DT4GS

Digital Twins for Green Shipping

D3.1: DT4GS Knowledge Hub v1

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Executive summary

The goal of this deliverable is to provide a comprehensive taxonomy of a database that includes shipping-related information, with a focus on green shipping technologies and emission factors. The purpose of this taxonomy is to organize and classify the data in a way that is easy to access and understand.

The work carried out includes the identification and categorization of different types of ships, technologies, and emission factors. The taxonomy is organized into three main categories: shipping types, green shipping technologies, and emission factors and key performance indicators (KPIs).

The innovations introduced in this work include a detailed categorization of different types of ships, as well as a comprehensive overview of green shipping technologies and emission reduction measures. This taxonomy can be used by researchers, policymakers, and industry professionals to better understand the marine industry and to develop effective strategies for improving its environmental performance.

The main conclusions of this work are that green shipping technologies and emission reduction measures are essential for mitigating the environmental impact of shipping. The taxonomy presented in this deliverable provides a useful framework for organizing and analysing shipping-related data in a way that can inform future research and decision-making.

The creation of an observatory for enhanced visibility of shipping emissions and the performance of Green Shipping (GS) solutions is a crucial component of the report. GS can be achieved through a variety of measures, including the use of alternative fuels such as biofuels and hydrogen, the installation of energy-efficient engines and propulsion systems, the optimization of ship design and operation to minimize fuel consumption, the adoption of waste reduction and recycling programs, and the implementation of measures to protect marine ecosystems. GS is increasingly becoming a key focus area for the shipping industry, as environmental concerns continue to grow and stricter regulations are introduced to reduce emissions and protect the marine environment. By adopting sustainable practices and technologies, the shipping industry can reduce its environmental impact and contribute to the global efforts to address climate change and achieve sustainable development.

The observatory for green shipping is a critical tool for stakeholders to access reliable and up-to-date information on the environmental impact and costs of green shipping (GS) technologies. By providing a centralized platform for monitoring and evaluating these technologies, the observatory aims to promote sustainable practices in the shipping industry. To ensure the observatory is comprehensive and useful, it will incorporate outputs from Living Labs (LLs), which are research and development facilities designed to test and validate new GS technologies in real-world scenarios. The LLs generate valuable data that can inform the development of the observatory, and it is essential to integrate this data effectively into the platform.

The following chapters will provide a detailed explanation of the possible methodologies to be employed in collecting, organizing, validating, and integrating information from LLs into the observatory. This will include a discussion of the challenges and opportunities associated with this process.

Capturing relevant LL use cases where decision support can be useful is also an important aspect of the observatory. This involves identifying LLs that have tested and validated GS technologies in real-world scenarios and capturing the data generated from these tests. The data can then be used to evaluate the performance of GS technologies in different scenarios and inform the development of future GS solutions.

Classifying data by frequency, pertinence, scope, users, providers, etc., is crucial to ensure that the observatory is organized and useful for stakeholders. The classification process will help to categorize the data into different types, making it easier to analyse and interpret.

Engaging GS data providers and users is also critical to the success of the observatory. By involving data providers and users in the development process, the observatory can be designed to meet their specific needs and requirements. This will ensure that the data provided by the observatory is relevant, accurate, and useful for decision-making purposes.

To create this observatory, the report proposes a structured methodology that builds on the results of the most relevant projects in the domain of Green Shipping. The methodology will help identify relevant data sources across the Green Shipping technologies, capture LL use cases where decision support can be useful, classify data by frequency, pertinence, scope, users, providers, and engage GS data providers and users.

Identifying relevant data sources for Green Shipping technologies is a crucial step in establishing an observatory. This entails identifying various data sources that can provide valuable insights into the environmental impact and costs of GS technologies. These sources may include academic research, industry reports, and government data, including data from the European Union (EU) statistics.

EU statistics can provide a wealth of information on the environmental impact and costs of GS technologies, including data on energy consumption, emissions, and waste generation in the shipping industry. For example, the EU's Emissions Database for Global Atmospheric Research (EDGAR) provides detailed data on greenhouse gas emissions from various sectors, including shipping. Additionally, the European Environment Agency (EEA) publishes reports on various environmental topics, including air and water quality, that can help inform the development of the observatory.

By including EU data sources in the identification process, the observatory can provide a more comprehensive and nuanced understanding of the environmental impact and costs of GS technologies, and support evidence-based policy making at the EU level.

Overall, the creation of the observatory represents an important step forward in promoting sustainability and driving innovation in the shipping industry. By providing stakeholders with a centralized platform to monitor and evaluate the environmental impact and costs of different GS technologies, the observatory can help accelerate the transition towards a more sustainable future.

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Glossary of terms and acronyms used

Table 1 Glossary of acronyms and terms

Acronym / Term	Description
EDGAR	Emissions Database for Global Atmospheric Research
EEA	European Environment Agency
GS	Green Shipping
IMO	International Maritime Organization
KPIs	Key Performance Indicators
LH2	Liquified Hydrogen
LNG	Liquified Natural Gas
LL	Living Labs
MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine Diesel Oil
MGO	Marine Gas Oils
SVO	Straight Vegetable Oil

1 Introduction

As digitalisation in the shipping industry has been maturing over the recent years, DT adoption will be dependent on establishing trusted and convincing DT application exemplars and ensuring that ship operators and other industry stakeholders can set up their own DTs based on their own business models, building their own confidential knowledge at reasonable cost. This requirement is at the heart of the DT4GS approach as illustrated in the figure below.

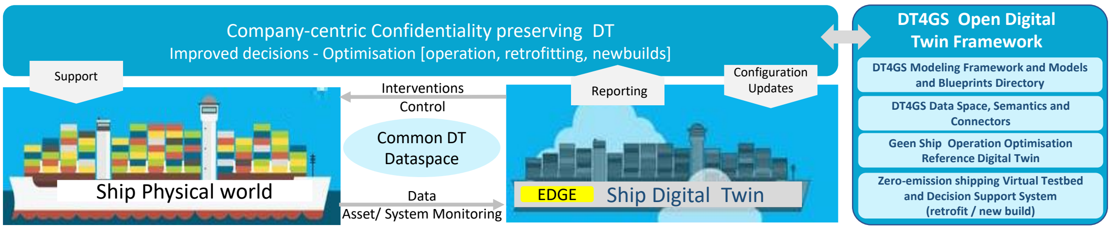

Figure 1 DT4GS approach

DT4GS will provide a virtual representation of ships and physical transport entities with a bi-directional communication links from sensing to actuation/control and data driven simulation and AI based decision support to people who will implement necessary actions.

DT4GS aims to enhance the relationship between physical and virtual entities, utilizing machine learning and artificial intelligence models to create digital twins (DTs) that learn from experience. These DTs will evolve along with their physical counterparts, mirroring vessel lifecycles, and will be capable of reflecting vessel states at any given time and predicting future states. Moreover, DTs will learn from observed evolutions of physical states and their deviation from associated predictions, improving upon future predictions and reinforcing forecasting capability in DT4GS models.

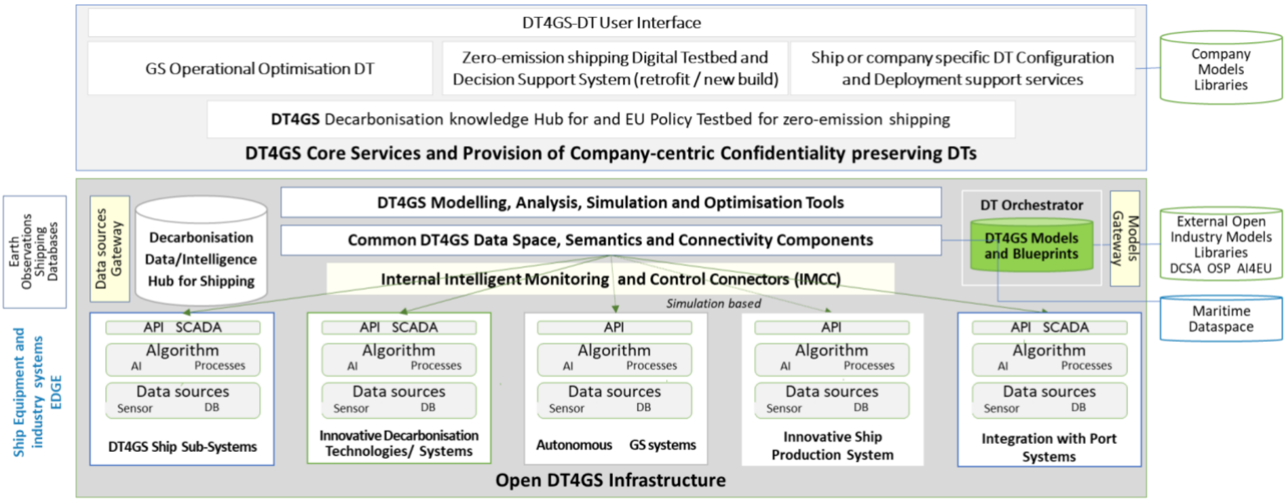

Figure 2 High-level conceptual DT4GS architecture

Unlike digital shadows with learning capability, DTs will enable real-time analytics to trigger timely actuation on physical objects, enabling the sensing-analysis-action cycle to become completely automated without supervision. To improve accuracy and reduce computational resource usage, DT4GS will investigate Quantum-inspired analogues of ML/AI optimization algorithms in key application areas. DTs will work in conjunction with conventional communication and computational systems, but enhancements will be expected with higher-performance computers and high-bandwidth, low-latency communications such as 5G.

DT4GS will provide a virtual representation of ships and physical transport entities with a bi-directional communication links from sensing to actuation/control and data driven simulation and AI based decision support to people who will implement necessary actions. In DT4GS extra emphasis will be given to:

- DT applications onboard the ship utilising advanced IoT and edge computing infrastructure.
- Using labelled data for AI/ML training and to provide the ground truth for accurate predictions (supervised learning), and where there is need to learn from experience to provide the reward function (reinforcement learning).
- Creating a common point of reference in the digital world for shipping vessels, which different stakeholders can access and utilise and adapt in line with their own internal business needs.

To reach its goals DT4GS is divided into 6 WPs each with different goals, tasks, and deliverables.

DT4GS's objectives are to:

- Support shipping companies in achieving up to 20% reduction in CO2e with a 2026 horizon, by developing and deploying real-time configurable DTs for ship and fleet operational performance optimisation in 4 Living Labs involving shipping companies, with different vessel types, and establishing fully validated industry services for Green Shipping Operational Optimisation DTs expected to be adopted by 1000+ ships by 2030.
- Establish a comprehensive zero-emission shipping methodology and support Virtual Testbed and Decision Support Systems that address both new builds and retrofits comprising:

A DT4GS (Green Shipping) Dataspace for the broader shipping sector contributing to GAIA-X by establishing a core European industry resource that accelerates the green and digital transition of waterborne shipping and transport value chains.

Simulation based solutions to retrofit ships, targeting 55% reduced CO2e reduction by 2030.

A smart green "new-build" reference design per vessel type.

Virtual Testbed services for reducing the cost of physical testing of GS solutions by 20%.

<u>The objective of this Deliverable is to provide an overview of the ongoing work related to Work Package 3, with a focus on Task 3.1. The partner Institute of Atmospheric Pollution Research of the National Research Council (IIA CNR) is leading this task, which involves defining and implementing the DT4GS knowledge Hub within the broader DT4GS framework.</u>

The deliverable includes two releases: the first release of the observatory for GS solutions (A) and the final release of the observatory that incorporates the results from the Living Labs (LLs) (B).

The first version, scheduled for release at month 12, includes the initial version of the database and observatory (A). This release will serve as a key milestone for the project, showcasing the progress made in Work Package 3 and Task 3.1. The second version of the observatory (B), scheduled for release at month 35, will build upon the initial release by incorporating the results from the Living Labs (LLs) into the database. This will provide stakeholders in the shipping industry with a more comprehensive platform for monitoring and evaluating the environmental impact and costs of different green shipping technologies. The methodologies for collecting, organizing, validating, and integrating information from the LLs will be described in detail in the upcoming chapter, highlighting the challenges and opportunities associated with this process.

The first release of the observatory, which refers to month 12, will be presented in this version of the deliverable along with the first release of the database (A). In this first version of the deliverable, only the methodologies for incorporating data from Living Labs will be presented, while the actual integration of the data into the observatory will be completed in the second version.

1.1 Mapping DT4GS Outputs

The purpose of this section is to map DT4GS Grant Agreement commitments, both within the formal Deliverable and Task description, against the current document.

Table 2 Adherence to DT4GS Grant Agreement deliverable and work description.

DT4GS GA Component Title	DT4GS GA Component Outline	Respective Document Chapter(s)	Justification
DELIVERABLE			
D3.1 DT4GS Knowledge Hub v1	*Observatory for GS Solutions first release. This deliverable includes the outputs of T3.1*	*Chapter 2 (Sections 2.1, 2.2, 2.3)* *Chapter 3 (Sections 3.1, 3.2)* *Chapter 4 (Sections 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.7, 4.8, 4.9)*	*D3.1 presents a thorough analysis of the implementation of a Knowledge Hub, which serves as a centralized platform for monitoring and evaluating the effectiveness of green shipping technologies. It provides insights into the database structure, taxonomy, and schema used to store and query data.*
TASK			
T3.1 DT4GS Knowledge Hub	*Create an observatory for enhanced visibility of shipping emissions and the performance of GS solutions, across the sector, incorporating outputs from the LLs. The task will use a structured methodology building on the results of the most relevant projects, in the domain of Green Shipping. This Decarbonisation Data/Intelligence Hub for Shipping will notably: a) Identify relevant data sources*	*Chapter 2 (Sections 2.1, 2.2, 2.3)* *Chapter 3 (Sections 3.1, 3.2)*	*Chapter 2 emphasizes the critical steps involved in creating an observatory for green shipping. This includes identifying data sources from academic research, industry reports, government data, and Living Labs (LLs). The chapter also highlights essential activities involved in data analysis and classification,*

	across the GS technologies; b) Capture relevant LL use cases where decision support can be useful; c) Classify data by frequency, pertinence, scope, users, providers, etc; d) Engage GS data providers and users	*Chapter 4 (Sections 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.7, 4.8, 4.9)*	*which involves the systematic collection, processing, and interpretation of data from various sources.* *Within Chapter 3, there is a subsection focused on Green Shipping technologies (GS technologies), which discusses the different technologies and solutions that have been developed to promote sustainability in the shipping industry. This subsection provides a detailed overview of the various types of green shipping technologies, including alternative fuels, navigation parameters, and ship features/components.* *Overall, Chapter 4 provides a comprehensive overview of the implementation of a Knowledge Hub for green shipping technologies. It covers the essential components of the Hub, including the database structure, taxonomy, and schema, as well as the processes involved in maintaining and expanding the database over time. The chapter also outlines the benefits of transitioning to a Knowledge Graph and the tools and technologies that can be used to support this process.*

1.2 Deliverable Overview and Report Structure

In this section, a detailed overview of the Deliverable's Structure will be provided, outlining the different chapters and their respective content. This information aims to provide a clear understanding of the key components of the deliverable and their organization.

Chapter 1 Generic Introduction to the DT4GS ecosystem. Mapping outcomes and results of D3.1 to WP3 tasks.

Chapter 2 of the report begins by defining an Information Hub as a centralized platform that collects and shares information on a particular subject area. The chapter then introduces the Information Hub on Shipping Sector, which provides an overview of the shipping industry and its impact on the environment.

Overall, Chapter 2 emphasizes the importance of knowledge sharing and collaboration in driving sustainable development in the shipping sector, and highlights the role that Information Hubs can play in facilitating these efforts.

In addition to introducing the Information Hub on Shipping Sector, Chapter 2 of the report emphasizes the critical steps involved in creating an observatory for green shipping. This includes identifying data sources from academic research, industry reports, government data, and Living Labs (LLs). The chapter also highlights essential activities involved in data analysis and classification, which involves the systematic collection, processing, and interpretation of data from various sources. Furthermore, engagement with stakeholders is considered a crucial component in the development and implementation of the observatory, which fosters collaboration and partnerships between different actors in the shipping industry, promotes dialogue and knowledge-sharing, and ensures that the observatory is designed to meet the needs of the industry. Overall, Chapter 2 sets the foundation for the development and implementation of the observatory, providing a roadmap for the creation of a centralized platform to collect and share information on green shipping solutions.

Chapter 3 focuses on gathering data to inform the development and implementation of green shipping technologies. This chapter outlines the main technologies of green shipping and discusses various sources of data that can be used to evaluate these technologies. The subsections of this chapter include Use of new fuels, Navigation parameters, Features/components of ships, and Other green shipping technologies. It also explores deeper into the Green Shipping technologies (GS technologies) that have been developed to promote sustainability in the shipping industry. The subsection dedicated to GS technologies provides an in-depth overview of the different types of technologies and solutions that are available in the market. The purpose of this subsection is to inform the stakeholders about the advancements in green shipping technologies and the benefits they offer.

The subsection starts by highlighting the need for green shipping technologies, given the environmental impact of the shipping industry. It then proceeds to discuss the various types of green shipping technologies, such as alternative fuels, navigation parameters, and ship features/components. Alternative fuels like Liquified Natural Gas (LNG), Liquified Hydrogen (LH2), and Straight Vegetable Oil (SVO) are discussed in detail, including their advantages and disadvantages. The navigation parameters section covers topics like speed reduction, route optimization, and hull cleaning, among others.

In addition to established technologies, the subsection also covers emerging technologies like wind power and electric propulsion, which have gained significant interest in recent years due to their potential to reduce greenhouse gas emissions. The subsection provides detailed explanations of how these technologies work and how they can be implemented in the shipping industry.

In **Chapter 4** of the report, the focus is on the implementation of a Knowledge Hub (KH) for the purpose of monitoring and evaluating green shipping technologies. The chapter begins by providing a definition of what a Knowledge Hub is and how it differs from an Information Hub. It then goes on to give a detailed overview of the database structure, taxonomy, and schema used to store and query data. The structure of the database is designed to support the different types of data that need to be stored and organized, such as data from Living Labs (LLs), academic research, industry reports, and government data.

The chapter also covers the process of expanding and maintaining the database, including data quality control and data enrichment techniques. This involves ensuring that the data stored in the database is accurate, relevant, and up-to-date. In addition, the chapter discusses the process of transitioning from a Knowledge Hub to a Knowledge Graph (KG) using various tools and technologies.

Overall, Chapter 4 provides a comprehensive overview of the implementation of a Knowledge Hub for green shipping technologies. It covers the essential components of the hub, including the database structure, taxonomy, and schema, as well as the processes involved in maintaining and expanding the database over time. The chapter also outlines the benefits of transitioning to a Knowledge Graph and the tools and technologies that can be used to support this process.

Moreover, the report presents a thorough analysis of the implementation of a Knowledge Hub, which serves as a centralized platform for monitoring and evaluating the effectiveness of green shipping technologies. It describes the differences between Information Hub and Knowledge Hub, and provides insights into the database structure, taxonomy, and schema used to store and query data. The report also covers the process of expanding and maintaining the database and transitioning to a Knowledge Graph using advanced tools and technologies. Overall, this report provides valuable insights into the development and implementation of sustainable solutions within the shipping industry.

Table 3 Summary of Chapters in the DT4GS Report – D3.1

Chapter	Focus
1	Introduction to the DT4GS ecosystem and mapping D3.1 outcomes and results to WP3 tasks
2	Information Hub on Shipping Sector, importance of knowledge sharing and collaboration, creating an observatory for green shipping
3	Overview of green shipping technologies, different sources of data for evaluation, subsections on types of green shipping tech
4	Implementation of a Knowledge Hub for monitoring and evaluating green shipping technologies, database structure and taxonomy

2 Information Hubs

2.1 Definition

Information Hubs can take many forms, including websites, online communities, social media groups, databases, and physical locations such as libraries or resource centres. They can be public or private, open to everyone or restricted to a specific audience, such as employees or members of an organization. The primary purpose of an information hub is to provide easy access to valuable information, resources, and knowledge related to a specific field or subject. This can include industry news, research, best practices, case studies, and other useful information that helps individuals and organizations stay up-to-date and informed. Overall, information hubs or knowledge hub are valuable resources that provide a centralized location for information and knowledge, making it easier for individuals and organizations to stay informed and make informed decisions.

Some examples of information hubs include:

1. Government websites that provide information on regulations, policies, and programs related to a specific industry or issue.
2. Online communities and forums where professionals in a particular field can connect, share knowledge, and ask questions.
3. Industry-specific databases that contain data on market trends, consumer behavior, and other key metrics.
4. Corporate intranets that serve as a central repository of information for employees, including company policies, procedures, and training materials.
5. Libraries and resource centres that provide access to books, journals, and other publications related to a specific field.

Establishing an information hub is a valuable tool for knowledge mobilization, sharing best practices, and informing policy and practice. One way to establish such a hub is through a systematic integrative review of existing scientific literature and databases.

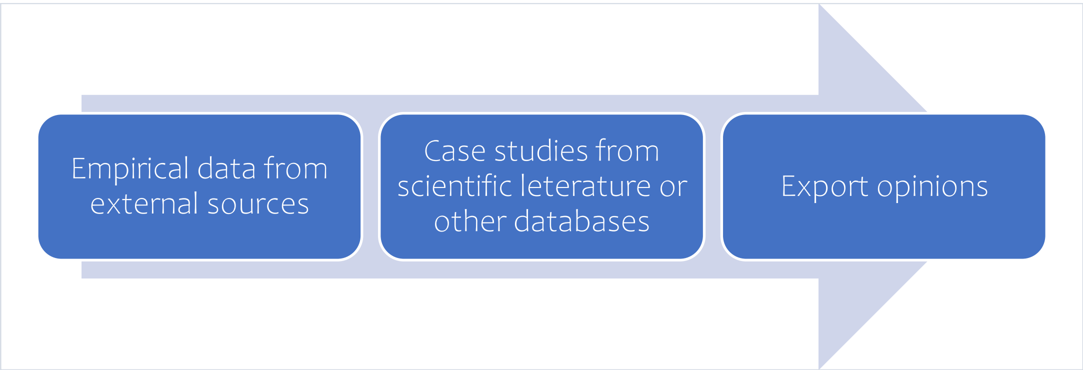

Figure 3 Range of information that will be used in an integrate review

An *integrative review* is a comprehensive review method that provides a thorough understanding of a particular issue by summarizing data from previous studies with diverse methodologies. The use of an integrative review is particularly useful for creating an information hub because it allows for the inclusion of a broad range of studies and data sources. This method involves synthesizing data from various studies and sources to create a more comprehensive and nuanced understanding of a particular topic. By using an integrative review, an information hub can incorporate a wide range of information, including empirical data, case studies, and expert opinions, to create a centralized platform for knowledge mobilization.

In addition to providing a comprehensive understanding of a particular issue, an integrative review can also identify gaps in existing knowledge, highlight areas for further research, and inform evidence-based decision-making. As such, establishing an information hub through an integrative review can help bridge the gap between research and practice, providing practitioners and policymakers with the information they need to make informed decisions and take action on pressing issues.

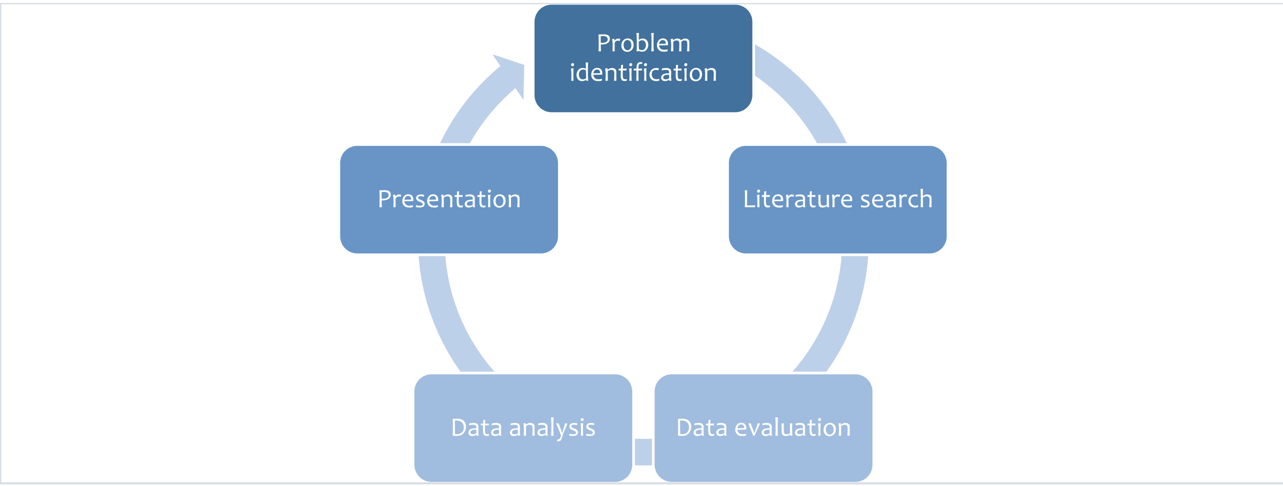

Figure 4 Systematic approach to information hub

The review followed the steps (as show in Figure 4): problem identification, literature search, data collection, data evaluation, data analysis, and interpretation and presentation of results. By establishing an information hub, the aim is to create a centralized platform for knowledge mobilization, sharing best practices, and informing policy and practice (as show in Figure 5).

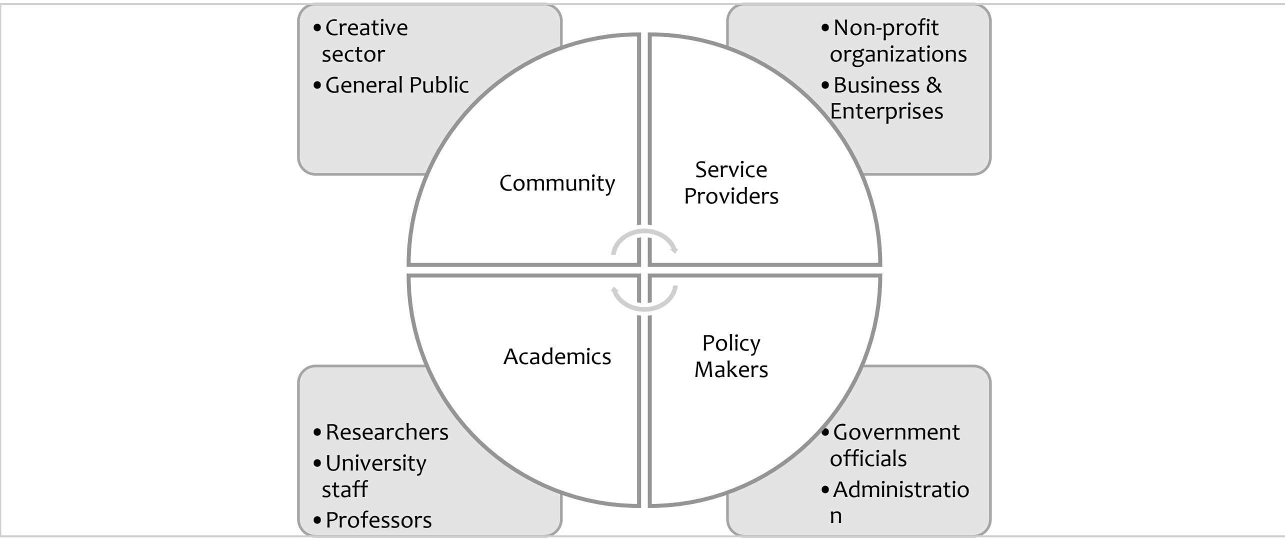

Figure 5 Knowledge Hub structure

2.2 Information Hub on Shipping Sector

Creating an information hub in the shipping sector involves several steps, as shown in Figure 6:

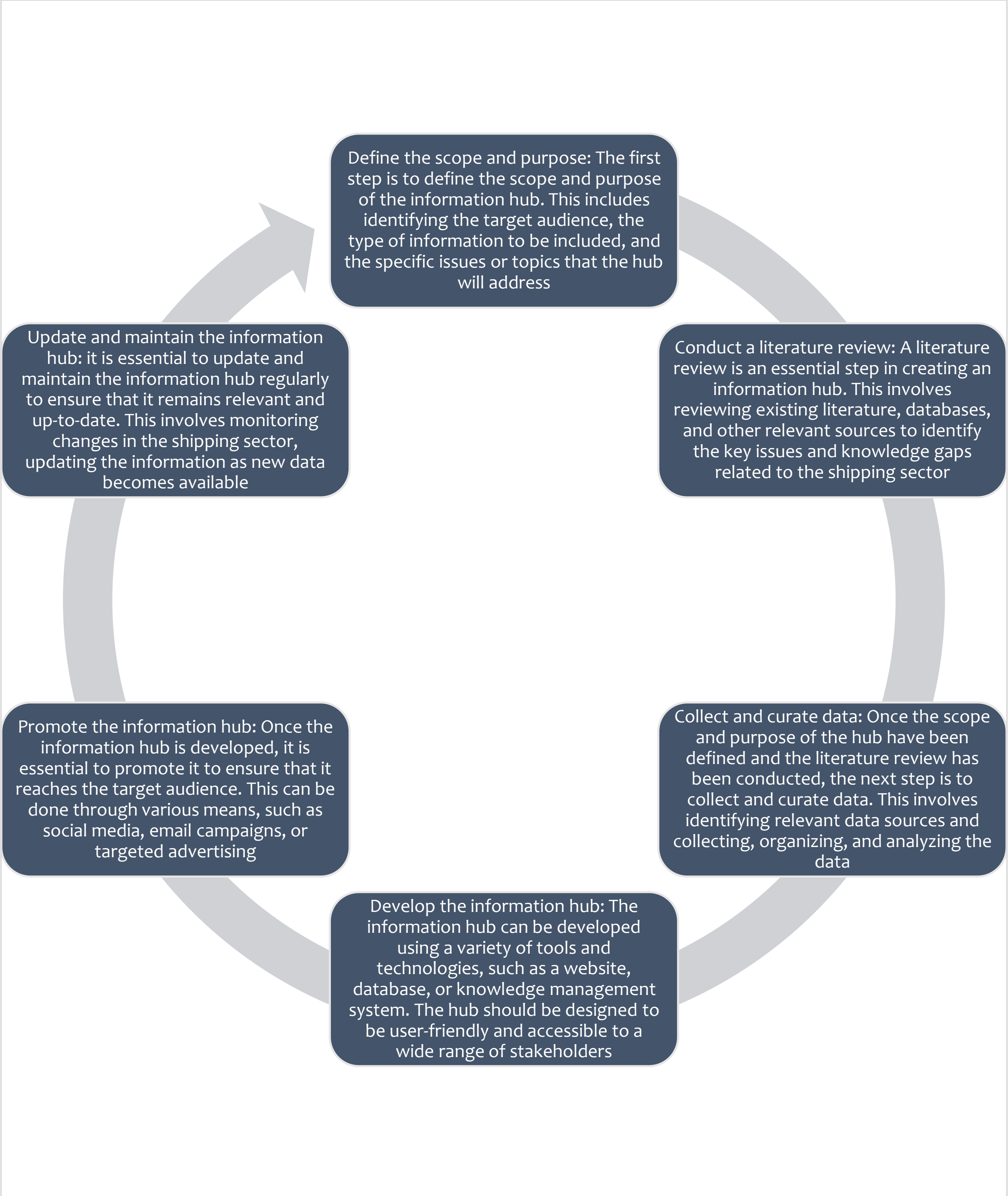

Figure 6 General definition and structure of Information Hub in the shipping sector

Overall, creating an information hub in the shipping sector requires careful planning, data collection, and curation, as well as the use of appropriate tools and technologies. By providing a centralized platform for information and knowledge-sharing, an information hub can help promote sustainability, compliance, and innovation in the shipping sector.

2.3 Identify Relevant Structure of Information Hub

This knowledge hub will serve as an observatory for monitoring ship emissions and the effectiveness of various green shipping solutions. By bringing together data from multiple sources and stakeholders, the aim is to create a centralized platform for sharing knowledge and fostering collaboration in the field of green shipping. Ultimately, this will help to drive innovation and promote sustainable practices across the shipping industry.

As shown in Figure 7 at the base of the pyramid is data. This includes raw data collected from various sources, such as sensors, surveys, and databases. Data is often vast and unstructured, making it difficult to understand and analyse on its own. However, by applying various techniques and technologies, such as data mining, machine learning, and natural language processing, data can be transformed into meaningful information.

In the middle of the pyramid is information. Information is the result of processing and analysing data, and it provides valuable insights and knowledge that can be used to support decision-making. Information is often presented in various formats, such as reports, dashboards, and visualizations, to make it easier to understand and communicate to stakeholders.

At the top of the pyramid are people and action. People are the ultimate users of the information, and they are responsible for taking action based on the insights and knowledge provided. This may involve making decisions, implementing new policies or procedures, or developing new solutions to address a particular challenge or opportunity.

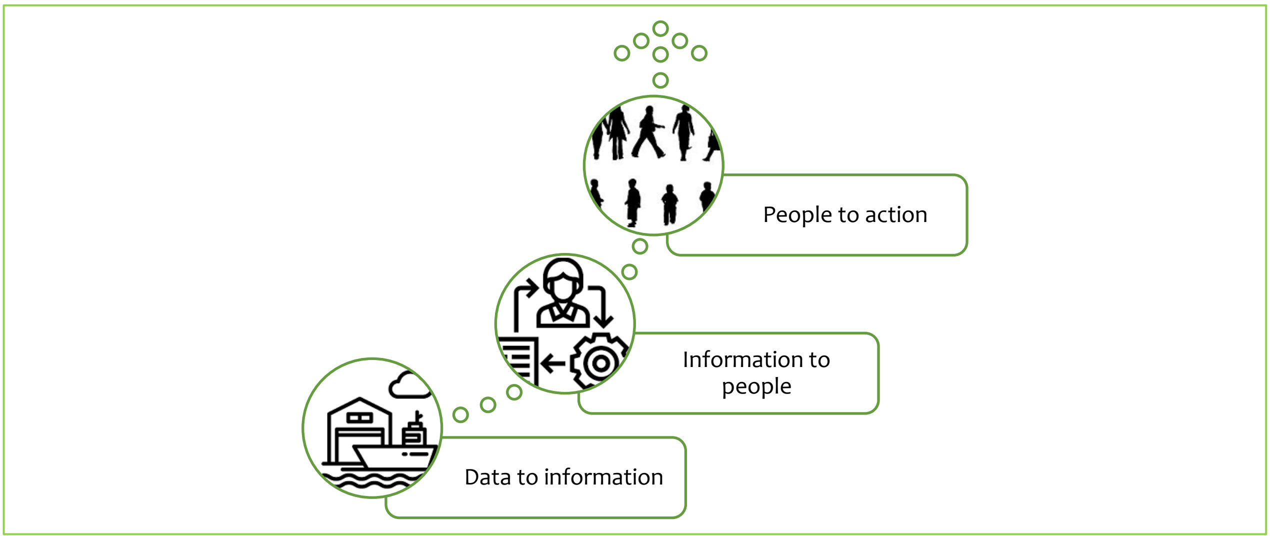

Figure 7 The Flow of Data to Action

The flow of data to information, information to people, and people in action is not always linear. Instead, it is often iterative, with feedback loops that allow for continuous improvement and optimization. For instance, people may provide feedback on the quality and relevance of the information they receive, which can be used to refine the data collection and analysis process.

As shown in Figure 8 **Identification of data sources** is a crucialstep in creating an observatory for green shipping. This process involves identifying and gathering relevant data from various sources that can provide valuable insights into the environmental impact and costs of green shipping technologies. There are many potential data sources that can be used to support the observatory, including academic research, industry reports, government data, and **data obtained from Living Labs (LLs)** - collaborative spaces where stakeholders can experiment with and develop new green shipping solutions.

