	Very small
	200 - 499	-	Small
	500 – 1,199	-	Medium
	1,200 – 1,999	1	Large
	> 2,000	-	Megaship

PAX HSC	Segmentation (Passengers)	No of ships	Name of the segment
	< 200	11	Very small
	200 - 499	4	Small
	500 – 1,199	-	Medium
	1,200 – 1,999	-	Large
	> 2,000	-	Megaship

RO-PAX	Segmentation (GT)	No of ships	Name of the segment
	<= 9,999	2	Very small
	10,000 – 19,999	5	Small
	20,000 – 49,999	14	Medium
	50,000 – 69,999	4	Large
	>= 70,000	-	Megaship

RO-PAX HSC	Segmentation (GT)	No of ships	Name of the segment
	<= 9,999	1	Very small
	10,000 – 19,999	-	Small
	20,000 – 49,999	-	Medium
	50,000 – 69,999	-	Large
	>= 70,000	-	Megaship

RO-RO	Segmentation (Lane metres)	No. of ships	Name of the segment
	<= 499	-	-
	500 - 999	2	-
	1,000 – 1,499	-	-
	1,500 – 1,999	4	-
	2,000 – 2,999	-	-
	>= 3,000	3	-

Figure 3: Taxonomy of STM fleet performing regular services (124 ships)

CRUISE	*Segmentation (GT)*	*No. of ships*	*Name of the segment*
	<= 9,999	-	Very small
	10,000 – 19,999	-	Small
	20,000 – 49,999	2	Medium
	50,000 – 69,999	3	Large
	>= 70,000	8	Megaship

Figure 4: Taxonomy of STM fleet performing cruise services

1.1.2 Use Cases and ships selection criteria

The number of ships to analyse was reduced to a meaningful subset of the STM fleet. There were two sets of criteria to make this selection, one concerning the type of service and another concerning the types of ship.

Regarding the types of service, only regular shipping was considered. The reasons for discarding the other types is related to one of the most important assumptions made in the project that “Port call synchronization will lead to the use of optimal steaming according to prevailing circumstances”. This synchronization implies the ability to, on the one hand, use real-time information and of, on the other hand, being able to offer or consume certain information, like accurate estimated times of arrival or departure (ETA/ETD), with a substantial anticipation. Expected outcomes of this synchronization are that cruising speed are lower and have less variation, for instance, leading to a lower fuel consumption and emissions.

To simulate these scenarios and be able to estimate the inefficiencies present in nowadays shipping, one needs data that captures multiple repetition of the same route or leg, performed by the same or similar vessels. This repetition allows capturing aspects like which trajectory or speed was more efficient for a certain type of ship as well as extracting statistical information of it.

Regular services consist on scheduled shipping services, offering the movement of goods on a regular basis, with a stable frequency regardless the availability of cargo. Moreover, in regular services ships regularly call at the same ports, so the number of ships, the time spent at sea and the average time spent in ports are key to their business model. However, the most important aspect for this analysis is that the number of ships performing the same route in parallel provide the required statistical consistency.

Tramp services are usually organized according to market demand, resulting in waiting periods for ships, anchoring until the commercial agreement is signed and the voyage immediately planned and cruising speeds that may exclusively depend on the delivery date on such commercial agreement [2]. These particularities make them less valuable for our analysis, given that a ship may not be following any route in a regular basis and, hence, will not allow enough information the type of analysis pursued. Moreover, it may happen that we had repetitions but some changes in speed or other parameters were due to the commercial agreement, which is unknown to us.

The case of cruise ships combines aspects of regular and tramp services, On the one hand, their port calls are usually programmed far in advance, up to two years in most of the cases. On the other hand, the same ship may follow many different itineraries throughout the year. For this reason, the number of repetitions of the same route is low or none, causing this type of traffic to be discarded as well.

Finally, the ships included in “other services” have been discarded because of the very heterogeneous nature of their services that would lead to a case per case analysis.

Regarding how to select the ships for the analysis out of the STM fleet, the criteria were the following:

- The analysis should be made in ships with STM bridge modules that allow real-time information sharing: ship-to-port, ship-to-ship, ship-to-shore and requesting assistance and information from service providers in order to make decisions during the voyage.
- The ships should be selected out of those historically calling at different PortCDM ports[1] during a representative period of time[2]. For this reason, those ships with with higher number of different PortCDM ports called or with a higher number of calls in those ports were prioritised. Car Carrier use case has been selected because of the regularity in between those type STM ships and was not calling at a PortCDM port.
- Finally, the selected ships should frequently cross the areas of those shore centre included in the project, namely, Tarifa, Gothenburg, Kvitsoy and Horten, in order to maximize the number of interactions when navigating in their area of influence in order to evaluate the ship-to-shore services.

As a result, we will define a set of use cases after each one of the types of ships comprehended in the STM fleet regular services category.

1.1.3 Use Case specific motivations

Due to the extension of the list of STM ships and given the complexity of data collection and data processing, the following cases have been selected case by case, taking into account the different factors in order to apply the hypotheses on their particular casuistry.

1.1.3.1 Car Carriers (CC1)

One of the characteristics of the car carrier services is that they usually link the car production centres located in specific countries. The car manufacturing industry is key, concerning on the one hand, automotive components, which often use maritime transport for the supply of pieces for final assembling and on the other hand, the final products that are distributed worldwide, meeting global demand for finished vehicles from all markets. Additionally, maritime transport for second hand machinery is included in this type of service.

Moreover, as regularity has a strong demand-driven component, ships are often shifted between the different car carrier services navigating around the world. However, there are car carrier services in the internal market, such as in Europe, where the regularity of these services can be explained by two main reasons: domestic demand and the use of hub ports for subsequent distribution to other countries.

This use case comprises two ships: MSC IMMACOLATA and MSC CRISTIANA, which operate a Car Carrier service for MSC Shipping Company linking North Europe with West Africa. These two ships manage the entire service on a fortnightly frequency.

Although these ships do not call any STM ports, the rest of the preselected ships were discarded because they do not follow a regular route pattern and continuously shift among the services offered by the shipping company.

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[1] The PortCDM ports are Gothenburg, Umea (Sweden), Vaasa (Finland) and Stavanger (Norway) in the Baltic Sea and Valencia, Sagunto, Barcelona (Spain) and Limassol (Cyprus) in the Mediterranean Sea.

[2] In particular, the analysis focused on the period between June 2017 and May 2018.

CAR CARRIER (CC1)

9463205 - MSC IMMACOLATA >= 4,000 cars

9453298 - MSC CRISTIANA >= 4,000 cars

West Africa Service

Frequency: Fortnightly

Service route (8 ports):

LE HAVRE – ANTWERP – DAKAR – CONAKRY – ABIDJAN – LOME – DOUALA - MALABO

Average distance navigated: 9,030 nm

Figure 5: Regular car carrier route of MSC Immacolata and MSC Cristiana

1.1.3.2 Container Ships 1 (CS1)

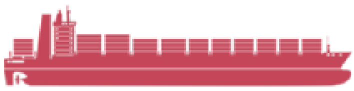
Container traffic has represented a revolution in the transport of goods in recent years, because it facilitates economies of scale and standardizes the way goods are transported, facilitating their intermodality as well as their distribution.

The STM project has been able to include 50 container ships of different sizes and this use case covers containerships with capacity of less than 1,000 TEU. Only the NJORD is actually included in the STM testbed and navigating through European ports and even the Kiel Canal. Precisely, the shipping service passage through the Kiel Canal provides some peculiarities to the analysis.

The size of the ships, the planned route across the Nordic test bed, the clear feeder service design as well as their ongoing transit through some of the shore centre areas of the STM project are other factors that have led to the selection of this use case.

The use case comprises three ships: NJORD, PIRITA and ATLANTIC COAST, which operate a service for Sea Connect, an operator of container feeder and short sea services. The company operates high frequency services between Europe major ports including St. Petersburg.

CONTAINERSHIP (CS1)



9123805 - NJORD <=999 TEU

9108063 – PIRITA <=999 TEU

9129469 - ATLANTIC COAST <=999 TEU

Rotterdam - St. Petersburg Service

Frequency: 3 per week

Service route (4 ports/2 optional / Kiel Canal):

ROTTERDAM 1 - HAMBURG - (AARHUS) - (KLAIPEDA) - ST PETERSBURG

Average distance navigated: 2,454 nm

Figure 6: Regular containership service of SEA CONNECT operated by three ships

1.1.3.3 Container Ships 2 (CS2)

This use case comprises five ships: E.R. PUSAN, DIMITRIS Y, MSC LAUSANNE, MSC CAROUGE and MSC GENEVA, which operates the shipping service “North Europe Service 1” (previously called Israel Express) linking Mediterranean seaports and Northern Europe ports. The shipping line is operated by two shipping companies, which are ZIM Integrated Shipping Services Ltd. and MSC (Mediterranean Shipping Company).

CONTAINERSHIP (CS2)

9211169 - E.R.PUSAN 5,400 - 9,999 TEU

9189354 - DIMITRIS Y 5,400 - 9,999 TEU

9320398 - MSC LAUSANNE 5,400 - 9,999 TEU

9320441 - MSC CAROUGE 5,400 - 9,999 TEU

9320427 - MSC GENEVA 5,400 - 9,999 TEU

North Europe Service 1

Frequency: 1 per week

Service route (10 ports):

FELIXSTOWE - ROTTERDAM - HAMBURG - ANTWERP - LE HAVRE - LIMASSOL - ASHDOD - HAIFA - ASHDOD - VALENCIA

Average distance navigated: 7,898 nm

Figure 7: Regular containership service of ZIM operated by five ships

Only one of the ships in the rotation is included in the STM project (E.R.PUSAN). However, service performance is not understood without including all ships that have been used to design the shipping line and the port sequence.

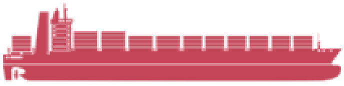
This use case takes into account the fact that it operates through the two testbeds (Nordic and Mediterranean), passes through the STM shore centre located in the Strait of Gibraltar and calls at two STM ports, Valencia and Limassol.

The average size of the containership is around 6,000 TEU with a frequency of 1 per week, which is an interesting outlook for the analysis that concerns STM validation.

1.1.3.4 Container Ships 3 (CS3)

This regular service covers a deep-sea route linking Europe with the west coast of the United States. This line, called "California Express service", is operated by MSC (Mediterranean Shipping Company).

CONTAINERSHIP (CS3)



9702065 - MSC LETIZIA 5,400 - 9,999 TEU

9704996 - MSC JULIE 5,400 - 9,999 TEU

9605152 - MSC ANTALYA 5,400 - 9,999 TEU

9710438 - MSC CHANNE 5,400 - 9,999 TEU

9618317 - MSC ATHOS 5,400 - 9,999 TEU

9605231 - MSC ARBATAX 5,400 - 9,999 TEU

9705005 - MSC CATERINA 5,400 - 9,999 TEU

9720512 - MSC MICHELA 5,400 - 9,999 TEU

9720524 - MSC CLEA 5,400 - 9,999 TEU

9720457 - MSC SILVIA 5,400 - 9,999 TEU

California Express Service

Frequency: 1 per week

Service route (19 ports/Panama Canal):

BARCELONA - GIOIA TAURO - CIVITAVECCHIA - LA SPEZIA - FOS - VALENCIA - SINES - CRISTOBAL - BALBOA - MANZANILLO - LONG BEACH - OAKLAND - VANCOUVER - SEATTLE - OAKLAND - LONG BEACH - MANZANILLO - BALBOA - CRISTOBAL

Average distance navigated: 19,713 nm

Figure 8: Regular containership service of MSC operated by ten ships

The reason for selecting this use case is that offers a typical long-distance container-shipping-route vision. Deep-sea navigation has a strong component of uncertainty due to navigation at open sea, current and weather conditions. This means that there is room for improvement in this type of service if the ships share information on their voyage plan and their ETA is very significant.

This type of service use to be operated by mother ships or ocean-going ships, much bigger than short sea ships, and that are selected in order to cover the high fixed costs and to benefit from economies of scale. In this type of route, the selection of hub ports is particularly important in order to reduce overall costs. This use case calls two STM ports, Valencia and Barcelona, crosses a shore centre project area, Gibraltar Strait, and crosses the Panama Canal.

This use case comprises five STM ships, MSC LETIZIA, MSC JULIE, MSC CLEA, MSC CATERINA, MSC CHANNE, and four non-STM ships MSC ARBATAX, MSC ANTALYA, MSC MICHELA, and MSC SILVIA.

1.1.3.5 High Speed Craft 1 (HSC1)

The selection of this use case covers a type of regular line that is commonly used in Europe. About 4.5% of STM ships are high-speed ships. Most HSCs in Europe move passengers, although a small percentage move both passengers and cargo. Some features of this type of regular service are the following:

- These lines move mainly passengers and usually connect main ports with islands.
- Mostly cover short voyages with a high frequency (similar to a bus line).
- The time at the port is very limited due to the urgency of calling at the next port according to the schedule. Moreover, ships operating the service have priority access to the ports because they are passenger traffic.
- The fuel used is usually low-sulphur (Marine Diesel Oil) and, due to the high speeds of its operation, its consumption is very high.
- The variable costs of this service are higher than the fixed costs. The investments to be made must take into account the operational costs (maximise the number of voyages per day).

The ships on these itineraries have a high degree of rotation and constantly change their route during the day. The route configuration takes into account the passenger flow during peak and off-peak hours and adapts its port calls in order to adjust the supply to the demand according to the variability of the circumstances.

This use case includes only the FJORDFART. The selected ship operates at the STM port of Stavanger (Norway) and links several locations near the port, also passing through the Kvitsoy shore centre area included in the project.

HIGH-SPEED CRAFT (HSC1)

9383376 - FJORDFART <= 200 passengers

Several services around Stavanger area

The service is usually operated by more than one ship

Frequency: 28 per week

Service route (3 ports/ 2 optional):

STAVANGER - TAU - JUDABERG - (JELSA) - (SAUDA)

Average distance navigated: 29 nm

Figure 9: HSC service at Stavanger port

1.1.3.6 Passenger Ships (PAX1)

The main characteristics of these kind of ships are:

- Usually cover short, low-speed, medium-frequency routes.
- Most ships are predominantly small size and often are linking tourist destinations
- Ro-pax services are often reinforced with this type of ship during high season time.
- They have a high seasonality factor.

PASSENGER SHIP (PAX1)

9273727 - BIRKA STOCKHOLM 1,200 - 1,999 passengers

Archipelago cruise service

Frequency: 7 per week

Service route (2 ports):

STOCKHOLM - MARIEHAMN

Average distance navigated: 79 nm

Figure 10: Passenger service in the Baltic testbed

This use case includes the BIRKA STOCKHOLM. It covers a regular service with Aland Islands near Stockholm with a medium frequency. It does not transport any type of cargo, only passengers

1.1.3.7 Ro-Pax 1 (RPX1)

Ro-pax services are included in wheeled cargo traffic but combine cargo and passengers on their routes. Its main features include:

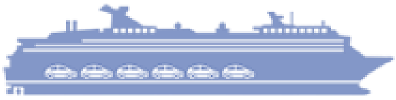
- Connecting more than one country or different national islands.
- These are relatively new ships that accept cargo, which is loaded/unloaded onto the ship using terminal trucks (commonly known as MAFIs), or directly loaded with accompanied drivers.
- The usual commercial loading unit is the lane metre (volume unit).

Regarding passengers, they usually travel with their own vehicle, facilitating intermodality.

This use case involves two ships: STENA GERMANICA and STENA SCANDINAVICA. This service operates from Gothenburg (Sweden) to Kiel (Germany) and is a clear example of the Short Sea Shipping service. The shipping line is Stena Line.

These ships call at a STM port, navigate through two project shore centres areas and are both STM ships. In addition, they cross each other during their navigation and could use the 'Route Exchange Ship-to-Ship' service from the project.

ROPAX (RPX1)



9145176 - STENA GERMANICA 50,000 - 69,999 GT

9235517 - STENA SCANDINAVICA 50,000 - 69,999 GT

Gothenburg to Kiel service

Frequency: 7 per week

Service route (2 ports):

GOTHENBURG - KIEL

Average distance navigated: 452 nm

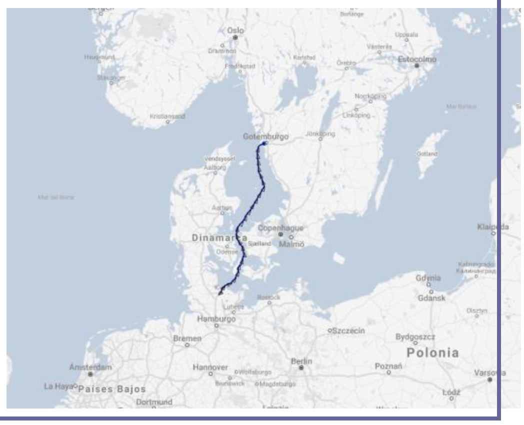
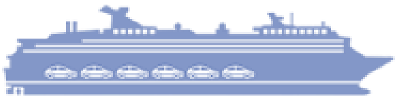


Figure 11: Gothenburg-Kiel service including both ships

1.1.3.8 Ro-Pax 2 (RPX2)

Compared to the case RPX1, RPX2 ships are smaller as they are used to move lower volumes of cargo and passengers. One of the peculiarities of these ships is that are usually propelled with dual LNG engines. This use case includes two STM ships, the STAVANGERFJORD and the BERGENSFJORD. Both call at port of Stavanger. Moreover, these ships are passing through two shore centre areas. The company Fjordline operates this service, which connects Denmark with Southern Norway.

ROPAX (RPX2)



9586605 – STAVANGERFJORD 20,000 - 49,999 GT

9586617 – BERGENSFJORD 20,000 - 49,999 GT

Hirtshals - Norway service

Frequency: 7 per week

Service route (6 ports):

HIRTSHALS - STAVANGER - BERGEN - STAVANGER - HIRTSHALS – LANGESUND

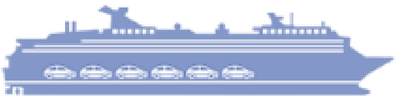
Average distance navigated: 712 nm

Figure 12: Denmark-Norway Ropax service including both ships

1.1.3.9 Ro-Pax 3 (RPX3)

The ships in the RPX3 segment are smaller than those in the previous RPX segments. In particular, this use case includes two ships, GABRIELLA and AMORELLA that are operating two similar services for Viking Line, connecting Sweden and Finland. These Ro-Pax services transport passengers and wheeled cargo across the northern Baltic Sea and, although they share the route, different companies operate them. Both ships are included in STM testbed, navigate through a shore centre area within the project.

ROPAX (RPX3)



8601915 - VIKING AMORELLA 20,000 - 49,999 GT

8917601 - VIKING GABRIELLA 20,000 - 49,999 GT

TURKU/HELSINKI – STOCKHOLM SERVICE

Frequency 14 per week

Service route (5 ports):

TURKU – HELSINKI – MARIEHAMN – STOCKHOLM – LANGNAS

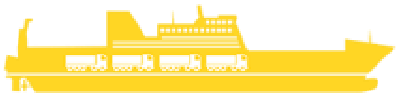
Average distance navigated: 326/454 nm

Figure 13: Finland-Sweden Ro-pax connection using two STM ships

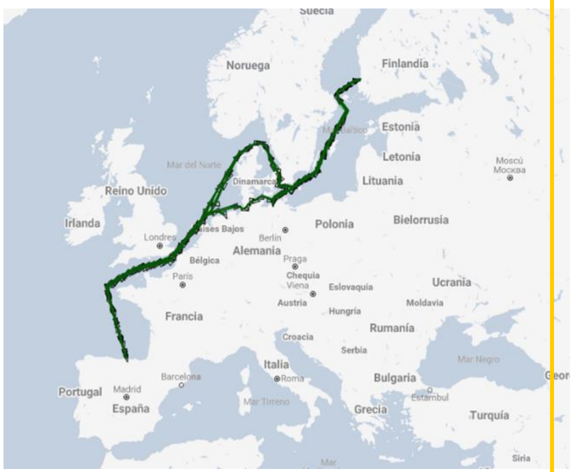
1.1.3.10 Ro-Ro 1 (RO1)

Ro-ro traffic is included in wheeled cargo traffic and mainly focuses on the movement of goods by truck on board a ship. This type of traffic takes place mainly on SSS lines, where trade takes place between nearby countries, solving geographical barriers. One of the characteristics is that this traffic promotes intermodality because it proposes the shift mode automatically. Sometimes the goods travel without a cab and it is in the port of arrival where the management of the trailer using platforms takes place. The used unit is the lane metre (unit of volume) and they are usually very regular and very frequency traffics in which the time of stay at the port is short. In some infrastructures in northern Europe, loading and unloading solutions in decks at different heights have been promoted using linkspans. The frequency is fortnightly. The goods accepted for shipment are all types of self-propelled vehicles, containers and any general dry cargo on tug master The route covers six ports in three countries, namely Spain, Germany and Finland, with small-capacity vessels.

RO-RO (RO1)



9129263 - BALTIC BRIGHT **500 - 999 lm**
8716100 - POLARIS VG **500 - 999 lm**
8805602 - LINK STAR **<=499 lm**



Baltic, North Sea and Biscay service
Frequency: Fortnightly

SANTANDER – RAUMA- ROSTOCK – RAUMA –ROSTOCK – RAUMA

Service route (6 ports/Kiel Canal):
Average distance navigated: 5,272 nm

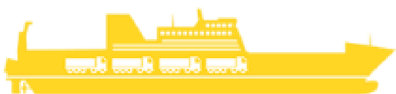
Figure 14: Finland-Spain Ro-Ro connection using three STM ships

1.1.3.11 Ro-Ro 2 (RO2)

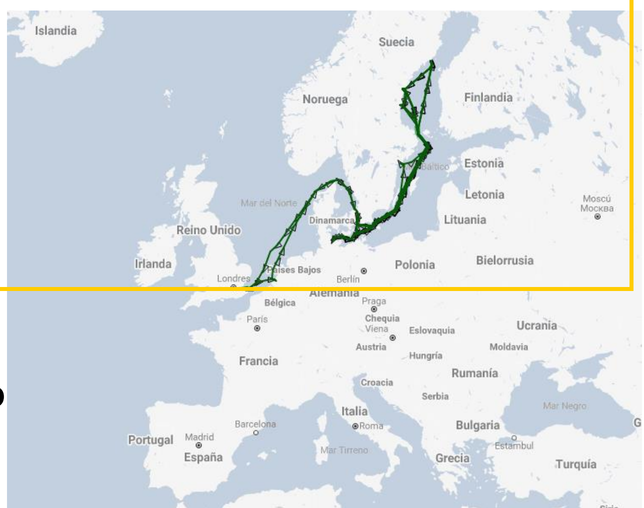
The following use case involves larger ships than the previous one. There are three ships connecting Swedish ports with the Netherlands and the UK. The frequency is weekly and uses three sister ships. These vessels are specialised in handling forest products in the Baltic and North Sea and are calling at the Port CDM port of Umea.

The company is SCA and produces packaging paper for consumer and transport packaging, largely based on fresh wood fibre.

RO-RO (RO2)



9087350 - SCA OBBOLA 1,500 - 1,999 lm
9087362 - SCA OSTRAND 1,500 - 1,999 lm
9087374 - SCA ORTVIKEN 1,500 - 1,999 lm



SCA LOGISTICS service

Frequency: 1 per week

Service route (14 ports):

SUNDSVALL - SHEERNESS - ROTTERDAM - HELSINGBORG - OXELOSUND - UMEA - SUNDSVALL - IGGESUND - KIEL - MALMO - UMEA

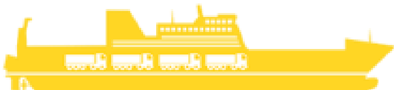
Average distance navigated: 5,888 nm

Figure 15: Northern Sweden- UK Ro-Ro connection using three STM ships

1.1.3.12 Ro-Ro 3 (RO3)

Finally, the Bore Bank operates routes between Russia and Finland with Germany and the United Kingdom. This vessel has similar characteristics to those of the previous use case but with the peculiarity that passes through the Kiel canal. The frequency is fortnightly. This use case adds more information about the Ro-Ro traffic due to its importance in the EU SSS.

RO-RO (RO3)



9160774 - BORE BANK 1,500 - 1,999 lm

HANKO - KOTKA service

Frequency: 0.5 per week

Service route (8 ports/Kiel Canal):

LUBECK - KOTKA - HANKO - TILBURY - HANKO - ST PETERSBURG - KOTKA - ROSTOCK

Average distance navigated: 3,743 nm

Figure 16: Russia with UK through Kiel Canal Ro-Ro Connection using one STM ship

1.2 Data used in the analysis

The goal of the current analysis relays on quantifying the potential benefits of introducing STM in the shipping industry. To do so, AIS data for 50 ships (including the 34 enumerated in Section 2.3), was purchased from Marine Traffic [3]. These data correspond to the period comprehended between June 1st of 2017 and May 31st of 2018 and consists of more than 5.3

million registers. Note that these data did not include satellite AIS data. Table 1 shows an excerpt of 10 registers of the AIS data purchased. Each register includes the following fields:

- IMO: ship identifier.
- Status: identifies whether the ship is navigating or stopped, either at berth or in anchoring.
- Speed: ground speed in knots.
- Longitude
- Latitude
- Timestamp
- Draught
- Reported ETA: ETA reported by the ship.

IMO	STATUS	SPEED_KNOTSx10	LON	LAT	TIMESTAMP_UTC	DRAUGHT	REPORTED _ETA
8716100	0	122	20.06762	59.43006	2017-06-01 00:00:32	54	2017-06-01 13:00:00
8716100	0	122	20.076	59.43745	2017-06-01 00:03:04	54	2017-06-01 13:00:00
8716100	0	123	20.08547	59.4458	2017-06-01 00:05:53	54	2017-06-01 13:00:00
8716100	0	122	20.09385	59.45313	2017-06-01 00:08:23	54	2017-06-01 13:00:00
8716100	0	122	20.10456	59.46252	2017-06-01 00:11:34	54	2017-06-01 13:00:00
8716100	0	123	20.11473	59.47132	2017-06-01 00:14:33	54	2017-06-01 13:00:00
8716100	0	122	20.13634	59.48992	2017-06-01 00:20:53	54	2017-06-01 13:00:00
8716100	0	122	20.14439	59.4967	2017-06-01 00:23:12	54	2017-06-01 13:00:00
8716100	0	116	20.15367	59.50801	2017-06-01 00:26:37	54	2017-06-01 13:00:00

Table 1: Excerpt of the AIS data used in the analysis.

Additionally, data from the PortCDM testbeds were consumed as well. The data from the PortCDM testbeds are very extensive and include many different types of information related to the different events occurring during a port call. These data spans nine European ports and more than 43,000 port calls, mainly from 2018. From these data, in particular, we measured the *efficiency* as the time the ships spend at berth compared to the time used for (un)load operations, for different types of ship and ports.

1.3 Data processing

1.3.1 Baseline static data: VESSL Database Sources

The static data regarding the use cases are extracted from the Valenciaport European Short Sea Lines Database where the following information can be consulted:

Ship Characteristics	Shipping Service Characteristics
Flag	Name
Classification Society	Shipping Company / Operator
Year of built	Type of Traffic
GT	Frequency
DWT	Number of Ships
Capacity	Itinerary
Service Speed	Number of port calls
Main Engine Power	Distances (port to port)
Auxiliary Engine Power	Distance (total turnaround)

Table 2: Ships Characteristics

1.3.2 Initial data processing

In order to perform the analysis, there is an initial processing of the AIS data, jointly with the addition of some extra data for each ship of interest. This extra data is input through configuration files to our algorithms. The AIS data is not used directly and raw, there is some initial treatment. In particular, the data is cleansed and some interpolations are computed when required. The data is expanded, adding some additional information to make other computations easier later, like time or distance deltas. It is also expanded by adding an estimation, per register, of the fuel consumed and pollutants emitted in the timeslot corresponding to that register. Finally, the data is aggregated for each individual leg and for the repetitions of that leg and a set of waypoints, coming from all the AIS coordinates, are assigned to each leg. The following subsections describe these steps. Additionally, Figure 17 provides an summarized view of this process, showing the actions performed in each step.

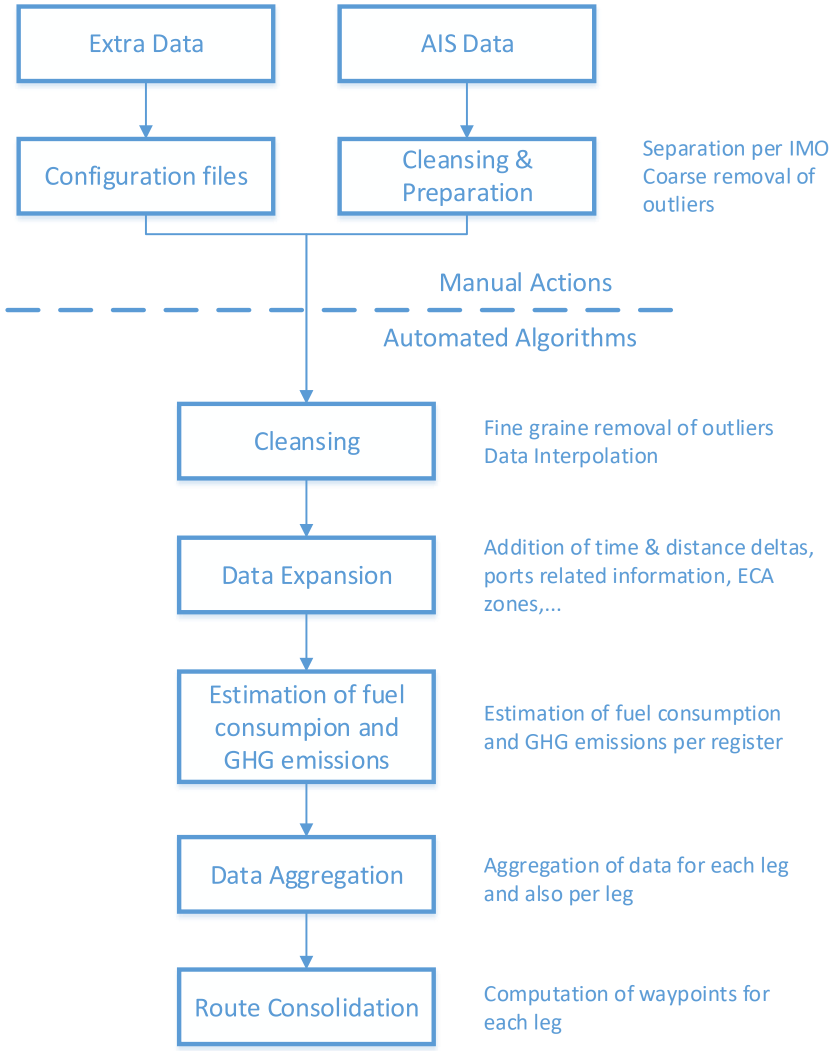


Figure 17: Overview of the processing applied to the data used in the analysis

1.3.2.1 Configuration files

Before working with the AIS data, a set of configuration files for each of the ships of interest was created. This configuration files included information such as:

- The total engine power of the ship for each navigation phase, i.e., cruising, anchoring, manoeuvring, or in berth; and for the main, boiler or auxiliary engines
- The engine emissions per pollutant in each one of these states, for ECA and non-ECA zones per engine.
- Other parameters of interest like its DAF or SAF per phase, among others.

Observe that this information included in these configuration files is needed to compute aspects like the fuel consumption and emissions. These data were different for almost each ship, except in those cases where one or more ships where of the same type/model.

Other information, such as the ports in the ship's itinerary and their locations was included as well. An example of the data included in the configuration files is shown below.


```
{
"engine_power": {
        "Cruising": {"main": 21600, “aux": 2006, "boiler": 0},
        "Maneuvering": {"main": 21600, "aux": 2006, "boiler": 200},
        "Anchor": {"main": 0, "aux": 2006, "boiler": 200},
        "Berth": {"main": 0, "aux": 2006, "boiler": 200},
```

"IdleTime": { "main": 21600, "aux": 2006, "boiler": 200}
},
"engine_emissions": {
"ECA": {
"main": {"CO2": 372.76, "NOX": 5, "SOX": 0.0022, "PM": 0.02},
"aux": {"CO2": 457.72, "NOX": 5, "SOX": 0.0022, "PM": 0.02},
"boiler": {"CO2": 0, "NOX": 0, "SOX": 0, "PM": 0}
},
"NO ECA": {
"main": {"CO2": 412.5, "NOX": 1.3, "SOX": 0.0027, "PM": 0.03},
"aux": {"CO2": 457, "NOX": 1.3, "SOX": 0.0027, "PM": 0.03},
"boiler": {"CO2": 0, "NOX": 0, "SOX": 0, "PM": 0}
}
},
"constants": {
"SAF": {"Cruising": 1.07, "Maneuvering": 1.43, "IdleTime": 1.43, "Anchor": 1,"Berth": 1},
"vmax": 26,
"HFFI": 1.02595,
"K1(um)": 120,
"K2(um)": 150,
"L(m)": 170,
"coastal_Wt": 1.1,
"international_Wt": 1.15,
"DAF": 0.9113,
"CO2_res": 2.75,
"CO2_dis": 2.75
},
"ports": ["DKCPH", "DKHIR", "NOTAE", "NOLAD", "NOBGO", "DKFDH", "NOKIA"],
"port_coordinates": [{"latitude": 55.70022, "longitude": 12.601}, {"latitude": 57.59593, "longitude": 9.973117}, {"latitude": 58.92135, "longitude": 5.5834}, {"latitude": 59.00712, "longitude": 9.74765}, {"latitude": 60.39268, "longitude": 5.308283}, {"latitude": 57.43419, "longitude": 10.54602}, {"latitude": 63.56604, "longitude": 9.897487}]
}

1.3.2.2 Data cleansing and preparation

The cleansing and preparation of data was an interleaved process. The first step was to separate the data, as all the AIS data were together in CSV files. The data were separated in different files, one per ship, and sorted by date.

The second step required to make an initial cleanse of the data. An initial visualization of the data would show that there were registers that were clearly out of place for some ships. For instance, it was possible to find series of consecutive registers, separated by 2-3 minutes in time each, where all data were located in Europe and, suddenly, one datum was located in Australia or America. This cleansing consists of a two-step process. Firstly, automated and simply removing those points that where extremely far from its preceding and next registers. Of course, although it removed most of the outliers, it was a coarse grain cleanse, and a finer grain and manual second step was performed, visualizing the routes of each vessel to remove the few remaining outliers.

The third step consisted in introducing interpolations. As Satellite AIS data was not purchased, there are some blackout areas were no AIS signal is received. Some intermediate interpolated points were added, in an automated fashion, in those areas, simply by calculating the midway distance and time between points and average speed to cover that distance in that period of time.

1.3.2.3 *Expanding the data*

The preparation and cleansing phase was followed by an expansion phase were several additional fields were added to the original data. Some of them were trivial and to be used to simplify some subsequent calculations. Some examples are:

- Time and distance deltas with the Haversine distance or the time difference between registers.
- The bearing of the vessel, based on current and next locations.
- Distance to and from port. The distance from the port is calculated as the accumulated distance since its departure. The distance to the port is calculated as the Haversine distance between the current location and the next port coordinates.
- Path, identifier of the current path, i.e., departurePort_arrivalPort.
- Navigation phase: cruising, manoeuvring, idle time, anchoring or berth. These phases are identified depending on the distance to port and speed of the ship and according to the conditions presented in Table 3.
- ECA zone and coastal zone flags, binary values indicating whether the ship is on an ECA zone or near (< 5 nm) the coast. These parameters are of interest given that they affect the fuel consumption and emissions of the ship due to the restrictions in those areas.
- Load factor of the engine, estimation that depends on the speed or maximum speed of the vessel, among others.
- Emissions and fuel consumption: an estimation of the fuel consumption and CO2, NOX, SOX and PM emissions of the ship per register, based on the time and distance deltas between registers.

	DISTANCE FROM PORT (Nm)			
SPEED (Knots)	**<1**	**<3**	**<5**	**>5**
< 0.3	Berth	Anchoring	Idle time[3]	Idle time[3]
<3	Manoeuvring	Manoeuvring	Idle time	Idle time
<5	Manoeuvring	Manoeuvring	Manoeuvring	Cruising
< 20	Manoeuvring	Manoeuvring	Cruising	Cruising
>20	Cruising	Cruising	Cruising	Cruising

Table 3: Navigation phases depending on speed and distance to port. This table is inspired in a similar one from [1].

1.3.2.4 *Computation of fuel consumption and emissions*

As mentioned in the previous subsection, the fuel consumption and emissions of the ship being analysed we compute for the last time slot and for each AIS data register. This computation is based on the methodology proposed in [1].

This report provides estimations for different parameters needed to compute the fuel consumption and emissions of a ship per types of ship and segments. Given that cannot know the exact parameters for each one of the ships in the analysis, the information in this report was used to build the per-ship configuration files described in Section 1.3.2.1.

The computation of the emissions depends on the total power of the main engine, the load factor and the emission factor of the pollutant as well as on the total power of the auxiliary

[3] There were some exceptions to the 5 miles' rule. Some ports have their anchoring area beyond those 5 miles, like Hamburg or Antwerp, for instance.

and boiler engines and the pollutant emission factor for them. The addition of these magnitudes is then multiplied by the corresponding time period.

For the fuel consumption, the computation is similar. First, the emissions of CO2 are computed. Then, this value is divided by the CO2 intensity for fuel factor.

Bear in mind that, both for fuel and emissions of pollutants, the load factor is a key variable that estimates the regime at which the engine is working. This load factor is adjusted with Draught Adjustment Factors (DAF), or Speed Adjustment Factors (SAF) depending on the phase.

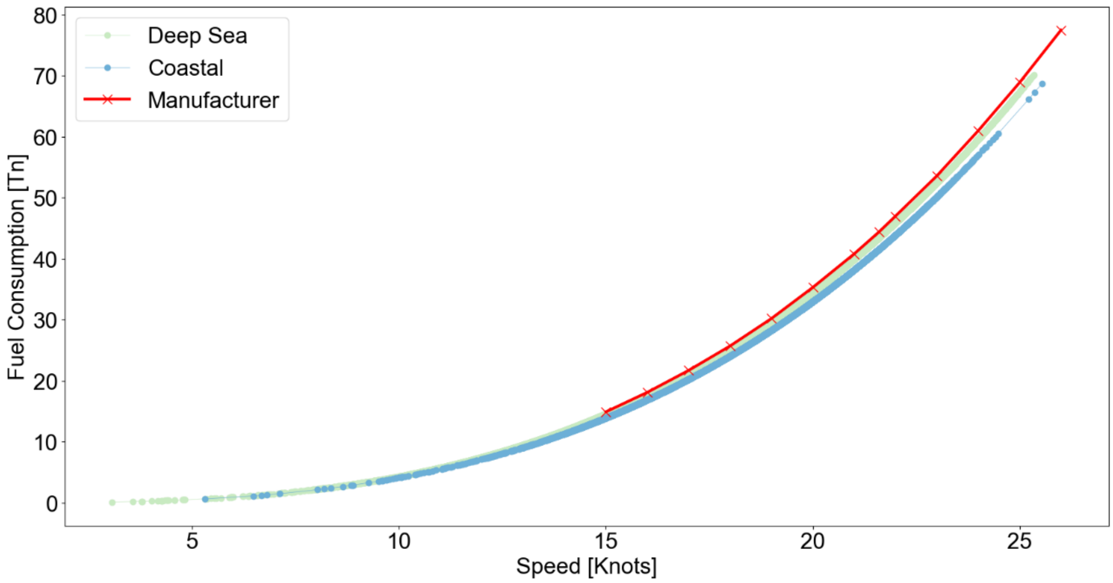


Figure 18: estimation of the fuel consumption for an engine of a Ro-Pax vessel in Deep sea and Coastal areas compared to data provided by a manufacturer. The difference between our estimation and the data provided by the manufacturer is minimal for deep sea and below 5% for most of the curve when in coastal navigation.

In order to evaluate the accuracy of our calculations, we contacted an engine manufacturer and asked whether they could evaluate our estimations. Figure 18 shows the comparison between our calculations for an engine of a Ro-Pax vessel and the data provided by the manufacturer. The error is minimal while in Deep Sea navigation and within a 5% for most of the curve while in coastal navigation, not reaching a 10% in the worst case.

1.3.2.5 Aggregating the data

Once the data has been expanded and completed with the fuel and emissions data, two summary files are created: per leg and per aggregation of legs.

The leg summary includes aggregated data per phase and statistics for each one of the different legs the ship went through. Some examples would be the total time, distance, fuel or emissions of pollutants during the leg, these same values per phase, e.g., total fuel consumed while cruising, average or median speed and distance, first and third quartiles of the speed, etc. This per leg summary, also includes information related to dates, like the departure or arrival date, ETAs or ATAs that are not included in the aggregation of legs summary.

The aggregation of legs includes the similar information but aggregated for all the occurrences of a leg, i.e., if a ship went 10 times between Valencia and Felixstowe, this file will present only one register with the summary of these 10 trips, not 10 registers as in the case of the per leg summary.

1.3.2.6 Route consolidation

The route followed by a ship in a particular leg is usually similar but not identical. If all the locations of a ship in a leg received by AIS were drawn, the result would not be a line, but a blurry and thick constellation of points around the expected trajectory, even with some deviations.

One the goals of the analysis is the design and evaluation of a set of scenarios, which are introduced in a forthcoming section. To do so, we required to have a clear or unique route between two ports. To compute it, we devised an algorithm that combines the use of k-medians clustering and minimax distances between occurrences to obtain a simplified set of waypoints or coordinate pairs describing a route out of all the pairs of coordinates contained in the AIS data. In addition, not only the pair of coordinates is stored, but also the median of the speed of the AIS samples conforming the cluster associated to the waypoint.

Figure 19 shows an example of this procedure. In particular, it plots the AIS data for the Rotterdam – Saint Petersburg (in green) and the waypoints that resulted of applying our algorithm (in red).

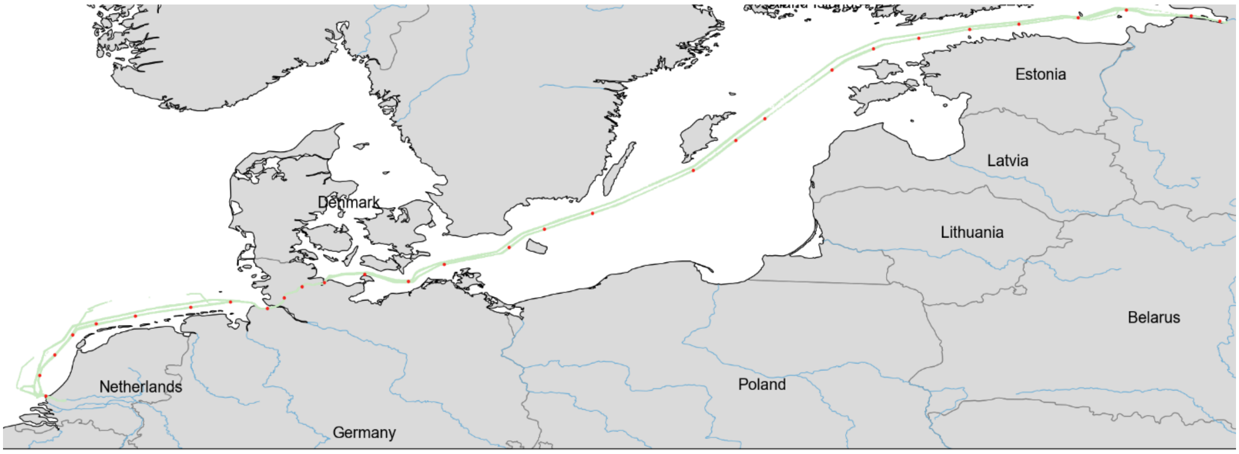


Figure 19: Example of route consolidation for the leg Rotterdam – Saint Petersburg through the Kiel canal. In green, all the AIS pairs of coordinates. In red, the waypoints obtained as result of executing our algorithm.

1.4 Efficiency analysis: demonstrating the need for STM

As mentioned in Section 2, a series of hypothesis were defined at the beginning of the project. These hypotheses targeted different problems that exist in the shipping industry nowadays, but could not quantify their effects.

This section presents some of these problems, explains why they are relevant and describes how we quantified them. In particular, we focus on the variability of the speed while navigating, the deviation between reported ETAs and ATAs and the time ships spend in anchor.

1.4.1 Speed variation

Some of the STM hypothesis are aimed at the need for just in time arrivals and departures, of improving the planning of traffic, using of slow/right steaming or port call synchronization, among others. There are two major reasons for these goals: improving port efficiency, maximizing the number of ships they can handle, and reducing the fuel consumption and the emission of pollutants of ships. This subsection focuses on the latter one.

The relation between the amount of fuel consumed or of pollutants emitted is not linear with the speed but cubic. Hence, a navigation where the ship continuously varies its speed is inherently more inefficient that one that barely changes speed while cruising.

Changes in speed can be caused for several reasons:

- having to speed up due to a change in the window of availability at the destination port,
- accelerating or decelerating to avoid a potential risk situation for being too close to another ship, or
- congestion in areas like straits or canals, among other.

We show this problem by displaying the distribution of speeds of the different studied ships, both per ship and per leg in their route. Ideally, these distributions should be very wide around the median cruising speed with thin lower tails due to the reduction of speed that occurs when the ship approaches the port. Moreover, this median speed should be almost constant regardless of the leg the ship is at, as its speed should be close to its right steaming speed, in order to optimize fuel consumption and emission of pollutants.

Figure 20 and Figure 21 are an example of the figures generated for each use case. Relevant aspects to analyse are, for instance, the wideness or narrowness of the violins. The wider the violins the more variation the ships experiment in their cruising speed. Figure 20 shows that speeds from 10.5-11 to 21-22 Knots are quite usual. This range of speeds shows that there is too much variation on speeds. This is clearly observed, as well, on the different legs for this use case, shown in Figure 21. Ideally, the narrower the gap between the median and the lines for the first and third quartile, the lower this variation and the more efficient the ship navigates. Additionally, the lower are these lines, the less fuel it consumes and less pollutants emit. The maximum efficiency would be achieved if this line coincides with the right steaming speed of the ship.

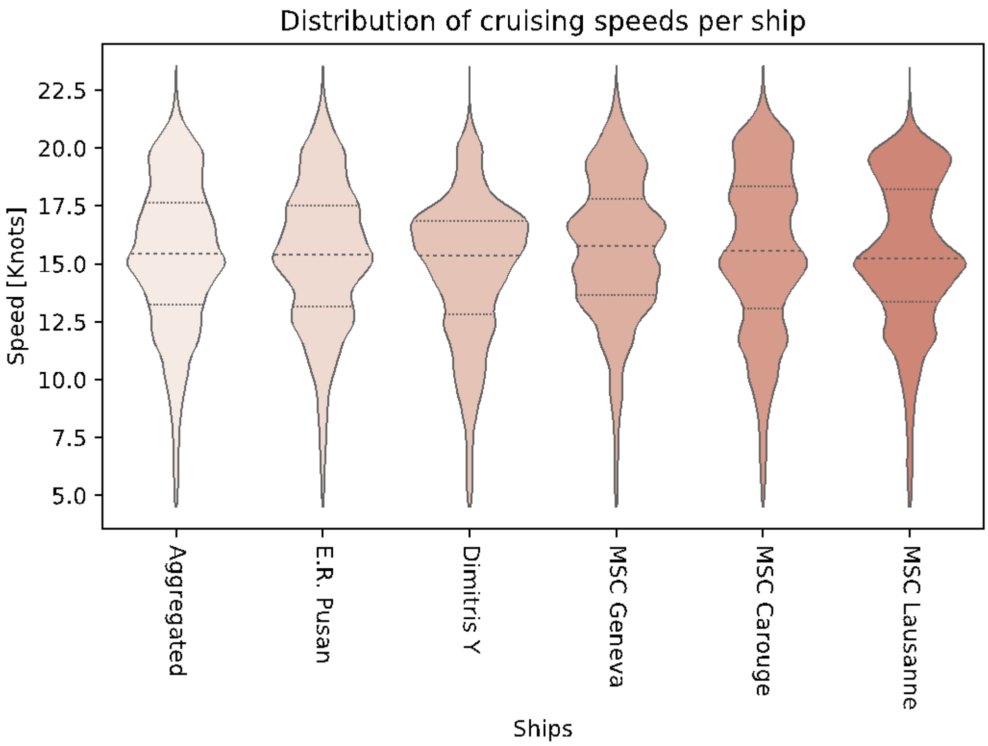


Figure 20: Example of distribution of cruising speeds per vessel in one of the use cases (CS2).

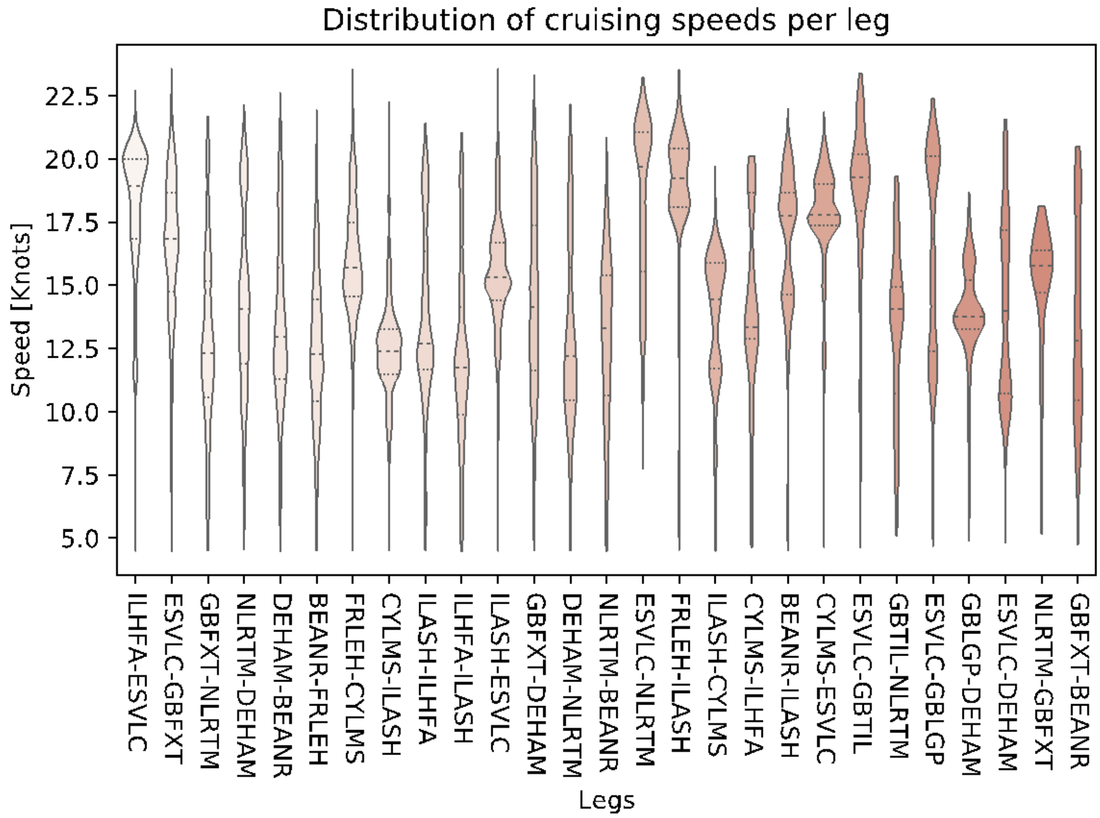


Figure 21: Example of distribution of cruising speeds per leg in one of the use cases (CS2).

1.4.2 ETA / ATA Deviation

The following item of study is how accurate is the ETA provided by the ship at the beginning of a leg. This aims again at the need for synchronization, improved communications between ship and port based on real-time data, if possible, improved coordination between agents in the port or facilitating just in time arrivals and departures.

The analysis of the Estimated Time of Arrival (ETA) versus Actual Time of Arrival (ATA) allows studying how badly is the lack of these factors affecting the planning and synchronization of port calls at the moment. The implementation of STM will lead to a minimization of this gap in the future.

The analysis of each use case will include, when possible[4], figures like Figure 22 and Figure 23. These figures show the ratio of calls that arrived late or early. Afterwards, includes Cumulative Distribution Functions (CDF) of the eta deviation for each vessel (port) for the cases were the ships were late or early. Additionally, another line is displayed showing the aggregated CDF for all the port calls. These figures provide valuable information about, first, whether the behaviour is consistent among ports and ships, or there is any performing better or worse. It is possible that there are ships arriving later that other in their itinerary in a regular basis, or ports for which deviations are larger, maybe because of more unexpected changes in the berth availability windows. Similarly, in this figures it is easy to see how bad these deviations are and in what percentage

[4] These figures depend on whether the ships are reporting the ETA adequately. We found that some ships were not updating the ETA after arriving at a port and leave it obsolete it for the following legs.

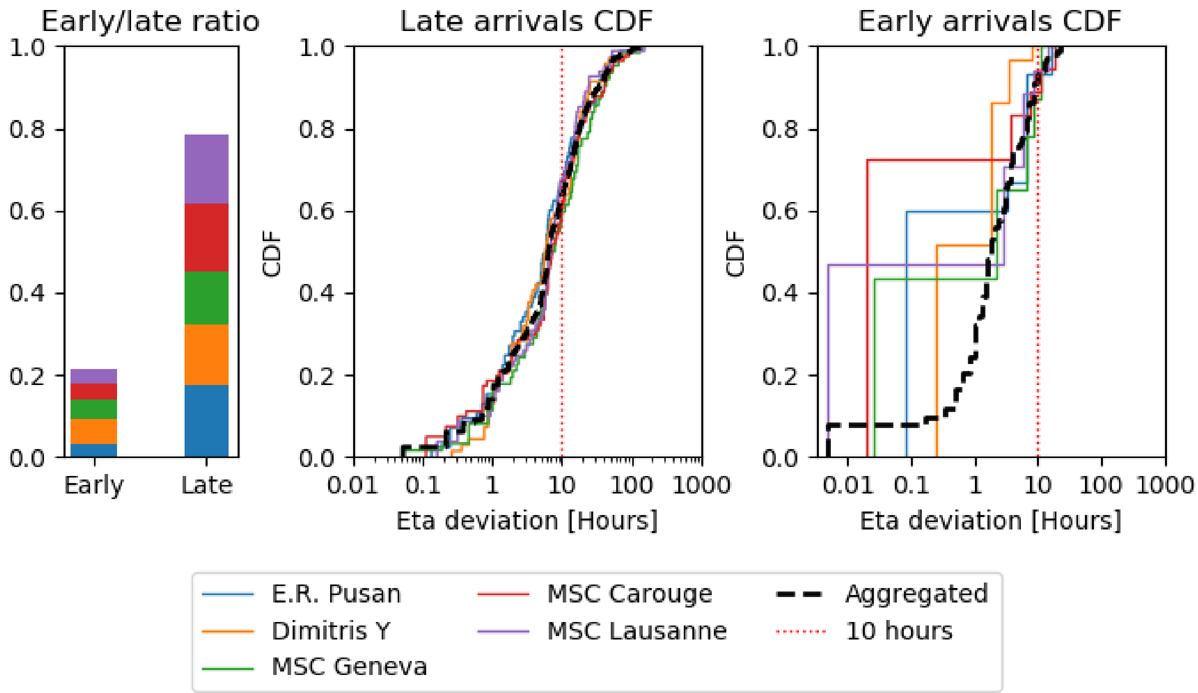


Figure 22: Example of the ETA deviation analysis per ship for CS2.

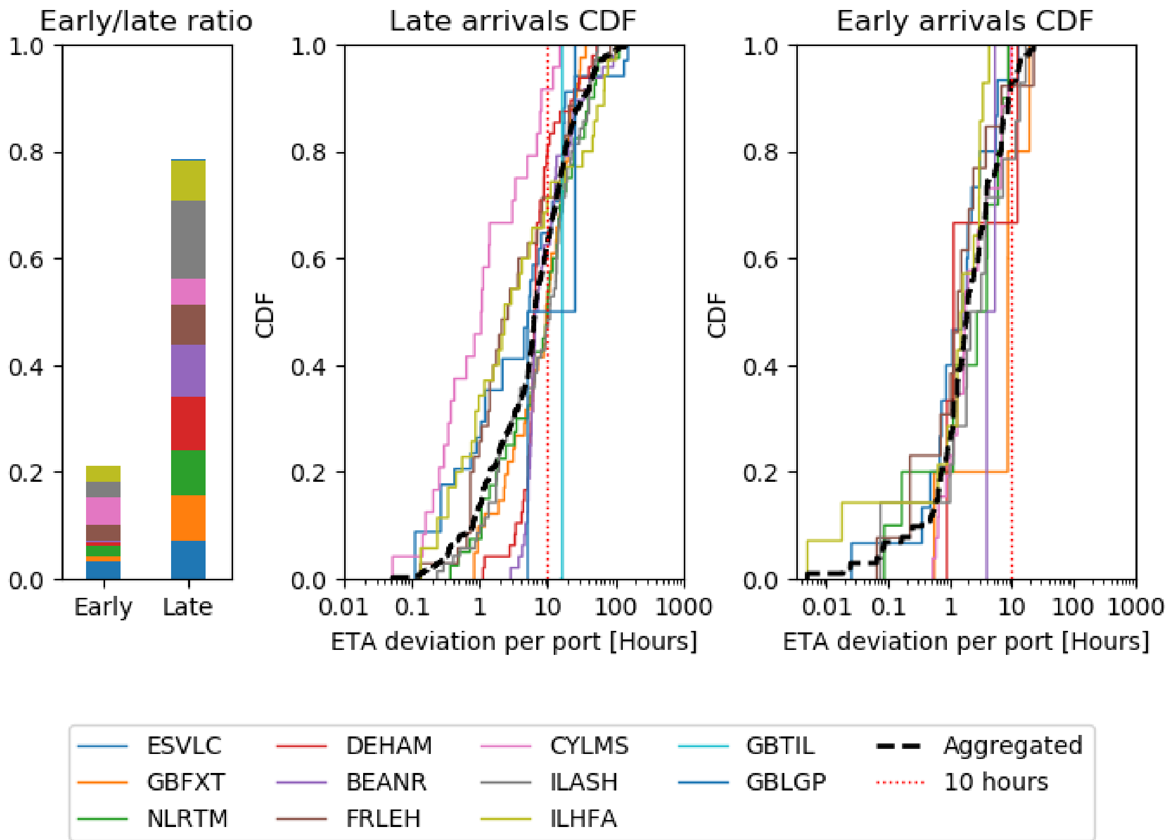


Figure 23: Example of the ETA deviation analysis per port for CS2.

1.4.3 Anchoring time

Another proof of how bad is the synchronization between ships and ports is the amount of time vessels in a regular itinerary spend in anchor. The reasons for this anchoring can be from delays in previous port that are carried on to lack of resources, in terms of technical-nautical services, for letting the ship in the port. The latter can also be due to miscommunications between agents or simply because of a bad planning. The implementation of STM should lead to the elimination, or at least a wide reduction, of anchoring time.

The analysis of each use case includes a figure related to the time spent by its ships in anchoring, as for instance Figure 24. In this figures we show the ratio of port calls in the use case that needed anchoring time, a CDF of the time in hours needed by all the ships per port and the aggregated anchoring time per port.

These figures allow us to have an idea of how much anchoring impacts the ships in the use case. Bear in mind that different types of vessels have different priority at the time of entering into the port and, hence, those with lower priority will be sent to anchoring more repeatedly. Similarly, the time spend in anchor shows the ability of the port to let the ship in once its entrance has been delayed or the ship has not met its ETA. Note that there may be other factors affecting the time spent in anchoring, like the congestion of the port, or geographical aspects like being located in a canal, which is the case of Hamburg or Rotterdam, for instance. Finally, the aggregated time per port gives an idea of the amount of time lost at the end of the year.

