Impact assessment of green RoPax shipping corridors – The case of decarbonizing the Helsinki-Tallinn corridor

Thesis for M.Sc. in Chemical and Process Engineering

by

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Abstract

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The objective of this thesis is to validate and further develop an existing impact assessment framework for green maritime corridors (GMCs) by applying it to the shipping corridor between Helsinki and Tallinn. The GMC in focus is adapted to a potentially fully electric vessel, with the same proportions as the one running the route today for Viking Line, Viking XPRS. The impact assessment for the corridor uses an impact assessment framework developed earlier in the DECATRIP project, which serves as a base for this potential corridor. There are some major differences between the two corridors. The framework has been revised and adjusted for the potential electric vessel with new impacts. The impacts from the previous DECATRIP project that were not applicable for this case have been removed, *e.g.*, this assessment emphases newbuilds instead of retrofits. By replacing the conventional fossil fuel-powered vessel with an electric one running on 100% renewable energy, it is possible to not only decrease the emissions from the shipping industry, but also have impacts on various industries that are connected and affected by the change. The concept of a fully electric vessel is relatively new, which implies that a potential electrically powered GMC would not only have an impact on a national level but also on global level to encourage other corridors to evolve and facilitate the transition into a green era.

Keywords

Alternative fuels, climate change, electrification, GMC, impact assessment framework, renewable energy, RoPax, vessel

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Abbreviations

AFIR	Alternative Fuels Infrastructure Regulation
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
GHG	Greenhouse gas
GMC	Green maritime corridor
HFO	Heavy fuel oil
HVO	Hydrotreated vegetable oil
ICE	Internal combustion engine
IMO	International Maritime Organization
LBG	Liquefied biogas
LNG	Liquefied natural gas
MDO	Marine diesel oil
MGO	Marine gas oil
NO	Nitric oxide
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
N_2O	Nitrous oxide
O_3	Ozone
RoPax	Roll-on/roll-off passenger
RoRo	Roll on, roll off
SNG	Synthetic natural gas
SO_x	Sulphur dioxide
SSS	Short sea shipping
TEU	Twenty-foot Equivalent Units
WEB/WEI	Wider Economic Benefits/Impacts

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1 Introduction

Maritime transportation is a massive global contributor of greenhouse gas (GHG) emissions, standing for 3% of the total GHG emissions in the world (Gillingham & Huang, 2020). As most trade is in some aspect transported overseas today, decarbonizing the shipping industry would have a massive impact on reducing global emissions. However, decarbonizing the shipping industry requires cooperative efforts from different partners and stakeholders involved. Therefore, it cannot be solved solely by one actor. Due to new regulations and commitments made by companies and countries such as Finland, in order to reach a more sustainable future the decarbonization of shipping is one of the top priorities in the industry. One way of decarbonizing maritime transportation is to establish so-called green maritime corridors (GMCs). These GMCs are more environmentally friendly shipping routes, with less emissions due to the use of renewable energy sources which emit less emissions. It is not only the environmental targets and goals that have to be met, but also the economic criteria need to be fulfilled in order to make the GMCs profitable. In other words, the establishment of GMCs requires a revision of the whole value chain and may lead to changes in current business models. To conclude, the impacts of a GMC are far beyond just removing emissions from the original corridor and to fully understand if the potential project of a GMC would accelerate a green transformation, all the impacts of the corridor and its establishment need to be assessed.

In the DECATRIP[1] project, an impact assessment framework was developed for a potential green RoPax corridor between Turku and Stockholm. The impact assessment included different fields that are affected by the GMC both directly and indirectly. As maritime corridors have different traffic profiles, volumes, and other characteristics, it is necessary to understand the framework and how it can be generalized and applicable onto other RoPax corridors. The purpose of this thesis is to reapply the impact assessment framework from the DECATRIP project on another maritime corridor that could be decarbonized. The chosen corridor for this study is the Helsinki-Tallinn route and the decarbonization is to be achieved through introducing an electric vessel on the route. The main outcomes of this thesis are:

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[1] A consortium with the aim to establish a carbon-neutral sea route between Turku and Stockholm.

1. An empirical assessment of the potential impacts of such a decarbonization project.
2. Improvement of the impact assessment framework based on this exercise.
3. Recommendations for adjusting the impact assessment framework for other corridors.

The thesis will begin with a review of existing literature in chapter 2, investigating the concept of decarbonized shipping, the alternatives of GMCs and the theory behind impact assessments. In chapter 3, the methodology of the project is described, including the research objective and the theory behind the impact assessment framework. Chapter 4 presents and discusses the result of the assessment of the GMC. In chapter 5 follows a discussion of the implications of the GMC and the impact assessment framework. Chapter 6 concludes the discussion and finds of the thesis.

2 Literature review

2.1 Decarbonization of shipping

Global emissions of CO_2 in the world come from various sources, of which transportation stands for 23% of the emissions. Over 95% of the world's fleet today run on fossil-based fuels, such as marine diesel oil (MDO), marine gas oil (MGO) and heavy fuel oil (HFO), and these vessels are powered by internal combustion engines (ICEs) (Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, 2023b).

Today, 80% of the international trade is moved overseas by maritime transportation at some point (European Commission, 2015). The shipping industry stands for 11% of the global transport industry's GHG emissions, and 3% of the total global GHG emissions, which is equivalent to one billion tons a year. On a smaller geographical scale, the shipping industry stands for 4% of the EU's total GHG emission and around 50% of the particulate matter (PM 2.5) emissions (Gillingham & Huang, 2020). Even though the shipping sector is one of the most fuel-efficient forms of transportation compared to other transportation forms, the shipping industry's GHG emissions are expected to grow continuously due to the sector itself growing, with an expected growth of 50-250% by 2050 (Serra & Fancello, 2020; Wan et al., 2018; Xiao et al., 2022). As other sectors of transportation with GHG emission are more effective at decarbonizing, this seems to lead to the shipping industry's GHG emissions rising in percentage as the others decrease (Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, 2021; Xiao et al., 2022).

2.1.1 Policy and governance measures to reduce the GHG emissions from shipping

Different legal and political targets with the aim to cut emissions have been set by governances as the European Union (EU) and the International Maritime Organization (IMO). The timeline for the targets is relatively short-term/mid-term and more regulations are likely to appear in the future, *e.g.,* in May 2023, the EU set the world's first green transportation fuel law, the FuelEU Maritime law. According to the EU's FuelEU Maritime law, at least 2% of the Union's shipping vessels need to run on electro-fuels (e-fuels), fuels with renewable energy by 2034 (Kontos, 2023).

The Paris Agreement, entered into force in November 2016 set a global framework to counteract climate change with the aim to limit the global warming and improve the nations' ability to overcome the impacts of climate change. The Paris Agreement's long-term goal is to keep the increase of the global temperature well below 2℃ compared to pre-industrial levels. The ultimate goal is to keep the increase to 1.5℃, as this would reduce the impacts of the climate change (European Commission, n.d.). In regard to the Paris Agreement and to counteract the impacts on the shipping the International Maritime Organization (IMO) has decided in April 2018 to reach a 50% reduction in greenhouse gases (GHG) by 2050, compared to the levels from 2008 (International Maritime Organization, 2018; Zis et al., 2020).

During the United Nations Climate Conference in 2021, 22 countries signed the Clydebank Declaration. The aim of the declaration is to drive forward and encourage the goals of the Paris Agreement as well as the goals set by the IMO, promoting the concept of GMCs as a specific initiative. The committed countries of the Clydebank Declaration have a main objective to establish a total of six GMCs by 2025 with more planned for the future. The collaboration between nations, ports, companies and other stakeholders is vital when it comes to conquer the current challenges in establishing GMCs and working towards a net-zero future (PierNext, 2022; Procter, 2022).

In 2023, the European Parliament and the Council issued the Alternative Fuel Infrastructure Regulation (AFIR) to increase the supply of electric charging and hydrogen refueling stations that are publicly accessible inside the EU. This also includes the supply at maritime ports, at inland waterway ports, for the road sector and aviation. This transformation would enable zero emission transportation and overall reduce the emissions from the transport industry. The regulation ensures and encourages the transition to low carbon and renewable fuels. The regulation enables the EU's targeted goal to reach a 55% reduction of GHG emissions by 2030 (European Commission, 2023).

2.1.2 Greenhouse gas and pollutant emissions from shipping

The greenhouse gases in the atmosphere include different ratios of various gases. These include Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), all non-fluorinated gases (Eurostat, 2016). There are several gases that do not directly have a radiative forcing effect but still have an influence on the radiation budget on a global level. These indirect GHG gases include carbon monoxide (CO), nitrogen oxides (NO_x), sulphur oxides (SO_x) and ozone (O_3) (ACS, 2023).

Pollutant emissions as NO_x and SO_x are emissions from fuel combustion, which have negative impacts both on animal and human health as well as the environment. NO_x is a highly toxic gas, consisting of NO and NO_2 emissions that are emitted from vehicle engines and combustion processes using fossil fuels. NO_x emissions cause both acid rain and photochemical smog, disturbances in the vegetation and lowers the air quality affecting both the human and the animal health (Lasek & Lajnert, 2022). SO_x emissions are released as sulphur containing fuels are combusted (Islam et al., 2023), which includes commonly used marine fuels such as MDO and HFO. Just like NO_x emissions, SO_x emissions have a negative impact on the environment and can affect the human health. It can lead to acid rain and is known to cause problems with lung function or worsen current symptoms for patients with lung related diseases (Yara, 2023).

CO_2 constitutes 66% of all GHGs in the atmosphere. As CO_2 is such a major part of the total GHG emissions it is of utter importance to regulate the emissions to be able to control climate change. CH_4 is the following biggest source for radiative forcing, accounting for around 16%. N_2O is a potent GHG gas, accounting for around 7% of the GHG emissions and this gas is harmful to the ozone layer. Other GHGs accounts for the remaining 11% in the atmosphere. The amounts of CO_2, CH_4 and N_2O have increased with 44% (CO_2),131% (CH_4) and 22% (N_2O) during the period of 1850-2019 (WMO, 2022).

Despite the current decarbonization efforts, the GHG emissions are still increasing. The actions that are taken are not sufficient enough to reach the goals of the Paris Agreement in order to reduce the GHG emissions, as is shown in Figure 1. Figure 1 describes the direction of where the GHG emissions would be headed in different scenarios, such as if there were not any decarbonization or if the path continues in the same direction as it does today. The other circumstances that can be seen in the graph are if the ongoing efforts pay off and what the efforts would need to look like for the goals to be reached, well below 2°C (WB2°C) and the 1.5°C target. The WB2°C describes a 25% emissions reduction between the years 2010-2030, with the possibility to reach a net zero target by 2070. The 1.5°C target describes a 45% emission reduction, resulting the net zero to be reached in 2050. (Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, 2021).