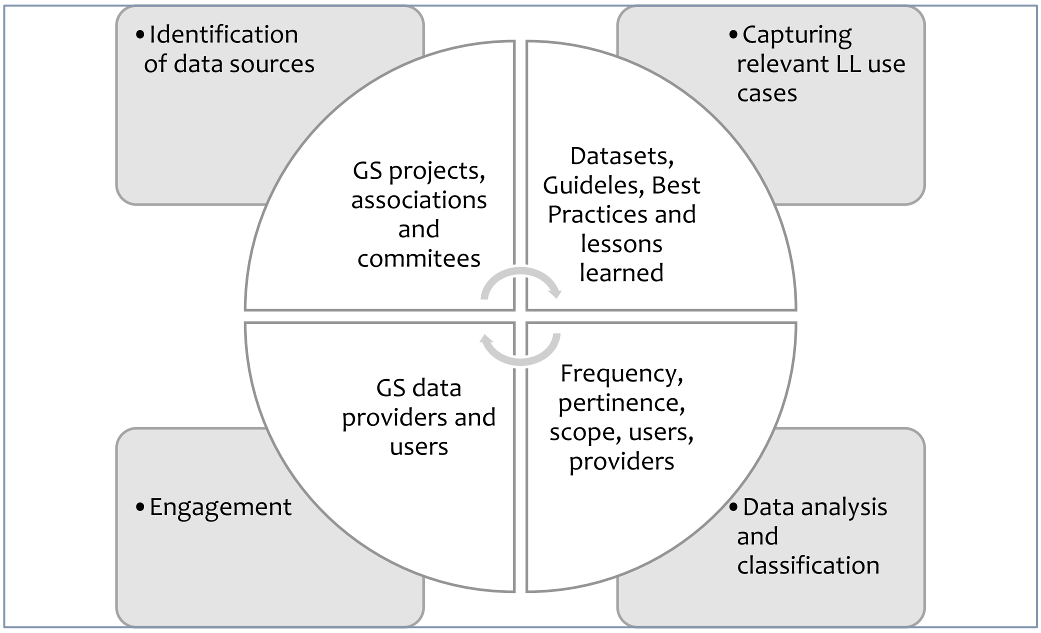

Figure 8 Structure and relations of database

To identify relevant data sources, it is meaningful to first define the scope of the observatory and the types of data that are needed to support its objectives. This may involve conducting a needs assessment to determine what data is required to support decision-making and knowledge-sharing in the industry. Once the scope and objectives of the observatory have been defined, it is important to develop a systematic approach to identifying data sources. It can be associated by conducting literature reviews, consulting with industry experts and stakeholders, and using web crawlers or other automated tools to collect data from relevant websites and databases.

Table 4 Components of Observatory for Green Shipping

Components	Description
Identification of Data Sources	Critical step in creating an observatory for green shipping. Involves gathering relevant data from various sources like academic research, industry reports, government data, and data obtained from Living Labs (LLs).
Data Analysis and Classification	Essential activities involving the systematic collection, processing, and interpretation of data from various sources. Data analysis involves using statistical methods and

	algorithms to extract insights and knowledge from the data while data classification involves organizing and categorizing data according to various criteria.
Engagement	Involves actively involving stakeholders in the development and implementation of the observatory, fostering collaboration and partnerships between different actors in the shipping industry. The goal is to promote dialogue and knowledge-sharing among stakeholders and ensure that the observatory is designed and implemented in a way that meets the needs of the industry.

Furthermore, it is also important to ensure that the data sources are reliable and up-to-date, and to establish mechanisms for data validation and quality control. This may involve establishing partnerships with data providers and developing data-sharing agreements that define the terms of data use and confidentiality.

Overall, the process of identifying data sources is a critical component of creating an observatory for green shipping. By systematically identifying and gathering relevant data from a variety of sources, it can be developed a comprehensive knowledge hub that supports informed decision-making and promotes sustainable practices in the shipping industry.

As shown in Figure 8 and in Table 4 **Data analysis and classification** are essential components of the process of creating an observatory for green shipping. These activities involve the systematic collection, processing, and interpretation of data from various sources in order to extract meaningful insights and knowledge about the environmental impact and costs of green shipping technologies.

Data analysis typically involves using statistical methods and algorithms to identify patterns and trends in the data. This can include descriptive statistics, such as mean, median, and standard deviation, as well as more advanced techniques like regression analysis and machine learning algorithms. The goal of data analysis is to extract insights and knowledge from the data that can inform decision-making and support the development of new green shipping technologies and practices.

Data classification, on the other hand, involves organizing and categorizing data according to various criteria, such as frequency, pertinence, scope, users, providers, etc. This process can be manual or automated, and typically involves creating a taxonomy or ontology that defines the relationships between different data points. The main scope of data classification is to make it easier to search and access the data, as well as to facilitate analysis and interpretation.

Together, data analysis and classification can provide valuable insights into the environmental impact and costs of green shipping technologies, as well as the challenges and opportunities associated with their implementation. By systematically collecting and organizing data from various sources, and applying statistical and machine learning techniques to extract knowledge and insights, the development of a more sustainable shipping industry can be supported.

Also, **Engagement** is a crucial component of creating an observatory for green shipping, involving the active involvement of stakeholders in the development and implementation of the observatory. This fosters collaboration and partnerships between different actors in the shipping industry, with engagement taking many forms, including workshops, conferences, webinars, online forums, and social media. The scope of engagement is to promote dialogue and knowledge-sharing among stakeholders, ensuring that the observatory is designed and implemented in a way that meets the needs of the industry.

Engagement with stakeholders also promotes awareness and understanding of green shipping technologies and practices, building support for their adoption. This is particularly important in a complex and rapidly evolving industry like shipping, where there are often competing interests and perspectives. To facilitate engagement, a clear communication strategy that identifies the target audience, key messages, and communication channels is essential, and mechanisms for feedback and evaluation should be included to ensure the effectiveness of engagement activities in achieving their goals. Overall, engagement is critical to creating a relevant, useful, and widely adopted observatory for green shipping.

Living Labs (LLs) are spaces where stakeholders collaborate and develop innovative green shipping solutions. To integrate information from Living Labs into a green shipping observatory, it is important to take the following steps:

1. Identify relevant Living Labs: The first step is to identify the Living Labs that are relevant to your knowledge domain and objectives.
2. Gather information from Living Labs: Information can be gathered from Living Labs through various sources such as websites, publications, reports, and workshops.
3. Extract and organize data from Living Labs: After gathering information, data should be extracted and organized according to categories defined in the taxonomy or ontology.
4. Validate and quality check data: Data validation is important to ensure that the data obtained from Living Labs is reliable and up-to-date. Partnerships can be established with Living Labs to verify the data and develop data-sharing agreements.
5. Integrate data into the observatory: After data validation and quality checking, it can be integrated into the green shipping observatory. Data visualization tools and machine learning algorithms can be used for analysis and automation.

The following table summarizes the key steps involved in integrating information from Living Labs into a green shipping observatory:

Table 5 Steps for Integrating Living Labs Data into an Observatory for Green Shipping

Step	Description
1.	Identify relevant Living Labs
2.	Gather information from Living Labs
3.	Extract and organize data from Living Labs
4.	Validate and quality check data

5.	Integrate data into the observatory

To integrate data from Living Labs into an observatory, a data integration process must be developed. This process can involve using tools like Apache NiFi or Talend to extract data from Living Labs and load it into the database. Alternatively, if the data is provided in a CSV format, it can be directly uploaded into the observatory.

Once the data is in the observatory, data visualization tools can be used to create interactive dashboards and reports. These tools can help to identify patterns and trends in the data and can provide stakeholders with valuable insights.

It is important to note that the specific tools used will depend on the requirements of the observatory. Additionally, it is important to ensure that the data is validated, and quality checked before integration into the observatory to ensure that it is reliable and up to date.

3 Green Shipping Technologies (GS Technologies)

There are many data sources available that can contribute to our understanding of green shipping practices. These sources include information on green shipping projects, associations promoting sustainable shipping practices, local actions taken to reduce emissions, and commitments made by businesses and governments to support environmentally friendly shipping. In addition to these sources, data obtained from Living Labs (LLs) will be integrated- collaborative spaces where stakeholders can experiment with and develop new green shipping solutions - to create a comprehensive knowledge hub on green shipping.

There are many projects at international level on green shipping; **green shipping is understood as a combination of practices and technologies used in order to reduce the GHG and other pollutant emissions from the ship sector, minimizing the consumption of energy and resources; referring not only to emission produced directly from the ship during the navigation, but also during the port operations, in the phase of construction, throughout the entire lifecycle**.

In recent years, the EU has tackled the problem of air pollution by limiting the sulphur content of fuels (Directive 1999/32/EC). This has resulted in a reduction of the levels of sulphur emitted by land-based sources and air transport. However, air quality in Europe, is failing to meet all the standards set by EU/UN Gothenburg protocol. Further steps are therefore required to reach the targets set. These steps have included looking at other sulphur emitting industries.

As the combustion characteristics of marine engines, along with the wide-spread use of unrefined fuel, results in significant amounts of SO_2, NO_x and particulate being released into the atmosphere (as summarized in Figure 9), shipping has now become the focus of efforts to reduce air pollution and gain greener ships.

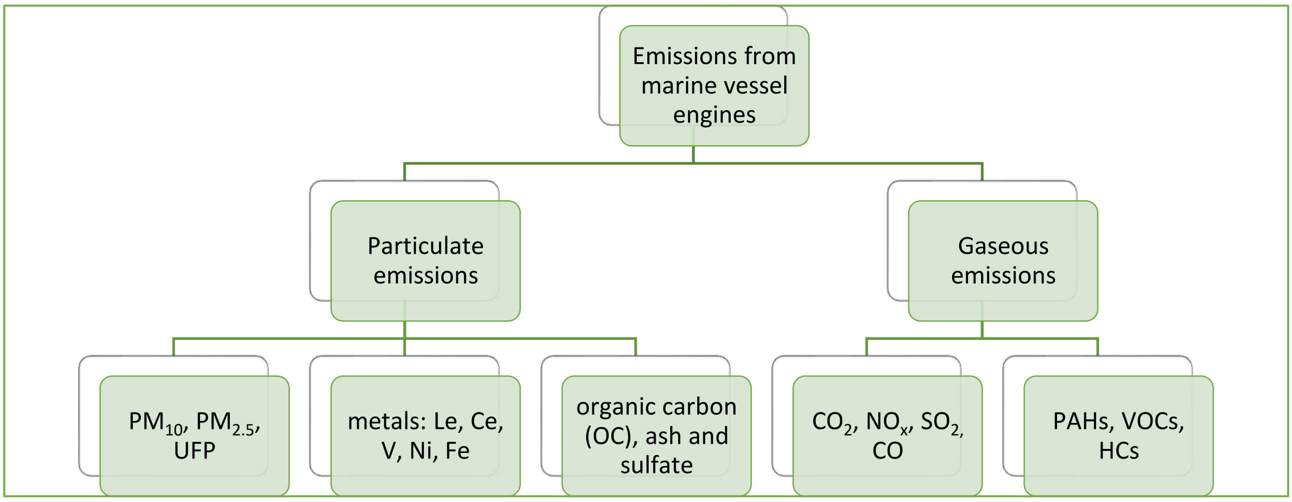

Figure 9 Emission from marine vessel engines

The shipping sector is responsible for about 3% of the total GHG emissions around the world, about one million tons/years of CO_2 (Lindstad et al. 2021); it has an high environmental impact concerning the emission of GHG and other air pollutants, such as SO_2, NOx, PM_{10}, that reduce the air quality in port cities, as well as favouring the acidification and eutrophication of the seas; the ships are the main mean of transport of goods (about 90% of goods, Busch et al. 2018), they have a less environmental impact than other means of transport in proportion to the goods, express as emission per ton/km, but still high. The European Union aims to achieve zero CO_2 emissions by 2050, and a reduction by 55% in 2030 compared to 2008. Green shipping technologies (GS technologies) refer to a variety of technologies and practices that are designed to reduce the environmental impact of shipping. These technologies and practices are aimed at minimizing the use of fossil fuels, reducing greenhouse gas emissions, and minimizing other environmental impacts such as air pollution, noise pollution, and waste generation.

Seeing that there is a need of minimizing the serious problems caused by emissions various sustainability projects are funded by the EU that aim to reduce emissions in the shipping industry by showcasing innovative technologies and practices. These projects focus on promoting new "environmental trends" such as alternative fuels and energy-efficient technologies, as well as creating new business models to support the transition to a more sustainable shipping sector. Below are listed several EU-funded projects:

1. Green Maritime Methanol Project (https://greenmaritimemethanol.nl/introduction/): This is a collaboration between major shipping companies, including Maersk and NYK Line, aimed at developing methanol as a sustainable fuel for the shipping industry. The project aims to demonstrate the feasibility of using methanol as a marine fuel, as well as to promote the development of the necessary infrastructure for its widespread use.
2. Poseidon Med II (https://trimis.ec.europa.eu/project/poseidon-med-ii): This is an EU-funded project focused on the deployment of liquefied natural gas (LNG) as a marine fuel in the Mediterranean region. The project involves the development of the necessary infrastructure, as well as the demonstration of LNG-powered vessels in the region.
3. Greening of European Shipping (https://transport.ec.europa.eu/transport-themes/sustainable-transport/european-sustainable-shipping-forum_en): This is an initiative of the European Sustainable Shipping Forum (ESSF), aimed at promoting sustainable practices and technologies in the European shipping industry. The initiative focuses on areas such as energy efficiency, emissions reduction, and waste management.
4. The Fuel Cells and Hydrogen Joint Undertaking (FCH JU), the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) and The Clean Hydrogen Partnership (https://www.clean-hydrogen.europa.eu/media/publications/hydrogen-roadmap-europe-sustainable-pathway-european-energy-transition_en): FCH JU and FCH 2 JU are public-private partnership between the European Union, industry, and research organizations focused on the development of hydrogen and fuel cell technologies. These projects support research, development, and demonstration projects related to fuel cells and hydrogen technologies for a variety of applications, including marine transport. The Clean Hydrogen Partnership programme, successor to the FCH JU and FCH 2 JU, aims to strengthen and integrate the European Union's research and innovation capacity to accelerate the development and improvement of market-ready advanced clean hydrogen applications in the fields of energy, transport, construction and industrial end-uses, while strengthening the competitiveness of the Union's clean hydrogen value chain. The three members of the partnership are the European Commission, the fuel cell and hydrogen industries represented by Hydrogen Europe and the research community represented by Hydrogen Europe Research.
5. ENGIMMONIA (https://www.engimmonia.eu/) – The project tackles IMO challenges targeting decarbonization by proving the capabilities and the key role of ammonia as the most promising clean fuel for the future of the shipping sector, demonstrating clean energy solutions for on-board electricity and HVAC, fostering replicability at business, regulatory, policy and naval classification. Decarbonising long distance shipping ENGIMMONIA is a project that aims to develop sustainable technologies for future long-distance shipping to achieve complete decarbonisation. The project focuses on the use of alternative fuels and energy-efficient technologies to reduce emissions and

promote sustainability in the shipping industry.

6. First Bio-LNG Production Plant for Marine Shipping (https://nordsol.com/project-wilp/) - With the FirstBio2Shipping project, partners Attero, Nordsol and Titan aim to decarbonize the maritime sector by demonstrating the first industrial plant producing renewable, low-carbon bio liquified natural gas (bio-LNG) in a standardised and scalable fashion, enabling the cost-effective substitution of heavy fuel oil (HFO).
7. Electrically powered vessels TrAM - Transport: Advanced and Modular (https://tramproject.eu/) - The aim of the TrAM project was to develop a zero emission fast going passenger vessel through advanced modular production. The project was revolutionary both in terms of zero emission technology and manufacturing methods, and will contribute to making electric-powered high-speed vessel competitive in terms of both cost and the environment. The TrAM project vessel Medstraum is currently operating a daily route in Stavanger, Norway.
8. Low-cost wind propulsion system Aspiring Wingsail (http://aspiringwingsails.eu/) - The specific objective of the project was to provide the fishing and the maritime sectors with a novel aspiring wingsail suitable for vessels which do not require a foldable solution while offering up to 30% savings in fuel use, reducing CAPEX (hardware costs) and making the solution accessible to more vessels.
9. On-Shore Power Supply TWIN-PORT III (https://trimis.ec.europa.eu/project/twin-port-iii) - This is a project that focuses on infrastructure developments on the Tallinn-Helsinki maritime link TWIN-PORT. The project aims to promote sustainability in the shipping industry by providing on-shore power supply to ships, reducing emissions and improving air quality in ports.

In addition to the EU-funded projects, there are also numerous international sustainability projects aimed at reducing emissions in the shipping industry through the implementation of innovative technologies and practices. These projects share similar objectives to the EU-funded initiatives, including the promotion of alternative fuels and energy-efficient technologies, as well as the development of new business models to facilitate the transition to a more sustainable shipping sector. Below are listed several International-funded projects:

1. Global Maritime Energy Efficiency Partnerships Project - GloMEEP (https://glomeep.imo.org/): This is a project of the International Maritime Organization (IMO), aimed at promoting energy efficiency and reducing greenhouse gas emissions from the shipping sector. The project provides technical assistance and training to developing countries to support the adoption of sustainable practices and technologies in the shipping industry.
2. Getting to Zero Coalition (https://www.globalmaritimeforum.org/getting-to-zero-coalition): This is an international partnership of more than 100 companies and organizations that are working together to develop and deploy zero-emission vessels by 2030. The coalition is focused on promoting the development of new technologies, fuels, and infrastructure to support the transition to a more sustainable shipping industry.
3. Clean Shipping Alliance 2020 - CSA 2020 (https://www.cleanshippingalliance2020.org/): CSA 2020 is an international association of shipping companies that are committed to reducing emissions by implementing exhaust gas cleaning systems (also known as scrubbers) on their vessels. The project aims to reduce emissions of sulfur oxides (SOx) and particulate matter (PM) by up to 90%.
4. Smart Green Shipping Alliance - SGSA (https://smartgreenshipping.com/): The SGSA is an international organization that aims to accelerate the transition to a more sustainable shipping industry through the development and deployment of new technologies and practices. The project focuses on promoting the use of alternative fuels, such as hydrogen and ammonia, as well as the adoption of digital technologies to improve efficiency and reduce emissions.
5. Ship Recycling Transparency Initiative - SRTI (https://www.shiprecyclingtransparency.org/) - This project is a global platform for sharing information and promoting best practices in ship recycling.

The initiative is focused on improving transparency and accountability in the ship recycling industry, with the aim of reducing environmental and social impacts.

6. Sustainable Shipping Initiative - SSI (https://www.sustainableshipping.org/) - The SSI is an international coalition of shipping companies and stakeholders that are working together to promote sustainability in the shipping industry. The initiative focuses on a range of issues, including reducing emissions, improving ship design and operation, and promoting sustainable practices throughout the supply chain.
7. Carbon War Room Shipping Efficiency Advisory Service - SEAS (https://rmi.org/our-work/shipping-efficiency/) - SEAS is a program of the Rocky Mountain Institute's Carbon War Room initiative that provides technical and financial advice to shipping companies to help them improve their efficiency and reduce emissions. The program offers a range of services, including energy audits, fuel efficiency assessments, and guidance on technology and operational improvements.
8. Poseidon Principles (https://www.poseidonprinciples.org/finance/) - The Poseidon Principles is an international framework for assessing and disclosing the climate alignment of ship finance portfolios. The initiative is aimed at promoting investment in ships that are aligned with the goals of the Paris Agreement, including reducing emissions and improving energy efficiency.
9. Port of Los Angeles Shore-to-Ship Power Program (https://www.portoflosangeles.org/environment/air-quality/alternative-maritime-power-(amp) : This program, launched in 2004, was the first of its kind and has become a model for other ports around the world. The program provides shoreside power to container ships at berth, allowing them to turn off their diesel engines and reduce emissions.
10. Port of Vancouver Cold Ironing Project (https://sustainableworldports.org/wp-content/uploads/Deltport_Technical-Paper-Port-of-Vancouver.pdf): This project, launched in 2009, provides shore power to container ships at the Port of Vancouver. It is part of the port's overall strategy to reduce emissions and improve air quality.

The following paragraph gives an overview and analyse in depth several green shipping technologies, including:

Alternative fuels: Alternative fuels, also known as non-conventional and advanced fuels, are fuels that derives from sources other than fossil fuels. Some well- known alternative fuels includes biofuels, hydrogen, liquefied natural gas (LNG), e-fuels, which can reduce the carbon footprint of shipping by emitting fewer greenhouse gases than traditional fossil fuels;

Energy-efficient designs: Energy-efficient ship designs, such as hull coatings, propeller designs, and waste heat recovery systems, can reduce fuel consumption and greenhouse gas emissions;

Renewable energy: Renewable energy sources, such as solar and wind power, can be used to provide auxiliary power to ships, reducing reliance on fossil fuels;

Smart shipping technologies: Smart shipping technologies such as autonomous vessels, digitalization, and artificial intelligence, can optimize ship operations, reducing fuel consumption and environmental impact. Smart shipping technologies represent the modern features that companies and the entire maritime industry strive to achieve.

Port-based solutions: Port-based solutions, such as shore power, can help reduce air pollution by providing ships with electricity while they are at port, allowing them to turn off their engines;

Waste management: Effective waste management practices, such as waste segregation and recycling, can reduce the amount of waste generated by ships and minimize the impact of waste on the environment.

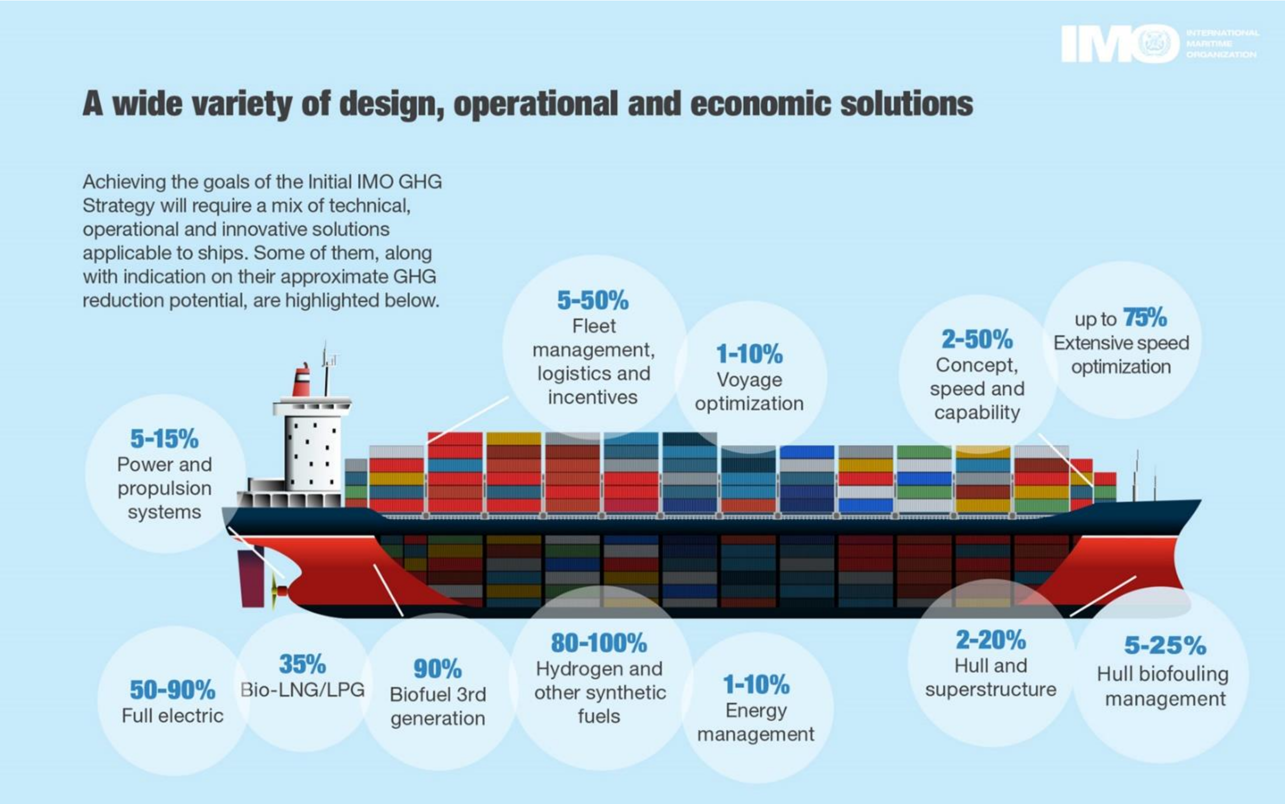

Figure 10 Design and solutions for Green Shipping [1]

Overall, GS technologies are essential for promoting sustainable shipping practices and reducing the environmental impact of shipping. These technologies and practices are becoming increasingly important as the shipping industry faces increasing pressure to reduce its carbon footprint and comply with environmental regulations. By adopting GS technologies, shipping companies can not only reduce their environmental impact but also improve their bottom line by reducing fuel consumption and operating costs.

3.1 Main Technologies of Green Shipping

Maritime transport is a vital component of the global economy and trade, and is therefore heavily globalized. Within the EU, maritime transport accounts for 77% of external trade and 35% of intra-EU trade. As of 2019, ships registered under an EU Member State flag represented 17.6% of the total world fleet measured in dead weight tonnage (DWT). EU passenger ships have the capacity to carry up to 1.3 million passengers, which is equivalent to 40% of the world's passenger transport capacity.

Almost half of maritime traffic in the EU in 2019 came from ships engaged solely in domestic routes, mainly due to roll-on, roll-off passenger ships and ferries making frequent crossings. In terms of the weight of goods traded between the EU-27, the UK, and the rest of the world, EU ports handled close to

[1] Available online: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx

4 billion tonnes of goods, accounting for roughly half of all traded goods. Maritime transport is a crucial pillar of the Blue Economy; however, it also puts immense pressure on the environment[2].

Maritime transport is a significant contributor to environmental issues, with greenhouse gas emissions, air pollution, and particulate matter from shipping and port activities leading to global warming, increased extreme weather events, and rising sea levels. The sector emits approximately 940 million tonnes of CO_2 per year, representing about 2.5% of global greenhouse gas emissions.

Without rapid implementation of mitigation measures, these emissions are expected to rise considerably in the future. Furthermore, other environmental impacts of maritime transport include noise pollution, waste disposal, and ballast water discharge, which can introduce invasive species into ecosystems and cause significant ecological damage. In response to these issues, various international regulations have been put in place to reduce emissions and promote sustainable practices, such as the International Maritime Organization's (IMO) Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) guidelines, as well as the Ballast Water Management Convention.

Green shipping aims to minimize the environmental impact of the shipping industry by reducing ship emissions through various practices and technologies. This includes adopting different strategies that can be summarized in:

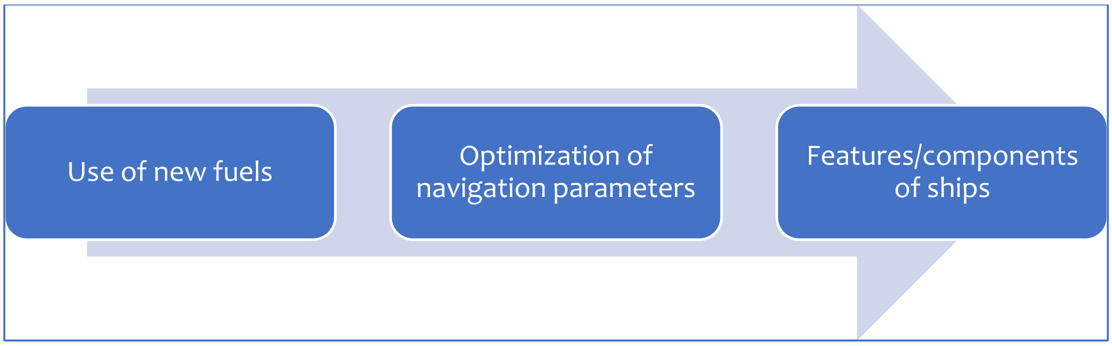

Figure 11 GS approach and strategy

With increasingly strict emission regulations from governments and international environmental protection organizations, the shipbuilding industry faces significant challenges in utilizing cleaner energy and implementing more efficient exhaust gas treatment technologies. Table 6 provides a review of recent advancements in ship exhaust control technology and lists the applications of clean energy sources such as liquefied natural gas, biodiesel, methanol, hydrogen, ammonia, and shore power in ships.

Table 6 Summary of ship exhaust control technology (Zhao et al., 2021)

Ref	Technologies	Raw materials/research purposes/methods
Taccani et al., 2020	LNG	Natural gas/High energy density storage of gaseous marine fuel/Innovative pressure cylinder
Peng et al., 2020	LNG	Diesel, natural gas/The impact of ship emissions on health and climate change/Dual-fuel engine

[2] https://op.europa.eu/o/opportal-service/download-handler?identifier=156eecbd-d7eb-11ec-a95f-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part=

Ref	Technologies	Raw materials/research purposes/methods
Yoo, 2017	LNG	LNG/Economic evaluation of LNG as marine fuel/Develop natural gas systems and infrastructure
Yang et al., 2016	Biodiesel	Biological oil/Reduce exhaust emissions from marine diesel engines/Biodiesel blended fuel
Arvindnarayan et al., 2019	Biodiesel	Microalga biodiesel/Reduce exhaust emissions from marine diesel engines/Biodiesel blended fuel
Viornery-Portillo et al., 2020	Biodiesel	Waste cooking oil/Environmental impact of ship emissions/Life cycle assessment
Ganesan et al., 2018	Biodiesel	Neem oil/Reduce NOX emissions from biodiesel/Add pentanol
Nour et al., 2020	Biodiesel	Used frying oil/Reduce NOX emissions from biodiesel/Add n-butanol, n-heptanol, n-octanol
Varatharajan and Cheralathan, 2013	Biodiesel	Soybean biodiesel/Reduce NOX emissions from biodiesel/Add aromatic amine antioxidants
Manikandan et al., 2018	Biodiesel	Mustard oil biodiesel/Reduce NOX emissions from biodiesel/Add carbamide
Venu and Appavu, 2020	Biodiesel	Polanga biodiesel/Reduce NOX emissions from biodiesel/Add alumina nanoparticles
Venu et al., 2021	Biodiesel	Jatropha biodiesel/Reduce NOX emissions from biodiesel/Add alumina nanoparticles
Wei et al., 2021b	Methanol	Diesel-methanol blends/Improvement of combustion process and thermophysical properties of methanol blended fuel/Add aluminium oxide nanoparticles
Wei et al., 2021a	Methanol	Diesel-methanol blends/Improvement of combustion process and thermophysical properties of methanol blended fuel/Add alumina, ceria and silica nanoparticle
Paulauskiene et al., 2019	Bio-methanol/Biodiesel	Bio-methanol-biodiesel-diesel blends/Reduce exhaust emissions and corrosive effects of methanol/Add tert-butylamine
Manigandan et al., 2020	Hydrogen	Hydrogen blends/Reduce NOX emissions from hydrogen/Add TiO_2, CNT nanoparticles
Rehbein et al., 2019	Ammonia	Ammonia-methanol blends/Keep the gaseous ammonia in the liquid phase and reduce CO_2 emissions/Add methanol as solvent

Ref	Technologies	Raw materials/research purposes/methods
Ramacher et al., 2020a	Shore power	–/Simulate the emissions of ships during berthing/Meteorological and chemical coupling forecast transportation model
Ramacher et al., 2020b	Shore power	–/Simulate the emissions of ships during berthing/One-way nested chemistry transport modelling system
Lisi and Cimino, 2020	SCR	V_2O_5-WO_3/TiO_2/Reduce catalyst deactivation/Use acid carrier and improve formulation
Yang et al., 2020	SCR	$CuMnFeO_4$/Improve selective catalytic reduction activity and anti-poisoning ability/Enhance metal-metal interaction
Ushakov et al., 2019b	EGR/LNG	LNG/Reduce methane leakage and NOX emissions/Combine low-pressure EGR and seawater washing technology
Jiang et al., 2019	EGR	Diesel/Low fuel consumption and NOX emission reduction/Combine engine multiple injection and EGR
Balasubramanian et al., 2021	EGR/Biodiesel	Biodiesel blended fuel/Reduce NOX emissions/EGR

The following chapters of the report will describe several parameters that can contribute to reducing greenhouse gas emissions from shipping. These parameters include implementing different strategies such as:

- **Alternative/new fuels**: this involves using fuels that emit lower levels of greenhouse gases, such as biofuels, hydrogen, ammonia, e-fuels, methanol, etc.
- **Energy-efficient designs**: this involves designing ships with more energy-efficient engines and hull shapes, which can help reduce fuel consumption and emissions.
- Slow steaming: this is a practice of operating ships at slower speeds, which can significantly reduce fuel consumption and emissions.
- **Port optimization**: this involves optimizing port operations to reduce idle time and improve efficiency, which can lead to lower emissions.
- Emissions abatement technologies: this includes installing technologies such as scrubbers and selective catalytic reduction systems to reduce emissions of pollutants like nitrogen oxides and sulphur oxides.
- **Operational measures**: this includes measures like route optimization, which can reduce fuel consumption and emissions by finding the most efficient route for a given journey.
- **Renewable energy**: this involves using renewable energy sources such as wind and solar power to supplement a ship's energy needs.

3.1.1 Use of New Fuels

The shipping industry is transitioning towards the use of alternative fuels to reduce, if not completely eliminate, CO_2 and other gas emissions. Fossil fuels such as gas oil are being replaced by fuels such as ***methane, electricity, ammonia, hydrogen, methanol, and biodiesel***, each with its own advantages and disadvantages (Table 7).

Several studies (Burel et al. 2013, Al-Aboosi et al. 2021, Cheliotis et al. 2021, Zincir 2022, El-Enazi et al. 2021, Hansson et al. 2019, Lindstad et al. 2021, Elkafas et al. 2021, Sharafian et al. 2019, Adamo et al. 2018, Gribi et al. 2021, Iannaccone et al. 2020) suggest that the most promising fuels for the future are methane and ammonia. However, these fuels are not widely available in the market yet and are still at an experimental stage.

Table 7 Features of alternative fuels (Gilbert et al. 2018)

Fuel	Net calorific value	SFC	Operational fuel emission factor (g/kWh)					
	MJ/kg	g/kWh	CO_2	CH_4	N_2O	SO_x	NO_x	PM
LSHFO	40.5	179	541	0.010	0.027	3.23	15.8	0.72
MDO	42.6	170	524	0.010	0.026	0.32	14.8	0.16
LNG	48.6	150	412	3.0	0.016	0.003	1.17	0.027
LH_2	120.0	57	0	0	0	0	0	0
Methanol	20.0	381	522	0	0	0	3.05	0
SVO Soy	37.5	195	–	0.0064	0.013	0.37	17.1	0.19
SVO Rape	37.4	195	–	0.0064	0.013	0.37	17.1	0.19
Biodiesel Soy	37.8	187	–	0.0061	0.013	0.36	17.9	0.18
Biodiesel Rape	37.9	187	–	0.0061	0.013	0.36	17.9	0.18
LSHFO: Light Sulphur Heavy Fuel Oil, MDO: Marine Diesel Oil with 0,1% of sulphur, LNG: Liquified Natural Gas, LH_2 Liquified Hydrogen, SVO: Straight Vegetable Oil								
Biodiesel is substantially different than **SVO** and results in better engine performance. The process of converting plant oils or greases to biodiesel reduces the fuel's viscosity and boiling point, making the product more like conventional diesel fuel. Biodiesel is most commonly blended with petroleum diesel fuel.								

Methane is already widely used for road vehicles, and in the last years it has also been distributed in the ship sector. Methane can be found naturally in large quantities, and it can be easily produced in anaerobic processes, such as biogas, at low cost, and it is then stored liquified with a certain pressure. Although methane alone cannot reset CO_2 emissions, its use instead of heavy fuel oil reduces CO_2 emissions up to 25% (Burel et al. 2013); it also drastically reduces NO_x (80%), SO_2 (90%) and PM_{10} (100%) emissions (Burel et al. 2013). Methane requires large and well-insulated tanks, and, as it is highly flammable, it can constitute a potential hazard and it could not be suitable for all ship types.

Since **ammonia** does not contain carbon atoms, it is not responsible for CO_2 emissions. However, during combustion, it produces a high quantity of nitrogen compounds, such as NOx, which requires an abatement system like a scrubber (Cheliotis et al. 2021, Zincir 2022, Al-Aboosi et al. 2021). Ammonia is stored in tanks as a liquid under certain pressure. It has a valuable calorific value, which allows for achieving high power output comparable to diesel engines, and it also has low flammability. Nonetheless, its production process incurs high costs and has a strong environmental impact, as it involves the production of hydrogen from methane, which is then oxidized to CO_2. Therefore, it is necessary to explore new ways of producing ammonia with lower economic and environmental impacts.