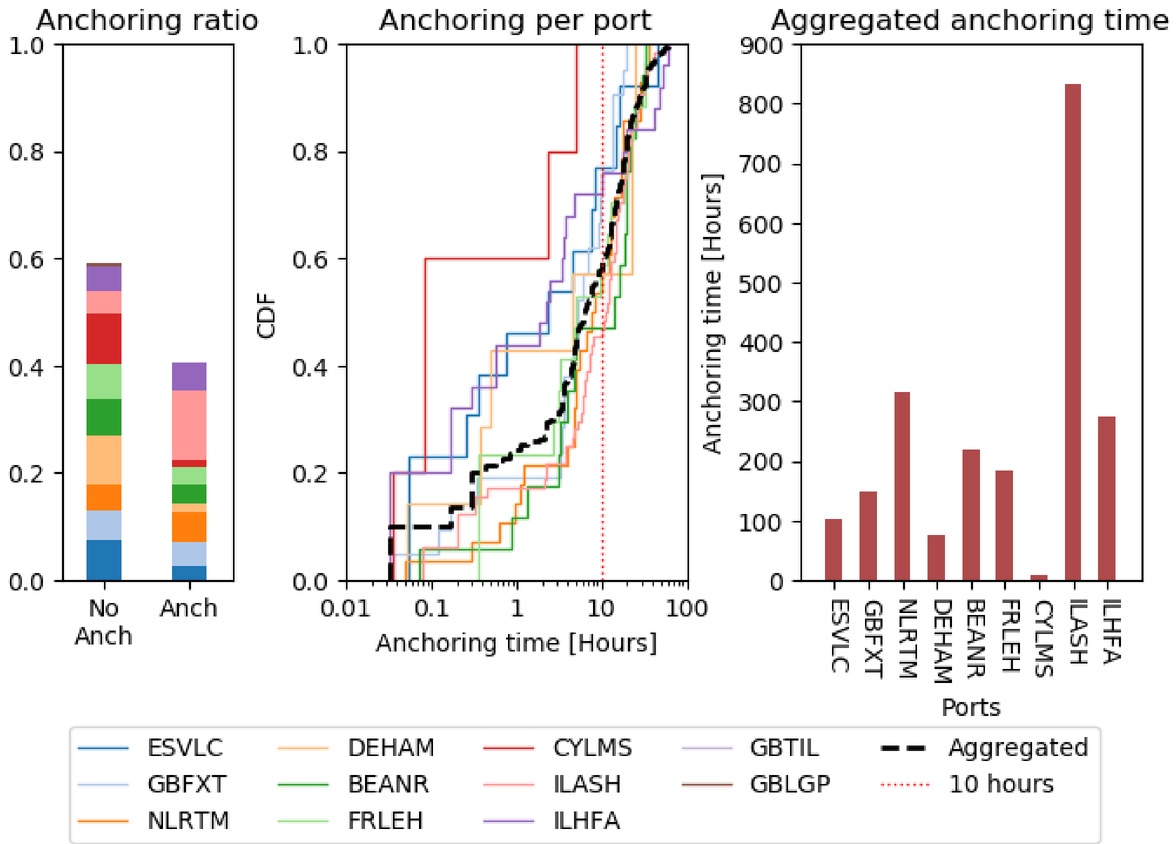


Figure 24: Example of the anchoring time per port for CS2.

1.5 Environmental Sustainability Analysis

This section presents estimations on the impact on fuel consumption and GHG emissions that could have the implementation of STM. These estimations are made taking into account different levels of maturity of the systems included in STM, e.g., PortCDM or the Voyage management, among others. To represent these different levels of maturity, we have devised different scenarios with different assumptions that reflect an increasingly mature deployment of STM in the shipping industry and ports. Note that are all these scenarios are built on top of the AIS data, adapting it to the corresponding assumptions.

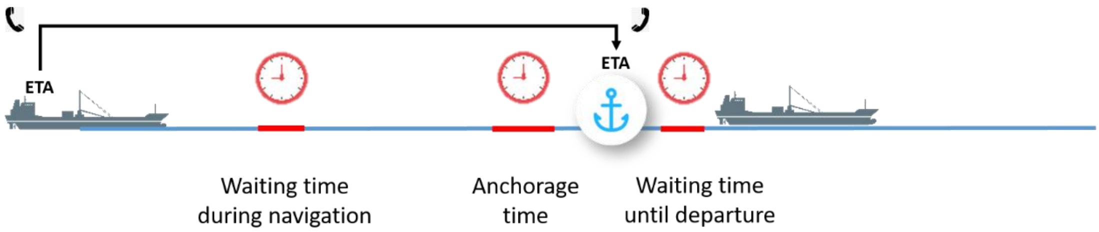


Figure 25: Current Situation in Port Call Synchronization

This section will first describe the different scenarios and their assumptions. Secondly, will describe in detail the figures provided for each use case.

1.5.1 Scenario 1: An improved synchronization between ships and ports

This first scenario assumes that ports, thanks to PortCDM, can provide more accurate recommended times of arrival, that vessels, thanks to the consumption of STM services, can avoid congestion or risks that otherwise would have affected their speed and meet their ETAs, and that both can communicate smoothly. As a consequence, anchoring times are minimized or eliminated.

This is reflected in our analysis by eliminating the anchoring times, and shifting the port call to the time at which the anchoring previously started. The time freed by avoiding the anchoring is used in the following port call, allowing the ship to reduce its speed.

The speed reduction is limited to the first quartile of the distribution of speeds obtained in the performance analysis. We assume that this speed is high enough to be acceptable for navigation. When the buffer of time is large enough so even navigating at the first quartile speed, the following call is shifted as well. As a result, the time that was previously assumed to be wasted in anchoring is now used in navigation consequently reducing the median cruising speed, the fuel consumption and the GHG emissions.

Is it worth mentioning, as well, that we assume that the ship navigates through the route computed with our route consolidation algorithm. Moreover, we are assuming that STM will allow for a better synchronization of the navigation, helping to avoid congestion. Hence, we assume that those ships that cover routes that can go through a canal, e.g., Kiel canal, will always go through that canal, not taking the longest route. Similarly, we assume that the vessel navigates at a constant speed that will allow her to arrive at the expected ETA to the port of call. Figure 26 summarizes this scenario.

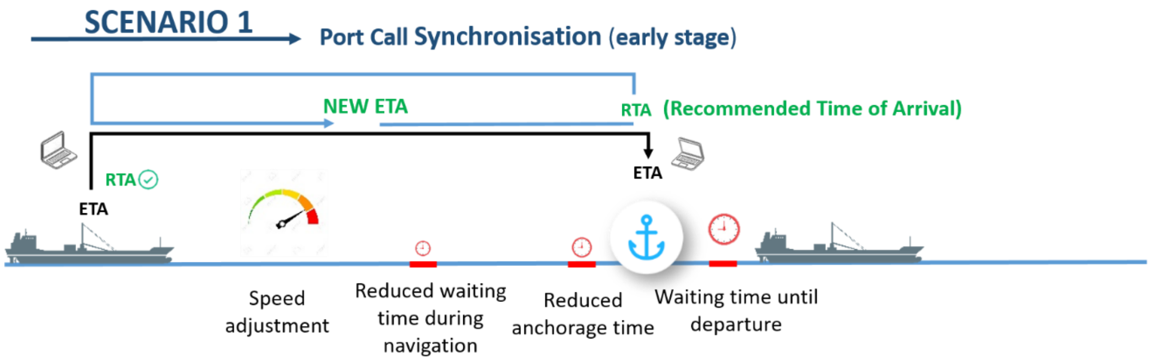


Figure 26: Scenario 1 - Port Cal Synchronization at early stage

1.5.2 Scenario 2: An advanced PortCDM deployment

In scenario 2 we assume that ports have fully deployed PortCDM and its use is already increasing the efficiency in ports. PortCDM will not only improve the communication between agents in the port, but also allow gathering, processing and analysing more data regarding the operations taking place in a port. This will result in a better resource planning, avoiding congestion in the port and increasing their efficiency.

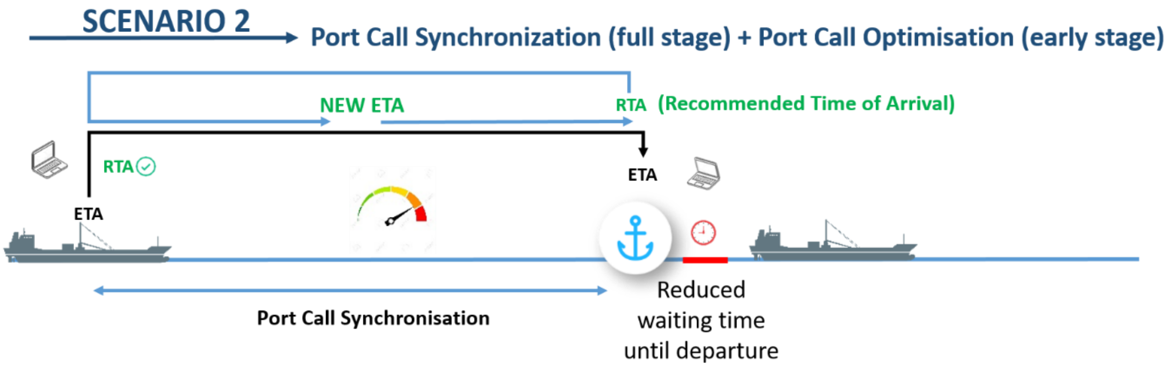


Figure 27: Scenario 2 - Port Call Synchronization full stage + Port Call Optimisation

This improvement is built on top of Scenario 1, reducing the duration of the port calls by a percentage. This value has been set to a 10% based on data from the 8 out of the 13 testbed ports from Activity 1. Figure 28 shows that, for all ship types except for Ro-Pax and Passenger ships, more than 10% of their time in berth is not for (un)loading operations. In fact, it is worth noting that general cargos, car carriers, bulk carriers or tankers are well above 20% of their in time in berth in median. This can be caused for several reasons, like the ships waiting for the start of the next stevedoring shift, or the ship not being in a hurry to get to its next call and the terminal having no new vessels arriving. On the other hand, Ro-Pax and Passenger ships are different because their operations are related to people and their operative is also faster. Seeing these values, proposing a 10% of improvement thanks to STM seems doable, except for the cases or Ro-Pax and passengers.

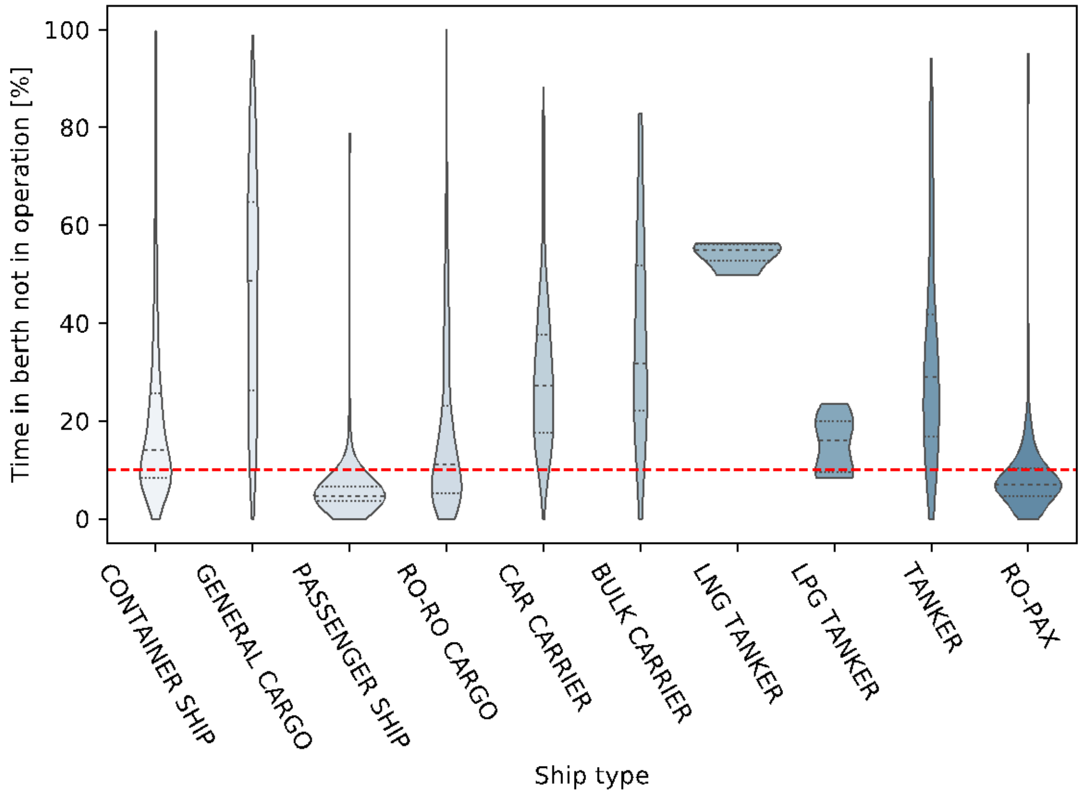


Figure 28: Distribution of the percentage of time a ship is not operation while in berth for different types of ship. The red line corresponds to the 10%, the value chosen as possible reduction thanks to STM.

1.5.3 Scenario 3: STM in operation. Adapting the ship cruising speeds.

Scenario 3 is more ambitious that the preceding ones. In this case, in addition to the assumptions of the previous scenarios, we analyse the effect on fuel consumption and GHG emission of having the ships navigating at different speeds.

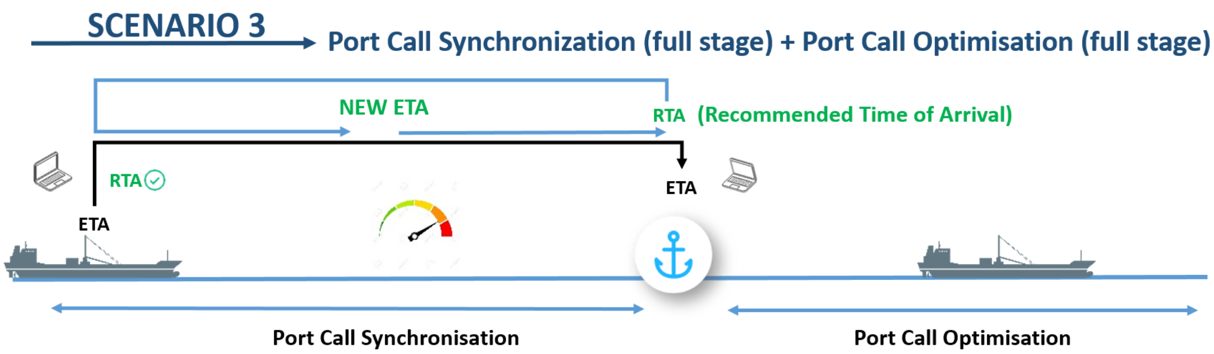


Figure 29: Scenario 3 - Port Call Synchronization + Port Call Optimization full stage

In particular, we used three different speeds, corresponding to the median, the first and third quartile speeds of the distribution of cruising speeds of each ship. The goal of this analysis is finding what would be the impact of having the ships navigating at speeds similar to nowadays, at a situation closer to slow steaming, or faster than today. Beware that this will have an impact not only in the fuel consumption and GHG emissions, but also in the time used to cover a particular route.

We assume that the calls are completely synchronized and that the ships are let into port upon their arrival. Basically, we are assuming Just-In-Time arrivals and departures, adapted to the election of the aforementioned speeds.

1.5.4 Fuel consumption and GHG emissions analysis

Two different figures will be presented per use case. The first figure presents the fuel consumption of one of the ships in the use case for the real AIS data and for each one of the proposed scenarios, disaggregated per navigation phase. Figure 30 shows an example of these figures. The results and savings are expected to be similar in the different ships of a use case, as the ships in the itinerary are normally similar. Moreover, the shape of the figures for the different GHG emissions are similar to that of the fuel consumption, as they are relatively proportional. For these reasons, only one figure is presented for the entire use case and different types of emission.

The second figure aims at offering a broader view of the savings for the use case. An example of this figure can be seen in Figure 31. Here, we show the average percentage of savings in each scenario and for fuel consumption and emissions jointly with error bars giving an intuition of the deviation across the different ships in the use case. This figure offers a clear overview of the benefits of each scenario in terms of fuel consumption and emissions. It is interesting to remark that in some cases, especially in Scenario 3 with high speed, there may be no savings in terms of fuel consumption or GHG emissions, as the increment associated to speed is larger than the reduction due to other improvements associated to STM.

Jointly with these figures, each of the use cases include different tables with the real consumption and GHG emissions per ship, and per ship and joint savings in fuel consumption and GHG emissions.

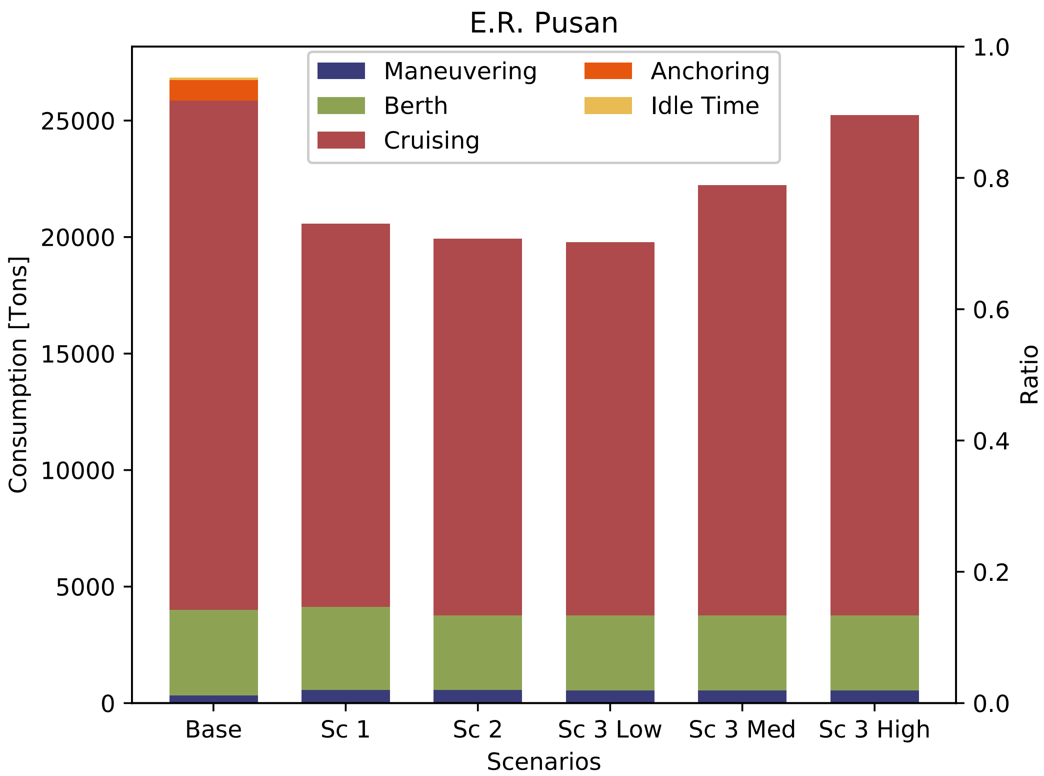


Figure 30: Estimation of the fuel consumption disaggregated per phase for one of the vessels in CS2, the E.R. Pusan.

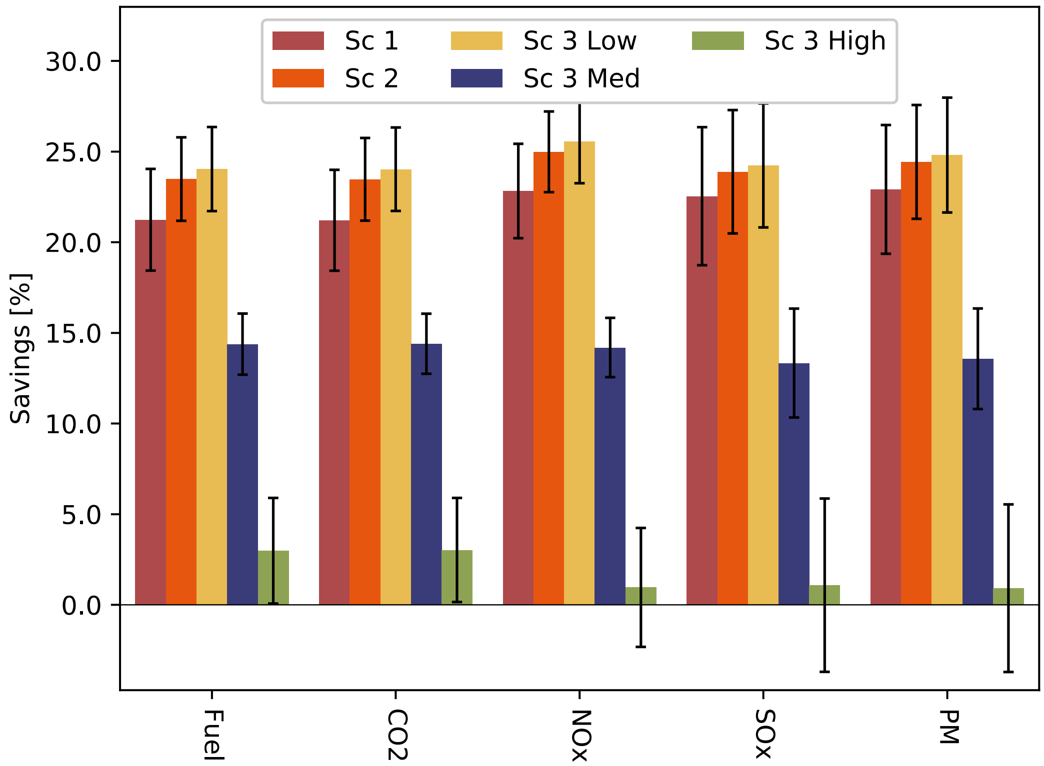


Figure 31: Overview of the savings in fuel consumption and emissions in each scenario for CS2.

1.5.5 Impact on navigation time

Finally, the analysis is completed by presenting the impact that each of the scenarios would have on the navigation time. The reader must bear in mind that, besides the impact on the fuel consumption and GHG emissions, the shipping lines must take into account how this is reflected in the time a ship needs to cover its route. Figure 32 shows an example of this figure for CS2.

As it was mentioned before, in general, lower speeds result in lower fuel consumption and emissions, but also longer navigation times. The improvements associated to the deployment of STM will also help compensating the use of lower speeds, but each use case has its own reality. Hence, it will be possible to observe that there are cases where the savings achieved by applying Scenario 3 do not compensate the impact on navigation time, or cases where it does. The goal of this analysis is to provide shipping lines with more information to make better decisions.

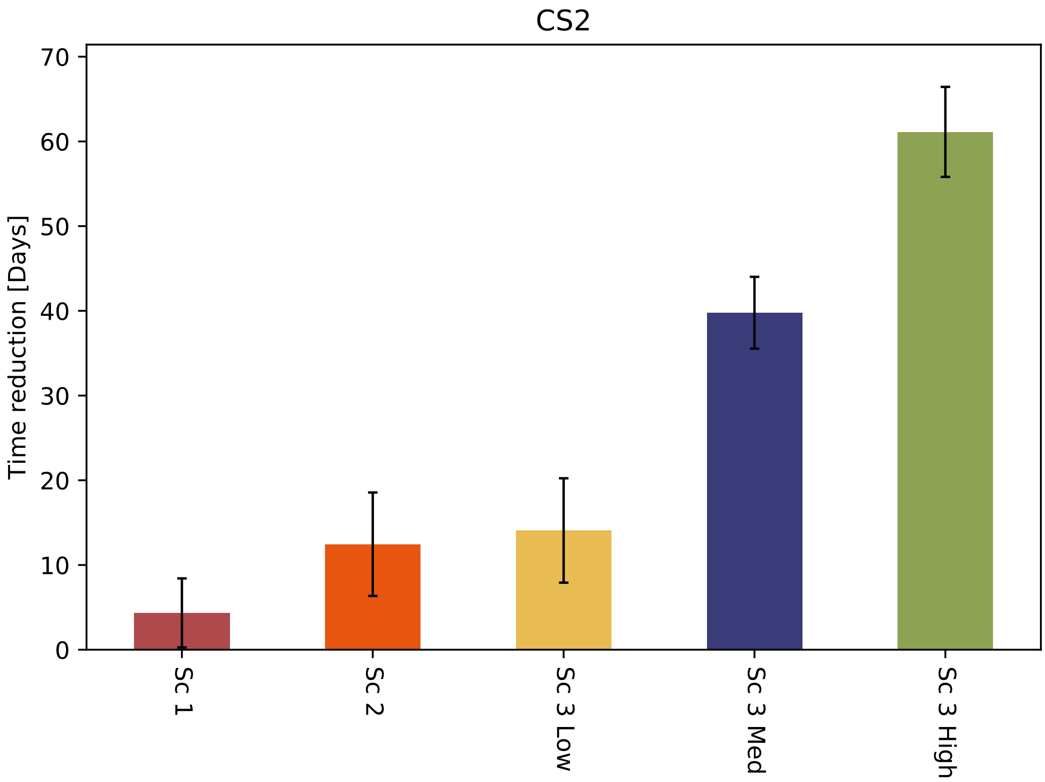


Figure 32: Variation in navigation time for each scenario in CS2

4 STM MACRO EVALUATION METHODOLOGY

Valenciaport Foundation has developed a unique and ad-hoc tool that features information about all the regular lines calling at any core and/or comprehensive port of the Trans-European Transport Network in the European Union, including the Norwegian ports incorporated in the STM validation project. This tool is called VESSL, Valenciaport European Short Sea Shipping Lines Database, and it is being developed by Valenciaport Foundation team with the objective of providing a solution to the lack of information of the regular services in the maritime connections calling at the ports included in the TEN-T comprehensive network.

The scope of this database is to compile the information of the regular services along the Mediterranean and North Europe sea area that comply with the criteria used to define Short Sea Shipping. Short Sea Shipping is defined as ‘the movement of cargo and passengers by sea between ports situated in Europe or between those ports and ports situated in non-European countries which have a coastline on the enclosed seas bordering Europe' (on the Mediterranean and Black Seas, etc.). As a result, short sea shipping also includes feeder services: a short-sea network between ports with the objective of consolidating or redistributing freight to or from a deep-sea service in one of these ports, the so-called hub port.

Thousands of data are being collected and compiled from different sources such as the different agents implied: Sea Carriers, Shipping Agents, Port Authorities, Specific Press, Private Databases, etc. Data accuracy is continuously verified with updated information provided by the actors concerned along the transport chain. The main groups of data are:

- Regular Shipping Services Data: name of the service, sea carrier, actual schedule, itinerary of ports, main ships operating the service, type of traffic, number of port calls, number of different countries where the service is being provided, frequency, seasonality, etc.
- Ports Data: The ports included in the different itineraries are characterised in detail by country, sea, coordinates, continent, geographic area, Ten-T Corridor comprised, UNLO CODE, among other details.
- Ships Data: IMO number, name of the ship, ship type, ship operator, shipyard, MMSI number, flag, GT, DWT, year of build, dimensions, cargo capacity, total power, group of engines configuration, service speed, fuel consumption, etc.
- Distances Data: port-to-port distance for every two ports in a service is calculated and registered. A smart selection of waypoints to cover the distance from port-to-port is included in the database.
- Times Data: figures like the navigation time, port call time, etc. are calculated and registered.
- Engine characteristics Data: data from prime and auxiliary engines of the ships operating in regular services are collected and registered.
- Bunkering Data: related to the ports and estimates the market price of the different fuels including LNG (Liquefied Natural Gas), HFO, MGO, MDO, etc.

The type of services has been categorised based on the cargo transported by each service and the characteristics of the vessels used. According to these criteria, services have been classified as car carrier, container, passenger, cruises, ro-ro and ro-pax services.

VESSL will collect a huge variety of information for more than 200 core and comprehensive ports in 23 Member States (Bulgaria, Cyprus, Croatia, Greece, Spain, France, Italy, Malta, Portugal, Romania, Slovenia, Belgium, Germany, Denmark, Estonia, Finland, Ireland, Lithuania, Latvia, Netherlands, Poland, Sweden and United Kingdom). More than 2,800 ships characterised; more than 4,000 couples of port distances; 1,203 ports featured; more than 450 different ship engines, and thousands of transit and port call times will be collected in this repository.

The large number of ports under study and the vast amount of information and variables to be considered in the database has resulted in an exhaustive monitoring process of information, which is essential in terms of future evaluation, meeting the expected analysis objectives. The information is continuously updated, validated and standardised in parallel to the search for information.

The result of this compilation of data is a SQL database containing essential information about the morphology of the Short Sea Shipping situation in the European Union. It will permit to extrapolate the data extracted in STM test beds into a macro level and that will permit to provide general results of the potentiality of applying STM.

Potential reductions in both port call and navigation times, fuel consumption and consequently, GHG emissions will be calculated during the analysis and its consequences analysed both for the society and for the environment in the whole European Union.

The verified results obtained will provide criteria for the shipping actors to make decisions regarding their business models and the adaptation towards the future by adopting STM concept. Decisions such as fleet management, resources utilisation, and optimised strategic voyage plans could be enhanced by the use of this smart tool: Valenciaport Short Sea Shipping Lines Database (VESSL).

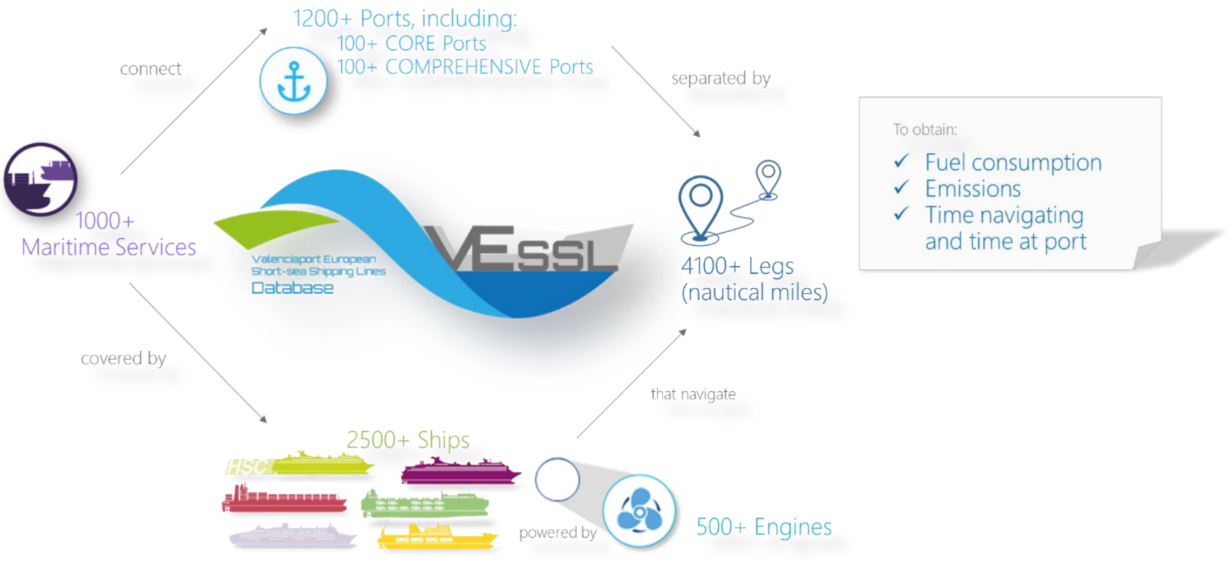


Figure 33: Data included in VESSL tool collected and compiled by Fundación Valenciaport

VESSL with respect to STM offers accurate information of regular lines of Short-Sea Shipping and National. With this tool, it will be estimated the impact of the implementation in all or part of the STM concept. Therefore, VESSL should be used as a tool to extract from it macro data estimating the impact that STM would have for the European Union concerning regular lines. VESSL is able to calculate navigation and port times, consumption and emissions using a calculation methodology that is explained in the ad-hoc report of the tool. It is also capable of calculating the fuel consumption of ships in various scenarios, including ECA areas or not and the consumption of auxiliaries in ports. For the exercise of extrapolation of data from use cases to VESSL an MGO scenario will be used for further simplification of the calculations.

The task of defining queries has followed the following steps:

1. Correspondence of STM regular line use cases with specific segmentation explained in this methodology. Each type of traffic and ship in the database can be classified within a specific segment.

USE CASE	TRAFFIC TYPE	VESSEL TYPE	HSC	UNIT	From	To	Range
CS1	CONTAINER	CONTAINERSHIP	N	TEU	0	999	<=999 TEU
CS1	CONTAINER	CONTAINERSHIP	N	TEU	1000	1999	1000 - 1999 TEU
CS1	CONTAINER	CONTAINERSHIP	N	TEU	2000	2999	2000 - 2999 TEU
CS2	CONTAINER	CONTAINERSHIP	N	TEU	3000	5399	3000 - 5399 TEU
CS2	CONTAINER	CONTAINERSHIP	N	TEU	5400	9999	5400 - 9999 TEU

CS3	CONTAINER	CONTAINERSHIP	N	TEU	10000		> 10000 TEU
CS1	CONTAINER	GENERAL CARGO	N	DWT	0	4999	<= 4999 DWT
CS1	CONTAINER	GENERAL CARGO	N	DWT	5000	9999	5000 - 9999 DWT
CS1	CONTAINER	GENERAL CARGO	N	DWT	10000	14999	10000 - 14999 DWT
CS1	CONTAINER	GENERAL CARGO	N	DWT	15000	19999	15000 - 19999 DWT
CS1	CONTAINER	GENERAL CARGO	N	DWT	20000	29999	20000 - 29999 DWT
CS1	CONTAINER	GENERAL CARGO	N	DWT	30000		> = 30000 DWT
CS1	CONTAINER	RO-RO	N	LaneMeters	0	499	<= 499 lane metres
CS1	CONTAINER	RO-RO	N	LaneMeters	500	999	500 - 999 lane metres
CS1	CONTAINER	RO-RO	N	LaneMeters	1000	1499	1000 - 1499 lane metres
CS1	CONTAINER	RO-RO	N	LaneMeters	1500	1999	1500 - 1999 lane metres
CS1	CONTAINER	RO-RO	N	LaneMeters	2000	2999	2000 - 2999 lane metres
CS1	CONTAINER	RO-RO	N	LaneMeters	3000		>= 3000 lane metres
RPX 1	RO-PAX	RO-PAX	N	GT	0	9999	<= 9999 GT
RPX 1	RO-PAX	RO-PAX	N	GT	10000	19999	10000 - 19999 GT
RPX 2	RO-PAX	RO-PAX	N	GT	20000	49999	20000 - 49999 GT
RPX 3	RO-PAX	RO-PAX	N	GT	50000	69999	50000 - 69999 GT
RPX 3	RO-PAX	RO-PAX	N	GT	70000		>= 70000 GT
RPX 1	RO-PAX	RO-PAX	Y	GT	0	9999	<= 9999 GT
RPX 1	RO-PAX	RO-PAX	Y	GT	10000	19999	10000 - 19999 GT
RPX 2	RO-PAX	RO-PAX	Y	GT	20000	49999	20000 - 49999 GT
RPX 3	RO-PAX	RO-PAX	Y	GT	50000	69999	50000 - 69999 GT
RPX 3	RO-PAX	RO-PAX	Y	GT	70000		>= 70000 GT
RO1	RO-RO	RO-RO	N	LaneMeters	0	499	<= 499 lane metres
RO1	RO-RO	RO-RO	N	LaneMeters	500	999	500 - 999 lane metres
RO2	RO-RO	RO-RO	N	LaneMeters	1000	1499	1000 - 1499 lane metres
RO2	RO-RO	RO-RO	N	LaneMeters	1500	1999	1500 - 1999 lane metres
RO3	RO-RO	RO-RO	N	LaneMeters	2000	2999	2000 - 2999 lane metres

RO3	RO-RO	RO-RO	N	LaneMeters	3000		>= 3000 lane metres
RO1	RO-RO	GENERAL CARGO	N	DWT	0	4999	<= 4999 DWT
RO1	RO-RO	GENERAL CARGO	N	DWT	5000	9999	5000 - 9999 DWT
RO2	RO-RO	GENERAL CARGO	N	DWT	10000	14999	10000 - 14999 DWT
RO2	RO-RO	GENERAL CARGO	N	DWT	15000	19999	15000 - 19999 DWT
RO3	RO-RO	GENERAL CARGO	N	DWT	20000	29999	20000 - 29999 DWT
RO3	RO-RO	GENERAL CARGO	N	DWT	30000		> = 30000 DWT
RO1	RO-RO	RO-PAX	N	GT	0	9999	<= 9999 GT
RO2	RO-RO	RO-PAX	N	GT	10000	19999	10000 - 19999 GT
RO3	RO-RO	RO-PAX	N	GT	20000	49999	20000 - 49999 GT
RO3	RO-RO	RO-PAX	N	GT	50000	69999	50000 - 69999 GT
RO3	RO-RO	RO-PAX	N	GT	70000		>= 70000 GT
RO1	RO-RO	CAR CARRIER	N	Cars	0	499	< 500 cars
RO1	RO-RO	CAR CARRIER	N	Cars	500	999	500 - 999 cars
RO2	RO-RO	CAR CARRIER	N	Cars	1000	1499	1000 - 1499 cars
RO2	RO-RO	CAR CARRIER	N	Cars	1500	1999	1500 - 1999 cars
RO3	RO-RO	CAR CARRIER	N	Cars	2000	2999	2000 - 2999 cars
RO3	RO-RO	CAR CARRIER	N	Cars	3000	3999	3000 - 3999 cars
RO3	RO-RO	CAR CARRIER	N	Cars	4000		>= 4000 cars
PAX 1	PAX	PAX	N	Passengers	0	199	< 200 passengers
PAX 1	PAX	PAX	N	Passengers	200	499	200 - 499 passengers
PAX 1	PAX	PAX	N	Passengers	500	1199	500 - 1199 passengers
PAX 1	PAX	PAX	N	Passengers	1200	1999	1200 - 1999 passengers
PAX 1	PAX	PAX	N	Passengers	2000		> 2000 passengers
PAX 1	PAX	PAX	Y	Passengers	0	199	< 200 passengers
PAX 1	PAX	PAX	Y	Passengers	200	499	200 - 499 passengers
PAX 1	PAX	PAX	Y	Passengers	500	1199	500 - 1199 passengers
PAX 1	PAX	PAX	Y	Passengers	1200	1999	1200 - 1999 passengers
PAX 1	PAX	PAX	Y	Passengers	2000		> 2000 passengers
RO1	CAR CARRIER	CAR CARRIER	N	Cars	0	499	< 500 cars
RO1	CAR CARRIER	CAR CARRIER	N	Cars	500	999	500 - 999 cars
RO2	CAR CARRIER	CAR CARRIER	N	Cars	1000	1499	1000 - 1499 cars
RO2	CAR CARRIER	CAR CARRIER	N	Cars	1500	1999	1500 - 1999 cars
RO3	CAR CARRIER	CAR CARRIER	N	Cars	2000	2999	2000 - 2999 cars

RO3	CAR CARRIER	CAR CARRIER	N	Cars	3000	3999	3000 - 3999 cars
RO3	CAR CARRIER	CAR CARRIER	N	Cars	4000		>= 4000 cars
PAX 1	MIXED PAX AND RO-PAX	PAX	N	Passengers	0	199	< 200 passengers
PAX 1	MIXED PAX AND RO-PAX	PAX	N	Passengers	200	499	200 - 499 passengers
PAX 1	MIXED PAX AND RO-PAX	PAX	N	Passengers	500	1199	500 - 1199 passengers
PAX 1	MIXED PAX AND RO-PAX	PAX	N	Passengers	1200	1999	1200 - 1999 passengers
PAX 1	MIXED PAX AND RO-PAX	PAX	N	Passengers	2000		> 2000 passengers
PAX 1	MIXED PAX AND RO-PAX	PAX	Y	Passengers	0	199	< 200 passengers
PAX 1	MIXED PAX AND RO-PAX	PAX	Y	Passengers	200	499	200 - 499 passengers
PAX 1	MIXED PAX AND RO-PAX	PAX	Y	Passengers	500	1199	500 - 1199 passengers
PAX 1	MIXED PAX AND RO-PAX	PAX	Y	Passengers	1200	1999	1200 - 1999 passengers
PAX 1	MIXED PAX AND RO-PAX	PAX	Y	Passengers	2000		> 2000 passengers
RPX 1	MIXED PAX AND RO-PAX	RO-PAX	N	GT	0	9999	<= 9999 GT
RPX 1	MIXED PAX AND RO-PAX	RO-PAX	N	GT	10000	19999	10000 - 19999 GT
RPX 2	MIXED PAX AND RO-PAX	RO-PAX	N	GT	20000	49999	20000 - 49999 GT
RPX 3	MIXED PAX AND RO-PAX	RO-PAX	N	GT	50000	69999	50000 - 69999 GT
RPX 3	MIXED PAX AND RO-PAX	RO-PAX	N	GT	70000		>= 70000 GT
RPX 1	MIXED PAX AND RO-PAX	RO-PAX	Y	GT	0	9999	<= 9999 GT
RPX 1	MIXED PAX AND RO-PAX	RO-PAX	Y	GT	10000	19999	10000 - 19999 GT
RPX 2	MIXED PAX AND RO-PAX	RO-PAX	Y	GT	20000	49999	20000 - 49999 GT
RPX 3	MIXED PAX AND RO-PAX	RO-PAX	Y	GT	50000	69999	50000 - 69999 GT
RPX 3	MIXED PAX AND RO-PAX	RO-PAX	Y	GT	70000		>= 70000 GT

Figure 34: Correspondence between use cases and segmentation in VESSL

2. Assumption of diverse criteria for sample size such as:
   a. Consultation year
   b. MGO 2020 scenario has been selected
   c. Regular SSS and cabotage services excluding deep-sea services and cruises
   d. Seasonal lines are taken into account
   e. HSC ships routes have been identified
   f. Other type of ships (i.e. general cargo,etc.)that operates in container or Ro-Ro traffic routes have been included in the consultations
   g. Navigating and port times for simultaneous ships have been calculated.

   h. Emissions calculations of CO_2, NOX, SOX and PM in current situation and STM scenario implementation has been identified according to the segmentation.
3. Additional data to carry out the final results calculations have been added such as:
   a. Total number of services included in the sample
   b. Total number of different itineraries
   c. Number of shipping companies per type of service
   d. Shipping companies' list
   e. Total number of ships analysed
   f. Total number of ports analysed
   g. Total number of port connections
   h. Total number of countries in which VESSL ships are calling
   i. Etc.
4. Elaboration of the overall data results table for consumptions and emissions savings
5. Elaboration of the overall data results table for time savings
6. Conclusions

With the results of the use cases taken to the VESSL database, the macro-level impact on the SSS and *cabotage* across the European Union could be analysed, resulting in fuel savings, lower pollutant emissions and shorter port times thanks to the implementation of the STM concept throughout Europe.

5 USE CASES RESULTS

5.1 Use Case CS1

5.1.1 Abstract

The containerisation of cargo has represented a revolution in the transport of goods in recent decades, because it facilitates economies of scale and standardizes the way goods are transported, facilitating intermodality as well as their distribution. The containerships represent 5.7% of the total world fleet (5,202 units) in 2017 (EQUASIS, 2018).

The STM project has been able to include 50 container ships of different sizes and this use case covers containerships with capacity of less than 1,000 TEU. It comprises three ships: NJORD, PIRITA and ATLANTIC COAST, which operate a service for Sea Connect, an operator of container feeder and short sea services. The company operates high frequency services between Europe major ports including St. Petersburg.

Only the NJORD is actually included in the STM testbed, navigating through European ports and even the Kiel Canal. Precisely, the shipping service passage through the Kiel Canal provides some peculiarities to the analysis. The size of the ships, the planned route across the Nordic test bed, the clear feeder service design as well as their ongoing transit through some of the shore centre areas of the STM project are other factors that have led to the selection of this use case.

5.1.2 Use Case Data

The data used to analyse the use cases is divided in two sets. On the one hand, static data related to the characteristics of each of the ships, like those shown in Table 4 or other derived from it, that are captured in their configuration file. On the other hand, AIS navigation data from the period comprehended between June 1st 2017 and May 31st 2018, that shows real location, time and speed data from the routes they covered. Altogether, these data are used to compute the fuel consumption and emissions of the ships in the use cases.

SHIP	IMO No.	GT	FLAG	YEAR OF BUILD	SIZE (L/ B/ D) in metres	CAPACITY (TEU)	MAIN ENGINE POWER (kW)	AUX. ENGINE POWER (kW)	BOILER
NJORD	9123805	6,326	NL	1995	133 x 19 x 7	660	6,600	375	N/A
ATLANTIC COAST	9129469	6,326	CY	1995	133 x 19 x 7	660	6,600	375	N/A
PIRITA	9108063	7,946	PT	1995	133 x 19 x 7	646	6,600	375	N/A

Table 4: CS1 Ships Characteristics

5.1.3 Use Case Analysis

Figure 35 displays the itinerary covered by the ships in Use Case CS1. During the voyage, the ships shift through different phases: berth, manoeuvring, anchoring and cruising. The phases of berth, manoeuvring and cruising are part of the natural flow of the voyage.

However, the anchoring phase is usually the result of an inefficient port call synchronization between ships and ports. Similarly, Idle Time can be the result of events that force the ship to reduce its speed or stop while navigating, being possible to tag it, as well, as an inefficiency.

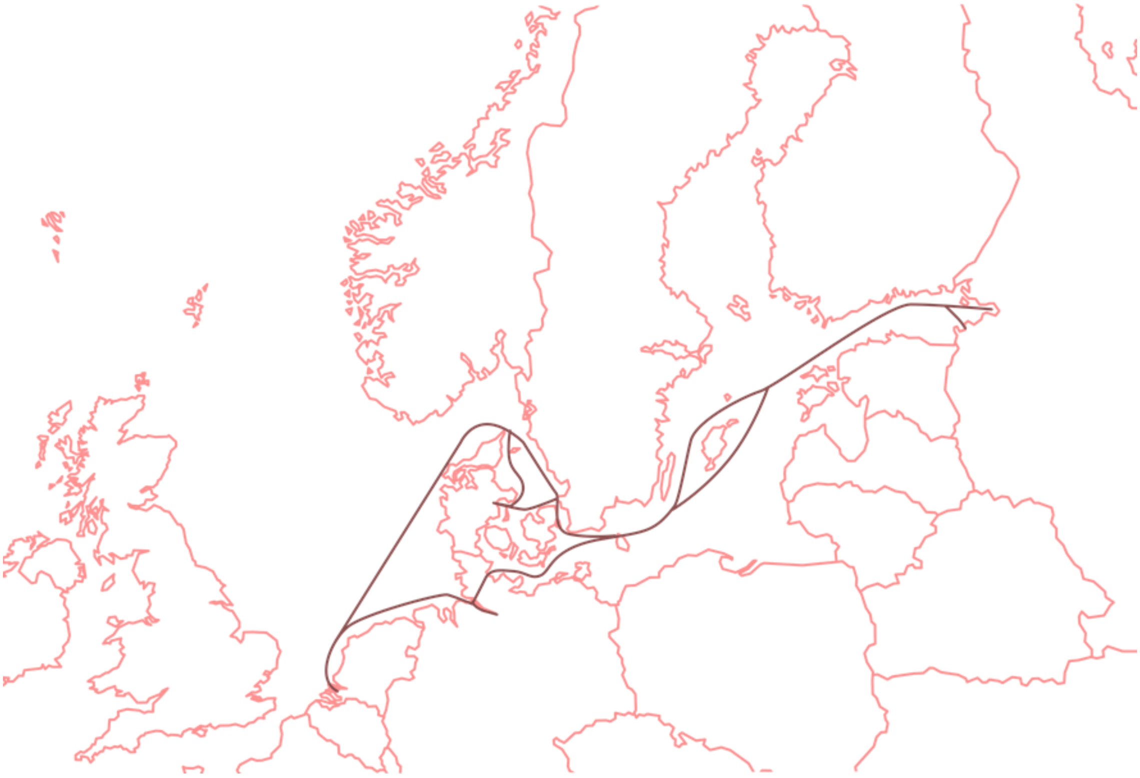


Figure 35: CS1 Use Case itinerary

During the voyage, there can be events that can have an effect in the navigational efficiency of the ships and the shipping service. There might be unnecessary variations of speeds due to several reasons: changes in the availability of arrival port resources, crossing a strait or canal, traffic restrictions or congestion. These avoidable speed variations and other causes can result in extra costs.

9.1.1.1 Efficiency

In order to provide an intuition about the mentioned inefficiencies we analyse the speed variation of the set of ships while cruising, their punctuality, their navigation and anchoring times.

1. ***Speed Variation***

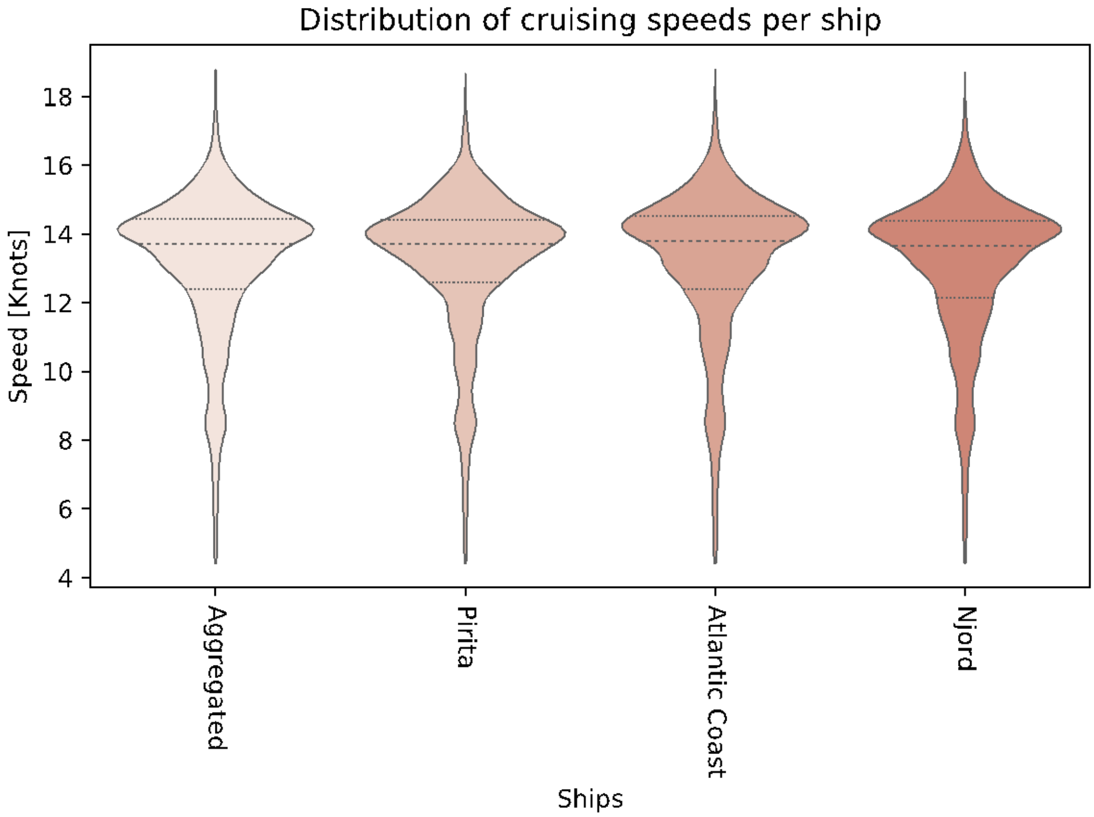


Figure 36: Aggregated distribution of cruising speeds for the ships in CS1

As we observe in Figure 36, the distribution of cruising speeds in the case of this shipping service has a relevant frequency of cruising speeds between 12 and 15 knots. This means that the variability in speed during navigation is moderate, around 3 knots, representing around 21% of the entire range of speeds recorded during the cruising phase. The three ships have similar distributions, implying low variability in their speed during navigation.

When it comes to distribution of cruising speeds per leg, the picture differs. In Figure 37 some inefficient legs are observed. In some of them, the navigation through Kiel canal is involved, with bimodal distributions in the cruising speeds which could be explained as the canal passage particularities, related to traffic congestion and waiting times. However, some legs showing inefficiencies are glimpsed that may also be related to port access or other inefficiencies, for instance the leg between Hamburg and Rotterdam, two of the biggest ports in Europe, and the return leg between Klaipeda and Aarhus in the North Sea where some geographical obstacles could lead to this bimodality (Oresund strait in the Jutland peninsula).

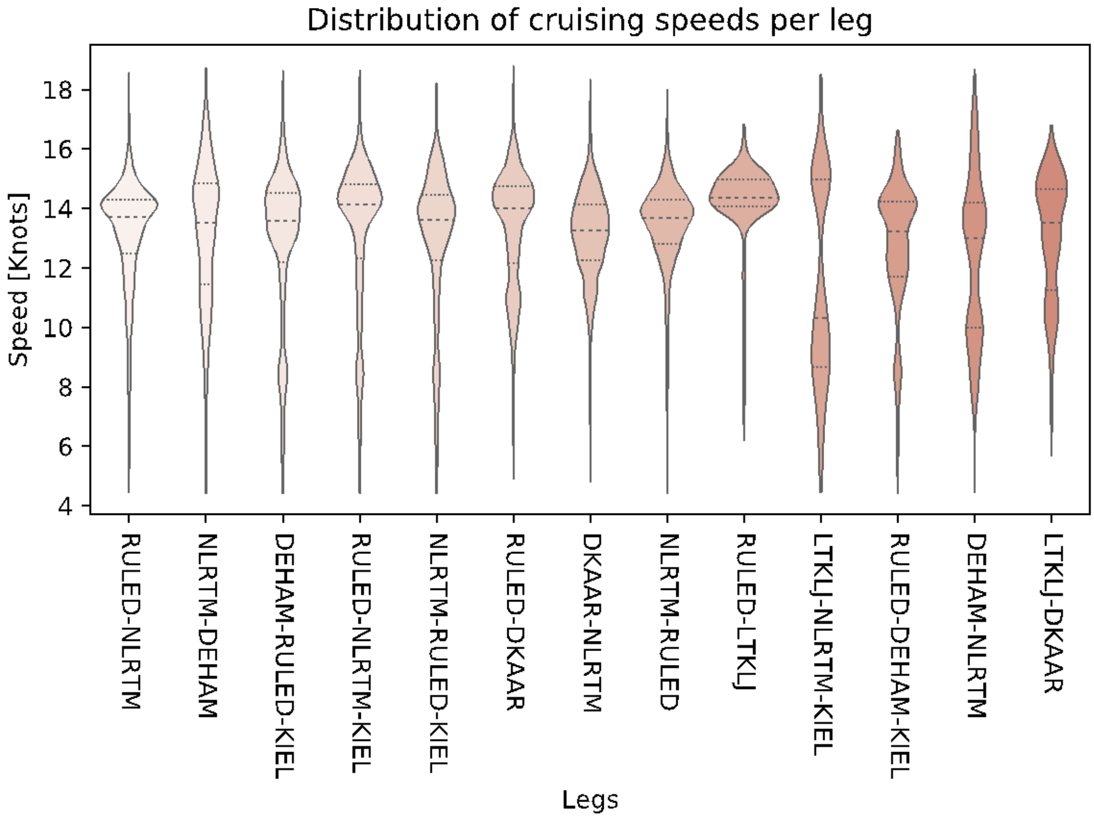


Figure 37: Aggregated distribution of cruising speeds per leg for the ships in CS1

2. Punctuality

One of the indicators of a shipping service in terms of efficiency is punctuality. Figure 38 and Figure 39 show the distributions of the deviation between the Estimated Time of Arrival (ETA) reported at the beginning of a leg and its Actual Time of Arrival (ATA), in order to capture, also, its capacity to provide accurate ETAs in advance.

In Figure 38, we can observe that more than the 70% of the times, the ships in this service will arrive later than reported. Moreover, the CDFs (Cumulative distribution function) show that, when late, the difference between ETA and ATA is larger than 10 hours the half of the times. For early arrivals, roughly a 90% of the cases were within these 10 hours range. Regarding unpunctuality between ships in the service, the CDFs are similar in the case of lateness but very different in earliness.

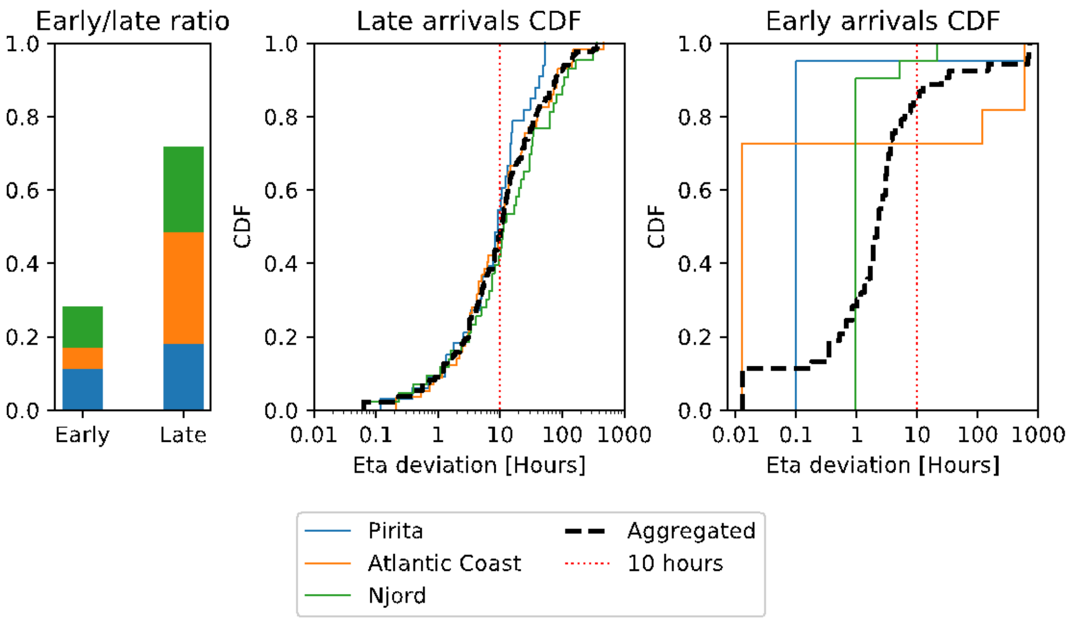


Figure 38: distribution of ETA deviations per ship in CS1

Conversely, in Figure 39, we observe that in the case of some ports like Rotterdam, the time of arrival seems hard to predict and the ships in this service are late more than 30% of the times in contrast with the 5% of early arrivals to this port. Moreover, the 50% of the times, the delay result in more than 10 hours. However, more than 80% of the times the early arrival is less than 10 hours.

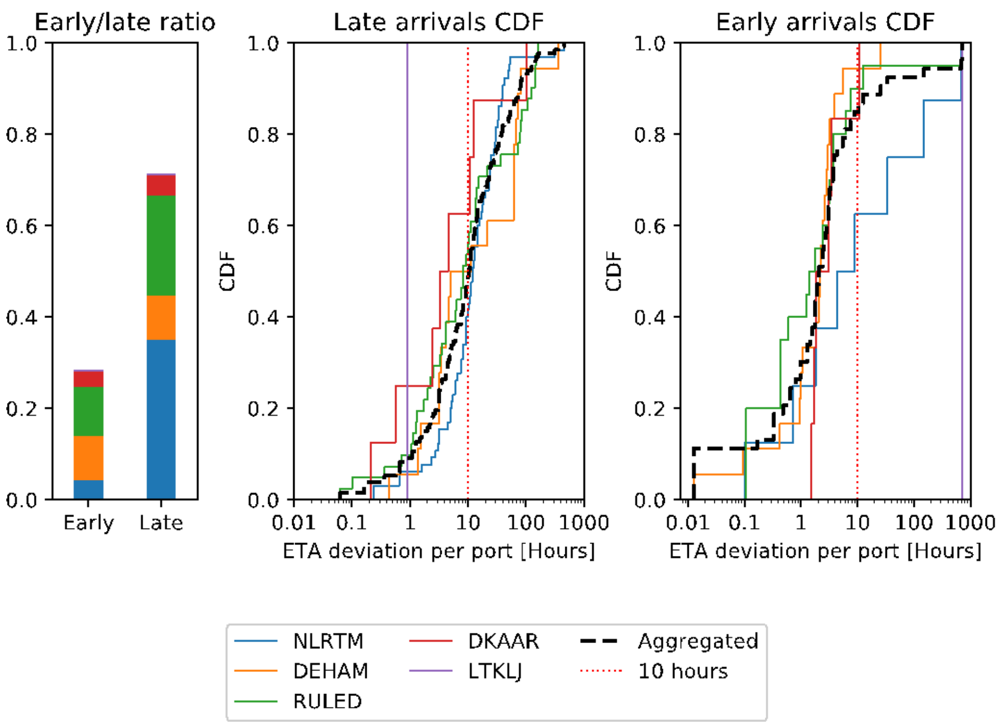


Figure 39: ETA deviations per port in CS1

3. Anchoring Times

Figure 40 presents the results related to anchoring times per port for CS1. Concerning the anchoring time per port, we observe that almost 20% of the times, the duration of the anchoring is more than 10 hours and as the aggregated anchoring shows, the ports of Rotterdam and St. Petersburg are the ones that cumulate more anchoring.

The reasons for this facts could be wide: the size of the port, their geographical situation, and other situations such as traffic congestion, availability of stevedoring service, etc.