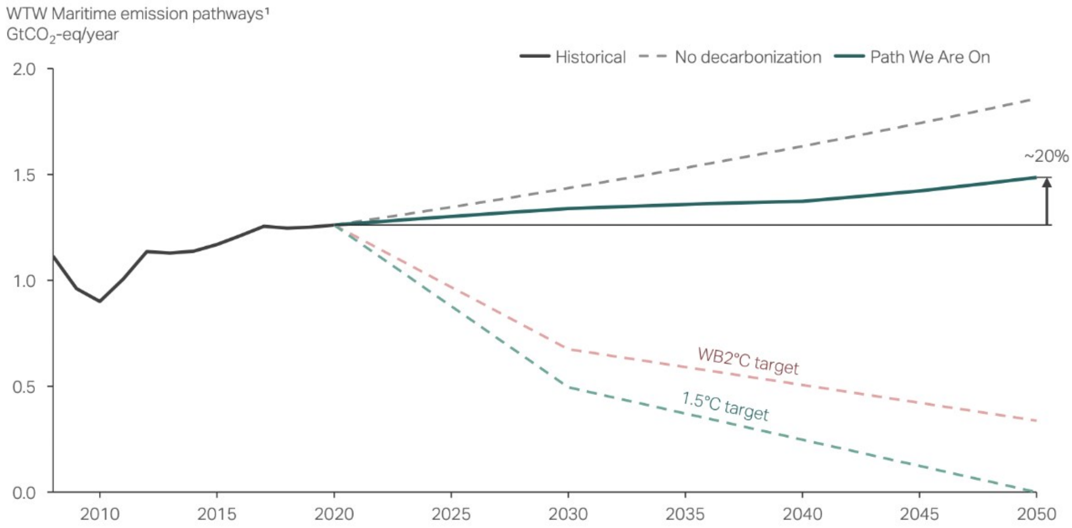
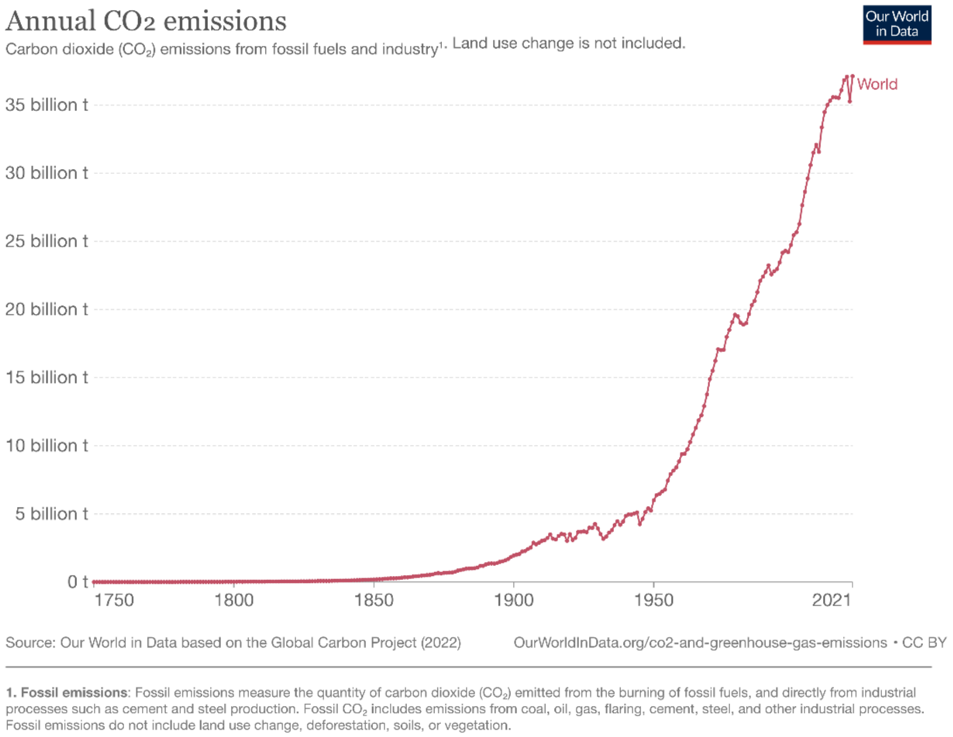


Figure 1. The direction of where the GHG emissions would be headed in different scenarios. Adopted from Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, 2021.

During 2020, the CO_2 emissions from fossil-based fuels were over 34 billion tons globally. Compared to what the CO_2 emission levels were in 1950's, when the global total was on average around 6 billion tons, it is safe to say emissions have grown enormously over the last seven decades. The CO_2 levels have about quadrupled from the 1950's, as can be seen in the Figure 2 below.



Annual CO2 emissions

Carbon dioxide (CO_2) emissions from fossil fuels and industry[1]. Land use change is not included.

Source: Our World in Data based on the Global Carbon Project (2022) OurWorldInData.org/co2-and-greenhouse-gas-emissions • CC BY

1. Fossil emissions: Fossil emissions measure the quantity of carbon dioxide (CO_2) emitted from the burning of fossil fuels, and directly from industrial processes such as cement and steel production. Fossil CO_2 includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes. Fossil emissions do not include land use change, deforestation, soils, or vegetation.

Figure 2. The annual emissions of CO_2 since 1750. Adopted from Ritchie et al., 2020.

2.1.3 Technical and operational measures to reduce the GHG emissions from shipping

The topic of environmental impact from different industries is a subject that is well discussed. Different methods to decrease GHG emissions are also frequently debated as the concern for the subject is increasing globally. As often stated, it is not possible to reach the GHG emission reduction goals with only one single measure, as no individual measure is sufficient enough (Bouman et al., 2017). When it comes to reducing GHG emissions from the shipping industry by establishing GMCs there are several different actions that can be taken, both technical and operational. The technical solutions that enable a green transformation for a shipping corridor are *e.g.,* alternative fuels. Some measures are only possible and feasible for new vessels, and others can be adapted to existing vessels. Renewable fuels are the primary technological drivers when it comes to full decarbonization. However, the development of many sources of renewable fuels are still ongoing and there are different aspects that require further research regarding the different parts of its lifecycle, *e.g.,* storage, bunkering and handling the fuel onboard. The operational solutions include actions that focus on coordination, optimization, and other practicalities to increase the efficiency, *e.g.,* the speed and voyage planning (Schwartz et al., 2020; Serra & Fancello, 2020; Wan et al., 2018). The most discussed measures in previous studies that would be possible to adapt in the maritime industry include: power and propulsion, hull design, economy of scale, speed, scheduling and weather routing, alternative energy sources and the choice of fuel (Bouman et al., 2017; Schwartz et al., 2020; Zis et al., 2020).

- The power and propulsion refer to the power system's design and the machinery used on the vessel. To reduce emissions, some possible solutions could be different hybrid powered engines, recovery of wasted heat, propulsion efficiency and possible energy saving devices. The use of batteries is also pointed out as a complement to the ICE, as batteries can be used as a buffer, utilizing the peak power from the ICE to avoid the low powers.
- Hull design refers to the vessel's dimensions and its weight. By controlling these properties, the vessel can achieve better hydrodynamic performance and the resistance of the vessel can be minimized.
- Economy of scale implies that bigger vessels are often more energy efficient per freight unit. Usually, when a vessel freight capacity is doubled, the required fuel and power is increased by two-thirds. This means that the fuel and power needed to transport the cargo is reduced.
- The speed of the vessel includes the operational speed and the design speed. The design of the vessel is made to control their maximum hydrodynamic speed. The consumption of fuel can be reduced by a reduction of speed as the product of speed is proportional to the power requirement.
- Scheduling and weather routing is an approach that focuses on finding the most optimal speed and route for the specific voyage, taking aspects such as the weather conditions and deliveries into account. This measure can reduce fuel consumption and minimize resistance caused by weather, such as heavy wind or wave conditions.
- Alternative energy sources and the choice of fuel, include the different possibilities that focus on replacing or complementing fossil-based fuels. GMCs can be constructed with alternative energy sources such as solar and wind and fuels with lower emissions (Bouman et al., 2017; Wan et al., 2018; Zis et al., 2020).

2.2 Definition of green maritime corridors

A GMCs is a shipping route with a GHG emission reduction. The GMCs are possible actions that minimize GHG emissions, improving the quality of the air and sea, especially in coastal areas. The GMCs play an important role in the current new economic area that focuses on alternative, clean fuels and innovative technology to reduce GHG emissions. GMC are an example for the rest of the shipping industry to re-think and adapt to the changes needed to be made by the actors in the industry (C40 cities, 2023).

Transport corridors are networks that allow a smoother and faster way of transportation with an enhanced connectivity. The concept of transport corridors can focus on one or different modes of transportation. Maritime corridors refer solely to maritime transportation between ports. There are several definitions of GMCs, and the concept is still in an evolving phase. In this study, we will proceed from the definition by the Global Maritime Forum that describes GMCs as, "Specific shipping routes where the technological, economic and regulatory feasibility of the operation of zero-emission ships is catalyzed by a combination of public and private actions. " (Global Maritime Forum, 2022a)**.**

2.2.1 Corridor types and the concepts

There are different types of GMCs that can be adapted in the maritime shipping industry. The type of corridor used depends on the purpose of the voyage.

Single point: These corridors center around one single point. The single point corridor is focused on establishing shipping routes that have zero emission around this location.

Point to point: This route consists of two points and describes the green voyage between the two ports.

Network: A network of GMCs consists of three or more ports and the transport of vessels between them (Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, 2022).

Two single points that are connected make up a point-to-point route. If more ports are involved, it becomes a network of GMCs. The concept of what a corridor should include and how they should be implemented may differ. The different concepts are presented below but it is important to keep in mind that a GMC may also be a combination of different concepts, as the lines between the concepts are flexible.

Port-centric: This is a corridor initiated by collaborating ports. In this case the ports are the center of the whole system, and the raison d'être of the corridor. The ports have the authority to make the decisions about the activities and voyages between them, which could be implementing usage of technology that would benefit the green transition. An example of a port-centric corridor is the Shanghai-Los Angeles corridor, where the ports are the ones who sets the boundaries for the corridor (C40 cities, 2022). These boundaries at the port gates affect cargo and port operations. The port restrictions may be set to counteract the local environmental and air emission and pollution related issues.

Route-centric: In the corridors that are not as driven by ports but more by companies using the route have more of an influence, usually emphasizing the accessibility and infrastructure around the designated route. A case that is route-centric is the Australia-East Asia Iron Ore Green Corridor, which has been regulated by Australia's and Japan's energy strategies and the focus is on the economics of fuel and voyages and getting them to work smoothly (Global maritime forum, 2022b).

Pilot/demonstration project-centric: This corridor focuses on test projects by showcasing the whole process of the corridor in order to understand and trust the technology behind it. This does not automatically mean that they are replicable, as the project of the corridor may be unique.

Programmatic/niche market: This approach is focuses on developing the strategy for different pilots, with the aim to eventually progress into a full-scale commercial strategy. These kinds of corridors focus on building a whole environment leading to a broad operation instead of focusing on one specific establishment, *e.g.*, the Shanghai-Los Angeles corridor is based on a programmatic approach (Global maritime forum, 2022a**).**

The incentives behind establishing a GMC may look very different. Generally, there are two different kinds of incentives:

Bottom-up: In this case it is the involved actors of the value chain that take initiative to establish a GMC. In the shipping industry these actors can for example be ports, ship suppliers, cargo owners or the suppliers of fuel. Here the employees make an input, wide collaboration and the results and completed tasks are discussed by the higher-ups. In this case the tasks are gradually built up, naturally leading the process forward.

Top-down: This approach means that the government commits to the project, the project and jobs are altered from what is needed and the specific tasks will be completed based on what the higher authorities' demand. The process is a successive decomposition, the tasks gradually reaching the elementary tasks (Nationalencyklopedin, 2023).

2.3 RoPax shipping

When discussing maritime transportation there are various kinds of vessels, *e.g.*, RoPax (roll-on/roll-off passenger vessels), RoRo (roll-on/roll-off vessels) and ferries (passenger vessels). The RoPax shipping corridors are an alternative to road transportation and globally, there are over 630 RoPax vessels. This study will focus mainly on the RoPax shipping corridors, as they are the most popular in short sea shipping (SSS), which refers to shorter and often fast waterborne connections between countries or within a country. The RoPax shipping corridors enable excellent connectivity opportunities for both cargo and passengers (Kalvi et al., 2017).

The high share of GHG emissions generated by the shipping industry and the escalating greenhouse effect underlines the importance of reducing the GHG emissions generated by the shipping industry. A more decarbonized shipping industry would have a major impact on the feasibility of different environmental goals, such as the Paris Agreement. Currently, the global shipping industry's fleet is dominated by containerships, tankers and dry bulkers while RoPax and RoRo vessels only stand for 7.7% of the total fleet as shown in Table 1 (Zis et al., 2020).