According to a study by Zincir (Zincir et al. 2022), the economic and environmental impact of using ammonia in a hybrid engine ammonia-gas oil was evaluated using real data from a vessel's journey. The study included 13 different scenarios and three types of ammonia, namely brown, blue, and green, which differ in terms of their production method. Brown ammonia derives from fossils sources, as well as the blue one which however is made with carbon capture and storage systems; the green one is rather produced from renewable energies. Moreover brown ammonia gives the highest emissions, while the blue and the green have a reduction of CO_2 emissions between 40 and 80% compared to diesel engines with similar values, and a reduction of SO_2 and PM10 emissions up to 95%.

Hydrogen can be considered as a fuel that has zero emissions of CO2 and other polluting gases when burned, making it a promising alternative to traditional fuels. However, its use is challenging due to high production costs and storage requirements, given its highly flammable nature.

Different studies (such as one by Atilhan et al. 2021) have been conducted to address these issues and promising to reduce the environmental impact and cost of producing and storing hydrogen, particularly through the use of renewable electricity sources for the process known as "green hydrogen" production. Despite the relatively high production costs of green hydrogen compared to non-renewable energy sources, it has the potential to reduce CO2 emissions by up to 75%, depending on the type of renewable energy used in production. Studies indicate that wind power produces the lowest emissions among various renewable energy sources (Gemechu, Eskinder Demisse, and Amit Kumar 2021). This suggests that green hydrogen could be a valuable alternative to traditional fossil fuels in reducing greenhouse gas emissions and promoting sustainable energy practices. As a result, green hydrogen has emerged as a promising alternative fuel that could significantly reduce the environmental impact of transportation, making it an attractive option for a more sustainable future.

The use of **electric or hybrid ships** is one of the main trends in the green shipping, the electric engines allows to reset, or reduce in hybrid ships (electric with gas oil or methanol), the pollutant emissions; the main issue is the electricity storage (He et al. 2022, Zhang et al. 2022), in big ships there are an huge power consumption, so it would be necessary an important battery volume (BESS, battery energy storage systems), higher than fuel tanks volume; to limit this problem is necessary to reduce the energy consumption, with the possibility of producing energy on board, using photovoltaic or wind power. Due to further reduce the impact the energy storage in batteries, which come on shore, should come from renewable sources (He et al. 2022); another disadvantage is represented by the high cost of the lithium batteries. Therefore, for an electric vessel it is important to use an adequate battery size and an efficient energy management strategy for navigation, which can be mainly reach by adjusting the navigation speed (Zhang et al. 2022).

Biodiesel and methanol are not considered particularly promising new fuels, and there are not a lot of studies concerning them. Biodiesel is usually mixed with gas oil, while methanol ~~is~~ can be mixed or used as a particular fuel; their use does not allow an important reduction of the pollutant emissions (particularly for the biodiesel), except for NO_x in the case of methanol. CO_2 is compensated if they are produced from vegetable biomass (only for the quantity of biofuel); but they have the advantage to be able to be easily employed without having to change engine type, moreover, they can be stored in tanks in the ships without requirement of particular safety systems (Hansson et al. 2019). In Hansson et al. 2019, it has been evaluated the use of 7 fuel types, classified using a multicriteria approach, which include economic, environmental, social and technical criteria.

The 7 fuel types under study were: liquified natural gas, liquified biogas, methanol from natural gas, hydrogen from natural gas or from electrolysis with electricity from renewable sources, hydrotreated vegetable oil, and heavy fuel oil as reference. Hansson et al. 2019 stated that the best types of fuel were the liquified natural gas and heavy fuel oil, followed from methanol from natural gas, then the other biofuels (biogas, renewable methanol, hydrotreated vegetable oil) and as last hydrogen from natural gas or electrolysis.

Marine Fuel	Onboard fuel mass ● = Light ■ = Medium ▲ = Heavy	Onboard fuel volume ● = Small ■ = Medium ▲ = Large	Relative WTW Energy ● = Low ■ = Medium ▲ = High	Relative WTW Cost ● = Low ■ = Medium ▲ = high	Relative WTW GHG Emissions ● = Low ■ = Medium ▲ = High	Relative Non-GHG Emissions ● = Low ■ = Medium ▲ = High	WTT Scalability ● = Scalable ■ = Challenging ▲ = Unlikely	Fuel safety ● = Safe ■ = Intermediate ▲ = Dangerous	Regulations & guidelines ● = Available ■ = Amendment ▲ = N.A.	Technology readiness ● = Commercial ■ = Small scale ▲ = R&D	Total Scores
HFO (base case)	●	●	●	●	▲	▲	●	●	●	●	78.3
HFO (ICE,CCS)	●	●	■	●	●	▲	●	●	●	■	85.3
NG-LNG (ICE)	●	●	●	●	■	●	●	●	●	●	82.4
NG-LNG (ICE,CCS)	●	●	■	●	●	●	●	●	●	■	86.6
NG-H2 (ICE)	●	■	■	●	●	●	●	▲	■	■	73.8
NG-H2 (FC)	●	■	●	■	●	●	●	▲	■	■	74.2
NG-NH3 (ICE)	●	■	■	■	●	●	●	▲	▲	■	65.1
NG-NH3 (FC)	●	●	■	■	●	●	●	▲	▲	■	66.8
NG-MeOH (ICE)	●	●	■	●	▲	●	●	■	■	■	62.5
NG-MeOH (ICE,CCS)	●	●	▲	●	■	●	●	■	■	■	67.0
NG-E (EM)	▲	▲	●	▲	●	●	●	●	●	●	65.6
BLUE-E-H2 (FC)	●	■	■	▲	●	●	■	▲	■	■	62.1
BLUE-E-NH3 (FC)	●	●	▲	▲	●	●	■	▲	▲	■	55.2
BLUE E-MeOH (ICE)	●	●	▲	■	▲	●	■	■	■	■	48.5
BIODIESEL (ICE)	●	●	●	●	●	■	■	■	●	■	85.9
BIO-MeOH (ICE)	●	●	■	■	●	■	■	■	■	■	72.6
SOLAR E (EM)	▲	▲	●	▲	●	●	▲	●	●	●	65.5
SOLAR-E-H2 (FC)	●	■	■	▲	●	●	▲	▲	■	■	63.4
SOLAR-E-NH3 (FC)	●	●	■	▲	●	●	▲	▲	▲	■	58.7
SOLAR E-MEOH (ICE)	●	●	▲	■	●	●	▲	■	■	■	62.8
SOLAR-T-H2 (FC)	●	■	■	▲	●	●	▲	▲	■	■	62.7
SOLAR-T-MeOH (ICE)	●	●	▲	▲	●	●	▲	■	■	■	57.3

Figure 12 Score for alternative fuels

In Law et al. (2021), **various alternative fuels were compared to Heavy Fuel Oil (HFO) based on energetic, physical, cost, and environmental parameters** rated on a scale of 0 to 10 for quantitative and qualitative evaluations. The study examined 22 fuel types across 6 quantitative parameters, including mass, volume, cost, energy, GHG emissions, non-GHG emissions, and 4 qualitative parameters, including scalability, hazard, regulations and guidelines, and technological preparation.

Table 8 Percentage reduction of CO_2 emission factors in the various green shipping technologies

Green shipping technologies	Percentage reduction of CO_2 emission factors	Sources of data
LNG	23 ± 5	Burel et al. 2013, Gilbert et al. 2018, Fincantieri, Balearia, Costa crociere
Ammonia	70 ± 17	Zincir 2022, Czermansky et al. 2022, Kanchiralla et al. 2022
Hydrogen	81 ± 4	Atilhan et al. 2021, Kanchiralla et al. 2022
Hybrid/electric	78	Kanchiralla et al. 2022

Biomethanol	80	Kanchiralla et al. 2022
Biodiesel	45 ± 30	Dos Santos et al. 2022, Estevez et al. 2022, Stathatou et al. 202, Yacout et al. 2022
Slow steaming	38 ± 8	Ammar 2018, Degiuli et al. 2021, Czermansky et al. 2022
Cold ironing	59 ± 11	Zis et al. 2014
Wind propulsion	39 ± 25	14 Technologies to Make the Ultimate Green Ship (marineinsight.com), Czermansky et al. 2022
Route optimization	6 ± 2	Moradi et al. 2022, Corsica ferries
Antifouling paints	8	14 Technologies to Make the Ultimate Green Ship (marineinsight.com)
New propellers and rudders	8 ± 4	14 Technologies to Make the Ultimate Green Ship (marineinsight.com), Czermansky et al. 2022
Heat recovery systems	9 ± 6	14 Technologies to Make the Ultimate Green Ship (marineinsight.com) Diaz-Secades et al. 2022
Improving pumps and cooling systems	2	14 Technologies to Make the Ultimate Green Ship (marineinsight.com)
Air layer to reduce the friction	36	Busch et al. 2018
On board consumption optimization	8	MSC crociere
Load optimization	33	Container xChange | Containers on Demand in 2500+ Locations (container-xchange.com)

Scores were calculated for each fuel based on the various features and compared to HFO, with a maximum score of 100. The results are presented in Figure 12. The highest scores (>80) were obtained by HFO with carbon capture systems (CCS) (but with high GHG emissions), LNG, LNG with CCS, and biodiesel. Lower scores (<60) were obtained by blue ammonia, blue methanol, ammonia from solar energy, and methanol from solar energy, which, however, have a lower emission impact, except for blue methanol with regards to GHG emissions.

Table 8 and Figure 12 show the results of the analysis of the percentage reduction in emission factors for various alternative fuels used in shipping, such as ammonia, hydrogen, and electric ships. The results indicate that these alternative fuels can significantly reduce the emission of pollutants compared to conventional fossil fuels. However, each of these fuels has its own set of advantages and disadvantages.

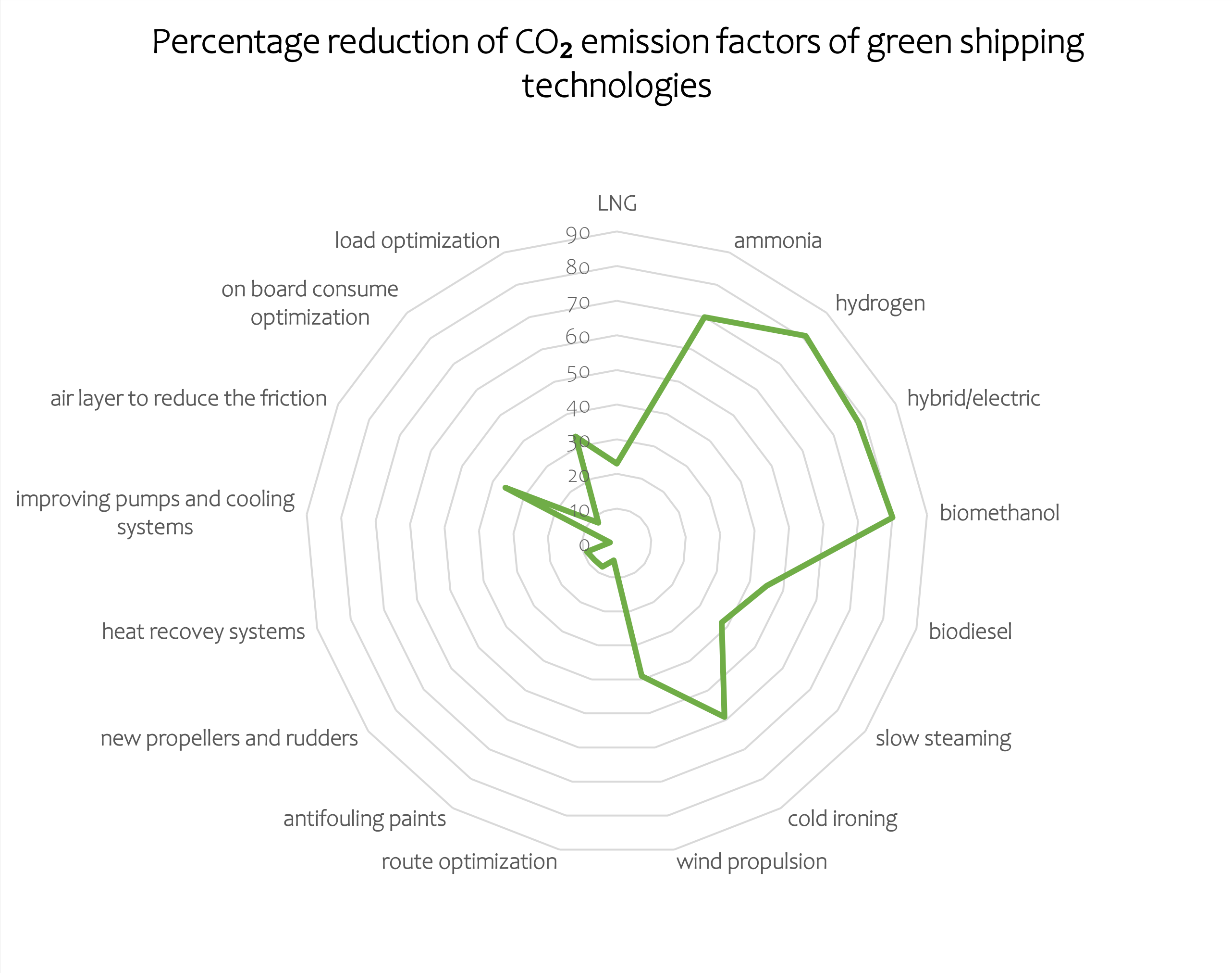

Figure 13 Percentage reduction of CO_2 emission factors of green shipping technologies

Ammonia, for instance, is a clean and efficient fuel that produces no greenhouse gas emissions when burned. However, it is highly toxic and can pose significant safety risks during handling and transportation. Hydrogen, on the other hand, is another promising alternative fuel that produces only water as a byproduct. However, its production and transportation can be expensive, and it can also pose safety risks. Electric ships have also gained significant attention due to their potential for zero-emission operations. They can be powered by batteries, fuel cells, or a combination of both, depending on the specific design and operational requirements. However, the limited range of batteries and the high cost of fuel cells remain significant challenges for their widespread adoption in the shipping industry.

Apart from alternative fuels, various technologies and operational conditions can also contribute to reducing emissions. Slow steaming, for instance, involves operating ships at lower speeds, which can significantly reduce fuel consumption and emissions. Cold ironing, another option, involves connecting ships to onshore power supplies while at berth, thereby reducing emissions from auxiliary engines. Wind propulsion, utilizing wind power to propel ships, is also an attractive option, particularly for short-sea shipping.

It is important to note, however, that the effectiveness of these technologies and operational conditions can vary depending on the specific context and conditions of the shipping operations. For example, cold ironing can only reduce emissions during port activities and not during the entire voyage.

In addition to alternative fuels and technology solutions, load optimization can also contribute to reducing emissions. This involves ensuring that ships are loaded to their maximum capacity, reducing the need for additional trips of empty containers, and thereby reducing emissions associated with transportation.

3.1.2 Navigation Parameters

The operational parameters influence considerably the fuel consumption, and consequently the pollutant emission; the most important parameter is the **ship speed**.

Some studies (Pastra et al. 2021, Degiuli et al. 2021, Ammar 2018) demonstrated that travelling at a speed lower than maximum (methodology called **slow steaming**) reduces the fuel consumption, reducing the travel cost, with the possibility of having smaller tanks on shore, reducing the total volume and/or increasing the load transported. In Ammar 2018 was obtained a reduction of CO_2 emission by 40% reducing the speed by 10% in a cargo ship; in Degiuli et al. 2021 it has been esteemed the reduction of CO_2 emission in a container ship with a diesel or LNG engine, obtaining an emission reduction between 30 and 50%, with a speed reduction by 15%. However, the slow steaming can give adverse effects in case of extended use (Dere et al. 2022), such as the formation of carbon deposits on the rings of pistons, boiler, turbocharger, injector, causing a reduction in the efficiency of the diesel engine, and an increase of CO_2 emission by about 2% at long-term.

Another important parameter is the **reduction of transport of empty containers**, it is estimated that a third of the 150 million containers that travel in a year are empty, occupying space and increasing unnecessarily the weight; optimizing the container filling, not loading empty container in container ship, would greatly reduce the fuel consumption, leading to the use of smaller ships and a lower number of ships[3].

Route optimization reduces the distance traveled and consequently reduces fuel consumption. Moradi et al. (2022) first developed a generic ship model using neural networks to predict fuel consumption, and then applied reinforcement learning approaches such as Deep Q-Network (DQN), Deep Deterministic Policy Gradient (DDPG), and Proximal Policy Optimization (PPO) to optimize the routes.

3.1.3 Features/Components of Ships

There are various ship features/components that can affect fuel consumption[4], including weight, pollution abatement systems, antifouling paints, advanced propeller and rudder systems, speed nozzles, recirculation of combustion gases in the engine, water in fuel, improved pumps and cooling systems, integration with wind propulsion systems, renewable energy production, and sandwich plate systems. Among these features, **weight is the most significant factor affecting fuel consumption**. The higher the weight, the greater the fuel consumption. To reduce weight, it is possible **to optimize the load**, reduce the weight of some components, and **eliminate ballast water**, which is typically present when the ship travels without any cargo.

[3] https://www.container-xchange.com/blog/5-green-shipping-initiatives-reduce-ghg/#:~:text=Green%20shipping%20is%20when%20people,port%20management%2C%20and%20equipment%20management

[4] https://www.marineinsight.com/green-shipping/13-technologies-to-make-the-ultimate-green-ship/

Ballast water is water that is taken on board a ship to adjust its weight and balance, primarily to ensure that it is stable and safe to operate. The water is typically loaded into ballast tanks in the ship's hull and then discharged at a different location when cargo is loaded or unloaded, or when the ship needs to adjust its weight and balance for other reasons. Ballast water can contain various organisms, such as bacteria, microbes, small invertebrates, and larvae, which may be harmful to the marine ecosystem in the new location where the water is discharged. To prevent the spread of invasive species and diseases, international regulations have been established to control the discharge of ballast water by ships. These regulations require ballast water to be treated using methods such as filtering, chlorine or UV treatment to reduce the presence of living organisms such as algae, bacteria, plankton, and other potentially harmful species before it is discharged into a new location.

Nonetheless, it is crucial to ensure that these weight reduction measures do not compromise the ship's safety and stability.

There are **emissions abatement systems**, such as scrubbers, that are not designed to reduce fuel consumption and CO_2 emissions but are effective in reducing the emissions of other gases such as NO_x, SO_2, and PM_{10}. This helps to reduce the impact of ship emissions on both human health and aquatic ecosystems. Different types of scrubbers are available, with some specifically designed to **reduce SO_2 emissions**, as described in Tran et al. (2017). Starting from January 1st, 2020, the International Maritime Organization (IMO) mandated that marine fuels must contain less than 0.5% sulfur. Fuels with higher sulfur content can only be used with scrubbers or other emission abatement systems. The various types of scrubbers include dry, wet, open loop, and closed loop scrubbers.

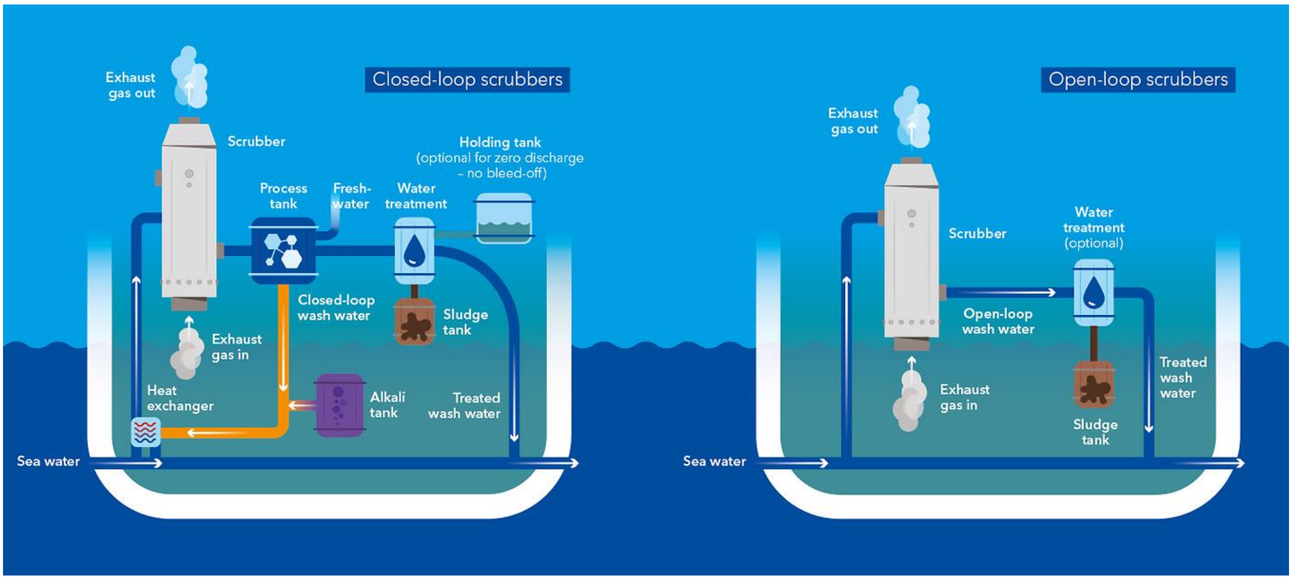

Figure 14 Closed-loop scrubbers and Open-loop scrubber[5]

As shown in Figure 14 Closed-loop scrubbers and open-loop scrubbers are two types of exhaust gas cleaning systems (EGCS) that are used to reduce emissions from ships. These systems are designed to remove sulfur oxides (SOx) from the exhaust gases before they are released into the atmosphere. Closed-loop scrubbers and open-loop scrubbers operate differently and have different advantages and disadvantages.

[5] Available online: https://www.dnv.com/expert-story/maritime-impact/Scrubbers-at-a-glance.html

Closed-loop scrubbers work by adding chemicals such as caustic soda to the wash water, which increases its alkalinity. This alkaline wash water is then sprayed into the exhaust gases, which reacts with the SOx to create a by-product known as sulfuric acid. The resulting wash water is then recirculated through the system and partially purged to remove the sulfuric acid. The remaining wash water is then used again in the scrubbing process. Closed-loop scrubbers are known for their high efficiency in removing SOx from the exhaust gases, and they are particularly effective in areas where discharge of wash water into the sea is not allowed. However, they require additional space and equipment to manage the chemicals used in the process, and the wash water needs to be disposed of onshore.

Open-loop scrubbers, on the other hand, use seawater which is naturally alkaline to wash the SOx out of the exhaust gases. The seawater is then discharged into the sea after meeting the requirements set by the International Convention for the Prevention of Pollution from Ships (MARPOL). Open-loop scrubbers are less expensive to operate than closed-loop scrubbers, as they do not require additional equipment for managing chemicals or disposing of wash water. However, they can cause environmental concerns due to the discharge of wash water containing pollutants such as heavy metals and other contaminants. Additionally, open-loop scrubbers may not be effective in areas with low alkalinity in seawater.

The dry scrubber does not use liquid, but instead uses hydrated granules treated with lime, while the wet scrubber uses water to solubilize SO_2 presents in exhaust gases. In Yang et al. 2021, has been utilized a wet scrubber in a container ship, obtaining a reduction by 95% of SO_2 emissions and only 10% for the PM2,5 emissions.

Nitrogen oxides (NOx) are another major pollutant emitted by ships, and reducing their concentration is crucial to achieve the Tier III emission standard set by the International Maritime Organization (IMO). However, treating NOx is more challenging than treating SO2, and there are currently two main technologies used to reduce NOx emissions.

Selective Catalytic Reduction (SCR) is a technology that involves injecting a urea-based solution into the exhaust gas stream, which then reacts with NOx in the presence of a catalyst. This reaction converts NOx into nitrogen gas and water, which are harmless to the environment. SCR systems can achieve NOx reduction rates of up to 90%, making it an effective technology for meeting Tier III emission standards.

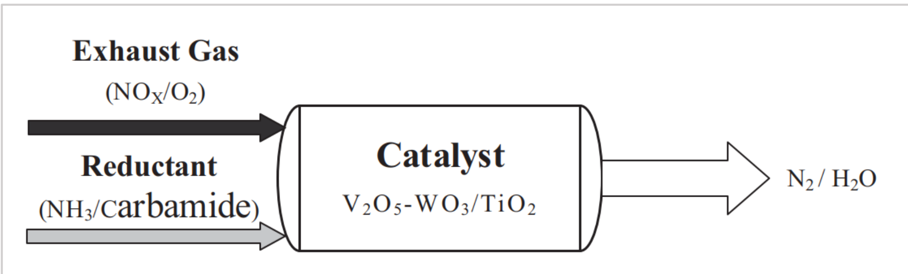

Figure 15 Schematic diagram of SCR catalytic device

SCR technology is mainly used in four-stroke diesel engines with higher exhaust temperature (Register, 2012), and the exhaust temperature of two-stroke diesel engines is lower than the ideal working temperature of the SCR system. Therefore, at present, very few SCR systems are equipped with two-stroke diesel engines, which achieve the reaction temperature by placing the catalytic device behind the turbocharger.

Exhaust Gas Recirculation (EGR) is an effective technology to reduce NOx emissions, which is mainly used in large two-stroke marine diesel engines. The device reduces the peak temperature of the gas in the cylinder by recycling the burned gas back to the cylinder, thereby reducing the formation of NOX (Eriksson and Llamas, 2020).

As shown, the EGR system is mainly composed of exhaust gas wet scrubber, cooler, water mist catcher and high-pressure blower, etc. The functions of each part are as follows (Gregory and Confuorto, 2012; Register, 2012):

1. Exhaust gas wet scrubber: It is composed of a buffer tank with a freshwater supply, a sodium hydroxide quantitative unit, a circulating pump and water treatment equipment with sludge collection, which is used to remove sulfur oxides and particulate matter in the recycled exhaust gas, prevent corrosion and reduce fouling in system and engine;
2. Cooler: further lowering the temperature of the recycled exhaust gas;
3. Water mist catcher: Remove condensed and entrained water droplets from the purified exhaust gas;
4. High-pressure blower: used to increase the pressure of recirculated exhaust gas before it is reintroduced into the engine cylinder.

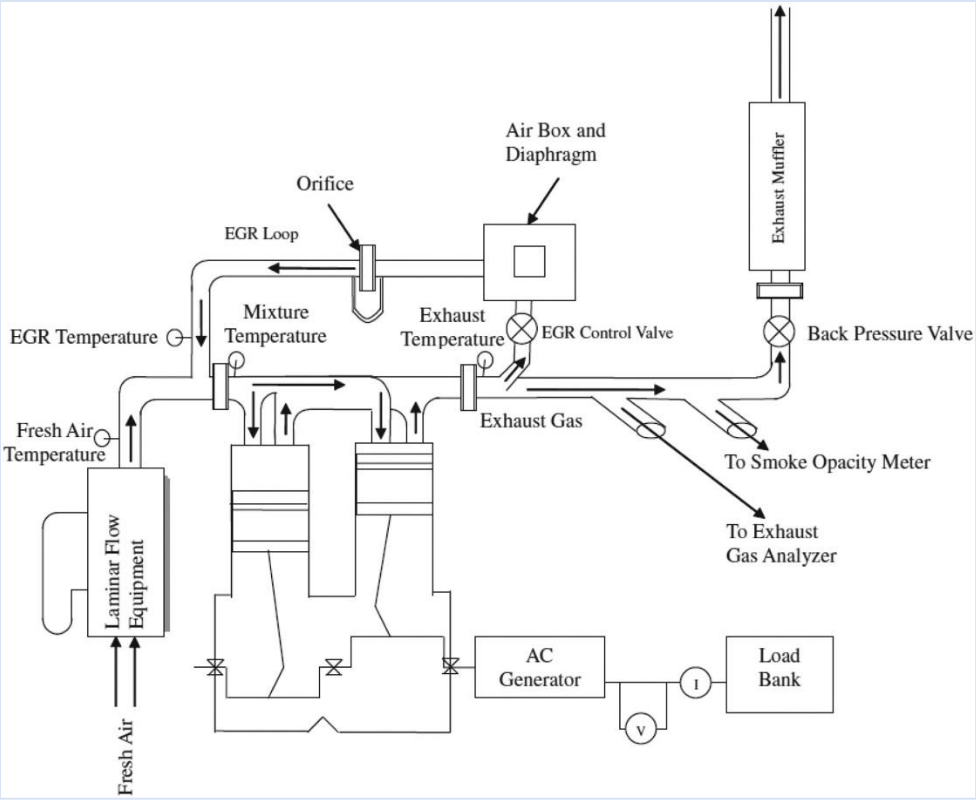

Figure 16 Schematic diagram of engine setup using EGR designed by Agarwal et al. (2011)

In recent years, researchers have studied the EGR technology of marine diesel engines. Ushakov et al. (2019b) studied the emission performance of an LPG carrier using high sulfur heavy fuel by combining low-pressure EGR with seawater scrubbing desulfurization. The results show that when the EGR rate is 25–35%, the engine runs reliably, and NOX emissions are reduced by about 70%, which meets the Tier III standard. The SOX emission has been reduced by 98%, which is equivalent to using fuel emissions with a sulfur content of 0.04% (m/m), far lower than ECA emission requirements.

Fouling occurs when living organisms accumulate on the hulls of ships, leading to increased friction and fuel consumption. While antifouling paints have been around for many years, most of them contain toxic chemicals that have a significant environmental impact. Consequently, it is crucial to use paints that are effective in preventing fouling and have minimal environmental impact. By adopting this approach, it is possible to achieve a fuel saving of up to 8%.

The implementation of **advanced propeller and rudder systems** can result in a fuel saving of up to 4% and increased ship speed. The use of a **speed nozzle in small ships** can improve propulsion efficiency and reduce fuel consumption by 5%. During fuel combustion, a lot of heat is generated, which is usually lost with exhaust gas. However, this heat can be recovered with a **heat exchanger** and used for various purposes on the ship, such as heating accommodation for the crew and providing hot water, leading to a maximum fuel consumption reduction of up to 14%.

3.1.4 Other Green Shipping Technologies

Other green tech in shipping concerns the port activities and the shipyards, both in construction/demolition, and during the permanence at the port.

One of the most important is the ***"cold ironing"*** (Prousalidis et al. 2014, Zis 2019, Martin-Lopez 2021, Zis et al. 2014): ships use shore energy during their permanence in ports, thus they can turn the engines off when are in ports, and yet maintain their activities. This allows a reduction of pollutant emissions during the stop in the ports, as the main goal is to improve the air quality in port cities.

The term **cold ironing** (Zis, T. P. 2019) is attributed to the practice of cooling down of the iron coal-fired engines while the ship was tied to the port in the past. By using cold ironing locally, there are reduced ship emissions in ports, as the ship's funnels do not release pollutants, and the ship's energy demand is met by the power plant providing current to the port (as shown in Figure 17, Figure 18, Figure 19 and Figure 20).

However, globally, the environmental trade-offs depend on the origin of the energy used to provide the shore power. Conceptual case studies have examined the environmental benefits and costs of cold ironing for ports with different characteristics, while other studies have focused on the technological side of cold ironing. For example, Sciberras et al. (2015) examined the effects of cold ironing systems on the electrical network and the quality of power delivered to the ship, while Prousalidis et al. (2014) considered combining cold ironing with smart grids and performing a cost-benefit analysis on a case-by-case basis. Innes and Monios (2018) examined the economic feasibility of cold ironing installations at smaller or medium-sized ports, finding that under certain assumptions, the external cost benefits would have a payback period of seven years without any other subsidies.

One of the potential benefits of cold ironing is that it can help to reduce local air pollution, particularly in heavily populated areas where ports are located. By connecting to a shore power source, ships can avoid emitting pollutants such as nitrogen oxides, sulfur oxides, and particulate matter into the local air.

However, there are also challenges associated with implementing cold ironing. As mentioned in the previous statement, Prousalidis et al. (2014) identified several of these challenges, such as the potential inadequacy of shore power capacity for larger vessels, the requirement for expert personnel to manually connect the vessel to the shore power source, the need for an efficient monitoring system to prevent blackouts, and the installation of suitable equipment, which could entail a significant investment of both time and money.

Despite these challenges, cold ironing continues to be seen as a promising technology for reducing emissions from the shipping industry, and many ports around the world are exploring ways to implement it.

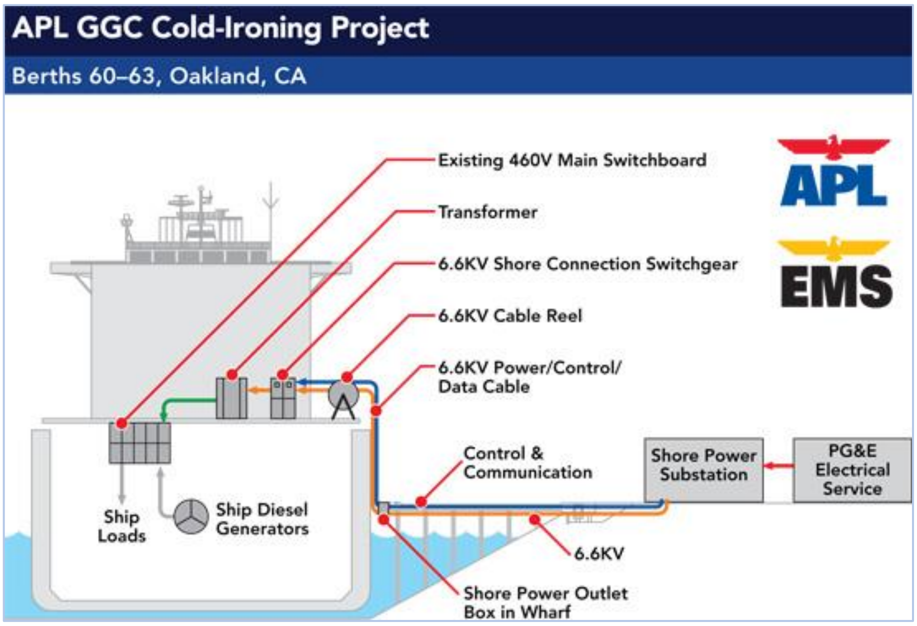

Figure 17 APL GGC Cold-Ironing Project[6]

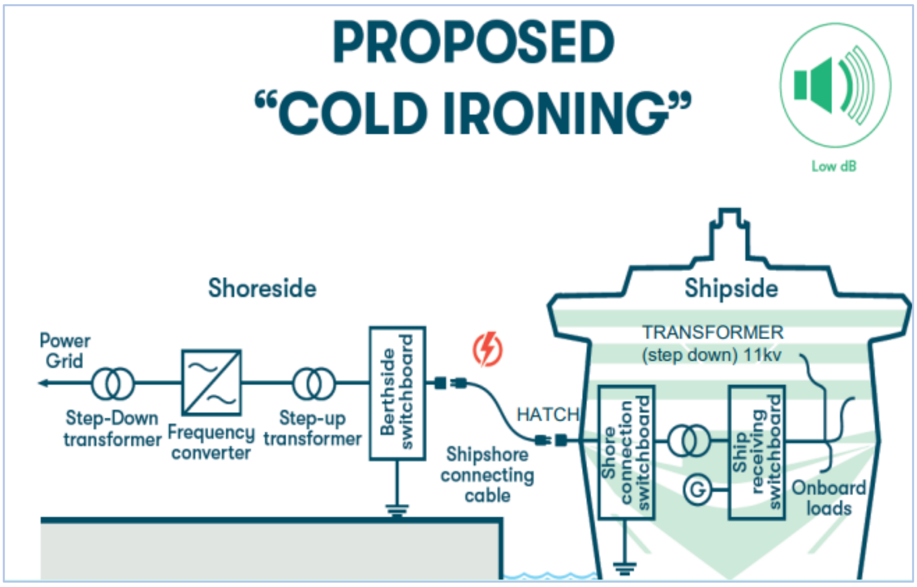

Figure 18 TWIN-Port III Cold-Ironing Project[7]

The emission savings from ships relying on AMP to power their hoteling activities can be distinguished into local savings that the port enjoys and global savings (or additional emissions) if the at-source emissions are accounted for. Overall, the highest emissions reduction potential would be present for ports with relatively longer berth durations. Looking at specific pollutants, it can be expected that

[6] https://www.dcvelocity.com/articles/24861-cold-ironing-to-have-electrifying-effect-on-california-port
[7] https://cinea.ec.europa.eu/system/files/2023-02/6.%20TwinPort3_OPS_TALLINK%20CASE_171122.pdf

SO_2 emissions reductions can be expected for non-EU and non-SECA ports where the baseline (relying on auxiliary engines) SO2 emissions would be significant due to the higher sulphur content.