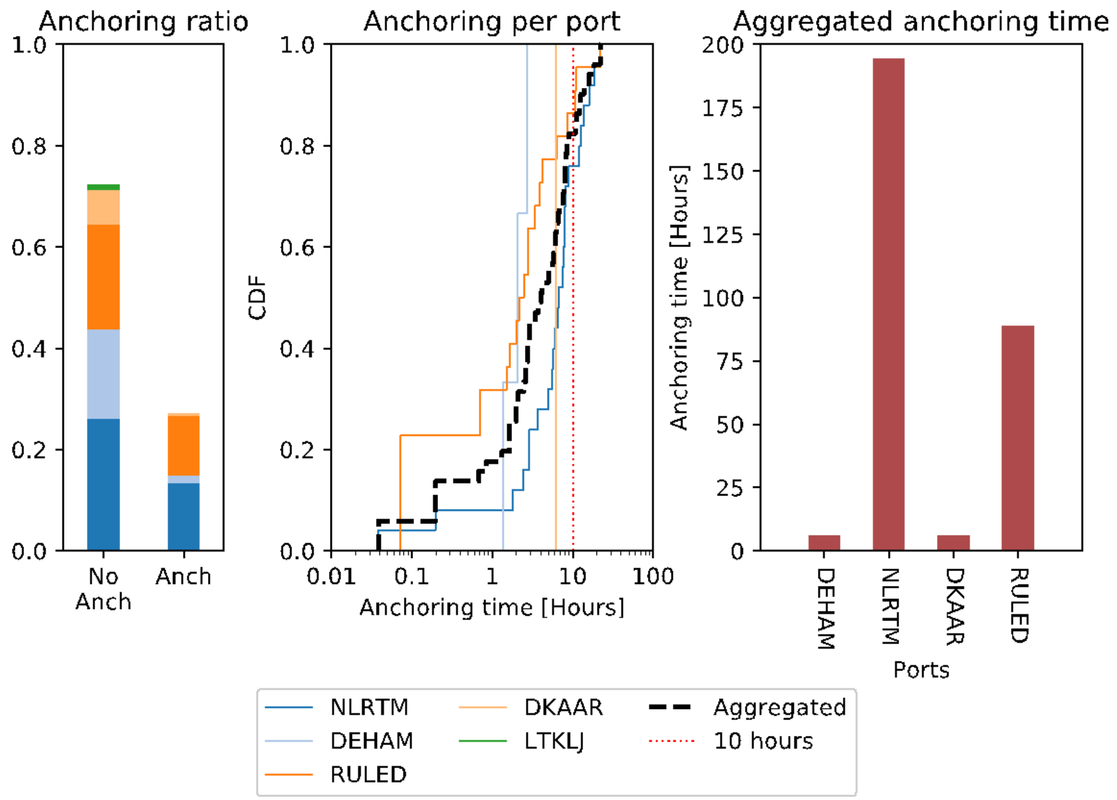


Figure 40: Anchoring times by port in CS1

In any case, STM will help to reduce or eliminate these timeframes of idleness by improving the communication ship-to-port and enabling the ports to improve their resource management. A better management should result in ports providing ships with better recommended times of arrival (RTA) that allow them to reduce their cruising speed, hence, save fuel and spend less time in anchoring.

9.1.1.2 Environmental Sustainability

Concerning environmental sustainability, this section presents an analysis of the navigation times, the fuel consumption and the different emissions in the current situation and shows the potential savings that the different proposed scenarios may introduce with STM implementation.

1. Navigation Times

Each of the scenarios will have, besides the impact on the fuel consumption and GHG (Greenhouse Gases) emissions, an impact on the navigation time and the shipping lines must take into account how this is reflected in the time a ship needs to cover its route. Figure 41 shows an example of this effect.

In general, lower speeds result in lower fuel consumption and emissions, but also longer navigation times. In Figure 41 we see that the savings achieved in Scenario 3 carry out a reduction in the itinerary of around 15 days. This could have an impact in the service configuration regarding the number of ships involved and the resources needed.

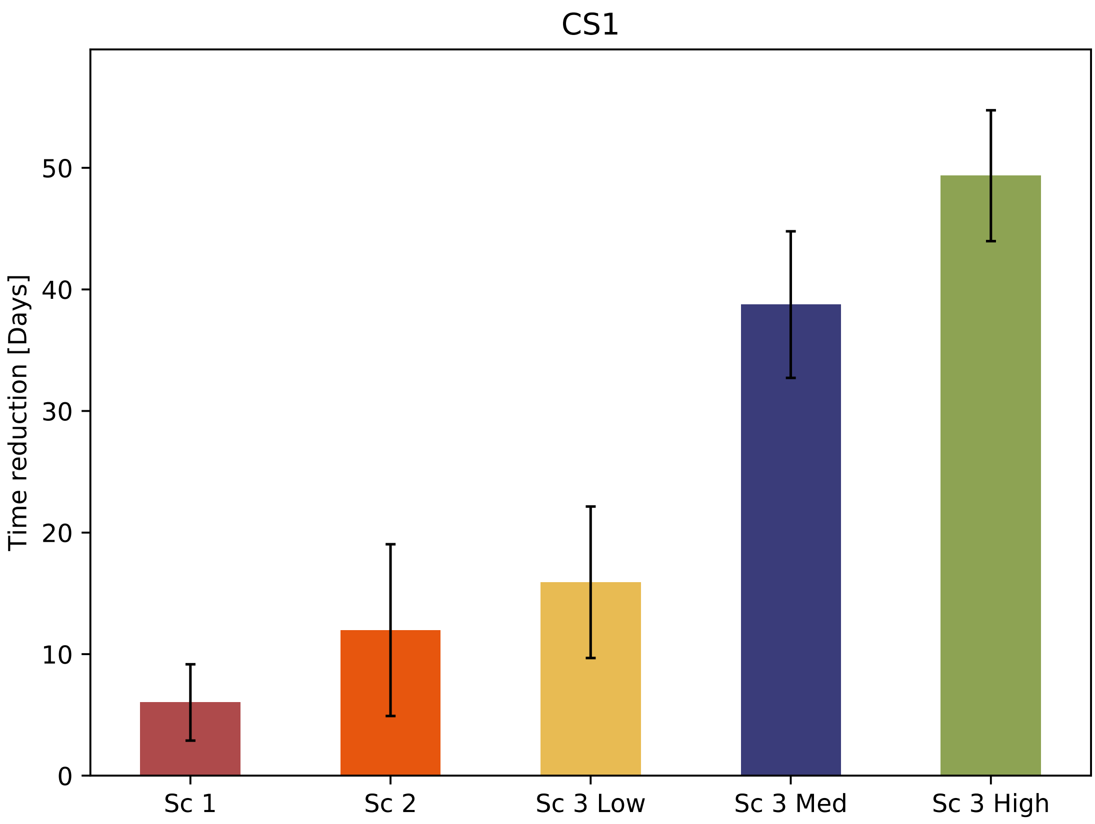


Figure 41: Variation in navigation time for each scenario in CS1

2. Fuel Consumption

Figure 42 presents an estimation of the fuel consumption of the NJORD ship, both for the real AIS (Automatic Identification System) data as for the proposed scenarios. The other ships in CS1 presented similar results as well and they can be consulted in ANNEXES.

As expected, cruising and berth are the dominating phases, where ships spend most of their time. In this case, the third scenario with the lowest median speed relates to the larger savings. This is due to a reduction on the speed variation and of the speed in general, as times spent in anchoring are used now to reduce the cruising speed.

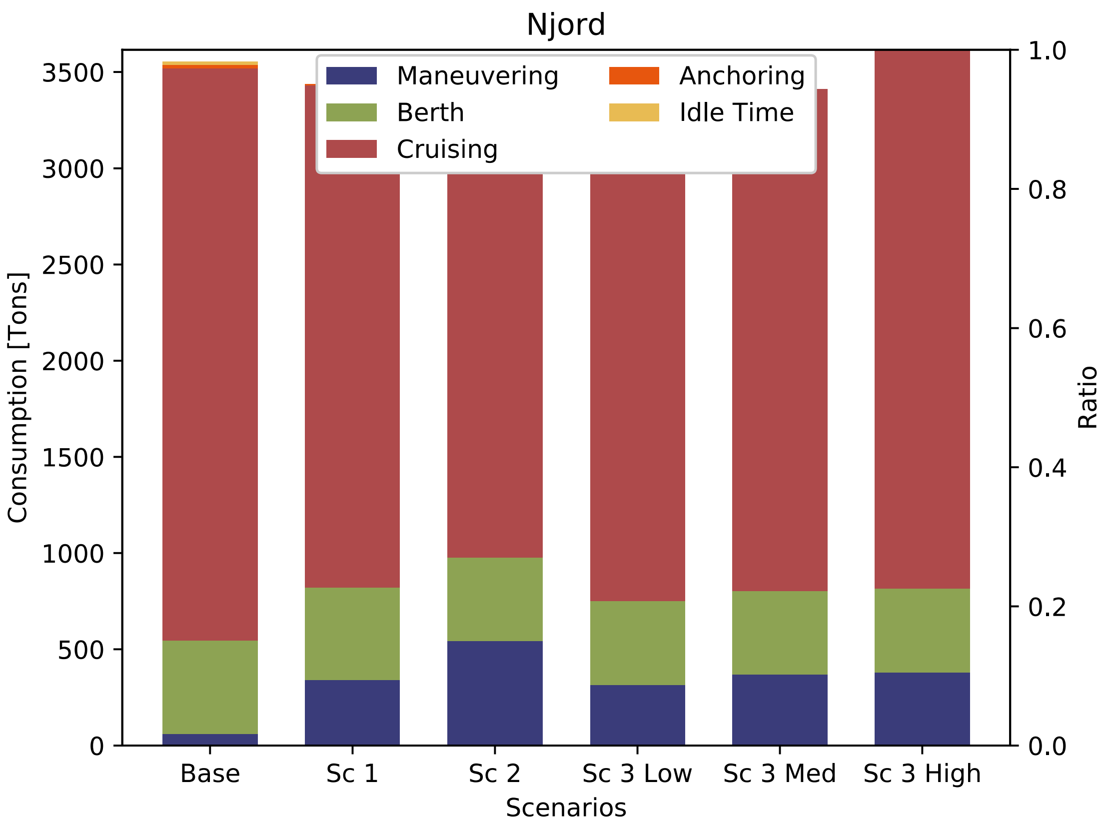


Figure 42: Fuel consumption of the Njord in the current situation and for the different proposed scenarios divided by phases.

3. GHG Emissions

Regarding GHG emissions, Figure 43 shows that both the savings for the consumption and emissions in each scenario as well as its variation are comparable. In addition, in the case of CS1, the results for the different ships are different, as implied by the extended length of the error bars. It can be observed that for Scenario 3 at low speed, which achieves the best results, the savings, both in consumption and in emissions, are roughly a 21% in average.

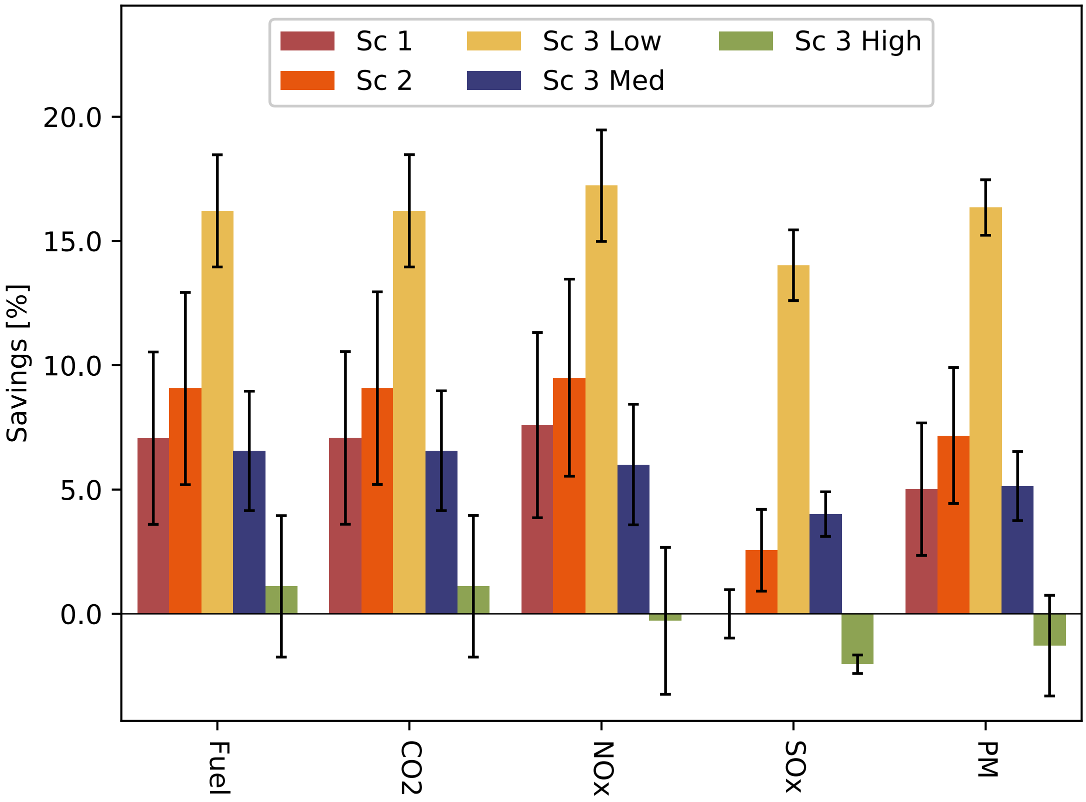


Figure 43: Mean values and deviations of the savings in fuel consumption and emissions for all the vessels in CS1

5.1.4 Use Case Evaluation

In this section the approximate savings of implementing the different scenarios of STM and the economic impact that this could have on the shipping companies' costs are shown.

Tones	Fuel Consumption	CO2 Emissions	NOx Emissions	SOx Emissions	PM
NJORD	3,557.43	11,397.42	249.12	12.59	4.08
ATLANTIC COAST	3,583.26	11,482.57	249.55	11.21	3.94
PIRITA	3,627.13	11,622.73	254.64	11.59	4.03

Table 5: Results of one year fuel consumption and GHG emissions in the current situation

In Table 5 we depict the results of one year fuel consumption and GHG emissions for the five ships. If we translate this information into US Dolars, using the price for the fuel, CO2, NOX, SOX and PM we will be able to quantify the costs savings for shipping companies and the emissions savings in monetary figures.

SHIP	Variable	Metric	SC 1	SC 2	SC 3 Low	SC 3 Med	SC 3 High
NJORD	Fuel	Ton	118.07	165.44	488.14	141.24	-61.11
		%	3.32%	4.65%	13.72%	3.97%	-1.72%
	CO2	Ton	378.91	530.36	1,563.63	452.23	-195.94
		%	3.32%	4.65%	13.72%	3.97%	-1.72%
	NOx	Ton	9.04	12.54	36.67	8.48	-7.86
		%	3.63%	5.03%	14.72%	3.40%	-3.15%

	SOx	Ton	-0.10	0.32	1.97	0.60	-0.30
		%	-0.76%	2.51%	15.68%	4.73%	-2.39%
	PM	Ton	0.08	0.16	0.62	0.15	-0.13
		%	1.95%	4.03%	15.07%	3.64%	-3.24%
PIRITA	Fuel	Ton	282.13	392.73	599.77	251.34	40.91
		%	7.87%	10.96%	16.74%	7.01%	1.14%
	CO2	Ton	905.28	1,259.72	1,922.55	806.00	131.63
		%	7.88%	10.97%	16.74%	7.02%	1.15%
	NOx	Ton	21.51	28.89	44.55	16.23	-0.70
		%	8.62%	11.58%	17.85%	6.50%	-0.28%
	SOx	Ton	0.09	0.43	1.61	0.38	-0.33
		%	0.82%	3.86%	14.37%	3.39%	-2.99%
	PM	Ton	0.24	0.36	0.66	0.21	-0.06
		%	6.06%	9.08%	16.82%	5.35%	-1.43%
ATLANTIC COAST	Fuel	Ton	366.61	423.45	657.33	315.37	143.07
		%	10.11%	11.67%	18.12%	8.69%	3.94%
	CO2	Ton	1,176.72	1,358.86	2,107.47	1,011.52	459.42
		%	10.12%	11.69%	18.13%	8.70%	3.95%
	NOx	Ton	27.93	31.28	48.72	20.97	7.07
		%	10.97%	12.28%	19.13%	8.24%	2.78%
	SOx	Ton	-0.14	0.04	1.48	0.36	-0.28
		%	-1.24%	0.36%	12.79%	3.08%	-2.45%
	PM	Ton	0.28	0.34	0.69	0.26	0.03
		%	6.94%	8.35%	17.13%	6.38%	0.79%
AGGREGATED	Fuel	Ton	766.81	981.62	1,745.24	707.96	122.87
		%	7.10%	9.10%	16.19%	6.56%	1.12%
	CO2	Ton	2,460.91	3,148.94	5,593.66	2,269.74	395.11
		%	7.11%	9.11%	16.20%	6.56%	1.13%
	NOx	Ton	58.49	72.71	129.95	45.68	-1.48
		%	7.74%	9.63%	17.24%	6.05%	-0.22%
	SOx	Ton	-0.15	0.79	5.07	1.33	0.92
		%	-0.39%	2.24%	14.28%	3.73%	2.61%
	PM	Ton	0.60	0.86	1.97	0.62	-0.16
		%	4.98%	7.15%	16.34%	5.13%	-1.29%

Table 6: Estimated savings for one year in fuel consumption and GHG emissions for the different scenarios

9.2 Use Case CS2

9.2.1 Abstract

The CS2 use case studies the shipping service "North Europe Service 1" linking Mediterranean and North European ports. This shipping service is operated by two shipping companies: ZIM Integrated Shipping Services Ltd. and MSC (Mediterranean Shipping Company).

There are nine ports involved: Valencia, Felixstowe, Rotterdam, Hamburg, Antwerp, Le Havre, Limassol, Ashdod and Haifa, and five ships in the rotation: E.R. Pusan, Dimitris Y, MSC Lausanne, MSC Carouge and MSC Geneva. Altogether they cover the north Europe service, with a frequency of one per week, that is to say that every port is visited once a week by one of the ships in this service. Only the E.R. Pusan is included in the STM project. However, service performance is not understood without including all the ships that have been used to design the shipping service and the port call sequence.

The reasons to study this use case are diverse. The ships operate through the two testbeds (Nordic and Mediterranean) included in the project, they pass through the STM shore centre located in the Strait of Gibraltar and they call at two STM ports: Valencia and Limassol.

9.2.2 Use Case Data

SHIP	IMO No.	GT	FLAG	YEAR OF BUILD	SIZE (L/ B/ D) in metres	CAPACITY (TEU)	MAIN ENGINE POWER (kW)	AUX. ENGINE POWER (kW)	BOILER
E.R. PUSAN	9211169	66,289	LU	2000	277 x 40 x 14	5,762	55,700	6,200	N/A
DIMITRIS Y	9189354	66,526	LR	2000	278 x 40 x 14	5,468	54,900	N/A	N/A
MSC LAUSANNE	9320398	62,702	MT	2005	283 x 40 x 13	6,336	39,970	4,000	N/A
MSC CAROUGE	9320441	62,702	PT	2007	283 x 40 x 13	6,336	39,970	4,000	N/A
MSC GENEVA	9320427	62,702	PT	2006	283 x 40 x 13	6,336	39,952	4,200	N/A

Table 7: CS2 Ship Characteristics

9.2.3 Use Case Analysis

Figure 44 displays the itinerary covered by the ships in Use Case CS2. During the voyage, the ships shift through different phases: berth, manoeuvring, anchoring and cruising. the phases of berth, manoeuvring and cruising are part of the natural flow of the voyage. However, the anchoring phase is usually the result from an inefficient port call synchronization between ships and ports. Similarly, Idle Time can be the result of events that force the ship to reduce its speed or stop while navigating, being possible to tag it, as well, as an inefficiency.

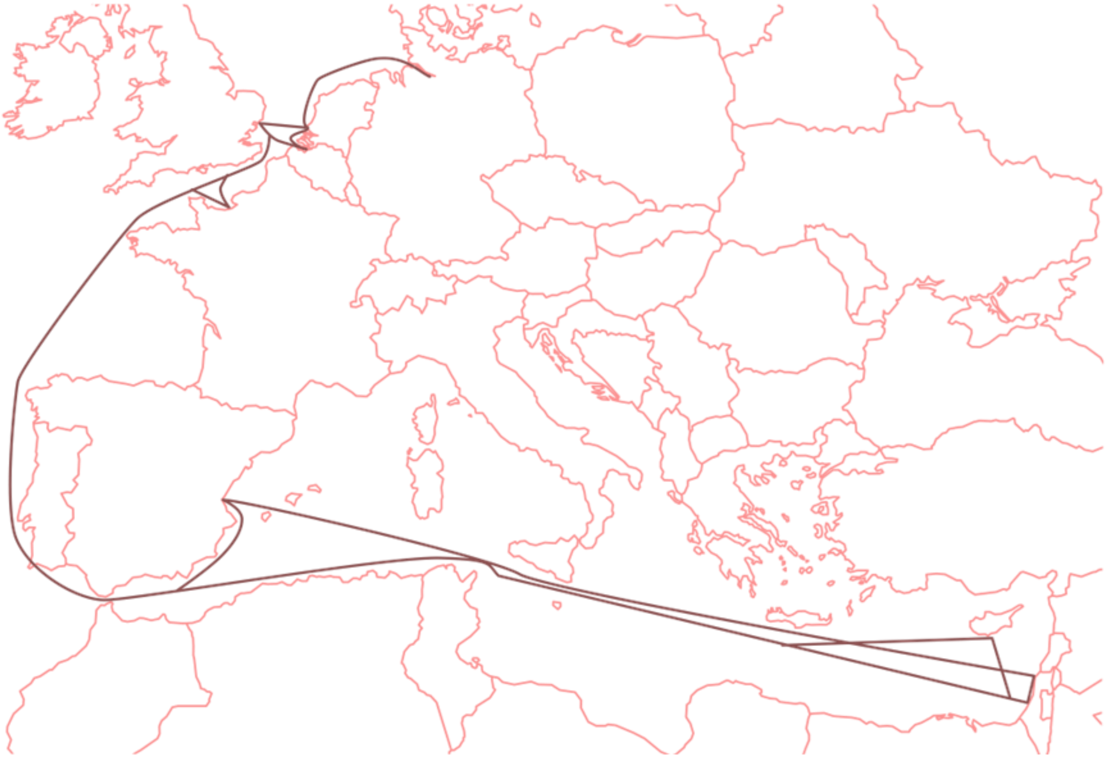


Figure 44: CS2 Use Case itinerary.

During the voyage, there can be events that can have an effect in the efficiency of the ships and the shipping service. There might be unnecessary variations of speeds due to several reasons: changes in the availability of arrival port resources, crossing a strait or canal, traffic restrictions or congestion. These avoidable speed variations will result in extra costs.

9.2.3.1 Efficiency

In order to provide an intuition about the mentioned inefficiencies we analyse the speed variation of the set of ships while cruising, their punctuality and their navigating and anchoring times.

1. Speed Variation

Figure 45 depicts the distribution of cruising speeds by ship and the aggregated one. We can observe that the distribution of speeds is relatively wide. Not only the interquartile range spans 5 knots already, between 13 and 18 knots approximately, but also the entire range between 11 and 21 knots has an apparently relevant frequency. Observe that this represents, approximately, a 60% of the entire range of speeds observed during the cruising phase. In fact, all five ships have wide distributions, implying high variability in their speed during navigation.

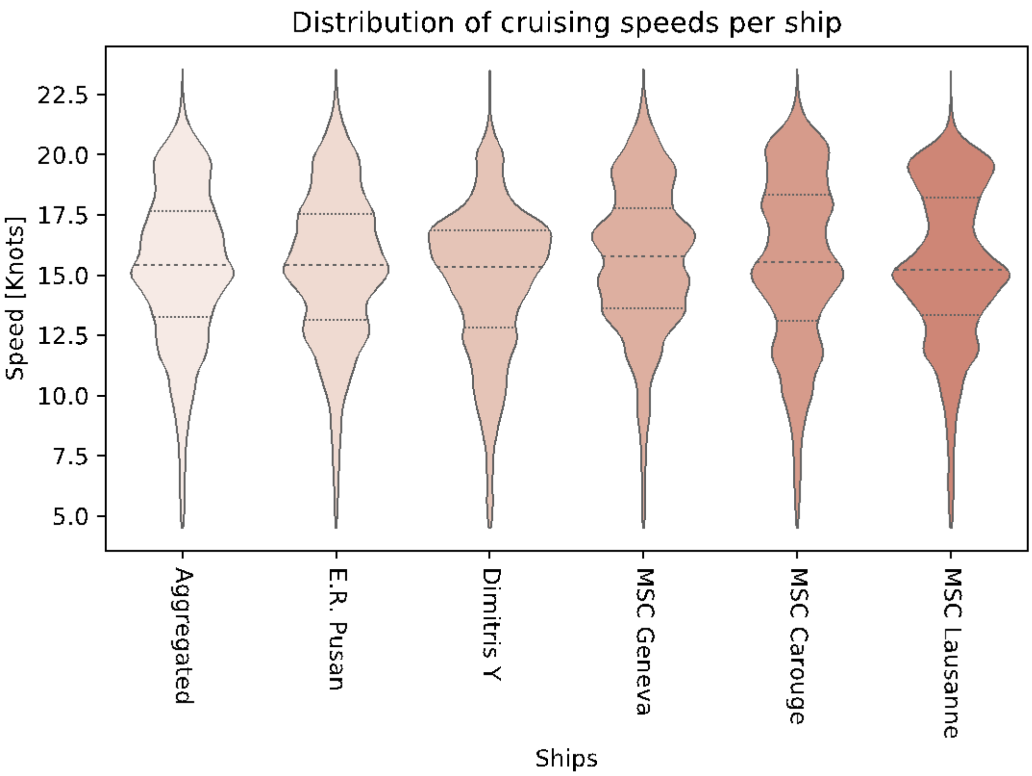


Figure 45: Aggregated distribution of cruising speeds for the ships in CS2.

Moreover, this non-uniformity is also captured in Figure 46. First, it can be observed that different legs are navigated at very different speeds. There are legs whose median speed is above 20 knots while others are below 13 knots. Second, the distribution of speeds in the same leg is also wide or in some cases bimodal (as in the case of Antwerp-Ashdod), implying again a large variability.

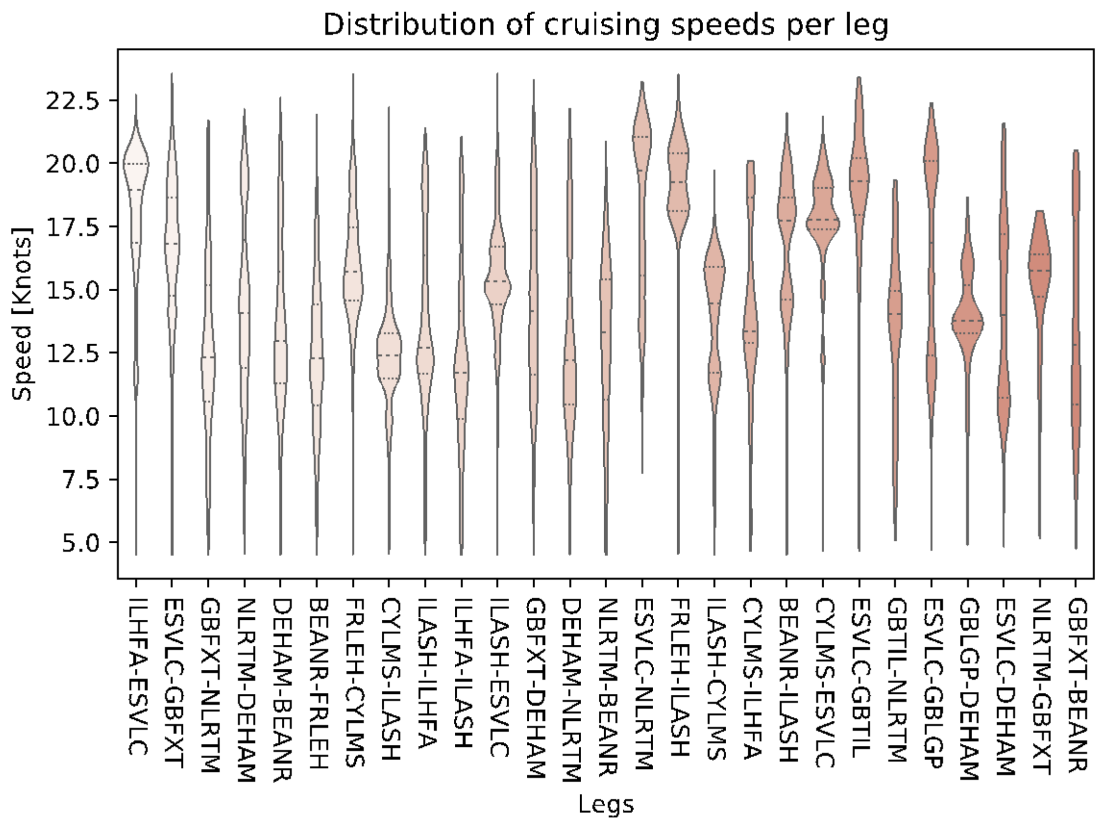


Figure 46: Aggregated distribution of cruising speeds per leg for the ships in CS2.

There are multiple possible reasons for this variability. From planning issues, having short time between port calls in some legs that could cause the ship to speed up, to congestion in some areas or to having to wait in anchoring in some ports and catching up again in the following leg.

STM will facilitate a better resource planning in ports that will allow ships to keep a constant speed during their legs and may increase the time they apply slow steaming.

2. Punctuality

One of the indicators of a shipping service in terms of efficiency is punctuality. Figure 47 and Figure 48 show the distributions of the deviation between the Estimated Time of Arrival (ETA) reported at the beginning of a leg and its Actual Time of Arrival (ATA), in order to capture, also, its capacity to provide accurate ETAs in advance.

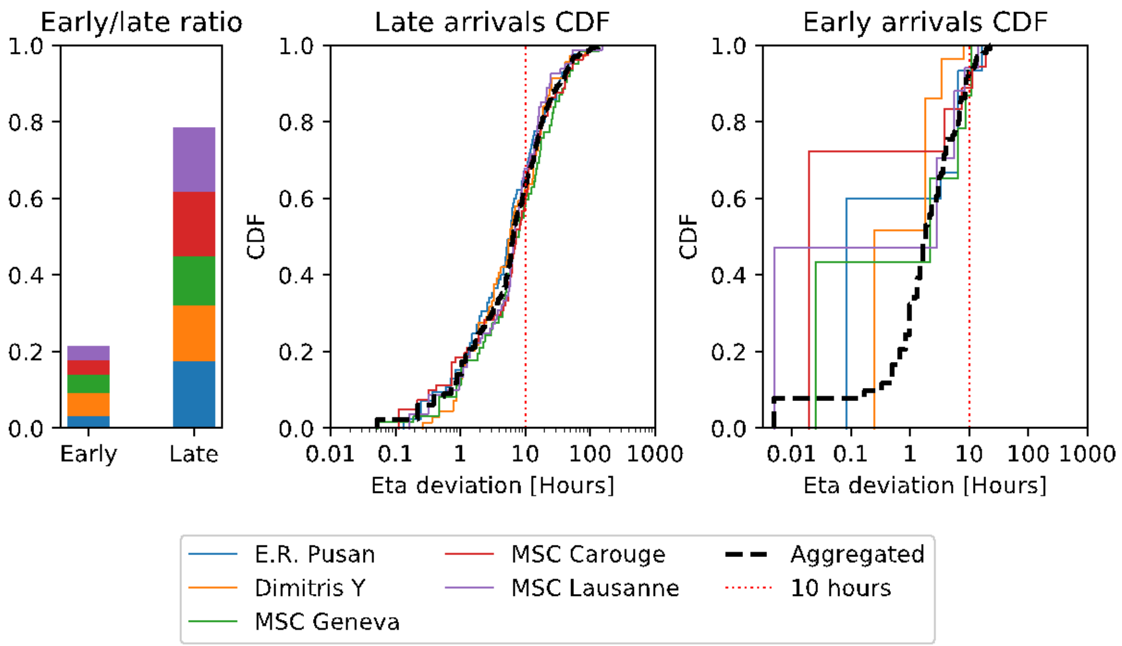


Figure 47: distribution of ETA deviations per ship in CS2.

In Figure 47, we can observe that almost an 80% of the times, for CS2, ships will arrive later than reported. Moreover, the CDFs show that, when late, the difference between ETA and ATA is larger than 10 hours in, approximately, a 40% of the time. For early arrivals, roughly a 95% of the cases were within these 10 hours range. Finally, we can see that the CDFs for each ship are similar, so it seems to be a common behaviour.

However, in Figure 48, we observe that the punctuality behaviour changes when it comes to ports. It seems that it is easier to predict the arrival time to some ports like Limassol, Le Havre, Valencia or Haifa, where the deviation is below 2 hours a 50% of the time or more. This could be caused for the variable weather conditions in the routes or for changes in the expected availability of the ports of destination.

Again, STM should be able to solve or minimize these issues thanks to the implementation of STM at ports that will eventually help to improve the resource management in ports, or enabling a better and earlier ship-to-port and port-to-port communication.

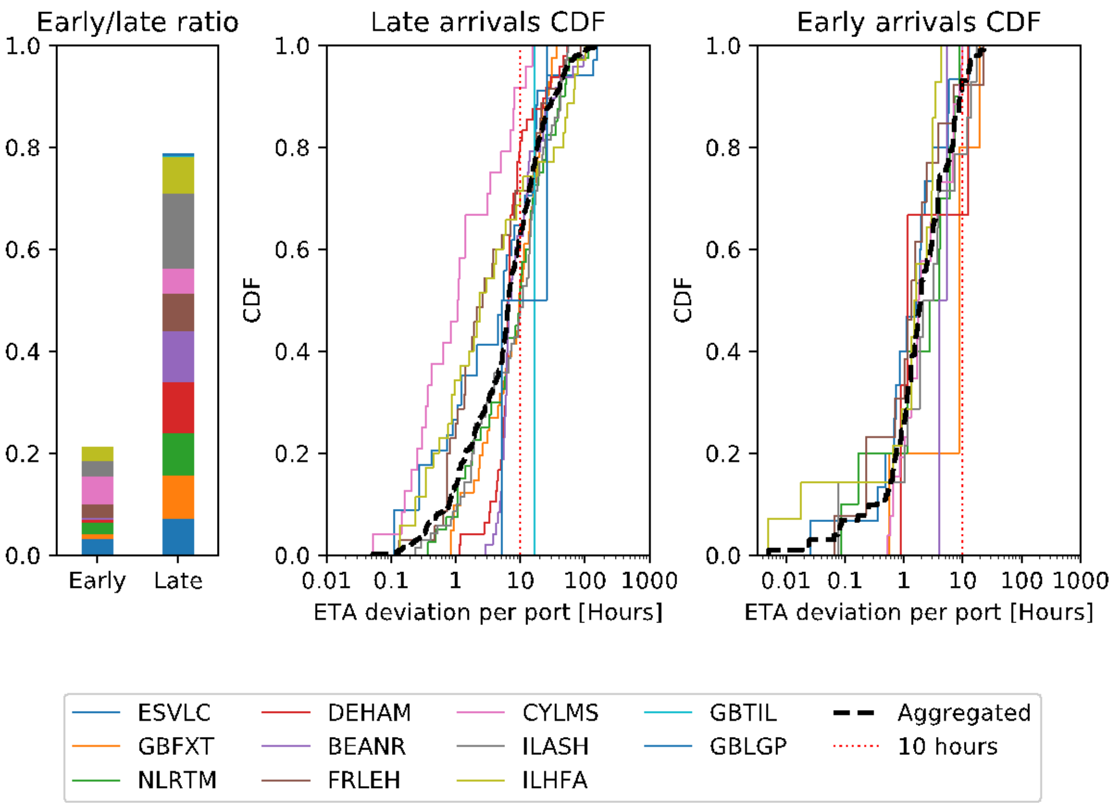


Figure 48: ETA deviations per port in CS2

3. Anchoring Times

Figure 49 presents the results related to anchoring for CS2. It is interesting to observe that slightly more than 40% of the times the ships had an anchoring period. Although this can be related with the high deviations on their ETAs, due to being late and missing their berthing windows, denotes either an incapability to react from the port side to adapt to this situation or from the ship to inform in time. In any case, it is also worth noting that more than 40% of these anchoring periods lasted more than 10 hours.

It is noticeable that there are substantial differences depending on the port. There could be several reasons for this. One of them could be the size of the port. In fact, Antwerp or Rotterdam behaviour is above the average. However, this does not seem to be the case, as other relatively large ports as Valencia or even Limassol, exhibit better results. A second feasible reason could be related to the geographical characteristics of the port, that could lead to difficulties in the access and to traffic congestion.

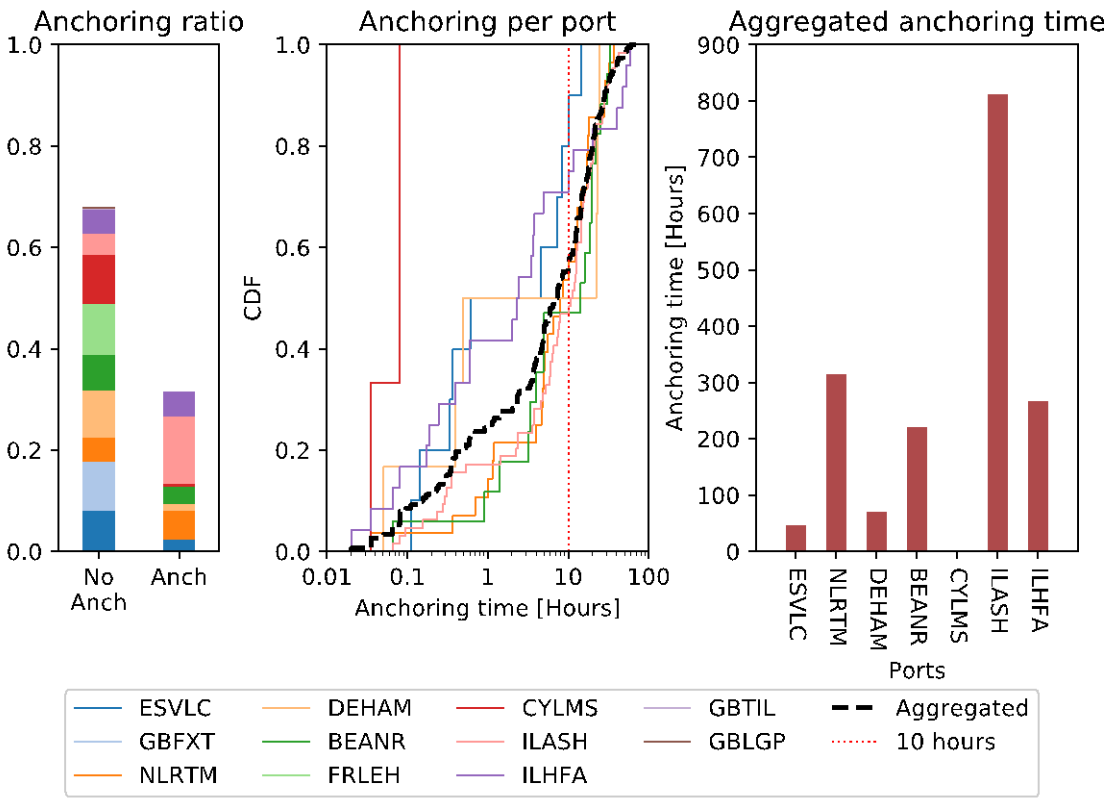


Figure 49: Anchoring times by port in CS2

9.2.3.2 Environmental Sustainability

1. Navigation Times

As we can see in Figure 50, each of the scenarios have an impact on the navigation time and this is essential information for shipping lines planning. For example, in Scenario 3 High Speed the time reduction for CS2 is clearly significant, around 60 days of time reduction, which would change completely the planning of the service.

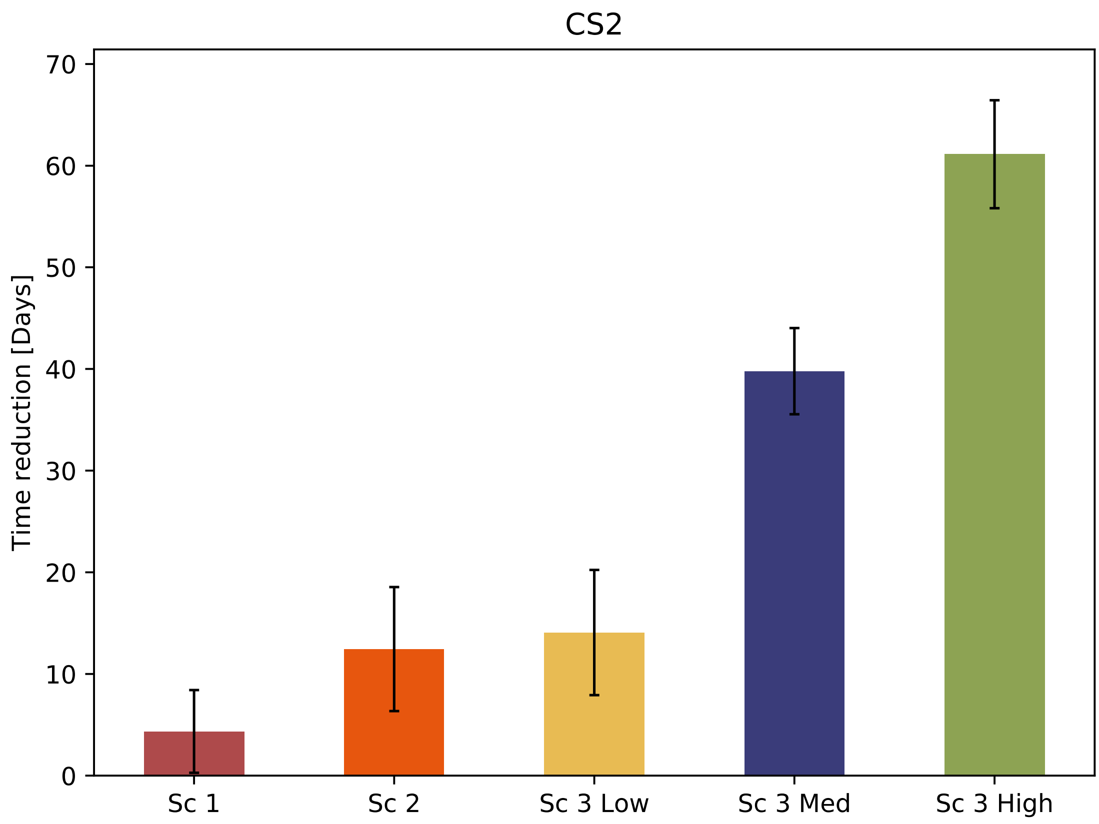


Figure 50: Variation in navigation time for each scenario in CS2

2. Fuel Consumption

Figure 51 presents an estimation of the fuel consumption of the E.R. Pusan both for the real AIS data as for the proposed scenarios. It is worth mentioning that the figures for the different types of GHG emissions follow a very similar pattern. Likewise, the other ships in CS2 presented similar results.

As expected, cruising and berth are the dominating phases, where ships spend most of their time. In the case of CS2, the first scenario already introduces large savings. This is not only thanks to eliminating the anchoring an idle time, but also thanks to a better synchronization between port and ship, and also due to a reduction on the speed variation and of the speed in general, as times spent in anchoring are used now to reduce the cruising speed.

Scenario 2 introduces some additional savings, due to an improved efficiency and reduced times in berth. This is, again, slightly improved in Scenario 3 by enforcing the use of a lower cruising speed. However, it is interesting to remark that even the use of the median speed (SC Med) or a higher speed[5], corresponding to the third quartile of its speed distribution, can introduce relevant savings in terms of fuel consumption.

[5] The low and high speeds correspond to the first and third quartile of speed distribution of each ship, that were shown in Figure 45 as was explained in [CITAR METODOLOGIA]

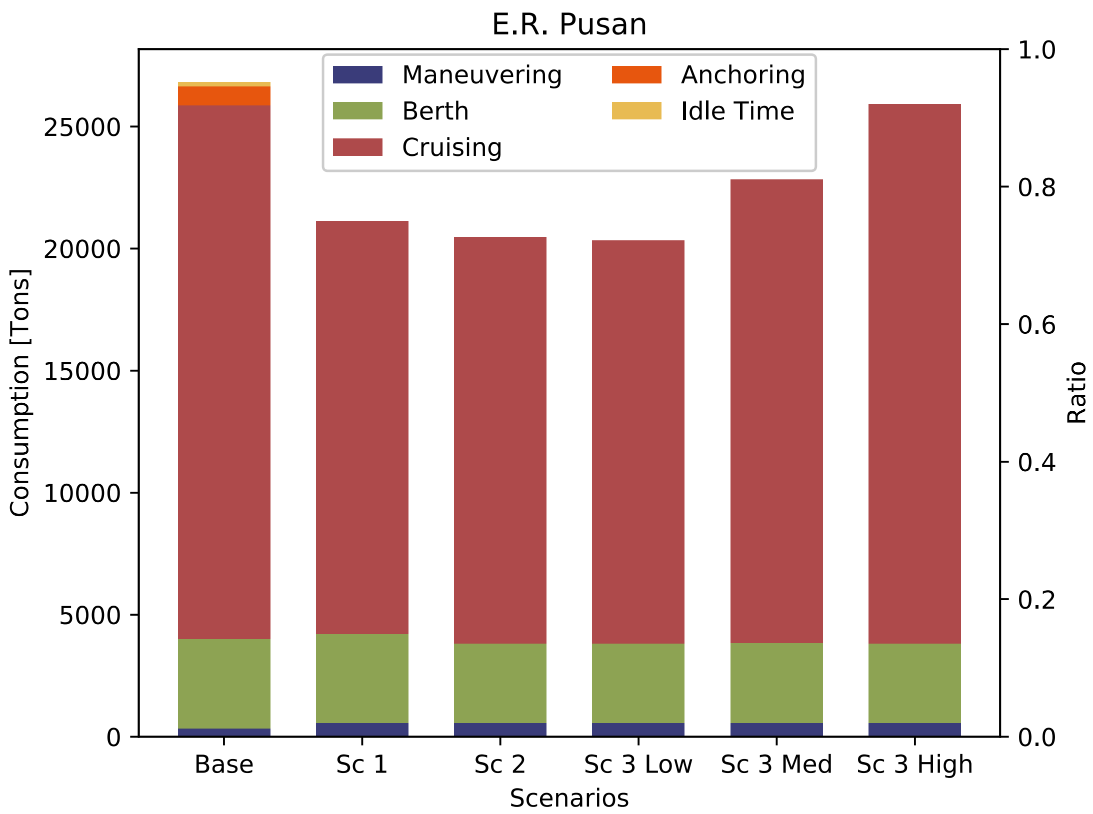


Figure 51: Fuel consumption of the E. R. Pusan in the current situation and for the different proposed scenarios divided by phases.

3. GHG Emissions

Figure 52 shows that both the savings for the consumption and emissions in each scenario, as well as its variation are comparable. In addition, in the case of CS2, the results for the different ships are similar, as implied by the short length of the error bars. It can be observed that for Scenario 3 at low speed, which achieves the best results, the savings, both in consumption and in emissions, are roughly a 24% in average.

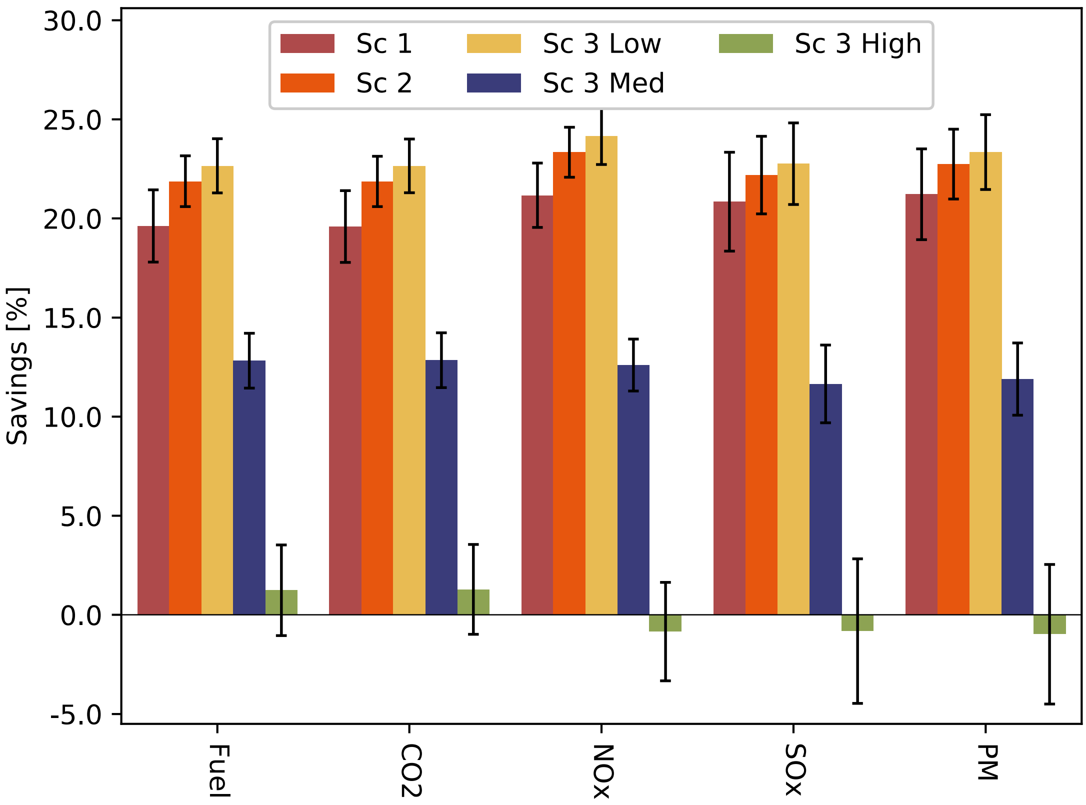


Figure 52: Mean values and deviations of the savings in fuel consumption and emissions for all the vessels in CS2.

9.2.4 Use Case Evaluation

In this section we show the approximate savings of implementing the different scenarios of STM and the economic impact that this could have on the shipping companies' costs.

Tons	Fuel Consumption	CO2 Emissions	NOx Emissions	SOx Emissions	PM
E.R. PUSAN	26,828.39	84,302.58	2,053.25	997.04	139.76
DIMITRIS Y	19,223.28	60,191.55	1,698.79	884.39	123.40
MSC GENEVA	18,505.89	58,143.31	1,594.03	772.22	107.83
MSC CAROUGE	19,213.75	60,371.66	1,659.66	798.69	111.80
MSC LAUSANNE	18,347.45	57,658.48	1,579.55	757.37	106.04

Table 8: Results of one year fuel consumption and GHG emissions

In Table 8 we depict the results of one year fuel consumption and GHG emissions for the five ships. If we translate this information into US Dolars, using the price for the fuel, CO2, NOX, SOX and PM we will be able to quantify the costs savings for shipping companies and express the emissions in monetary figures

SHIP	Variable	Metric	SC 1	SC 2	SC 3 Low	SC 3 Med	SC 3 High
E.R. PUSAN	Fuel	Tons	5,707.15	6,351.46	6,500.50	4,006.44	912.73
		%	21.27%	23.67%	24.23%	14.93%	3.40%
	CO2	Tons	17,890.62	19,936.86	20,407.52	12,596.24	2,909.98
		%	21.22%	23.65%	24.21%	14.94%	3.45%
	NOx	Tons	470.87	514.56	527.19	297.98	18.22
		%	22.93%	25.06%	25.68%	14.51%	0.89%
	SOx	Tons	235.81	247.81	252.05	145.11	10.74
		%	23.65%	24.85%	25.28%	14.55%	1.08%
	PM	Tons	33.31	35.25	35.89	20.47	1.24
		%	23.84%	25.22%	25.68%	14.65%	0.89%
DIMITRIS Y	Fuel	Tons	4,093.62	4,246.94	4,399.28	2,223.82	305.91
		%	21.30%	22.09%	22.89%	11.57%	1.59%
	CO2	Tons	12,801.31	13,285.12	13,764.27	6,957.02	946.70
		%	21.27%	22.07%	22.87%	11.56%	1.57%
	NOx	Tons	376.90	389.32	403.12	194.06	11.00
		%	22.19%	22.92%	23.73%	11.42%	0.65%
	SOx	Tons	199.25	204.15	209.93	106.12	20.02
		%	22.53%	23.08%	23.74%	12.00%	2.26%
	PM	Tons	27.96	28.68	29.51	14.77	2.48
		%	22.66%	23.24%	23.92%	11.97%	2.01%
MSC GENEVA	Fuel	Tons	3,649.25	3,871.46	3,983.96	2,448.35	618.71
		%	19.72%	20.92%	21.53%	13.23%	3.34%
	CO2	Tons	11,449.62	12,162.03	12,519.61	7,712.25	1,964.01
		%	19.69%	20.92%	21.53%	13.26%	3.38%
	NOx	Tons	339.79	354.12	363.83	205.35	19.30
		%	21.32%	22.22%	22.82%	12.88%	1.21%

	SOx	Tons	161.00	161.49	163.68	89.89	14.30
		%	20.85%	20.91%	21.20%	11.64%	1.85%
	PM	Tons	22.92	23.14	23.49	12.81	1.69
		%	21.25%	21.46%	21.79%	11.88%	1.57%
MSC CAROUGE	Fuel	Tons	3,627.38	4,283.45	4,539.70	2,228.79	-61.83
		%	18.88%	22.29%	23.63%	11.60%	-0.32%
	CO2	Tons	11,380.60	13,456.38	14,264.09	7,034.89	-154.15
		%	18.85%	22.29%	23.63%	11.65%	-0.26%
	NOx	Tons	343.87	402.44	426.69	187.64	-44.38
		%	20.72%	24.25%	25.71%	11.31%	-2.67%
	SOx	Tons	159.88	178.10	187.11	72.90	-26.35
		%	20.02%	22.30%	23.43%	9.13%	-3.30%
	PM	Tons	22.98	25.83	27.16	10.68	-3.79
		%	20.55%	23.10%	24.30%	9.55%	-3.39%
MSC LAUSANNE	Fuel	Tons	3,105.97	3,741.72	3,854.85	2,345.66	-331.23
		%	16.93%	20.39%	21.01%	12.78%	-1.81%
	CO2	Tons	9,755.83	11,763.65	12,122.18	7,393.46	-987.83
		%	16.92%	20.40%	21.02%	12.82%	-1.71%
	NOx	Tons	295.27	351.77	361.36	203.69	-67.64
		%	18.69%	22.27%	22.88%	12.90%	-4.28%
	SOx	Tons	130.01	149.90	152.75	82.79	-45.37
		%	17.17%	19.79%	20.17%	10.93%	-5.99%
	PM	Tons	18.88	21.92	22.34	12.12	-6.32
		%	17.80%	20.67%	21.07%	11.43%	-5.96%
Aggregated	Fuel	Tons	20,183.38	22,495.02	23,278.29	13,253.05	1,444.29
		%	19.62%	21.87%	22.66%	12.82%	1.24%
	CO2	Tons	63,277.98	70,604.04	73,077.66	41,693.86	4,678.71
		%	19.59%	21.87%	22.65%	12.85%	1.29%
	NOx	Tons	1,826.70	2,012.21	2,082.19	1,088.72	-63.49
		%	21.17%	23.34%	24.16%	12.60%	-0.84%
	SOx	Tons	885.95	941.45	965.52	496.81	26.66
		%	20.84%	22.19%	22.76%	11.65%	0.82%
	PM	Tons	126.04	134.82	138.40	70.86	-4.69
		%	21.22%	22.74%	23.35%	11.90%	-0.98%

Table 9: Estimated savings for one year in fuel consumption and GHG emissions for the different scenarios

9.3 Use Case CS3

9.3.1 Abstract

This regular service covers a deep-sea route linking Europe with the west coast of the United States. This shipping service, called "California Express service", is operated by MSC (Mediterranean Shipping Company).

The reason for selecting this use case is that it offers a typical long-distance container-shipping-route vision. Deep-sea navigation has a strong component of uncertainty due to open sea navigation, current and weather conditions. This means that there is room for improvement in this type of service if the ships share information on their voyage plan and their ETA is very significant.

This type of services is typically operated by mother ships or ocean-going ships, much bigger than short sea ships, and those are selected in order to cover the high fixed costs and to benefit from economies of scale. In this type of route, the selection of hub ports is particularly important in order to reduce overall costs. This use case calls two STM ports (Valencia and Barcelona,) crosses a shore centre project area, Gibraltar Strait, and crosses the Panama Canal.

This use case comprises five STM ships, MSC LETIZIA, MSC JULIE, MSC CLEA, MSC CATERINA, MSC CHANNE, and four non-STM ships MSC ARBATAX, MSC ANTALYA, MSC MICHELA, and MSC SILVIA.

9.3.2 Use Case Data

SHIP	IMO No.	GT	FLAG	YEAR OF BUILD	SIZE (L/ B/ D) in metres	CAPACITY (TEU)	MAIN ENGINE POWER (kW)	AUX. ENGINE POWER (kW)	BOILER
MSC JULIE	9704996	95,403	PA	2015	300 x 49 x 14	8,819	47,430	9,000	N/A
MSC CLEA	9720524	94,469	PT	2016	300 x 49 x 14	9,400	54,900	N/A	N/A
MSC CATERINA	9705005	95,043	PA	2015	300 x 48 x 15	8,800	47,430	9,000	N/A
MSC CHANNE	9710438	95,403	PT	2015	300 x 48 x 14	8,800	47,430	9,000	N/A
MSC ARBATAX	9605231	94,402	HK	2013	300 x 48 x 14	9,403	52,290	7,000	N/A
MSC ANTALYA	9605152	94,402	HK	2013	300 x 48 x 14	9,403	52,290	7,000	N/A
MSC MICHELA	9720512	94,469	PT	2016	300 x 48 x 14	9,400	54,900	9,000	N/A
MSC	9720457	94,469	PA	2015	300 x 48	9,400	52,290	9,000	N/A

SILVIA					x 14				

Table 10: CS3 Ships Characteristics

9.3.3 Use Case Analysis

Figure 44 displays the itinerary covered by the ships in Use Case CS2. During the voyage, the ships shift through different phases: berth, manoeuvring, anchoring and cruising. the phases of berth, manoeuvring and cruising are part of the natural flow of the voyage. However, the anchoring phase is usually the result from an inefficient port call synchronization between ships and ports. Similarly, Idle Time can be the result of events that force the ship to reduce its speed or stop while navigating, being possible to tag it, as well, as an inefficiency.

Figure 53: CS3 Use Case Itinerary

9.3.3.1 Efficiency

1. Speed Variation

Figure 54 shows the distribution of cruising speeds by ship and the aggregated of all the service. We can observe that the distribution of speeds is extremely wide. Not only the interquartile range spans 8 knots, between 12 and 20 knots approximately, but also they have bimodal distributions. All five ships have wide distributions, implying high variability in their speed during navigation.

Furthermore, in Figure 55 it can be observed that different legs are navigated at very different speeds. There are legs whose median speed is above 20 Knots while others are below 10 knots.

These facts could be due to the nature of the service, which is crossing the ocean and passes long time navigating without calling at any port with the uncertainties that this type of navigation could bring.