Table 1. Sectioning of the world's total fleet types, based on number of fleet. Adapted from Zis et al., 2020.

Fleet type	Percentage of the world fleet
RoPax & RoRo	7.7%
Containerships	15.6%
Tankers	23.2%
Bulkers	42.7%

In the EU, around 60% of the total shipping consists of SSS (European Shortsea Network, 2022b) and is a crucial part of both trade and movement. The European SSS routes include a coastland coverage of over 67,000 km and 25,000 km of canals and rivers (European Shortsea Network, 2022a). Yearly, over 400 million passengers are carried on RoPax vessels on over 100 different routes around Europe. The routes that exist enable trade inside the EU in an efficient and effective way, as the transportation is moved from the roads to the sea (European transport maps, n.d.). A map of the core network in Europe is shown in Figure 4 (The Motorways Of the Sea Digital Multichannel Platform, 2020). As the SSS plays a major role in the shipping industry, the SSS is one of the main areas that need improvement regarding decarbonization of the shipping industry (Eurostat, 2022).

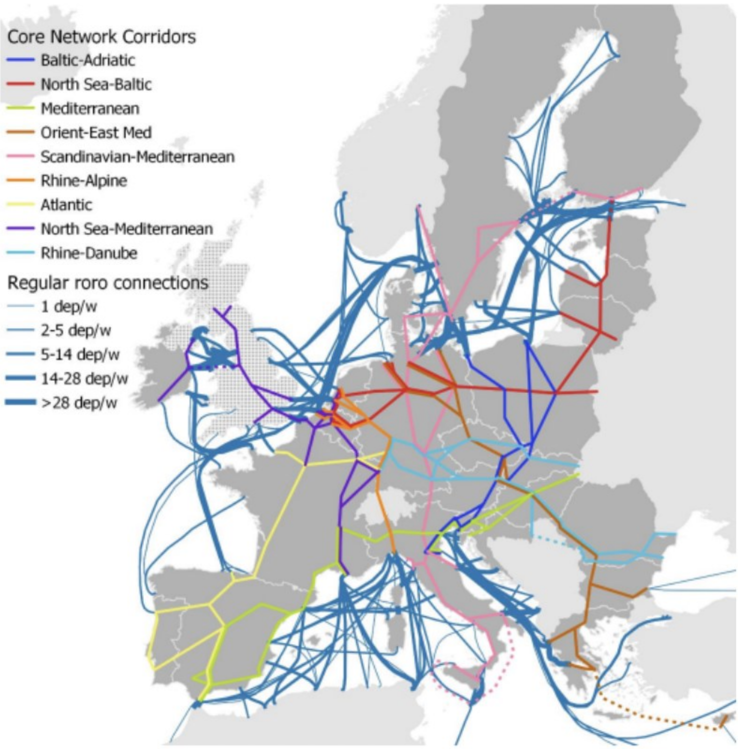


Figure 3. Europe's corridor network. Adopted from The Motorways Of the Sea Digital Multichannel Platform, 2020.

The SSS RoPax routes offer different advantages regarding seaborne transportation between ports. The quantity of fuel that is needed for the specific transportation route is easily assessed. As the voyage is waterborne, it means that there is less transportation on the road and this contributes to reducing the CO_2 emissions that are caused by the road transportation, which have a bigger environmental footprint compared to seaborne transportation. The SSS also makes the timeframes more reliable as the distances travelled are relatively short, which makes it easier to schedule the arrivals and departures than it would be for the road transport due to possible geographical benefits. The waterborne freight of goods is often more affordable than road freight, especially when larger, heavier loads and freight with a bigger volume are concerned (Zis et al., 2020).

2.4 Alternative fuel sources for decarbonizing shipping

The shipping industry is currently in a transitioning phase towards a greener future. New alternative fuel options are emerging, and the fuel choice plays an important role, since the chosen type of fuel will directly affect the amount of emitted GHG emissions. Some fuels can be used as drop-in fuels and function as substitutes for the original fuel, without further needed alterations to the ships or ports. Others alternative fuel sources will require investments, such as new engines in the existing vessels, propulsion designs. Some alternative fuel options may even require development of current fuel infrastructure at ports.

The umbrella term “alternative fuels” describes fuels that can be a substitute for fossil-based fuels, *e.g.,* biofuels, electro-fuels, and blue-fuels. These fuels often have a lower environmental impact than fossil-based fuels. Using alternative fuels means moving forward from fossil-based fuels to fuels produced from renewable or zero-carbon sources. Utilization of batteries or hybrid engines can also be an option for ships in the decarbonization process (Zis et al., 2020). As alternative fuels are currently more expensive than fossil-based fuels there needs to be measures made within the industry to cover the costs.

The practicality of alternative fuels differs, depending on the voyages and ship types. The deep-sea shipping vessels require more energy, so there is a need for technical solutions in order to store energy onboard for long distance voyages. For the SSS, the alternative fueling solutions may be more diverse and these types of vessels have more options*, e.g.,* utilization of electricity or hybrid powered systems (DNV, 2023b).

The current RoPax vessels are relatively old, as around 40% of the vessels operating today are built before 1996. This reflects that a large part of the vessels is built in a time when the focus on the environment was fractional. In order to use certain renewable fuels, the vessels need to be retrofitted or replaced by new vessels (Kalvi et al., 2017).

2.4.1 Alternative fuel options

The technology of carbon neutral fuels is moving forward as the new fuel types are evolving and are central in research. The different types of alternative fuels have different potentials and challenges, and the specific needed development may vary. A conclusion of a few different alternative fuels can be seen in Table 2. In the table it can be seen by color how much research is still needed for the steps of the specific fuel's lifecycle. Green (x) in Table 2 describes that the specific part is mature and proven, yellow (/) means that the solutions are identified but could be further evolved and red (-) means that there are challenges remaining and more research is needed.

Table 2. The different challenges of the lifecycle of alternative fuels during the years of transitioning. Based on Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, 2021., and information from Gasum., Man energy solutions, 2022., Morgestern, 2022. &ETIP Bioenergy, 2020.

Energy carrier	Feedstock availability	Fuel production	Fuel storage, bunkering & logistics	Onboard fuel conversion	Onboard safety and fuel management	Regulations
Fossil fuels	X	X	X	X	X	X
E-ammonia	X	/	-	-	-	-
E-hydrogen	X	/	-	-	-	-
E-methanol	/	/	X	X	/	/
LBG	X	X	/	/	X	X
SNG	X	X	X	X	/	/
E-methane	/	/	X	X	/	-
HVO	/	/	X	X	X	/
Renewable energy	/	X	X	X	/	/

As it can be seen in Table 2 fossil fuels is the only type of fuel that is totally known regarding how it should be handled during its whole lifecycle. Most of the other fuels that can be seen in Table 2 still have challenges ahead and need to be researched so that the use of them can be safe and as efficient as possible. Some of these alternative fuels are already in use but can be further developed in order to reach their best lifecycle potential.

Electro-fuels, or e-fuels, are produced from renewable sources, such as water, wind and solar power or decarbonized electricity. The carbon footprint that originates from e-fuels is a lot smaller than the carbon footprint of fossil-based fuels (ENGIE, 2022).

Synthetic ammonia or e-ammonia is produced in a synthetical process with hydrogen and nitrogen, whereas blue ammonia is produced from by-products from the fossil fuel production. Both e-ammonia and blue ammonia are possible options for zero-carbon fuels. The energy that is used for e-ammonia is renewable energy, form sources like hydro, solar and wind. These energy sources are available, and the scale is still growing. The engine technology for e-ammonia is in the process of becoming available. The main costs of producing synthetic ammonia are the low emission electricity and the electrolyzes that are needed to produce hydrogen (Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, 2023a). The different challenges that exist with synthetic ammonia are such as the high toxicity of ammonia, the safety risk for bunkering procedures and handling the fuel on board. Even though the emissions are carbon free, burning ammonia leads to emissions of NOx that needs to be controlled with gas cleaning systems. The production of synthetic ammonia will have to be ramped up significantly to meet the future restrictions from the global agriculture. In order to have great potential for the shipping industry the ammonia will need the right safety procedures, propulsion systems that can control harmful emissions, and skilled crews (DNV, 2022a, 2022c).

Synthetic hydrogen or e-hydrogen is carbon free. The production of it is relatively simple, it needs electricity, water, and the electrolysis process. It can be used as a building block for other zero-carbon fuels, such as renewable electro-fuels. The challenge with hydrogen is that it ignites easily and has a wider flammability risk than other fuels. It is also hard to contain. The safety regime onboard needs to account for these risks. In the absence of a regulatory framework the approval process is challenging and complex. Storage solutions need to be large, which is expensive. Its properties make hydrogen more suitable for smaller coastal vessels that can refuel regularly, such as ferries (DNV, 2022c, 2022d).

Synthetic methanol is easy to handle compared to other emerging fuels. The shipping industry already has experience as methanol tankers have been in use since 2014. The production of synthetic methanol is relatively easy. The challenge is that it will take years for the supply to meet the demands of the global shipping and until then the prices will remain high. Large fuel tanks are required and double walled piping systems. The interest in methanol as a ship fuel has grown during the last years and has spread beyond the tanker segment. The first container ships are already on order and as the production of green methanol is scaled up for the next decade so will its use as a fuel (DNV, 2022b, 2022e).

Liquefied biogas (LBG) mainly consists of methane and is produced from biodegradable materials as waste products. As the fuel is derived from renewable sources it is a more sustainable option. In 2022, over 100 vessels running on operations Liquefied natural gas (LNG) entered operation (MarineLink, 2023). LNG is also mainly consisting of methane, as the fuels have similar chemical composition and properties, they can be used in combination with each other and are also interchangeable. The difference between LBG and LNG is based on what they originate from. LNG is natural gas from where non-wanted compounds have been removed from. They both are transported and bunkered in their liquefied form. When LBG is burned the only emissions are CO_2 and H_2O. When burning, new CO_2 is not added to the atmosphere as the biodegradable material that it is made from would anyhow be a source of CO_2 when it would decompose (Gasum, n.d.). Compared to life cycle of conventional fuel the CO_2 emissions can be reduced with 90% with the use of LBG (Euramet, n.d.).

Synthetic natural gas (SNG), **Synthetic methane/Electro-methane** (E-methane) refer to fuel with the chemical composition of methane. The difference between the two is that the chemical, the difference between them is that SNG can be synthesized from various sources as coal biomasses Depending on the sources' composition, the SNG that are substituting fossil fuels can be carbon-free or low-carbon (Man energy solutions, 2021; Romano et al., 2014). E-methane is synthesized from recycled CO_2 with renewable energy (ENGINE, 2022). Depending on the raw material used and the production process for SNG the desired properties of the end-product can differ, as well as the process technology. Both types of methane have the advantage to be stored and used later on, which is a great advantage when it comes to fuel properties. Drying and compression can be applied for storage and transportation. Through pipelines the SNG can be transported to the end-user of the product. The user of the SNG can be individual households, commercial units, or units on an industrial level. When specifically looking closer at the maritime industry and SNG, the fuel can be used as a substitute for LNG. As SNG is produced to have the same constituents as LNG, it can be used as a direct substitute or as a combination of them both (Man energy solutions, 2022).

Hydrotreated vegetable oil (HVO) or renewable diesel has a similar chemical composition as conventional fossil diesel and is a type of biofuel. HVO is made of fatty acids and triglycerides from a variety of sources like natural gas plant oils, coal, and animal fats (ETIP Bioenergy, 2020). HVO can be used as a direct drop-in fuel for conventional diesel without any technical modifications needed as they have similar chemical composition and properties. It can be used as blended in any ratio with conventional diesel or be used as pure HVO. (Morgenstern, 2022; Neste, 2022)

When looking at the production of HVO it can be noted that the industry is still under development and the challenge is that the production is still relatively small. HVO is more expensive than the conventional diesel and has a more complex production process than biodiesel. The investments needed for HVO production facilitates are higher than those for the plants for biodiesel (ETIP Bioenergy, 2020).