Figure 19 TWIN-Port III - On-Shore Power Crane

Figure 20 TWIN-Port III - On-shore power cable and hatch

Zis et al. 2014 measured the emission reduction using cold ironing. Tests were made on a container ship, obtaining a CO_2, NOx, SO_2, black carbon reduction by 48-70%, 3-60%, 40-60%, 57-70% respectively. In this study, it was also esteemed the emission reduction within a speed reduction, obtaining a CO_2, NOx, SO_2, reduction by 8-20%, 9-40%, 9-17% respectively and an increase of black carbon by 10%. According to the directive 2014/94/EU all ports in Europe must provide structure for the use of LNG and shore power, the cold ironing by 2025.

Table 9 Pollutant %contribution of shipping sector divided in sea surface and coastal areas

	Sea surface		**Coastal areas**	
	Annual mean (µg/m³)	% contribution of shipping sector	Annual mean (µg/m³)	% contribution of shipping sector
NO_2	1,99	42	3,98	14
SO_2	0,41	44	0,66	16
SO_4	1,42	15	1,51	10
BC	0,18	8,6	0,3	3,4
$PM_{2.5}$	6,52	6,3	6,92	4,9

As already stated, the green shipping also concerns port activities, which can be various and with important environmental impacts, particularly in cities with a big port; there are studies (Hoang et al. 2022, Alamoush et al. 2022, Ngunyen et al. 2022, Yu et al. 2022) that aim to the assessment and the reduction of pollutant emission from ports.

The emissions reduction occurs through systems/technologies for electricity saving in various activities, and the production of renewable energy. Hoang et al. 2022 individuated some technologies for the reduction of pollutant emissions from port activities (summarized in Table 10), beginning from the sustainability assessment of ports with energy-based criteria, focusing on 3 main aspects:

- Energy production from renewable sources
- Improving energy efficiency
- Adoption of an energy management system

There are two main energy uses, direct and indirect: the direct uses are the sources that consume directly the energy such as lighting, office etc.; on the other hand, indirect uses depend on volume of port activities, such as cranes, fleet inside the port, refrigerated containers etc.

The clean energy systems in ports identified by this study are: power systems, energy storage systems, renewable energy in ports, efficient energy use strategies. For the feeding systems indicated to increasing electrification and hybridation, with the use of electric systems that substitute diesel ones, particularly in container terminal. Energy storage systems are one of the main methods to optimize the energy consumption and production, through batteries, supercapacitors and flywheels. A part of energy consumed in port activities can be produced from renewable sources, mainly through photovoltaic and on-shore or off-shore wind turbines, positioned near the ports; but also, other sources such as waves and currents energy, beyond the use of different fuels, such as LNG, hydrogen, biodiesel in the equipment used in various port activities. The use of berth automatic systems is a valid strategy for energy saving in ports, particularly, this system allows a simply berth of ship by vacuum and can be fixed to the berth with a simplified set of maneuvering, that corresponds to a lower demand of energy from ships. There are also other technologies that allow to reduce the fuel consumption such as start and stop engines, used in diesel equipment reducing the fuel consumption by 10/15%, in addition, methods were explored to use the reactive power consumed by electrical equipment for port energy management. In future scenarios, there will be the possibility of carbon capture and storage systems, to compensate the CO_2 emission from ports; another important factor of energy consumption in ports is lighting (3-5% of the total) and it is possible to reduce the consumption through energy-efficient lights.

Table 10 Summary of decarbonization technologies from 2017 to 2022 (Hoang et al. 2022)

Decarbonization technologies	Strengths	weaknesses	Use
Soot for lithium batteries	Circular economy for hybrid ships, waste valorization	Lack of industrialization, commercial application, influence of performance with soot from different ship parts	Container ships
Supercapacitor	Energy use from renewable sources, safety of energy continuity for all devises	Need in series and in parallel configuration, need more supercapacitor for high voltages, high costs	Electric ships
Shore energy or cold ironing	Reduction of pollutant emission, improving the air quality, noise reduction and reduction of equipment cost	Technology used only while the ship is berthed, high investment, high energy cost, many ships and ports aren't suitable	Various ports
Waste heat recovery	Emissions reduction, heat valorization produced in combustion	Not yet integrated in all ship types, high initial costs, require big space, require specific temperature and power	Diesel ships, LNG and LPG ships
Carbon capture optimization	Reduction of GHG emission	Difficulty to integrate in ship for little space, high initial costs	Various ships
Nuclear	No CO_2 emission, more convenient than traditional propulsion systems, long intervals among the supplies	Difficulty of stopping during the reactivity control, lack of harmonization between national	Military ships

Decarbonization technologies	Strengths	weaknesses	Use
		standards, safety, use only in military ships	
Flettner rotor	Fuel saving in short travel	No one knows how it combines with other on-board systems, lack of industrialization and on field tests	Various ships
Wind propulsion	Reduction of CO_2 emission, free source	Lack of industrialization and incentives, not suitable for big ships, compatibility problems for the retrofitting of old ships	Small/medium ships
Photovoltaic systems	Noise reduction, battery charge in continuum, easy to install and to find in the market	High initial cost, need a lot of space	Various ships
Solar/diesel hybrid	Reduction of CO_2 emission	Limit of solar efficiency, it doesn't work for all time in ships with certain power	Small ships
Electric hybrid	Reduction of CO_2 emission, noise reduction, utilizable with more fuel types, high efficiency, utilizable in different ship types	High initial costs, technology not fully industrialized, not suitable for short distance	Various ships
Air layer coating	Reduction of CO_2 emission, antifouling effect	Lack of studies and information about costs	Various ships
Distillation membrane for desalination	Volume reduction, fuel saving compared to other desalination technologies, production of pure water, waste and heat use combined with	Not commercialized, need pre-treatments, membrane substitution for fouling and scaling, high thermal energy consumption	Cruise

Decarbonization technologies	Strengths	weaknesses	Use
	renewable to improve the efficiency		
Ammonia	Easy storage and transport, availability of carbon capture systems in its production, less expensive than traditional fuels	Toxicity, often come from fossil hydrogen, need a develop of green production, few knowledge on safety, corrosive, so could have implication at long-term to fuel systems	Various ships
Hydrogen	Reduction of CO_2 emission	Need big tanks, infrastructure for hydrogen are limited and expensive	Various ships
LNG	Reduction of CO_2 emission	High environmental impact if discharged at sea, high investment costs, flow costs not predictable	Various ships
Synthetic fuels	Abundant raw materials, potentiality to combine with other blue economy activity	Have to optimize the lifecycle assessment, the impact at long-term are unknown, the cost esteems have to improve, lack of industrialization	Various ships

3.2 Emission and Impact of Green Shipping

3.2.1 Assessment Methods

In order to evaluate the impact of green shipping technologies, it is important to have tools for assessing the effects on emissions reduction, human health, and economic factors[8]. The **EEXI (Energy Efficiency Existing Ship Index)** is one such tool for measuring fuel consumption and has been implemented in studies such as Czermański et al. 2022 and Bortuzzo et al. 2022. In line with the International Maritime Organization's target of reducing emissions, Czermański et al. 2022 aims to analyze the global marine fleet in terms of energy demand, deadweight, and marginal abatement costs of CO_2 reduction (MAC), in order to specify the implementation costs of EEXI.

The study presents two methodologies for achieving EEXI values, which involve common technologies for reducing demand and are subjected to MAC assessment. Alternative fuels and advanced technologies applicable to the ship sector are also investigated. The EEXI index provides an estimate of emissions in g CO_2/ton NM, with the aim of achieving lower values using new technologies that reduce CO_2 emissions. For each ship, it is necessary to calculate the index during the operational phase and focus on the impact factors that determine the EEXI value, as presented in Bortuzzo et al. 2022. There are already established methods for reducing CO_2 emissions, such as the **Ship Energy Efficiency Management Plan (SEEMP) for existing ships and the Energy Efficiency Design Index (EEDI) for new ships**.

SEEMP is a scheme used for the control and the management at the operational level, with the aim of improving the energy efficiency, measuring the CO_2 emission in real condition. EEDI was created by IMO in order to reduce the CO_2 emissions such as the first step toward the decarbonization of ship sector, but is limited to ships introduced after 2015. The EEXI is based on the same calculation formulas of EEDI, but with a new target of CO_2 emission.

IMO, together with the World Maritime University (WMU) has been developing a model course on SEEMP promoting the energy efficient operation of ships. The first draft of the model course was submitted to MEPC 62[9]. It provides general background on the climate change issue and IMO's related work and aims at building the different operational and technical tools into a manageable course programme, which will promulgate best practice throughout all sectors of the industry. The Course will help create benchmarks against which operators can assess their own performance. The purpose of the IMO model courses is to assist training providers and their teaching staff in organizing and introducing new training courses, or in enhancing, updating or supplementing existing training material, so that the quality and effectiveness of the training courses may thereby be improved.

To simplify the calculation, is it possible to divide the fleet in 12 ship types and 27 size classes, for each class the medium parameters can be determined, in order to have a representative ship for each class, with also the people on board, based on: ship dimension, ship number before 2020, average ship weight, average ship length, average engine power (used parameters referring a certain speed, key feature of calculations).

From obtained data is possible to know the potential reduction of CO_2 emissions (summarized in Table 11) and associated costs for the whole fleet. The calculation model for the reduction of CO_2 emission and costs initially was intended to show the maximum level of technologies and solution adopted, thus is possible to distinguish the effective reduction of CO_2 emission for each ship type, and separately the

[8] https://www.imo.org/en/ourwork/environment/pages/technical-and-operational-measures.aspx
[9] https://www.imo.org/en/MediaCentre/SecretaryGeneral/Pages/MEPC-62.aspx

associated costs for each technology; then they aggregated the whole global fleet values according the EEXI regulation.

Table 11 Reduction factor of EEXI for ship type (Czermansky et al. 2022)

Ship type	Size (DWT and GT for cruise passenger ship)	Reduction factor (Y)
Bulk carrier	10,000–19,999	0–20 %*
	20,000 +	20 %
Gas carrier	2000–9999	0–20 %*
	10,000–14,999	20 %
	15,000 +	30 %
Tanker	4000–19,999	0–20 %*
	20,000 +	20 %
Container ship	10,000–14,999	15–30 %*
	15,000–39,999	30 %
	40,000–79,999	35 %
	80,000–119,999	40 %
	120,000–199,999	45 %
	200,000 +	50 %
General cargo ship	3000–14,999	0–30 %*
	15,000 +	15 %
Refrigerated cargo carrier	3000–4999	0–15 %*
	5000 +	15 %
Combination carrier	4000–19,999	0–20 %*
	20,000 +	20 %

Ship type	Size (DWT and GT for cruise passenger ship)	Reduction factor (Y)
LNG carrier	10,000 +	30 %
Ro-ro vehicle cargo ship	10,000 +	15 %
Ro-ro pure cargo ship	1000–1999	0–20 %*
	2000 +	20 %
Ro-ro passenger ship	400–999	0–20 %*
	1000 +	20 %
Cruise passenger ship	25,000–74,999 GT	0–30 %*
	75,000 + GT	30 %
DWT = deadweight tonnage; GT = gross tonnage; *Reduction rate is linearly interpolated between ship size with the lower target applying to the smallest ships.		

3.2.2 Environmental Impact and Costs

In Kanchiralla et al. 2022 an LCA was done on ships with 9 different set-up, for an assessment of the environmental impact and costs of some decarbonization solution applicable in green shipping: 1) internal combustion methanol engine with SCR (selective catalytic reduction); 2) internal combustion methanol engine with SCR and carbon capture systems; 3) pre-combustion to separate hydrogen and CO_2 in an internal combustion hydrogen engine; 4) internal combustion hydrogen engine; 5) internal combustion ammonia engine with SCR; 6) hydrogen with electric engine; 7) ammonia in SOFC (solid oxide fuel cells); 8) electric; 9) internal combustion diesel engine, which was also used as the reference for the comparation in the assessment. The evaluation did not take into account the building of the ship, its decommissioning, and any components unrelated to the fuel or propulsion systems, as these were not directly relevant to the study. The assessment was conducted using reference power levels of 20 and 100 MW.

They divided the results in 5 parts:

- fuel production
- construction
- fuel consumption
- other consumption
- maintenance, with a power of 20 and 100 MW, for the 9 set-ups: the first two has negative values in the fuel production because they come from a biomass, 1, 2 and 9 have the high values for fuel consumption, the 9 is this with higher emission such as predictable, not having green shipping technologies but it is the reference (Figure 21).

The Figure 22 is divided between A and B, in A there are the impact categories with lower values than reference, B represents one or more impact categories with higher values than reference, in particular concerning to human toxicity, both for cancerogenic or not, where the reference has the lowest value, and for the fresh water toxicity, where only the set-up 8 has a lower value than reference.

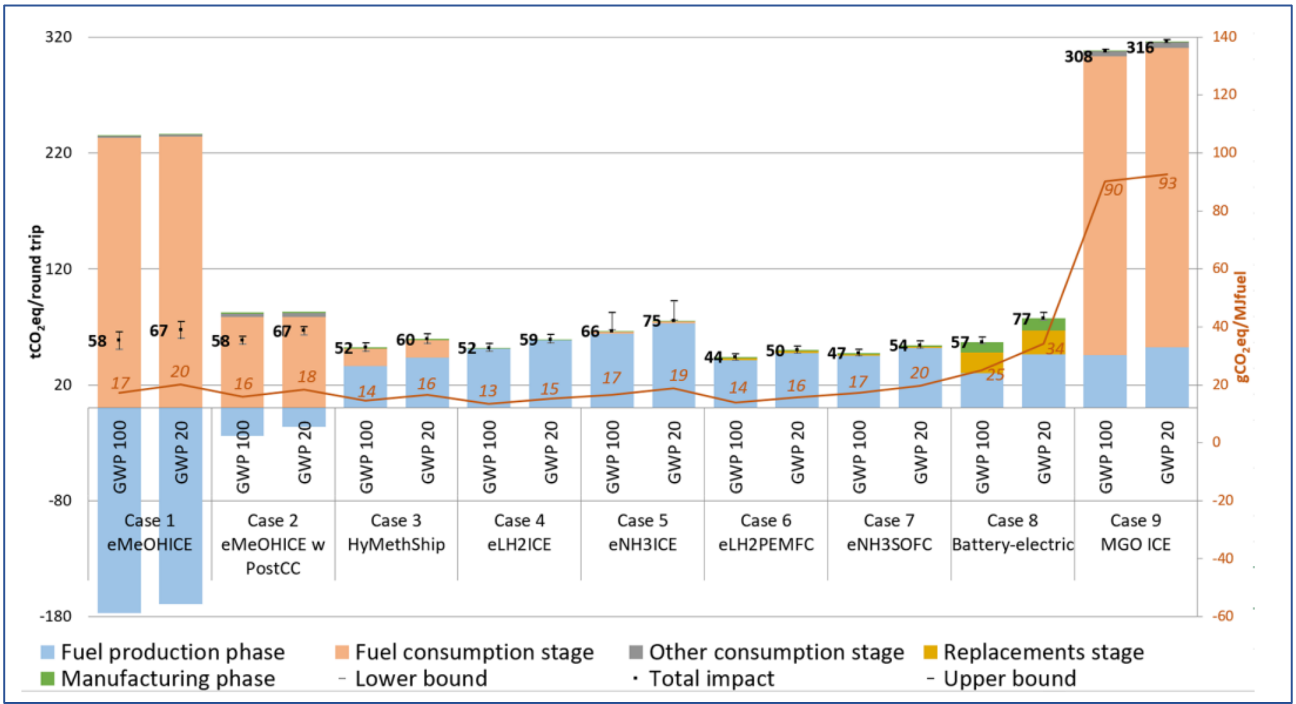

Figure 21 Impact on climate change of various set-up

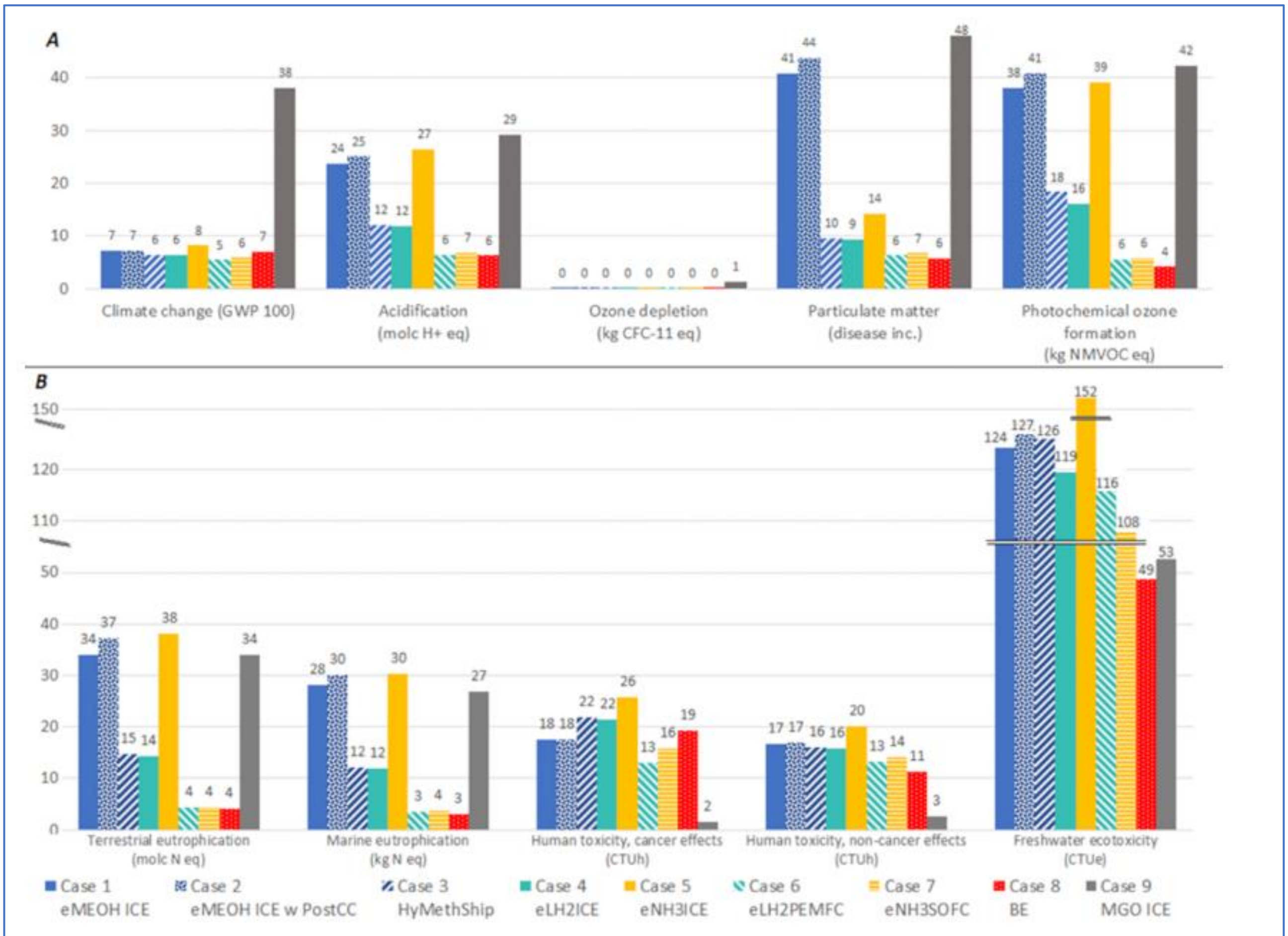

Figure 22 Normalized impact for other impact categories for the various set-up

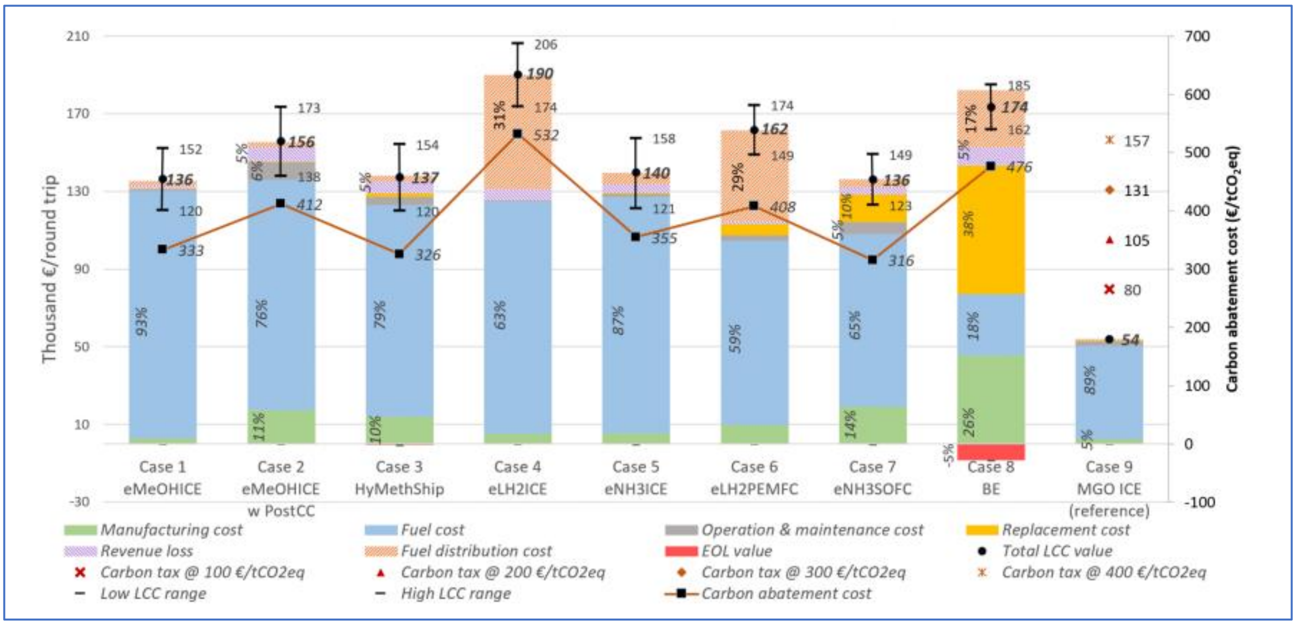

Figure 23 Economic assessment of different set-up

Figure 23 shows that the set-up 9 is the one with the lowest cost for travelling, the costs of the other set-up is similar, it varies between 130 and 190 thousand euros/round trip, and a cost of emission abatement system that have a similar trend. The lowest value is in set-up 7 (316 euro/CO_2 eq.) and the highest in the set-up 4 (532 euro/CO_2 eq.). In conclusion, the study sates that the various technologies assessed allow to reduce the GHG emissions, but they have averaged a higher impact on human health and fresh water, with a really higher cost. The set-up most promising, concerning both an environmental and economic point of view, are those with fuel cells, compared to internal combustion engines, with the same fuel type, although they present higher investment costs and the less lifespan.

3.2.3 Measure Technique of Ship Emissions

In Daousis et al. 2022 it is shown the main measure technique of ship emission, they individuated two main categories, sniffing and optimal remote sensing. The optimal remote sensing uses the radar laser, ultraviolet spectrometry and cameras; divided among active and passive, the active sensor emits the light, such as the lidar, the passive use reflected or emitted light in nature. The sniffing sensing measures the CO_2, SO_2, NO_x concentration and other gasses directly from plume, with fixed and mobile measurement systems. The best emission monitoring system is obtained with the use of a continuous emission monitoring systems (CEMS) on board.

In Mueller et al. 2022 it is described an impact assessment on human health from ships and port emissions, HIA (Health Impact Assessment) beginning from other studies; they used an HIA methodology, an air pollutant concentration assessment, assessing the impact on human health, quantify the impact on health attributable at respective scenario. Different methodologies applied in the various studies to esteem the impact on human health such as: CRA (comparative risk assessment), to calculate the mortality, cases of disease etc.; BDA (burden of disease assessment), to calculate the associated mortality to pollutant level from ship in the past and in the future; CBA (cost-benefit analysis) assess costs and benefits for each scenario; BA (benefit analysis) assess the benefit of the pollution avoided; CA (cost analysis) asses the cost due to the death and health associated costs in different reduction emission scenario; TSA (time-series analysis) esteems based on historic data in Hong Kong and Guangzhou ports in China; DD (difference-in-difference) compare the risk and monetized impact, using a disease cost approach. Except for TSA and DD, they used HIA approach to predict the impact on health. The emission reduction is very important not only for reducing GHG emission but also to reduce the air pollution in port cities, for gasses such as SO_2, NOx and the PM10, that cause by 0,5% of mortality in the world.

Table 12 Emission monitoring systems

Monitoring systems	advantages	disadvantages	Use condition
Stationery Sniffer	Low cost, technique already widespread, high automation level	Influenced by weather condition and position detection	Perennial winds from oceans toward shore
Mobile Sniffer	Rapid monitoring, extended application	High costs, utilizable only by trained staff, not available in rainy days	Weather that allows the flight
Continuous monitoring system and satellite communications	Rapid monitoring, high precision	Use on board, communication influenced by weather condition and for isolated locations	High budget, good weather condition, areas with satellite cover

3.2.4 Emission Factor

This paragraph presents a list of emission factors for the world's leading ship companies. The data used to compile this list were sourced from the companies' websites and include average values expressed in different units, which must be normalized to facilitate comparison.

- For the container ships, emission factors are principally expressed in gCO_2/ton·km or gCO_2/TEU·km, or NM (nautical miles). TEU is a reference container of 20 feet (twenty-foot equivalent unit), long about 6 meters, with a maximum weight of 24 tons.
- For cruises and ferries, this parameter is measured in gCO_2/passenger·km or gCO_2/ALB·km, where ALB (available low berth) is a standard measure in the cruises, intended as the capacity with two people on board for each cabin, so it corresponds to the real number of people if there are two people on board for each cabin.

Table 13 Emission factors of different ship typologies

Ship types	Shipping companies/data sources	Emission factors	Unit
Container ship	Maersk	13	gCO_2/ton·NM
	BSR	47-77	
	OOCL	41.25	gCO_2/TEU·km
	The green shipping project	58	gCO_2/TEU·km

Ship types	Shipping companies/data sources	Emission factors	Unit
	Kavasaki Kisen Kaishia	4.10	gCO_2/ton·NM
	WAN HAI	76.66	gCO_2/TEU·km
	Evergreen marine corporation	63.73	gCO_2/TEU·km
	Mitsui OSK lines	9.75	gCO_2/ton·NM
	CSR	44.81	gCO_2/TEU·km
Passenger ship	Carnival	330	gCO_2/ALB·km
	Cruises average in New Zeland	390	gCO_2/passenger·km
	Fincantieri	9-15	gCO_2/ton·NM
	Finnles	50-70	gCO_2/passenger·km
	MSC Crociere	251	
	AIDA	55.2	$kgCO_2$/passenger·day
	Costa crociere	420.7	gCO_2/ALB·km
	DFDS	13	gCO_2/ton·NM
Bulk carrier		12	gCO_2/ton·NM
Chemical tanker		23	gCO_2/ton·NM
Combination carrier		67	gCO_2/ton·NM
Container ship		27	gCO_2/ton·NM
Gas carrier		74	gCO_2/ton·NM
General cargo ship		48	gCO_2/ton·NM
Oil tanker		13	gCO_2/ton·NM
Other ship types		373	gCO_2/ton·NM
Refrigerated Cargo carrier		89	gCO_2/ton·NM

Table 14 Main technologies adopted or in prediction from companies

Ship companies	Main green shipping technologies	Emission reduction over time
Evergreen marine corporation	Terminal electrification, led light and photovoltaic in ports, SO_x scrubber, antifouling coating, new methods of container production, improving the load efficiency, improving the design, to reduce the ballast water	Reduction of 40 gCO_2/TEU·km in 2021 compared to 2007, total emission in growth

Ship companies	Main green shipping technologies	Emission reduction over time
Mitsui O.S.K. Line	Ship more aerodynamics, antifouling paints, heat recovery systems, reducing the shipping speed, to exploit the weather condition, optimal set-up, route optimization, carbon capture systems, LNG and electric ship	Reduction of 0.23 gCO_2/ton·NM in 2021 compared 2018, 4,4% of electricity from renewable sources
COSCO shipping holding	Use HSFO, better management of ballast water, less waste production, shore energy	Prediction to reduce by 12% in 2030 compared to 2019 of emission factor in gCO_2/TEU·km
Royal caribbean group	Use of LNG ship, advance emission purification (AEP), lubrification systems for microscopic bubble production, hull design optimization	Emission reduction of 35% in 2020 compared 2005 in gCO2/ALB·km
Carnival corporation	Fleet optimization, improving energy efficiency, more shore power, lithium battery energy storage systems, air lubrification systems of hull, test of hydrogen cells from methanol, carbon capture and storage systems, alternative fuels with LNG and from synthetic hydrogen, LNG already in use, other technologies in experimental phase	Emission growth of 84 gCO_2/ALB·km in 2021 compared to 2019, but total emission in decrease for the transport reduction, but they reduced the emission factor of SO_x and PM_{10}, increase from 78 to 103 g fuel/ALB·km, reduction of CO_2 emission factor by 25% in 2019 compared to 2008, from 327 to 246 gCO_2/ALB·km, goal 196 gCO_2/ALB·km to 2030
Maersk	Biodiesel (already in use) green methanol (13 ship in order, in use from 2023 and other after), green ammonia, terminal decarbonization, shore power	Emission factor reduced by 42,6% by 2021 compared to 2008, objective to achieve 0 in 2040
BSR	It is a no-profit organization, they calculated the emission long certain routes	Reduction of emission factor about by 4% in 2013 compared to 2012
CSR	Biofuel already in use since 2021, in prediction ammonia, methanol, LNG	Reduction of 3.55 gCO_2/TEU·km from 2018 to 2021, goal emission reduction by 70% in 2030 compared to 2008, 0 in 2050

Ship companies	Main green shipping technologies	Emission reduction over time
OOCL	New design technologies, weather-routing systems, improving energy efficiency, regularly hull clean, optimal set-up, reduction of ballast water, cold ironing, fuel use with low sulfur level, reduction NO_x systems	Emission factor reduced by 45.2% in 2021 compared 2008
Greenshipping line	Diesel-electric hybrid	-
Fincantieri	Use fan coil, regulation systems at variable speed for electric engines, heat recovery systems, led lightening, scrubber, LNG ship, research on fuel cells and lithium batteries	Almost halving of emission factor from 2016 to 2021, reduction of CO_2 emission with LNG compared to heavy fuel oil from 560 to 430 gCO_2/kWh
Balearia	already 4 LNG ships	Reduction by 0.67% of emission factor in 2018, reduction of CO_2 emission by 30% with LNG
Corsica ferries	Fuel with low sulfur level, use shore power, in prediction LNG and methanol ship, route optimization	Reduction of CO_2 emission by 8% for route optimization
DFDS	Scrubber, shore power, antifouling treatments, control propulsion systems and route planning, led light, in prediction ammonia, hydrogen and methanol	Goal reduction of CO_2 emission by 45% in 2030, reduction of 0.9 gCO_2/ton·NM from 2019 to 2021
Finn lines	Short-time 3 hybrid ships with other technologies for energy saving, exhaust gas cleaning systems, change propellers and rudders	-
vikingline	Use LNG, heat recovery systems	Reduction of total CO_2 emission but also customers reduction, CO_2 reduction by 15% with LNG ships
MSC crociere	First LNG ship in 2022, use digital twin, route optimization and speed reduction, study on	Reduction of 80 gCO_2/ALB·km from 2008 to 2020, emission reduction by 8% with improving

Ship companies	Main green shipping technologies	Emission reduction over time
	hydrogen ship for to exploit before to 2030 use hybrid exhaust gas cleaning systems (for the SOx), new propellers and rudders, shore power in 7 ships, heat recovery systems, antifouling paints, stability monitoring software	energy efficiency with digital twin and other technologies
AIDA	2 LNG ships, test in 2022 of batteries and fuel cells storage systems, heat recovery systems, air circulation optimization, air conditioners, travel speed	Reduction of 6.1 $kgCO_2$/person·day from 2017 to 2019
Costa Crociere	23% of fleet use LNG, 31% with shore power systems, 91% with advance air quality systems, research on batteries and fuel cells	Emission reduction by 20% with LNG ships
AMADEUS river cruises	Shore power, "fleet controlling system" route optimization and speed software	-
Cunard	Improving energy efficiency, scrubber, test of new technologies and alternative fuels	-
Holland America	Cold ironing, scrubber, route and speed optimization	Reduction of emission factor by 25% from 2005 to 2020, in gCO_2/ALB·km
Princess	Shore power, scrubber, various technologies to reduce the emission	-
SEABOURN	Route and speed optimization, improving energy efficiency, scrubber	Reduction of emission factor by 25% from 2005 to 2020, in gCO_2/ALB·km
Hamburgsud	Link with Maersk report being in the group	-
APL	LNG ships, scrubber	-
Kavasaki Kisen Kaishia	LNG ships, carbon capture systems, antifouling paints, cold	Reduction of emission factor of 1.26 gCO_2/ton·NM from 2017 to 2021

Ship companies	Main green shipping technologies	Emission reduction over time
	ironing, study on hydrogen ships and wind propulsion systems	
Pacific international lines	4 LNG LSFO hybrid ships to 2024, test on biofuel, antifouling paints, new propellers, cold ironing	-
ZIM	LNG ships from 2023, ammonia ships already in use	Objective to reduce the emission factor by 2% each year in gCO_2/TEU·km
Wan hai lines	Freezing more efficient, route and speed optimization, reduction of ballast water, new propellers	Reduction of emission factor of 33.24 gCO_2/TEU·km from 2008 to 2021

Data of emission factors from various shipping companies are expressed in different measure units based on ship type, but also in the same type, it is therefore necessary to find a conversion factor to compare data from different sources. One approach to normalization is to use the unit gCO_2/ton·km. To do this, a ratio between tons and twenty-foot equivalent units (TEU) has been calculated based on data from Figure 24 in the report by Malcow (2017). The ratio varies depending on the ship's capacity, with a 20000 TEU vessel having a ratio of 14 tons/TEU and a 10000 TEU vessel having a ratio of 16 tons/TEU (see Table 15 for more details).

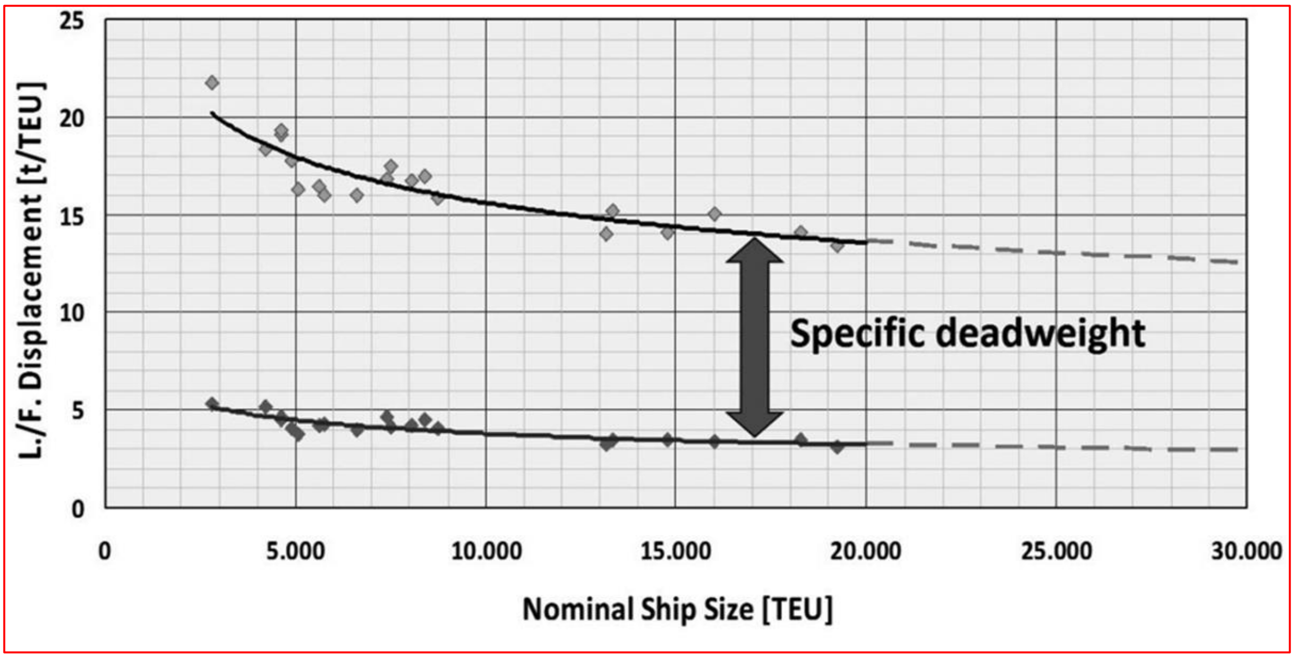

Figure 24 Tons/TEU ratio

The tons/ALB ratio has been calculated from weight and ALB number (2 for each cabin) data from **MSC Crociere and Oceania cruises fleets.** The tons/customer ratio derives from the ratio between the weight and the maximum customers number from **GNV, Tirrenia, Grimaldi lines, Adria ferries fleets** (only a part of the entire fleet, some ships as an example). The ratio km/NM is 1.852.