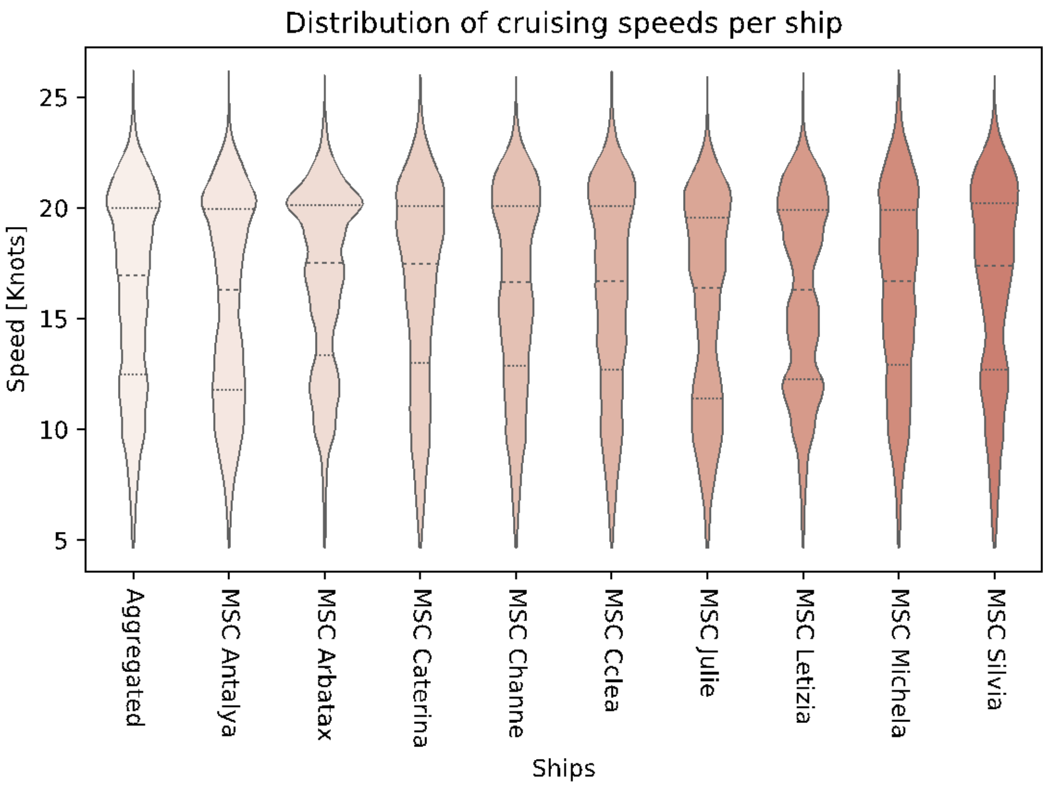


Figure 54: Aggregated distribution of cruising speeds for the ships in CS3

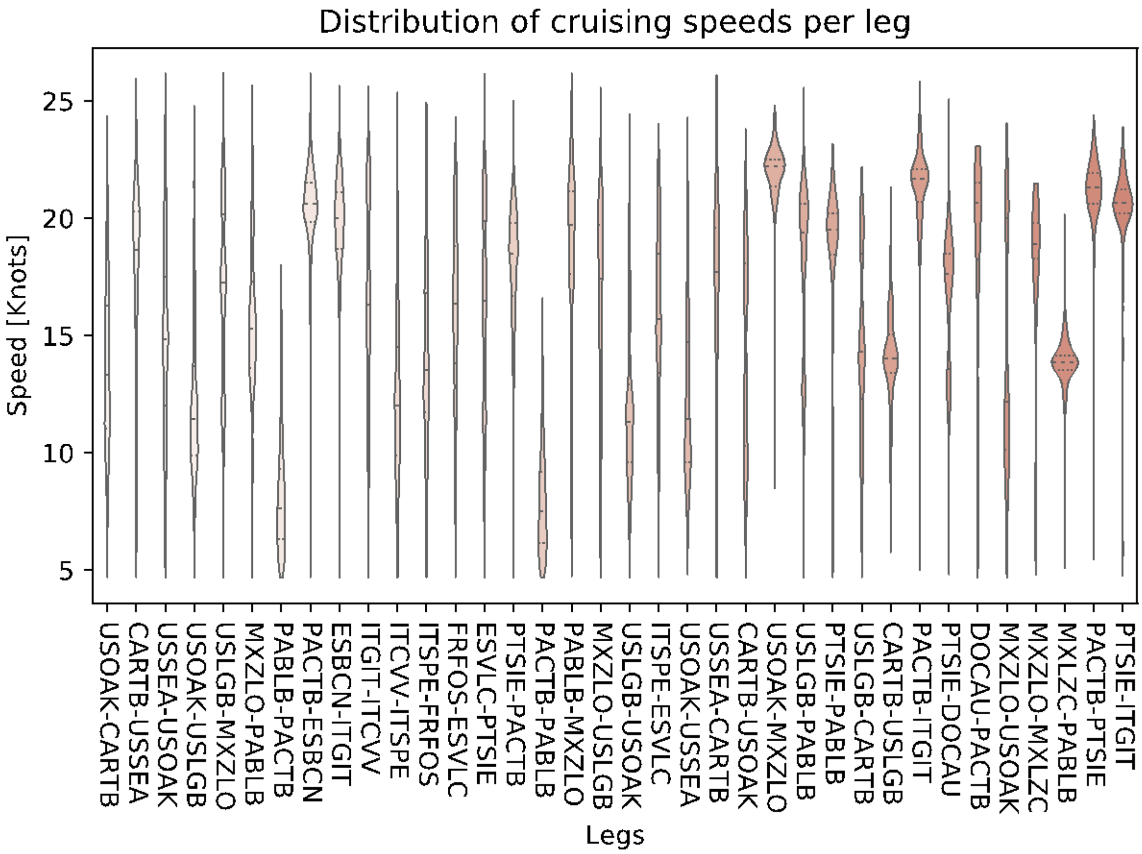


Figure 55: Aggregated distribution of cruising speeds per leg for the ships in CS3

2. *Punctuality*

One of the indicators of a shipping service in terms of efficiency is punctuality. Figure 56 and Figure 57 show the distributions of the deviation between the Estimated Time of Arrival (ETA) reported at the beginning of a leg and its Actual Time of Arrival (ATA), in order to capture, also, its capacity to provide accurate ETAs in advance.

In Figure 56, we can observe that almost the 80% of the times, ships will arrive later than reported. Moreover, the CDFs show that, when late, the difference between ETA and ATA is less than 10 hours in, approximately, a 60% of the time. For early arrivals, roughly an 85% of the cases were within the 10 hours range. Finally, we can see that the CDFs for each ship are similar for late arrivals but very different for early arrivals, so it seems to be a common behaviour being late in a similar proportion but not arriving early.

in Figure 57, It is difficult to relate the punctuality with the kind of port. Both for early and late arrivals, the ships behaviours are quite far from the CDFs and the ratios look quite different as well.

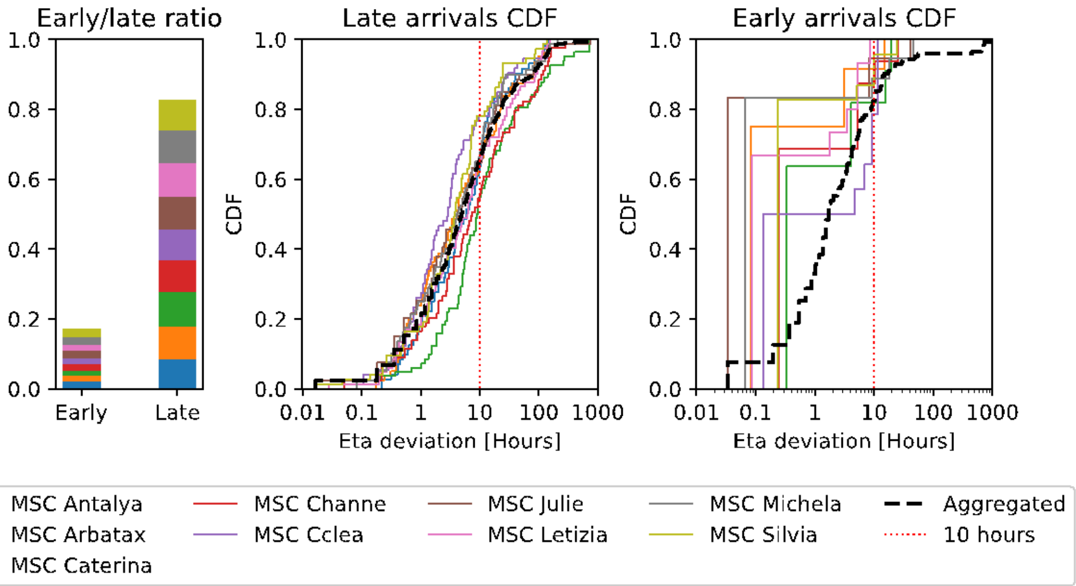


Figure 56: : distribution of ETA deviations per ship in CS3

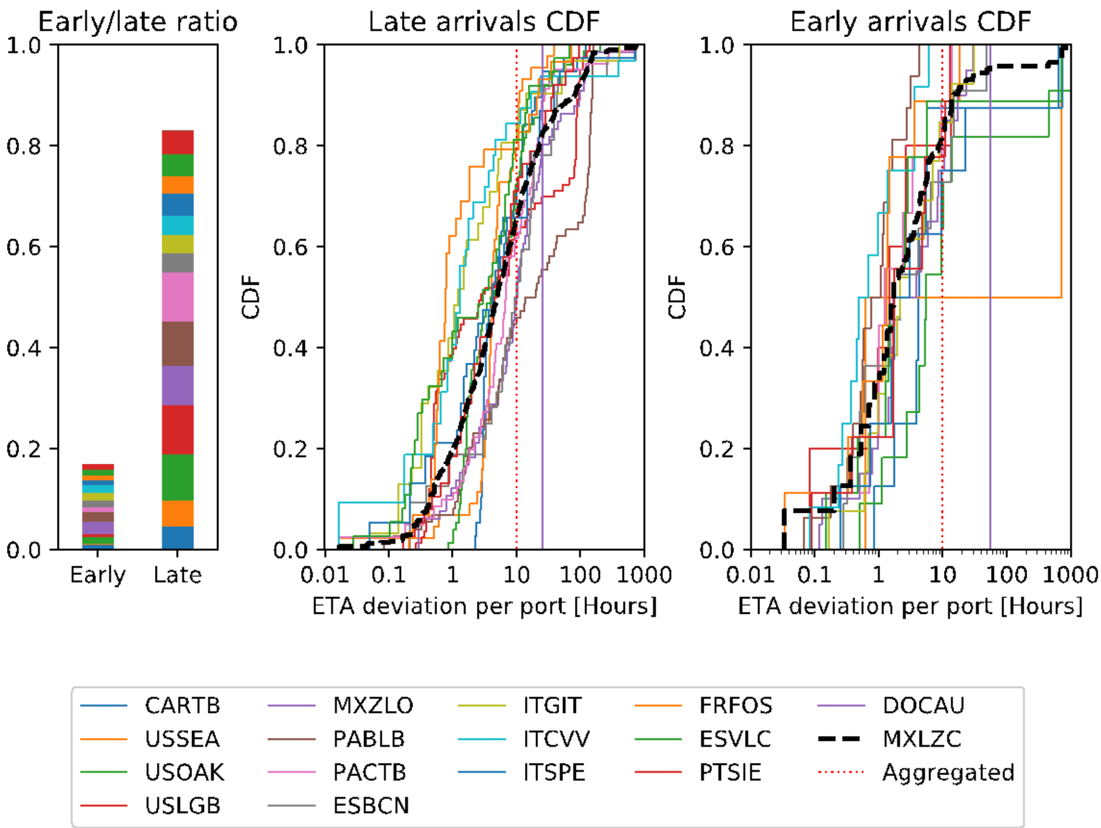


Figure 57: ETA deviations per port in CS3

3. Anchoring Times

Figure 58 presents the results related to anchoring times for the ships in CS3. It is good to detect that less than 40% of the times the ships had an anchoring period. It is also interesting that more than 80% of these anchoring periods lasted less than 10 hours.

The difference of anchoring times related to the port look remarkable bigger when it comes to Panama Canal crossing, which seems to present difficulties in the access, probably due to traffic congestion and the booking process resulting in long waiting times for the service.

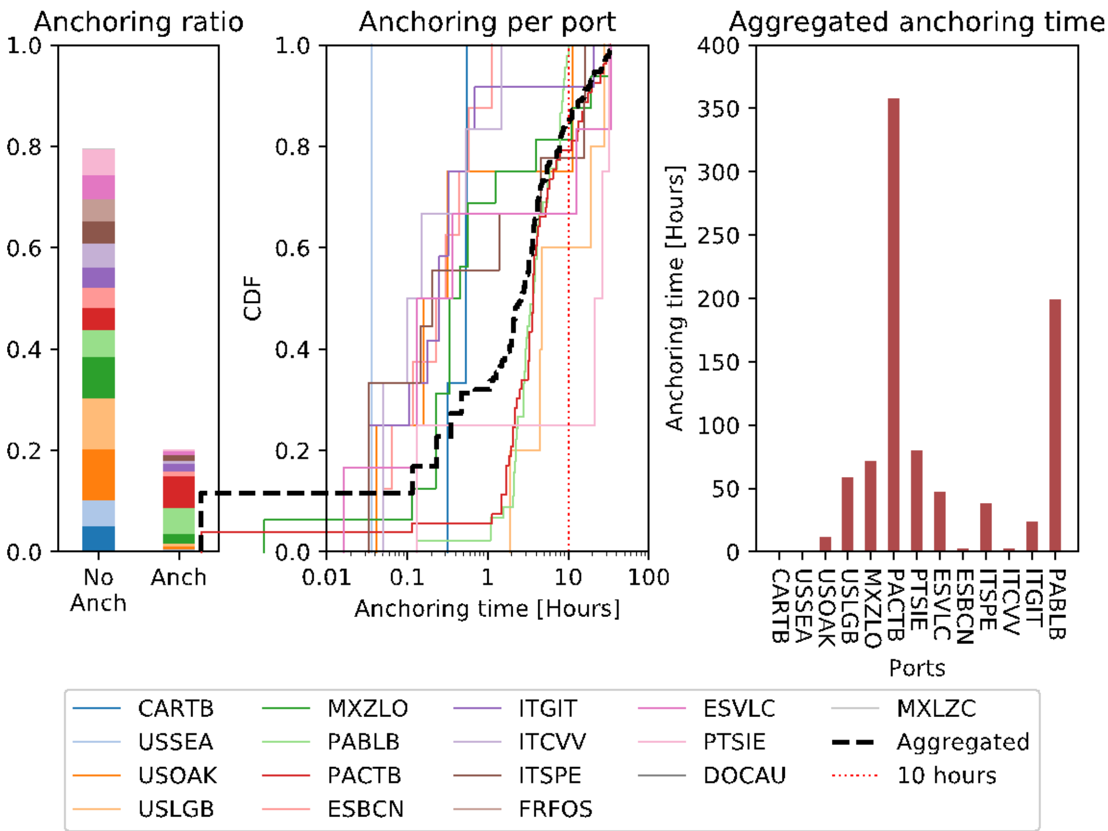


Figure 58: Anchoring times by port in CS3

9.3.3.2 Environmental Sustainability

1. Navigation Times

Figure 59 shows the variation in navigation time for each scenario in CS3. We see time increase in Scenario 3 at low speed around 20 days, which should be considered when deciding the service strategy. It could be reasonable to say that Scenario 3 at medium speed would be a better choice in terms of time and fuel savings.

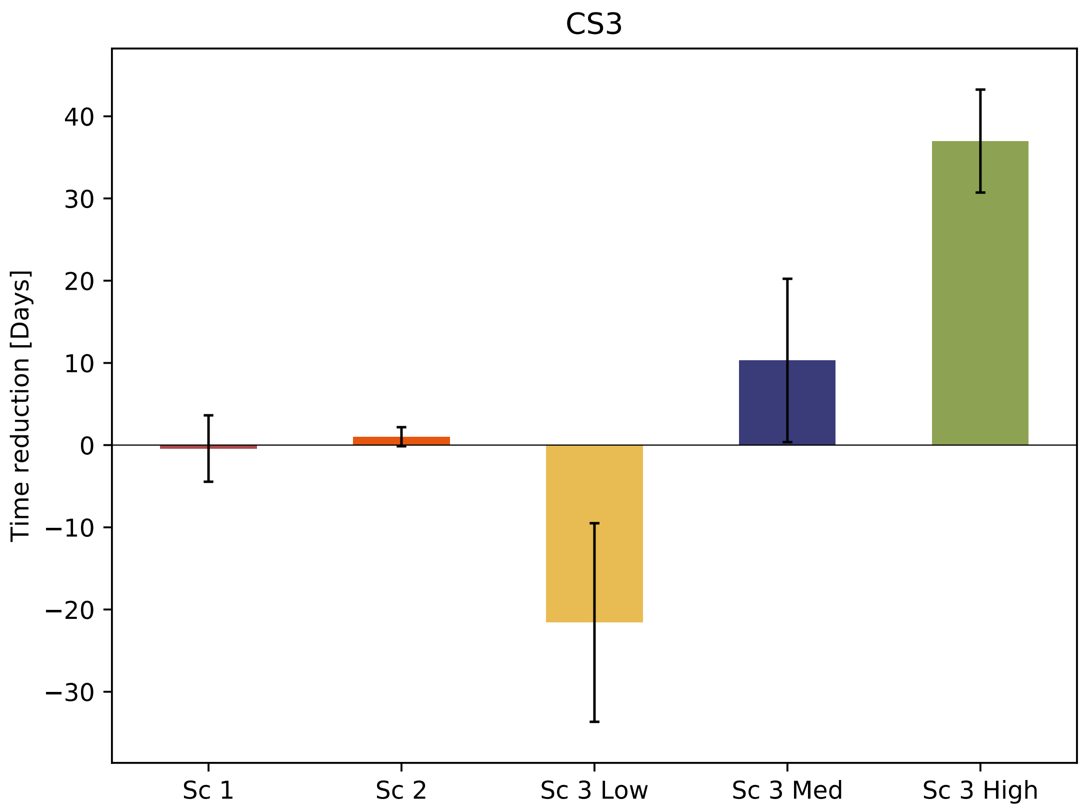


Figure 59: Variation in navigation time for each scenario in CS3

2. Fuel Consumption

Figure 60 presents an estimation of the fuel consumption of the MSC Caterina both for the real AIS data as for the proposed scenarios. It is worth mentioning that the figures for the different types of GHG emissions follow a very similar pattern which is the reason for not showing them all in this document, but they can be consulted in the ANNEXES.

As a result of the type of route that this service covers, a long distance service, cruising is the dominating phase, where ships spend most of their time. In the case of CS3, the first scenario does not bring savings but more expenses. This is because of the long distance covered by this group of ships. Scenario 2 introduces some slightly savings, which is improved in Scenario 3 by enforcing the use of a lower cruising speed.

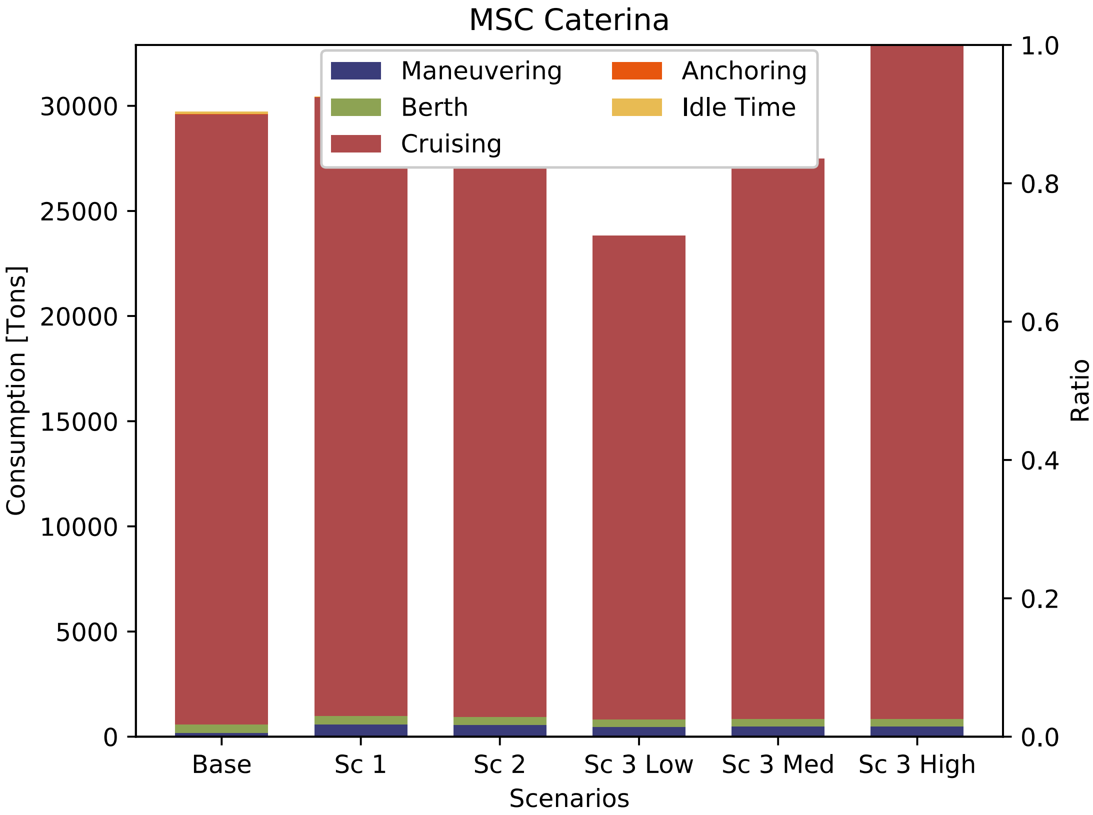


Figure 60: Fuel consumption of the MSC Caterina in the current situation and for the different proposed scenarios divided by phases.

3. GHG Emissions

Figure 61 shows that the savings for the fuel consumption and emissions vary significantly from one to another scenario, Scenario 1 does not show any improvements, only for SO_x and PM. Scenario 2 and Scenario 3 Med have reasonable savings around 5%. The greatest savings come from Scenario 3 in which the ships synchronizes with the port and adjust the speed to the lowest possible, getting savings of almost 20%. The worst picture is for Scenario 3 High, increasing the costs up to 10%.

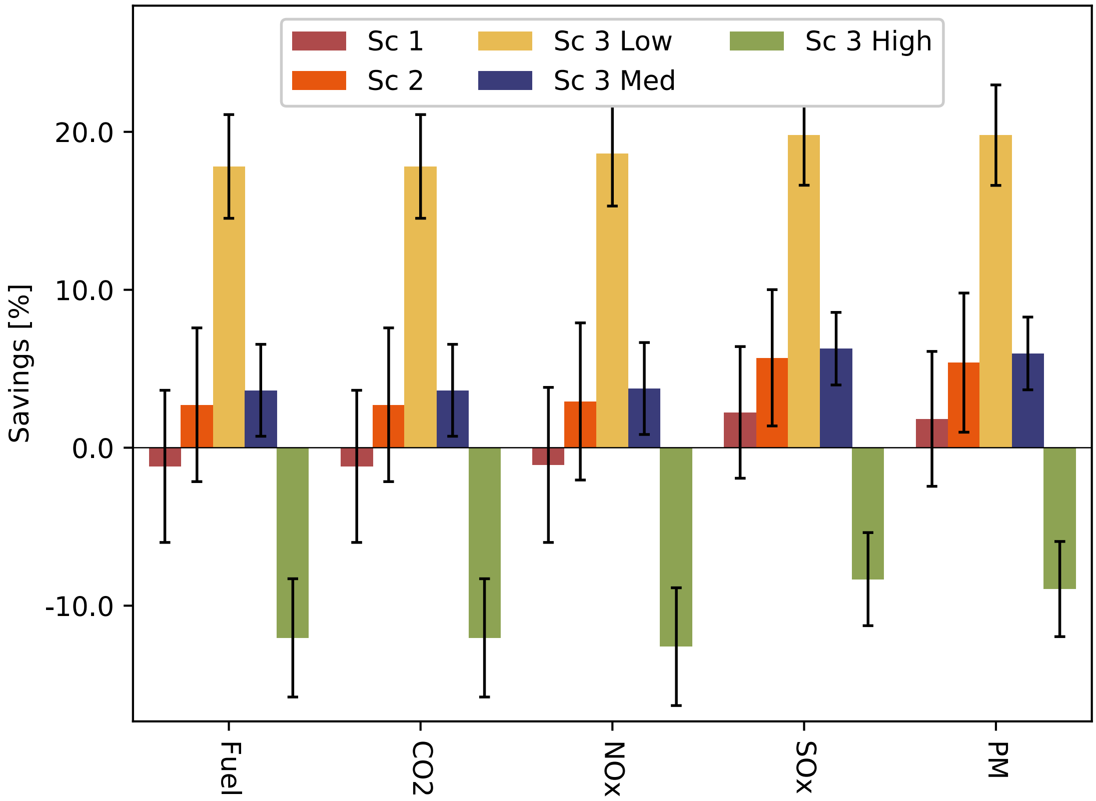


Figure 61: Mean values and deviations of the savings in fuel consumption and emissions for all the vessels in CS3

9.3.4 Use Case Evaluation

In this section we show the approximate savings of implementing the different scenarios of STM and the economic impact that this could have on the shipping companies' costs.

TONES	Fuel Consumption	CO2 Emissions	NOx Emissions	SOx Emissions	PM
MSC ANTALYA	30,793.09	95,889.67	2,463.04	1,637.69	226.61
MSC ARBATAX	31,977.51	99,577.97	2,563.45	1,680.90	233.01
MSC CATERINA	30,302.59	94,362.26	2,457.96	1,611.51	223.41
MSC CHANNE	29,596.38	92,163.14	2,398.00	1,569.24	217.51
MSC CCLEA	30,983.57	96,482.83	2,480.24	1,613.87	224.01
MSC JULIE	29,278.15	91,172.16	2,370.95	1,555.86	215.54
MSC LETIZIA	29,413.00	91,592.08	2,384.23	1,576.81	218.29

MSC MICHELA	34,342.35	106,942.09	2,756.66	1,821.22	252.33
MSC SILVIA	34,294.69	106,793.67	2,754.94	1,813.37	251.39

Table 11: Results of one year fuel consumption and GHG emissions

TONES	Fuel Consumption	CO2 Emissions	NOx Emissions	SOx Emissions	PM
MSC ANTALYA	30,793.09	95,889.67	2,463.04	1,637.69	226.61
MSC ARBATAX	31,977.51	99,577.97	2,563.45	1,680.90	233.01
MSC CATERINA	30,302.59	94,362.26	2,457.96	1,611.51	223.41
MSC CHANNE	29,596.38	92,163.14	2,398.00	1,569.24	217.51
MSC CCLEA	30,983.57	96,482.83	2,480.24	1,613.87	224.01
MSC JULIE	29,278.15	91,172.16	2,370.95	1,555.86	215.54
MSC LETIZIA	29,413.00	91,592.08	2,384.23	1,576.81	218.29
MSC MICHELA	34,342.35	106,942.09	2,756.66	1,821.22	252.33
MSC SILVIA	34,294.69	106,793.67	2,754.94	1,813.37	251.39

Table 11 we depict the results of one year fuel consumption and GHG emissions for the five ships. If we translate this information into US Dollars, using the price for the fuel, CO2, NO_x, SO_x and PM we will be able to quantify the costs savings for shipping companies.

SHIP	Variable	Metric	SC 1	SC 2	SC 3 Low	SC 3 Med	SC 3 High
MSC ANTALYA	Fuel	Ton	-275.98	625.19	6,157.58	1,227.64	-2,499.87
		%	-0.90%	2.03%	20.00%	3.99%	-8.12%
	CO2	Ton	-859.39	1,946.86	19,174.71	3,822.87	-7,784.60
		%	-0.90%	2.03%	20.00%	3.99%	-8.12%
	NOx	Ton	-23.80	51.54	515.08	95.65	-219.10
		%	-0.97%	2.09%	20.91%	3.88%	-8.90%
	SOx	Ton	55.08	99.63	369.93	109.03	-74.53
		%	3.36%	6.08%	22.59%	6.66%	-4.55%
	PM	Ton	6.46	12.79	51.03	14.29	-11.74
		%	2.85%	5.64%	22.52%	6.30%	-5.18%
MSC ARBATAX	Fuel	Ton	-634.57	-429.79	3,821.68	-103.13	-3,666.69
		%	-1.98%	-1.34%	11.95%	-0.32%	-11.47%
	CO2	Ton	-	-1,338.37	11,900.71	-321.16	-11,418.07
		%	-1.98%	-1.34%	11.95%	-0.32%	-11.47%

	NOx	Ton	-53.34	-35.63	318.31	-13.84	-313.51
		%	-2.08%	-1.39%	12.42%	-0.54%	-12.23%
	SOx	Ton	5.83	15.06	212.15	33.98	-139.86
		%	0.35%	0.90%	12.62%	2.02%	-8.32%
	PM	Ton	0.07	1.44	29.46	3.90	-20.76
		%	0.03%	0.62%	12.64%	1.67%	-8.91%
MSC CATERINA	Fuel	Ton	-	211.24	5,329.00	1,457.45	-2,796.47
		%	-4.36%	0.70%	17.59%	4.81%	-9.23%
	CO2	Ton	-	657.81	16,594.49	4,538.51	-8,708.22
		%	-4.36%	0.70%	17.59%	4.81%	-9.23%
	NOx	Ton	-108.76	19.17	449.26	121.42	-236.50
		%	-4.43%	0.78%	18.28%	4.94%	-9.62%
	SOx	Ton	-14.14	57.81	302.90	109.12	-79.49
		%	-0.88%	3.59%	18.80%	6.77%	-4.93%
	PM	Ton	-2.97	7.30	42.11	14.66	-12.46
		%	-1.33%	3.27%	18.85%	6.56%	-5.58%
MSC CHANNE	Fuel	Ton	-657.12	493.18	5,886.68	2,235.07	-3,134.65
		%	-2.22%	1.67%	19.89%	7.55%	-10.59%
	CO2	Ton	-	1,535.76	18,331.13	6,960.02	-9,761.30
		%	-2.22%	1.67%	19.89%	7.55%	-10.59%
	NOx	Ton	-53.78	42.22	496.14	186.11	-266.71
		%	-2.24%	1.76%	20.69%	7.76%	-11.12%
	SOx	Ton	27.34	79.65	334.34	148.64	-131.43
		%	1.74%	5.08%	21.31%	9.47%	-8.38%
	PM	Ton	2.75	10.25	46.53	20.24	-19.19
		%	1.26%	4.71%	21.39%	9.30%	-8.82%
MSC CCLEA	Fuel	Ton	-	607.92	5,491.88	1,048.52	-4,053.47
		%	-3.38%	1.96%	17.73%	3.38%	-13.08%
	CO2	Ton	-	1,893.08	17,101.72	3,265.09	-12,622.49
		%	-3.38%	1.96%	17.73%	3.38%	-13.08%
	NOx	Ton	-83.78	53.85	461.15	84.76	-344.57
		%	-3.38%	2.17%	18.59%	3.42%	-13.89%
	SOx	Ton	0.06	79.64	305.98	76.71	-185.91
		%	0.00%	4.93%	18.96%	4.75%	-11.52%
	PM	Ton	-0.93	10.38	42.65	10.28	-26.73
		%	-0.42%	4.64%	19.04%	4.59%	-11.93%
MSC JULIE	Fuel	Ton	96.64	1,244.59	6,134.65	1,838.84	-3,763.54
		%	0.33%	4.25%	20.95%	6.28%	-12.85%
	CO2	Ton	300.93	3,875.65	19,103.31	5,726.16	-11,719.67
		%	0.33%	4.25%	20.95%	6.28%	-12.85%
	NOx	Ton	8.43	104.45	516.98	152.25	-319.35
		%	0.36%	4.41%	21.80%	6.42%	-13.47%
	SOx	Ton	63.14	120.04	364.34	143.62	-118.94
		%	4.06%	7.72%	23.42%	9.23%	-7.64%
	PM	Ton	7.76	15.83	50.39	19.18	-18.27
		%	3.60%	7.34%	23.38%	8.90%	-8.48%

MSC LETIZIA	Fuel	Ton	-	-1,177.72	3,913.98	-346.00	-5,884.48
		%	-8.63%	-4.00%	13.31%	-1.18%	-20.01%
	CO2	Ton	-	-3,667.42	12,188.14	-1,077.43	-18,324.28
		%	-8.63%	-4.00%	13.31%	-1.18%	-20.01%
	NOx	Ton	-210.14	-96.68	337.98	-22.30	-491.29
		%	-8.81%	-4.05%	14.18%	-0.94%	-20.61%
	SOx	Ton	-65.05	-4.45	308.74	103.20	-209.34
		%	-4.13%	-0.28%	19.58%	6.54%	-13.28%
	PM	Ton	-10.30	-1.60	41.71	12.44	-31.18
		%	-4.72%	-0.73%	19.11%	5.70%	-14.28%
MSC MICHELA	Fuel	Ton	2,859.27	4,234.96	7,266.11	1,851.99	-2,774.38
		%	8.33%	12.33%	21.16%	5.39%	-8.08%
	CO2	Ton	8,903.76	13,187.65	22,626.67	5,767.10	-8,639.41
		%	8.33%	12.33%	21.16%	5.39%	-8.08%
	NOx	Ton	238.00	352.01	605.58	147.57	-239.94
		%	8.63%	12.77%	21.97%	5.35%	-8.70%
	SOx	Ton	188.60	252.93	397.23	113.92	-110.40
		%	10.36%	13.89%	21.81%	6.26%	-6.06%
	PM	Ton	25.70	34.88	55.38	15.48	-16.34
		%	10.19%	13.82%	21.95%	6.13%	-6.48%
MSC SILVIA	Fuel	Ton	1,029.14	2,606.05	6,257.70	1,205.47	-4,800.63
		%	3.00%	7.60%	18.25%	3.52%	-14.00%
	CO2	Ton	3,204.73	8,115.24	19,486.49	3,753.82	-14,949.17
		%	3.00%	7.60%	18.25%	3.52%	-14.00%
	NOx	Ton	86.27	216.99	522.23	95.49	-405.88
		%	3.13%	7.88%	18.96%	3.47%	-14.73%
	SOx	Ton	96.00	169.52	347.46	86.48	-184.38
		%	5.29%	9.35%	19.16%	4.77%	-10.17%
	PM	Ton	12.66	23.14	48.33	11.54	-27.24
		%	5.04%	9.20%	19.22%	4.59%	-10.83%
Aggregated	Fuel	Ton	-275.98	625.19	6,157.58	1,227.64	-2,499.87
		%	-0.90%	2.03%	20.00%	3.99%	-8.12%
	CO2	Ton	-859.39	1,946.86	19,174.71	3,822.87	-7,784.60
		%	-0.90%	2.03%	20.00%	3.99%	-8.12%
	NOx	Ton	-23.80	51.54	515.08	95.65	-219.10
		%	-0.97%	2.09%	20.91%	3.88%	-8.90%
	SOx	Ton	55.08	99.63	369.93	109.03	-74.53
		%	3.36%	6.08%	22.59%	6.66%	-4.55%
	PM	Ton	6.46	12.79	51.03	14.29	-11.74
		%	2.85%	5.64%	22.52%	6.30%	-5.18%

Table 12: Estimated savings for one year in fuel consumption and GHG emissions for the different scenarios

9.4 Containerships Use Cases Comparison

As analized in the previous pages, in a large majority of the cases, the use of STM would facilitate the reducetion of fuel consumption, GHG and pollutant emissions, leading to a decrease in costs for shipping companies and ship operators. However, the implications of these results are not the same in all cases.

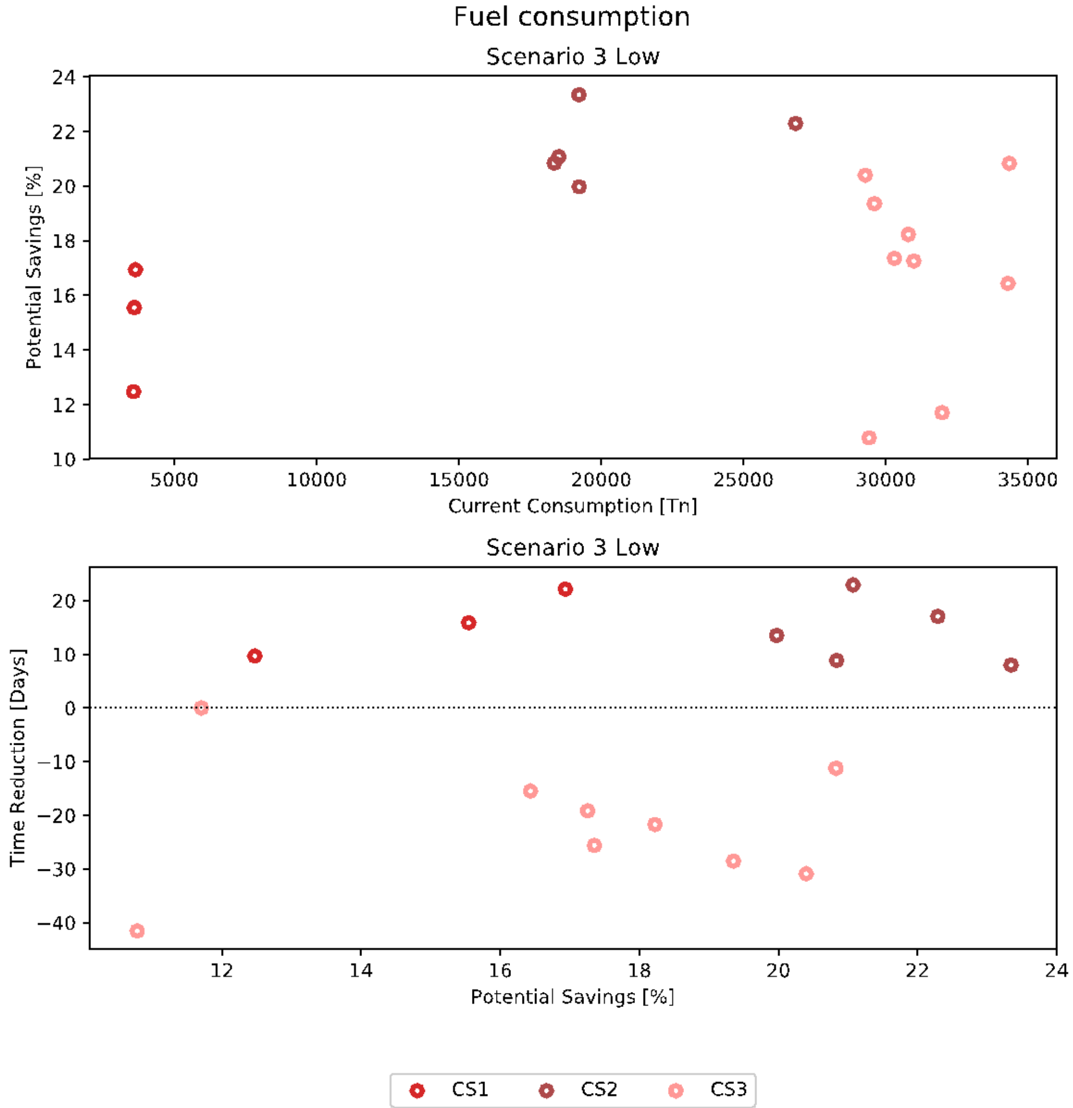


Figure 62: Comparison of potential savings with navigation time reduction applying low speed

As we see in Figure 62, the ships in CS1 have a lower consumption in their real situation per year but they still have good potential savings between 12% and 17% of fuel consumption per year. However, they experiment the higher time reduction in their itineraries when applying scenarioS 3 with low speed. One of the reasons could be that they are covering a short sea shipping service and so, the distance between ports is shorter and they are suffering more anchoring times than the rest as the time to take action is shorter.

The ships in CS2 have even more potential savings than CS1 and similar reduction in navigation times. Again, for the type of itinerary they are following, the use of STM seems to be beneficial even if the shipping line should check out the configuration of the service in frequency and number of ships in order to improve their operating costs.

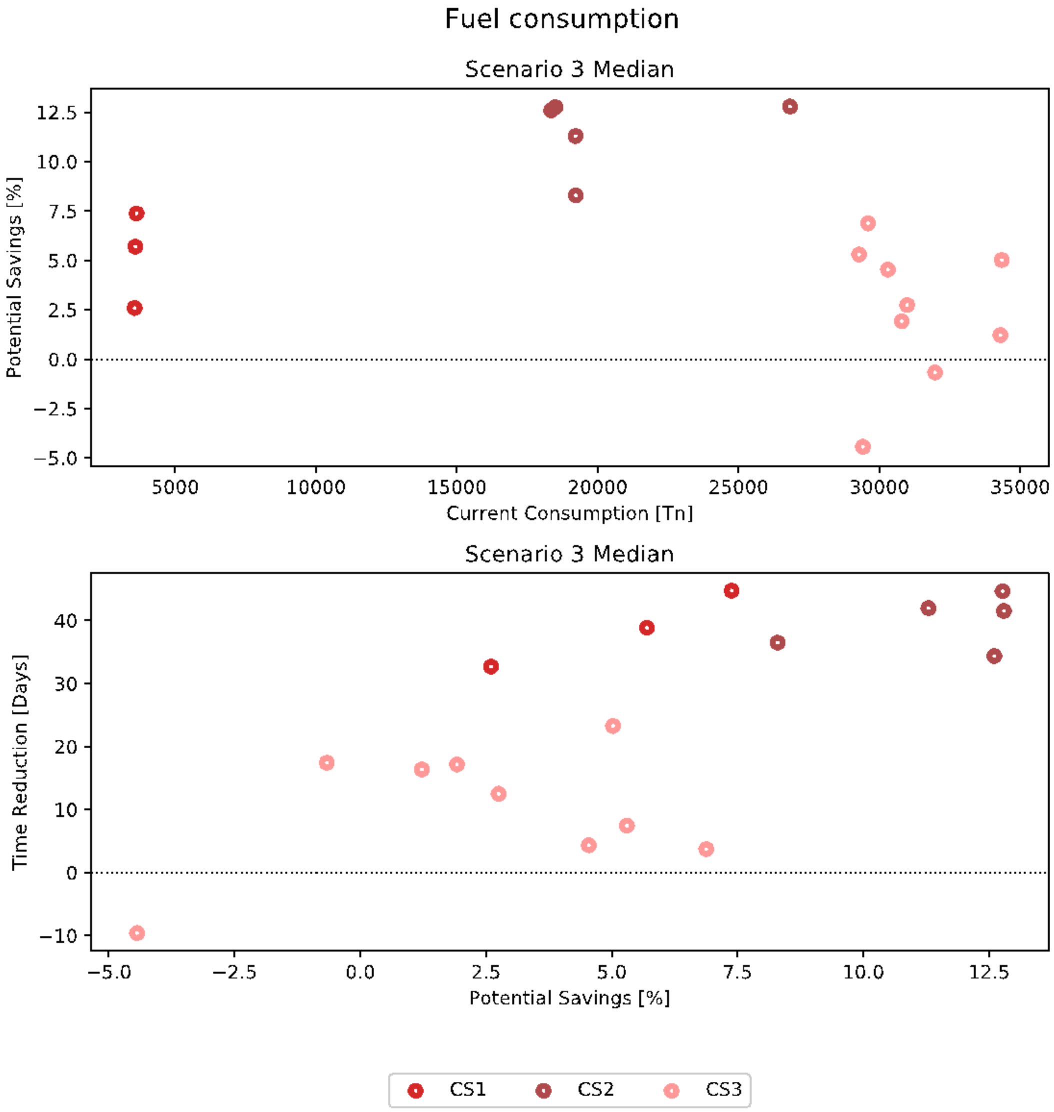


Figure 63: Comparison of potential savings with navigation time reduction applying median speed

CS3 has a totally different situation as we see in Figure 62. The ships are performing a trans-oceanic route in which the distance between ports is bigger and they spend less time in anchoring than CS1, as we see in Figure 64. These results for some ships in less savings compared to the other use cases and more days navigating because of the low speed within the whole of the use case.

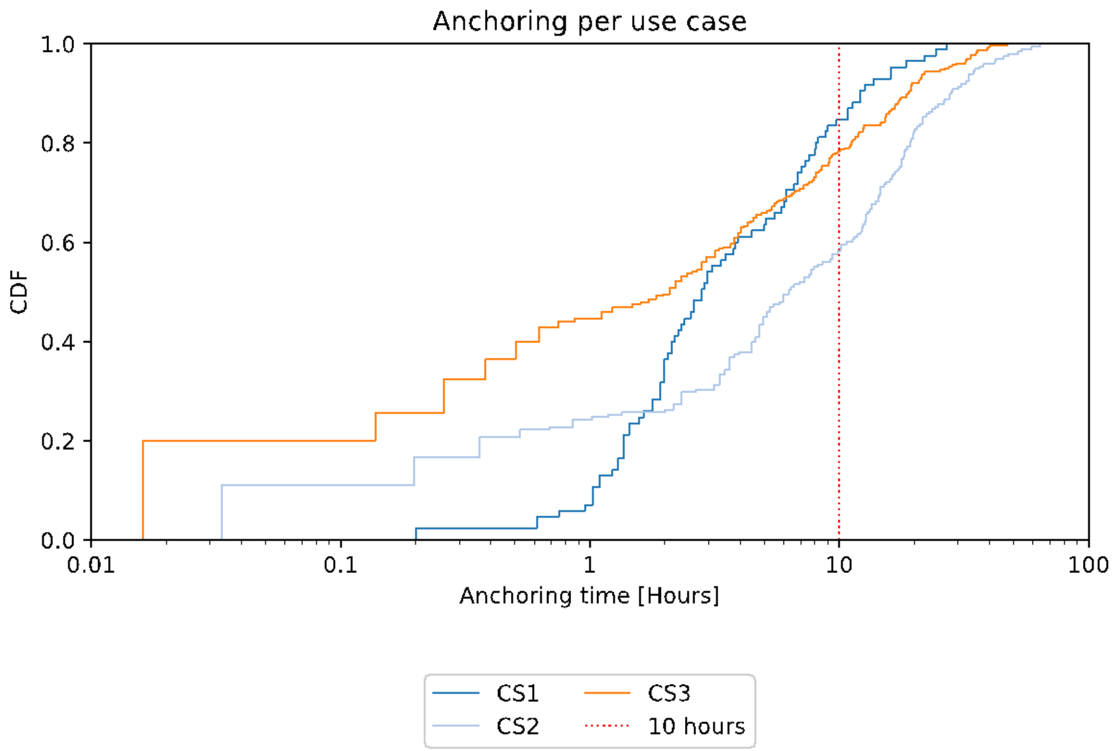


Figure 64: Anchoring time CDF per use case

9.5 Use Case PAX1

9.5.1 Abstract

This use case studies passenger ships, concretely the ship BIRKA STOCKHOLM, which covers a regular service within Aland Islands near Stockholm with a medium frequency of one per day and it is the only passenger ship included in STM testbed. It does not transport any type of cargo, only passengers.

The main characteristics of these kind of ships are that they usually cover short, low-speed, medium-frequency routes and they are predominantly small sized and often linking tourist destinations. Ro-pax services are often reinforced with this type of ship during peak season, so they have a high seasonality factor.

9.5.2 Use Case Data

The data used to analyse the use cases is divided in two sets. On the one hand, static data related to the characteristics of each of the ships, like those shown in Table 4 or other derived from it, that are captured in their configuration file. On the other hand, AIS navigation data from the period comprehended between June 1st 2017 and May 31st 2018, that shows real location, time and speed data from the routes they covered. Altogether, these data are used to compute the fuel consumption and emissions of the ships in the use cases.

SHIP	IMO No.	GT	FLAG	YEAR OF BUILD	SIZE (L/ B/ D) in metres	CAPACITY (PAX)	MAIN ENGINE POWER (kW)	AUX. ENGINE POWER (kW)	BOILER
BIRKA STOCKHOLM	9273727	34,924	SE	2004	177 x 28 x 7	1534	23,388	2,880	N/A

Table 13: PAX1 Ship Characteristics

9.5.3 Use Case Analysis

Figure 35 displays the itinerary covered by the ship in Use Case PAX1. During the voyage, the ship shifts through different phases: berth, manoeuvring, anchoring and cruising. The phases of berth, manoeuvring and cruising are part of the natural flow of the voyage. However, the anchoring phase is usually the result of an inefficient port call synchronization between ships and ports. Similarly, Idle Time can be the result of events that force the ship to reduce its speed or stop while navigating, being possible to tag it, as well, as an inefficiency.

Figure 65: PAX1 Use Case itinerary

During the voyage, there can be events that can have an effect in the navigational efficiency of the ships and the shipping service. There might be unnecessary variations of speed due to several reasons: changes in the availability of arrival port resources, crossing a strait or canal, traffic restrictions or congestion. These avoidable speed variations and other causes can result in extra costs.

9.5.3.1 Efficiency

In order to provide an intuition about the mentioned inefficiencies we analyse the speed variation of this ship while cruising, its punctuality, navigation and anchoring times.

1. ***Speed Variation***

As Figure 36 is showing below, the distribution of the cruising speeds for Birka Stockholm has a wide range of variability. On the one hand, we find a bimodal distribution with two big ranges of speeds: one between 7.5 and 11 knots and another between 11 and 15 knots. The median speed is approximately 12,5 and the difference between the first and the third quartile is of about 4 knots.

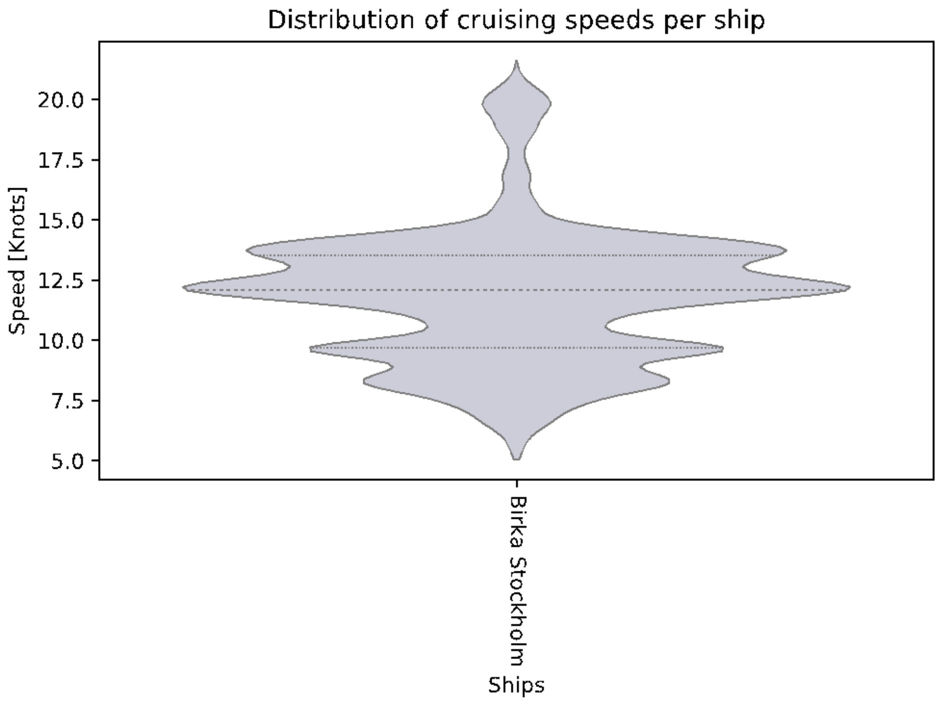


Figure 66: Aggregated distribution of cruising speeds for the ships in PAX1

When it comes to distribution of cruising speeds per leg, the picture differs. In Figure 37 it is possible to find some legs with a high degree of speed variability such as Mariehamn – Stockholm (FIMHQ- SESTO) and vice versa as well as some bimodal violins, however, the general distributions seem quite revealing compared to the previous figure. The distributions of speed seem quite regular between legs but very different one from other in terms of speed: some of them around 20 knots, some around 14, even around 10 knots. This fact could lead to think that there are some speed restrictions within the areas where the ship is sailing depending on the leg.

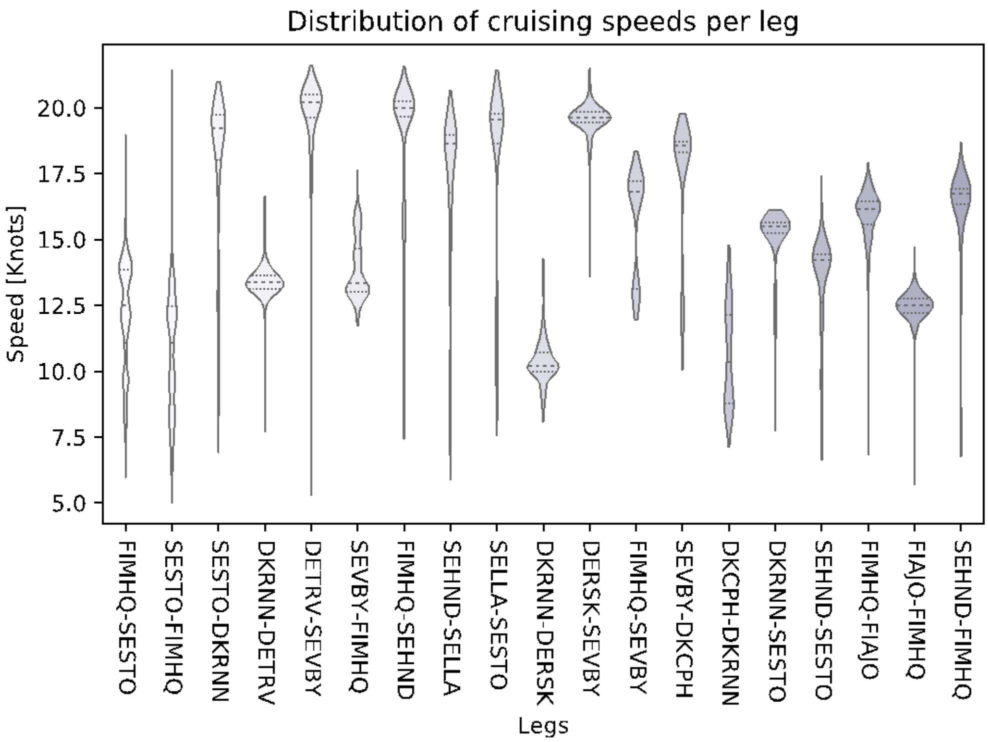


Figure 67: Aggregated distribution of cruising speeds per leg for the ships in PAX1

2. Punctuality

One of the indicators of a shipping service in terms of efficiency is punctuality. Figure 38 and Figure 39 show the distributions of the deviation between the Estimated Time of Arrival (ETA) reported at the beginning of a leg and its Actual Time of Arrival (ATA), in order to capture, also, its capacity to provide accurate ETAs in advance.

In Figure 38, we can observe that Birka Stockholm is usually on time, with a ratio of earliness of 90%. Moreover, the CDFs (Cumulative distribution function) show that, when late, the difference between ETA and ATA is less than 10 hours more than 60% of the times. For early arrivals, roughly an 80% of the cases were within one hour in advance, so quite adjusted ETA to ATA.

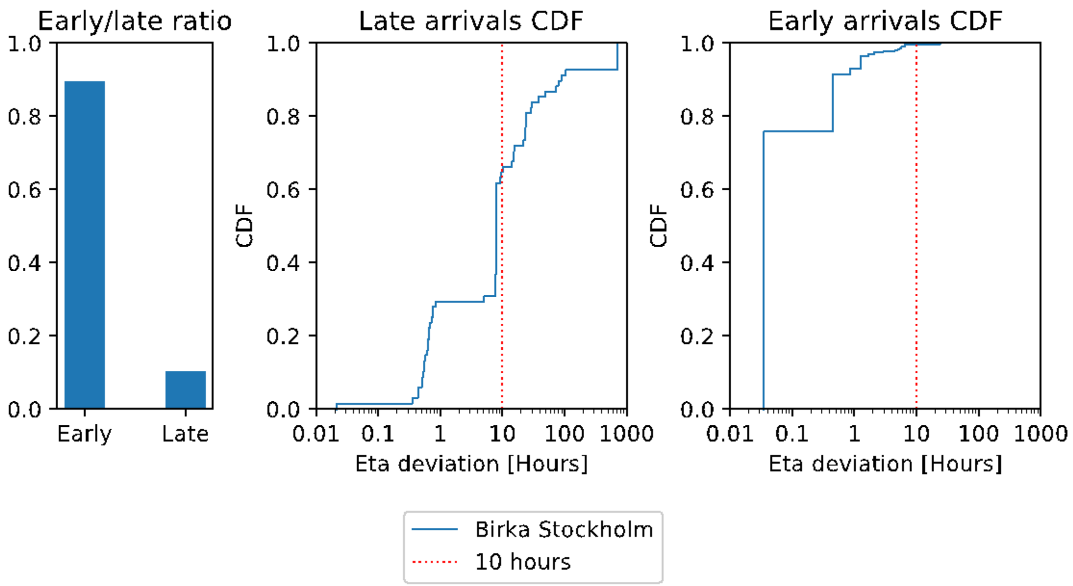


Figure 68: distribution of ETA deviations per ship in PAX1

In Figure 39, it is remarkable that the port calls are mostly split between Stockholm in Sweden and Mariehamn in Finland and it looks like it is similarly predictable in both ports. However, the data related to ETA reported does not seem to be reliable for this use case and, consequently, the reading of the figures could not throw the right conclusions. Usually, passenger ships have a priority pass into ports, turning the delays of more than one hour to be the result of a lack of ETA reporting.

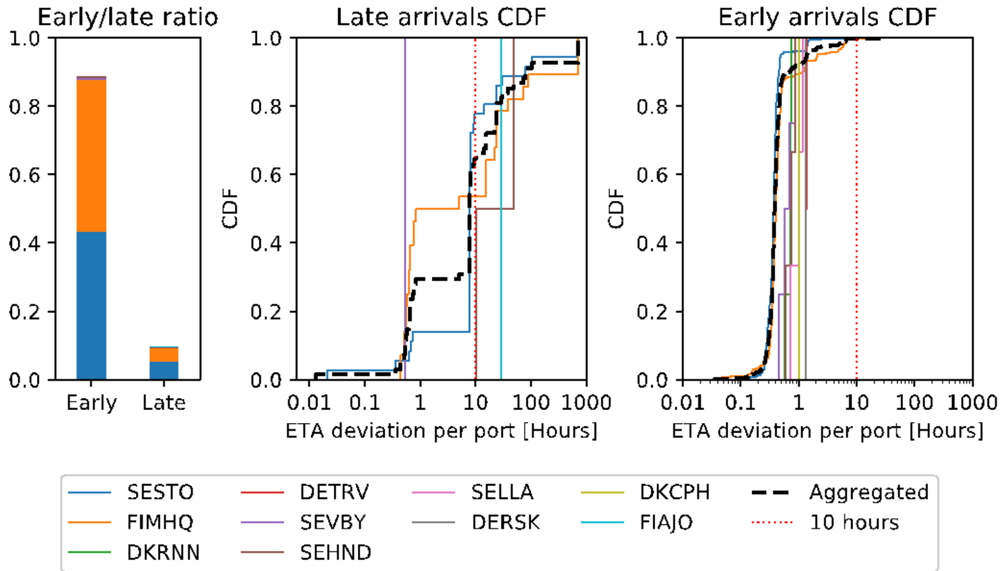


Figure 69: ETA deviations per port in PAX1

3. Anchoring Times

There are no anchoring times found in the data for this use case due to the nature of the traffic of this type of ship.

9.5.3.2 Environmental Sustainability

Concerning environmental sustainability, this section presents an analysis of the navigation times, the fuel consumption and the different emissions in the current situation and shows the potential savings that the different proposed scenarios may introduce with STM implementation.

1. Navigation Times

Each of the scenarios will have, besides the impact on the fuel consumption and GHG (Greenhouse Gases) emissions, an impact on the navigation time, and the shipping lines must take into account how this is reflected in the time a ship needs to cover its route. Figure 41 shows an example of this effect for Birka Stockholm.

In general, lower speeds result in lower fuel consumption and emissions, but also longer navigation times. In Figure 41 we see that the savings achieved in Scenario 3 with low speed carry out a reduction in the itinerary of around 50 days in a year or even almost 100 days per year in the high speed third scenario. These results provide an interesting perspective on the room of improvement that the shipping company has in the level of use of the ship as a resource, which could bring in more benefits to the company.