A shift to HVO from conventional fuel can reduce CO_2, NOx, and emissions of CO and particulate matter. HVO as a fuel has 10 times longer shelf life than conventional diesel. The benefits of HVO are mostly emission based as the price for it is 10-15% higher than conventional diesel, and as the efficiency of HVO is not better than conventional diesel the costs will not be regained through fuel cost savings. HVO is 100% biodegradable and renewable, and in total the use of HVO as a fuel could reduce 90% of GHG emissions (Neste, 2022).

E-fuels have the potential to replace fossil fuels as they use the same infrastructure and will compete well with different biofuels, produced from organic substances (eFUEL-TODAY, 2023).

2.4.2 Electricity as an energy source

Different technologies are already available for use of electricity as a fuel source. The subject of electrification is a popular topic and the interest in it has grown during the past years. The electrification technology has moved forward enabling a possible reduction in emissions and improved energy management. The cost-effectiveness of electric vessels depends on the available technology and battery costs (Serra & Fancello, 2020).

For electricity to be utilized as an energy source onboard, an energy storage system is needed and as well as an efficient network for energy supply in the port region. There are various aspects that need to be considered as far as electrification of shipping is concerned, *e.g.*, battery capacity, size of the vessel, cargo and passenger capacity, energy sources, charging possibilities, the technicalities of the vessel and performance attributes. For electrification to be possible the infrastructure at the ports needs to evolve in order to enable that charging possibilities. A few different kinds of electrically driven vessels exist:

Diesel-electric drive, in this case the electricity is generated from a diesel generator. The electricity produced drives the electric engine which moves the propeller of the ship.

Hybrid-drive, in addition to the engine there are batteries onboard. In this case, the battery can store surplus energy from the generator and the stored energy can be used as additional energy when needed. It is possible for the vessel to run only on electricity for short periods of time. There are different degrees of hybridization between the fully electric vessel and the conventional system.

A **fully electric-drive** vessel receives all its energy from batteries and has no ICE.

Most of the fully electric-drive vessels that exist today have an energy capacity between 50 and 500 kWh, median value is 140 kWh (Anwar et al., 2020). The industry of fully electric vessels is evolving and bigger vessels with a larger energy capacity are planned, *e.g.,* an electric vessel in China with a battery power of 7,500 kWh (Doll, 2022). Wärtsilä Oyj Abp is supplying the propulsion system for the potentially largest electric vessel planned with a battery power around 40 MWh (Suojanen, 2023). Usually, hybrid-drive vessels have a capacity of 500-5,000 kWh, median value is 1,000 kWh. Most of the electric vessels that exist today the majority, 69%, are hybrid-drive vessels. For a vessel to only use electricity as energy source, there needs to be a large battery bank that drives the electric motor, regular charging is necessary, and an effective cooling system (Anwar et al., 2020).

The concept of fully electrically driven vessels is relatively new and there has previously only been a few successful projects. As the use of batteries in the shipping industry grows, the requirements for regulating their distribution of power and output voltage may change. The batteries are direct sources of electricity with an unregulated output, as the voltage from the batteries fully depends on the charge of the battery (Haxhiu et al., 2022). The power systems of the different electric solutions vary depending on the kind of electrically driven vessel. The hybrid vessels' batteries are used to improve the vessels' energy efficiency. These batteries are not charged and do not bunker energy the same way as the fully electric vessels' batteries. A fully electric option is currently only relevant for the SSS, as the electric options available on the market are still in the starting phases and the battery capacities are not enough for longer voyages. Electrifying the SSS can be more efficient than the conventional fuel option. As far as electrification of vessels is concerned, the potential reduction of GHG emissions depends on the source of electricity. As the electricity is predicted to become more renewable, this would imply that an electric vessel in the future would have overall lower total emissions than today (Serra & Fancello, 2020).

The technology of EV batteries has evolved during the last decades. Lithium-ion batteries are used in various industries and are the most used battery for EV. During the last three decades, the price of Li-ion batteries has dropped by 97% and during recent years the price has still been falling steeply. A visual description of the Li-ion battery price decrease between 1991 and 2018 can be seen in Figure 4 (Ritchie, 2021).

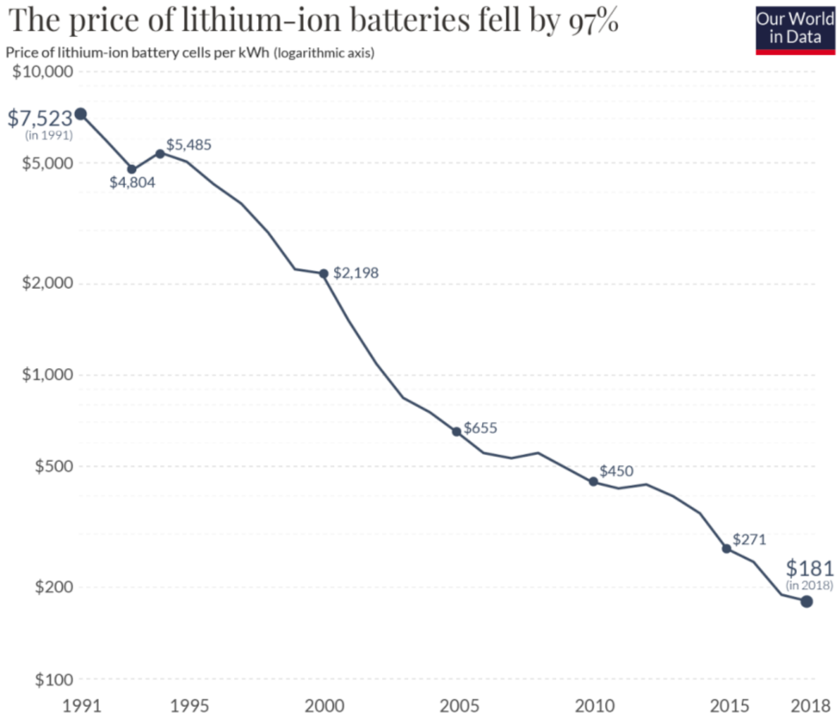


Figure 4. Statistics of the price drop for Li-ion batteries between the years of 1991-2018. Adopted from Ritchie, 2021.

The local air pollution that comes from the shipping industry would be possible to decrease with a change from fossil fuel to electricity. With a decrease of the air pollution, individuals living near the port area would no more be impacted by the pollution, when compared to before. A change to electricity could decrease the diseases that are connected to the air pollution, such as lung, respiratory and heart diseases. For the electric transformation to evolve there has to be a greater need to maximize the benefits. Both policymakers and port authorities have the possibility to drive the transformation forward, by evolving the grids’ infrastructure and optimizing port operations and activities (Blonsky et al., 2019). With the battery technology evolving and more producers appearing the overall battery prices are sinking, but still the battery costs are so high that ship owners chose to hold off. The technical challenges, when the ship owner chooses the electrical option, include the energy storage system and spaces, assessing ventilation systems, installation, the distance of the voyage, effective battery charging during short port stays and the weight of the vessel. While the owner must consider all of these aspects, they still need to observe the regulations concerning safety and installation. For the electric ship to minimize its emissions the operators would need to guarantee that the electricity used in the battery charging process are renewable. (Gillingham & Huang, 2020; Marine & Offshore, 2021).

2.4.2.1 Lifecycle of batteries

Another fact that challenges the ship owners when choosing the electric option is the lifespan and lifecycle of the batteries. The capacity of the battery is crucial and over time the capacity decreases naturally. To be sure that the battery’s capacity is maintained and high enough there is a need for testing the battery’s endurance. The predicted lifespan of an EV battery varies but is around 10 years, depending on charging, discharging, physical fray and available cooling system (Anwar et al., 2020). The needed energy density and size of the battery depends on the size of vehicle and the driving range, which also causes the cost to vary. The lifespan of the battery depends on various factors, such as temperature and the charge, discharge requirements, the present materials, and possible requirements of the specific application. The operating temperature has a great impact on the battery performance and lifespan. A temperature too high can cause a reduction in the lifespan, and too low temperatures can cause a reduction of the battery capacity. These are the main reasons why a temperature control system is necessary (Khan et al., 2022).

A shorter lifespan means a higher environmental impact of the batteries. The environmental impact is lowered with a more efficient system as it leads to decreased energy losses. The main challenge with an electric vessel is that the needed energy to move the vessel forward is high, which implies that the needed battery must have the power to be able to do it, without the battery taking up too much space and weight. So, a battery with enough energy density is needed to run the vessel. The batteries that have the highest energy and power densities are Li-ion batteries, and these are the most popular for the few existing fully electric vessels. These Li-ion batteries have a charge efficiency between 90-95%, and with a high efficiency the battery has lower charge and discharge cycle efficiency (Casals et al., 2017; Deng et al., 2020).

Once the battery's capacity has decreased so that it is not in use anymore, the battery owners are responsible for managing the recycling of it, so that the polluting elements are handled safely as the recycling process is part of the battery's lifecycle. The lifecycle of the batteries has been facing recycling issues and is a contributor to the batteries' environmental impacts (Casals et al., 2017).

2.4.2.2 Electric infrastructure onshore and offshore

The technical requirements for the charging station are dependent on the transferred energy to the batteries when charged, including the ambient conditions and the frequency of the charge. The required energy needed for an individual vessel depends on various factors, such as the average energy needed per km, route length, power demand for other systems than the propulsion system. Harsh weather conditions can also be problematic for electric vessels as the sea currents can force the route to be changed and increase energy consumption. The vessel's structure and form of the hull have an impact on the energy consumption as it affects how easily the vessel can move as it forms the resistance (Khan et al., 2022; Kumar et al., 2023).

A fully electric vessel needs to recharge at the ports to be able to continue its journey by connecting to the electrical grid at the port. The vessel could possibly have mobile batteries, that would be changed at the port to fully charged ones. Today battery swapping is used in electric buses and trucks, and it would be a possible option for short distance vessels. This option would reduce the need for the charging infrastructure at the ports, as well as reduce the impact of the power grid and would not require high-power converters. The batteries would not need to be charged during a limited time slot or even in the port area. The uncharged mobile batteries could be transported to charging stations with a renewable energy source. This option would be a more sustainable option for the batteries' health and lifespan (Khan et al., 2022). Another option is that the fully electric driven vessels' batteries are charged from the onshore charging network, while the vessel is at berth, with a wired charging system or wireless charging system. The charging can take place at the ports when passengers and vehicles are embarking and disembarking the vessel, trough opportunity charging. The main challenge when it comes to opportunity charging is the often the tight time schedule and requirement for a sufficiently powerful charging station. The vessel can also be charged overnight at the destination. However, destination charging can be problematic as the energy that must be transferred is much greater with a longer charging time. For a manual cable connection to be an alternative a crew that controls the connection and disconnection of the charge is required. The additional manpower required will however increase the vessel cost. The wired charging can also face problems caused by winter weather, but these can be avoided with the use of wireless charging systems. The use of manual labor to connect the cable is also more time consuming and might also reduce charging time at the port. By using an automatic charging system, the charging time can be increased as there is no need for manual intervention (Khan et al., 2022).