Table 15 Conversion factors

Ship types	Conversion factors
Container ships	15±2 ton/TEU
Cruises	40±4 ton/ALB
Ferries	18±6 ton/passenger

Table 16 Emission factors normalized

Ship companies/Ship types	Emission factors normalized in gCO_2/ton·km
Maersk	7.02
BSR	4.13
The green shipping project	3.87
OOCL	2.75
Kavasaki Kisen Kaishia	2.21
WAN HAI	5.11
Evergreen marine corporation	4.25
Mitsui OSK lines	5.26
CSR	2.99
Carnival	8.25
Fincantieri	6.48
Finnles	3.33
MSC crociere	6.28
Costa crociere	10.52
DSDF	7.02
Bulk carrier	6.48
Chemical tanker	12.42
Combination carrier	36.18
Container ship	14.58
Gas carrier	39.96
General cargo ship	25.92
Oil tanker	7.02
Refrigerated cargo carrier	48.06

The data presented in Table 16, Table 17 and Table 18, as well as from Figure 25 to Figure 28, provide insight into the normalized emission factors of various fleets of companies.

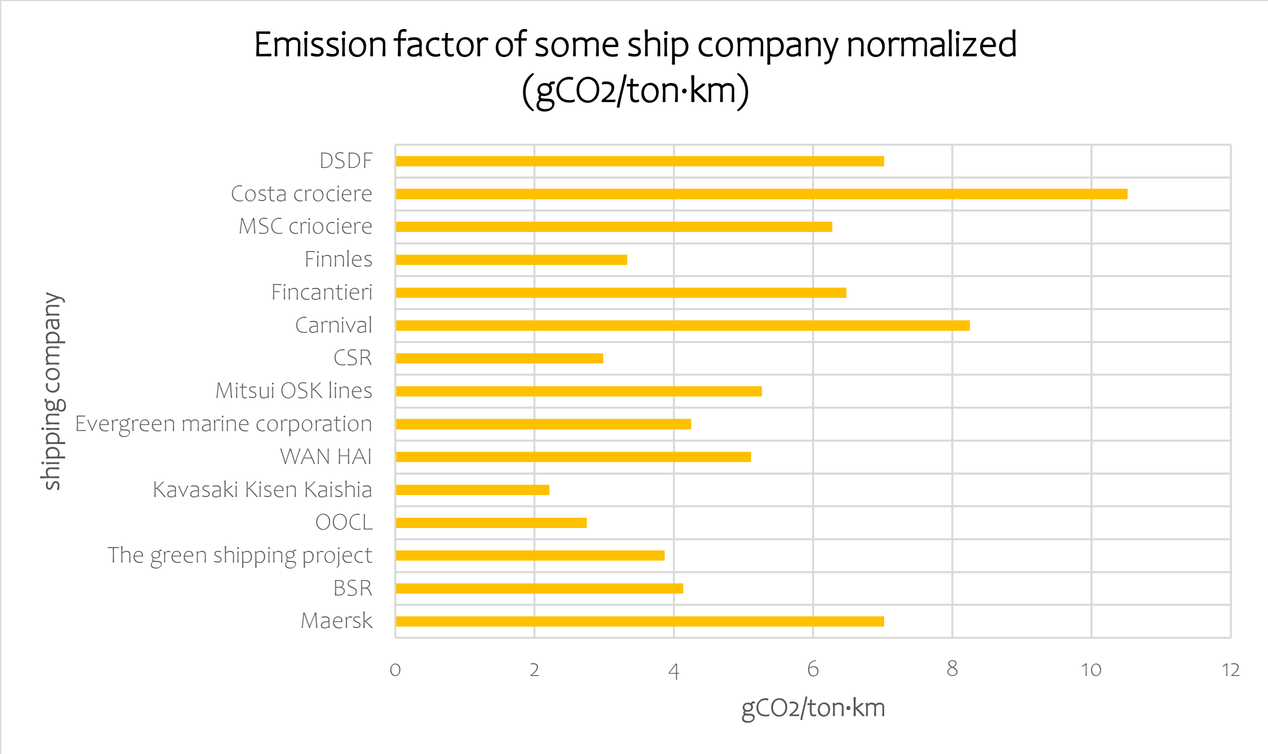

Figure 25 Emission factors of some ship companies normalized

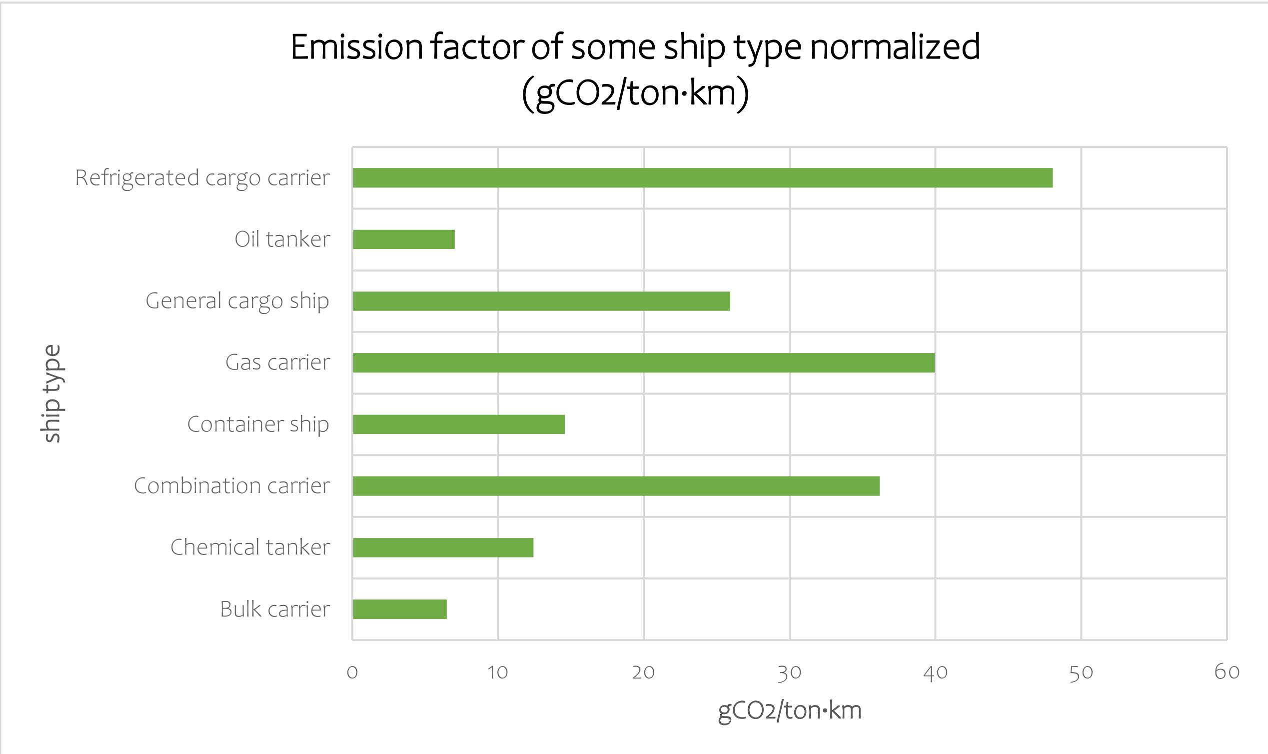

Figure 26 Emission factors of some ship type normalized

Table 17 Container ships emission factors normalized

Container ship companies	Emission factors in gCO_2/ton·km
Maersk	7.02
BSR	4.13
The green shipping project	3.87
OOCL	2.75
Kavasaki Kisen Kaishia	2.21
WAN HAI	5.11
Evergreen marine corporation	4.25
Mitsui OSK lines	5.26
CSR	2.99
Average	**4.18**

The findings indicate that the emission factors across various fleets are quite similar, without significant differences observed between them. However, it is important to note that certain types of ships, such as cruises and ferries, tend to have higher emission factors than container ships. These discrepancies may be attributed to the fact that activities on board these vessels, including passenger entertainment and accommodation, contribute to higher energy consumption and greater emissions.

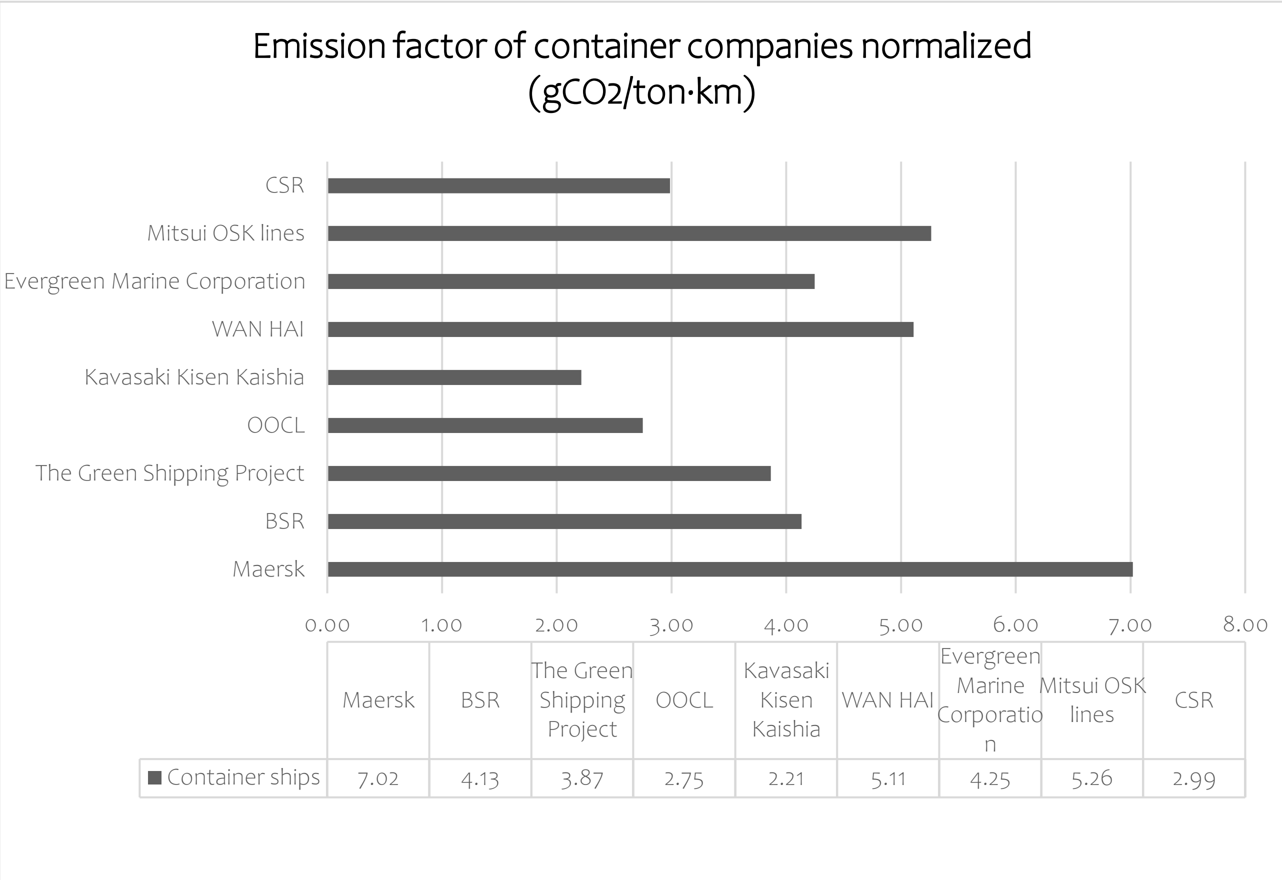

Figure 27 Emission factors of container ships normalized

Table 18 Cruises/ferries emission factors normalized

Cruise companies	Emission factor in g CO_2/ton km
Carnival	8.25
Fincantieri	6.48
Finnles	3.33
MSC crociere	6.28
Costa crociere	10.52
DSDF	7.02
Average	**6.98**

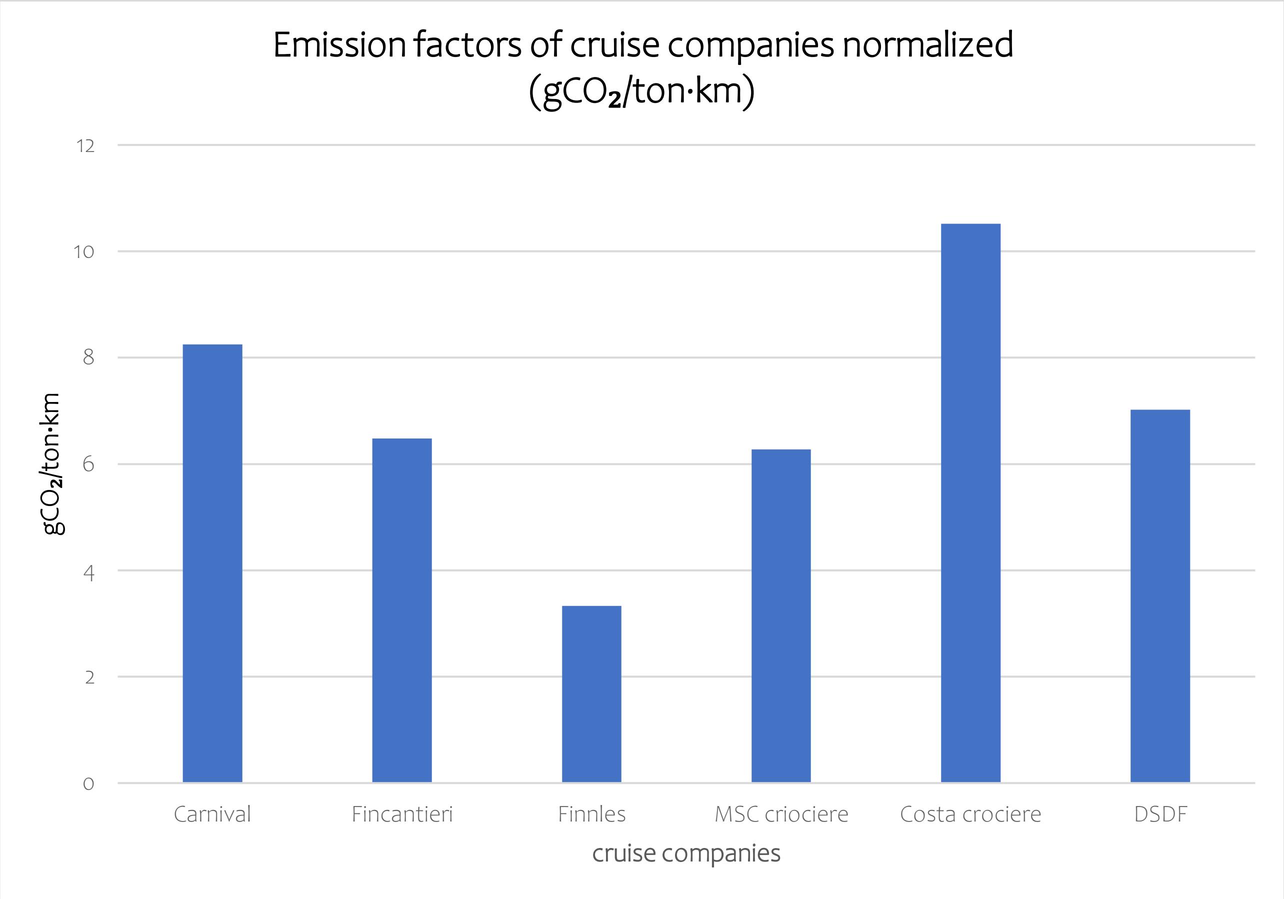

Figure 28 Emission factors of cruise companies normalized

The normalization process plays a crucial role in enabling comparisons of emission data from different sources. This process involves converting data to a common unit, which allows stakeholders to gain a more precise and comprehensive understanding of the environmental impact of the shipping industry. By analysing normalized data, policymakers and industry professionals can identify trends and patterns, and develop effective strategies to address environmental issues. Ultimately, normalization promotes transparency, consistency, and accuracy in data reporting and analysis, which are essential components in driving sustainable practices within the shipping industry.

4 Knowledge Hub Implementation

4.1 Definition of Knowledge Hub

There are several reasons why a repository of green shipping solutions and data sources is necessary:

1. Environmental impact reduction: Shipping is a significant contributor to greenhouse gas emissions and air pollution, which have a negative impact on the environment and human health. By having a repository of green shipping solutions, we can identify and implement solutions to get shipping on track to meet zero emissions targets, to reduce the impacts and move towards more sustainable and environmentally friendly shipping practices.
2. Regulatory compliance: Many countries and international organizations have regulations in place to reduce shipping emissions and environmental impacts. A repository of green shipping solutions and data sources can help companies comply with these regulations and avoid potential legal and financial penalties.
3. Cost savings: Implementing green shipping solutions can result in cost savings for companies in the long term. For example, using cleaner fuels or optimizing vessel routes can reduce fuel consumption and associated costs.
4. Reputation and brand image: In today's society, consumers are increasingly aware of environmental issues and are more likely to support companies that prioritize sustainability. Having a repository of green shipping solutions and data sources can help companies demonstrate their commitment to sustainability and improve their reputation and brand image.
5. Overall, a repository of green shipping solutions and data sources is essential for reducing the environmental impact of shipping, complying with regulations, saving costs, and improving reputation and brand image.

Reducing the environmental impact of shipping is a crucial global goal, as shipping is responsible for a significant portion of global greenhouse gas emissions and other environmental pollution (Figure 29). The International Maritime Organization (IMO) has set ambitious goals for the shipping industry to reduce greenhouse gas emissions, such as the goal to reduce carbon intensity by at least 40% by 2030 and 70% by 2050. To achieve these goals, it is crucial to have access to a repository of green shipping solutions that can help reduce emissions and environmental pollution.

In addition to environmental concerns, complying with regulations is also a major issue for the shipping industry. Many countries and international organizations have regulations in place to reduce shipping emissions and environmental impacts. Failure to comply with these regulations can result in legal and financial penalties, as well as damage to a company's reputation. A repository of green shipping solutions and data sources can help companies stay informed about these regulations and implement measures to comply with them.

Implementing green shipping solutions can also result in cost savings for companies in the long term. For example, optimizing vessel routes can reduce fuel consumption and associated costs, while using cleaner fuels can reduce maintenance and repair costs. By having access to a repository of green shipping solutions and data sources, companies can identify and implement cost-saving measures that are also environmentally friendly.

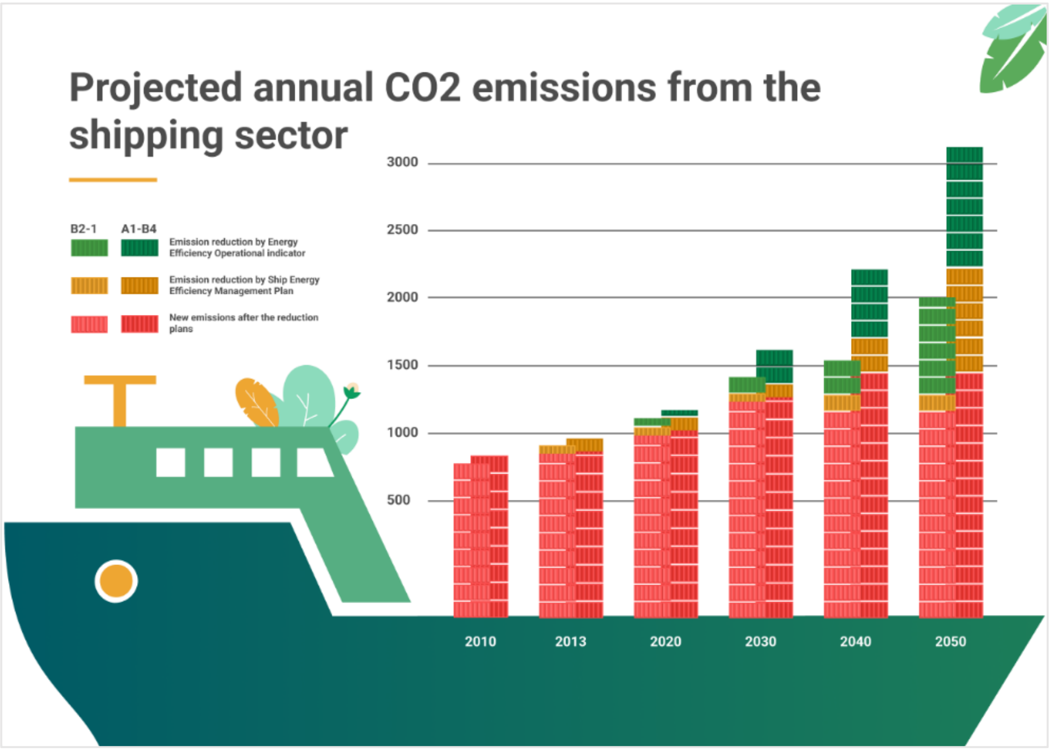

Figure 29 Projected annual CO2 emissions from the shipping sector (2030-2050)[10]

Finally, in today's society, consumers are increasingly aware of environmental issues and are more likely to support companies that prioritize sustainability. Having a repository of green shipping solutions and data sources can help companies demonstrate their commitment to sustainability and improve their reputation and brand image. This can, in turn, lead to increased business opportunities and competitive advantages for these companies.

Overall, a repository of green shipping solutions and data sources is essential for reducing the environmental impact of shipping, complying with regulations, saving costs, and improving reputation and brand image. It can help the shipping industry move towards more sustainable and environmentally friendly practices, while also benefiting companies financially and socially.

We have yet defined what information hubs are or how they work, but now we will explore the process of transforming information hubs into knowledge hubs. Information hubs are platforms designed to store and distribute information related to a particular field or topic. They can take many forms, such as online databases, digital libraries, or information portals. However, simply storing information is not enough to create a valuable resource that supports informed decision-making and promotes sustainability. To achieve this, information hubs must evolve into knowledge hubs.

Knowledge hubs take the information stored in information hubs and add value by organizing, synthesizing, and analysing it to create knowledge that can be used to solve problems, make decisions, and drive innovation. By transforming information hubs into knowledge hubs, users can gain a deeper understanding of the data and its implications, identify patterns and trends, and apply this knowledge to real-world challenges.

As an illustration, consider an information hub that stores data related to a particular field or topic. While this information is valuable, it may not be enough to fully understand the implications of the data or apply

[10] Available online: https://www.container-xchange.com/blog/sustainable-ports/

it to real-world challenges. By transforming this information hub into a knowledge hub, the data can be analyzed, synthesized, and organized to create knowledge that can be used to support informed decision-making and drive innovation. This knowledge can then be applied to solve complex challenges and promote sustainability in various fields, such as energy, healthcare, and climate change.

Here are a few examples of how information hubs have evolved into knowledge hubs:

1. Weather Information Hub to Climate Knowledge Hub (example: https://www.fao.org/climate-change/knowledge-hub/en/): An example of the evolution from an information hub to a knowledge hub can be seen in the field of climate science. Weather information hubs have long existed to provide data on current and forecasted weather conditions. However, as climate change has become a growing concern, these hubs have evolved into climate knowledge hubs that not only provide weather data but also synthesize research and analysis on climate patterns, trends, and impacts. These knowledge hubs are designed to support informed decision-making in fields such as agriculture, transportation, and urban planning, and to promote sustainable practices in response to climate change.
2. Healthcare Information Hub to Medical Knowledge Hub (example: https://www.medknowhub.com/en/): Healthcare information hubs have long been used to store and disseminate information on medical conditions, treatments, and procedures. However, as medical research has advanced and new treatments and technologies have emerged, these hubs have evolved into medical knowledge hubs that not only provide information but also synthesize and analyze the latest research and trends. These knowledge hubs are designed to support medical professionals in their decision-making, to improve patient outcomes, and to advance the field of medicine as a whole.
3. Energy Information Hub to Sustainable Energy Knowledge Hub (example: https://knowledgehub.seforall.org/): Energy information hubs have traditionally focused on providing data on energy production, consumption, and prices. However, as concerns about climate change and resource depletion have grown, these hubs have evolved into sustainable energy knowledge hubs that not only provide data but also synthesize and analyze research and best practices related to renewable energy, energy efficiency, and sustainable energy policies. These knowledge hubs are designed to support decision-making in fields such as energy policy, urban planning, and industry, and to promote the transition to a more sustainable energy future.

In each of these examples, the evolution from an information hub to a knowledge hub involves not only the gathering and dissemination of data but also the synthesis, analysis, and application of that data to support informed decision-making and promote sustainable practices in various fields.

As demonstrated by the examples provided, knowledge hubs have become increasingly important in addressing complex and interdisciplinary issues such as climate change, healthcare, and sustainable energy. By synthesizing and analyzing data from various sources, knowledge hubs can provide a comprehensive and up-to-date understanding of these issues and support the development of effective solutions.

Moreover, knowledge hubs can help bridge the gap between research and practice by translating complex research findings into actionable knowledge that can be used by policymakers, practitioners, and other stakeholders. This can lead to better decision-making, improved outcomes, and ultimately, a more sustainable future.

However, the effectiveness of knowledge hubs depends on the quality and reliability of the data and analysis they provide, as well as their accessibility and usability for different stakeholders. Ongoing collaboration and dialogue between knowledge hub developers and end-users are crucial to ensuring that knowledge hubs meet the needs of different users and support informed decision-making in various fields.

4.2 Development of Information Hubs into Knowledge Hubs: Methodologies and Technologies

To implement an information hub that can evolve into a knowledge hub, several technologies can be utilized, including:

1. Semantic Web Technologies: These technologies, such as RDF (Resource Description Framework), OWL (Web Ontology Language), and SPARQL (SPARQL Protocol and RDF Query Language), enable the creation of a semantic data layer that allows for more meaningful data connections and relationships.
2. Knowledge Graphs: Knowledge graphs are a type of graph database that use a network of nodes and edges to represent data and relationships between data points. They enable the creation of a more interconnected and contextualized understanding of data.
3. Machine Learning: Machine learning can be utilized to identify patterns and relationships within data, which can then be used to generate insights and predictions. This can be particularly useful in identifying correlations between different data sets.
4. Natural Language Processing: Natural language processing can be used to extract meaning and context from unstructured data sources, such as text documents, social media posts, and news articles.
5. Data Visualization: Data visualization tools can be used to create meaningful and easily understandable representations of complex data sets, making it easier for stakeholders to interpret and analyse the data.

Table 19 Technologies for Building Knowledge Hub

Technology	**Description**
RDF (Resource Description Framework)	A standard for describing resources on the web and their relationships
SPARQL (SPARQL Protocol and RDF Query Language)	A query language used to retrieve and manipulate data stored in RDF format
OWL (Web Ontology Language)	A language for creating ontologies that describe the relationships between resources
Knowledge Graphs	A type of graph database used to store and manage complex knowledge and information
PostgreSQL	An open-source relational database management system that can also be used to store and query RDF data
Natural Language Processing (NLP)	Techniques used to process and analyze natural language text, including named entity recognition and sentiment analysis
Machine Learning	Techniques used to automatically learn patterns and insights from data

Technology	Description
Data Visualization	Techniques used to visually represent data and insights, including charts, graphs, and maps

These technologies can be used to support knowledge representation, inference, and reasoning within knowledge hubs, enabling more sophisticated analysis and decision-making. For example, ontologies can help to standardize and organize domain-specific concepts and relationships, while knowledge graphs can help to identify patterns and connections within complex data sets.

Moreover, these technologies can be integrated with other data management systems such as PostgreSQL to support the storage, retrieval, and analysis of data within knowledge hubs, depending on the specific requirements of the information hub. For example, RDF data can be stored in PostgreSQL using the RDF data model and queried using SPARQL. Natural language processing and machine learning algorithms can be implemented within PostgreSQL using programming languages like Python and integrated with the database using the PL/Python extension. Data visualization tools can also be integrated with PostgreSQL to provide users with interactive dashboards and reports.

In the upcoming chapter of the report, we will further examine the database structure used to establish a knowledge hub for green shipping information. **PostgreSQL, an RDBMS, is a dependable option for creating such a hub as it enables efficient data organization and management, can manage vast amounts of information, and provides robust security features to safeguard the data**. Furthermore, PostgreSQL's flexibility and scalability allow for it to adjust to changing requirements over time.

Here is a table that lists some common plugins and extensions that can be used with PostgreSQL to implement the previous technologies for developing a knowledge hub:

Table 20 Technologies and Plugins/Extensions for enhancing PostgreSQL functionality

Technology	Plugin/Extension
RDF data model	Postgres-RDF
SPARQL	RDF4J, Virtuoso, Blazegraph
Natural Language Processing	PL/Python, PostgreSQL Full-Text Search
Machine Learning	PL/Python, MADlib
Data visualization	Tableau, Metabase, Grafana

This table is not exhaustive and there may be other plugins and extensions available for each technology. The specific plugin or extension used will depend on the specific requirements of the knowledge hub being developed.

4.3 Database Structure with PostgreSQL

Creating a knowledge hub for green shipping information requires an effective system to manage and organize the large amounts of data that need to be stored and accessed. PostgreSQL, a powerful RDBMS, provides an excellent solution for this task. With its robust features, PostgreSQL can efficiently handle and manage large amounts of data, while maintaining the integrity and consistency of the information.

In addition to its data management capabilities, PostgreSQL provides strong security features to protect sensitive data. It includes various authentication mechanisms, such as SSL and Kerberos, and supports encryption to ensure data confidentiality. PostgreSQL's advanced security features ensure that sensitive data remains secure and protected from unauthorized access.

Another advantage of PostgreSQL is its flexibility and scalability. It can be customized to meet the specific needs of the knowledge hub and can adapt to changes in requirements over time. PostgreSQL supports a variety of programming languages and provides a wide range of extensions and plugins that can be used to enhance its functionality.

Overall, PostgreSQL is an excellent choice for creating a knowledge hub for green shipping information. Its reliability, scalability, and strong security features make it a preferred choice for managing and organizing large amounts of data while maintaining the integrity and confidentiality of the information.

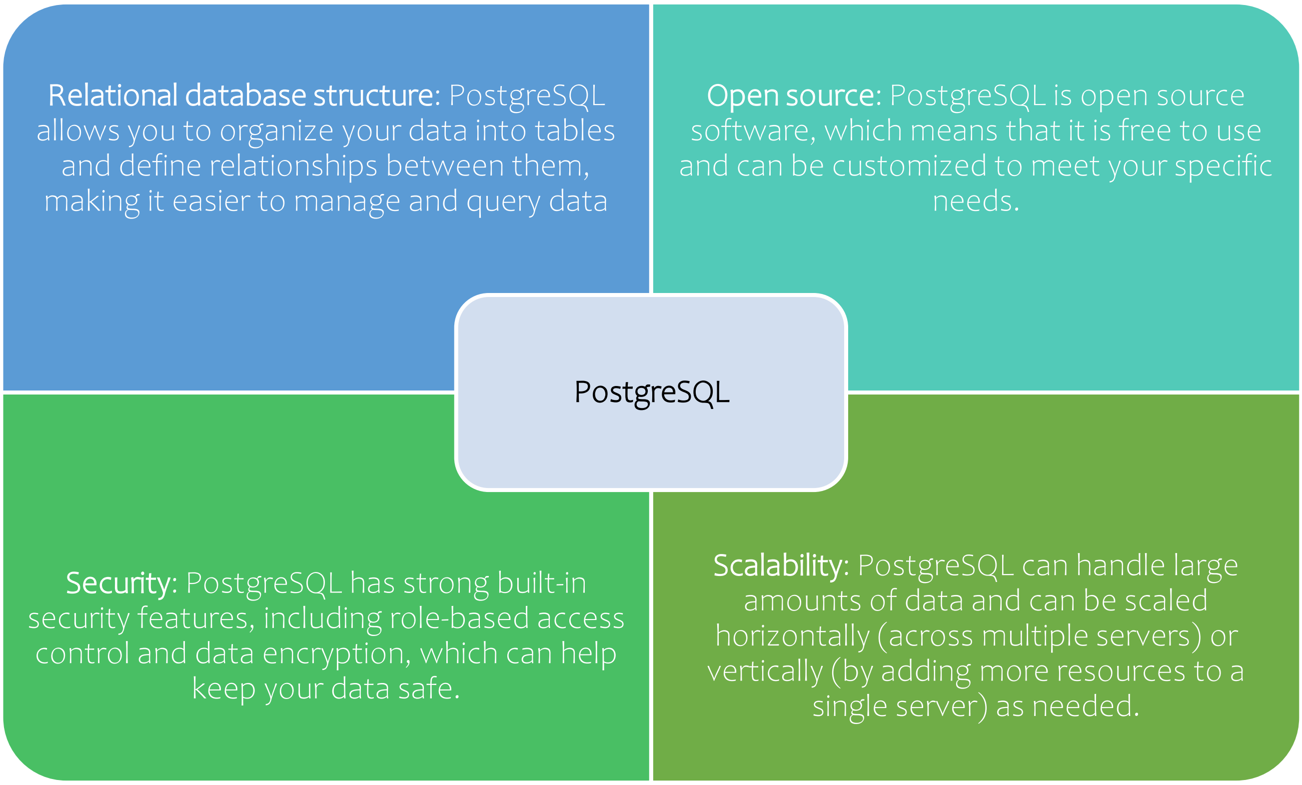

Figure 30 PostgreSQL

PostgreSQL is an open source, standard compliant and robust DBMS. It adopts and extends the Structured Query Language (SQL) - *ISO/IEC 9075-1:2016 Information technology - Database languages - SQL - Part 1: Framework (SQL/Framework)* - for data manipulation and querying[11]. PostgreSQL runs on all major operating systems and can handle big datasets. PostgreSQL is highly extensible: the users can define their own data types, build customised new functions and interact with the DBMS through the query language

[11] https://www.iso.org/standard/63555.html

SQL, using different programming languages like C, Perl, Java, Python, R, JavaScript, etc., and from shell scripts

PostgreSQL organizes data into tables consisting of rows and columns, with each table representing a different type of data or entity in the system. Relationships can be defined between tables to represent how different entities are related to each other. For example, in a green shipping knowledge hub, tables can be created for ships, routes, and ship_routes. The ships table (see Figure 31) could include columns for ship name, size, and fuel type, while the routes table could have columns for route name, start location, and end location. The ship_routes table would have columns for ship ID and route ID, allowing each ship to be associated with the routes it travels, and vice versa[12].