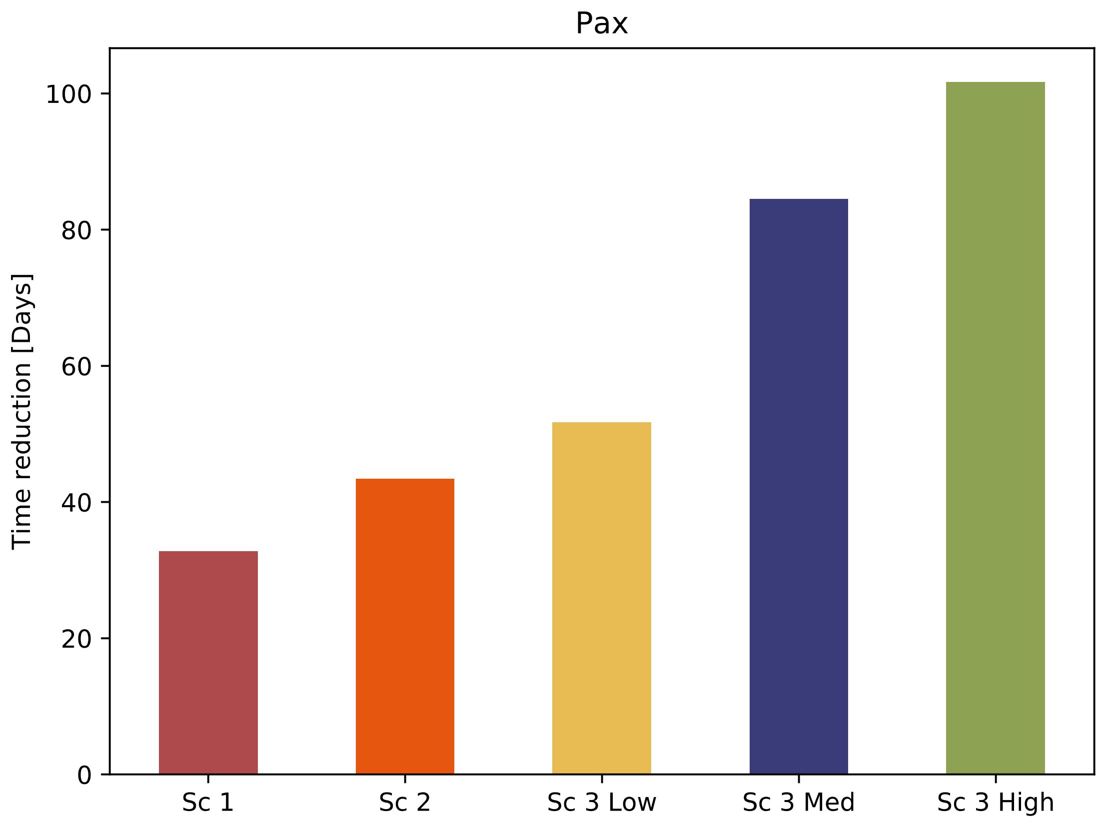


Figure 70: Variation in navigation time for each scenario in PAX1

2. Fuel Consumption

Figure 42 presents an estimation of the fuel consumption of Birka Stockholm, both for the real AIS (Automatic Identification System) data as for the proposed scenarios.

As expected, cruising and berth are the dominating phases, where ships spend most of their time. Anchoring was irrelevant in this case, due to the type of the traffic. It is worth mentioning that our analysis introduces some residual error for manoeuvring when we recompute the routes for the scenarios due to the granularity of the AIS data and the geographical separation between the waypoints generated.

In this case, both for the third scenario with the lowest median speed and with the median speed relates to the larger savings. In this case, the improvement comes from reducing times in berth and reducing, as much as possible, the speed variability during navigation, achieving potential savings of more than 18%.

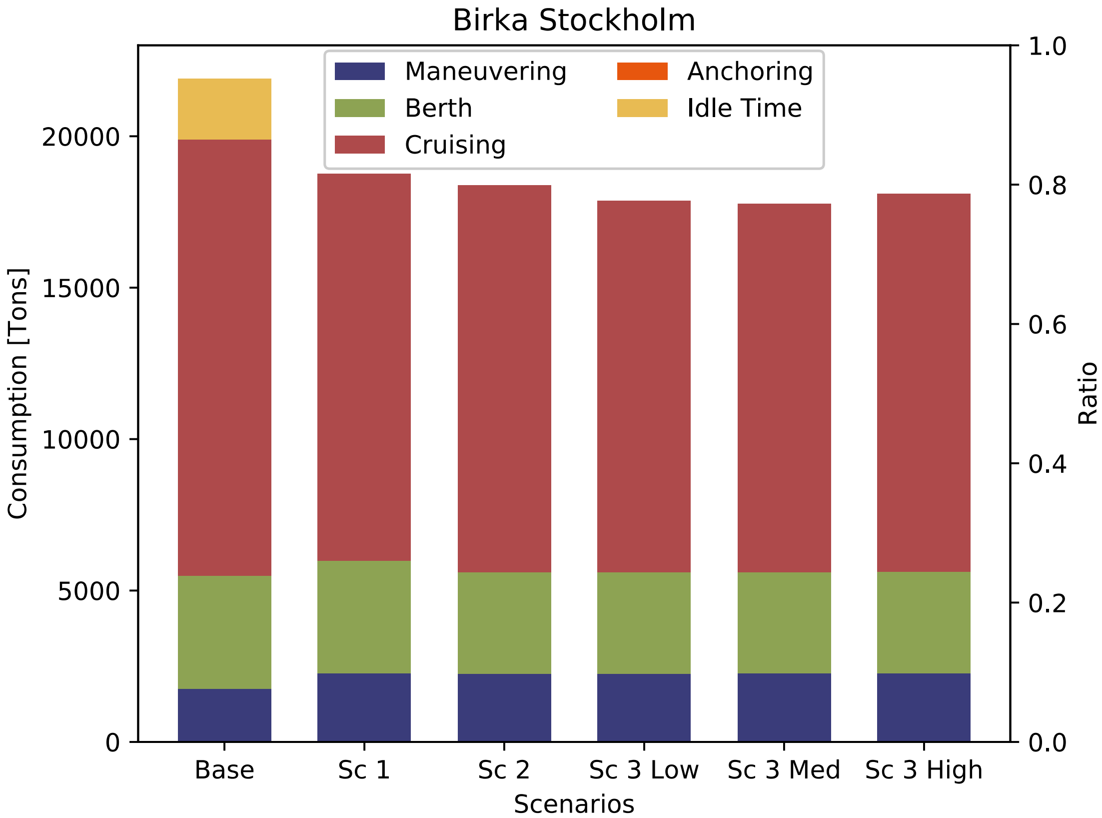


Figure 71: Fuel consumption of the Birka Stockholm in the current situation and for the different proposed scenarios divided by phases.

3. GHG Emissions

Regarding GHG emissions, Figure 43 shows that both the savings for the consumption and emissions in each scenario as well as its variation are comparable. It can be observed that for Scenario 3 at medium speed, which achieves the best results, the savings, both in consumption and in emissions, are roughly a 19% in average.

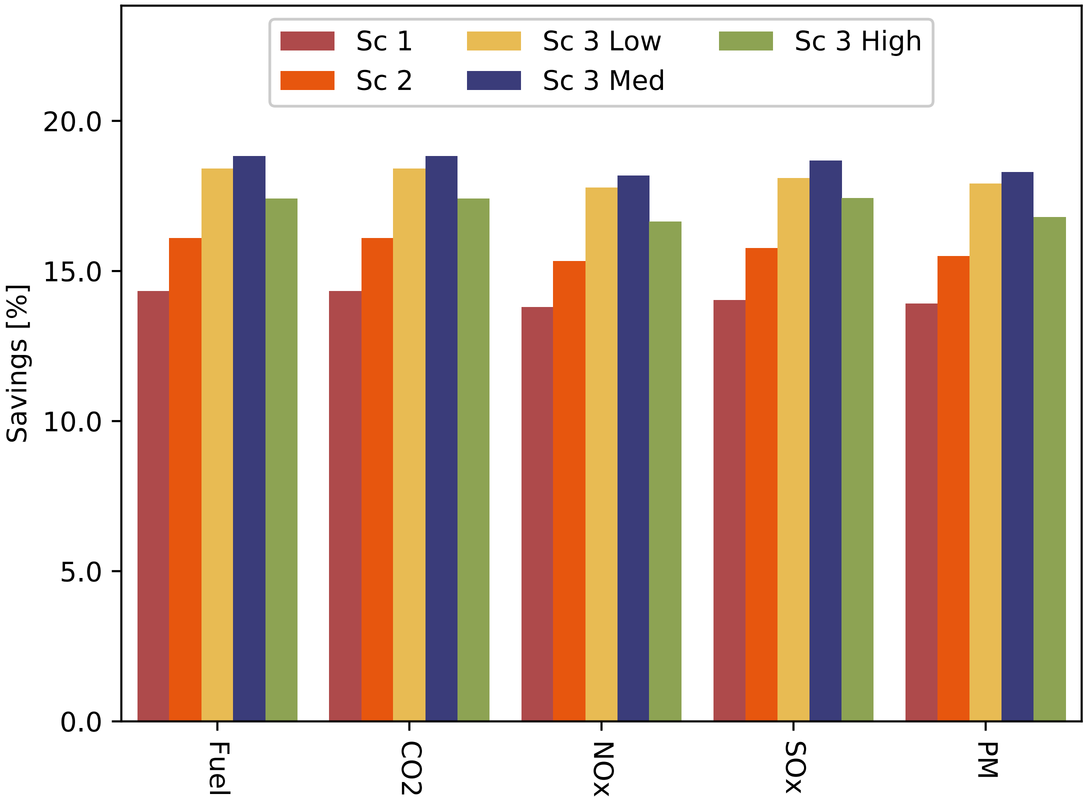


Figure 72: Mean values and deviations of the savings in fuel consumption and emissions for PAX1

9.5.4 Use Case Evaluation

In this section the approximate savings of implementing the different scenarios of STM and the economic impact that this could have on the shipping companies' costs are shown.

Tons	Fuel Consumption	CO2 Emissions	NOx Emissions	SOx Emissions	PM
BIRKA STOCKHOLM	21,904.65	70,225.85	1,470.15	53.11	23.17

Table 14: Results of one year fuel consumption and GHG emissions

In Table 5 we depict the results of one year fuel consumption and GHG emissions for Birka Stockholm.

SHIP	Variable	Metric	SC 1	SC 2	SC 3 Low	SC 3 Med	SC 3 High
BIRKA STOCKHOLM	Fuel	Ton	3,138.37	3,526.09	4,034.39	4,126.26	3,812.57
		%	14.33%	16.10%	18.42%	18.84%	17.41%
	CO2	Ton	10,061.60	11,304.64	12,934.23	13,228.83	12,223.11
		%	14.33%	16.10%	18.42%	18.84%	17.41%
	NOx	Ton	202.93	225.31	261.26	267.23	244.84
		%	13.80%	15.33%	17.77%	18.18%	16.65%
	SOx	Ton	7.45	8.37	9.61	9.92	9.26
		%	14.02%	15.76%	18.10%	18.68%	17.43%
	PM	Ton	3.22	3.59	4.15	4.24	3.89
		%	13.92%	15.50%	17.91%	18.29%	16.79%

Table 15: Estimated savings for one year in fuel con consumption and GHG emissions for the different scenarios

9.6 Use Case RPX1

9.6.1 Abstract

Ro-Pax services are included in wheeled cargo traffic but combine cargo and passengers on their routes. These are relatively new ships that accept cargo, which is loaded/unloaded using terminal trucks (commonly known as MAFIs), or directly loaded with accompanied drivers, connecting more than one country or different national islands. The usual commercial loading unit is the lane metre. Regarding passengers, they usually travel with their own vehicle, facilitating intermodality.

Ro-Pax ships represent around 8% of the total world fleet (3,973units) in 2017 (EQUASIS, 2018). The STM project includes 26 Ro-Pax ships of different sizes and this use case covers Ro-Pax ships with capacity of around 4000 lane meters. It involves two ships: STENA GERMANICA and STENA SCANDINAVICA. This service operates from Gothenburg (Sweden) to Kiel (Germany) and it is a clear example of the Short Sea Shipping service. The shipping line is Stena Line.

There were multiple reasons that led to select these ships as a use case. Both ships are STM ships. They belong to a different segment (50-69,999 GT) than other Ro-Pax selected. They are in the Nordic testbed area, call in a STM port, Gothenburg and navigate through two different shore centres. Finally, they may use the 'Route Exchange Ship-to-Ship' service while crossing one another in their route.

9.6.2 Use Case Data

The data used to analyse the use cases is divided in two sets. On the one hand, static data describing characteristics of the ships, like those shown in Table 4, or other derived from it, that are captured in their configuration file. On the other hand, AIS navigation data from the period comprehended between June 1st 2017 and May 31st 2018, that shows real location, time and speed data from the routes they covered. Altogether, these data are used to compute the fuel consumption and emissions of the ships in the use cases.

SHIP	IMO No.	GT	FLAG	YEAR OF BUILD	SIZE (L/ B/ D) in metres	CAPACITY (Lane Meters)	MAIN ENGINE POWER (kW)	AUX. ENGINE POWER (kW)	BOILER
STENA GERMANICA	9145176	51,837	SE	2001	241 x 29 x 6	3,980	24,000	375	N/A
STENA SCANDINAVICA	9235517	57,958	SE	2003	240 x 29 x 6	4,100	6,600	375	N/A

Table 16: RPX1 Ships Characteristics

9.6.3 Use Case Analysis

Figure 35 displays the itinerary covered by the ships in the RPX1 Use Case. During the voyage, the ships shift through different phases: berth, manoeuvring, anchoring (idle time when far from port) and cruising. The phases of berth, manoeuvring and cruising are part of the natural flow of the voyage. However, the anchoring phase is usually the result of an inefficient port call synchronization between ships and ports. Similarly, Idle Time can be the result of events that force the ship to reduce its speed or stop while navigating, being possible to tag it, as well, as an inefficiency.

Figure 73: RPX1 Use Case itinerary

During the voyage, there can be additional events that affect the navigational efficiency of the ships and the shipping service. For instance, there might be unnecessary variations of speeds due to several reasons: changes in the availability of arrival port resources, crossing a strait or canal, traffic restrictions or congestion. These avoidable speed variations and other causes can result in extra costs.

9.6.3.1 Efficiency

In order to provide an intuition about the mentioned inefficiencies we analyse the speed variation of the set of ships while cruising, their punctuality and their anchoring times.

1. ***Speed Variation***

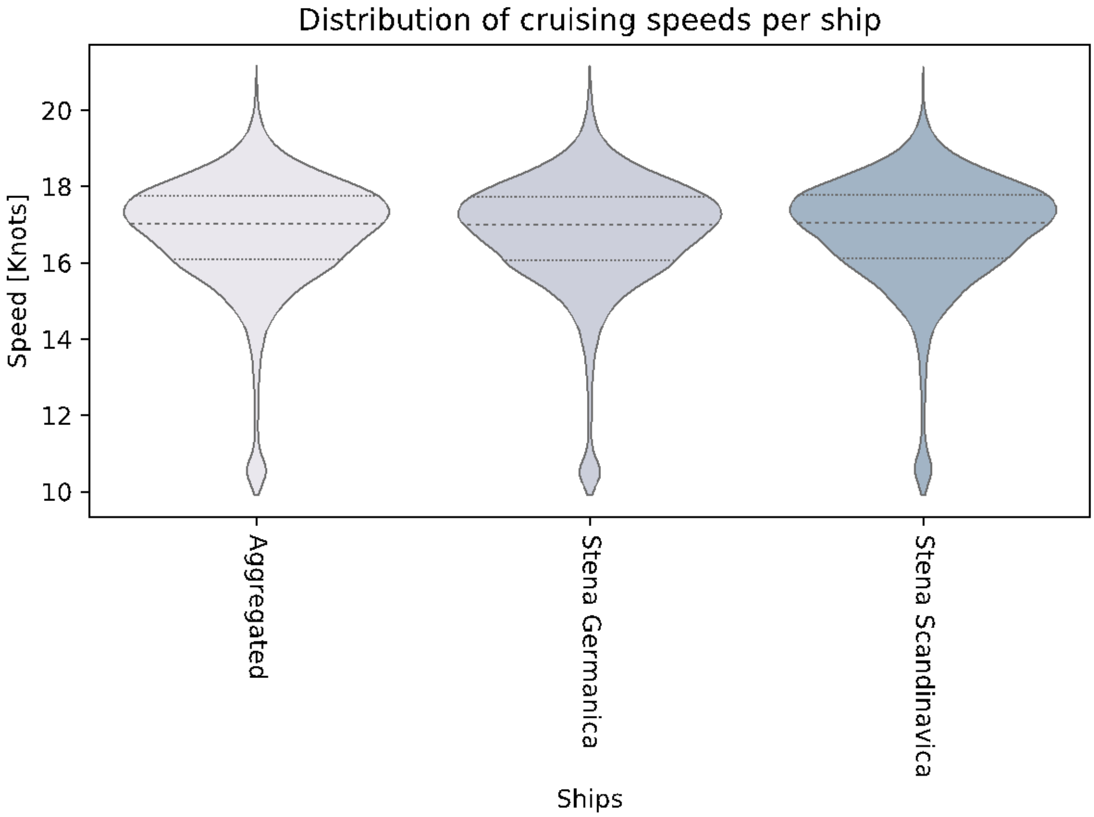


Figure 74: Aggregated distribution of cruising speeds for the ships in RPX1

As we observe in Figure 36, the distributions of cruising speeds for the Stena Germanica and Stena Scandinavica are relatively compact, navigating most of the time between, approximately, 15 and 19 Knots, and with an interquartile distance of less than 2 Knots. Both ships are able to keep stable speeds during navigation, with a low or moderate variability. The distribution of speeds per leg, shown in Figure 37, follows the same pattern, with almost identical median, 1st and 3rd quartile speeds in both distributions.

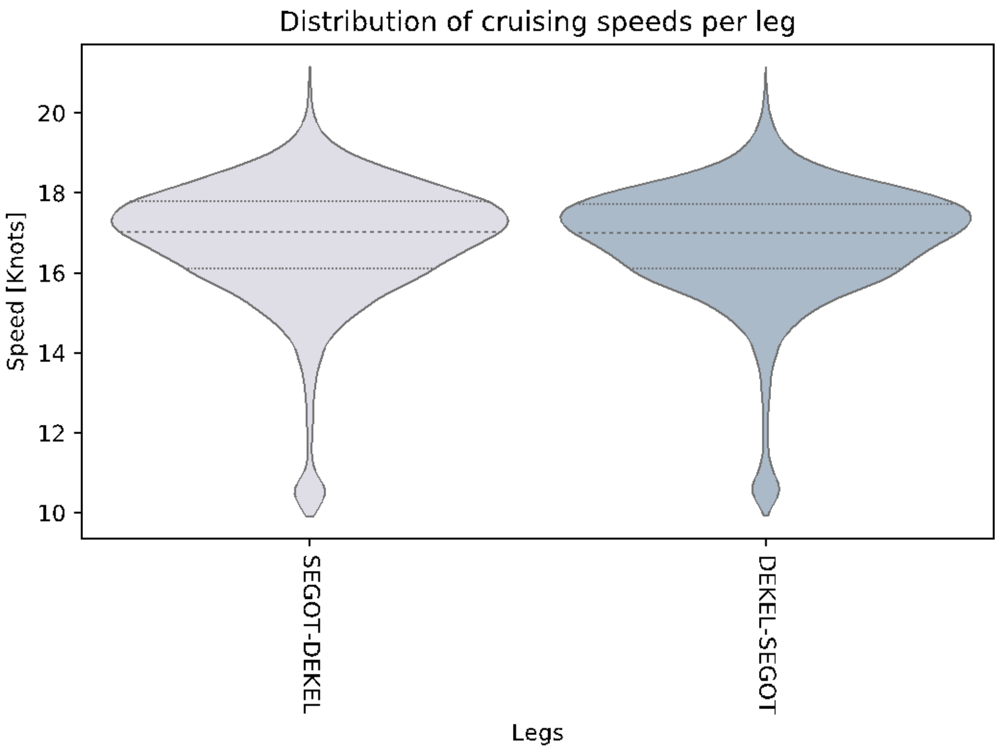


Figure 75: Aggregated distribution of cruising speeds per leg for the ships in RPX1

2. Punctuality

One of the indicators of a shipping service in terms of efficiency is punctuality. Figure 38 and Figure 39 show the distributions of the deviation between the Estimated Time of Arrival (ETA) reported at the beginning of a leg and its Actual Time of Arrival (ATA), in order to capture, also, its capacity to provide accurate ETAs in advance.

Some of the characteristics of Ro-Pax traffic are that, because they transport passengers, they usually have priority when entering into port and have very tight schedules. Hence, large deviations between ETAs and ATAs were not expected.

However, as Figure 38 and in Figure 39 show large ETA deviations, in the order of days, in approximately 80% of the times the ship arrived late and 10% of the times the ship arrived early. These results led to a deeper analysis of the data that showed that all these deviations were due to errors in the reported ETA. In fact, it is possible to identify a large step in the late arrivals box in Figure 38 around the 24 hours deviation, related to all those times where the ETA had a deviation of one day. Posterior steps are related, in most cases with multiples of 24 hours. The steps beyond one-hour deviation in the early arrivals, although less, are for the same reason.

Therefore, although the figures are not showing the real data, we can affirm that the real distribution is similar to that shown within the first hour of the early and late arrivals in Figure 38 and Figure 39. Most of the times both the Stena Germanica arrived less than 30 minutes early only a few times they were late, always by less than an hour. Except for an apparent higher reliability on the ETA data reported by the Stena Scandinavica, both vessels had similar behaviour regardless of the port of destination.

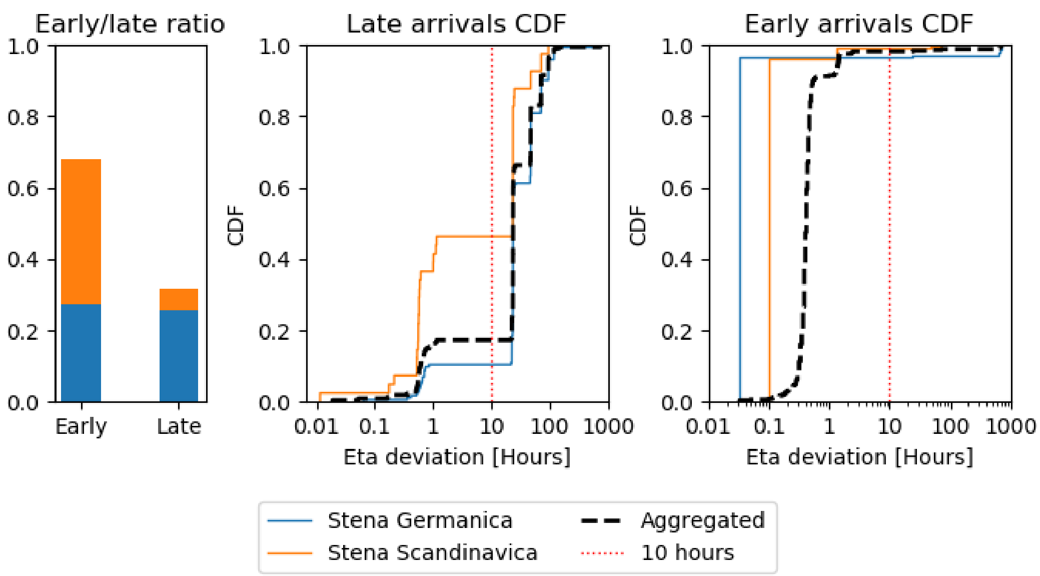


Figure 76: distribution of ETA deviations per ship in RPX1

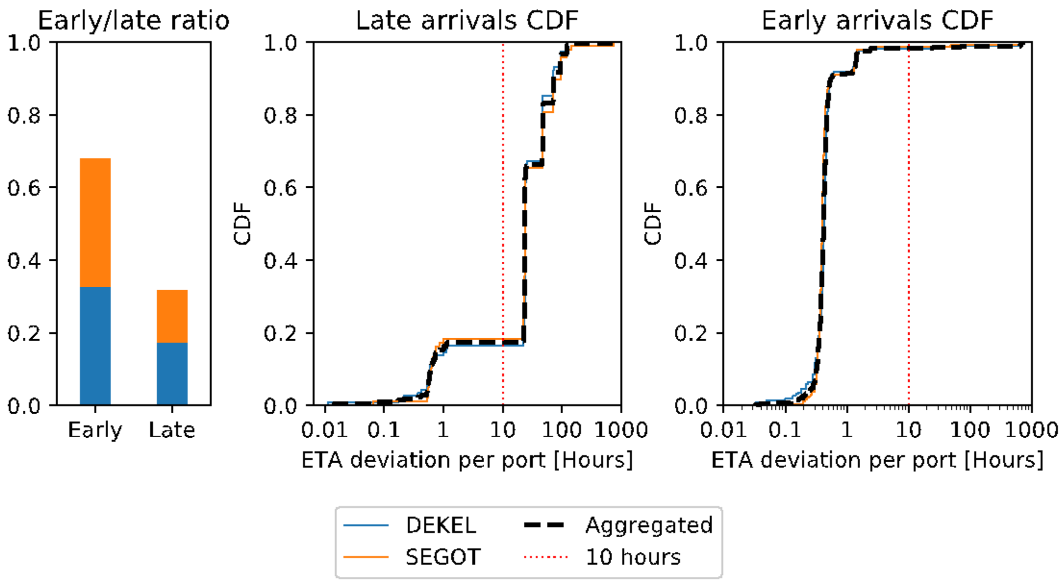


Figure 77: ETA deviations per port in RPX1

3. Anchoring Times

Figure 40 presents the results related to anchoring times per port for RPX1. As expected in Ro-Pax ships, there was few or no anchoring times. In fact, the only case detected is a roughly 20 minutes stop and go, probably caused for some other ship exiting the port or a similar reason.

This use case is a clear example of how anchoring should be for ships in general. STM will help to improve the synchronization of port calls becoming the frame for a better ship-to-port communication between ports and ships, reducing or eliminating these timeframes of idleness and enabling the ports to improve their resource management. A better resource management should result in ports providing ships with better recommended times of arrival (RTA) that allow them to adapt their cruising speed, hence, saving fuel and spending less time in anchoring.

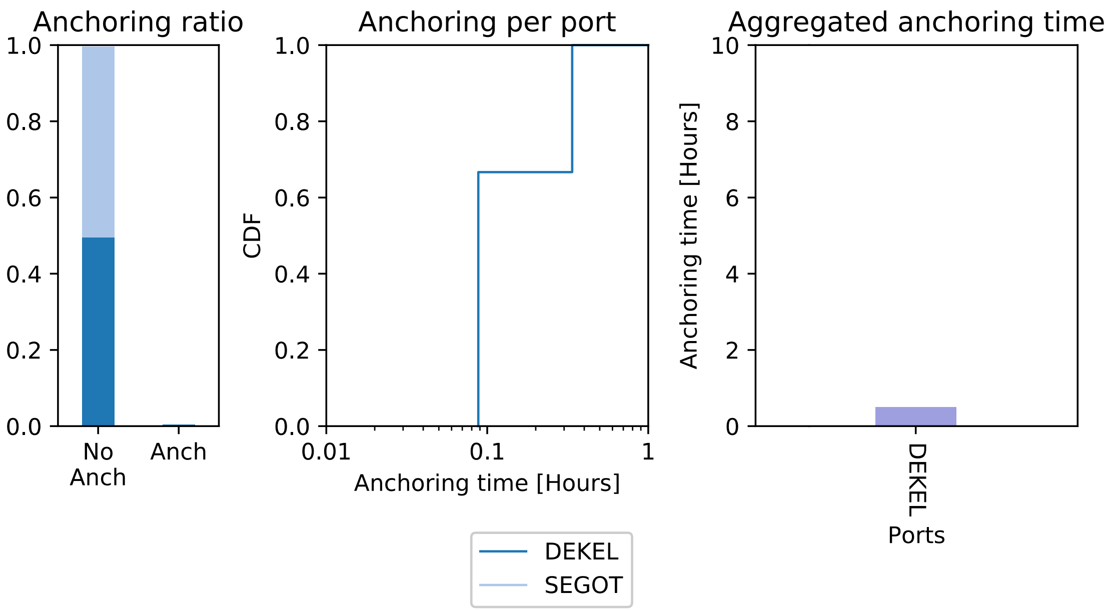


Figure 78: Anchoring times by port in RPX1

9.6.3.2 Environmental Sustainability

This section presents an analysis of the navigation times, the fuel consumption and the different emissions in the current situation and shows the potential savings that the different proposed scenarios may introduce with STM implementation.

1. ***Navigation Times***

The first aspect to evaluate is the variation in the times of navigation that each scenario introduces as a result of eliminating anchoring times or using different cruising speeds. This variation acts as a contrast to the potential savings in fuel or emissions that can be achieved by using slower cruising speeds, as this would also imply longer navigation times and has an impact on the time the ship needs to cover its route.

The Ro-Pax case is particular from the point of view of having tight schedules. Hence, our assumptions of STM being able to reduce the time at berth or needing to reduce the speed to save fuel may prove wrong. Still, it is interesting to see the effects for ships like the Stena Germanica and Stena Scandinavica, whose speed distribution is close to an ideal shape, as shown in Figure 36, and using the slower speed barely implies reducing one Knot the median speed.

Figure 41 these variations for the RPX1 use case. In this case, the speed reduction can be easily compensated by reducing some time at berth up to the point of still being able to reduce 10 days per year its navigation time. The reduction of time increases as the median speed increases. It is worth mentioning, as well, that there is no visible reduction for Scenario 1 as there was no time lost due to anchoring, and that the time saved in Scenario 2 corresponds to the time that is assumed can be reduced at berth.

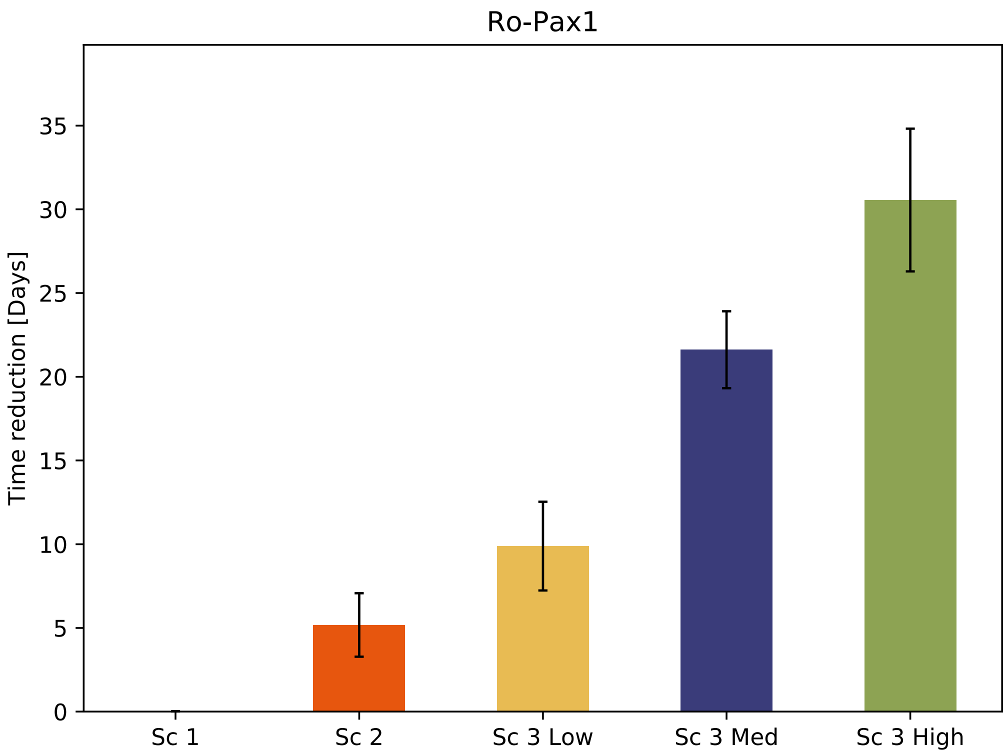


Figure 79: Variation in navigation time for each scenario in RPX1

2. Fuel Consumption

Figure 42 presents an estimation of the fuel consumption of the Stena Germanica for the real AIS (Automatic Identification System) data and for the proposed scenarios. The Stena Scandinavica presented similar results, that can be consulted in the ANNEXES.

As expected, cruising and berth are the dominating phases, where ships spend most of their time. Anchoring and Idle Times were irrelevant in this case, due to the type of the traffic. It is worth mentioning that our analysis introduces some residual error for manoeuvring when we recompute the routes for the scenarios due to the granularity of the AIS data and the geographical separation between the waypoints generated.

As expected, the third scenario with the lowest median speed results in the largest savings, although not very different to other scenarios due to the low variability of the speed distribution. In this case, the improvement comes from reducing times in berth and reducing, as much as possible, the speed variability during navigation. Even in this case, savings of slightly more than an 8% can be achieved.

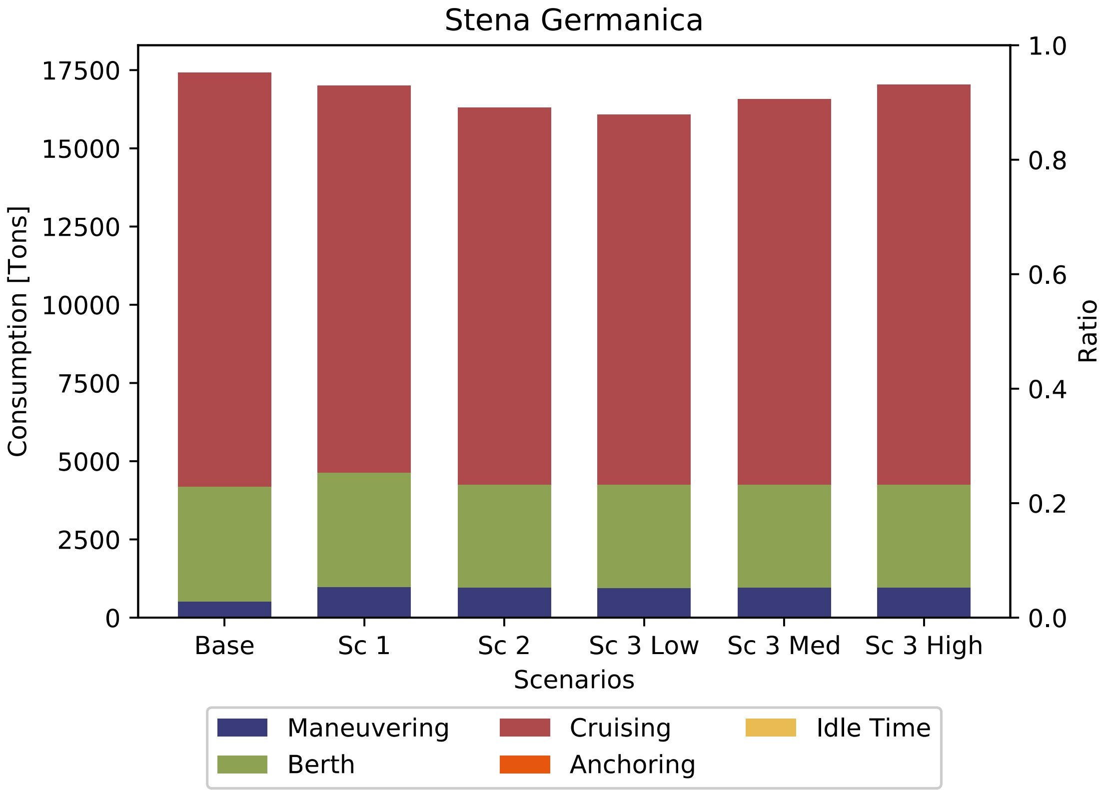


Figure 80: Fuel consumption of the Njord in the current situation and for the different proposed scenarios divided by phases.

3. GHG Emissions

Figure 43 shows together the savings in fuel consumption and GHG emissions in each one of the scenarios as well as its variation across ships, represented by the error bars. The best results are obtained for Scenario 3 at low speed. Moreover, due to the characteristics of the ship, the percentage of savings is similar across the different pollutants. It is worth to remark that, in this case, the second best case is not the Scenario 3 at median speed, but the Scenario 2, reaching slightly more than a 7% reduction. This is because in this scenario speed tends to be lower than the median and closer to the lower speed.

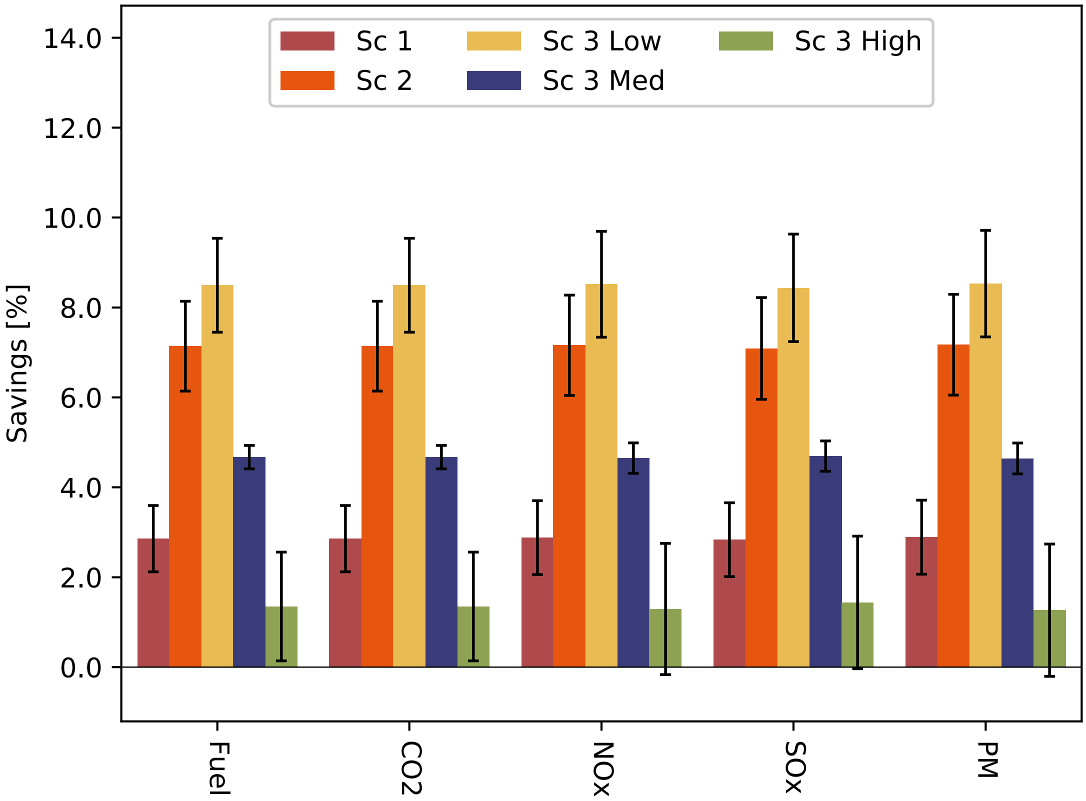


Figure 81: Mean values and deviations of the savings in fuel consumption and emissions for all the vessels in RPX1

9.6.4 Use Case Evaluation

This section summarizes in tables the approximate total consumptions and emissions for the ships in RPX1. Table 17: Results of one year fuel consumption and GHG emissions Table 5 presents the estimations on the real case, computed directly with the AIS data available for the two ships in the use case. On the other hand, Table 18 presents the potential savings that could be achieved for each pollutant and for fuel consumption for each ship and the aggregated results. The best achievable results appear shaded.

Tones	Fuel Consumptio n	CO2 Emissions	NOx Emissions	SOx Emission s	PM
STENA GERMANICA	17,422.60	55,856.86	1,194.41	41.24	18.6 1
STENA SCANDINAVICA	17,147.88	54,976.09	1,117.70	38.44	17.4 8

Table 17: Results of one year fuel consumption and GHG emissions

SHIP	Variable	Metric	SC 1	SC 2	SC 3 Low	SC 3 Med	SC 3 High
STENA GERMANICA	Fuel	Ton	407.32	1,120.57	1,351.00	845.53	383.71
		%	2.34%	6.43%	7.75%	4.85%	2.20%

	CO2	Ton	1,305.86	3,592.55	4,331.31	2,710.76	1,230.16
		%	2.34%	6.43%	7.75%	4.85%	2.20%
	NOx	Ton	27.48	76.07	91.77	58.38	27.75
		%	2.30%	6.37%	7.68%	4.89%	2.32%
	SOx	Ton	0.93	2.59	3.13	2.03	1.02
		%	2.25%	6.29%	7.59%	4.93%	2.48%
	PM	Ton	0.43	1.19	1.43	0.91	0.43
		%	2.31%	6.38%	7.69%	4.88%	2.31%
STENA SCANDINAVICA	Fuel	Ton	579.65	1,345.59	1,583.14	769.41	84.37
		%	3.38%	7.85%	9.23%	4.49%	0.49%
	CO2	Ton	1,858.36	4,313.95	5,075.55	2,466.74	270.49
		%	3.38%	7.85%	9.23%	4.49%	0.49%
	NOx	Ton	38.69	88.84	104.49	49.28	2.91
		%	3.46%	7.95%	9.35%	4.41%	0.26%
	SOx	Ton	1.31	3.03	3.57	1.71	0.15
		%	3.41%	7.89%	9.28%	4.45%	0.40%
	PM	Ton	0.61	1.39	1.64	0.77	0.04
		%	3.47%	7.96%	9.37%	4.40%	0.23%
AGGREGATED	Fuel	Ton	986.97	2,466.16	2,934.14	1,614.94	468.08
		%	2.86%	7.14%	8.49%	4.67%	1.35%
	CO2	Ton	3,164.22	7,906.50	9,406.86	5,177.50	1,500.66
		%	2.86%	7.14%	8.49%	4.67%	1.35%
	NOx	Ton	66.17	164.91	196.26	107.66	30.67
		%	2.88%	7.16%	8.52%	4.65%	1.29%
	SOx	Ton	2.24	5.63	6.7	3.75	1.17
		%	2.83%	7.09%	8.44%	4.69%	1.44%
	PM	Ton	1.04	2.58	3.07	1.68	0.47
		%	2.89%	7.17%	8.53%	4.64%	1.27%

Table 18: Savings in tones and percentages in fuel and the different pollutants in the different scenarios.

9.7 Use Case RPX2

9.7.1 Abstract

The RPX2 use case studies a shipping service that connects Denmark with Southern Norway, calling at the ports of Hirtshals, Stavanger, Bergen and Langesund although they occasionally stop in other ports as Copenhagen or Kristiansand as well. There are two ships studied in the use case, the Stavangerfjord and the Bergensfjord, operated by the company Fjordline. Both ships belong to the 20-49,999 GT segment, smaller than the ships studied in RPX1, and has a capacity of approximately 1,350 lane meters.

Some of the reasons to select these ships, beyond their segment, are passing through two different shore centre areas in the Nordic sea testbed or being propelled dual by LNG engines.

9.7.2 Use Case Data

As in RPX1, two sets of data are used, static and AIS data. Table 19 presents some of the characteristics of the two ships in this use case. The AIS data used comprehended the same period than for RPX1, June 1st 2017 to May 31st 2018.

SHIP	IMO No.	GT	FLAG	YEAR OF BUILD	SIZE (L/B/D) in metres	CAPACITY (Lane Metres)	MAIN ENGINE POWER (kW)	AUX. ENGINE POWER (kW)	BOILER
STAVANGERFJORD	9586605	34,384	DK	2013	170 x 28 x 6	1,350	21,600	1,463	N/A
BERGENSFJORD	9586617	31,678	DK	2014	170 x 28 x 6	1,350	21,600	1,463	N/A

Table 19: RPX2 Ship Characteristics

9.7.3 Use Case Analysis

Figure 44 displays the itinerary covered by the ships in Use Case RPX2. As described in RPX1, the analysis aims to quantify the potential reductions in fuel consumption and emissions derived from the events and inefficiencies arising during the navigation or due to lack of ship-port synchronization.

Figure 82: RPX2 Use Case itinerary.

9.7.3.1 Efficiency

In order to provide an intuition about the mentioned inefficiencies we analyse the speed variation of the set of ships while cruising and their punctuality. In this case, anchoring times are not studied given that the ships did not spend any time in anchoring.

1. ***Speed Variation***

Figure 45 depicts the distribution of cruising speeds by ship and the aggregated one. Both ships exhibit a certain bimodality, subtler in the Stavangerfjord and more noticeable in the Bergensfjord. This bimodality is apparently caused by the legs between DKHIR and NOTAE, whose median speeds are lower than those in the other most frequent legs, those connecting DKHIR, NOTAE, NOBGO and NOLAD, as can be seen in Figure 46. These difference between legs also leads to a relatively wide range of frequent speeds, between 17 and 23 Knots. However, despite of the clear difference between the DKHIR and NOTAE legs and the others, it can also be appreciated that the legs between NOTAE and NOBGO also distribute uniformly their speeds between 20 and 24 Knots, helping also to the width of the aggregated distribution of speeds.

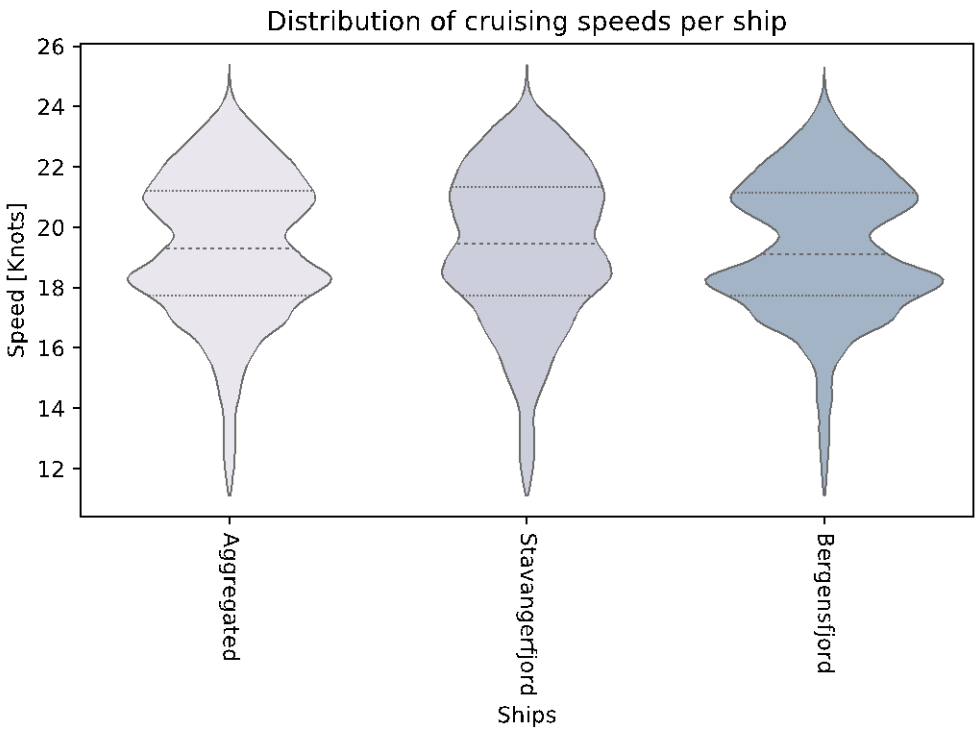


Figure 83: Aggregated distribution of cruising speeds for the ships in RPX2.

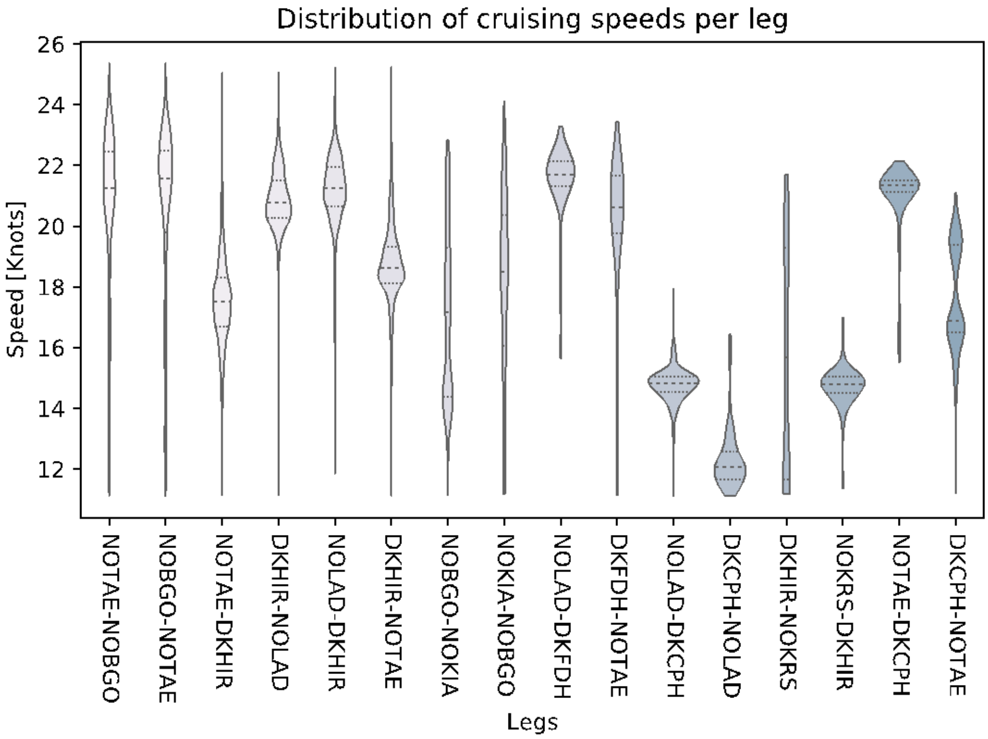


Figure 84: Aggregated distribution of cruising speeds per leg for the ships in RPX2.

Again, we believe than STM can help to reduce this variability through the offering of services that provide additional information about the route to be covered or that optimize it.

2. Punctuality

Figure 47 and Figure 48 show the distributions of the deviation between the Estimated Time of Arrival (ETA) reported at the beginning of a leg and its Actual Time of Arrival (ATA) by ship and by port. As in the case of RPX1, the data proved not to be reliable, with many incorrect values for the reported ETA. In this case, beyond errors caused by inputing the right hour but the wrong day, it is possible to find also errors due to not updating the ETA after arriving to a port, reporting that same ETA for the next leg. For this reason, the data related to the early arrivals is closer to reality, in particular the first 85% of the reports, that show that the ships used to arrive around 20 minutes before the ETA, which actually looked more like and ETD for those ports. For late arrivals, those reports beyond the hour are mostly errors as well.

STM will help with portcall synchronization and automate the communication of these reports to the port. However, in these cases, the reliability issue seems to be related to the ships not being enforced to report this information, as seems to affect multiple Ro-Pax and Pax ships operating in the Nordic testbed.

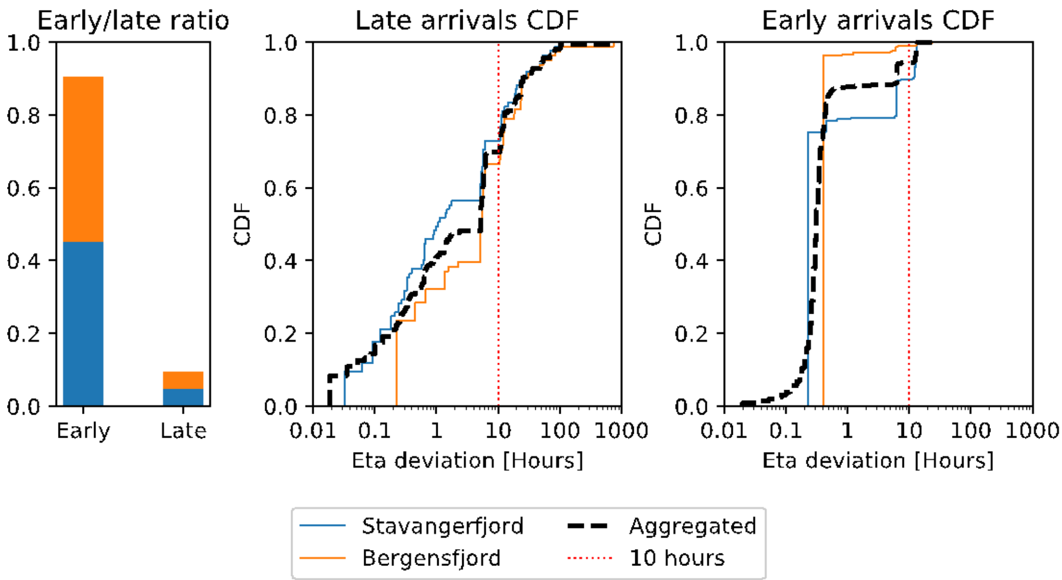


Figure 85: distribution of ETA deviations per ship in RPX2.

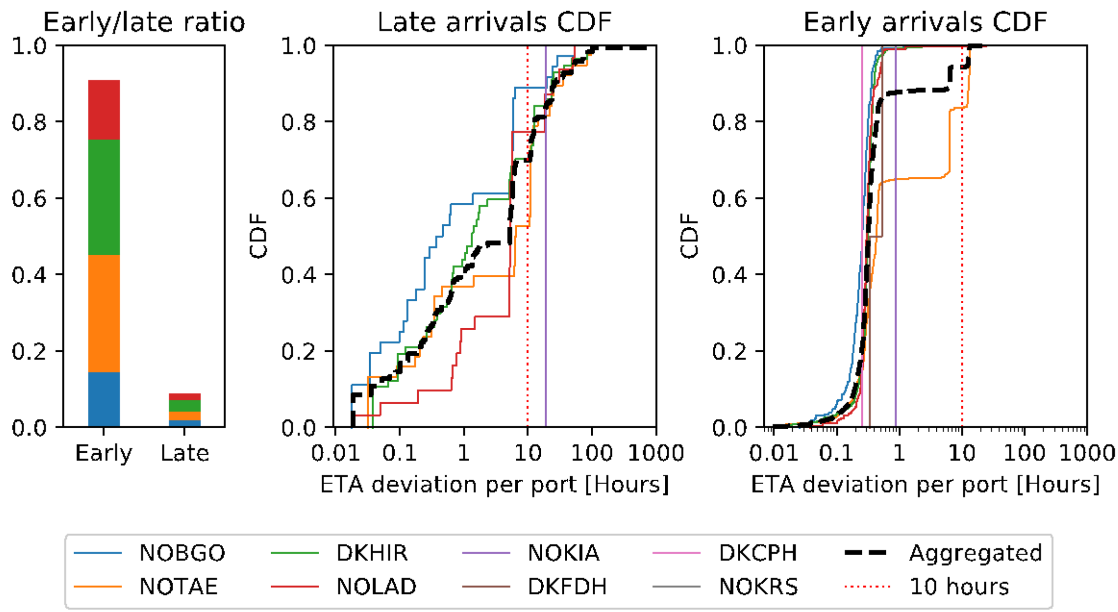


Figure 86: ETA deviations per port in RPX2

3. Anchoring Times

The ships in RPX2 did not spend any time in anchoring. This is in line with what is expected from Ro-Pax and Pax ships, that are given high priority when entering into ports and should not be (at least not usually) affected by these issues.

9.7.3.2 Environmental Sustainability

1. Navigation Times

The variations on the navigation time are shown in Figure 50. Due to the absence of anchoring times, Scenario 1 reflects no variation. Scenario 2 shows the potential reduction that could be achieved from improving the stay in ports. Scenario 3 low is able to introduce some additional savings, due to those legs which are covered at speeds substantially lower than the low speed used at this case, of roughly 18 Knots. Scenarios 3 Median and High can reduce substantially more the days of navigation but have a common issue with Scenario 3 Low. At the end, these ships have tight schedules and any change of the speed must be deeply studied to see if it can be adopted in a way that suits the end users.

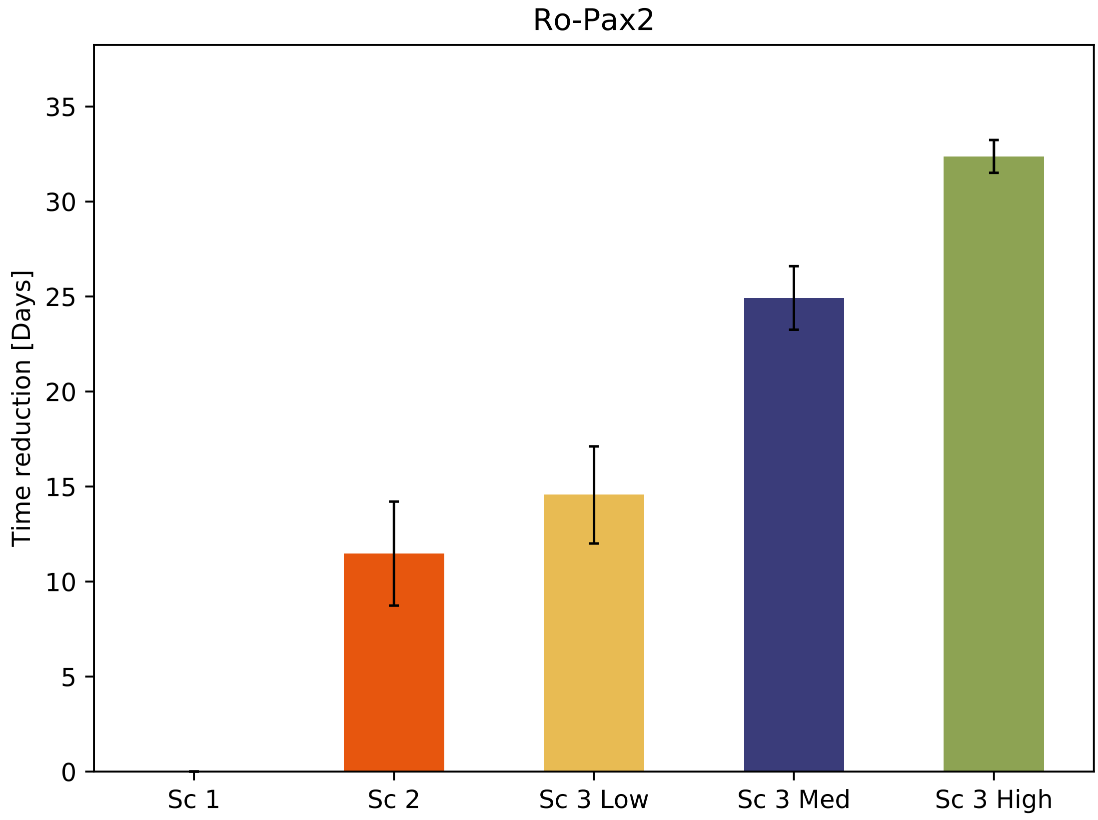


Figure 87: Variation in navigation time for each scenario in RPX2

2. Fuel Consumption

Figure 51 presents an estimation of the fuel consumption of the Stavangerfjord for the real data and for the proposed scenarios. The results for the Bergensfjord are similar, as can be inferred from the error bars in Figure 50 and Figure 52.

RPX2 is in line with RPX1, and the Scenario 2 and Scenario 3 Low are the ones throwing the best results. This is mainly a consequence of the type of traffic and lack of anchoring idle times, being the main source of improvement the time saved at berth and the reduction on speed and of tis variability. Scenario 3 Median, navigating at a higher speed than Scenario 2, consumes more fuel and has larger emissions. It is worth noting, as well, that Scenario 3 High would result in a consumption larger than that of the original data.

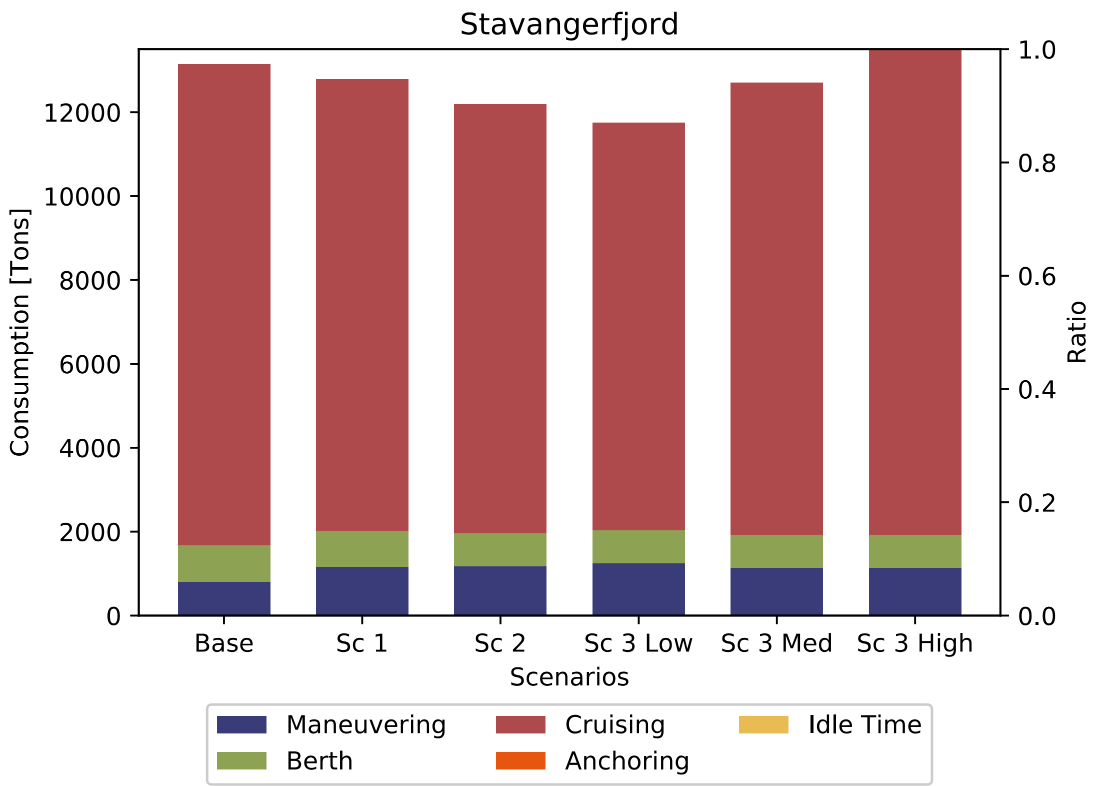


Figure 88: Fuel consumption of the E. R. Pusan in the current situation and for the different proposed scenarios divided by phases.