To protect the vessel's electric power systems, the charging related safety is of utter importance as there are extremely high voltages and currents involved. Especially when connecting and disconnecting is when the highest risk of damage occurs. In addition to systems related damage, there is also risk of electric shocks as well as equipment damage as there are large currents and high voltages involved. Suitable firefighting systems are necessary to handle emergency situations. To minimize the risk of damage, insulation is crucial between the charging system and the electric storage system (Anwar et al., 2020; Duan et al., 2020). By monitoring the battery state as well as by balancing the charge, dangerous situations and conditions can be prevented. One of the main challenges with lithium-ion batteries that lead to safety issues are that the battery contains metal oxides that are relatively unstable which might decompose when elevated temperatures occur. When connecting the ship power system and the land grid, electrochemical corrosion may occur due to stray currents initiating a chemical reaction with the surroundings, causing properties to break down and have a corrosion effect. Corrosion can also be an effect of overcharging the battery as it can raise the temperature too much, leading to expansion of the electrolytes and causing a corrosion build-up (Gabryelczyk et al., 2021). To protect the battery health the battery's current carrying components need to be carefully constructed and dimensioned, to prevent external short circuit. In addition to this, thermal sensors and thermostats need to be a designed in a way that makes it impossible to start an explosion. When the electric ferry is connected to the onshore charging station, power converters, transformers, circuit breakers, cable management systems as well as a possible local energy storage system are all crucial for the battery charging to function properly, this can be seen in Figure 5. One of the most important components onshore is the AC grid: a strong enough local grid makes it possible to make a direct connection to it and the substation and port. If this is not possible there are special lines that can be installed to charge ferries. For the connection arrangements between all parts the right cables are crucial, so the power can be transferred without the cables being overheated. The chosen charging system determines the charging time, generally slow charging can be done in 1 to 8 hours, but the charging time also depends on the size of the battery.

The electric on shore system includes the shore to ship connection and its infrastructure which describes how the connection is maneuvered. The onshore system can also consist of a buffer energy storage can help to reduce the stress on the local grid and it can also be a key for cheaper electricity. The on ship systems consist of various parts and spaces: battery room, battery, AC/DC converters that transform the alternating current into direct current, energy management systems, transformers and electric motor (Khan et al., 2022).

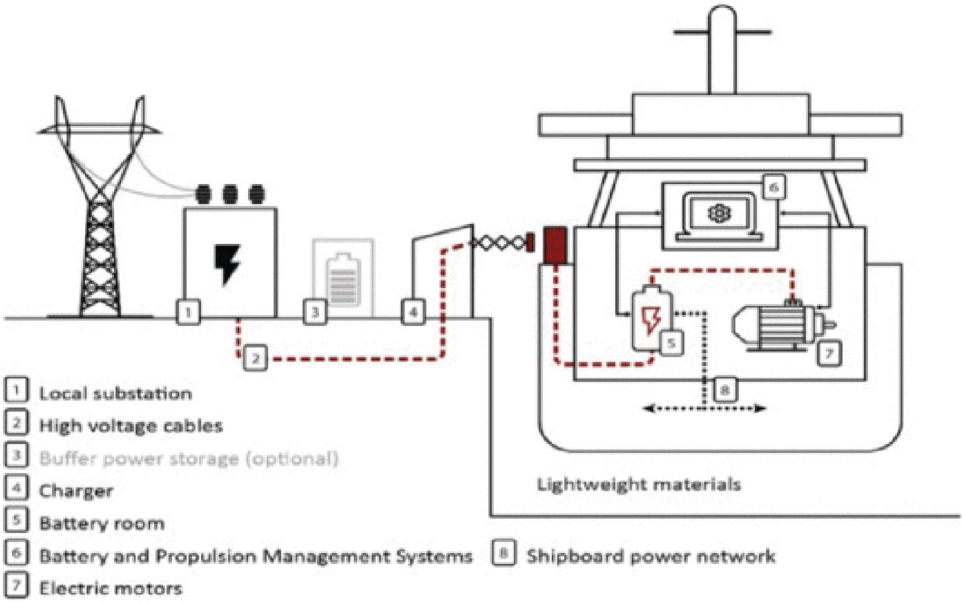


Figure 5. Electric ferry and onshore infrastructure scheme. Adopted from Khan et al., 2022.

As discussed, there are various challenges when it comes to electrification of vessels. However, there are several advantages of using electric propulsion systems onboard.

Listed below are the most significant advantages of an electric vessel (Sulligoi et al., 2016).

1. When it comes to speed variations and acceleration, electric engines are more effective than ICE.
2. Less technical crew is needed in the engine rooms as the system has a high level of automatization.
3. There are less vibrations onboard, due to the efficient vibration filtering and the thermal engines running at a constant rate.
4. Reduction of the industry's fossil fuel consumption, as the electric vessel is fully powered by another energy source.
5. Possibility to improve maneuverability.

2.4.2.3 Successful electric vessels

There are already a few fully electric vessels successfully sailing the seas, *e.g.,* the fully electric RoPax vessel Ellen in Denmark. This vessel has made the longest voyage on a single charge, it can travel up to 92 km on one charge. This is more than double the distance that previous fully electric vessels have managed to travel on one charge. The vessel has room to carry 31 cars and up to 196 passengers. Ellen has an energy efficiency of 82% from the grid connection to the propeller, it is common for electric systems to be more energy efficient compared to the traditional systems. The operation costs are 24% less than a new diesel fueled vessel. Ellen saves about 2,000 tons of CO_2 emissions per year. It has two battery rooms, each room has 10 battery strings that consists of 42 modules and each battery string has a nominal capacity of 215 kWh. Together the two rooms of the battery have a mass of 56 tons of Li-ion batteries, with a capacity of 4,3 MWh and without a backup oil generator. There is a safety repercussion, to ensure there is always enough battery capacity to get the vessel back to harbor if for any reason one of the battery rooms should fail (Vasilantonakis, 2020). The vessel has been since 2019 between Ærø and Als, but so far it can only travel on electricity one of the ways, as the charging possibilities in Als were not available until the summer of 2023 (MarineLink, 2022).

Yara Birkeland was the first fully electric container vessel built in 2020 and commercially operating since the spring of 2022 between Porsgrunn and Brevik, a 13 km route in Norway. Yara will reduce truck haulage, around 40,000 truck journeys are removed from the road thanks to Yara. The CO_2 emissions have been reduced by 1,000 tons per year. As the truck traffic is reduced the traffic noise will reduce and traffic safety will improve (Yara, 2021a).

Yara Birkeland is 80 meters long and has room for 120 TEU (Twenty-foot Equivalent Units, containers) and it can carry deadweight up to 3,120 tons. The vessel is powered by 20 batteries and has a total battery capacity of 6,8 MWh and can reach a maximum speed of 13 knots (Vesselfinder, n.d.; Yara, 2021b). The budget of Yara Birkeland lands on an amount around 25 million €, and approximately half of the cost was allocated from the Norwegian government (Manthey, 2021; Rote, 2018).

2.5 Impact assessment of transport and infrastructure projects

The aim of an impact assessment is to focus on the direct outcome and impacts that the change project has on the recipient. Impact assessment is a way for businesses, policy makers, and authorities to consider and examine different outcomes of a project, as a tool to maximize the positive impacts and control the negative ones. The impact assessment takes into account economic, environmental and social impacts, aiming the business to be more "shockproof" in the case of unexpected events. The impact assessment can also help to examine the direct and indirect impacts to identify different risks that may appear during the project, such as cost benefits and losses. No impact assessment can foresee everything, but it is an effective way to avoid and recover from different obstacles (Zewo, n.d.).

A project's timeline is built up by different parts, in a so-called "result chain" describing the whole project and the aim of it. The result chain can be divided into five major parts: inputs, activities, outputs, outcome, and impact as can be seen in Figure 6. The first steps of the result chain include the planned activities, and the work that is to be done. The later steps of the result chain view the results of the project, both short-term and long-term. When implementing an impact assessment, one focuses on the long-term results, including the two last parts of the result chain including the outcome and impacts. The five major parts of the result chain are described below (Fichter et al., 2023; Odhiambo, 2013; Zewo, n.d.).

Inputs: Describes the first steps to implement a project to ensure that the results are possible to be delivered. Inputs in a project can *e.g.*, be financing, personnel and human resources and the necessary equipment.

Activities: Activities are the actions that need to be taken in order to achieve the project goals. These include, *e.g.,* the different activities of the personnel needed to reach the aim of the project.

Outputs: Outputs describe the primary results of the project activities have achieved and is often described over a short period. This is not to be mixed with the end results, but to be seen as the immediate results of the different activities.

Outcome: Outcome is the second part of the results of the project. These results refer to a medium long period of the project. Outcome should not be considered an end result but should still perspicuously be connected to the end-goal of the project. The outcome also describes the project's effect for the stakeholders.

Impact: Impact is the long-term consequences of the project and the third part of the results. Impact describes the specific final results from the actions that have been taken in the project. The impacts describe both the production of positive externalities and the reduction of negative externalities.

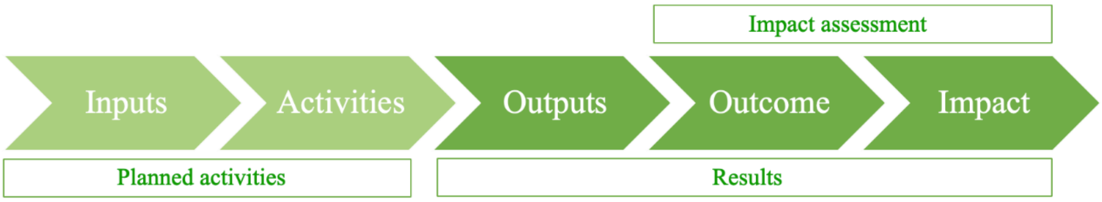


Figure 6. The result chain of a project. Adapted from Zewo, n.d.

There are two different objectives to an impact assessment: ex ante impact analysis, and ex post impact assessment. These two are made in different times of a project's timeline. Ex ante is a part of the planning process. It focuses on the future of the business and what impacts may occur. Ex ante impact analysis can be a helpful tool in designing the project, specifically to point out what to be included and what to be excluded. The ex post impact assessment focuses on the impacts that have occurred and is a part of an evaluation of the project. In this case the actual impacts can be used as valuable information to improve future projects (Fleurbaey & Peragine, 2013).

Depending to which project the impact assessment is done for it will include different information and look different. The questions to be answered should describe the potential environmental, social, and economic impacts, including both positive and negative perspectives. The indirect and direct impacts and outcomes of the project should be presented as well. An impact assessment can be a helpful tool to determine what to be included and excluded. With the information from the impact assessment future projects can be improved.

In the case of establishing an ex ante impact assessment of a green RoPax shipping corridor there are different aspects to consider, much depending on the specific corridor analyzed. Focus is on the following aspects: the alternative fuel or energy source that is used for the vessel, how it is produced and supplied, the technology used on the vessel, the ports that are part of the specific corridor, the potential effect on tourism and job opportunities, export, and the cargo industry. The impact assessment of the aspects regarding the choice of fuel and the technology for the specific vessel might not be easy, as the impacts of the price, availability and policy of fuels makes it more complex (DNV, 2023b).

Systemic impact refers to wide-ranging consequences that occur due to a specific action or event. It is a consequence that may not immediately be evident and the consequences may be interconnected to different aspects such as, economic, environmental and social (Vataja, 2019). Systemic effects that may occur in the context of decarbonizing maritime corridors include encouraging and empowering other connected industries to green growth and this will have a gradual decarbonation effect on the environment. Industries that are connected include tourism, transportation, fuel, and energy. It is also possible that decarbonizing one maritime corridor will have an impact on replicability for other maritime corridors. The gradual systemic impacts of the GMC are illustrated in Figure 7.

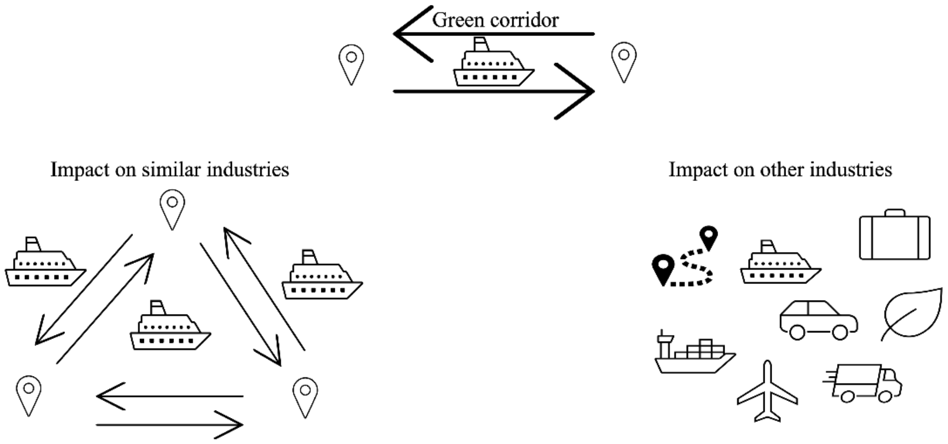


Figure 7. Green growth of decarbonizing maritime transportation.