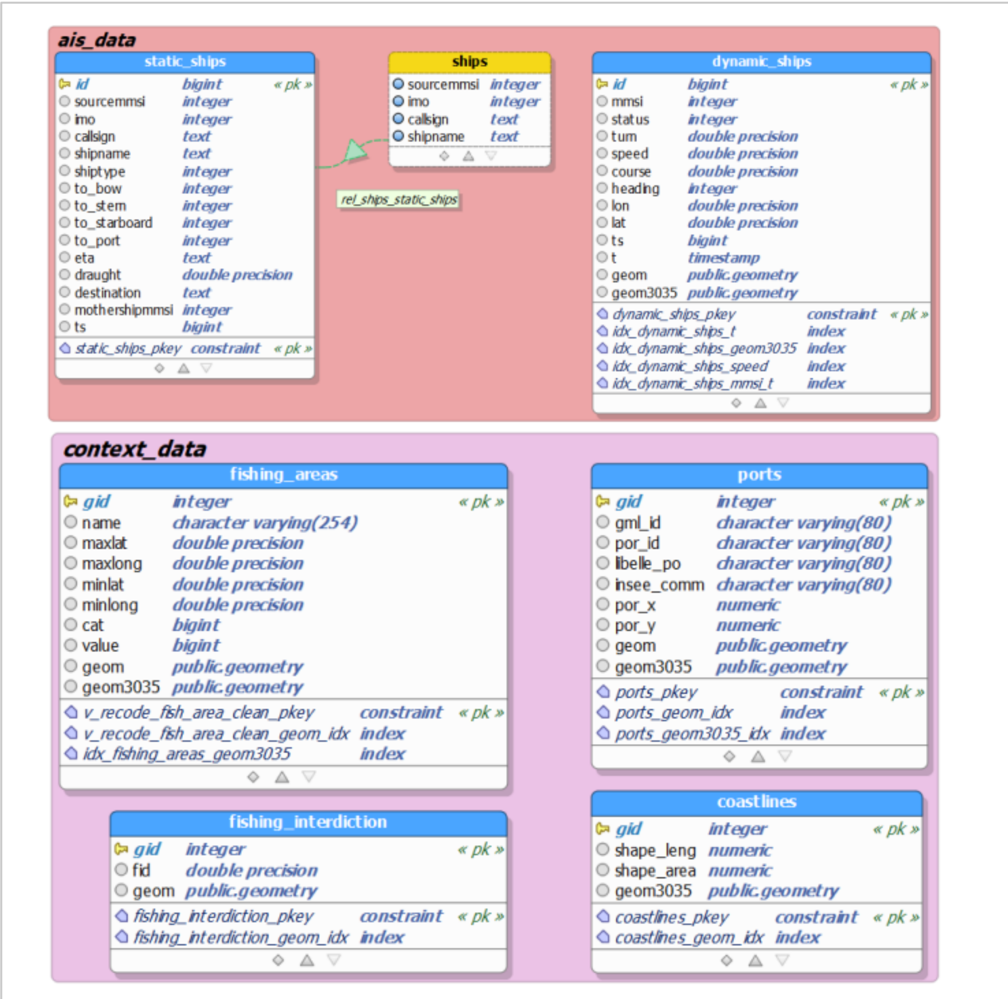

Figure 31 Example of ships table

Once the tables have been created and relationships have been defined, SQL (Structured Query Language) can be used to retrieve specific information from the database. Queries can be written to retrieve information such as all ships that use renewable fuels and are over a certain size, or all routes that pass through a particular port.

[12] https://hal.science/hal-03137050/document

In conclusion, PostgreSQL is a powerful tool for creating a knowledge hub for green shipping information. Its ability to organize, manage, and secure data, as well as its flexibility and scalability, make it a reliable choice for businesses seeking to create a database system for their green shipping needs. A database in PostgreSQL is organised and structured using one or more database schemas and several tables. Each schema defines a workspace where new data types, functions and operators can be defined. Organising a database using different schemas is useful for various reasons:

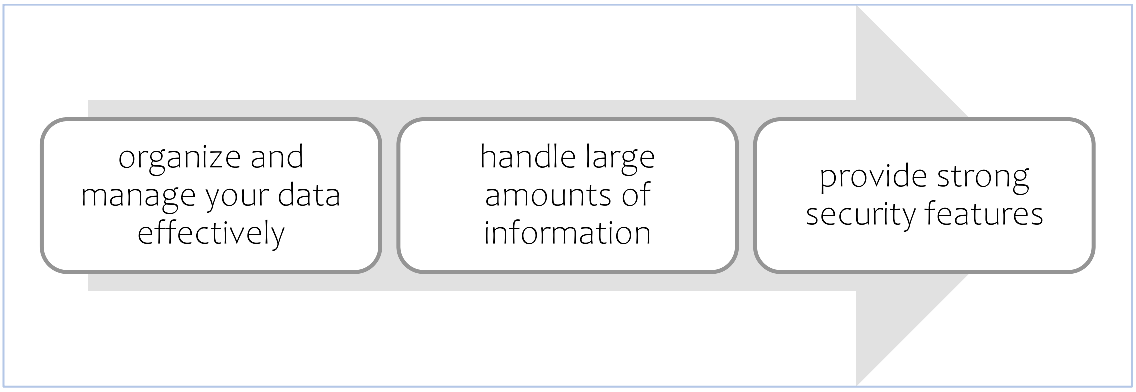

Figure 32 Database properties

The creation of a knowledge hub with information on green shipping solutions involves several essential steps, with determining the taxonomy being the first step.

To achieve this, entities that require classification such as different types of ships, green shipping solutions, or emission factors need to be identified. Categories and subcategories can then be defined based on the entities identified, such as having a top-level category for ships with subcategories for cargo ships, tankers, and passenger ships, or a top-level category for green solutions with subcategories for renewable fuels, energy-efficient designs, and sustainable materials.

Once the taxonomy has been determined, the next step is to create a schema in the PostgreSQL database that reflects the categories and subcategories identified in the taxonomy. This is done to create a logical container for tables that share a common purpose, making it easier to organize and manage data within the database.

For example, a schema called "green_shipping" can be created to hold all tables related to the knowledge hub. Within the schema, tables for each category or subcategory are created, such as "cargo_ships" with columns for ship name, size, fuel type, and emissions data, or "renewable_fuels" with columns for fuel type, emissions data, and availability. The tables can be further organized into subcategories as needed, such as "electric_cargo_ships" or "biofuels."

By creating a schema that reflects the taxonomy, it will be easier to navigate and manage the database, especially as it grows in size and complexity. It also ensures consistency and accuracy in the data, as each table will be focused on a specific category or subcategory. This approach can ultimately lead to more efficient queries and analytics, and a more effective and impactful knowledge hub. The relationships between the tables are then defined based on the taxonomy determined. This involves creating a table called "ship_solutions" with columns for ship ID and solution ID to represent the relationship between different ships and the green solutions they use.

After defining relationships, the tables are populated with data obtained from research and analysis of green shipping solutions, best case user, and emission factors of ships. SQL queries can be used to insert data into the tables. Queries can also be used to retrieve specific information from the database, such as all cargo ships that use renewable fuels and have low emissions, or all green solutions that have been proven to reduce emissions in real-world applications.

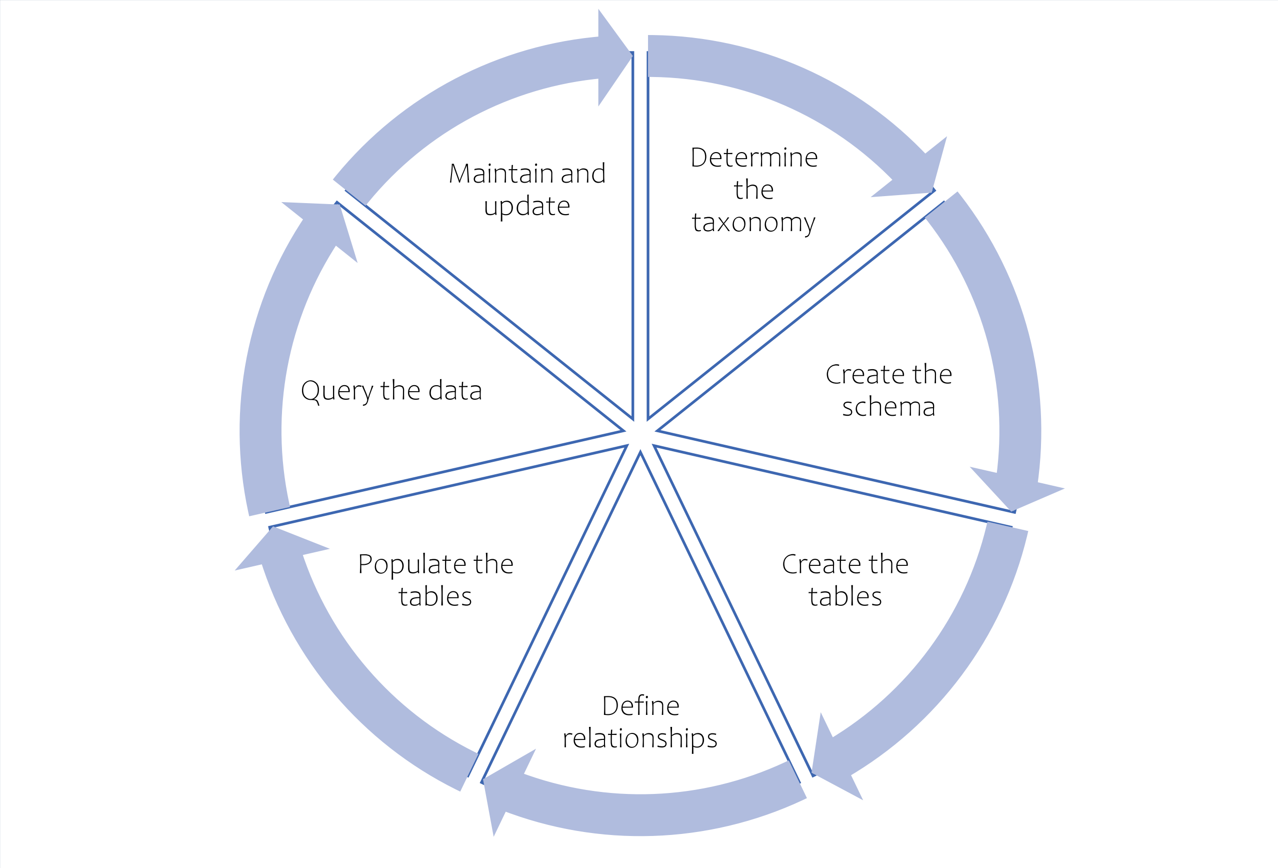

Figure 33 Workflow

Creating a comprehensive knowledge hub about green shipping solutions is a complex process that involves several steps. Once the taxonomy has been determined, the next step is to create a schema and tables within the database to hold the relevant data. In this process, it is important to identify the specific categories of data that will be included and how they will be organized within the schema. This may involve creating tables for different types of ships and the green solutions they use, as well as tables for emissions factors, best case user examples, and other relevant data.

Once the schema and tables have been defined, the next step is to populate them with data obtained from research and analysis of green shipping solutions. This can involve gathering information from a range of sources, including industry reports, academic studies, and government publications. SQL queries can be used to insert the data into the tables, ensuring that the information is accurately and efficiently recorded.

Finally, it is crucial to maintain and update the database over time as new information becomes available to ensure that it remains relevant and accurate. This involves regularly reviewing and updating the data to ensure its integrity, as well as adding new data sources and refining the schema and tables as necessary. By maintaining the database over time, it can remain a valuable resource for stakeholders in the shipping industry, providing up-to-date and comprehensive information to support informed decision-making and promote sustainability. Overall, creating a knowledge hub with PostgreSQL involves determining the taxonomy, creating the schema and tables, defining relationships, populating the tables with data, querying the data, and maintaining and updating the database over time.

The next paragraphs provide a detailed explanation of the process involved in creating a knowledge hub with PostgreSQL. This process includes defining the taxonomy and schema, populating the tables with data, defining relationships between the tables, querying the data, and maintaining the database over time to ensure its relevance and accuracy.

4.4 The Database Taxonomy

PostgreSQL is a powerful and widely used open-source relational database that can handle complex data and query operations. It offers support for advanced features such as spatial data types, JSON data types, and full-text search capabilities, which are useful for building knowledge graphs.

To implement a knowledge hub with PostgreSQL and to achieve effective knowledge management, **it is essential to design a taxonomy or schema that accurately represents the knowledge domain**. This taxonomy should include a hierarchy of categories, concepts, and relationships between them. After designing the taxonomy, the next step is to populate the database with relevant data, ensuring that the data is properly tagged and classified according to the taxonomy.

Once the database is populated, it is important to create queries and algorithms to extract insights and build relationships between data points. These algorithms can include natural language processing and machine learning techniques to facilitate data analysis and knowledge discovery. Additionally, other technologies such as ontologies, RDF, and SPARQL can be used to further enhance the functionality of the knowledge hub by providing advanced data modeling and querying capabilities. By integrating these technologies, a PostgreSQL-based knowledge hub can become a powerful tool for managing complex knowledge domains and promoting data-driven decision-making.

By supporting a wide range of data types, PostgreSQL provides a flexible and powerful platform for storing and manipulating data. This allows users to choose the most appropriate data types for their data, which can help to improve performance, simplify queries, and increase the accuracy and reliability of data stored in the database. The taxonomy of a database refers to the way in which the data is organized and categorized within the database. This includes identifying the entities (objects, concepts, or events) that are represented in the database, as well as the attributes and relationships between those entities.

A well-organized taxonomy can help ensure that data is accurately and consistently categorized, making it easier to search, retrieve, and analyse. Common taxonomies used in databases include hierarchical taxonomies, which organize data into a hierarchical structure, and network taxonomies, which represent data as interconnected nodes and edges. In addition to organizing data within the database, the taxonomy can also inform the design of the database schema and the development of database queries and analytics. By carefully considering the taxonomy of the database, designers and developers can create databases that are efficient, accurate, and easy to use.

The taxonomy of the database for shipping-related information consists of three main categories (as shown in Figure 34). Each category is further broken down into specific subcategories to better organize and classify the data:

- **Ship types:** Includes different types of vessels used in the marine industry, such as container ships, tankers, bulk carriers, Ro-Ro ships, passenger ships, and fishing vessels. This category helps to provide a general understanding of the various types of ships, their features, and their typical cargo.

- **Green shipping technologies:** Focuses on technologies and measures aimed at reducing the environmental impact of ships. This includes technologies related to energy efficiency, such as waste heat recovery systems and advanced propeller designs, as well as emission reduction technologies, such as scrubbers and alternative fuels. This category also includes information on regulatory compliance standards, industry trends, and sustainability and environmental impact considerations.
- **Emission factors and key performance indicators (KPIs)**: Includes information related to the measurement and reporting of ship emissions, such as carbon dioxide, nitrogen oxides, and sulfur oxides. This category also includes information on key performance indicators, which are used to evaluate and compare the environmental performance of different ships or shipping companies. The emission factors and KPIs category is important for analyzing the impact of shipping on the environment and for assessing the effectiveness of emission reduction technologies and measures.

Overall, the taxonomy of the database provides a framework for organizing and classifying data related to shipping and logistics, with a focus on environmental sustainability and impact reduction. This classification system can help researchers, policymakers, and industry professionals to better understand the marine industry and to develop effective strategies and solutions for improving its environmental performance.

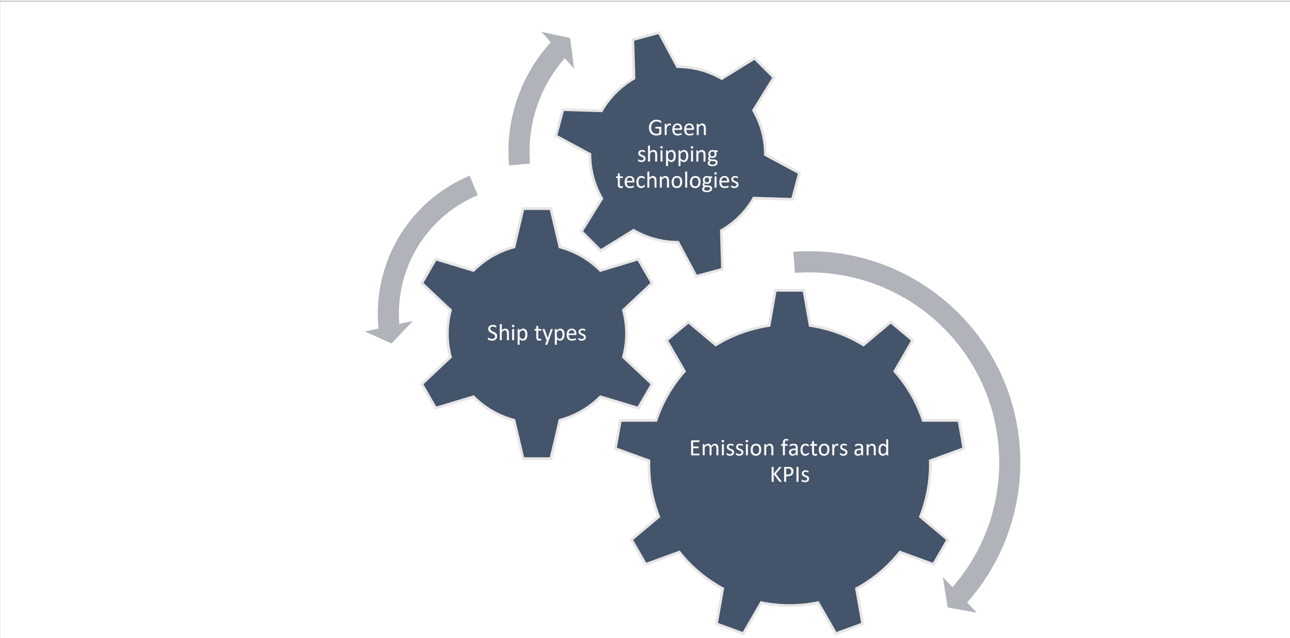

Figure 34 Taxonomy categories used for the KH.

4.4.1 Ship Types

Ships are typically classified into several different types based on their design, size, and purpose. Some of the most common ship types include:

- Container ships: Container ships are cargo ships designed to transport large quantities of cargo in standardized containers. These ships are often used to transport manufactured goods and other products between ports around the world.
- Tankers: Tankers are designed to transport liquids, such as crude oil, petroleum products, and chemicals, in bulk. These ships are typically very large and can carry millions of gallons of cargo.
- Bulk carriers: Bulk carriers are designed to transport large quantities of dry bulk cargo, such as coal, iron ore, and grain. These ships are often very large and have large open cargo holds for loading and unloading bulk cargo.
- Ro-Ro ships: Ro-Ro ships are designed to transport wheeled cargo, such as cars, trucks, and trailers. These ships have large ramps that allow vehicles to be loaded and unloaded directly onto the ship's deck.
- Passenger ships: Passenger ships are designed to transport people, such as cruise ships, ferries, and ocean liners. These ships often have a wide range of amenities, including restaurants, bars, and entertainment venues.
- Fishing vessels: Fishing vessels are designed for commercial fishing operations, such as trawlers, longliners, and purse seiners. These ships are typically equipped with fishing gear and storage facilities for holding and transporting fish.

Overall, the type of ship used for a particular cargo or passenger transport operation depends on the nature of the cargo or passengers, the distance to be covered, and other factors such as cost and availability. Different ship types have different environmental impacts, and efforts are being made to develop green technologies and practices for each type of ship to reduce their environmental impact.

The table, Table 21, provides an overview of different types of ships used in the marine industry, including container ships, tankers, bulk carriers, Ro-Ro ships, passenger ships, and fishing vessels. It also includes information on the typical cargo transported by each ship type and provides an estimate of the gross weight intervals for each category. This table can be a useful reference for those interested in the marine industry or for those looking to collect and analyse data related to shipping and logistics.

Table 21 Ship type

Ship Type	Description	Typical Cargo	Gross Weight Interval (in Gross Tons)
Container ships	Designed to transport large quantities of cargo in standardized containers	Manufactured goods, products	5,000 - 200,000 GT
Tankers	Designed to transport liquids, such as crude oil, petroleum products, and chemicals, in bulk	Crude oil, petroleum products, chemicals	10,000 - 550,000 GT

Bulk carriers	Designed to transport large quantities of dry bulk cargo, such as coal, iron ore, and grain	Coal, iron ore, grain	10,000 - 400,000 GT
Ro-Ro ships	Designed to transport wheeled cargo, such as cars, trucks, and trailers	Cars, trucks, trailers	1,000 - 75,000 GT
Passenger ships	Designed to transport people	Cruise ships, ferries, ocean liners	1,000 - 225,000 GT
Fishing vessels	Designed for commercial fishing operations	Fish	10 - 1,500 GT

Defining the ship types is important for a database that includes green shipping solutions and emission factors because different ship types have different environmental impacts and require different green solutions to reduce their emissions. For example, container ships often rely on bunker fuel, which is a heavy and polluting fuel source, whereas passenger ships may use cleaner-burning LNG fuel. By categorizing ships based on their type, the database can provide more targeted and relevant information on green solutions and emission factors for each category.

A relational schema for such a database might include tables for different ship types, as well as tables for green solutions, emissions factors, and other relevant data. Here's an example of what such a schema might look like:

- Ship Types table
    - ➢ ShipType_ID (PK)
    - ➢ ShipType_Name
- Ships table
    - ➢ Ship_ID (PK)
    - ➢ Ship_Name
    - ➢ Ship_Type_ID (FK)
- Green Solutions table
    - ➢ Solution_ID (PK)
    - ➢ Solution_Name
    - ➢ Solution_Description
- Ship_Green_Solutions table
    - ➢ Ship_ID (FK)
    - ➢ Solution_ID (FK)
- Emissions Factors table
    - ➢ Factor_ID (PK)
    - ➢ Factor_Name
    - ➢ Factor_Description

- Ship_Emissions_Factors table
    - Ship_ID (FK)
    - Factor_ID (FK)
    - Factor_Value

In this schema, the Ship Types table provides a list of the different types of ships and their associated IDs. The Ships table holds data on individual ships, including their names and the IDs of their associated ship types. The Green Solutions table provides information on different green solutions, such as renewable fuels or emission reduction technologies. The Ship_Green_Solutions table establishes a many-to-many relationship between ships and green solutions, allowing for multiple solutions to be associated with each ship.

The Emissions Factors table holds data on different factors that contribute to ship emissions, such as fuel type or engine efficiency. The Ship_Emissions_Factors table establishes a many-to-many relationship between ships and emissions factors, allowing for multiple factors to be associated with each ship along with their corresponding values.

An example table for the Ship Types table might look like this:

Table 22 Ship Type table

ShipType_ID	ShipType_Name
1	Container
2	Tanker
3	Bulk Carrier
4	Ro-Ro
5	Passenger
6	Fishing

This table provides a list of ship types and their associated IDs, which can be used to categorize ships in the Ships table and other tables within the database.

Overall, by defining ship types and organizing the database around them, users can more easily access and analyze data related to green solutions and emissions factors for each ship category, ultimately supporting more informed and sustainable decision-making in the shipping industry.

4.4.2 Green Shipping Technologies

As mentioned previously carbon emissions and other greenhouse gases are produced through various human activities, including the burning of fossil fuels in industries, transportation, and power generation. This results in an increase in the concentration of gases such as carbon dioxide, methane, and nitrous oxide in the atmosphere, which contributes to global warming and climate change.

A "green ship" is a term used to describe any seagoing vessel that takes measures to reduce its environmental impact. These measures include adopting eco-friendly technologies, implementing efficient procedures, and reducing fuel consumption to lower carbon emissions. **Green ship technology focuses on reducing emissions, increasing energy efficiency, and minimizing the use of natural resources**. The adoption of advanced propulsion systems, such as hybrid engines or fuel cells, can help reduce the amount of fuel consumed, thereby decreasing carbon emissions. Additionally, implementing energy-efficient technologies, such as LED lighting or waste heat recovery systems, can contribute to further reductions in energy consumption and greenhouse gas emissions.

Overall, the development of green ship technology and its adoption by the shipping industry is essential for mitigating the adverse effects of climate change and protecting the environment.

To store information on green shipping solutions in a structured and organized manner, a PostgreSQL table can be used:

Table 23 Table green_shipping_solutions

Column Name	Data Type	Description
solution_id	SERIAL	Unique identifier for each green shipping solution
solution_name	VARCHAR(50)	The name of the green shipping solution
technology_type	VARCHAR(20)	The type of technology used in the green shipping solution (e.g., hybrid engines, fuel cells)
emissions_reduction	FLOAT	The percentage of emissions reduction achieved by the green shipping solution
energy_efficiency_gain	FLOAT	The percentage of energy efficiency gain achieved by the green shipping solution
implementation_cost	FLOAT	The estimated cost of implementing the green shipping solution

The table could include columns such as a unique identifier for each solution, the name of the solution, the type of technology used, the percentage of emissions reduction achieved, the percentage of energy efficiency gain achieved, and the estimated cost of implementing the solution. This table could then be linked to other tables in the database, such as tables on different ship types, to enable analyses on the impact of green shipping solutions on specific types of ships.

Overall, the development and adoption of green shipping solutions are essential for the shipping industry to meet the goals of reducing greenhouse gas emissions and mitigating the adverse effects of climate change. By using a PostgreSQL database to store and analyze information on green shipping solutions, stakeholders in the shipping industry can make informed decisions on the adoption of green technologies and practices, support sustainability efforts, and drive innovation in the field.

This table includes different types of technology that can be used in green shipping solutions, including hybrid engines, fuel cells, wind-assisted propulsion, hull air lubrication, and dynamic positioning systems. These technologies are designed to improve the efficiency of ship operations, reduce fuel consumption, and lower emissions.

In addition to the "green_shipping_solutions" table, a PostgreSQL schema can be created to organize and manage the different tables related to green shipping. Here is an example schema for a database focused on green shipping solutions:

Table 24 Schema of green_shipping_db

Table Name	Description
green_shipping_solutions	Stores information on different green shipping solutions, including the technology used and its effectiveness
ship_types	Provides information on different ship types and their characteristics
emission_factors	Stores information on different emission factors associated with each ship type and technology used
best_case_scenarios	Contains information on best case scenarios for each ship type and technology used

An example of how the "best_case_scenarios" table may appear in a green shipping database is presented below:

Table 25 Table best_case_scenarios

Column Name	Data Type	Description
scenario_id	SERIAL	Unique identifier for each best case scenario
ship_type	VARCHAR(20)	The type of ship that the best case scenario applies to, such as container ship or tanker
technology_type	VARCHAR(20)	The type of technology used in the best case scenario, such as hybrid engines or fuel cells
emission_factor	FLOAT	The estimated emission factor achieved in the best case scenario, expressed in grams of CO_2 per ton of cargo mile
energy_efficiency	FLOAT	The estimated energy efficiency achieved in the best case scenario, expressed as a percentage
cost_savings	FLOAT	The estimated cost savings achieved in the best case scenario, expressed as a percentage of overall operating costs

For example, a best-case scenario for a container ship using hybrid engines might include an estimated emission factor of 50 grams of CO_2 per ton of cargo mile, an estimated energy efficiency gain of 20%, and an estimated cost savings of 15% compared to traditional diesel engines.

4.4.3 Definition of Emission Factors and KPIs

In this section, will be utilized the output from Task 1.3, which includes a modelling and benchmarking framework, reference blueprints for energy solutions, and benchmarking to identify key performance indicators (KPIs). These indicators describe the performance of ships in terms of energy efficiency and GHG and pollutant emissions in a synthetic but exhaustive way.

The KPIs and Green Shipping Technologies tables can be used together in a PostgreSQL database to store and manage data related to the environmental performance of different types of ships and the technologies used to reduce their environmental impact.

Specifically, the KPIs table includes different environmental performance indicators, such as Specific Fuel Consumption (SFC), Specific CO_2 Emissions (Tank-to-Wake), EU GHG II (Well-to-Wake), Specific Pollutants

Emissions, and Carbon Intensity Indicator (CII). These indicators are calculated using specific formulas and provide information on the fuel efficiency and environmental impact of ships.

The Green Shipping Technologies table includes different types of technologies that can be used to reduce the environmental impact of ships, such as Exhaust Gas Cleaning Systems (scrubbers), Selective Catalytic Reduction (SCR) Systems, Alternative Fuels, Carbon Capture and Storage (CCS), and Other Emission Reduction Technologies. These technologies are designed to improve the efficiency of ship operations, reduce fuel consumption, and lower emissions.

The identified KPIs are listed and described below.

1) $\boldsymbol{Specific\ Fuel\ consumption\ (SFC)} \left[\frac{g}{kWh}\right] = \frac{m_{fuel}}{kWh_{propulsion}}$

Where:

- m_{fuel} is the mass of fuel consumed in grams
- $kWh_{propulsion}$ is the net energy exerted by the engine for propulsion expressed in kWh

2) $\textbf{Specific CO2 emissions (Tank} - \textbf{to} - \textbf{Wake)} \left[\frac{kg}{kWh}\right] = \frac{kg\ CO_2}{kWh_{propulsion}}$

Where:

- kg CO_2 is the mass of CO_2 emitted in kilograms
- $kWh_{propulsion}$ is the net energy exerted by the engine for propulsion expressed in kWh

The specific CO2 emissions are evaluated "Tank-to-wake" (TtW). Tank-to-Wake refers to lifecycle assessments of GHG from the fuel in a ship tank to the ship exhaust (downstream emissions only).

3) $\textbf{EU GHG II (Well} - \textbf{to} - \textbf{Wake)} \left[\frac{g}{kWh}\right] = \frac{g\ CO_2\ eq}{MJ_{fuel}}$

Where:

- g CO_2 eq is the mass of equivalent CO_2 emitted in kilograms
- MJ_{fuel} is the energy released as heat during the fuel combustion in MJ

The EU GHG II KPI is evaluated "Well-to-wake" (WtW). Well-to-Wake refers to the entire process, from the fuel production to the delivery and use onboard ships, and considering all emissions produced therein.

For this reason, the KPI "EU GHG II WtW" refers to lifecycle assessments of GHG from fuel production (upstream emissions), carriage of the fuel in the ship tank, to the ship exhaust (downstream emissions).

4) $\boldsymbol{Specific\ pollutants\ emissions} \left[\frac{g}{kWh}\right] = \frac{grams\ of\ other\ pollutants}{kWh_{propulsion}}$

The specific pollutants emissions describe how many grams of other pollutants (CH_4, N_2O, NO_x, SO_2, SO_4, PM_{tot}) are emitted by the ship T-t-W per kWh of energy exerted by the engine for propulsion in kWh.

5) $\boldsymbol{Carbon\ Intensity\ Indicator\ (CII)} \left[\frac{g}{tons \cdot nautical\ mile}\right] = \frac{gCO_2}{C \cdot D_t}$

Where (CII definition by IMO resolution MEPC.336(76)):

- gCO_2 is the sum of CO2 emissions (in grams) from all the fuel oil consumed on board a ship in a given calendar year.
- C represents the ship's capacity:

- For bulk carriers, tankers, container ships, gas carriers, LNG carriers, ro-ro cargo ships, general cargo ships, refrigerated cargo carrier and combination carriers, deadweight tonnage (DWT) should be used as Capacity.

- For cruise passenger ships, ro-ro cargo ships (vehicle carriers) and ro-ro passenger ships, gross tonnage (GT) should be used as Capacity.

- D_t represents the total distance travelled (in nautical miles), as reported under IMO DCS.

The Carbon Intensity Indicator (CII) is a measure of how efficiently a ship transports goods or passengers and is given in grams of CO2 emitted per cargo-carrying capacity and nautical mile.

Here is an example of a PostgreSQL table that could be used to store the KPIs for green shipping solutions:

Table 26 Table green_ship_kpis

KPI Name	**Formula**	**Description**
Specific Fuel Consumption (SFC)	m_fuel/kWh_propulsion	Mass of fuel consumed in grams per net energy exerted by the engine for propulsion in kWh
Specific CO2 Emissions (Tank-to-Wake)	kg_CO2/kWh_propulsion	Mass of CO2 emitted in kilograms per net energy exerted by the engine for propulsion in kWh, evaluated Tank-to-Wake (TtW)
EU GHG II (Well-to-Wake)	g_CO2eq/MJ_fuel	Mass of equivalent CO2 emitted in kilograms per energy released as heat during fuel combustion in MJ, evaluated Well-to-Wake (WtW)
Specific Pollutants Emissions	g_other_pollutants/kWh_propulsion	Grams of other pollutants (CH4, N2O, NOx, SO2, SO4, PMtot) emitted by the ship Tank-to-Wake per net energy exerted by the engine for propulsion in kWh
Carbon Intensity Indicator (CII)	g_CO2/(tons * nautical mile)	Grams of CO2 emitted per cargo-carrying capacity and nautical mile, a measure of the ship's efficiency in transporting goods or passengers

These KPIs are important for measuring and evaluating the environmental impact of different green shipping solutions. They can be used to compare the efficiency and effectiveness of different technologies and practices, and to identify areas for improvement in the shipping industry. By storing and analyzing data on these KPIs, stakeholders can make more informed decisions about how to reduce carbon emissions and promote sustainability in the maritime sector.

The KPIs and Green Shipping Technologies tables can be used together in a PostgreSQL database to store and manage data related to the environmental performance of different types of ships and the technologies used to reduce their environmental impact.

Furthermore, the KPIs table includes different environmental performance indicators, such as Specific Fuel Consumption (SFC), Specific CO_2 Emissions (Tank-to-Wake), EU GHG II (Well-to-Wake), Specific Pollutants Emissions, and Carbon Intensity Indicator (CII). These indicators are calculated using specific formulas and provide information on the fuel efficiency and environmental impact of ships.

The Green Shipping Technologies table includes different types of technologies that can be used to reduce the environmental impact of ships, such as Exhaust Gas Cleaning Systems (scrubbers), Selective Catalytic Reduction (SCR) Systems, Alternative Fuels, Carbon Capture and Storage (CCS), and Other Emission Reduction Technologies. These technologies are designed to improve the efficiency of ship operations, reduce fuel consumption, and lower emissions.

To create a relational schema for these tables in PostgreSQL, we could start with the following code:

```
CREATE TABLE KPIs (
  kpi_id SERIAL PRIMARY KEY,
  kpi_name VARCHAR(255) NOT NULL,
  formula VARCHAR(255) NOT NULL,
  description TEXT
);
CREATE TABLE Green_Shipping_Technologies (
  tech_id SERIAL PRIMARY KEY,
  tech_name VARCHAR(255) NOT NULL,
  description TEXT
);
CREATE TABLE Ship_Tech_KPIs (
  stkp_id SERIAL PRIMARY KEY,
  tech_id INT NOT NULL,
  kpi_id INT NOT NULL,
  FOREIGN KEY (tech_id) REFERENCES Green_Shipping_Technologies(tech_id),
  FOREIGN KEY (kpi_id) REFERENCES KPIs(kpi_id)
);
```

The KPIs table has a kpi_id column that serves as the primary key and is automatically generated using the SERIAL data type. The table also has columns for kpi_name, formula, and description. The kpi_name and formula columns are required and cannot be NULL. The description column is optional and can store additional information about each KPI.

The Green_Shipping_Technologies table also has a tech_id column that serves as the primary key and is automatically generated using the SERIAL data type. The table also has columns for tech_name and description. The tech_name column is required and cannot be NULL. The description column is optional and can store additional information about each technology.

The Ship_Tech_KPIs table serves as a join table between the Green_Shipping_Technologies and KPIs tables, and has columns for stkp_id (which serves as the primary key), tech_id (which references the tech_id column in the Green_Shipping_Technologies table), and kpi_id (which references the kpi_id column in the KPIs table). This table allows us to store data on the KPIs associated with each technology used in green shipping solutions.

Overall, this relational schema allows us to store and manage data on the environmental performance of different types of ships and the technologies used to reduce their environmental impact, and provides a foundation for further data analysis and reporting.

4.5 The Database Schema and the Tables

To create a comprehensive knowledge hub for green shipping, a well-organized schema called "green_shipping" can be developed. This schema can be designed to hold all the necessary tables related to the knowledge hub.

In order to ensure efficient and effective organization, tables for each category or subcategory can be created within the schema. For instance, a table called "cargo_ships" can be created with columns for ship name, size, fuel type, and emissions data. Similarly, a table called "renewable_fuels" can be created with columns for fuel type, emissions data, and availability.

To further refine the organization, these tables can be subdivided into more specific subcategories as needed. For instance, tables can be created for "electric_cargo_ships" or "biofuels," depending on the type of information being stored.

By using this schema, all relevant information can be logically categorized and efficiently stored. This can help users to quickly and easily locate the information they need, improving the overall usability of the knowledge hub. Furthermore, as new information is added, it can be easily integrated into the existing schema, ensuring that the knowledge hub remains up-to-date and relevant.