3. GHG Emissions

Figure 52 shows that both the savings for the consumption and emissions in each scenario, as well as its variation are comparable. In addition, in the case of RPX2, the results for the different ships are similar, as implied by the short length of the error bars. It can be observed that for Scenario 3 at low speed, which achieves the best results, the savings, both in consumption and in emissions, are roughly a 24% in average.

Figure 52 shows together the savings in fuel consumption and GHG emissions in each one of the scenarios as well as its variation across ships, represented by the error bars. As mentioned, the best results are obtained for Scenario 3 at low speed followed by Scenario 2. These results are similar across the different pollutants. In this case, reductions in the order of a 9% and a 6%, respectively, can be achieved for each pollutant and ship.

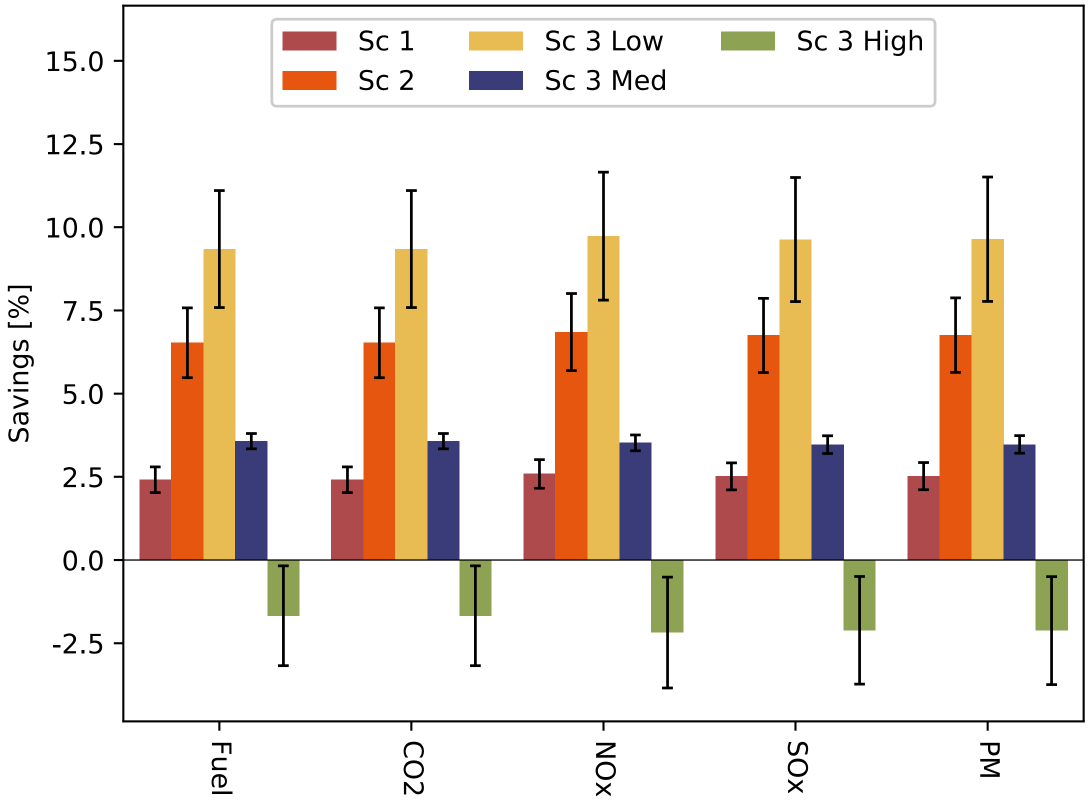


Figure 89: Mean values and deviations of the savings in fuel consumption and emissions for all the vessels in RPX2.

9.7.4 Use Case Evaluation

This section summarizes in tables the approximate total consumptions and emissions for the ships in RPX2. Table 8 presents the estimations on the real case, computed directly with the AIS data available for the two ships in the use case. On the other hand, Table 21 presents the potential savings that could be achieved for each pollutant and for fuel consumption for each ship and STM scenario and the aggregated results. The best achievable results appear shaded.

Tones	Fuel Consumption	CO2 Emissions	NOx Emissions	SOx Emissions	PM
STAVANGERFJORD	13,143.72	36,145.22	121.82	0.20	1.86
BERGENSFJORD	13,061.28	35,918.54	120.93	0.20	1.84

Table 20: Results of one year fuel consumption and GHG emissions

SHIP	Variable	Metric	SC 1	SC 2	SC 3 Low	SC 3 Med	SC 3 High
STAVANGERFJORD	Fuel	Ton	353.04	955.37	1,391.45	447.77	-359.66
		%	2.69%	7.27%	10.59%	3.41%	-2.74%
	CO2	Ton	970.87	2,627.26	3,826.49	1,231.37	-989.06
		%	2.69%	7.27%	10.59%	3.41%	-2.74%
	NOx	Ton	3.52	9.34	13.51	4.08	-4.09
		%	2.89%	7.67%	11.09%	3.35%	-3.36%
	SOx	Ton	0.01	0.02	0.02	0.01	-0.01
		%	2.80%	7.54%	10.95%	3.28%	-3.26%

	PM	Ton	0.05	0.14	0.2	0.06	-0.06
		%	2.81%	7.55%	10.96%	3.29%	-3.27%
BERGENSFJORD	Fuel	Ton	279.35	755.75	1,058.33	487.68	-79.93
		%	2.14%	5.79%	8.10%	3.73%	-0.61%
	CO2	Ton	768.21	2,078.32	2,910.41	1,341.11	-219.81
		%	2.14%	5.79%	8.10%	3.73%	-0.61%
	NOx	Ton	2.76	7.29	10.13	4.46	-1.21
		%	2.28%	6.03%	8.37%	3.69%	-1.00%
	SOx	Ton	0.00	0.01	0.02	0.01	0.00
		%	2.23%	5.96%	8.31%	3.66%	-0.97%
	PM	Ton	0.04	0.11	0.15	0.07	-0.02
		%	2.24%	5.97%	8.32%	3.66%	-0.97%
AGGREGATED	Fuel	Ton	632.39	1711.12	2449.78	935.45	-439.59
		%	2.41%	6.53%	9.34%	3.57%	-1.67%
	CO2	Ton	1739.08	4705.59	6736.9	2572.49	-1208.88
		%	2.41%	6.53%	9.34%	3.57%	-1.67%
	NOx	Ton	6.28	16.63	23.64	8.54	-5.3
		%	2.59%	6.85%	9.73%	3.52%	-2.18%
	SOx	Ton	0.01	0.03	0.04	0.01	-0.01
		%	2.52%	6.75%	9.63%	3.47%	-2.11%
	PM	Ton	0.09	0.25	0.36	0.13	-0.08
		%	2.52%	6.76%	9.64%	3.47%	-2.12%

Table 21: Savings in tones and percentages in fuel and the different pollutants in the different scenarios.

9.8 Use Case RPX3

9.8.1 Abstract

The RPX3 use case studies two shipping services that connect Sweden with Finland and that belong to the Viking Line. The first of these services calls at the ports of Helsinki, Mariehamn and Stockholm, while the second one calls at Stockholm, Mariehamn, Langnas and Turku. Occasionally, these ships will stop in other ports, e.g., Tallinn. There are two ships studied in this use case, the Amorella and the Gabriella, operated by the company Viking. Both ships belong to the 20-49,999 GT segment but are smaller than those studied in RPX2, with a capacity of only 970 lane meters.

Both ships are included in the STM fleet and navigate through a shore centre area included in the project as well.

9.8.2 Use Case Data

SHIP	IMO No.	GT	FLAG	YEAR OF BUILD	SIZE (L/ B/ D) in metres	CAPACITY (Lane Metres)	MAIN ENGINE POWER (kW)	AUX. ENGINE POWER (kW)	BOILER
VIKING AMORELLA	8601915	34,384	FI	1988	170 x 28 x 6	970	23,760	4,280	N/A
VIKING GABRIELLA	8917601	35,492	FI	1992	170 x 28 x 6	970	23,760	4,280	N/A

Table 22: RPX3 Ships Characteristics

9.8.3 Use Case Analysis

Figure 90 and Figure 91 display the itineraries covered by the Amorella and the Gabriella. Their routes are slightly different. Amorella calls at Stockholm, Mariehamn, Langnas and Turku, while the Gabriella calls at Stockholm, Mariehamn, Helsinki and, occasionally Tallinn. As described in RPX1, the analysis aims to quantify the potential reductions in fuel consumption and emissions derived from the events and inefficiencies arising during the navigation or due to lack of ship-port synchronization.

Figure 90: Amorella itinerary

Figure 91: Gabriella Itinerary

9.8.3.1 Efficiency

In order to provide an intuition about the mentioned inefficiencies we analyse the speed variation of the set of ships while cruising and their punctuality. In this case, anchoring times are not studied given that the ships did not spend any time in anchoring.

1. Speed Variation

Figure 54 shows the distribution of cruising speeds by ship and the aggregated one. We can observe that the distribution of speeds is extremely wide and multimodal. There are different groups of frequent speeds between 14 and 17 and 17 to 20 Knots in the Amorella, and even more groups for Gabriella. In addition, it is easy to see that there is a great variability on speeds between 11 and 20 Knots.

This great variability is observed as well in Figure 55, where the speed distributions are completely different one another and barely "flat" in some cases, like FILAN-SESTO. These wide changes in speed for the same legs are certainly a symptom of something not being as efficient as it should be. The reasons could be congestion, weather, or other. In any case, STM can offer the tools to improve this navigation that can be certainly denoted as inefficient.

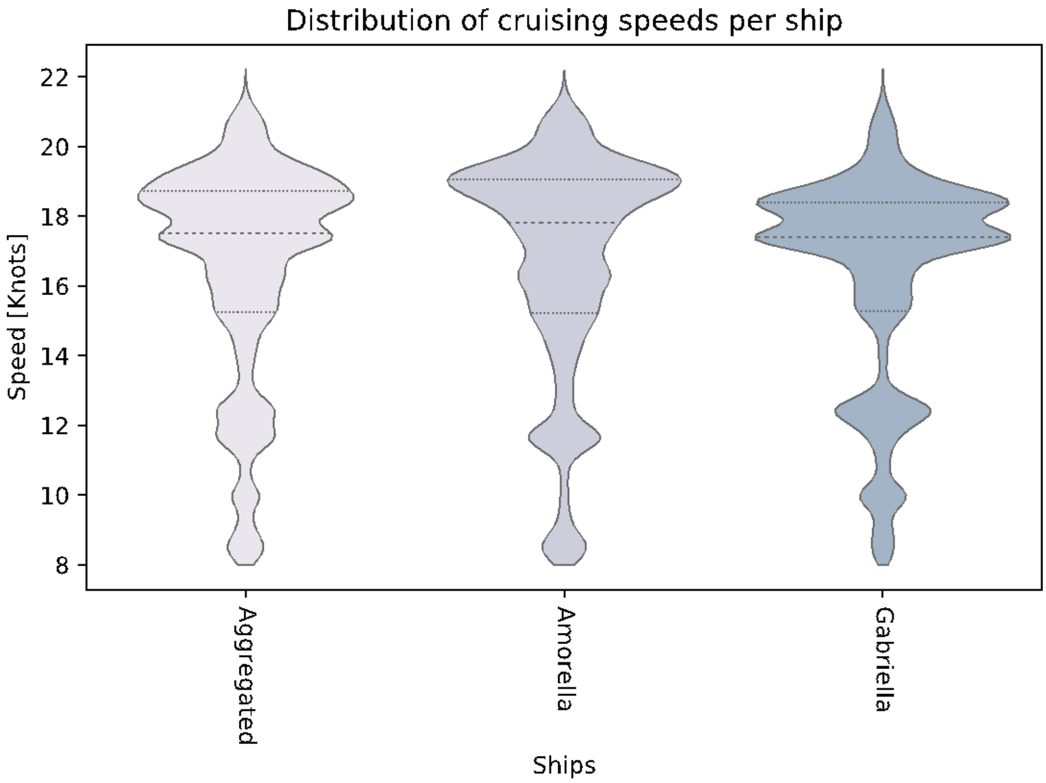


Figure 92: Aggregated distribution of cruising speeds for the ships in RPX3

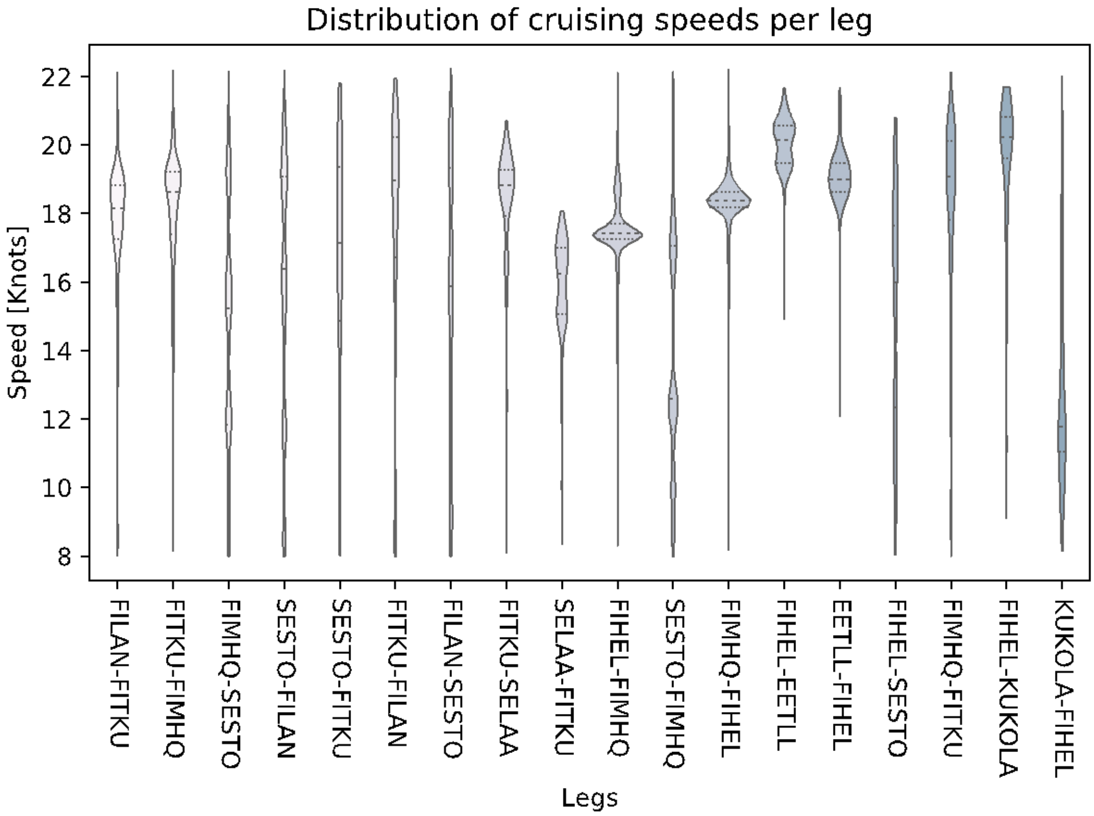


Figure 93: Aggregated distribution of cruising speeds per leg for the ships in RPX3

2. Punctuality

Figure 56 and Figure 57 show the distributions of the deviation between the Estimated Time of Arrival (ETA) reported at the beginning of a leg and its Actual Time of Arrival (ATA) by ship and by port. As in the other Ro-Pax cases, the data proved not to be reliable, with many incorrect values for the reported ETA. The reasons were similar, swapping day and month, not updating the ETA, etc. Again, all the data below 1 hour, both in early or late arrivals, is correct, larger delays or early arrivals are due to errors inputing the ETA. Similarly, in many cases the reported ETA seems to be more like the ETD from the destination port.

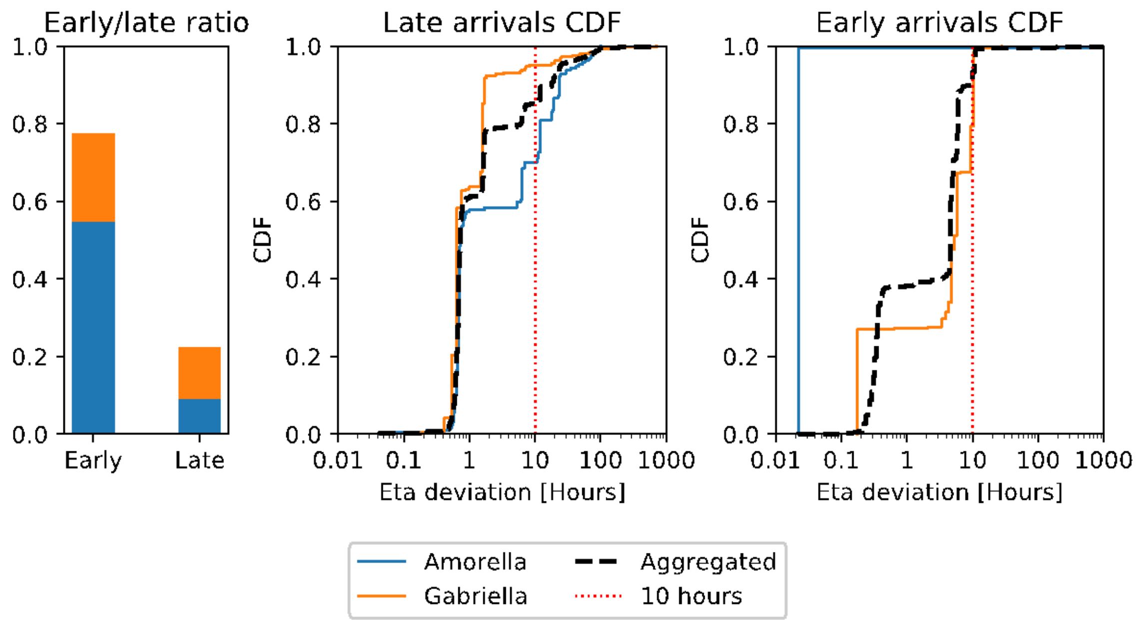


Figure 94: : distribution of ETA deviations per ship in RPX3

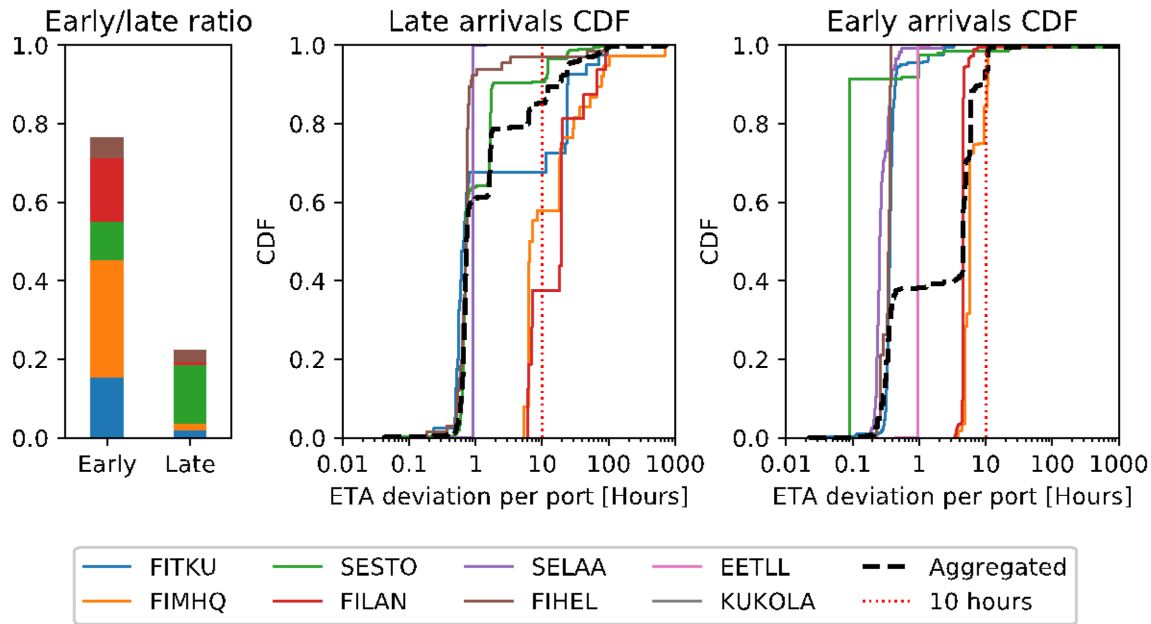


Figure 95: ETA deviations per port in RPX3

3. Anchoring Times

Similarly to the case of the RPX2 use case, the ships in RPX3 did not spend any time in anchoring, in line with what is expected from Ro-Pax and Pax ships.

9.8.3.2 Environmental Sustainability

1. Navigation Times

Figure 59 shows the variation in navigation time for each scenario in RPX3. Scenario 1 is not exactly 0, as in RPX2, because in this case there are some occasional idle times. However, the impact is almost negligible. Interestingly, for Scenario 2, despite of reducing time at berths, given the large separation between the median speed and the first quartile, and that speeds in this scenario usually fall between these two values, there is barely any time saved. This is a direct consequence of the high variability of speeds shown in Figure 54 and Figure 55. Scenario 3 is affected in a similar way, but requiring more time than in Scenario 2. Scenario 3 Median and High, are able to reduce time.

The reader must bear in mind that these results are extremely conditioned by the poor performance in terms of speed variability of these vessels. With a more uniform distribution, all results for Scenario 3 should be shifted upwards.

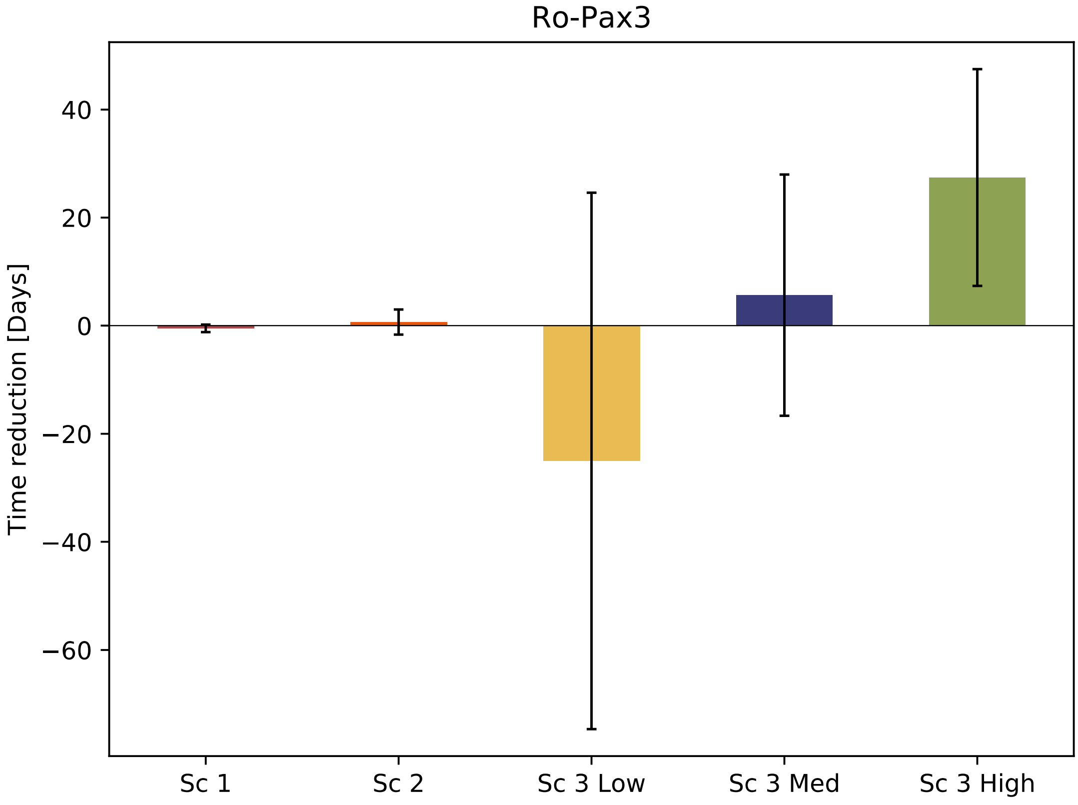


Figure 96: Variation in navigation time for each scenario in RPX3

2. Fuel Consumption

Figure 60 presents an estimation of the fuel consumption of the Amorella both for the real AIS data as for the proposed scenarios. The results for the different emissions are similar in terms of potential savings and slightly different for the Gabriella.

As seen for the other Ro-Pax cases, Scenario 3 Low and Scenario 2 achieve the best results. The difference between scenarios is more substantial in this case due to the large speed variability. In fact, this is not the case for the Gabriella, where its speed distribution is more concentrated around the median and the Scenario 3 Median obtain better results than the Scenario 2. Similarly, while Scenario 3 High is worse than the estimation for the real data for the Amorella, for the Gabriella Scenario 3 High is still better than it.

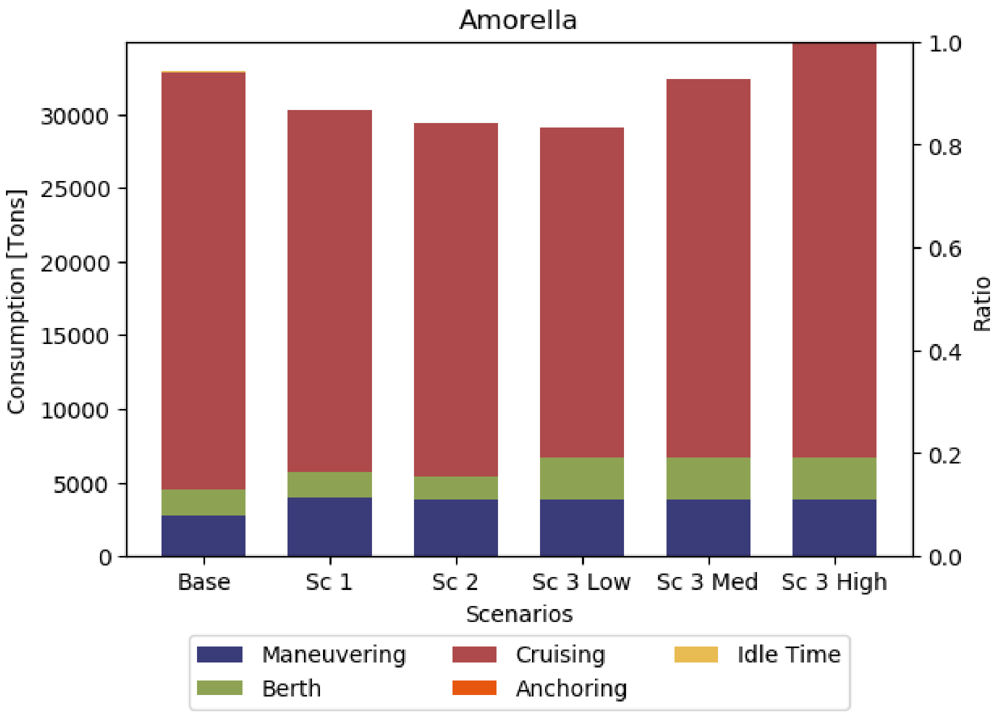


Figure 97: Fuel consumption of the VIKING AMORELLA in the current situation and for the different proposed scenarios divided by phases.

3. GHG Emissions

Figure 61 shows that the savings for the fuel consumption and emissions vary significantly between the Amorella and the Gabriella. This is mostly caused because of the shape of the distribution of cruising speeds in both ships. Although both distributions are quite wide, Gabriella's is relatively better, having a larger density of speeds close to the median, and this causes the differences between both ships.

In fact, it is worth noticing that the error bars for Scenario 3 High are quite long, caused by the Amorella obtaining a -6.2% of savings, i.e., consuming more than the real data estimation, and the Gabriella saving a 2.3% of fuel. The conclusion that can be extracted is that two ships are similar as the Gabriella and Amorella, that share most of their route should not have results that are this different. Again, STM can help here to improve the navigation of these vessels, reducing this variability and increasing their efficiency on navigation.

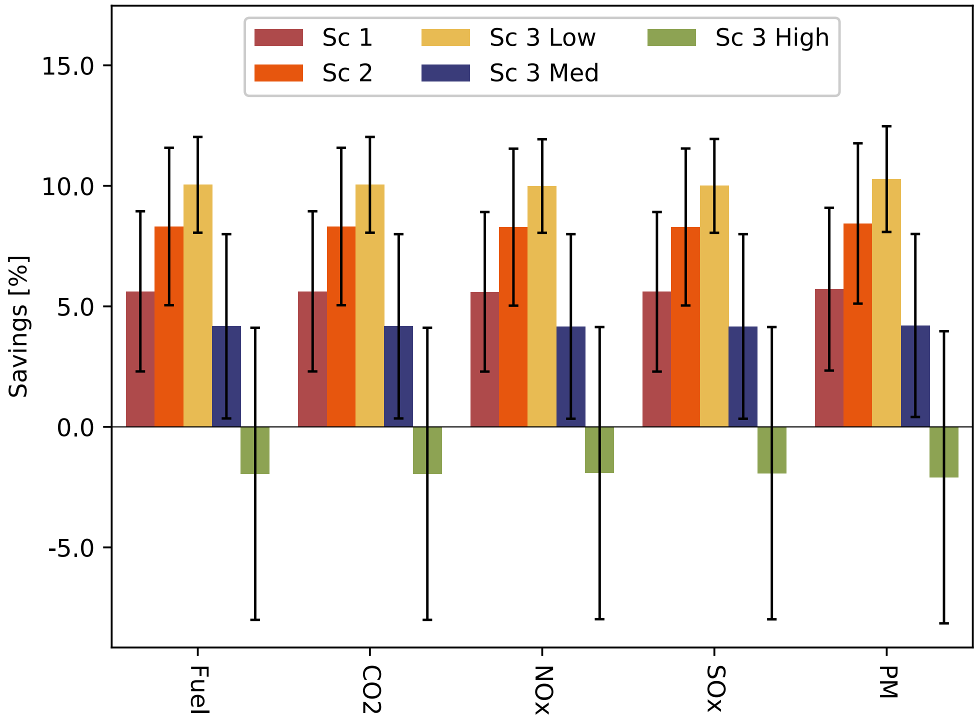


Figure 98: Mean values and deviations of the savings in fuel consumption and emissions for all the vessels in RPX3

9.8.4 Use Case Evaluation

Table 23 and Table 24 summarize the approximated total consumptions and emissions as well as the potential savings for each pollutant and STM scenario for the ships in RPX2. Table 8 presents the estimations on the real case, computed directly with the AIS data available for the two ships in the use case. On the other hand, Table 22 presents the potential savings that could be achieved for each pollutant and for fuel consumption for each ship and STM scenario and the aggregated results. The best achievable results appear shaded.

TONES	Fuel Consumption	CO2 Emissions	NOx Emissions	SOx Emissions	PM
VIKING AMORELLA	32,877.91	105,406.58	2,366.47	73.69	33.59
VIKING GABRIELLA	29,085.05	93,246.68	2,094.28	65.21	29.67

Table 23: Results of one year fuel consumption and GHG emissions

SHIP	Variable	Metric	SC 1	SC 2	SC 3 Low	SC 3 Med	SC 3 High
VIKING AMORELLA	Fuel	Ton	2,621.27	3,493.88	3,764.65	483.96	-2,048.47
		%	7.97%	10.63%	11.45%	1.47%	-6.23%
	CO2	Ton	8,403.78	11,201.36	12,069.47	1,551.57	-6,567.40
		%	7.97%	10.63%	11.45%	1.47%	-6.23%
	NOx	Ton	188	250.6	268.94	34.55	-146.69

		%	7.94%	10.59%	11.36%	1.46%	-6.20%
	SOx	Ton	5.86	7.81	8.38	1.08	-4.57
		%	7.95%	10.60%	11.38%	1.46%	-6.20%
	PM	Ton	2.72	3.63	3.97	0.51	-2.14
		%	8.10%	10.79%	11.83%	1.52%	-6.37%
VIKING GABRIELLA	Fuel	Ton	952.46	1,746.67	2,512.90	2,000.44	680.53
		%	3.27%	6.01%	8.64%	6.88%	2.34%
	CO2	Ton	3,053.59	5,599.81	8,056.36	6,413.40	2,181.78
		%	3.27%	6.01%	8.64%	6.88%	2.34%
	NOx	Ton	68.35	125.38	180.52	143.98	49.67
		%	3.26%	5.99%	8.62%	6.87%	2.37%
	SOx	Ton	2.13	3.91	5.62	4.48	1.54
		%	3.27%	5.99%	8.62%	6.88%	2.37%
	PM	Ton	0.99	1.81	2.59	2.04	0.65
		%	3.32%	6.09%	8.73%	6.89%	2.20%
AGGREGATED	Fuel	Ton	3573.73	5240.54	6277.55	2484.39	-1367.94
		%	5.62%	8.32%	10.05%	4.17%	-1.95%
	CO2	Ton	11457.37	16801.18	20125.83	7964.97	-4385.62
		%	5.62%	8.32%	10.05%	4.17%	-1.95%
	NOx	Ton	256.34	375.98	449.46	178.53	-97.01
		%	5.60%	8.29%	9.99%	4.17%	-1.91%
	SOx	Ton	7.99	11.71	14.01	5.56	-3.03
		%	5.61%	8.29%	10.00%	4.17%	-1.92%
	PM	Ton	3.71	5.43	6.56	2.56	-1.49
		%	5.71%	8.44%	10.28%	4.21%	-2.09%

Table 24: Savings in tones and percentages in fuel and the different pollutants in the different scenarios.

9.9 Ro-Pax Use Case Comparison

As analized in the previous pages, in most cases, the use of STM would facilitate the reduction of fuel consumption, and of GHG pollutant emissions, leading to a decrease in costs for shipping companies and ship operators.

However, the savings that can be achieved are not the same in all cases, as was shown in this document. Figure 27 puts together the fuel consumption results for all 3 Ro-Pax cases for the Scenario 3 Low and Median. The upper part of the figures relates the total consumption (X axis) to the potential savings (Y axis). The lower part relates the potential savings (X axis) to the time reduction (Y axis).

The first thing to notice is that the ships in RPX1 and RPX2 are similar in their total consumptions, as they cover the same route and are similar ships. These similarities are relatively maintained in the potential savings, and time variation, from the point of view that they remain positive for both use cases.

This is not the case for the Amorella and the Gabriella. Although we already mention that their routes are slightly different, the results that can be achieved for them, specially in the Scenario 3 Median, are completely different. Despite of the routes, the most influent factor, from our point of view, are their speed distributions, as their behaviour is, in general, worse than that of the ships in RPX1 and RPX2.

Finally, although Ro-Pax traffic does not have idle times or does not go to anchoring as frequently as other traffics, like containerships, the potential savings are still relevant. Taking

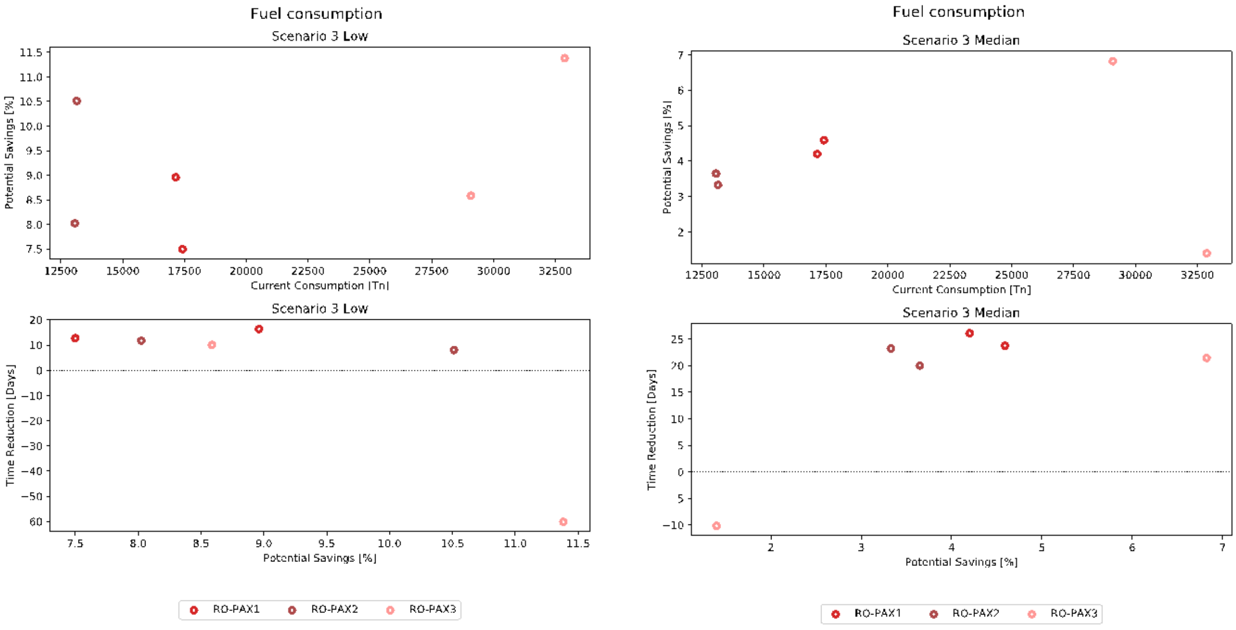


Figure 99

as reference the RPX1 and RPX2 cases, savings between a 3-4% from the Scenario 3 Median and the 8—10% from Scenario 3 Low speed (bearing in mind that Scenario 2 is in between as well) should be feasible studying the speed and frequency of the ships. Specially of those that have long stays at berth, like the Stena Germanica or Stena Scandinavica.

9.10 Use Case RO1

9.10.1 Abstract

Ro-Ro traffic is included in wheeled cargo traffic and mainly focuses on the movement of goods by truck on board a ship. This type of traffic takes place mainly on Short Sea Shipping lines, where trade takes place between nearby countries, solving geographical barriers.

One of the characteristics is that this traffic promotes intermodality because it proposes the shift mode automatically. Sometimes the goods travel without a cab and it is in the port of arrival where the management of the trailer using platforms takes place.

The used unit is the lane metre (unit of volume) and they are usually very regular and very frequency traffics in which the time of stay at the port is short. In some infrastructures in Northern Europe, loading and unloading solutions in decks at different heights have been promoted using link-spans.

The frequency is fortnightly. The goods accepted for shipment are all types of self-propelled vehicles, containers and any general dry cargo on Tug Master. The route covers more than six ports in three countries, namely Spain, Germany and Finland, with small-capacity ships, which are BALTIC BRIGHT, POLARIS VG and LINK STAR.

9.10.2 Use Case Data

The data used to analyse the use cases is divided into two sets. On the one hand, static data related to the characteristics of each of the ships, like those shown in Table 4 or other derived from it, that are captured in their configuration file. On the other hand, AIS navigation data from the period comprehended between June 1st 2017 and May 31st 2018, that shows real location, time and speed data from the routes they covered. Altogether, these data are used to compute the fuel consumption and emissions of the ships in the use cases.

SHIP	IMO No.	GT	FLAG	YEAR OF BUILD	SIZE (L/ B/ D) in metres	CAPACITY (Lane metres)	MAIN ENGINE POWER (kW)	AUX. ENGINE POWER (kW)	BOILER
BALTIC BRIGHT	9129263	9,708	SE	1996	134 x 20 x 6	830	5,280	N/A	N/A
POLARIS VG	8716100	7,944	FI	1988	124 x 20 x 6	540	5,100	650	N/A
LINK STAR	8805602	5,627	FI	1989	107 x 17 x 6	375	2,960	350	N/A

Table 25: RO1 Ships Characteristics

9.10.3 Use Case Analysis

Figure 35 displays the itinerary covered by the ships in use case RO1. During the voyage, the ships shift through different phases: berth, manoeuvring, anchoring and cruising. The phases of berth, manoeuvring and cruising are part of the natural flow of the voyage. However, the anchoring phase is usually the result of an inefficient port call synchronization between ships and ports. Similarly, Idle Time can be the result of events that force the ship to reduce its speed or stop while navigating, being possible to tag it, as well, as an inefficiency.

Figure 100: RO1 Use Case itinerary

During the voyage, there can be events that can have an effect in the navigational efficiency of the ships and the shipping service. There might be unnecessary variations of speeds due to several reasons: changes in the availability of arrival port resources, crossing a strait or canal, traffic restrictions or congestion. These avoidable speed variations and other causes can result in extra costs.

9.10.3.1 Efficiency

In order to provide an intuition about the mentioned inefficiencies we analyse the speed variation of the set of ships while cruising, their punctuality, their navigation and anchoring times.

1. ***Speed Variation***

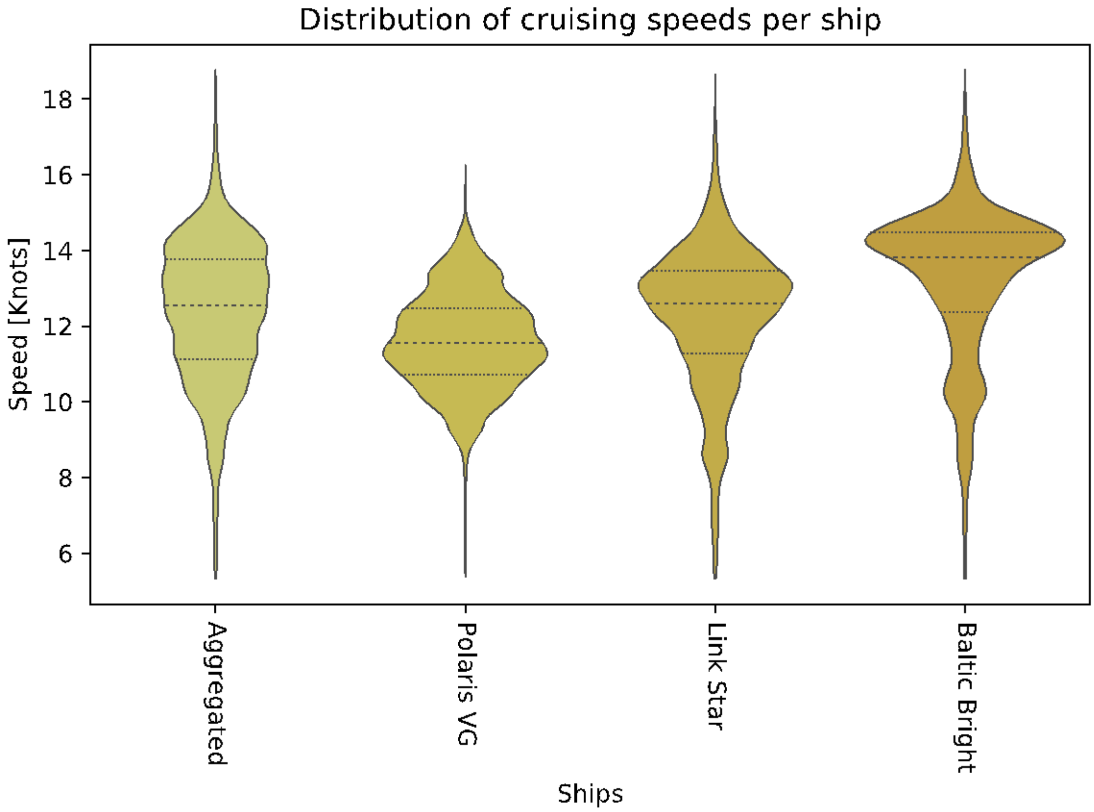


Figure 101: Aggregated distribution of cruising speeds for the ships in RO1

As we observe in Figure 36, the distribution of cruising speeds in the case of this shipping service has a relevant frequency of cruising speeds is different for the three ships which are between 10 and 15 knots. BALTIC BRIGHT variability in speed during navigation is relatively low; around 2 knots but there are some speeds in the range of 10 knots. LINK STAR variability in speed during navigation is high, around 4 knots in total. The speed range is changing during the year between 10 and 14 knots. Finally, POLARIS VG variability in speed during navigation is similar to LINK STAR but in a range lower. The median speed for this ship is 12 knots but the variability is around a range of 6 knots. The three ships have not similar distributions, implying high variability in their speed during navigation.

When it comes to distribution of cruising speeds per leg, the picture differs. In Figure 37 some inefficient legs are observed. In some of them, the navigation through Kiel Canal is involved, with bimodal distributions in the cruising speeds that could be explained as the canal passage particularities, related to traffic congestion and waiting times. However, some legs showing inefficiencies are glimpsed that may also be related to port access or other inefficiencies, for instance the leg between Santander and Rauma, and the return leg between Pietarsaari and Emden in the Baltic Sea. In these areas, some geographical obstacles could lead to this bimodality (access to the Bremerhaven canal access or the intensive shipping traffic in this area).

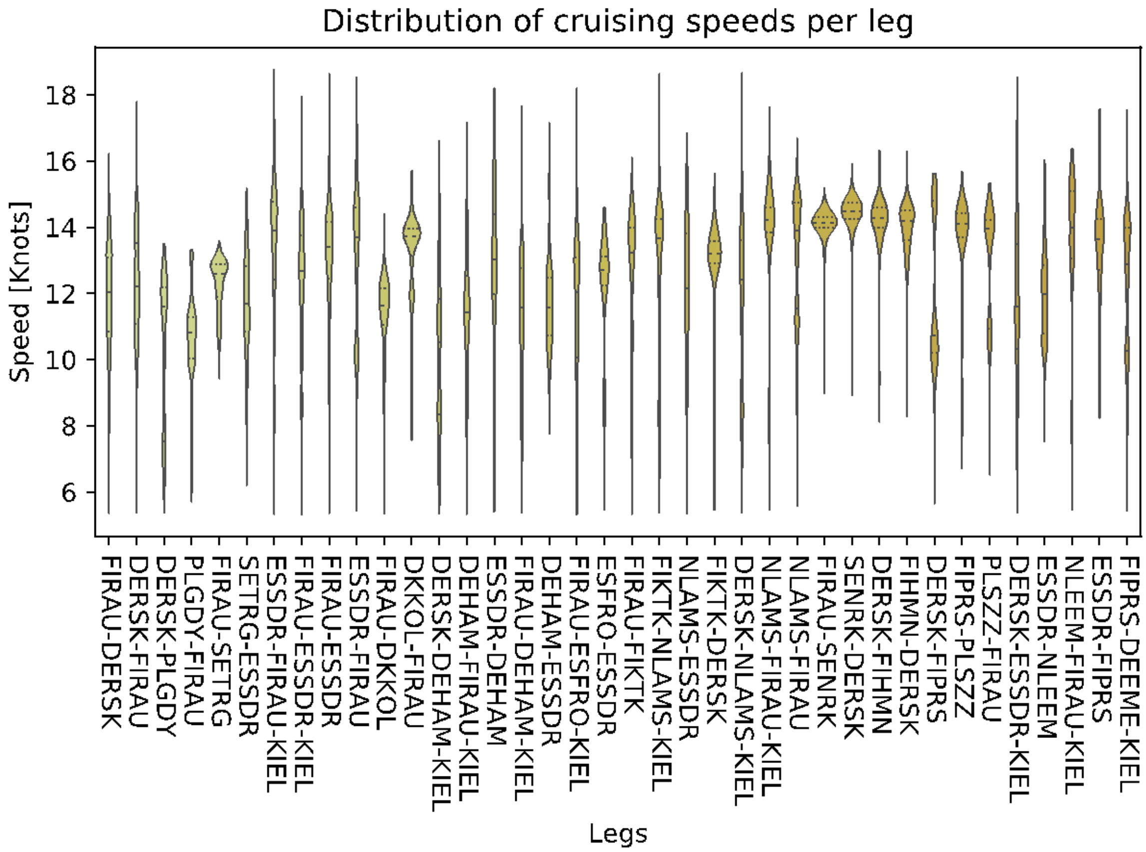


Figure 102: Aggregated distribution of cruising speeds per leg for the ships in RO1

2. *Punctuality*

One of the indicators of a shipping service in terms of efficiency is punctuality. Figure 38 and Figure 39 show the distributions of the deviation between the Estimated Time of Arrival (ETA) reported at the beginning of a leg and its Actual Time of Arrival (ATA), in order to capture, also, its capacity to provide accurate ETAs in advance.

In Figure 38, we can observe that more than the 75% of the times, the ships in this service will arrive later than reported. Moreover, the CDFs (Cumulative distribution function) show that, when late, the difference between ETA and ATA is larger than 10 hours a 35% of the time. For early arrivals, roughly a 90% of the cases were within these 10 hours range. The ratio of early calls is more than 60% and the late calls the 40%.

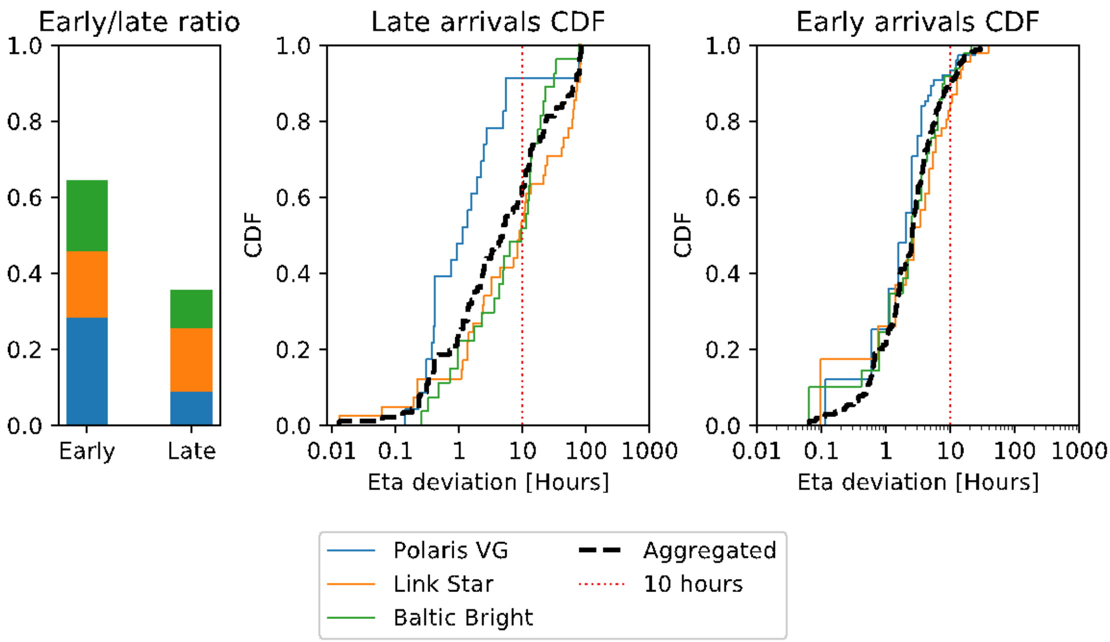


Figure 103: Distribution of ETA deviations per ship in RO1

Conversely, in Figure 39, we observe that the punctuality behaviour changes when it comes to ports. It seems that it is easier to predict the arrival time to some ports like Santander, Kotka and Rostock, where the deviations is below 2 hours a 40% of the time or more. They coincide with the starting/finish point of the roundtrip. For Moreover, the 30% of the times, the delay result in more than 10 hours. However, more than 90% of the times the early arrival is less than 10 hours.

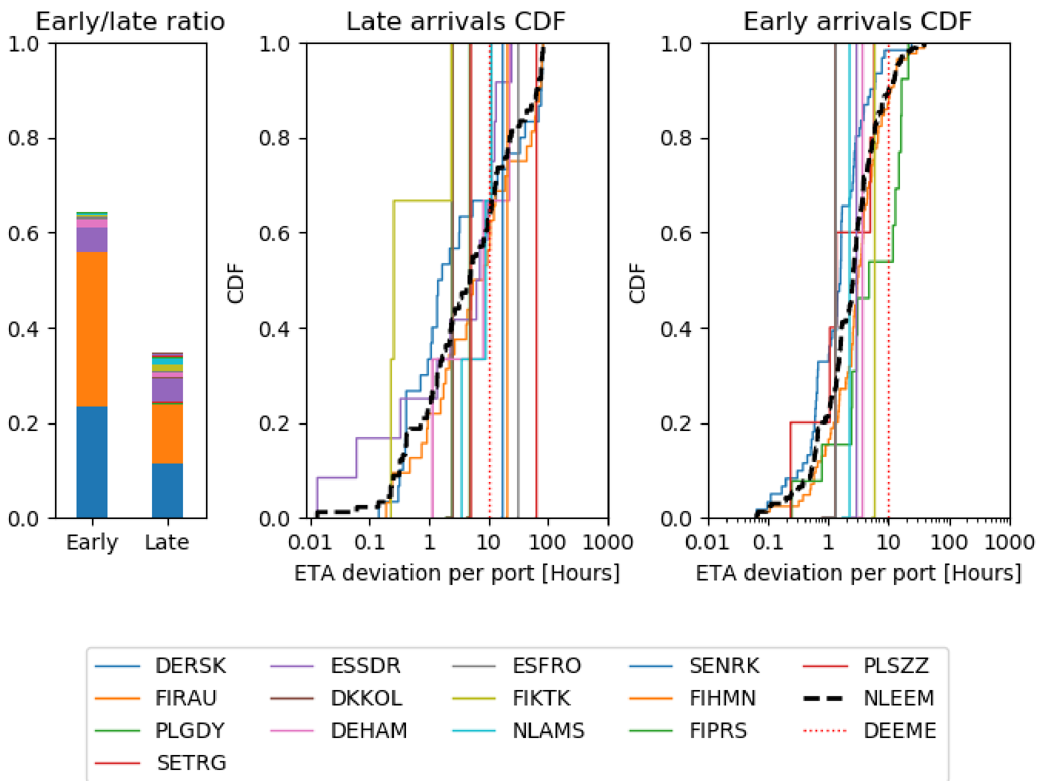


Figure 104: ETA deviations per port in RO1

3. ***Anchoring Times***

Figure 40 presents the results related to anchoring times per port for RO1. Concerning the anchoring time per port, we observe that this service does not have anchoring times because only the 1% the ships arrive late and less than 18 hours in the worst scenario (annual aggregated anchoring time), that is Rostock, Germany.

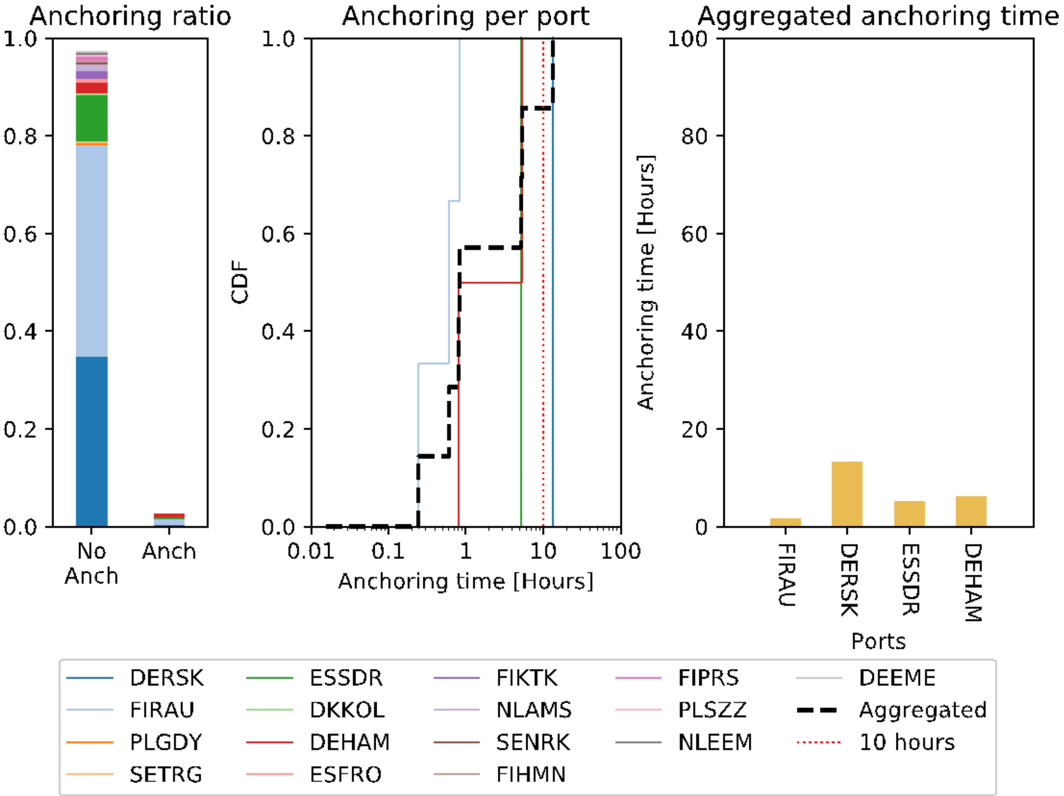


Figure 105: Anchoring times by port in RO1

In this case, STM could not help to eliminate these timeframes of idleness by improving the communication ship-to-port and enabling the ports to improve their resource management because the anchoring time is residual.

9.10.3.2 Environmental Sustainability

Concerning environmental sustainability, this section presents an analysis of the navigation times, the fuel consumption and the different emissions in the current situation and shows the potential savings that the different proposed scenarios may introduce with STM implementation.

1. ***Navigation Times***

Each of the scenarios will have, besides the impact on the fuel consumption and GHG (Greenhouse Gases) emissions, an impact on the navigation time and the shipping lines must take into account how this is reflected in the time a ship needs to cover its route. Figure 41 shows an example of this effect.

In general, lower speeds result in lower fuel consumption and emissions, but also longer navigation times. In Figure 41 we see that the average annual savings achieved in Scenario 3 carry out a reduction in the itinerary of around 26 days. This could have not an impact in the service configuration regarding the number of ships involved and the resources needed.

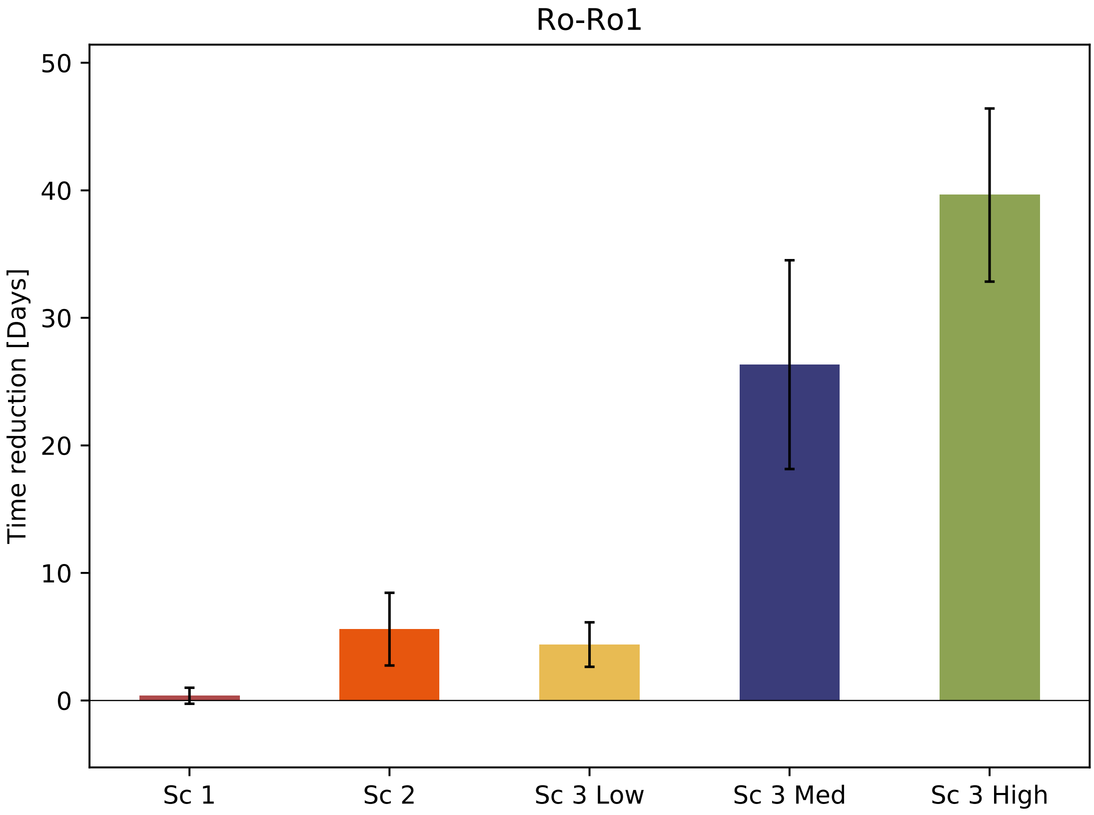


Figure 106: Variation in navigation time for each scenario in RO1

2. Fuel Consumption

Figure 42 presents an estimation of the fuel consumption of the BALTIC BRIGHT ship, both for the real AIS (Automatic Identification System) data as for the proposed scenarios. The other ships in RO1 presented similar results as well and they can be consulted in the ANNEXES.