Successful growth of green shipping would impact the GHG emissions. For this growth to happen the needed actions must be big enough, as one organization cannot solve the decarbonization questions alone. A successful green shipping corridor could stand as a basis for other corridors to imitate and with this popularity the growth effect becomes bigger and more powerful. This would decrease the impact on the carbon footprint as the emissions would be reduced.

The concept of electric ferries is still new and growing, and there is no assortment of similar impact assessments about electric vessels open to the public. For the electric vessel Ellen a short evaluation about its performance, economy, environmental impacts and passenger reception is discussed briefly in a document. This specific evaluation was done after the project, part of an ex post impact assessment. The result of the evaluation indicates that the electric ferry has an energy efficiency around 85%, which is more than double the energy efficiency of conventional ICE driven vessel. In combination with the battery capacity of the vessel and the fast-charging possibility proves that the vessel is a valid commercial alternative to the conventional vessels. The vessel spares the environment annually from 2,050 tons of CO_2 in comparison to a modern diesel vessel. The passenger feedback on green tourism has described their enthusiasm to travel sustainably in a less noisy environment (El-færgeprojektet, 2020). Other previous studies about impact assessments in the field of electric vessels, emphasizes that battery driven vessels are not totally emission free, as the whole lifecycle needs to be considered. This includes the battery lifecycle, the energy source emissions and the byproducts of the electricity production (Jeong et al., 2020) .

Park et al. (2022) discuss a life cycle assessment in the article *Live-life cycle assessment of electric propulsion ships for solar PV*. Here the benefits and drawbacks of solar powered ships are discussed. The article includes literature about shipboard tests, cost-benefit analysis, geographic impact, structure, and efficiency. For the solar power to be used as the electricity source the weather conditions determine the performance. This impact assessment had similar challenges as this study, with the lack of previous similar studies made, there were a lack of data and information of previous relevant available studies. The goal with the article was mainly to find a better research technique in order to collect more precise data to be adapted into assessment studies.

3 Methodology

3.1 Research design

The aim of this study is to investigate and assess the impacts on sustainability and green growth a potential GMC would have. This study focuses on a GMC between Helsinki and Tallinn using an electric vessel as a method of decarbonization. The assessment of the potential GMC will be done using an existing impact assessment framework developed for the DECATRIP project. The aim is to evaluate the corridor's potential to strengthen the green transition and explain the expected outcomes of the decarbonized maritime shipping corridor for key actors involved and the society.

The involved policy actors in the GMC can be seen in Figure 8. The impacts evaluated in the study have an individual effect on the policy actors, but some can also be interconnected between the policy actors. With a change from a fossil-powered vessel to an electric, different actors involved in the value chain would have individual objectives depending on their interest and policies.

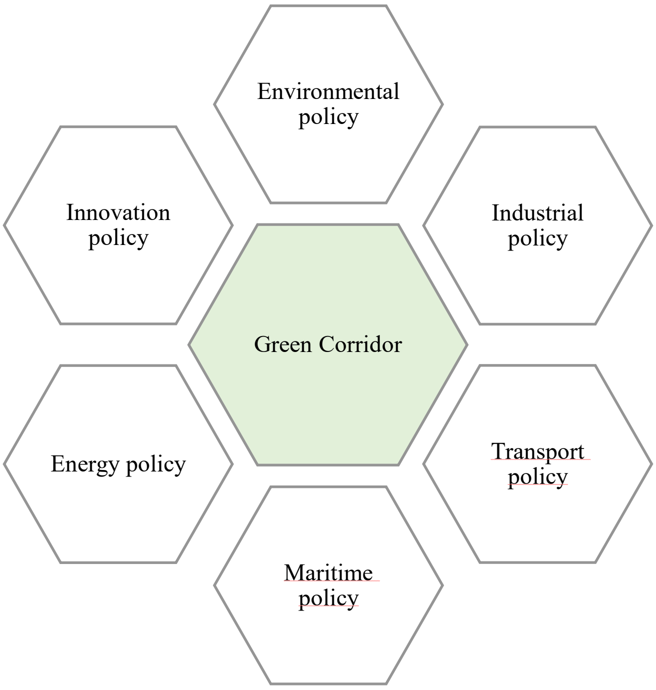


Figure 8. The involved industries' policy actors in the maritime GMC.

The impact assessment is a framework based on both quantitative and qualitative research. Quantitative research includes calculations for relevant indicators based the data gathered during this Master's thesis project and within the DECATRIP project.

Qualitative research concerns the exploration of relevant impacts in the decarbonization scenario. It also includes the analysis of the applicability of the original impact assessment framework when a different route and decarbonization technology is scrutinized.

3.2 Impact assessment framework for the decarbonization of maritime corridors

The multi-organizational project, DECATRIP, has the aim to assess the feasibility of decarbonizing the Turku-Stockholm maritime corridor. As a part of this study, an impact assessment framework was developed, which aimed to gain understanding of larger impacts on the involved stakeholders, relevant states, and society.

The impact assessment framework was in the original case developed and applied to the Viking Line shipping route between Turku and Stockholm. This framework is presented further in more detail in chapter 3.4 and will be used as the base for assessing the impact of decarbonizing the Helsinki-Tallinn route. The specific impacts that had been selected for the Turku-Stockholm corridor have been adapted, as necessary, to accommodate the specifics of the Helsinki-Tallinn shipping corridor. Some of the selected impacts differ from the DECATRIP project, as the decarbonization technology differs for these two cases. This impact assessment does not take consideration the on-land cargo transportation, and it is to be noted that the scenario of the potential vessel does not consider the opportunity of electric vehicle charging onboard. Within this study, decarbonization of the Helsinki-Tallinn corridor implies the scenario where one vessel on the route is replaced with an electric vessel. In particular, the case vessel is the Viking XPRS operated by Viking Line, working the route between Helsinki and Tallinn.

3.3 Data collection

To perform the impact assessment, different calculations needed to be implemented. The data needed for the specific calculations was collected from the involved companies. Secondary data from the DECATRIP project's calculations was also utilized. Additional information was needed regarding the RoPax business logic, renewable energy, shipbuilding, and regulations. This information was collected and researched from various sources, *e.g.*, interviews with experts working on feasibility on electric ships, internal meetings with creators of the original DECATRIP framework, research articles, newspaper articles, company web pages, industry reports and presentations.

When beginning the impact assessment and its calculations, the logic and data needed to be defined, as well as the specific timeframe and the scope of the project. For a successful impact assessment to be done a useful order of the information is needed. When the impacts of the corridor were chosen, they were organized in the most practical order. Some of the impacts are relatively closely connected and this may lead to calculations overlapping, if numbers are summed up. However, this is not a cost benefit analysis, thus, it is not suggested to sum up the values of the impacts for economic purposes. This impact assessment aims to demonstrate the range of impacts raised from a GMC.

3.4 Application of the framework

The impact assessment framework that was reapplied for the Helsinki-Tallinn corridor needed to be altered for the specific corridor. The different steps that were needed to be accomplished are defined in Figure 9. These specific steps included identifying the specific impacts as well as their indicators. Impacts not needed had to be removed from the framework, and new impacts were added. Data from various sources was collected and the calculations completed in the refined framework.

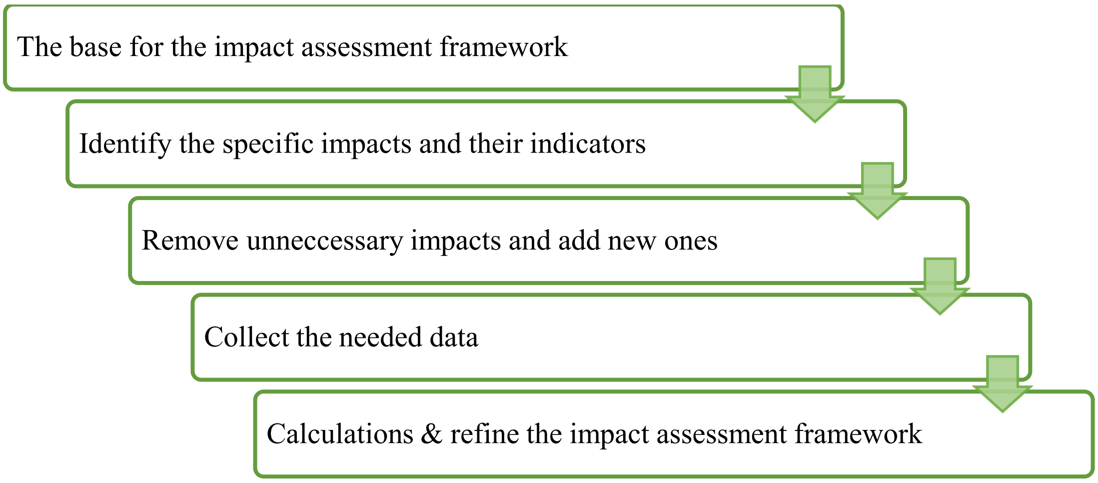


Figure 9. The different steps of adapting the impact assessment to a new corridor.

The impacts used as the base for this impact assessment were included in the DECATRIP project and can be seen in Table 3. The table also indicates which impacts are relevant for the Helsinki-Tallinn corridor. Within the scope of this Master’s thesis project, the relevant impacts are highlighted in green (X), and the impacts highlighted in red (-) denote the impacts that are out of scope of this specific corridor between Helsinki-Tallinn. As Table 3 presents, this scenario does not consider the opportunity of vehicle charging possibilities onboard.

Table 3. The list of impacts included in the impact assessment for decarbonizing the Turku-Stockholm corridor.

	Impact: Turku-Stockholm	**Indicators for the Turku- Stockholm corridor**	**Relevant for Helsinki-Tallinn corridor**
1.	Impact of GHG emission	Reduction of GHG emissions per ship	X
2.	Impact on noise	Noise reduction in ports and at sea	X
3.	Impact on pollutant emissions	Reduction of NOx, SOx and PM 2.5	X
4.	Impact on health	Reduction of health impacts, noise, and vibration	X
5.	Impact on GDP	Impact on GDP	X
6.	Impact on the security of supply	Decreased dependency on imported fossil maritime fuels in Finland and Sweden	X
7.	Impact on export potential	Export potential alternative fuels Export potential for vessel newbuilds Export potential for vessel retrofitting Export potential for ship related clean technologies	X
8.	Impact on jobs	Jobs created in fuel production Jobs created in shipbuilding (retrofit of existing RoPax + newbuilds)	X
9.	Impact on R&D	Number of new patents Number of scientific articles R&D investments in clean fuel and maritime clean tech	X
10.	Impact on the value of transportation	Price premiums on passenger and cargo transport on ships	X
11.	Impact on the cost of transportation	Increased cost for passenger and cargo transport due to higher cost of renewable fuel and required retrofits	X
12.	Impact on the safety of transportation	Impact on safety of transportation and related costs (*e.g.*, onboard fuel handling)	X
13.	Impact on sustainable tourism	Carbon footprint per traveller-day Increased travelling on route	X
14.	Impact on sustainable manufacturing	The share of goods likely to be exported and imported by green ship	X
15.	Impact on renewable energy	The required power for producing the energy needed	X
16.	Impact on electrification of road vehicles	Additional number of EV trucks utilizing the GMC thanks to onboard charging possibility	-

3.5 Analysis

The differences between the Turku-Stockholm and Helsinki-Tallinn route include route, vessel type, fuel used by vessels, number of passengers, and volume of freight transported. Specific differences are the Helsinki-Tallinn corridor having a fully electric vessel and the potential scenario would not consider EV charging for vehicles onboard. So, the impact on future electric road vehicles is not assessed in this study. The scenario used for the impact assessment does not imply retrofitting the conventional vessel but building a new electric ship. This means that the retrofit industry would not be affected in the same way as in the Turku-Stockholm corridor, assessed in the DECATRIP project. The impact of using an electric ship for decarbonizing the focal corridor will naturally include the effect on the shipbuilding industry. These effects are qualitatively described further but no quantitative indicators have been developed for the impact on shipbuilding in this study. Below in Table 4, the specific impacts with indicators for this corridor are shown, without the EV-charging and with an additional impact on the shipbuilding industry. The impact of "GHG, pollutants and noise" have been put together and will be discussed as one whole impact on emissions. The impacts that are assessed have been estimated for a timeframe between 2023-2030.