Here's an example table that could be used within the "green_shipping" schema to store information about cargo ships:

Table 27 Example table: cargo_ships

Column Name	Data Type	Description
ship_name	VARCHAR(50)	The name of the cargo ship
ship_size	INT	The size of the cargo ship in TEUs (twenty-foot equivalent units)
fuel_type	VARCHAR(20)	The type of fuel used by the cargo ship (e.g., diesel, LNG, hydrogen)
fuel_consumption	FLOAT	The amount of fuel consumed by the ship per day in metric tons
emissions_CO2	FLOAT	The amount of CO2 emissions produced by the ship per day in metric tons
emissions_NOx	FLOAT	The amount of NOx emissions produced by the ship per day in metric tons

The above table would allow for the storage of information about cargo ships in a well-organized and efficient manner, making it easy for users to search and retrieve information about specific ships, as well as to conduct analyses on the data as a whole.

Similar tables could be created for each type of ship in order to provide more specific information about the characteristics and emissions of each type.

For example, a table could be created specifically for container ships, with columns for information such as the maximum capacity in TEUs, the average speed, and the average distance traveled. Another table could be created for tanker ships, with columns for information such as the maximum capacity in barrels, the type of cargo carried, and the average age of the ships in the fleet.

By creating tables specific to each type of ship, users would be able to easily access and analyze data that is most relevant to their needs. This would help to ensure that the knowledge hub is useful and effective for a wide range of stakeholders in the shipping industry.

Here's an example of a table that could be used within the "green_shipping" schema to store information about green solutions:

Table 28 Example table: green_solutions

Column Name	Data Type	Description
solution_name	VARCHAR(50)	The name of the green solution
solution_type	VARCHAR(20)	The type of solution (e.g. renewable energy, energy efficiency)
description	TEXT	A brief description of the solution
benefits	TEXT	A summary of the environmental, economic, and social benefits of the solution
challenges	TEXT	A summary of the challenges and barriers to the adoption of the solution
case_studies	TEXT	Examples of successful implementation of the solution in the shipping industry
references	TEXT	References and resources related to the solution

The above table would allow for the storage of information about green solutions related to shipping in a well-organized and efficient manner, making it easy for users to search and retrieve information about specific solutions, as well as to conduct analyses on the data as a whole. Here's an example of a table that could be used to store emission factors related to shipping:

Table 29 Example table: emission_factors

Column Name	Data Type	Description
fuel_type	VARCHAR(20)	The type of fuel
CO2_factor	FLOAT	The CO2 emission factor for the fuel (in kg CO2 per kg of fuel)
CH4_factor	FLOAT	The CH4 emission factor for the fuel (in kg CH4 per kg of fuel)
N2O_factor	FLOAT	The N2O emission factor for the fuel (in kg N2O per kg of fuel)
PM_factor	FLOAT	The particulate matter (PM) emission factor for the fuel (in kg PM per kg of fuel)
SO2_factor	FLOAT	The sulfur dioxide (SO2) emission factor for the fuel (in kg SO2 per kg of fuel)

The above table would allow for the storage of emission factor data related to different types of fuel used in the shipping industry. Each fuel type would be assigned values for the CO_2, CH_4, N_2O, PM, and SO_2 emission factors, based on the specific characteristics of the fuel.

Table 30 Emission Reduction Technologies

Column Name	Data Type	Description
technology_type	VARCHAR(50)	The type of emission reduction technology used
description	TEXT	A brief description of the technology
implementation_cost	NUMERIC(10,2)	The estimated cost of implementing the technology
efficiency_improvement	NUMERIC(5,2)	The estimated improvement in fuel efficiency or emissions reduction achieved by the technology
maintenance_cost	NUMERIC(10,2)	The estimated cost of maintaining the technology

Possible schema:

```
CREATE TABLE emission_reduction_technologies (
id SERIAL PRIMARY KEY,
technology_type VARCHAR(50) NOT NULL,
description TEXT NOT NULL,
implementation_cost NUMERIC(10,2) NOT NULL,
efficiency_improvement NUMERIC(5,2) NOT NULL,
maintenance_cost NUMERIC(10,2) NOT NULL
);
```

The above table provides information on the different technologies that can be used to reduce emissions from ships. The data stored in this table includes the name of the technology and a brief description of how it works. The technology names are listed in the first column of the table, and the descriptions are listed in the second column. Some examples of emission reduction technologies that can be included in this table are exhaust gas cleaning systems (scrubbers), selective catalytic reduction (SCR) systems, alternative fuels, carbon capture and storage (CCS), and other emission reduction technologies.

Table 31 Emission Regulations

Column Name	Data Type	Description
regulation_type	VARCHAR(50)	The type of regulation
description	TEXT	A brief description of the regulation
enforcement_authority	VARCHAR(50)	The authority responsible for enforcing the regulation
compliance_deadline	DATE	The deadline for compliance
penalty_for_noncompliance	NUMERIC(10,2)	The penalty for noncompliance

Possible schema:

```
CREATE TABLE emission_reduction_technologies (
id SERIAL PRIMARY KEY,
technology_type VARCHAR(50) NOT NULL,
```

```
description TEXT NOT NULL,
implementation_cost NUMERIC(10,2) NOT NULL,
efficiency_improvement NUMERIC(5,2) NOT NULL,
maintenance_cost NUMERIC(10,2) NOT NULL
);
```

The above table provides information on the various regulations and compliance standards related to ship emissions. The data stored in this table includes the name of the regulation or standard, a brief description of its requirements, and the date it was implemented. The regulatory bodies responsible for each regulation can also be included. Some examples of emission regulations that can be included in this table are International Maritime Organization (IMO) regulations, national regulations, classification society rules, and other regulatory compliance standards.

Table 32 Energy Efficiency Technologies

Column Name	Data Type	Description
technology_type	VARCHAR(50)	The type of energy efficiency technology used
description	TEXT	A brief description of the technology
implementation_cost	NUMERIC(10,2)	The estimated cost of implementing the technology
efficiency_improvement	NUMERIC(5,2)	The estimated improvement in fuel efficiency or emissions reduction achieved by the technology
maintenance_cost	NUMERIC(10,2)	The estimated cost of maintaining the technology

Possible schema:

```
CREATE TABLE energy_efficiency_technologies (
id SERIAL PRIMARY KEY,
technology_type VARCHAR(50) NOT NULL,
description TEXT NOT NULL,
implementation_cost NUMERIC(10,2) NOT NULL,
efficiency_improvement NUMERIC(5,2) NOT NULL,
maintenance_cost NUMERIC(10,2) NOT NULL
);
```

The above table provides information on the different technologies that can be used to increase energy efficiency on ships. The data stored in this table includes the name of the technology and a brief description of how it works. The technology names are listed in the first column of the table, and the descriptions are listed in the second column. Some examples of energy efficiency technologies that can be included in this table are waste heat recovery systems, energy-efficient lighting, energy management systems, hull coatings and designs, advanced propeller designs, and other energy-efficient technologies.

Table 33 Operational Parameters

Column Name	Data Type	Description
vessel_speed	NUMERIC(5,2)	The speed of the vessel in knots
load_factor	NUMERIC(5,2)	The percentage of cargo capacity utilized by the vessel
weather_conditions	VARCHAR(50)	The prevailing weather conditions
other_parameters	TEXT	Any other operational parameters that may impact emissions

Possible schema:

```
CREATE TABLE operational_parameters (
id SERIAL PRIMARY KEY,
vessel_speed NUMERIC(5,2) NOT NULL,
load_factor NUMERIC(5,2) NOT NULL,
weather_conditions VARCHAR(50) NOT NULL,
other_parameters TEXT
);
```

The above table provides information on the various operational parameters that can affect ship emissions and energy efficiency. The data stored in this table includes the name of the parameter, a brief description of what it represents, and the units of measurement used. Some examples of operational parameters that can be included in this table are vessel speed, load factor, weather conditions, and other operational parameters.

4.6 Query the Data

An example of a query for the "cargo_ships" table in the "green_shipping" schema that retrieves information about cargo ships that use renewable fuels:

```
SELECT ship_name, size, fuel_type, emissions_data
FROM green_shipping.cargo_ships
```

This query selects the ship name, size, fuel type, and emissions data from the "cargo_ships" table in the "green_shipping" schema, and then filters the results to only include ships that use renewable fuels. This query can be used to retrieve specific information about cargo ships that are using renewable fuels, which could be useful for analyzing trends or making decisions related to green shipping solutions.

4.7 Expanding the Database with More Information

To extract a corpus from web pages related to the decarbonization of the maritime industry, the first step is to utilize a web crawler. A web crawler is a software program that systematically browses the internet, usually starting from a list of URLs, to gather information and data from web pages. In this case, the web crawler will be used to collect information and data related to the decarbonization of the maritime industry. Once the web crawler has collected the relevant data, the next step is to enrich the database initially constructed. This can be done by using the data collected by the web crawler to add new information to the database. The new data can be added to the existing tables or new tables can be created to store the additional information.

Web crawlers can be an effective tool for extracting data from web pages related to decarbonization of the maritime industry. However, they do have some limitations that need to be taken into consideration. One limitation is that web crawlers can only access public information on the internet. If information is behind a login or paywall, a web crawler may not be able to access it. Additionally, web crawlers may not be able to extract certain types of data, such as data embedded in images or videos. Another limitation is that web crawlers can be limited by the quality of the URLs used to initiate the crawl. If the URLs are incomplete, inaccurate, or outdated, the web crawler may not be able to access all relevant web pages. Furthermore, web crawlers may not be able to accurately identify and filter out irrelevant information, such as ads or duplicate content.

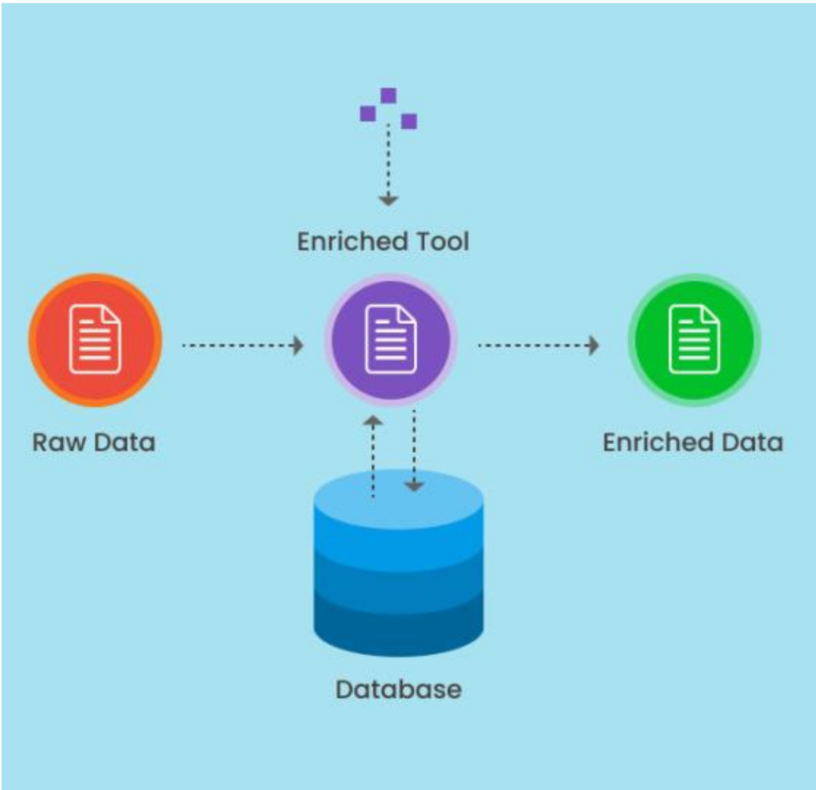

Figure 35 Enrich the database

To ensure that the data is relevant and accurate, it is important to filter the data collected by the web crawler. This can be done by using specific keywords related to the decarbonization of the maritime industry. The web crawler can be programmed to search for specific keywords or phrases on web pages to ensure that only relevant information is collected. It is also important to remove duplicate data to avoid redundancy in the database. This can be achieved by using data deduplication techniques to identify and remove identical or similar data.

Web crawling is the process of automatically gathering data from websites across the internet. By using web crawlers or spiders, it is possible to gather information on various topics, including green shipping technologies, emission reduction solutions, and regulatory requirements. To update and maintain the green shipping database, web crawling can be used to regularly scan relevant websites and collect new data as it becomes available. This data can then be integrated into the database, ensuring that it remains up-to-date and relevant.

In addition to updating the database with new data, web crawling can also be used to ensure data integrity by verifying the accuracy of existing data. By periodically checking the information in the database against the information on the source websites, any inconsistencies or inaccuracies can be identified and corrected. Overall, web crawling can be an effective tool for maintaining the accuracy and relevance of a knowledge hub, such as a green shipping database. By regularly updating the database with new data and verifying the accuracy of existing data, the database can continue to serve as a valuable resource for those in the shipping industry and those interested in promoting sustainable transportation solutions.

Finally, it is important to review and validate the data before adding it to the database. This can be done by manually reviewing the data collected by the web crawler and ensuring that it meets the relevant criteria and standards.

Overall, by using a web crawler to extract a corpus from web pages related to the decarbonization of the maritime industry, and then enriching the database with this new data, stakeholders can access a wider range of information and insights related to sustainable shipping practices. This can help to inform decision-making and drive innovation in the maritime industry towards a more sustainable future.

In order to maintain an up-to-date and comprehensive database related to decarbonization in the maritime industry, it is important to regularly collect and integrate new data. One way to do this is through web crawling, a process that involves automatically gathering data from websites across the internet. This process can be broken down into several steps, including identifying relevant websites, choosing a web crawler, setting up the web crawler, extracting data, and enriching the database with the newly collected data. By following these steps, a more comprehensive database can be created that can be used to inform research, policy, and practice related to decarbonization in the maritime industry:

1. Identify relevant websites: Identify websites that contain information related to decarbonization in the maritime industry. These may include industry publications, academic journals, government websites, and news sites.
2. Choose a web crawler: Choose a web crawler that is capable of extracting data from the identified websites. There are several web crawlers available, such as Scrapy and Beautiful Soup.
3. Set up the web crawler: Set up the web crawler to extract relevant data from the identified websites. This may include text, images, and other media.
4. Extract data: Run the web crawler to extract data from the identified websites. This will create a corpus of data related to decarbonization in the maritime industry.
5. Enrich the database: Once the data has been extracted, enrich the initial database by adding the new data to it. This will create a more comprehensive database that can be used to inform research, policy, and practice related to decarbonization in the maritime industry.

4.7.1 Data from Living Labs

As described in previous section, when integrating data from a Living Lab into a Postgres observatory for green shipping, the first step is to create a schema in Postgres that represents the data to be stored. This involves creating tables and defining columns that correspond to the categories in the taxonomy or ontology. Once the schema is established, the next step is to extract the data from the Living Lab and format it for loading into the database. This may require converting data from one format to another, such as from CSV to SQL.

After the data is formatted correctly, it can be loaded into the Postgres database using SQL statements. For example, the "COPY" command could be used to load data from a CSV file into a table. Once the data is loaded, Postgres tools can be used to query and analyze the data. For instance, SQL queries could be used to extract specific data points or generate reports on trends and patterns in the data.

It is important to note that normalization is crucial when integrating data from different sources. Normalization is the process of organizing data in a database to minimize redundancy and dependency. By standardizing data in a common format, stakeholders can make more accurate comparisons across different sources of data. This, in turn, can help inform policy decisions and guide the development of sustainable practices within the shipping industry.

Integrating data into the observatory can be done using various tools depending on the specific requirements of the observatory. Some tools that can be used for data integration include ETL (extract, transform, load) tools like Talend or Apache NiFi, which can help to transform and transfer data from various sources into the observatory. Other tools like Tableau or Metabase can be used for data visualization and building interactive dashboards and reports.

ChatGPT, on the other hand, can be used to analyze and interpret the data, and extract insights and knowledge from it. It can also be used to categorize the data using a taxonomy or ontology, which can make it easier to search and analyze. However, ChatGPT is not specifically designed for data integration, and other tools like ETL tools or data integration platforms may be more suitable for this purpose.

Overall, the choice of tools for integrating data into the observatory will depend on the specific requirements and goals of the observatory.

Here is an example Python code that reads data from a CSV file and inserts it into a Postgres database using the **psycopg2** library:

```
import psycopg2

import csv


# Establish a connection to the database

conn = psycopg2.connect(

  host="yourhost",

  database="yourdatabase",

  user="yourusername",

  password="yourpassword"

)


# Open a cursor to perform database operations

cur = conn.cursor()
```

```
# Define the table schema
cur.execute("""
    CREATE TABLE IF NOT EXISTS mytable (
        id SERIAL PRIMARY KEY,
        name VARCHAR(255),
        age INTEGER,
        email VARCHAR(255)
    )
""")

# Load data from CSV file
with open('data.csv', 'r') as csvfile:
    reader = csv.DictReader(csvfile)
    for row in reader:
        # Insert each row into the database
        cur.execute("""
            INSERT INTO mytable (name, age, email)
            VALUES (%s, %s, %s)
        """, (row['Name'], row['Age'], row['Email']))

# Commit the transaction and close the cursor and connection
conn.commit()
cur.close()
conn.close()
```

In this example, we create a table called **mytable** with three columns: **name**, **age**, and **email**. We then open a CSV file called **data.csv**, read each row, and insert it into the **mytable** table using an SQL **INSERT** statement. Finally, we commit the transaction and close the cursor and connection.

Here is an example of a Python code snippet that demonstrates how to scrape information from a website using the BeautifulSoup library and store it in a PostgreSQL database using the psycopg2 library:

```
import requests

from bs4 import BeautifulSoup

import psycopg2


# Connect to the PostgreSQL database

conn = psycopg2.connect(database="mydatabase", user="myuser", password="mypassword",
host="localhost", port="5432")

cur = conn.cursor()


# Scrape data from the Living Lab website

url = "https://www.livinglabexample.com/data"

response = requests.get(url)

soup = BeautifulSoup(response.text, "html.parser")

data = soup.find_all("div", class_="data-point")


# Insert data into PostgreSQL database

for point in data:

    name = point.find("h3").text

    value = point.find("p").text

    cur.execute("INSERT INTO living_lab_data (name, value) VALUES (%s, %s)", (name, value))


# Commit changes and close connection

conn.commit()

cur.close()

conn.close()
```

This code connects to a PostgreSQL database using the psycopg2 library, then uses the requests library to retrieve HTML content from a Living Lab website. The BeautifulSoup library is used to parse the HTML and extract the relevant data points, which are then inserted into the database using SQL statements executed with psycopg2.

Using also ChatGPT can be beneficial because it is a language model that has been trained on a large amount of text data, and can therefore effectively process and extract information from a variety of sources, including LL websites, reports, and publications. CHATGPT can also understand the context and meaning of the information it extracts, allowing it to provide more accurate and relevant data.

The benefit of using ChatGPT to extract information from LLs saves time and effort compared to manual extraction, especially when dealing with large amounts of data. It can also help to ensure consistency and accuracy in the extracted data, as CHATGPT will use the same rules and processes for each extraction.

Additionally, ChatGPT can be integrated with other tools and technologies, such as databases and visualization tools, to further analyze and utilize the extracted data. This can lead to better insights and decision-making regarding the environmental impact of the shipping industry, as well as potential solutions and improvements.

4.7.2 Use of ChatGPT

When combined with a web crawler, ChatGPT, a language model that generates human-like responses, can be used to extract information from web pages related to green shipping and automatically enrich a database. To use this approach, one would first define the types of information to extract from web pages, such as green shipping technologies, regulations, and industry trends, and configure the web crawler to search for web pages containing this information.

Once the web crawler extracts the information, ChatGPT can be used to analyze and interpret the data. For example, it can identify key concepts and relationships between different pieces of information, as well as categorize the data using a taxonomy or ontology. This categorization makes it easier to search and analyze the data.

Finally, the enriched data is stored in the database, where it can be used for trend analysis, decision-making, reporting, and even to train machine learning models that can automate certain green shipping processes. The table below summarizes the key steps involved in using ChatGPT and a web crawler to enrich a database with information related to green shipping.

Table 34 Methodology for Extracting and Analysing Web Data for Knowledge Hubs

Step	Description
Define information to extract	Identify the types of information to extract from web pages
Configure web crawler	Configure the web crawler to search for relevant web pages
Extract information	Extract the relevant information from web pages
Analyze and interpret data	Use ChatGPT to analyze and interpret the extracted data
Categorize data	Use a taxonomy or ontology to categorize the data
Store enriched data	Store the enriched data in the database for future use

An example of using ChatGPT with a web crawler to enrich a green shipping database could involve extracting information on the latest green shipping technologies from industry news websites. The web crawler would be configured to search for articles on green shipping technologies, and then extract the relevant text from the articles.

The extracted text could then be passed through ChatGPT's API, which would analyze the text and generate a summary of the key concepts and relationships between the different pieces of information. The resulting summary could be added to the database, along with the original text and any other relevant metadata.

Here is a sample piece of code that demonstrates how to use ChatGPT's API in Python:

```
import openai

import requests

# Set up OpenAI API credentials
```

```
openai.api_key = "YOUR_API_KEY"

# Define function to generate summary using ChatGPT

def generate_summary(text):

    response = openai.Completion.create(

        engine="davinci",

        prompt=text,

        max_tokens=100,

        n=1,

        stop=None,

        temperature=0.5,

    )

    summary = response.choices[0].text.strip()

    return summary


# Example usage with a sample text

text = "A new green shipping technology has been developed that uses hydrogen fuel cells to power cargo ships. The technology is expected to reduce carbon emissions by up to 50%. The fuel cells generate electricity by combining hydrogen and oxygen, with the only byproduct being water."

summary = generate_summary(text)

print(summary)
```

This code uses the OpenAI API to generate a summary of a sample text about a new green shipping technology that uses hydrogen fuel cells. The resulting summary could be added to the database, along with the original text and any other relevant metadata.

4.7.3 Scrapy

Scrapy is a free and open-source web crawling framework written in Python. It is designed to help developers and data analysts to easily extract structured data from websites. Scrapy provides a powerful set of features for web scraping, including built-in support for handling HTTP requests, parsing HTML and XML documents, and storing data in various formats.

With Scrapy, you can write web crawlers that can navigate through websites, follow links, and extract data from web pages. The framework is highly customizable and provides developers with the flexibility to write their own spider logic to handle complex scraping tasks.

Apart from that Scrapy is also designed to be scalable, meaning it can handle large-scale web scraping tasks without compromising on performance. It provides an asynchronous architecture that allows for concurrent processing of requests, enabling it to crawl and scrape large volumes of data quickly.

In the context of updating and maintaining a database, Scrapy can be used to automatically retrieve and parse data from websites on a regular basis. For example, if you have a database of green shipping solutions and want to keep it up to date with the latest developments, you can use Scrapy to crawl relevant websites and extract new data as it becomes available.

By automating the data collection process with Scrapy, you can ensure that your database remains accurate and up to date, saving you time and effort in manually updating the data. The following diagram shows an overview of the Scrapy architecture with its components and an outline of the data flow that takes place inside the system (shown by the red arrows):

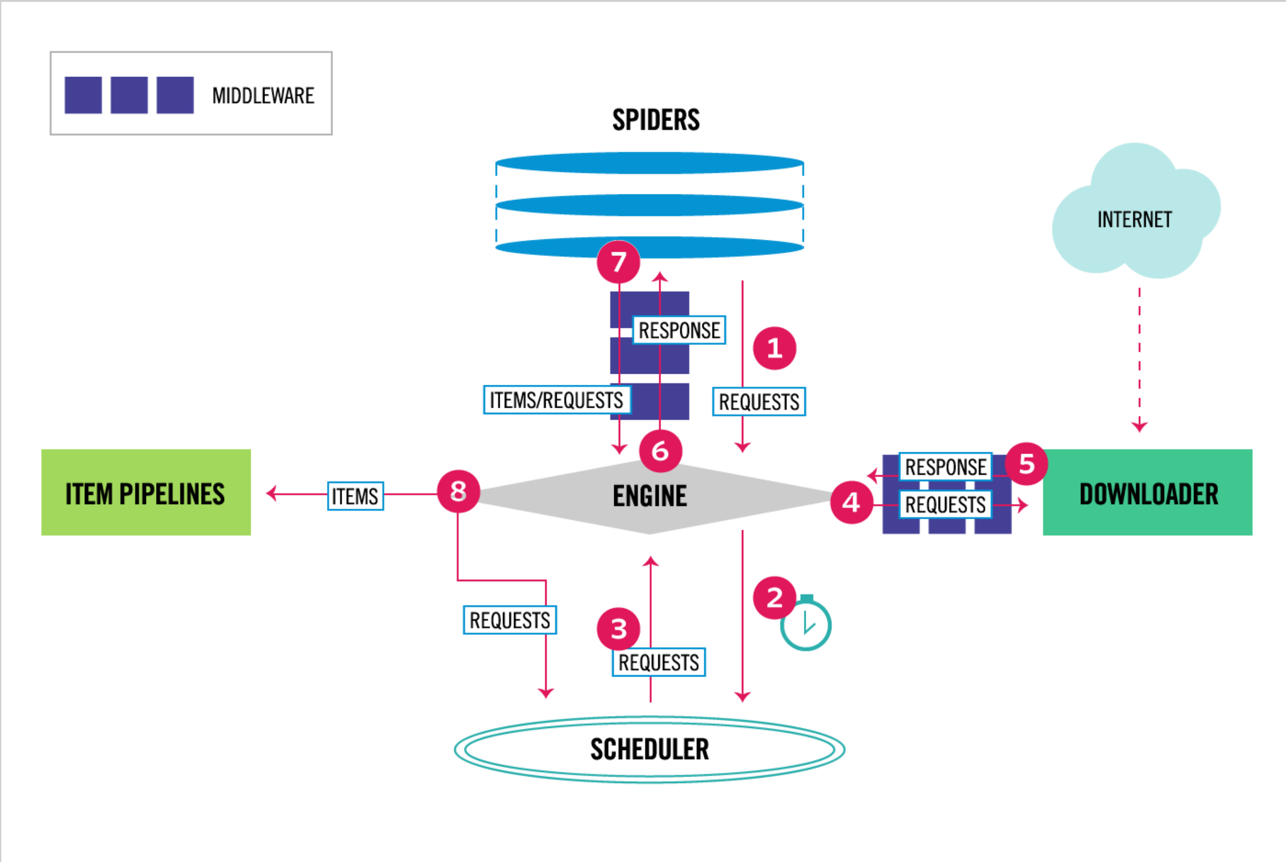

Figure 36 Architecture overview: data flow[13]

In the context of green shipping, Scrapy can be used to collect data on various aspects related to shipping, such as the use of green technologies and emissions reduction measures by different shipping companies. This data can then be processed and stored in a PostgreSQL database, allowing for easy access and analysis.

One approach to using Scrapy for green shipping data collection could be to start by identifying a list of websites or online resources that contain relevant information, such as news articles, reports, and company websites. Scrapy can then be used to crawl these sites and extract specific data fields, such as company names, technologies used, and emission reduction figures. Scrapy can also be used to crawl and extract data from APIs that provide access to real-time shipping data, such as vessel positions and other operational metrics. This data can be integrated with the existing database to provide a more comprehensive view of the shipping industry's environmental impact.

[13] Available online: https://docs.scrapy.org/en/latest/topics/architecture.html

To ensure data integrity and relevance, it is important to regularly update and maintain the database with the latest information. Scrapy can be scheduled to run at regular intervals to ensure that the database is always up-to-date with the latest information. Additionally, data validation techniques, such as data cleaning and normalization, can be applied to ensure the accuracy and consistency of the data in the database. Overall, Scrapy can be a valuable tool for enriching a green shipping database with relevant and up-to-date information. By using Scrapy to automate the data collection process, organizations can save time and resources while also ensuring that their data is accurate and relevant.

Here is an example of how Scrapy can update a Postgres database related to green shipping solutions. First, you would need to create a Scrapy project and define the items you want to scrape and store in the database. For example, you might define an item class called GreenShippingItem with attributes for the name of the technology, a description, and a link to the source website.

Next, you would define a spider that uses Scrapy to scrape relevant websites for information on green shipping technologies. For each technology found, the spider would create a GreenShippingItem object and add it to a list of items. Once the spider has finished scraping, you can use Scrapy's item pipelines to process the items and store them in the database. To do this, you would create a pipeline that connects to the Postgres database and inserts the scraped data into a table.

Here's an example of what the pipeline might look like:

```
import psycopg2

class GreenShippingPipeline(object):

    def __init__(self):

        self.conn = psycopg2.connect(

            host="localhost",

            database="mydatabase",

            user="myusername",

            password="mypassword"

        )

        self.cur = self.conn.cursor()

    def process_item(self, item, spider):

        self.cur.execute("INSERT INTO green_shipping_technologies (name, description, link) VALUES (%s, %s, %s)",

            (item['name'], item['description'], item['link']))

        self.conn.commit()

        return item

    def close_spider(self, spider):

        self.cur.close()
```

```
    self.conn.close()
```

In this example, the GreenShippingPipeline class connects to a Postgres database using the psycopg2 library, and inserts each item into a table called green_shipping_technologies. The process_item method is called for each item scraped by the spider, and the close_spider method is called when the spider has finished. Finally, you would add the pipeline to your Scrapy settings to enable it:

```
ITEM_PIPELINES = {

'myproject.pipelines.GreenShippingPipeline': 300,

}
```

In this example, the GreenShippingPipeline is assigned a priority of 300, meaning it will be executed after other pipelines with lower priorities. With this setup, Scrapy will scrape relevant websites for information on green shipping technologies, process the data using the defined item class, and store the scraped data in a Postgres database table using the defined pipeline.

4.7.4 Beautiful Soup

Beautiful Soup is a Python package used for web scraping purposes to pull the data out of HTML and XML files. It creates parse trees that are helpful to extract the data easily. Beautiful Soup provides a few simple methods and Pythonic idioms for navigating, searching, and modifying a parse tree. It sits on top of an HTML or XML parser, providing Pythonic idioms for iterating, searching, and modifying the parse tree.

The basic use of Beautiful Soup involves creating a Beautiful Soup object and specifying the HTML or XML source. Once you have created the Beautiful Soup object, you can use various methods and attributes to navigate and search the parse tree.

For web scraping, Beautiful Soup can be used to extract data from websites and save it to a file, or to a database such as Postgres. Beautiful Soup can be used in combination with other Python libraries such as Requests to scrape data from a website and store it in a Postgres database.

For example, if you wanted to scrape data from a green shipping website and store it in a Postgres database, you could use Beautiful Soup to extract the relevant data from the website and then use the psycopg2 Python library to connect to the Postgres database and insert the data into the appropriate tables. This would allow you to build and maintain a comprehensive database of green shipping information that could be used for research and analysis. Here's a simple example of how Beautiful Soup can be used as a web crawler in Python:

```
import requests

from bs4 import BeautifulSoup
```

```
# Specify the URL to scrape
url = "https://www.example.com"

# Send a GET request to the URL and retrieve the HTML content
response = requests.get(url)
html_content = response.content

# Parse the HTML content using Beautiful Soup
soup = BeautifulSoup(html_content, 'html.parser')

# Extract the desired information from the parsed HTML content
title = soup.title.text
paragraphs = [p.text for p in soup.find_all('p')]
links = [a['href'] for a in soup.find_all('a')]

# Print the extracted information
print("Title:", title)
print("Paragraphs:", paragraphs)
print("Links:", links)
```

In this example, the requests and BeautifulSoup modules are imported first. The URL of the website to be scraped is then specified, and a GET request is sent using the requests.get() method to retrieve the HTML content. The HTML content is parsed using Beautiful Soup, and the desired information is extracted using various methods provided by Beautiful Soup, such as soup.title.text to get the page title, soup.find_all('p') to get all paragraphs on the page, and soup.find_all('a') to get all links on the page. Finally, the extracted information is printed. This is a simple example, and Beautiful Soup can be used to extract much more complex and specific information from websites.

4.8 Updating and Maintaining the Database

Regularly updating and maintaining the database is crucial to ensure its continued usefulness and relevance to stakeholders in the shipping industry. To achieve this, a systematic approach must be adopted that includes a range of activities.

1. The accuracy and completeness of the existing data must be verified on a regular basis to ensure its integrity. This involves identifying any inconsistencies or errors in the data and taking corrective action to address them. For instance, data validation procedures can be implemented to ensure that the data entered into the database is accurate and complete, and any discrepancies are flagged for review and resolution.
2. New data sources can be identified and incorporated into the database to expand its scope and relevance. This includes sourcing and integrating new data on topics such as emissions factors, fuel efficiency, and regulatory developments in the shipping industry. By adding new data, the database can remain up-to-date with the latest information, trends, and insights that are of interest to stakeholders.
3. The database structure and schema can be reviewed and updated as necessary to ensure it remains optimized for the intended purposes. This can involve refining the existing schema to better align with the evolving needs of stakeholders, or creating new tables or categories to better organize and present the data. For example, as new types of ships or technologies emerge, new tables can be created to capture this information.
4. It is essential to monitor the quality of the data and ensure that it meets the expected standards. This can be achieved through regular quality checks and audits, including data profiling, data cleansing, and data matching activities. These checks help to identify any issues with the data, such as data redundancy or inconsistency, and ensure that it is fit for purpose.
5. The ongoing process of updating and maintaining the database is critical to its success in supporting informed decision-making and promoting sustainability in the shipping industry. By staying up-to-date with the latest information and trends, the database can provide a valuable resource for stakeholders seeking to improve their understanding of the industry and drive positive change.

To automate the update of a PostgreSQL database, you can use a variety of tools and techniques. Below are a few options:

1. Use triggers: Triggers are database objects that are automatically executed in response to specified events, such as when data is inserted, updated, or deleted. By using triggers, you can automate the update of the database based on specific conditions or actions.
2. Use stored procedures: Stored procedures are pre-written sets of SQL commands that can be executed within the database. By creating stored procedures that update the database based on specific conditions, you can automate the update process.
3. Use batch scripts: Batch scripts can be used to automate the process of updating the database. These scripts can be scheduled to run at specific intervals using a task scheduler or cron job, and can be used to execute SQL commands or other database operations.
4. Use an ETL tool: ETL (extract, transform, load) tools can be used to automate the process of updating the database by extracting data from external sources, transforming the data to conform to the database schema, and loading the data into the database.

Overall, automating the update of a PostgreSQL database can help ensure that data is accurate and up-to-date, and can save time and resources compared to manual updates. By choosing the appropriate tools and techniques for your specific use case, you can streamline the update process and improve the efficiency and effectiveness of your database operations.

4.8.1 Use of Triggers

Triggers are a type of database object in PostgreSQL that can be used to automate the update of the database based on specific conditions or actions. Triggers are automatically executed in response to specified events, such as when data is inserted, updated, or deleted. They can be used to enforce complex business rules or to perform automated updates of the database. Below are some ways that triggers can be used to automate the update of a PostgreSQL database:

- Enforce data integrity: Triggers can be used to enforce data integrity by preventing invalid data from being inserted into the database or by enforcing referential integrity between tables.
- Update derived values: Triggers can be used to update derived values, such as calculated fields or summary statistics, based on changes to the underlying data.
- Generate notifications: Triggers can be used to generate notifications or alerts based on specific events or conditions in the data.
- Synchronize data: Triggers can be used to synchronize data between different tables or databases, ensuring that data is consistent and up-to-date.
- Audit changes: Triggers can be used to audit changes to the data, providing a record of when changes were made and who made them.

To use triggers in PostgreSQL, you need to define the trigger function and then associate it with a table using the CREATE TRIGGER statement. The trigger function is called automatically whenever the specified event occurs, allowing you to perform custom actions based on the data in the table. By using triggers, you can automate the update of your PostgreSQL database based on specific conditions or actions, reducing the need for manual updates and improving the efficiency and accuracy of your database operations.