As expected, cruising and berth are the dominating phases, where ships spend most of their time. In this case, the third scenario with the lowest median speed relates to the larger savings. This is due to a reduction on the speed variation and of the speed in general, as times spent in anchoring are used now to reduce the cruising speed.

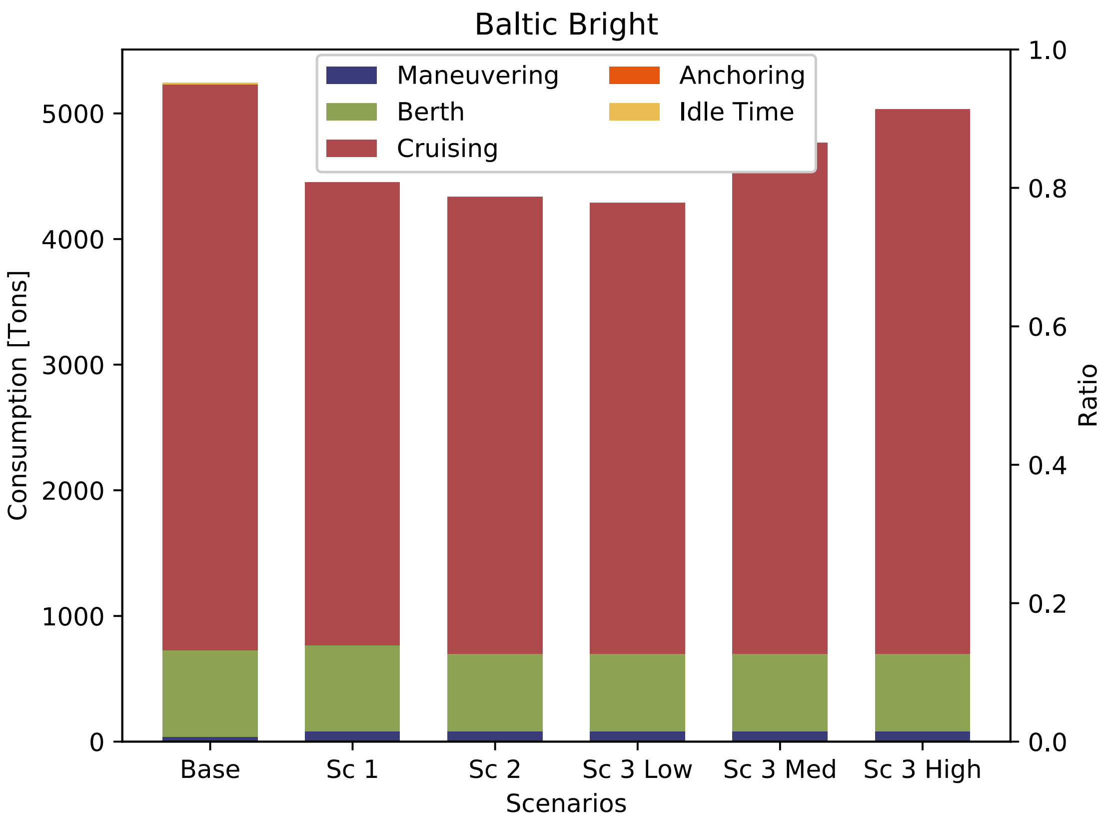


Figure 107: Fuel consumption of the BALTIC BRIGHT in the current situation and for the different proposed scenarios divided by phases.

3. GHG Emissions

Regarding GHG emissions, Figure 43 shows that both the savings for the consumption and emissions in each scenario as well as its variation are comparable. In addition, in the case of RO1, the results for the different ships are different, as implied by the extended length of the error bars. It can be observed that for Scenario 3 at low speed, which achieves the best results, the savings, both in consumption and in emissions, are roughly a 13-14% in average.

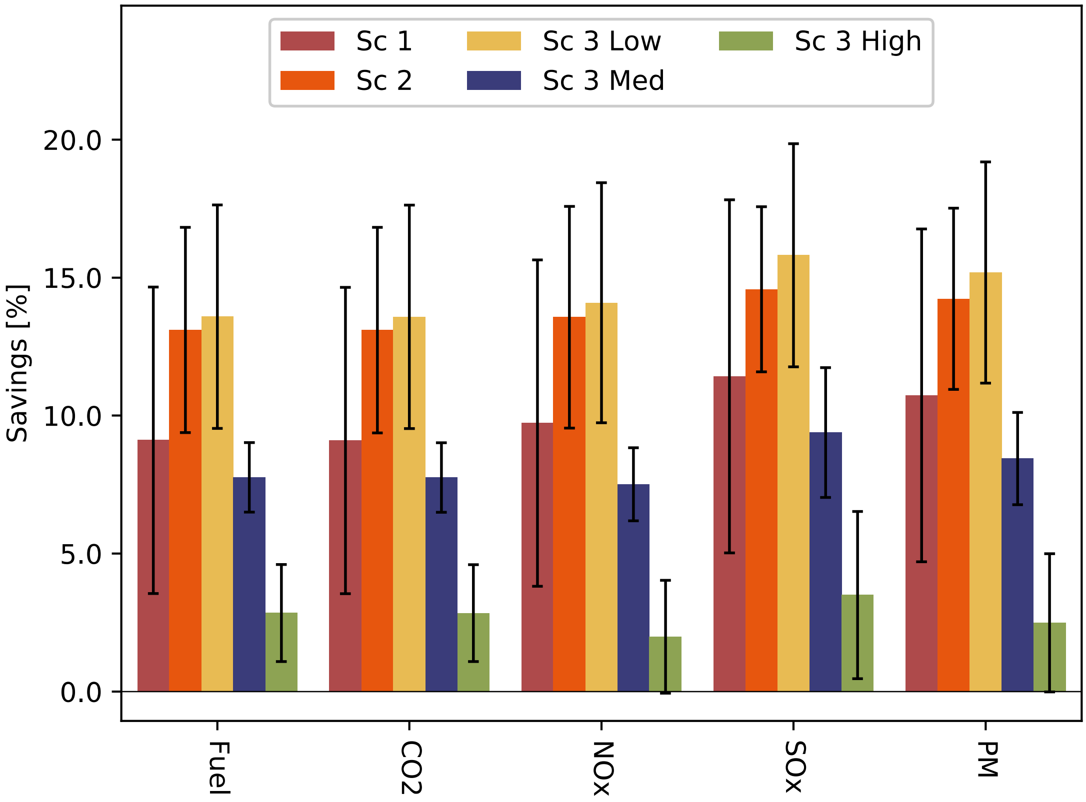


Figure 108: Mean values and deviations of the savings in fuel consumption and emissions for all the ships in RO1

9.10.4 Use Case Evaluation

In this section, the approximate savings of implementing the different scenarios of STM and the economic impact that this could have on the shipping companies' costs are shown.

Tons	Fuel Consumption	CO_2 Emissions	NO_x Emissions	SO_x Emissions	PM
BALTIC BRIGHT	5,076.39	16,212.33	345.52	49.17	9.19
POLARIS VG	4,626.96	14,834.05	293.33	9.70	4.23
LINK STAR	3,191.02	10,199.84	196.15	23.23	4.65

Table 26: Results of one year fuel consumption and GHG emissions

In Table 5 we depict the results of one year fuel consumption and GHG emissions for the three ships. If we translate this information into US Dollars, using the price for the fuel, CO_2, NO_X, SO_X and PM we will be able to quantify the costs savings for shipping companies and the emissions savings in monetary figures.

SHIP	Variable	Metric	SC 1	SC 2	SC 3 Low	SC 3 Med	SC 3 High
BALTIC BRIGHT	Fuel	Tons	755.39	871.73	914.29	467.08	218.16
		%	14.88%	17.17%	18.01%	9.20%	4.30%
	CO_2	Tons	2,411.27	2,783.91	2,918.82	1,490.56	696.50
		%	14.87%	17.17%	18.00%	9.19%	4.30%
	NO_X	Tons	55.86	62.71	65.99	31.10	11.91
		%	16.17%	18.15%	19.10%	9.00%	3.45%

	SO_x	Tons	8.23	8.73	9.79	5.10	1.92
		%	16.74%	17.75%	19.92%	10.38%	3.91%
	PM	Tons	1.52	1.65	1.81	0.89	0.32
		%	16.58%	18.01%	19.71%	9.70%	3.47%
POLARIS VG	Fuel	Tons	191.40	524.70	525.68	310.68	38.45
		%	4.14%	11.34%	11.36%	6.71%	0.83%
	CO_2	Tons	613.62	1,682.18	1,685.33	996.04	123.28
		%	4.14%	11.34%	11.36%	6.71%	0.83%
	NO_x	Tons	13.32	34.84	34.91	18.95	-1.04
		%	4.54%	11.88%	11.90%	6.46%	-0.35%
	SO_x	Tons	0.42	1.15	1.15	0.65	0.03
		%	4.32%	11.81%	11.83%	6.70%	0.28%
	PM	Tons	0.19	0.51	0.51	0.28	-0.02
		%	4.54%	12.06%	12.08%	6.55%	-0.36%
LINK STAR	Fuel	Tons	257.97	337.90	355.40	236.57	115.27
		%	8.08%	10.59%	11.14%	7.41%	3.61%
	CO_2	Tons	822.44	1,078.58	1,134.12	754.62	367.29
		%	8.06%	10.57%	11.12%	7.40%	3.60%
	NO_x	Tons	16.63	20.92	22.09	13.87	5.61
		%	8.48%	10.66%	11.26%	7.07%	2.86%
	SO_x	Tons	3.07	3.29	3.64	2.57	1.46
		%	13.21%	14.18%	15.68%	11.08%	6.30%
	PM	Tons	0.52	0.59	0.64	0.42	0.20
		%	11.08%	12.62%	13.76%	9.09%	4.36%
AGGREGATED	Fuel	Tons	1,204.75	1,734.33	1,795.37	1,014.32	371.88
		%	9.03%	13.03%	13.50%	7.78%	2.91%
	CO_2	Tons	3,847.33	5,544.66	5,738.27	3,241.22	1,187.06
		%	9.02%	13.03%	13.49%	7.77%	2.91%
	NO_x	Tons	85.81	118.47	123.00	63.92	16.48
		%	9.73%	13.56%	14.09%	7.51%	1.98%
	SO_x	Tons	11.72	13.17	14.58	8.33	3.41
		%	11.42%	14.58%	15.81%	9.39%	3.50%
	PM	Tons	2.23	2.75	2.96	1.59	0.51
		%	10.73%	14.23%	15.18%	8.45%	2.49%

Table 27: Estimated savings for one year in fuel consumption and GHG emissions for the different scenarios

9.11 Use Case RO2

9.11.1 Abstract

The RO2 use case involves larger ships than the previous one. There are three ships connecting Swedish ports with the Netherlands and the UK. The frequency is weekly and uses three sister ships which are SCA OBBOLA, SCA OSTRAND and SCA ORTVIKEN. These ships are specialised in handling forest products in the Baltic and North Sea and are calling at the PortCDM port of Umea.

The company is SCA and produces packaging paper for consumer and transport packaging, largely based on fresh wood fibre.

9.11.2 Use Case Data

SHIP	IMO No.	GT	FLAG	YEAR OF BUILD	SIZE (L/ B/ D) in metres	CAPACITY (Lane metres)	MAIN ENGINE POWER (kW)	AUX. ENGINE POWER (kW)	BOILER
SCA OBBOLA	9087350	20,186	SE	1996	170 x 23 x 7	1,900	9,000	1,220	N/A
SCA OSTRAND	9087362	20,171	SE	1996	170 x 23 x 7	1,900	9,002	1,220	N/A
SCA ORTVIKEN	9087374	20,154	SE	1996	170 x 23 x 7	1,900	9,000	1,220	N/A

Table 28: RO2 Ship Characteristics

9.11.3 Use Case Analysis

Figure 44 displays the itinerary covered by the ships in Use Case RO2. During the voyage, the ships shift through different phases: berth, manoeuvring, anchoring and cruising. The phases of berth, manoeuvring and cruising are part of the natural flow of the voyage. However, the anchoring phase is usually the result from an inefficient port call synchronization between ships and ports. Similarly, Idle Time can be the result of events that force the ship to reduce its speed or stop while navigating, being possible to tag it, as well, as an inefficiency.

Figure 109: RO2 Use Case itinerary.

During the voyage, there can be events that can have an effect in the efficiency of the ships and the shipping service. There might be unnecessary variations of speeds due to several reasons: changes in the availability of arrival port resources, crossing a strait or canal, traffic restrictions or congestion. These avoidable speed variations will result in extra costs.

9.11.3.1 Efficiency

In order to provide an intuition about the mentioned inefficiencies we analyse the speed variation of the set of ships while cruising, their punctuality and their navigating and anchoring times.

1. ***Speed Variation***

Figure 45 depicts the distribution of cruising speeds by ship and the aggregated one. We can observe that the distribution of speeds is relatively narrow. The median speed for the three ships is the same and during the most part of the legs, 14 knots. The distribution of speeds for the three ships is similar between 13 and 15 knots. The speed is almost constant.

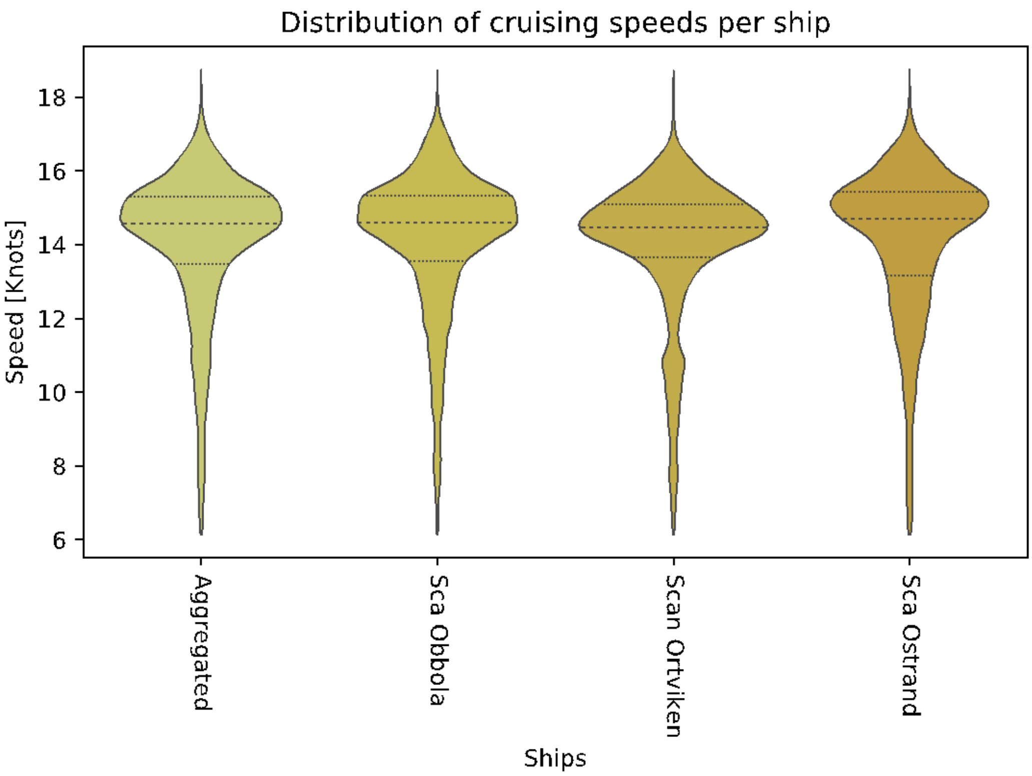


Figure 110: Aggregated distribution of cruising speeds for the ships in RO2.

However, this non-uniformity is also captured in Figure 46. First, it can be observed that different legs are navigated at very different speeds. There are legs whose median speed is above 14 knots while others are below 8 knots. Second, the distribution of speeds in the same leg is also wide or in some cases bimodal (as in the case of Sundsvall–Holmsund or Sundsvall-Iggesund), implying again a large variability.

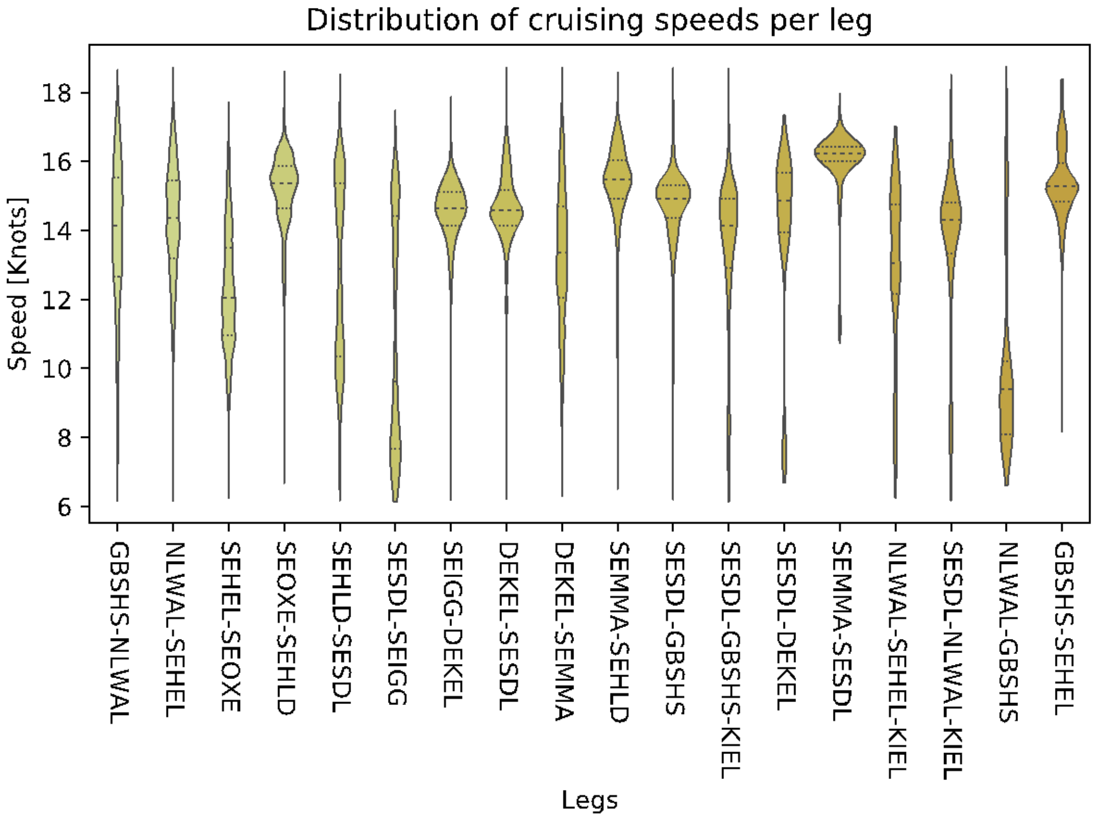


Figure 111: Aggregated distribution of cruising speeds per leg for the ships in RO2.

There are multiple possible reasons for this variability. From planning issues, having short time between port calls in some legs that could cause the ship to speed up, to congestion in some areas or to having to wait in anchoring in some ports and catching up again in the following leg.

STM will facilitate a better resource planning in ports that will allow ships to keep a constant speed during their legs and may increase the time they apply slow steaming.

2. Punctuality

One of the indicators of a shipping service in terms of efficiency is punctuality. Figure 47 and Figure 48 show the distributions of the deviation between the Estimated Time of Arrival (ETA) reported at the beginning of a leg and its Actual Time of Arrival (ATA), in order to capture, also, its capacity to provide accurate ETAs in advance.

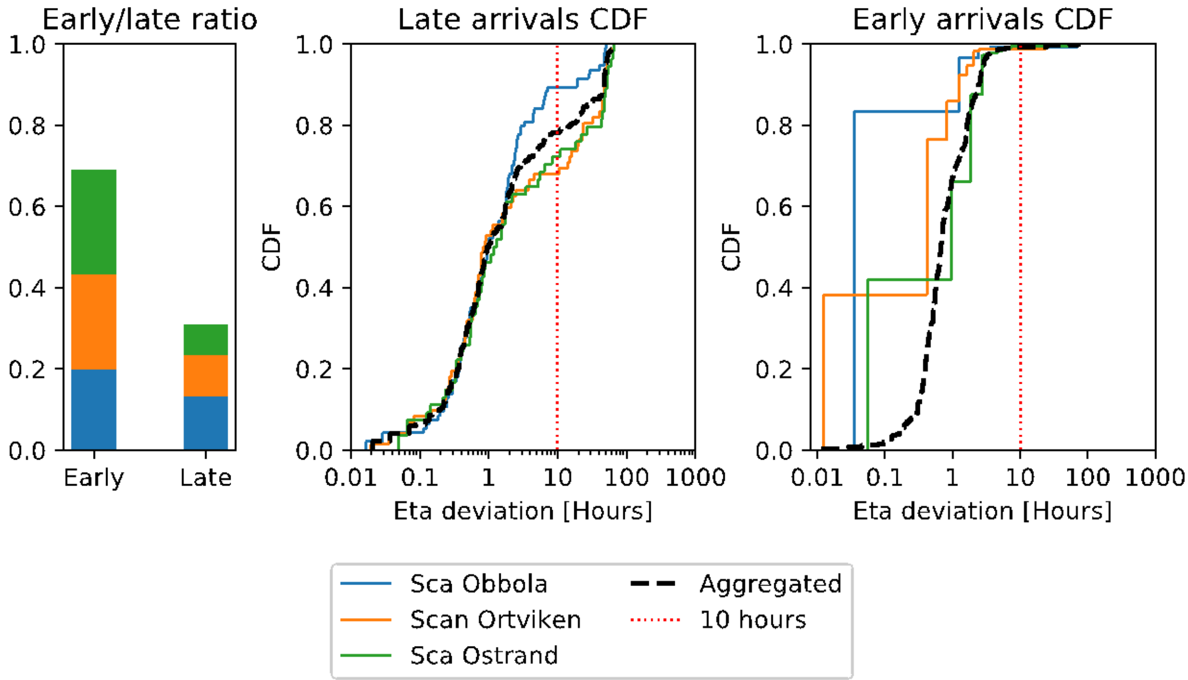


Figure 112: Distribution of ETA deviations per ship in RO2.

In Figure 47, we can observe that only a 30% of the times, for RO2, ships will arrive later than reported. Moreover, the CDFs show that, when late, the difference between ETA and ATA is larger than 10 hours in, approximately, a 25% of the time. For early arrivals, roughly a 100% of the cases were within these 10 hours range. Finally, we can see that the CDFs for each ship are similar, so it seems to be a common behaviour.

However, in Figure 48, we observe that the punctuality behaviour changes when it comes to ports. It seems that it is easier to predict the arrival time to some ports like Malmö, Helsingborg, Iggesund and Kiel, where the deviation is below 2 hours a 65% of the time or more. The 35% of the calls arrive late and this time is similar to all the ports.

Again, STM should be able to solve or minimize these issues thanks to the implementation of STM at ports that will eventually help to improve the resource management in ports, or enabling a better and earlier ship-to-port and port-to-port communication.

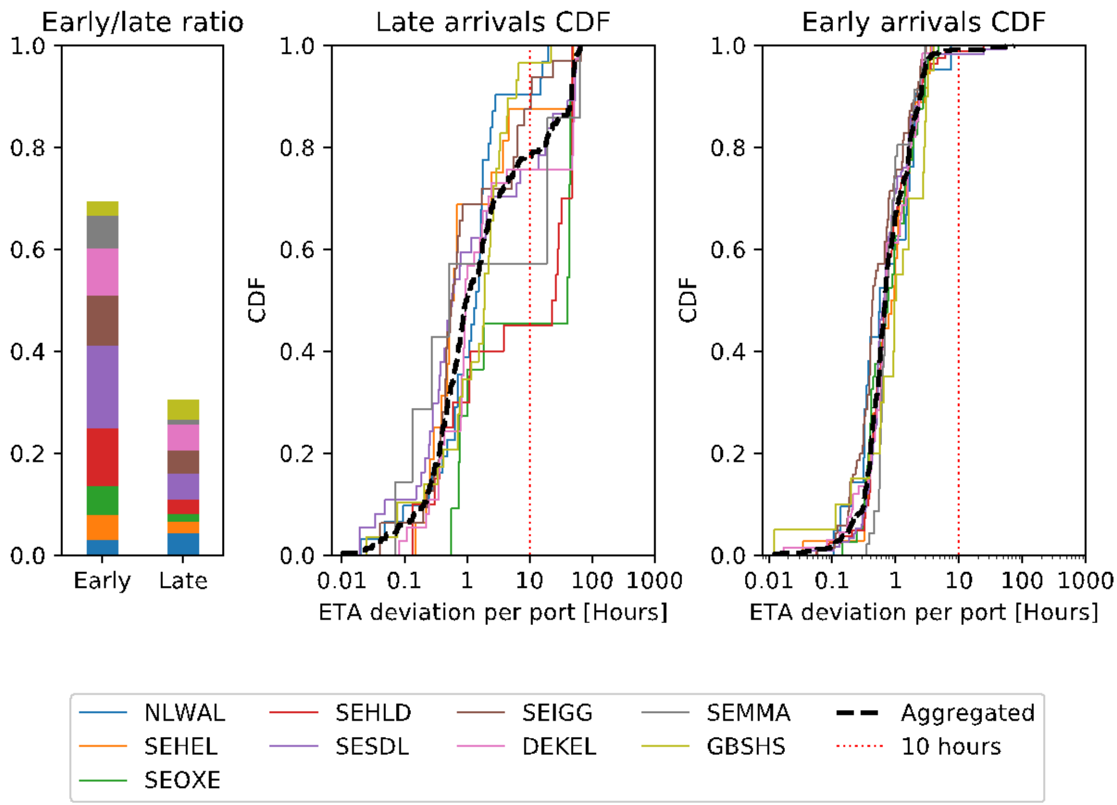


Figure 113: ETA deviations per port in RO2

3. Anchoring Times

Figure 49 presents the results related to anchoring for RO2. It is interesting to observe that only in one port call in Oxelosund has anchoring time. This service does not have room for improvement in the different scenarios. The ships enter the port avoiding anchoring areas maybe for the availability of the terminals. The company is SCA and moves forest cargo in dedicated terminals. That could mean these results.

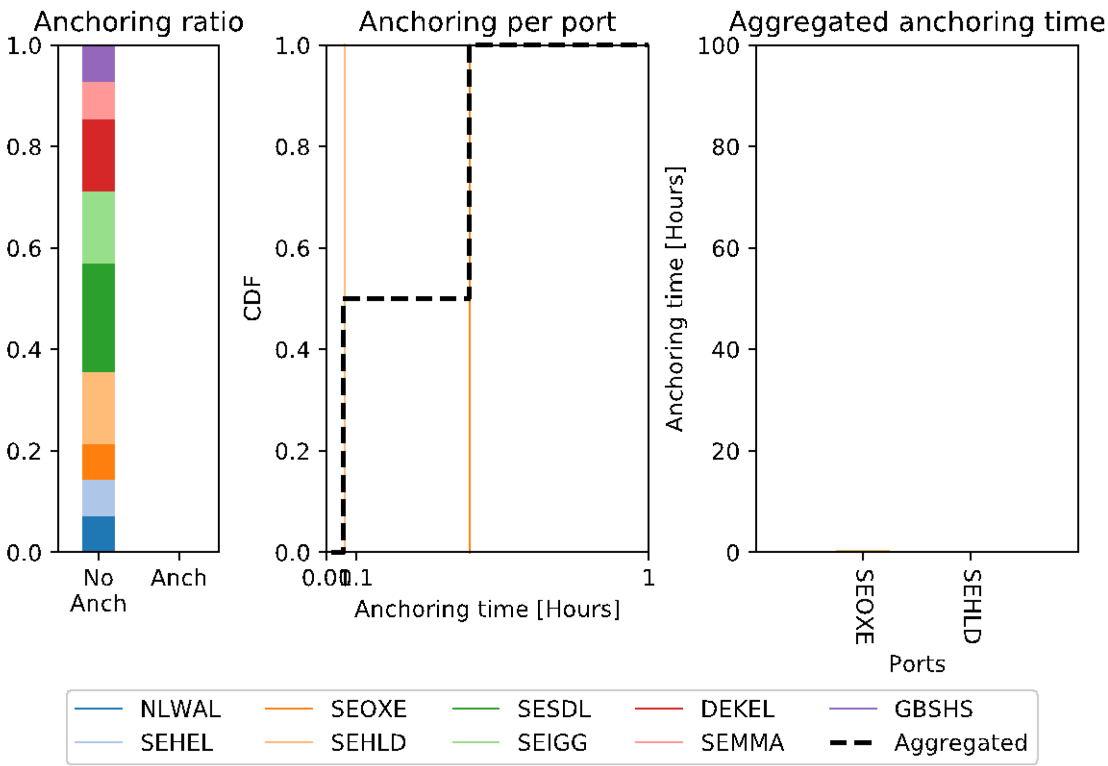


Figure 114: Anchoring times by port in RO2

9.11.3.2 Environmental Sustainability

1. Navigation Times

As we can see in Figure 50, each of the scenarios have an impact on the navigation time and this is essential information for shipping lines planning. Any scenario for RO2 provides a significant time reduction, only around 12 days of time, which would not change the planning of the service.

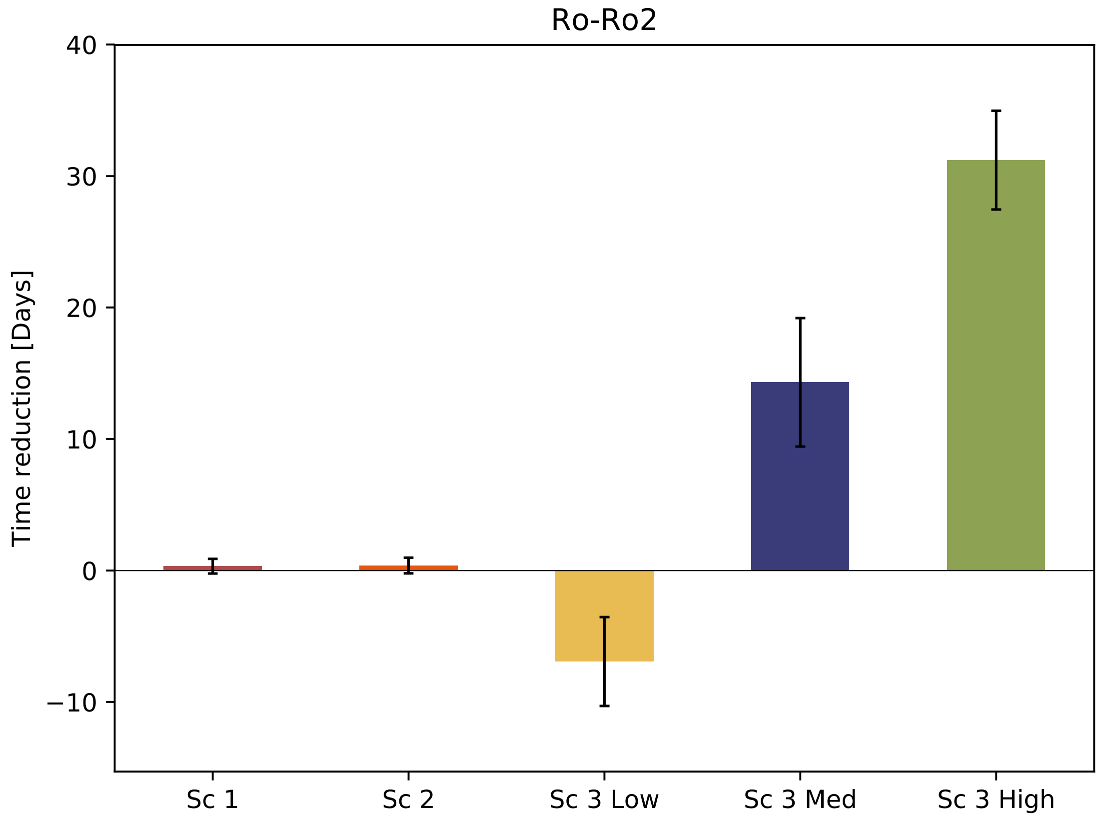


Figure 115: Variation in navigation time for each scenario in RO2

2. Fuel Consumption

Figure 51 presents an estimation of the fuel consumption of the SCA OBBOLA both for the real AIS data as for the proposed scenarios. It is worth mentioning that the figures for the different types of GHG emissions have a very similar aspect although for different magnitudes. Likewise, the other ships in RO2 presented similar results.

As expected, cruising and berth are the dominating phases, where ships spend most of their time. In the case of RO2, the first scenario already introduces savings. This is not only thanks to eliminating the anchoring an idle time, but also thanks to a better synchronization between port and ship, and also due to a reduction on the speed variation and of the speed in general, as times spent in anchoring are used now to reduce the cruising speed.

Scenario 2 introduces some additional savings, due to an improved efficiency and reduced times in berth. This is again slightly improved in Scenario 3 by enforcing the use of a lower cruising speed.

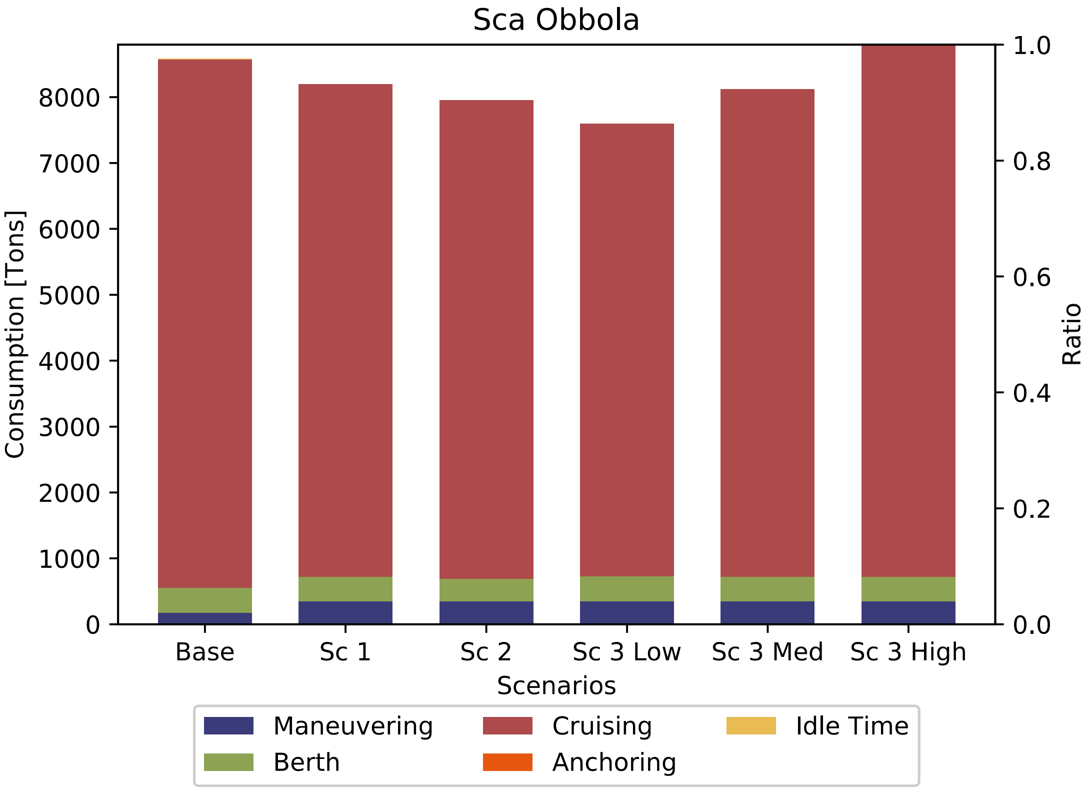


Figure 116: Fuel consumption of the SCA OBBOLA in the current situation and for the different proposed scenarios divided by phases.

3. GHG Emissions

Figure 52 shows that both the savings for the consumption and emissions in each scenario, as well as its variation are comparable. In addition, in the case of RO2, the results for the different ships are similar, as implied by the short length of the error bars. It can be observed that for Scenario 3 at low speed, which achieves the best results, the savings, both in consumption and in emissions, are roughly an 11% in average.

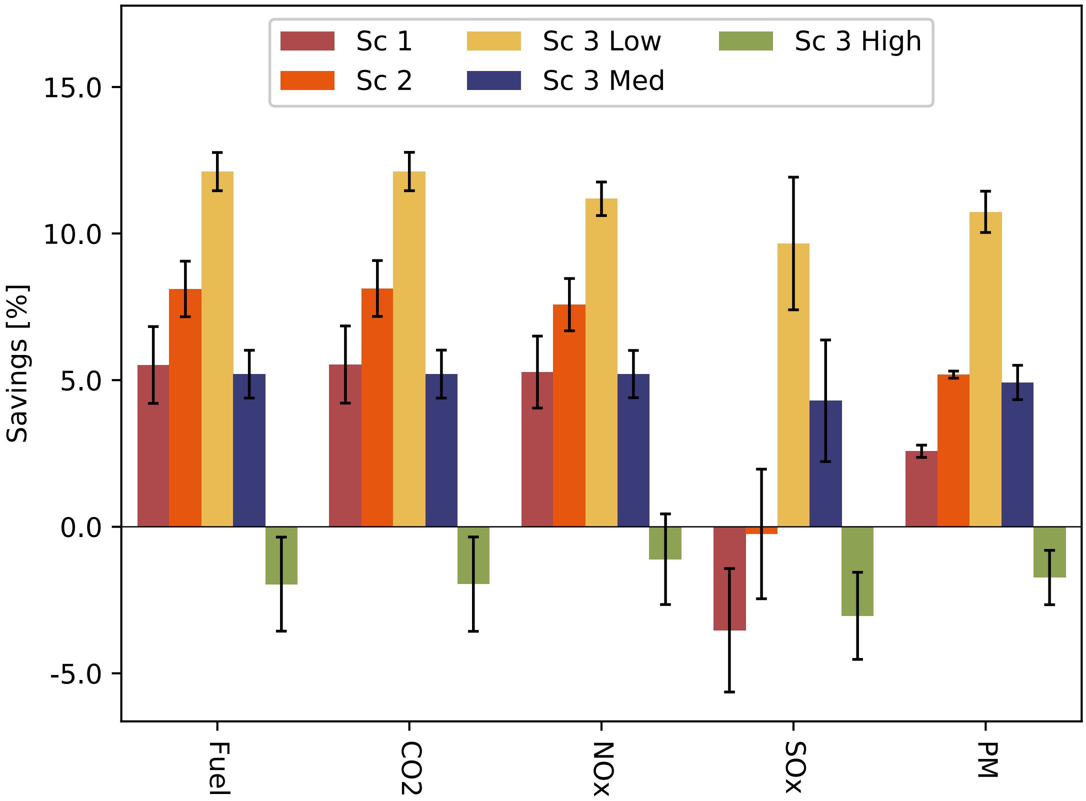


Figure 117: Mean values and deviations of the savings in fuel consumption and emissions for all the ships in RO2.

9.11.4 Use Case Evaluation

In this section, we show the approximate savings of implementing the different scenarios of STM and the economic impact that this could have on the shipping companies' costs.

Tons	Fuel Consumption	CO_2 Emissions	NO_x Emissions	SO_x Emissions	PM
SCA OBBOLA	8,580.25	27,498.94	621.63	25.54	9.54
SCA OSTRAND	8,590.32	27,531.47	622.74	25.48	9.55
SCA ORTVIKEN	8,486.32	27,197.36	616.58	25.72	9.50

Table 29: Results of one year fuel consumption and GHG emissions

In Table 29 we depict the results of one year fuel consumption and GHG emissions for the three ships. If we translate this information into US Dollars, using the price for the fuel, CO_2, NO_X, SO_X and PM we will be able to quantify the costs savings for shipping companies and express the emissions in monetary figures

SHIP	Variable	Metric	SC 1	SC 2	SC 3 Low	SC 3 Med	SC 3 High
SCA OBBOLA	Fuel	Tons	385.74	629.85	985.78	460.08	-215.88
		%	4.50%	7.34%	11.49%	5.36%	-2.52%
	CO_2	Tons	1,238.97	2,020.95	3,158.71	1,473.84	-692.00
		%	4.51%	7.35%	11.49%	5.36%	-2.52%
	NO_x	Tons	26.41	41.83	64.43	32.50	-9.41
		%	4.25%	6.73%	10.36%	5.23%	-1.51%
	SO_x	Tons	-0.51	0.31	2.83	1.60	-0.35
		%	-2.01%	1.22%	11.06%	6.26%	-1.39%
	PM	Tons	0.23	0.49	1.02	0.53	-0.16
		%	2.39%	5.14%	10.73%	5.55%	-1.62%
SCA OSTRAND	Fuel	Tons	435.28	675.99	1,099.58	373.58	-277.35
		%	5.07%	7.87%	12.80%	4.35%	-3.23%
	CO_2	Tons	1,398.31	2,169.31	3,524.08	1,197.11	-888.24
		%	5.08%	7.88%	12.80%	4.35%	-3.23%
	NO_x	Tons	29.54	44.72	71.46	27.32	-13.04
		%	4.74%	7.18%	11.48%	4.39%	-2.09%
	SO_x	Tons	-0.68	0.21	2.77	1.15	-0.88
		%	-2.65%	0.83%	10.87%	4.51%	-3.47%
	PM	Tons	0.24	0.51	1.09	0.42	-0.26
		%	2.53%	5.33%	11.45%	4.39%	-2.71%
SCA OTVIKEN	Fuel	Tons	596.06	781.82	1,038.61	510.66	-8.77
		%	7.02%	9.21%	12.24%	6.02%	-0.10%
	CO_2	Tons	1,915.61	2,510.31	3,329.68	1,637.71	-26.27
		%	7.04%	9.23%	12.24%	6.02%	-0.10%
	NO_x	Tons	40.24	51.81	68.40	36.82	4.85
		%	6.53%	8.40%	11.09%	5.97%	0.79%
	SO_x	Tons	-1.53	-0.72	1.81	0.55	-1.10

		%	-5.93%	-2.79%	7.05%	2.12%	-4.26%
	PM	Tons	0.27	0.49	0.95	0.46	-0.08
		%	2.80%	5.10%	10.04%	4.83%	-0.86%
AGGREGATED	Fuel	Tons	1,417.08	2,087.66	3,123.96	1,344.31	-502.00
		%	5.53%	8.14%	12.18%	5.24%	-1.95%
	CO_2	Tons	4,552.89	6,700.57	10,012.48	4,308.66	-1,606.51
		%	5.54%	8.15%	12.18%	5.24%	-1.95%
	NO_x	Tons	96.18	138.35	204.29	96.64	-17.60
		%	5.17%	7.44%	10.98%	5.20%	-0.94%
	SO_x	Tons	-2.71	-0.20	7.41	3.29	-2.33
		%	-3.53%	-0.25%	9.66%	4.30%	-3.04%
	PM	Tons	0.74	1.48	3.07	1.41	-0.50
		%	2.57%	5.19%	10.74%	4.92%	-1.73%

Table 30: Estimated savings for one year in fuel consumption and GHG emissions for the different scenarios

9.12 Use Case RO3

9.12.1 Abstract

The Bore Bank ship operates routes between Russia and Finland with Germany and the United Kingdom. This ship has similar characteristics to those of the previous use case but with the peculiarity that passes through the Kiel Canal. The frequency is fortnightly. This use case adds more information about the Ro-Ro traffic due to its importance in the EU Short Sea Shipping. This use case comprises only one STM ship.

9.12.2 Use Case Data

SHIP	IMO No.	GT	FLAG	YEAR OF BUILD	SIZE (L/ B/ D) in metres	CAPACITY (Lane metres)	MAIN ENGINE POWER (kW)	AUX. ENGINE POWER (kW)	BOILER
BORE BANK	9160774	10,585	FI	1998	138 x 23 x 7	616	14,480	640	N/A

Table 31: RO3 Ship Characteristics

9.12.3 Use Case Analysis

Figure 118 displays the itinerary covered by the ships in Use Case CS2. During the voyage, the ships shift through different phases: berth, manoeuvring, anchoring and cruising. the phases of berth, manoeuvring and cruising are part of the natural flow of the voyage. However, the anchoring phase is usually the result from an inefficient port call synchronization between ships and ports. Similarly, Idle Time can be the result of events that force the ship to reduce its speed or stop while navigating, being possible to tag it, as well, as an inefficiency.

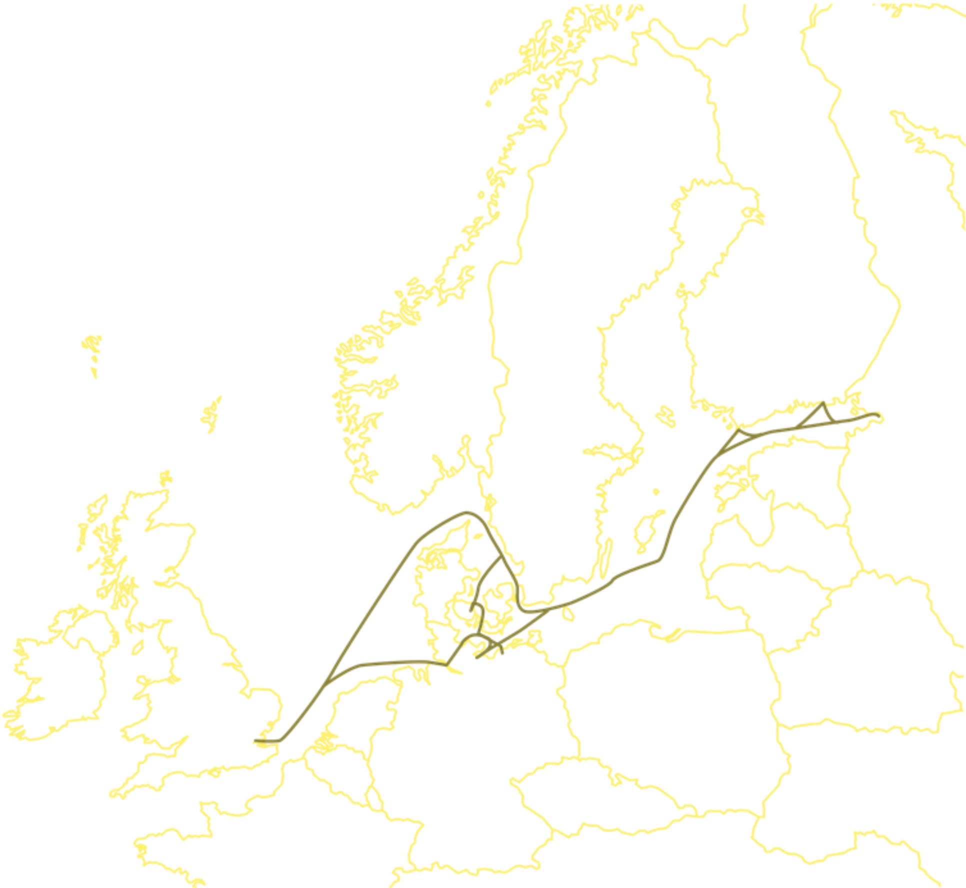


Figure 118: RO3 use case Itinerary

9.12.3.1 Efficiency

1. ***Speed Variation***

Figure 54 shows the distribution of cruising speeds of the BORE BANK. We can observe that the distribution of speeds is extremely wide. Not only the interquartile range spans 7 knots, between 14 and 21 knots approximately, but also they have bimodal distributions. Bore Bank has a wide distribution, implying high variability in her speed during navigation.

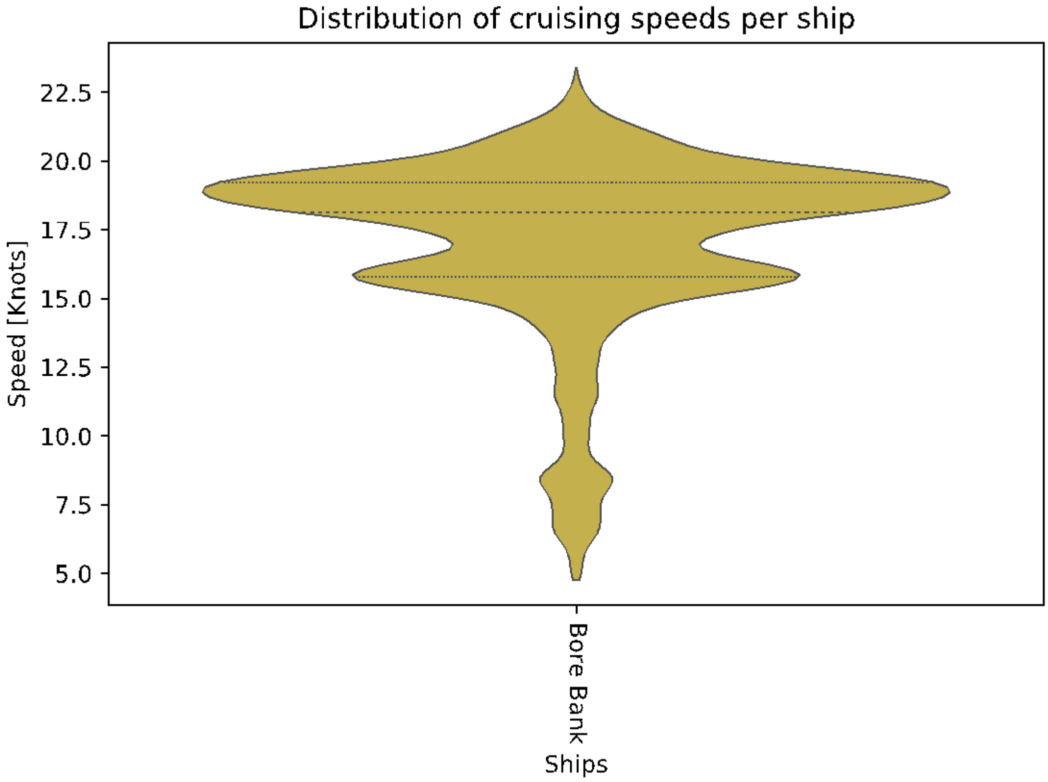


Figure 119: Aggregated distribution of cruising speeds for BORE BANK in RO3

Furthermore, in Figure 55 it can be observed that different legs are navigated at very different speeds. There are legs whose median speed is above 18 Knots while others are below 15 knots. Second, the distribution of speeds in the same leg is also wide or in some cases bimodal (as in the case of Sundsvall–Holmsund or Sundsvall-Iggesund), implying again a large variability.

These facts could be due to the nature of the service, the congestion in the Kiel Canal and the Baltic Sea, etc.

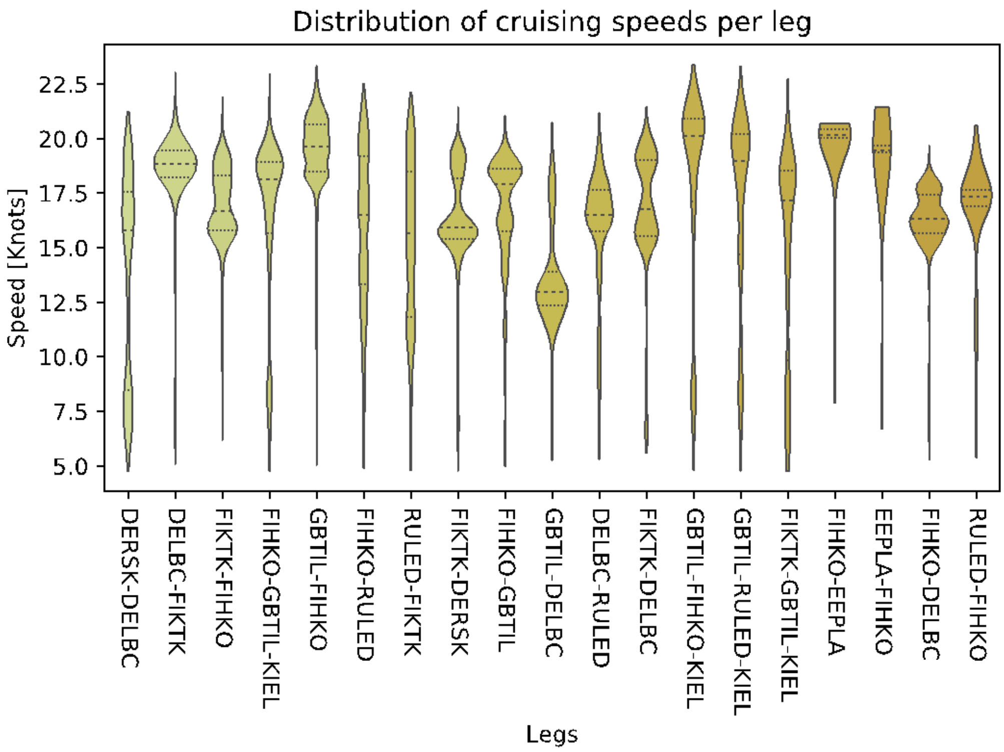


Figure 120: Aggregated distribution of cruising speeds per leg for the ship in RO3

2. Punctuality

One of the indicators of a shipping service in terms of efficiency is punctuality. Figure 56 and Figure 57 show the distributions of the deviation between the Estimated Time of Arrival (ETA) reported at the beginning of a leg and its Actual Time of Arrival (ATA), in order to capture, also, its capacity to provide accurate ETAs in advance.

In Figure 56, we can observe that the 38% of the times, the ship will arrive later than reported. Moreover, the CDFs show that, when late, the difference between ETA and ATA is less than 10 hours in, approximately, an 80% of the time. For early arrivals, roughly a 100% of the cases were within the 10 hours range.

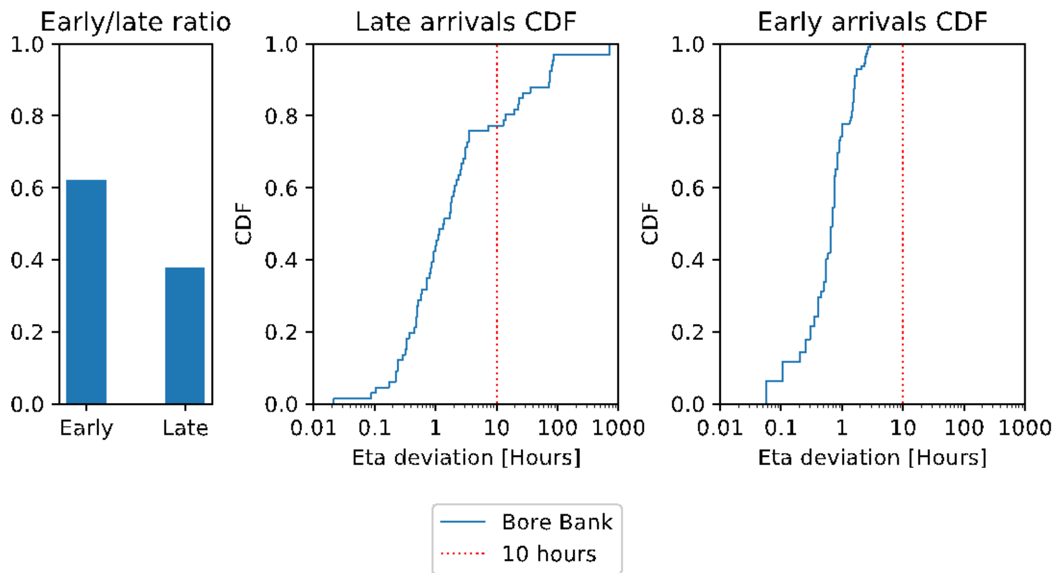


Figure 121: Distribution of ETA deviations of the ship in RO3

In Figure 57, it is difficult to relate the punctuality with the kind of port. Both for early and late arrivals, the ship behaviour are quite close from the CDFs.

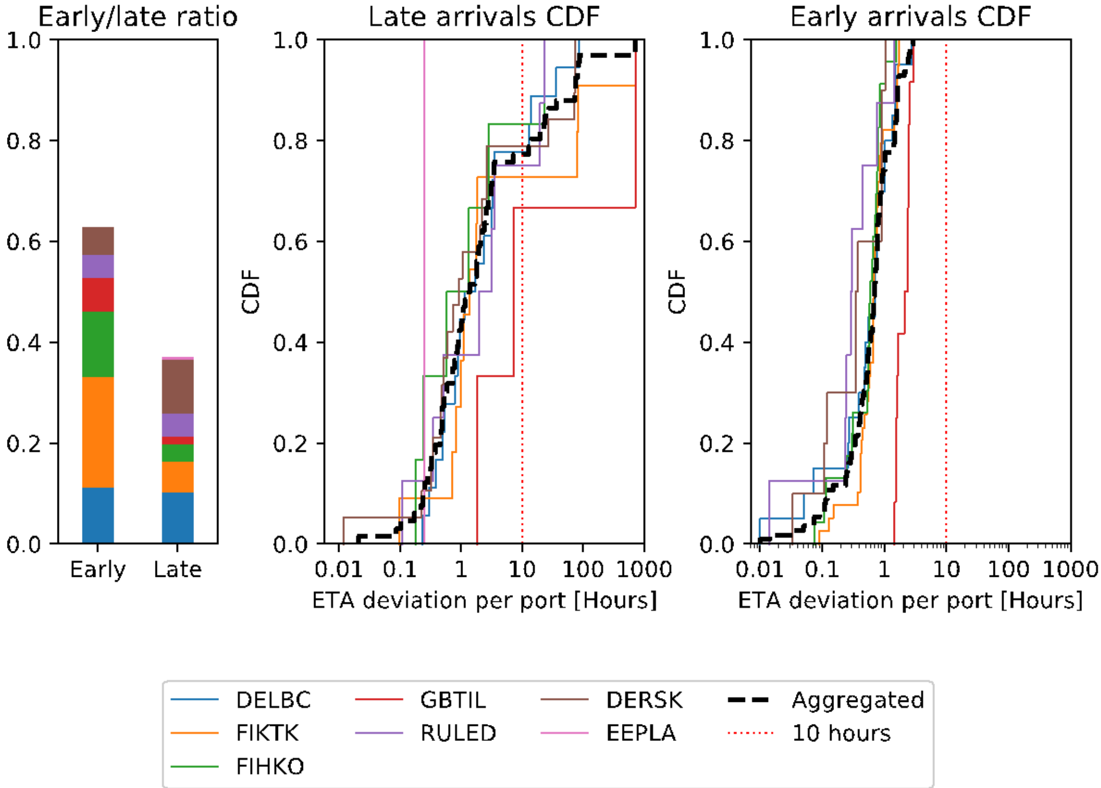


Figure 122: ETA deviations per port in RO3

3. Anchoring Times

Figure 58 presents the results related to anchoring times for the ship in RO3. The anchoring time represent less than the 2% of the time. The only port in where there were anchoring times was St Petersburg in Russia. Only 30 hours aggregated, the ship was performing anchoring time in a yearly data available. This means a short room for improvement in this variable.

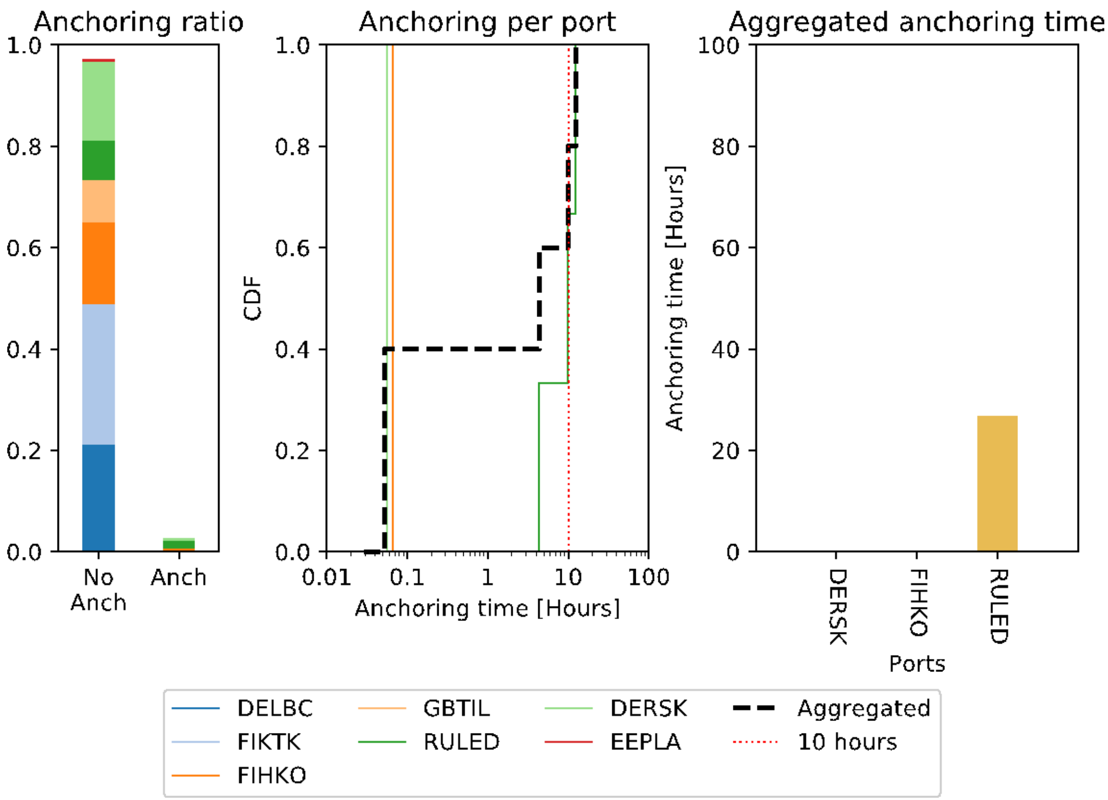


Figure 123: Anchoring times by port in RO3

9.12.3.2 Environmental Sustainability

1. Navigation Times

Figure 59 shows the variation in navigation time for each scenario in RO3. We see time increase in Scenario 3 at high speed around 40 days, which should be considered when deciding the service strategy.