Table 4. The list of impacts that are included in the impact assessment of decarbonizing the Helsinki-Tallinn corridor.

	Impact: Helsinki - Tallinn	**Indicator**	**Unit**	**Quantified in the impact assessment**
1	Impact of GHG, pollutant emissions and noise emissions	Reduction of CO_2, NOx, SOx and PM 2.5 emissions per ship Nosie reduction during voyage and at ports	Metric tons dB	Partly
2	Impact on health	Reduction in health impacts, noise, and vibration	EUR	Yes
3	Impact on GDP	Impact on GDP	EUR	
4	Impact on the security of supply	Decreased dependency on imported fossil maritime fuels in Finland and Estonia	% and metric tons	Yes
5	Impact on export potential	Export potential for renewable energy Export potential for vessel newbuilds Export potential for ship related clean technologies	EUR	Yes
6	Impact on jobs	Jobs created in renewable energy production Jobs created in shipbuilding	Job-years	Yes
7	Impact on R&D	Number of new patents Number of scientific articles	EUR	Partly

		R&D investments in clean fuel and maritime clean tech		
8	Impact on the value of transportation	Price premiums on passenger and cargo transport on ships	EUR/ year	Yes
9	Impact on the cost of transportation	Increased cost for passenger and cargo transport due to higher cost of renewable fuel and required retrofits	%/ticket %/lane-meter %	Yes
10	Impact on the safety of transportation	Impact on safety of transportation and related costs (*e.g.*, onboard fuel handling)	N/A	No
11	Impact on sustainable tourism	Carbon footprint per 82km	Kg CO_2	Yes
12	Impact on sustainable manufacturing	The share of goods likely to be exported and imported by green ship	%	Yes
13	Impact on renewable energy	The required power for producing the energy needed	%	Yes
14	Impact on shipbuilding	Increase of local shipbuilding	N/A	No

4 Results

4.1 Helsinki-Tallinn corridor

The corridor between Helsinki and Tallinn is currently operated by three different companies: AS Tallink Grupp, Rederiaktiebolaget Eckerö and Viking Line Abp. AS Tallink Grupp has two vessels operating the route, whereas Rederiaktiebolaget Eckerö and Viking Line Abp both have one vessel on the route between Helsinki and Tallinn. These companies operate over 10 roundtrips on the corridor daily. Yearly, around 8 million passengers travel from Helsinki to Tallinn over sea (*Port of Helsinki*, n.d.). The voyage between the port of Helsinki and the port of Tallinn takes on average 2.5 hours. The route between the two is 82 km, as visualized as a map of Viking Lines' routes in Figure 10. The Helsinki-Tallinn corridor is circled in the figure, it also shows the original framework's corridor between Turku and Stockholm.

Figure 10. The maritime corridors of Viking Line vessels. Adopted from (Viking Line, n.d.).

The main vessel travelling the Helsinki-Tallinn route for Viking Line today is the Viking XPRS, which was built in 2008. The Viking XPRS travels the whole year around. During the summer season (June-August) two additional Viking Line vessels travel the route, to manage the increasing passenger volume during the busiest time of the year. The two additional Viking Line vessels that work the route during the summer months are Viking Cinderella and Viking Gabriella.

More practical information about the potential electric vessel is described in Table 5. The potential electric vessel is assumed to imitate the profile properties of Viking

XPRS, as passenger capacity, number of trips and working days. Depending on the weekday the Viking XPRS travels the route a different number of times. During an average week, the vessel travels the route four times on Monday-Thursday and Saturday, during Friday it travels the route six times and during Sundays it travels the route five times.

Table 5. Practical information about the potential electric vessel.

Route	**Helsinki - Tallinn**
Route length	82 km
Trips per day	4-6
Average trips per week	31
Working days per year	365
Passenger capacity	2,500
Estimated cost of the potential electric newbuild (vessel and batteries)	300,000,000 €
Estimated energy needed per year to power the electric vessel	200,000 MWh
Timeline for calculations	2024-2030

4.2 Scope of the impact assessment

This impact assessment was done to estimate the impact of decarbonizing the maritime corridor through a particular technology, electrification, and identify the outcome for the involved key industry actors in the assessed scenario. Instead of the current focal vessel, the Viking XPRS, which runs on MGO and connects to an onshore power supply when in Tallinn. In this potential scenario the new electric vessel would run fully on electricity from locally produced renewable energy sources. The impact assessment is done by comparing the current situation with the Viking XPRS in operation to the potential scenario when a fully electric vessel replaces it.

This impact assessment points out actors that would need to be directly involved in such a decarbonization initiative and experience individual impacts from a value chain perspective. Below are several types of actors for whom the impacts assessed in this study would be relevant. Tier 1 describes actors that are directly involved in the project and are needed to drive it forward. Tier 2 describes consumers of the corridor. Tier 3 are actors in an even broader perspective affected by the corridor.

Tier 1

- Renewable energy producers

- Ship operators on the route Helsinki-Tallinn: This impact assessment focuses on one vessel.
- Shipyard and technology providers: The electric ferry possibility requires advanced technology both onshore and on the vessel.

Tier 2

- Cargo owners: Specifically, the ones who are interested in purchasing zero-carbon shipping.
- Private consumers: Sustainable travel
- Ports of Helsinki and Tallinn

Tier 3

- Policy makers: including laws and legislation.
- Owners and financiers of RoPax vessels
- Sustainable tourism actors
- The city of Helsinki and Tallinn, as well as the Finnish and Estonian states

The impact assessment was made for a fully electric vessel, with the possibility to charge at both the involved ports. The vessel would automatically connect to the charging station when it arrives at the port, charging the batteries onboard the vessel. For this impact assessment it is assumed that the vessel is only charged with renewable energy.

4.3 Impact assessment of decarbonizing Helsinki-Tallinn corridor

The impact assessment of the GMC between Helsinki and Tallinn (within the scenario specified earlier) includes impacts that are enabled by the change to the fully electric vessel. The Figure 11 illustrates the different impacts, the impacts in the center of the graph are the most direct impacts of a decarbonization project and the further out from the center, the less direct the impact is. The different impacts are examined to grasp how a GMC can contribute to a transformation.

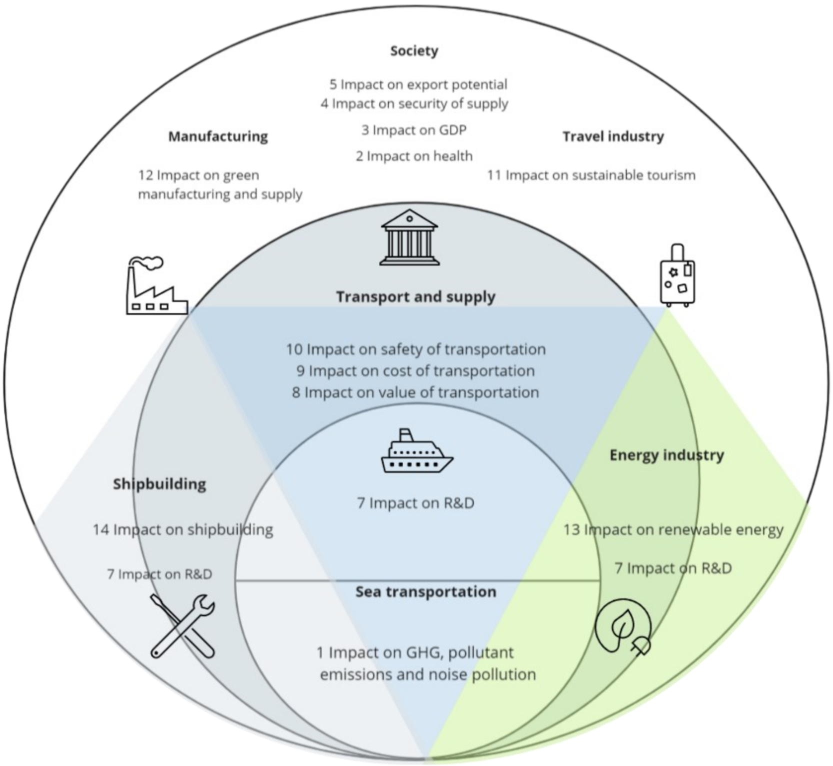


Figure 11. Impacts ordered from most direct to impacts that are less direct.

The impacts that are included in the following subsections are described and discussed individually. The detailed calculations used in the impact assessment framework will not be shared as they include confidential information.

4.3.1 Impact on GHG, pollutant emissions and noise pollution

For a vessel to run forward, there needs to be an engine that works as the powerhouse. The engine combusts fuel and forms it to energy, in the combustion process different emissions are released into the atmosphere. The process also releases noise pollution. All these indicators have major impacts on the surrounding environment and life. These individual impacts have their own specific area.

1. **GHG emissions** are released in the combustion process and have a negative effect on the atmosphere and environment increasing climate change. An electric vessel running on renewable energy would contribute to decreasing the emissions from the shipping industry.
2. **Pollutant emissions** are chemical pollutants and are released in the combustion process. These have toxic and negative health effects on individuals who are exposed to them, which could lead to major health impacts.

The pollutant emissions that are emitted from the combusted MGO are NOx, SOx and PM 2.5.

3. **Noise pollution** is an unwanted sound that affects the well-being of individuals and animals. It is a major indicator, both over and under the water surface and for individuals both onboard during the voyage and around the ports. The noise pollution from a vessel depends on various factors, such as the machinery type, design of the vessel, size, speed, and operational state. The noise level is also affected by the distance from the noise source, the machinery and engine rooms, the accommodations onboard or the vehicle deck. The engine room has the highest noise level of these three, due to the conventional engine running. On the vehicle deck, the noise level peaks during operation especially when vehicles are embarking/disembarking the vessel. In the onboard accommodations and passenger areas, the noise pollution is connected to the specific insulation and location. The noise pollution adds to health impacts, which will be discussed as an individual impact. The specific impacts of noise could be divided as follows:
    - Impact at port
        - Impact on the sea life living near the port area
        - Impact on people living near the port area
    - Impact during voyage
        - Impact on crew and passengers
        - Impact on sea life

The noise level depends on various factors including, speed, size, vibration, and hull design. The water crafts with the highest noise levels include icebreakers, ferries and container ships (Erbe et al., 2019). Between 2016 and 2020, the energy emitted as noise in the Baltic Sea grew by 59% and annual growth of noise emissions was 9.7%. RoPax vessels emit a noise energy around 1034 mJ/(ton*km) in the Baltic Sea, which is 10% of the total emissions from noise energy in that area (Jalkanen et al., 2020).

By switching the ICE to electric, there would be a decrease of GHG emissions, pollutant emissions and noise pollution. With the switch, the GHG and pollutant emissions are assumed to be 0, as in this scenario it is assumed that the vessel will run on 100% renewable energy. The electric vessel would also decrease the noise level at the port to be relatively close to zero and the noise level during voyage would be reduced drastically as the vibrations from the vessel would be decreased.