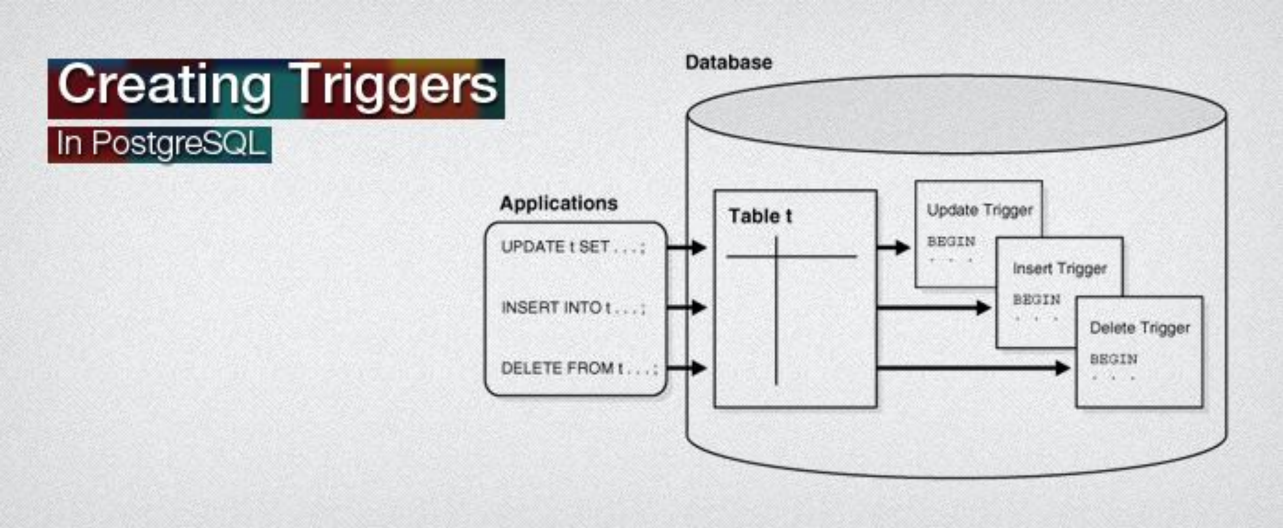

Figure 37 Creating triggers in PostgreSQL

4.8.2 Use an ETL Tool

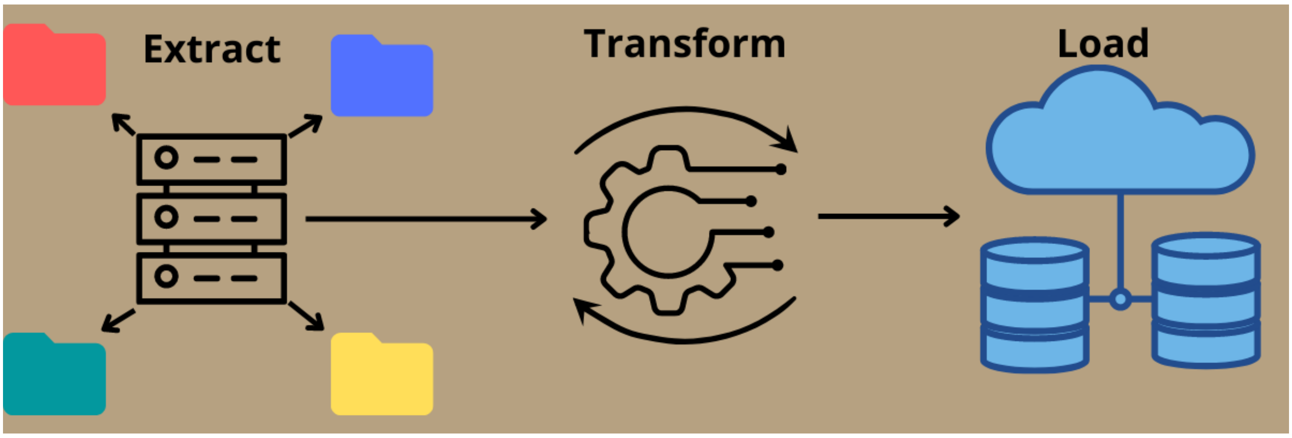

Figure 38 Use of ETL

ETL tools are software applications that can be used to automate the process of updating a database by extracting data from external sources, transforming the data to conform to the database schema, and loading the data into the database. ETL tools provide a way to automate the process of integrating data from multiple sources, making it easier to manage and analyze large volumes of data. There are many different ETL tools available, ranging from open-source solutions to commercial software packages. Some popular ETL tools include Apache NiFi, Talend, Informatica, and Microsoft SQL Server Integration Services (SSIS). Below are the key steps involved in using an ETL tool to update a PostgreSQL database:

1. Extract: The first step is to extract data from the external source, such as a CSV file or another database. This can be done using built-in connectors or custom scripts.
2. Transform: The extracted data needs to be transformed to conform to the schema of the PostgreSQL database. This may involve cleaning and formatting the data, merging data from multiple sources, and mapping the data to the appropriate tables and columns in the database.
3. Load: The transformed data is loaded into the PostgreSQL database. This can be done using SQL

scripts or other mechanisms provided by the ETL tool.

4. Schedule: The ETL process can be scheduled to run at regular intervals, such as daily or weekly, to ensure that the database stays up-to-date.
5. Using an ETL tool to update a PostgreSQL database can save time and resources compared to manual updates. It can also ensure that data is accurate and up-to-date, and provide a way to integrate data from multiple sources. By choosing the appropriate ETL tool for your specific use case, you can streamline the update process and improve the efficiency and effectiveness of your database operations.

4.8.3 Use of Stored Procedures

Using stored procedures in a database management system can help automate the update process by executing pre-written sets of SQL commands. Stored procedures can be created in the database using SQL or other query languages, and then executed based on specific conditions.

For example, in the context of a green shipping database, a stored procedure could be created to automatically update the database when new data is available on a particular website. The stored procedure could be designed to execute at regular intervals, such as daily or weekly, to ensure that the database remains up-to-date. To create a stored procedure in a PostgreSQL database, you can use the CREATE PROCEDURE statement followed by the SQL commands to be executed. Once the stored procedure is created, it can be executed using the EXECUTE statement, passing in any required parameters.

Overall, using stored procedures can help automate the update process in a database, reducing the need for manual updates and ensuring that the database remains accurate and up-to-date.

Stored procedures are pre-written sets of SQL commands that can be executed within a database to automate the update process. By creating stored procedures that update the database based on specific conditions, updates can be performed without manual intervention. For instance, if there is a specific condition that triggers an update, such as a new entry being added to a specific table, a stored procedure can be created to execute the necessary SQL commands to update the database accordingly. This approach can save time and increase the efficiency of the database update process.

Consideration will be given to a database for a shipping company that stores information on the company's fleet of ships. A stored procedure will be created to automatically update the database whenever a ship's fuel tank level falls below a certain threshold. The following steps can be followed:

1. Create a new function in PostgreSQL that checks the fuel tank level of a given ship:

```
CREATE OR REPLACE FUNCTION check_fuel_level(ship_id INTEGER, threshold FLOAT)
RETURNS VOID AS $$
BEGIN
 IF (SELECT fuel_level FROM ships WHERE id = ship_id) < threshold THEN
  -- perform update or other action here
 END IF;
END;
$$ LANGUAGE plpgsql;
```

This function takes two parameters: the ID of the ship to check and the fuel level threshold. It checks the fuel level of the specified ship and performs an update or other action if the fuel level is below the threshold.

2. Create a trigger on the ships table that calls the **check_fuel_level** function whenever a row is updated:

```
CREATE TRIGGER fuel_level_trigger

AFTER UPDATE ON ships

FOR EACH ROW

EXECUTE FUNCTION check_fuel_level(NEW.id, 0.25);
```

This trigger is called **fuel_level_trigger** and is executed after a row is updated in the **ships** table. It calls the **check_fuel_level** function and passes in the ID of the updated ship and a fuel level threshold of 0.25. Now, whenever a row is updated in the **ships** table, the **fuel_level_trigger** trigger will call the **check_fuel_level** function for that ship. If the fuel level is below the threshold, the function will perform the specified update or other action. By using stored procedures and triggers in this way, you can automate the process of updating your database based on specific conditions, saving time and improving the accuracy of your data.

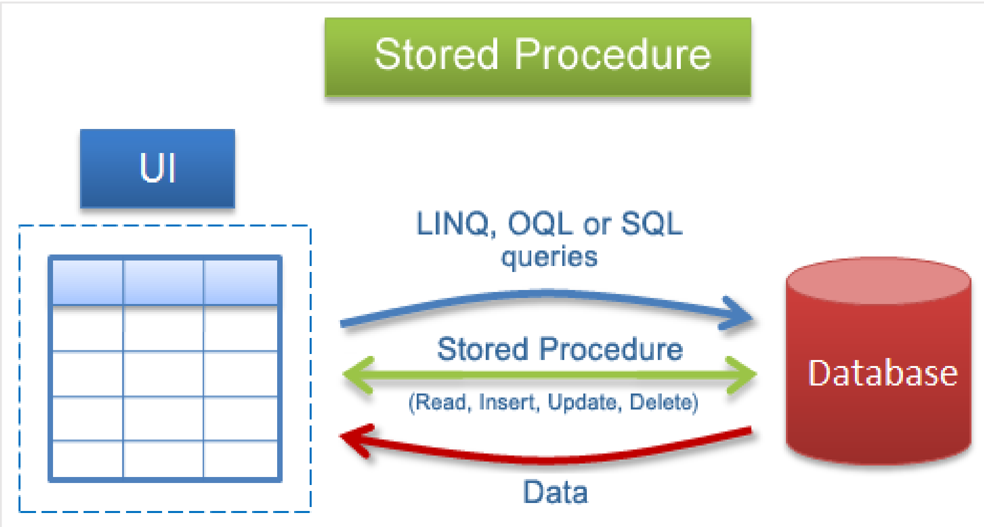

Figure 39 Stored procedure

4.9 From KH to KG

A knowledge graph is a type of database that is used to store and manage complex knowledge and information. It is a type of graph database that uses a network of nodes and edges to represent data and relationships between data points.

In a knowledge graph, data is organized into nodes, which represent entities, and edges, which represent relationships between those entities. Each node is labeled with a specific attribute, such as a name, type, or description, and edges are labeled with the type of relationship between the nodes they connect. One of the key features of a knowledge graph is its ability to represent complex, multi-dimensional data relationships in a simple and intuitive way. This makes it an effective tool for managing and analyzing large amounts of data, particularly in fields such as healthcare, finance, and scientific research.

For example, a knowledge graph could be used to represent relationships between different medical conditions, symptoms, and treatments, allowing healthcare professionals to easily navigate and analyze large amounts of medical data. Overall, knowledge graphs are a powerful tool for managing and analyzing complex data relationships, and are increasingly being used in a wide range of fields to support research, decision-making, and innovation.

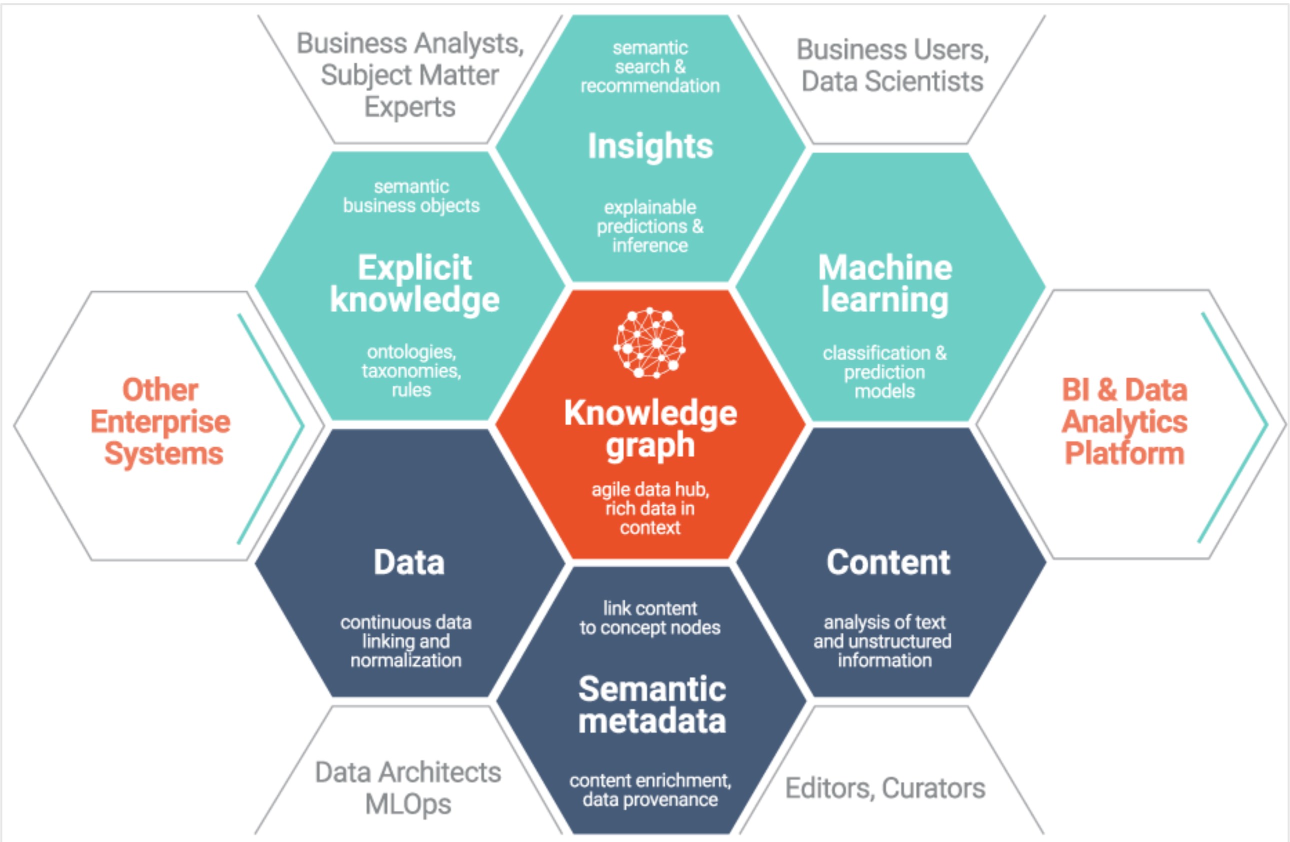

Figure 40 Knowledge strucute

Knowledge graphs are used in a variety of applications such as search engines, recommendation systems, and question answering systems, as they allow for complex queries and inferences to be made based on the relationships between entities. Some examples of knowledge graphs include:

- **Google Knowledge Graph – Link available at:** https://blog.google/products/search/introducing-knowledge-graph-things-not/: This is a knowledge graph created by Google to provide users with quick, informative answers to their search queries. It contains information about people, places, things, and concepts, and their relationships to each other.
- **Wikidata – Link available at:** https://www.wikidata.org/wiki/Wikidata:Main_Page: This is a knowledge graph created by the Wikimedia Foundation, which powers Wikipedia. It is a free and open knowledge base that can be read and edited by humans and machines alike. It contains structured data about entities, such as people, places, and events.
- **Microsoft Academic Knowledge Graph – Link available at:** https://makg.org/: This is a knowledge graph created by Microsoft to help researchers discover and analyze academic publications. It contains information about authors, institutions, conferences, and papers, and their relationships to each other.
- **OpenCyc – Link available at:** https://cyc.com/: This is a knowledge graph created by the Cyc project, which aims to build a comprehensive ontology and common sense knowledge base for artificial intelligence applications. It contains information about common concepts, relationships, and rules.

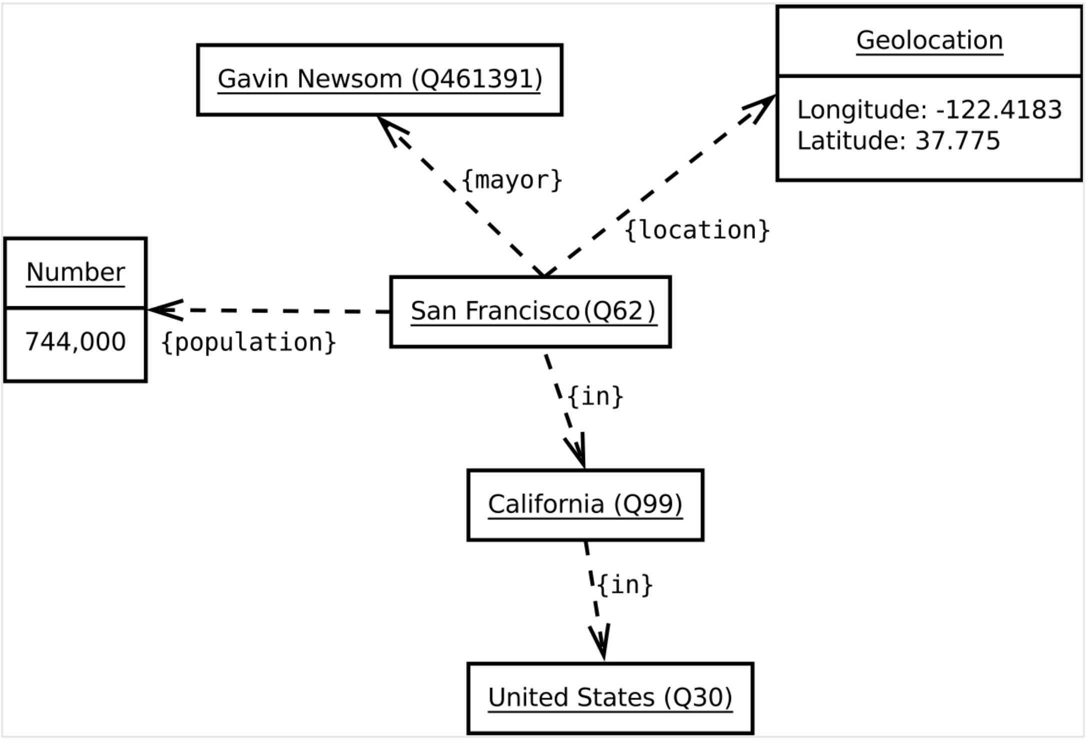

Figure 41 Wikidata structure: Items and their data are interconnected

Creating a knowledge graph from a PostgresSQL database involves several steps:

1. Define the scope and purpose: The first step is to define the scope and purpose of the knowledge graph. This includes identifying the target audience, the type of information to be included, and the specific relationships and connections that will be represented in the graph.
2. Model the data: Once the scope and purpose of the knowledge graph have been defined, the next step is to model the data. This involves identifying the entities, attributes, and relationships in the database and mapping them to the nodes and edges in the graph.

3. Map the data to the graph: Using a graph database tool, such as Neo4j or Amazon Neptune, map the data from the PostgresSQL database to the knowledge graph. This involves creating nodes for entities and edges for relationships and connections between them.
4. Define the schema: Define the schema for the knowledge graph, including the types of nodes and edges, their properties, and the constraints and rules for the graph.
5. Populate the graph: Populate the knowledge graph by importing the data from the PostgresSQL database into the graph database. This may involve transforming the data to conform to the schema of the graph.
6. Query and analyze the graph: Once the data has been imported into the knowledge graph, you can use graph database query languages, such as Cypher, to query and analyze the data in the graph. This can help identify patterns, relationships, and insights that may not be apparent in the original database.

All in all, creating a knowledge graph from a PostgresSQL database involves modeling the data, mapping it to the graph, defining the schema, populating the graph, and querying and analyzing the data in the graph. By creating a knowledge graph, you can gain new insights into the relationships and connections between entities in the database, and use this knowledge to inform decision-making and improve knowledge mobilization.

Connecting to a knowledge hub can be done via several ways, depending on the type of hub and its accessibility:

- Web Interface: Many knowledge hubs have a web interface that allows users to access the hub's content through a web browser. This may require creating an account or signing in to access certain features or content.
- API: Some knowledge hubs offer an API (application programming interface) that allows users to access the hub's content programmatically. This may require an API key or other authentication to access the data.
- Linked Data: Some knowledge hubs publish their content as linked data, which allows the data to be accessed and queried using semantic web technologies such as RDF (Resource Description Framework) and SPARQL (SPARQL Protocol and RDF Query Language).
- Integration with other tools: Some knowledge hubs may offer integration with other tools such as data visualization or analysis software, allowing users to connect to the hub's content within those tools.

4.9.1 Use Neo4j

Neo4j is a graph database management system designed to store, manage and query graph data. It is a popular database management system for creating and managing graph databases. Neo4j uses the Cypher query language to retrieve data and perform operations on the graph data. It is commonly used for applications such as social networks, recommendation systems, and network analysis, where data relationships are important. Neo4j is an open-source software with a strong community of developers and users, and it offers high scalability and performance for graph data.

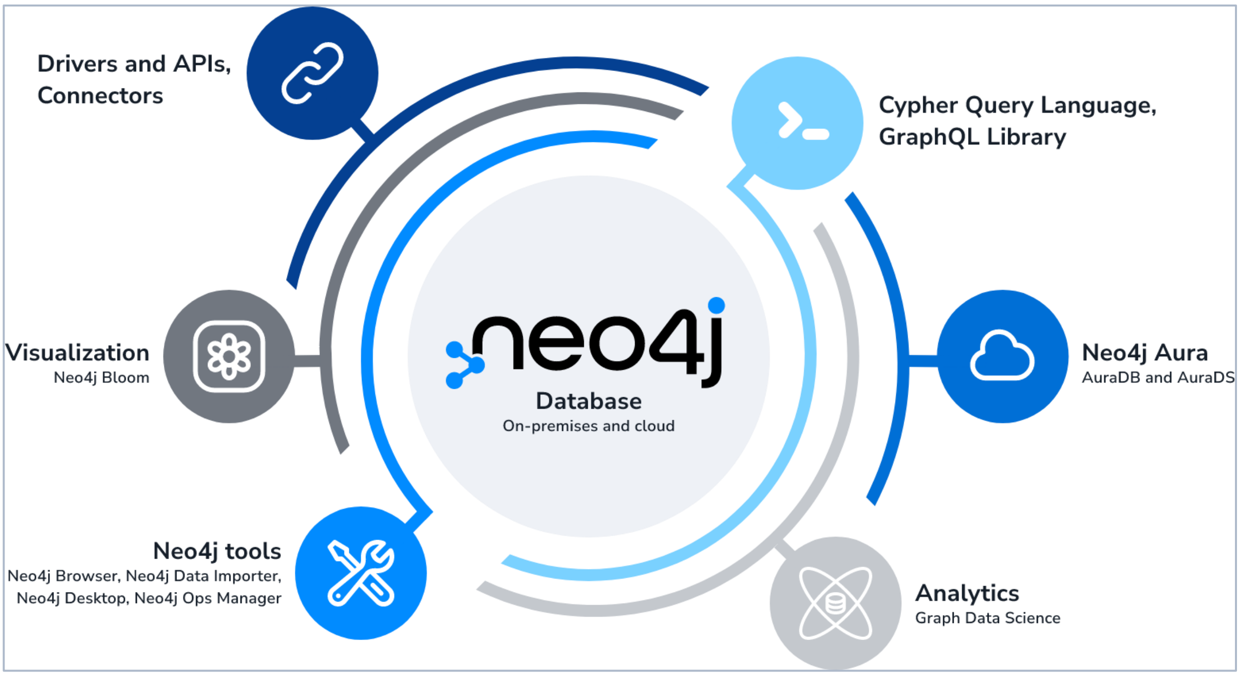

Figure 42 NEO4J

Below are the steps to create a knowledge graph from a Postgresql database using Neo4j:

1. Export data from Postgresql database: Export the relevant data from the Postgresql database that you want to include in the knowledge graph.
2. Model the data: Identify the entities, attributes, and relationships in the exported data and map them to the nodes and edges in the knowledge graph.
3. Import the data into Neo4j: Import the data from the Postgresql database into Neo4j. This can be done using the Neo4j import tool or a third-party tool, such as the APOC library.
4. Define the schema: Define the schema for the knowledge graph, including the types of nodes and edges, their properties, and the constraints and rules for the graph.
5. Populate the graph: Populate the knowledge graph by importing the data from the Postgresql database into Neo4j. This may involve transforming the data to conform to the schema of the graph.
6. Query and analyze the graph: Once the data has been imported into the knowledge graph, you can use the Cypher query language to query and analyze the data in the graph. This can help identify patterns, relationships, and insights that may not be apparent in the original database.

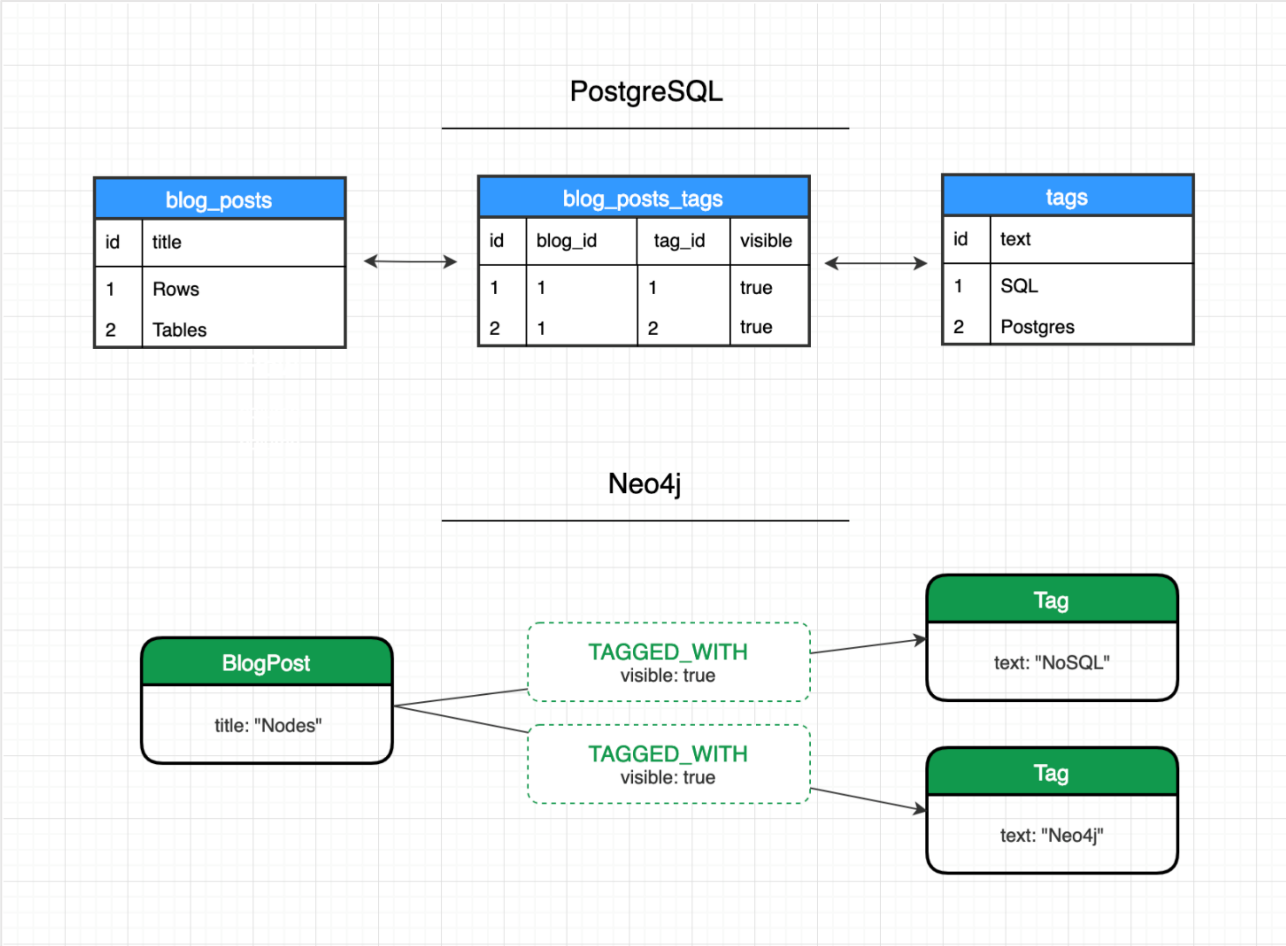

Figure 43 From PosgreSQL to Neo4j

4.9.2 Use AgensGRAPH

AgensGraph is a graph database management system (DBMS) that is built on top of PostgreSQL. It provides advanced features for managing and querying graph data, including support for the Cypher query language, flexible data modeling capabilities, and powerful graph analytics tools.

Below are some ways one can use AgensGraph:

- Data management: AgensGraph can be used to manage and store large volumes of graph data, including data from social networks, supply chains, and other complex systems.
- Graph analytics: AgensGraph provides powerful graph analytics tools, including algorithms for centrality, community detection, and shortest path analysis, that can be used to gain insights into complex relationships and connections in the data.
- Knowledge graph creation: AgensGraph can be used to create knowledge graphs, which are powerful tools for organizing and analyzing complex information across multiple domains.
- Recommendation engines: AgensGraph can be used to build recommendation engines, which can help businesses provide personalized recommendations to customers based on their interests and preferences.
- Fraud detection: AgensGraph can be used to detect fraudulent behavior by analyzing patterns and

connections in the data.

- Network analysis: AgensGraph can be used for network analysis, including the analysis of social networks, supply chains, and other complex systems.
- AgensGraph can be accessed using various programming languages and interfaces, including Python, Java, JDBC, and ODBC. It also provides connectors to popular data visualization and BI tools such as Tableau, QlikView, and Power BI.

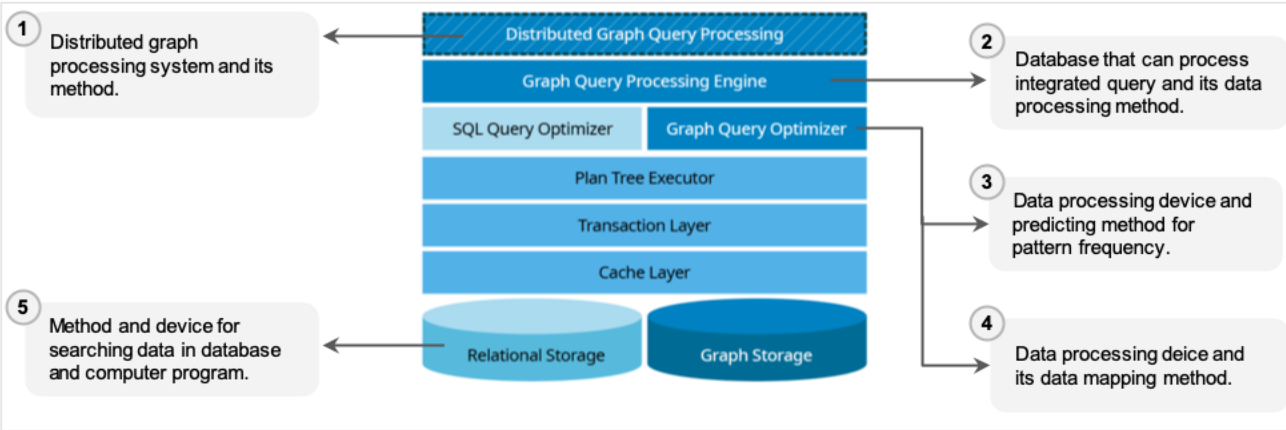

Figure 44 AgensGRAPH core architecture

5 Conclusion and next steps

In conclusion, knowledge hubs can be compelling tools for sharing and disseminating information among stakeholders in various domains, including green shipping. However, they also present a number of challenges related to avoiding static and obsolete knowledge, making knowledge easily accessible, and motivating people to contribute to and use the hub.

To address these challenges, it is important to establish systems and processes for regularly reviewing and updating the content of the hub, designing user-friendly interfaces that allow for easy navigation and search, and fostering a culture of knowledge sharing and collaboration. By doing so, knowledge hubs can become valuable resources that support informed decision-making, innovation, and sustainability in various industries.

In green shipping in order to address the challenges of knowledge hubs, several methodologies can be employed. One approach is to use knowledge graphs, which enable the organization and representation of information in a way that facilitates data discovery and analysis. This method allows for the creation of an interconnected network of data points that can be easily updated and expanded as new information becomes available. Additionally, natural language processing (NLP) and machine learning techniques can be used to automate the extraction and classification of data from unstructured sources, such as websites and reports, thereby increasing the speed and accuracy of knowledge hub updates.

Finally, the use of collaborative platforms can help to foster a culture of knowledge sharing and engagement among stakeholders, encouraging participation and knowledge exchange. By implementing these methodologies, knowledge hubs can become more dynamic and responsive to the needs of users, providing valuable insights and support for decision-making in the field of green shipping.

The following report introduced the methodologies and technologies that will be subsequently implemented to:

1. Avoiding static and obsolete knowledge: One challenge with knowledge hubs is that the information contained within them can become outdated or irrelevant over time. To address this challenge, it is important to have a system in place to regularly review and update the content of the hub. Several tools can help to track changes to the content over time, making it easier to identify and address obsolete knowledge.
2. Chapter 4 provides a comprehensive overview of the implementation of the Knowledge Hub and it covers the essential components of the Hub, including the database structure, taxonomy, and schema, as well as the processes involved in maintaining and expanding the database over time (chapter 4.7 and 4.8).
3. Making knowledge easily accessible: Another challenge with knowledge hubs is ensuring that the information contained within them is easily accessible and usable by stakeholders. To address this challenge, it is important to have a user-friendly interface that allows users to easily search and navigate the content of the hub. This could involve designing an intuitive navigation system, using clear and concise language in the content, and providing tools like search functionality and interactive visualizations to help users find the information they need.
4. Chapter 4 explore the benefits of transitioning to a Knowledge Graph and the tools and technologies that can be used to support this process (chapter 4.9).
5. Motivating people to contribute to and use the hub: A final challenge with knowledge hubs is motivating people to contribute to and use the hub. To address this challenge, it is important to establish a culture of knowledge sharing and collaboration among stakeholders.

In the case of Consortium partners as hub providers and users, these challenges could be addressed by establishing also clear guidelines and protocols for content creation and review, as well as providing ongoing training and support for users to ensure they can effectively navigate and utilize the hub. In addition, establishing regular feedback mechanisms and incorporating user feedback into the design and development of the hub can help to ensure that it meets the evolving needs and expectations of its users.

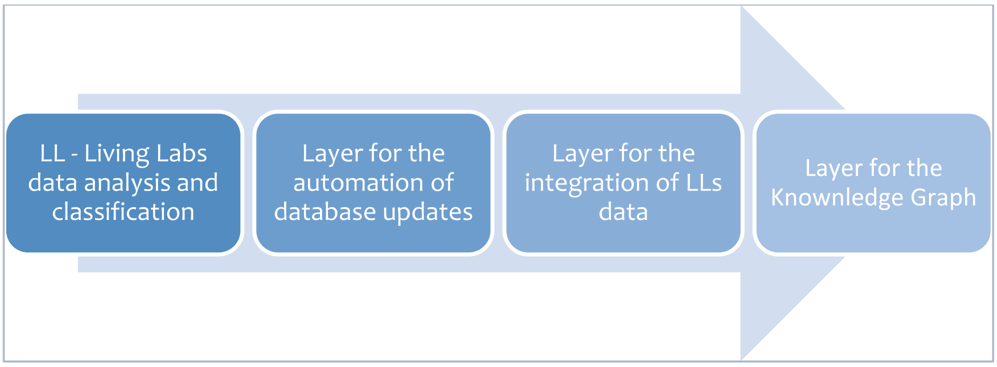

Figure 45 Process Flowchart for Integrating Information from Living Labs into a Database for Green Shipping

The first step in the process of integrating information from Living Labs (LL) into a database for green shipping is to analyze and classify the data. This involves reviewing the data collected from LL and categorizing it based on its relevance and importance to the database The categorization is carried out based on the previously described taxonomy. This step could be aided also by using machine learning algorithms or natural language processing tools to help identify patterns and relationships in the data.

Once the data has been analysed and classified, the next step is to define a clear layer for the automation of database updates. This means establishing a systematic process for regularly updating the database with new information from LL or other data sources. This can be achieved through various techniques such as web scraping or API integration. By automating the update process, the database will always have the most current and relevant information.

After the database update layer has been defined, the next step is to integrate all the analysed and classified data into the first version of the database. This involves creating a schema or a data model that represents the data structure of the LL and mapping it to the database. This step can be time-consuming but it is crucial for ensuring that the LL data is integrated properly and efficiently.

Last but not least, to make the LL data more accessible and user-friendly, a clear layer for the knowledge graph needs to be defined. This layer will allow users to explore and navigate the database in a more intuitive and visual way. This can be achieved by using ontology-based tools or graph-based databases that can represent the relationships between different data entities.

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