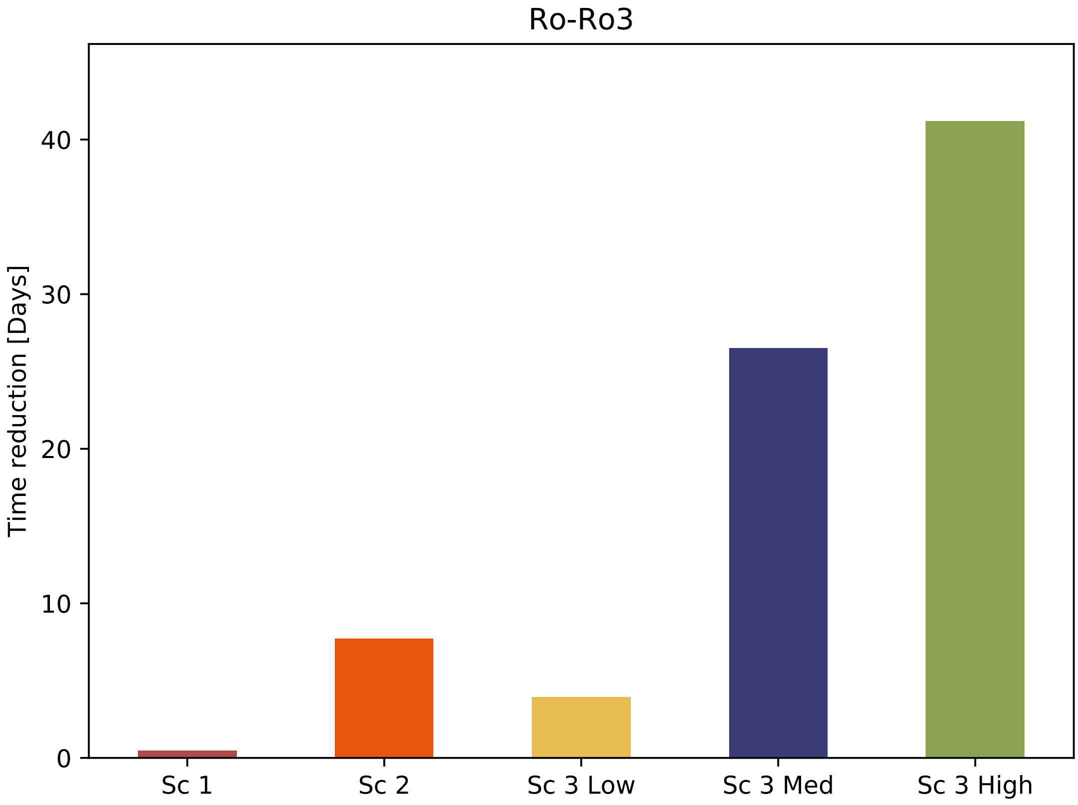


Figure 124: Variation in navigation time for each scenario in RO3

2. Fuel Consumption

Figure 60 presents an estimation of the fuel consumption of the BORE BANK both for the real AIS data as for the proposed scenarios. It is worth mentioning that the figures for the different types of GHG emissions have a very similar aspect although for different magnitudes that is the reason for not showing them all in this document, but they can be consulted in ANNEXES.

Because of the type of route that this service covers, a long distance service, cruising is the dominating phase, where ships spend most of their time. In the case of RO3, the first scenario does not bring savings but more expenses. Scenario 2 introduces some slightly savings, which is improved in Scenario 3 by enforcing the use of a lower cruising speed.

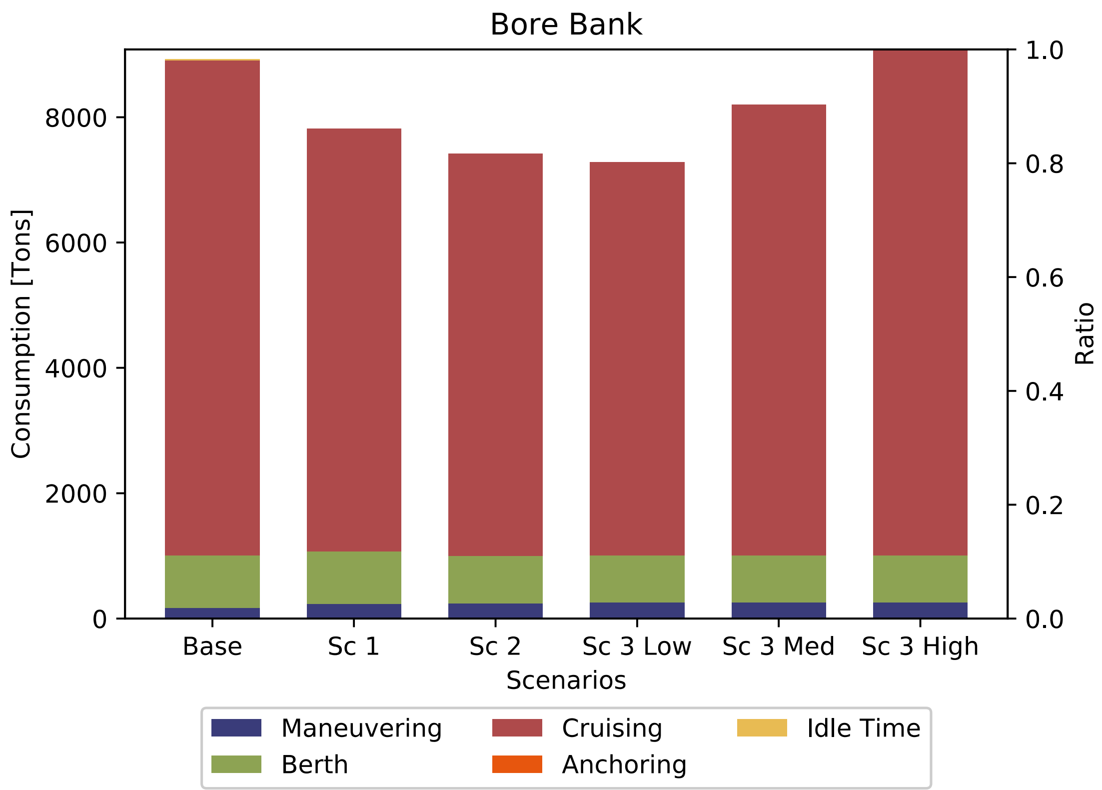


Figure 125: Fuel consumption of the BORE BANK in the current situation and for the different proposed scenarios divided by phases.

3. GHG Emissions

Figure 61 shows that the savings for the fuel consumption and emissions vary significantly from one to another scenario, Scenario 1 does not show any improvements, only for SO_x and PM. Scenario 2 and Scenario 3 Med have reasonable savings around 4%. The greatest savings come from Scenario 3 in which the ship synchronizes with the port and adjust the speed to the lowest possible, getting savings of almost 8%. The worst picture is for Scenario 3 High, increasing the costs up to 5%.

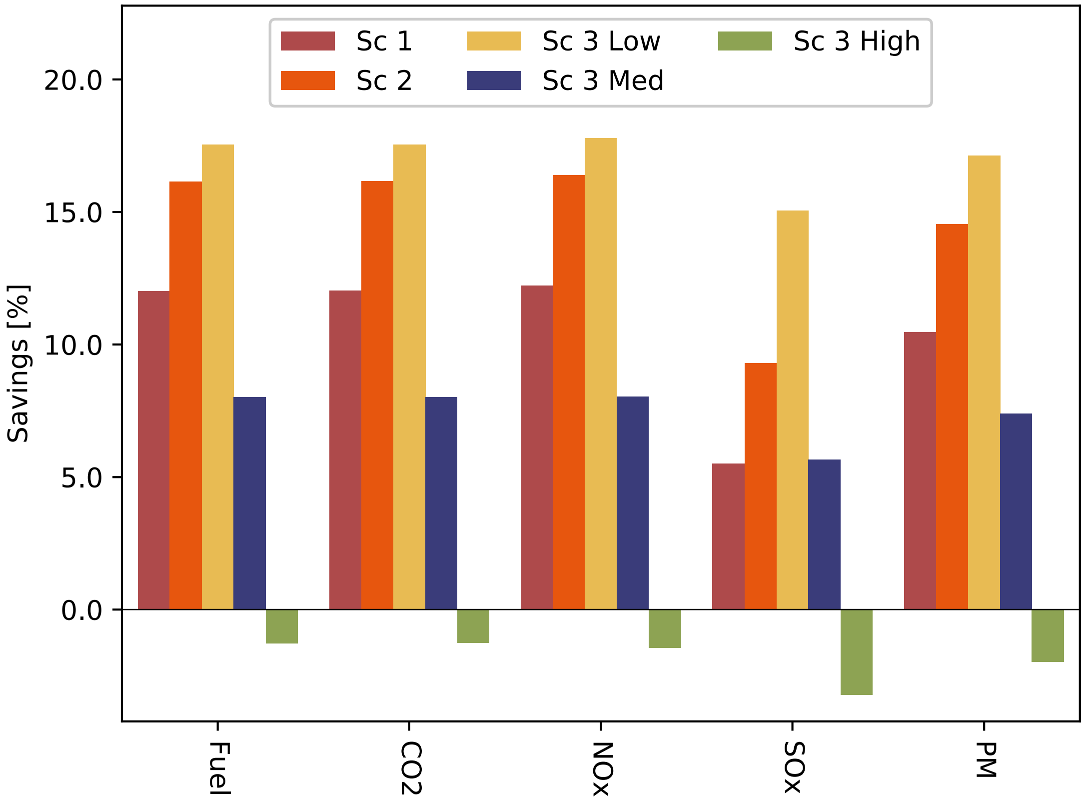


Figure 126: Mean values and deviations of the savings in fuel consumption and emissions for the ship in RO3

9.12.4 Use Case Evaluation

In this section, we show the approximate savings of implementing the different scenarios of STM and the economic impact that this could have on the shipping companies' costs.

Tons	Fuel Consumption	CO_2 Emissions	NO_x Emissions	SO_x Emissions	PM
BORE BANK	8,928.53	28,621.70	680.10	24.01	10.03

Table 32: Results of one year fuel consumption and GHG emissions

In Table 32 we depict the results of one year fuel consumption and GHG emissions for the BORE BANK ship. If we translate this information into US Dollars, using the price for the fuel, CO2, NO_x, SO_x and PM we will be able to quantify the costs savings for shipping companies and express the emissions in monetary figures.

SHIP	Variable	Metric	SC 1	SC 2	SC 3 Low	SC 3 Med	SC 3 High
BORE BANK	Fuel	Tons	1,112.95	1,512.20	1,644.75	727.36	-152.97
		%	12.47%	16.94%	18.42%	8.15%	-1.71%
	CO_2	Tons	3,570.24	4,850.20	5,273.28	2,332.38	-489.80
		%	12.47%	16.95%	18.42%	8.15%	-1.71%
	NO_x	Tons	82.12	110.39	119.80	54.60	-8.79

		%	12.07%	16.23%	17.62%	8.03%	-1.29%
	SO_x	Tons	1.40	2.35	3.69	1.50	-0.57
		%	5.85%	9.78%	15.35%	6.23%	-2.37%
	PM	Tons	1.05	1.46	1.72	0.75	-0.18
		%	10.42%	14.56%	17.11%	7.49%	-1.78%

Table 33: Estimated savings for one year in fuel consumption and GHG emissions for the different scenarios

9.13 Ro-Ro Use Case Comparison

As analized in the previous pages, in a large majority of the cases, the use of STM would facilitate the reduction of fuel consumption, GHG and pollutant emissions, leading to a decrease in costs for shipping companies and ship operators. However, the implications of these results are not the same in all cases. As we see in Figure 62, the ships in RO1 have a lower consumption in their real situation per year because of their size but they still have good potential savings between 10% and 16% of fuel consumption per year. However, RO1 reduce around 5 days than the other case studies that increase the navigation time up to 25 days (use case RO3).

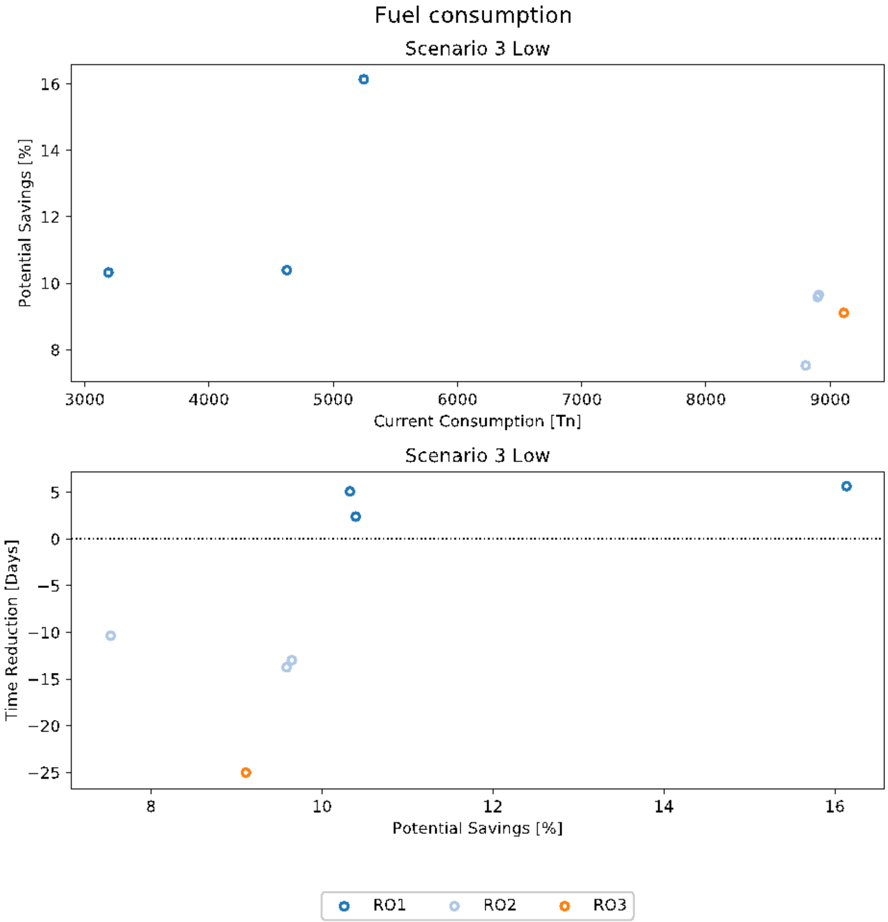


Figure 127: Comparison of potential savings with navigation time reduction applying low speed

In Scenario 3 median, the average potential savings are lower because the speed of the ships are higher. RO1 potential savings are around 6% and the savings in the other use cases are lower than 2%, even in RO3 there is no savings.

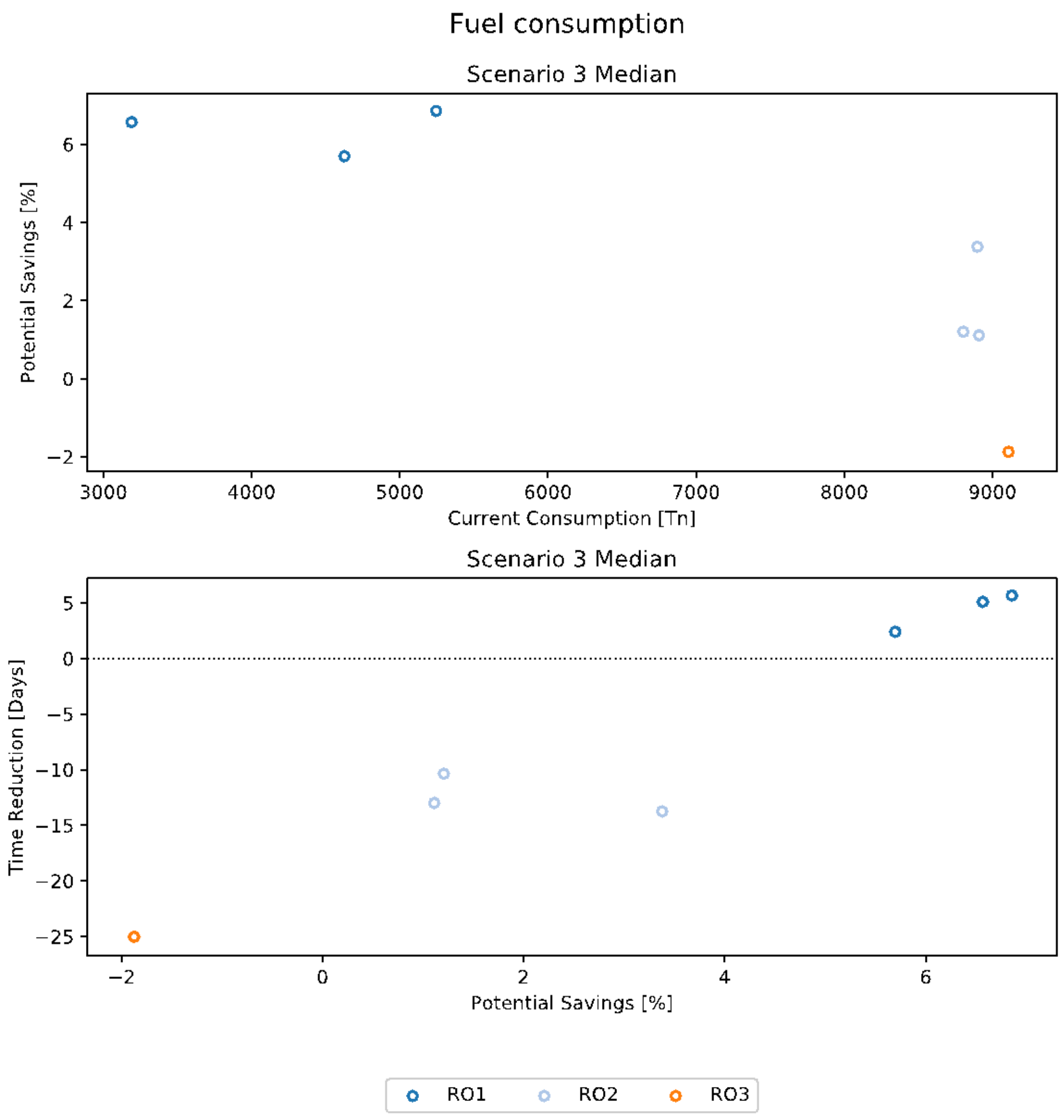


Figure 128: Comparison of potential savings with navigation time reduction applying median speed

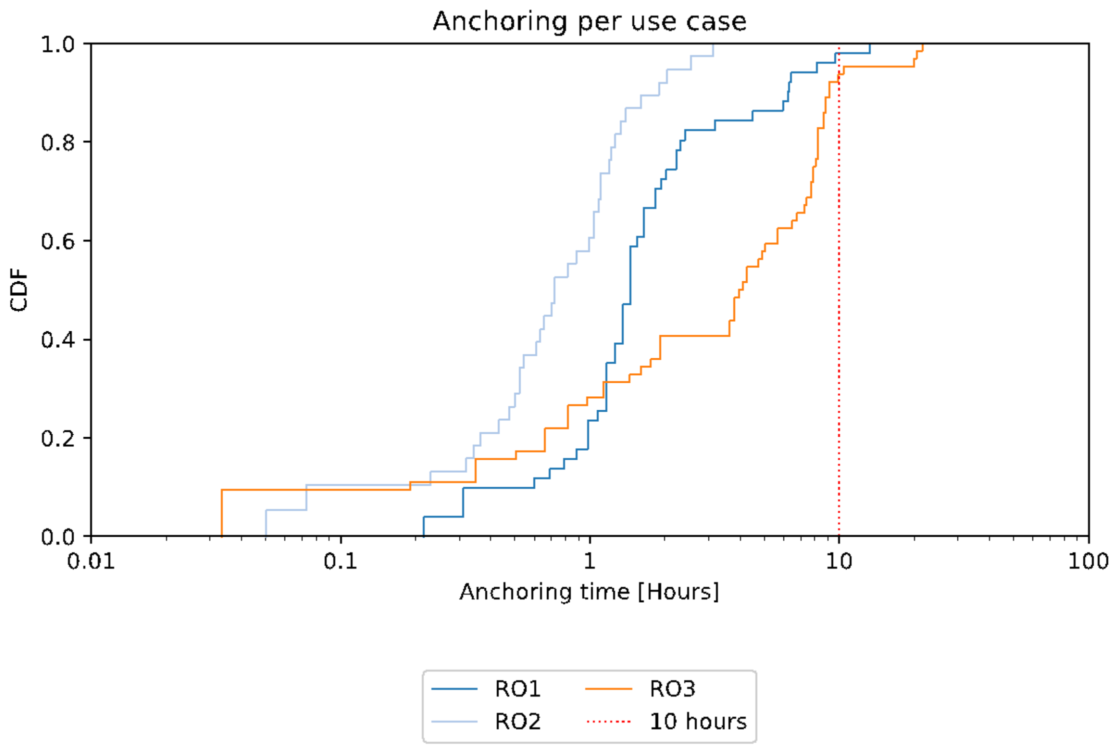


Figure 129: Anchoring time CDF per use case

6 USE CASES OVERALL EVALUATION

This section presents results of the analysis across all the use cases. The individual results for each use case can be found in their respective booklets, the results presented here serve as summary of comparison of all of them. We will present results concerning the aggregated speed per use case, the anchoring times and fuel consumption and emissions. The latter figures correspond to the Sc 3 Low and Med scenarios, as those achieved the best results. In these figures we will show the savings in fuel or pollutant emissions with respect to the real total consumption or emissions, but also the corresponding variation in navigation time. Note that, in some cases, large savings are obtained at the expense of cruising at a lower speed, implying more days of navigation and a relevant economic impact. We will not present results concerning the ETA deviations as this datum was reported incorrectly in some use cases.

First, it is important to remark that two use cases were discarded, use cases CC1 and HSC1. Despite of having several car carrier ships in the STM fleet, we found that none of them was actively covering a regular route. Although MSC Cristiana and MSC Immacolata were, in principle, doing it, we found that roughly a 15% of their port calls were related to the itinerary and were not even coincident between them. As their behaviour was closer to that of a tramp, we had to discard it.

The reason to discard the HSC1 was technical, though. High Speed Crafts perform very quick stops in ports, that quick that, in many cases, this was not captured by the AIS. We would observe how speed was decreasing when getting close to the port but, as many times when in port the frequency of the AIS report descends, the next AIS register would correspond to the vessel already leaving the port. Despite implementing several fine tuning adjustments, the number of port calls that were still being missing was more than considerable. Eventually, we opted to discard this use case due to the low quality of the data.

6.1 Anchoring results

Figure 130 shows the CDFs of anchoring times for the different use cases. It is worth noting that we also account possible waiting times during the entrance to port as anchoring times.

There are three differentiated groups, Containerships, Ro-Ro traffic, and Ro-Pax/PAX. Containerships go to anchoring between 20-40% of the times, as can be seen in the different Containership use cases. This is reflected here in the smoothness of the curves, showing much more occurrences that for the other traffics. Similarly, their stays in anchoring are substantially longer. In fact, CS2 ships stay in anchoring for more than 10 hours more than 40% of the times, while CS1 and CS3 ships go beyond the 10 hours approximately a 10% of the times.

Interestingly, Ro-Ro ships stop substantially less times in anchoring. This may be caused by Ro-Ro traffic being lower than containers and easier to allocate in the devoted terminals. We can observe how the number of times they stop in anchoring is not only low, but most of the times is short or, as in the case of RO3, merely stopping by before mooring at berth as the longest wait was in the order of 30 minutes.

Finally, RO-PAX and Pax do not stop in anchoring, with very little exceptions possibly caused for exceptional reasons. These ships carry passengers and that grants them very high priority when entering into any port. Ro-Pax2 was the only Ro-Pax case showing some waiting times. However, for both Ro-Pax2 and Pax these waiting times were very few and in the order of minutes

In contrast with Ro-Pax, and Pax, Ro-Ro and Containerships traffic have low priority when entering into ports, having to wait outside of the port if any passenger traffic is arriving at the same time. Hence, the mix of higher traffic, lower priority, and more complicated and elevated number of operations at berth adds a certain degree of unpredictability that complicates synchronization. STM will help solving these issues primarily by improving the real time communication between actors in ports and between ports and ships. Additionally, the digitization of this communication and the analysis on the resulting data will help to improve resource management in ports and, hence, avoid congestion through a better management of incoming and outgoing traffic.

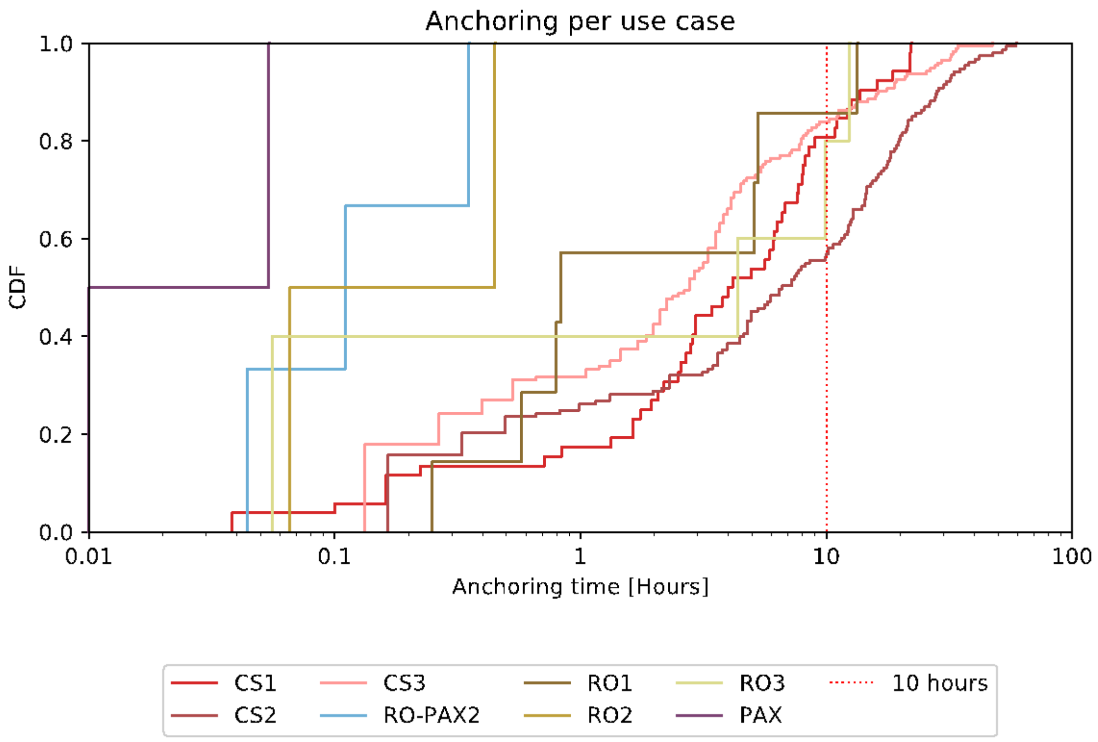


Figure 130: CDFs of the anchoring times per Use Case

6.2 Speed variation

As described in Section 1.4.1, the variation of cruising speed for ships is, from our point of view, one of the clearest symptoms of inefficiency in shipping. Figure 131 shows the variation of speeds in each one of the use cases. The behaviour exhibited by Ro-Pax2 and Ro2, and even by CS1 are close to what we would expect to be the a rational or uneventful navigation. There is a narrow tail due to the approximation and departure from port but, most of the time, speeds are concentrated around its median value. Ideally, the upper tail should be narrow and short as well. The ships in Ro-Pax1 individually meet this patter as well, but due to differences in the types of ship, this is not reflected in the aggregated patter of Figure 131.

The rest of the use cases exhibit very wide distributions, like CS2 or CS3, or bimodal or multimodal ones, like Ro3 or Pax. These distributions of speed have an immediate conclusion; it is impossible that these ships are navigating at their most efficient speed during most of their time. While we do not know this fact for CS1, Ro-Pax1, Ro-Pax2 or Ro2, there is a chance it is the case and, at least, the lack of high variations is more efficient than using a wide range.

The reasons that can led to these speed distributions is wide. From aspects that are inherent to the routes covered by the ships, e.g., more or less calmed waters or complicated geography, to unexpected changes in the berth availability in the destination ports, passing by congestion or meteorological difficulties/events during navigation. Most of these issues can be solved with STM. With better synchronization with ports, between ships, or by the use of weather forecasting services and route optimization made now available to the ships, speed variations can be reduced at large.

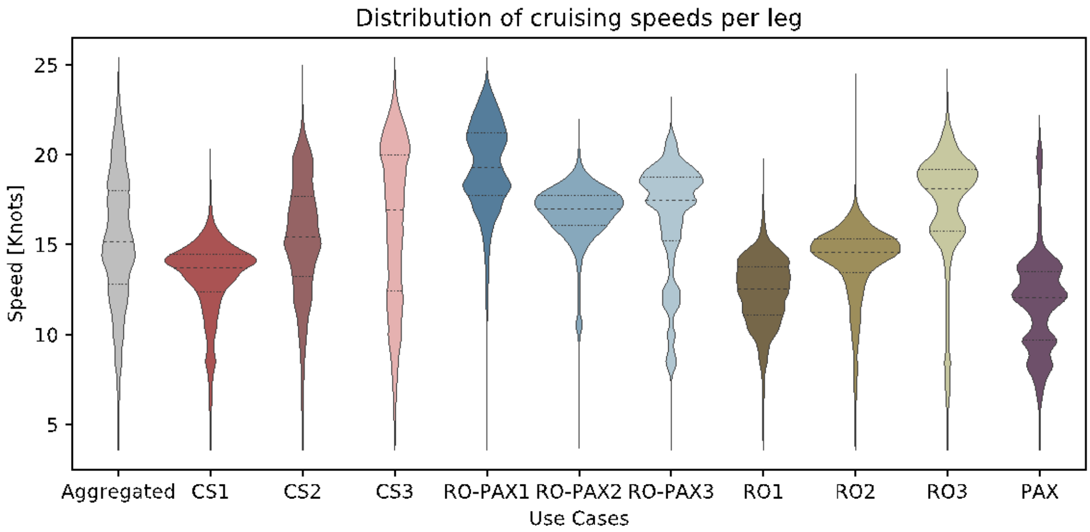


Figure 131: Distribution of cruising speeds per use case plus the aggregated distribution.

6.3 Scenarios Evaluation

The figures below present the results for Scenario 3 low and median for the fuel consumption and for each one of the GHG pollutants. Each figure has two plots. The first one shows the total savings versus the total consumption/emissions for each use case. The second one relates these savings with the reduction in days of navigation for each use case. Bear in mind that a negative variation implies that more days of navigation are required at that speed. Each circle is a ship; the use case is indicated by its colour.

In general, the ships belonging to the same use case have similar total current consumption or emissions. However, there are substantial differences for some cases. For instance, in Ro-Pax3, the Amorella and Gabriella cover the same route, but spend different amount of time at berth, one in the order of 1 hour in big ports such as Stockholm or Helsinki, while the other spends a time in the order of 6-8 hours. Another example could be the ships in CS3, that cover very long distances, and have some small variations in the ports covered, what also contributes to the apparent dispersion of its ships in the figures.

Figure 132 shows the results for the fuel consumption for the SC3 low (left) and median (right) scenarios. The upper part of the figures represents the total consumption versus the potential fuel savings for each use case. The lower part, the potential savings versus the estimated reduction in days of navigation. Note that a negative reduction implies more days of navigation.

Results for Scenario 3 at low speed, that uses the speed corresponding to the 1st quartile of the distribution of cruising speeds, shows that large savings can be achieved if itineraries are re-studied to allow ships to reduce their speed and STM is fully operational. Having completely synchronized port calls help to increase the time the ship can keep constant speeds during cruising. Although these are upper bounds to these potential saving, the thresholds go from 7 to 23%.

Even a 5% reduction in fuel consumption is considered a more than desirable reduction, here we are showing that the potential benefits could be larger than this 5%. Of course, adopting the low speed scheme implies a re-scheduling of the itineraries, given that, as the lower figure shows, transoceanic containerships like those in CS3 may need between 10-30 more days of navigation to cover the same number of port calls they currently cover. However, short sea shipping and medium distance containerships (CS1 and CS2 respectively), and

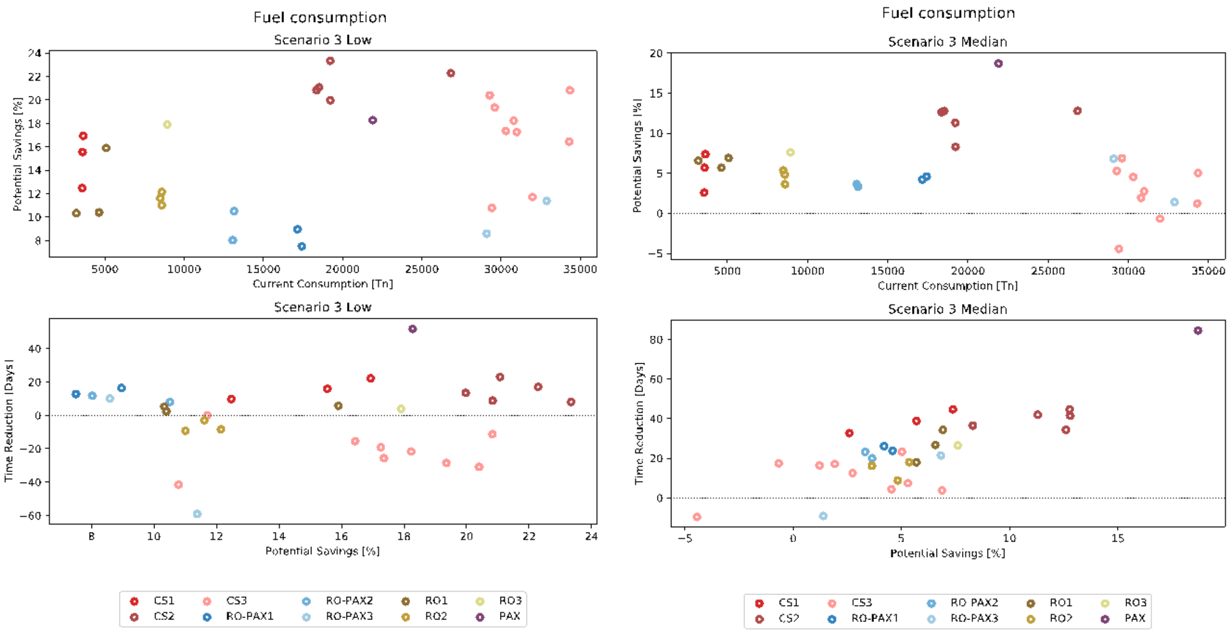


Figure 132: Fuel consumption results for the SC3 low (left) and median (right) scenarios.

some of the Ro-Ro examples can still reduce their navigation time despite of using a slow or relatively slow steaming speed only at the expense of reducing nowadays current inefficiencies. The Ro-Pax and Pax cases, however, are subject to strict schedules and varying their frequency has an impact on people commuting. Still, it could be studied whether a reduction of speed is feasible.

However, the Scenario 3 median speed uses the median speed of the ship during navigation, hence, giving a better intuition of the impact of nowadays inefficiencies. At this scenario, most ships are still able to reduce the fuel consumption, beyond a 5% in many cases, while the navigation time is reduced as well in all cases but two. Most of these savings can be directly associated to lack of synchronization between ports and ships or an excessive variation of the cruising speed.

The following figures show the impact of both scenarios on different types of GHG emissions, namely, CO2, NOx, SOx, and PM. The results for CO2 are comparatively similar to those shown for the fuel consumption. However, for NOx, SOx and PM the ships shift in the figure due to the influence of navigating in ECA and non-ECA zones. Consequently, CS2 and CS3, that have the most powerful engines and, additionally, do not, or barely cross ECA zones, appear on the left side of the figures. Whilst Ro-Pax2, Ro-Pax3 and Pax are still in an order of magnitude similar to that of CS2 and CS3 for NOx emissions, for SOx and PM the reduction due to ECA zones is more substantial and shift to the left side of the figure.

In general, all figures exhibit patterns similar to Figure 34. Most ships have upper bounds in their potential emission savings in the order of 10-25% for Scenario 3 Low, with the aforementioned implications in terms of days of navigation. For Scenario 3 Median, the upper bounds on the potential savings are lower but still in the order of 5-15% for most ships.

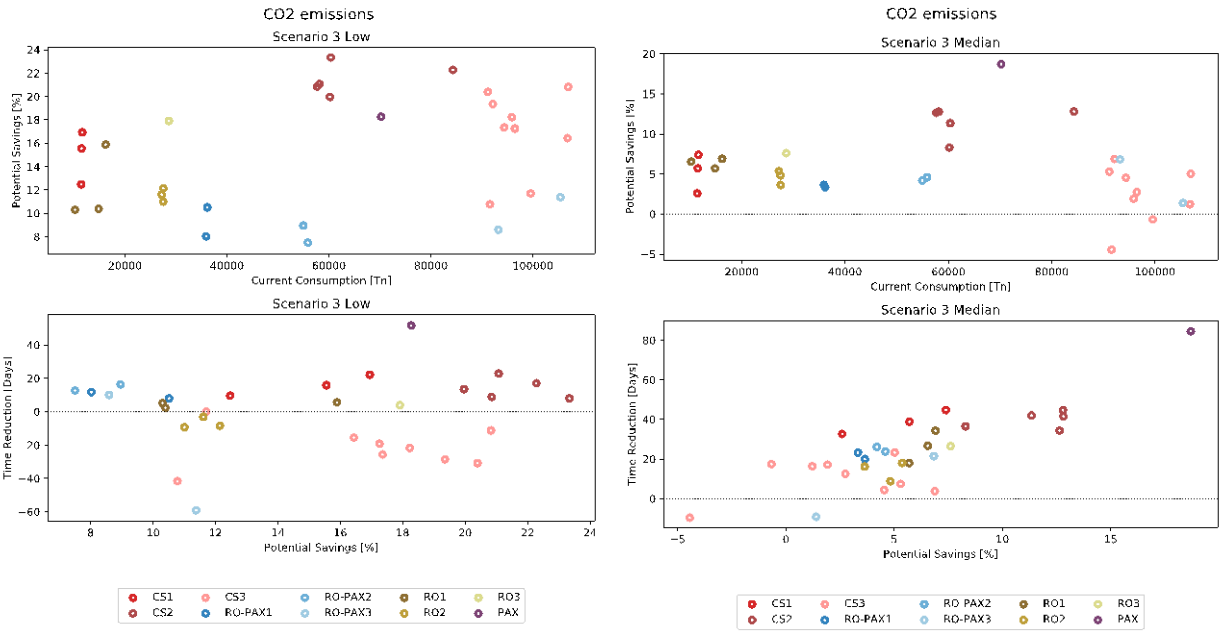


Figure 133: CO2 consumption results for the SC3 low (left) and median (right) scenarios.

The upper part of the figures represents the total consumption versus the potential NOx emission savings for each use case. The lower part, the potential savings versus the estimated reduction in days of navigation. Note that a negative reduction implies more days of navigation.

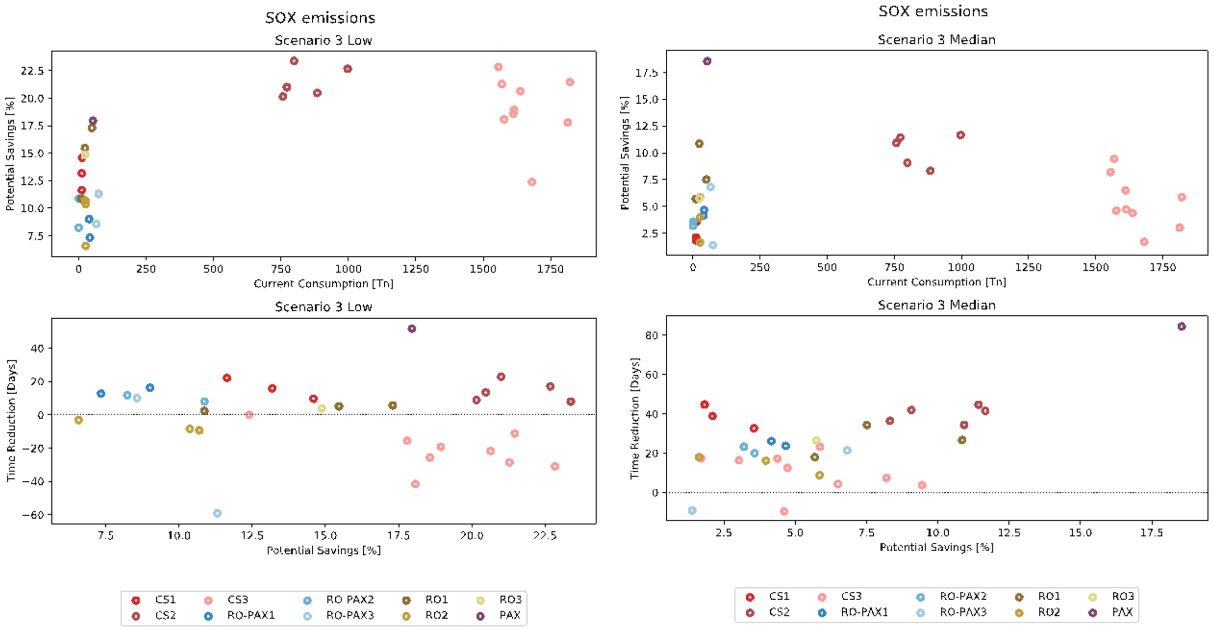


Figure 134: SOX savings for all use cases in scenario 3 low (left) and median (right) scenarios

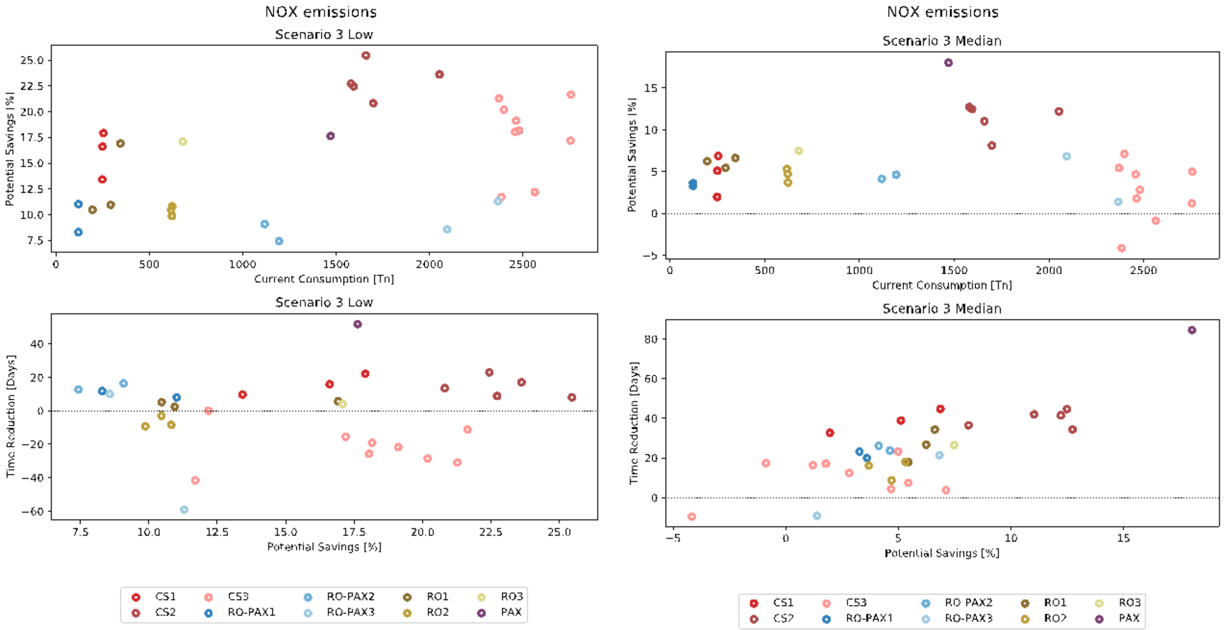


Figure 136: NOx savings for all use cases in scenario 3 low (left) and median (right) scenarios

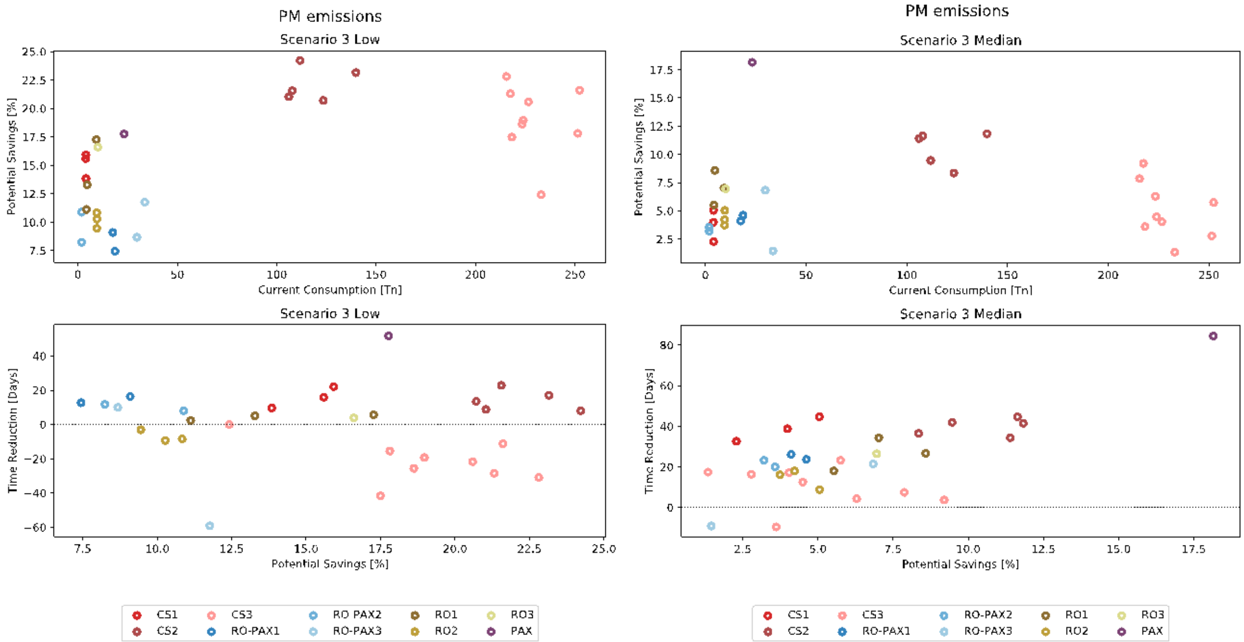


Figure 135: PM savings for all use cases in scenario 3 low (left) and median (right) scenarios

9.14 STM European Potential Added Value

Taking into account the results from the previous analyses, the percentages obtained have been extrapolated to apply to global fuel consumption and GHG emissions, calculated using the VESSL database, which estimates the potential impact of STM at the European level.
This unique, tailor-made tool, code-named VESSL (Valenciaport Short Sea Shipping Lines database), features detailed and reliable information about all the regular services calling at all Core Ports and Mediterranean Comprehensive Ports of the Trans-European Transport Network in the European Union (TEN-T Network). The focus has been on these SSS regular lines and cabotage since these could be potential beneficiaries in the implementation of STM.

More than 2 million data have been collected, compiled and validated from the various sources of the different agents involved in the maritime business. The types of services have been categorized based on the cargo transported and the characteristics of the ships used. According to these criteria, regular services have been classified as car carrier, container, passenger, cruise vessels, Ro-ro and Ro-pax services.

The large number of ports studied and the vast amount of information and variables to be considered in the database have resulted in an exhaustive information-monitoring process, which is essential for a reliable evaluation, and for meeting the expected objectives of the STM Validation Project.

The results of this data compilation are based on a SQL database containing essential information about the morphology of the Short Sea Shipping situation in the European Union.

The **main objective** of using VESSL is to have a comprehensive and reliable tool that enables the extrapolation of the impact of STM benefits at the macro level in terms of time, fuel consumption and GHG emission savings on all Short Sea Shipping and cabotage services in 23 Member States of the European Union.

The basis for calculations using VESSL, from which the main results of the project have been extrapolated, is delimited and shown in the following figure (2017):

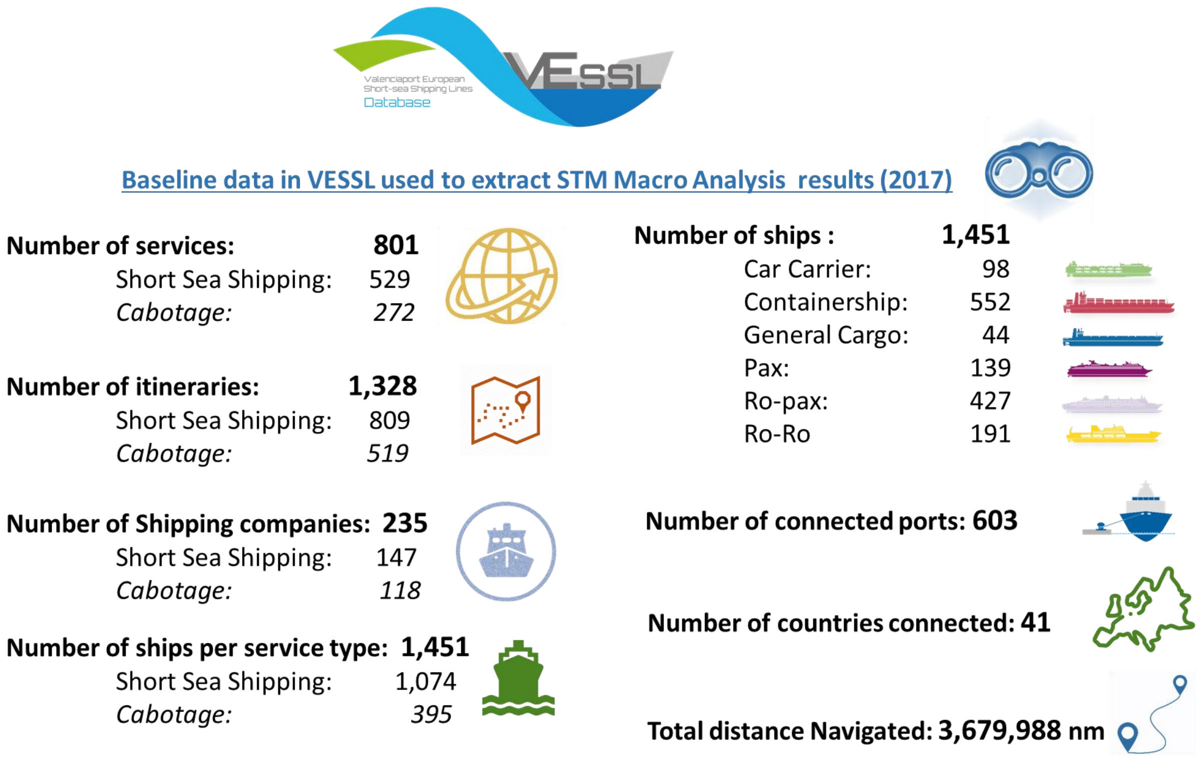


Figure 137: Baseline data in VESSL used to extract STM Macro Analysis Results (2017)

The assumptions for the calculation of savings derive directly from the results obtained in the use-cases, which also take into account some of the findings from the various results of the project, in line with conservative criteria.

The most significant results of the extrapolation of STM findings using VESSL are shown below, structured as savings in time, fuel consumption and GHG emissions for ports and navigation phases. The calculations are expressed in a MGO 2020 scenario that will comply with the 0.5% of sulphur content of fuels used in maritime sector recently approved by the IMO.

9.14.1 Impact of the potential improvement in the port call phase

The estimation of potential savings during port calls for the various types of ships analysed has been extracted from the results of the project. However, a more conservative percentage has been taken for the extrapolation of results. Thus, a 1% time saving in ports resulting from the implementation of STM concept has been established as the pessimistic scenario, a 5% saving as the moderate (most probable) scenario and a 10% saving as the optimistic scenario.

Consequently, the global results are obtained from a total of 217,127 hours at ports for 1,097,544 port calls analysed, operated by 1,451 different ships included in the database and applying the percentages mentioned above.

9.14.1.1 Potential Time Savings at Ports

In the moderate scenario, the average time saved in minutes per call would be 7.5 minutes as a result of the total time saved in minutes Table 34 divided by the total of 1,097,544 port calls. However, it is important to note that the potential savings in time at port for container ships, general cargo and car carriers are superior to the time savings of passenger-related traffic, due to the latter's priority access to the port. The results are expressed in days, hours and minutes for all the scenarios, as follows:

Table 34: Time saving in port estimation

Time Saving for 1,097,544 port calls (2017)	Pessimistic scenario	Moderate Scenario	Optimistic Scenario
Total Time saving (days)	2,169	5,730	10,183
Total Time saving (hours)	52,056	137,520	244,392
Total Time saving (mins)	3,123,360	8,251,200	14,663,520

9.14.1.2 Potential Fuel Consumption and GHG Emission Savings at Ports

As a result of the reduction in time at port, there is a consequent reduction in fuel consumption and GHG emissions.

The following tables summarize the potential fuel savings in the different scenarios on the basis that the total consumption of all ships included in the database amounts to 1,246,809 tons of MGO; 3,995,887 tons of CO_2; 78,500 tons of NOx; 2,500 tons of SOx and 1,637 tons of PMx at ports.

As observed in Table 35 the moderate scenario adds up to savings of more than 100,000 tons of GHG, while in the most optimistic scenario it amounts to more than 180,000 tons of GHG.

Table 35: Saving tons at ports

Savings in Ports	Pessimistic scenario	Moderate Scenario	Optimistic Scenario
Tons of Fuel (MGO) saving in Ports	12,468	31,757	55,869
Tons of CO2 saving in Ports	39,945	101,743	178,990
Tons of NOX saving in Ports	976	2,486	4,374
Tons of SOX saving in Ports	25	63	111
Tons of PM saving in Ports	19	47	83

The second table rates the GHG emissions on the basis of the following reference values:

- The monetary value in Euros of fuel (MGO) is based on the spot price in the Mediterranean, which amounts to €568/ton (Piraeus bunkering price, 2019 according to estimated values in www.bunkerindex.com)
- CO_2 emissions - €25.89/ton (reference according to the estimated costs included in the Cost Benefit Analysis of Investments Projects Guide (Sartori, Davide, et al., 2015)
- NOx emissions - €3,790/ton (average damage cost per ton for maritime transport included in the Update of the Handbook on External Costs of Transport (Gibson G., et al, 2014)
- SOx emissions - €17,240/ton (Gibson G., et al., 2014)
- Emissions PMx - €6,080/ton (Gibson G., et al., 2014)

In the moderate scenario, the estimated potential value of the tons of MGO fuel saved in port for the total calls amounts to €18 million, with €13.43 million of GHG emission savings valued according to the reference values in the previous section for the same scenario. The potential emission savings at ports in the optimistic scenario would double the figures mentioned above.

Table 36: Monetary savings in ports estimation

Monetary Savings in ports	Pessimistic scenario	Moderate Scenario	Optimistic Scenario
Amount of Fuel saving in Ports	7,081,873 €	18,038,119 €	31,733,425 €
Amount of CO2 saving in ports	1,034,171 €	2,634,120 €	4,634,056 €
Amount of NOX saving in ports	3,699,138 €	9,422,013 €	16,575,605 €
Amount of SOX saving in ports	428,813 €	1,092,221 €	1,921,482 €
Amount of PM saving in ports	113,224 €	288,391 €	507,349 €
Amount of GHG saving in ports	5,275,346 €	13,436,745 €	23,638,492 €

9.14.2 Impact of the potential improvement in navigation phase

In this section, the results obtained in the use-cases have been extrapolated to the VESSL database. For this purpose, we have used the time and fuel savings estimations for the five given scenarios.

Once the potential savings percentages Table 37 have been applied, the following figures are the MGO fuel and GHG emissions valued in tons that can be potentially saved with the progressive implementation of STM.

Table 37: Use Cases Aggregated Fuel Savings for each Scenario

USE CASES		Scenario 1	Scenario 2	Scenario 3 Low	Scenario 3 Med	Scenario 3 High
	CS1	7.10%	9.10%	16.19%	6.56%	1.12%
	CS2	19.62%	21.87%	22.66%	12.82%	1.24%
	CS3	-0.90%	2.03%	20.00%	3.99%	-8.12%
	PAX1	14.33%	16.10%	18.42%	18.84%	17.41%
	RPX1	2.86%	7.14%	8.49%	4.67%	1.35%
	RPX2	2.41%	6.53%	9.34%	3.57%	-1.67%
	RPX3	5.62%	8.32%	10.05%	4.17%	-1.95%
	RO1	9.03%	13.03%	13.50%	7.78%	2.91%
	RO2	5.53%	8.14%	12.18%	5.24%	-1.95%
	RO3	12.47%	16.94%	18.42%	8.15%	-1.71%

As can be seen, scenario 3 Low yields the most favorable results, accounting for 2.1 million tons of MGO and 6.8 million tons of CO_2 in potential savings. These amounts express the greatest potential for implementation of the STM concept in Short Sea Shipping and cabotage navigation across the European Union, taking into account the data for the base-year, 2017.

Table 38: Savings in Navigation estimation

Savings in Navigation	Scenario 1	Scenario 2	Scenario 3 Low	Scenario 3 Med	Scenario 3 High
Tons of Fuel (MGO) saving in Navigation	1,179,439	1,660,993	2,135,070	974,828	-37,862
Tons of CO2 saving in Navigation	3,778,646	5,321,430	6,840,262	3,123,120	-121,302
Tons of NOX saving in Navigation	92,329	130,026	167,137	76,311	-2,964
Tons of SOX saving in Navigation	2,353	3,314	4,259	1,945	-76
Tons of PM saving in Navigation	1,762	2,481	3,189	1,456	-57

Table 39 summarizes the monetary value in Euros of the MGO fuel, based on the spot price in the Mediterranean, as noted above. In Scenario 3 low, the estimated potential value of the tons of MGO fuel saved in navigation amounts to €1,212 million, with €903 million of GHG emissions savings, valued according to the reference values in the previous section for the same scenario.

Table 39: Monetary savings in Navigation estimation

Monetary Savings (€) in Navigation	Scenario 1	Scenario 2	Scenario 3 Low	Scenario 3 Med	Scenario 3 High
Amount of Fuel (MGO) saving in Navigation	669,921,549€	943,443,891€	1,212,719,733€	553,702,303€	-21,505,761€
Amount of CO2 saving in Navigation	97,829,149€	137,771,823€	177,094,378€	80,857,565€	-3,140,502€
Amount of NOX saving in Navigation	349,926,143€	492,797,526€	633,450,797€	289,220,300€	-11,233,297€
Amount of SOX saving in Navigation	40,564,238€	57,126,215€	73,431,064€	33,527,078€	-1,302,189€
Amount of PM saving in Navigation	10,710,603€	15,083,636€	19,388,777€	8,852,507€	-343,831€
Amount of GHG saving in Navigation	499,030,134€	702,779,201€	903,365,015€	412,457,451€	-16,019,820€

In conclusion, the implementation of the STM concept across the European Union would contribute to meeting the European Commission's goals regarding environmental issues in the maritime sector. This would offer a feasible solution to some of the concerns related to growing intra-European and international trade and the impact of shipping on climate change and society.

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8 ANNEXES

38 partners from 13 countries - Creating a safer more efficient and environmentally friendly maritime sector

Demonstrating the function and business value of the Sea Traffic Management concept and its services.

SAFETY - ENVIRONMENT - EFFICIENCY

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