4.3.2 Impact on health

As already discussed, the pollutant emissions and noise pollutants have a negative effect on the surrounding life. The pollutant emissions that are released during the combustion process can cause health problems for the individuals who are exposed. In 2015, there were over 2,000 deaths connected to air pollution from fossil fuels in Finland (Our World in Data, 2015). The health impacts of noise pollution have the potential to cause hearing loss, stress, and annoyance possibly leading to habitat abandonment. These factors require further research to evaluate the long-term impacts.

This specific impact assessment is based on data collected from previous research to analyze the local health impacts. With a switch from the conventional ICE to an electric, the pollutant emissions as well as the noise level would decrease, leading to a decrease of negative health impacts. The pollutant emissions from the conventional vessels end today up in Finland and Estonia, due to the short coastal sea route. As the emissions assumed for the electric vessel are 0, the health impact of the pollutant emissions would be removed completely. If the health impacts were entirely removed, the costs to take care of the health impacts caused by the pollutant emissions would decrease and over time disappear.

Table 6. Description of how impact on health is quantified.

Indicator	**Unit**	**Key data input**	**Logic**
The amount of money needed to take care of the health impacts for the conventional vessel	EUR	• Amount of local emissions released. • The cost needed to cover the impacts of a specific amount of local emissions generated.	Amount of local emissions released * The cost needed to cover the impacts of a specific amount of local emissions

4.3.3 Impact on GDP

The measurement of GDP describes how much an economy produces each year. With an increase of the GDP, it can be assumed that the economy of a state is doing well. A growth in GDP often means more money at disposal and the employment rate is likely to increase. A GMC would increase the activity of both shipbuilding and the renewable energy market. This would encourage other actors in similar and other industries to step toward the sustainable option. The value of zero emission transportation would increase compared to transportation dependent on fossil fuel. The green transition would also strengthen the sustainable travel possibility.

There are various ways of calculating the GDP, in this case the chosen method is the expenditure approach. This approach isolates relevant impacts for the GMC project. The formula used to calculate the GDP:

$$GDP = Consumption + Investment + Government\ Spending + Net\ Export$$

Table 7. Description on how impact on GDP is quantified.

Indicator	Unit	Key data input	Logic
Impact on GDP	EUR	• Additional sales • Government subsidies • Investments in shipbuilding • Investments in renewable energy production • Export potential • Reduction of imported fossil based maritime fuel	Impact on GDP = new consumption + Government spendings + new investments + change in Net exports

4.3.4 Impact on security of supply

With a change from fossil fuel to electricity, the need of the imported fossil fuel would decrease and change to a greater request for renewable energy. This would mean that the security of renewable energy supply is one impact that will be affected by the GMC. Today, the vessel Viking XPRS runs on MGO produced from fossil-based sources. This assessment is based on one RoPax vessel that would be exchanged from a vessel running on fossil fuel to one running on renewable energy. This change would mean that the countries that are involved in the GMC could reduce the amount of imported MGO and be less reliant on the imported fossil fuels as the new vessel would turn to locally produced renewable energy. This would, in turn, mean that the change to a vessel running on locally produced renewable energy would have an impact by improving the security of supply for the involved countries. When calculating the potential decrease of maritime fuel in the involved countries for the corridor, the specific fuel consumption by country needs to be measured. In this case Estonia does not have available the needed information on maritime fuel consumption so the number was based on assumptions.

The renewable energy source is also an indicator for the security of supply, as this would be the energy source for the vessel. Potentially, lead to a growth in the industry and possibly encourage other industries to turn to renewable energy.

Table 8. Description on how impact on security of supply is quantified.

Indicator	Unit	Key data input	Logic
Decrease of the costs of imported fossil marine fuel	€	• Total fossil based maritime fuels consumed in Finland and Estonia • Annually consumed fuel for Viking XPRS	Decrease in imported fossil maritime fuel= The amount of fuel the Viking XPRS uses

4.3.5 Impact on export potential

The GMC would have an impact on the export potential, including the maritime, energy and technology industry. Potentially, increase in the export potential for the involved countries of the GMC. The potential estimations of the impacts have a geographical scope in Europe and the timeframe that has been taken into consideration is 2024-2030.

To assess the potential of electric shipbuilding in Europe until 2030 all currently operating RoPax vessels in Europe with a capacity over 1,000 passengers were explored. Assuming that it would be most likely for older vessels that travels shorter distances to be exchanged for electric newbuild alternative. This study explored vessels older than 30 years, operating on routes shorter than 100 km. Considering these limitations, there are around 21 possible newbuilds until 2030 in Europe. It can be assumed that not all of them will become electric but choose another source to power the vessel. Previous studies state that fully battery-electric vessels are feasible and that the industry of electric vessels is expected to grow (DNV, 2023a; Korberg et al., 2021). With this information it is possible to assume that it would be possible for around 50% to make the choice to go fully electric, as previous studies suggest a growth in the industry.

The impact on export potential of shipbuilding examines Finnish shipyards that focuses on bigger passenger vessels (RMC and Meyer) and their yearly capacity for larger newbuilds. Based on the past few years production rate, on average they each build one larger newbuild per year. With this information it is assumed that during the timeframe 2024-2030, there is maximum potential for 10 electric vessels to be built. Even though this would constitute around 50% of the market as identified before (21 vessels), there is not yet any serious competition in electric shipbuilding and such a rate for Finnish yards could be reasonable.

Table 9. Description on how impact on export potential is quantified.

Indicator	Unit	Key data input	Logic
Export potential for renewable energy	EUR	• Estimation of the number of electric RoPax vessels built until 2030 • Average renewable electricity consumption of a RoPax ship • Average market price for MGO	Estimated number of electric newbuilds * average electricity consumption/ship * average market price for renewable energy
Export potential for RoPax newbuilds	EUR	• Estimated number of fully electric RoPax newbuilds until 2030 • Average CAPEX/RoPax newbuilds • Estimation of the market share for the Finnish yards for RoPax newbuilds	Number of newbuilds * average CAPEX/newbuild * market share for the Finnish yards

4.3.6 Impact on jobs created

The GMC would lead to a change to the industrial environment and as a result create new job possibilities. This assessment focus mainly on two kinds of jobs that will increase as an impact of the GMC due to industrial investments and a needed capacity growth. These are jobs in the shipbuilding segment and the renewable energy production. As the renewable energy production would potentially grow in order to produce more renewable energy there would be jobs created in construction of new plants and operations. Jobs would also be created in the shipbuilding industry, and in addition more personnel would potentially be needed in order to perform the installation of the charging infrastructure at the ports. As regards jobs in shipbuilding it is tricky to assess, given the changes in the shipbuilding processes and the different technology on the ship. The changes of jobs in shipbuilding can be related to the complexity of ship systems on an electric vessel compared to a conventional vessel. In order for this study to reach a potential outcome, the domestic origin of the electric newbuilds was assumed. In this scenario it was estimated to be lower than it is for conventional vessels built in the Finnish shipyards as the battery used in the electric vessel would be imported and not produced in Finland. With more established GMCs there would be an increase of jobs in the shipbuilding industry, related to the increased need of newbuilt electric vessels.

The renewable energy is an industry that has potential to grow and by replacing the conventional energy production with more sustainable choices the green transformation would move forward. As the potential vessel only running on renewable energy, the vessel would consume a noticeable share of the annual renewable energy production. This would potentially increase the renewable energy production as there would be a higher demand for it. This potential green corridor would also possibly encourage other corridors and industries to turn their energy source to renewable energy, which would again increase the demand of renewable energy. If there would be an increase of renewable energy production, there would be an increase of both jobs in construction and operation of plants. In this study it is assumed that wind turbines offshore and onshore can produce this additional capacity. These are the renewable energy production possibilities that can be expanded from the sources of renewable energy production in Finland. The estimations made relied on coefficients from the from a previous study that discusses job creation in the renewable energy transition (Ram et al., 2020).

Table 10. Description on how impact on jobs is quantified.

Indicator	Unit	Key data input	Logic
Jobs created in renewable energy production	Job-years	• Needed capacity • Market share • The need for construction of energy plants • The need for operation of energy plants	Number of jobs created= Needed installed capacity* market share* employment factor
Jobs created in shipbuilding	Man-years	• Number of new electric vessels • Value/vessel • Market share • Average salary/person	Number of jobs created= Number of electric vessels* contract values/ employment effect* market share* domestic origin

4.3.7 Impact on R&D

In the case of a new electric vessel there would be an impact on research and development (R&D) as there is a continuing need for further research on the subject of decarbonizing maritime corridors and the technology behind it. There are various potential indicators that can help show the impact of R&D including knowledge spillover, new technologies and shipbuilding development. There are also indicators that goes beyond shipbuilding as innovations, ship technology and energy management. The chosen indicators to show the impact of R&D in this study are:

- Patents
- Scientific publications
- Investments

The patent filing goes hand in hand with the growth in the shipbuilding industry and the growth of locally produced renewable energy. Not to forget the intensions and processes regarding growth and sustainability within the maritime shipping industry, including aspects like battery efficiency, shipbuilding and carbon and emission reductions. The number of publications and scientific articles correlates with the new information and knowledge about the GMC that is explored. Publications are also relevant when it comes to collaboration with different research institutions and academia, and certain stakeholders with a shared commitment to decarbonization.

R&D investments define the commitment in a financial perspective and plays a key role initiating the project. It also defines the collaboration between private partners and the public sectors.

This potential corridor will require R&D efforts both in ship and the battery technologies, both onshore and offshore. With increasing research on the subject, it is likely for numerous patents to appear by different partners involved. Combined with an increasing number of publications this could possibly result in higher investments for R&D in the interest of decarbonization of the corridor.

The outcome of the individual indicator is based on expectations but will be more reliable when based on the upcoming experience. Advocating that the impacts on R&D are more suitable for a post-project analysis. This impact is partly quantified as some assumptions are not able to be done in a pre-project analysis.

Table 11. Description on how impact on R&D is quantified.

Indicator	**Unit**	**Key data input**	**Logic**
Patents	#	• Estimated number of patents field correlating to the ship technology • Estimated number of patents filed correlating to the investments • Estimated number of patents filed correlating to renewable energy production • Estimated number of patents correlating to a GMC	An estimation is done by summarizing the information from the data input
Scientific publications	#	• Estimated number of scientific publications correlating to the GMC project	An estimation is done by summarizing the information from the data input
Investments in R&D	EUR	• The direct investments to the project, national subsidiaries and from companies that are participating in the project	The sum of investments from public and private actors to the project

4.3.8 Impact on value of transportation

When an electric vessel is introduced in the corridor there are major costs that need to be paid back in order for the vessel to be profitable. This can result in a change of the price for passengers and vehicles transported by the electric vessel. To estimate the potential increase of the value of the transportation costs, one alternative is to estimate the buyer’s willingness-to-pay. The buyers consist of passengers interested in travelling by green sea transportation, and cargo owners’ whose goods are transported by green sea transportation. By choosing the green alternative the goods can get a higher brand value and hence have a higher price premium. These products can be one step closer to be marketed as a sustainable choice.

The willingness to pay is also needed to be estimated for the passengers. In this case the passengers benefit from the green transportation they can travel sustainably. There are different ways to analyze the passengers’ willingness-to-pay for carbon neutral travel, *e.g.*, surveying passengers or analyzing similar cases. From earlier studies it is presented that customers are willing to pay more for zero-carbon shipping is increasing and in 2022, 82% of costumers were willing to pay a premium for transportation by zero-carbon shipping (BCG, 2022). The aim with the impact of value of transportation is to assess the average price premium needed to cover the changed cost of transportation. The average price premium for sustainable marketed goods versus their conventional equivalents is 27% (Kronthal-Sacco & Whelan, 2023). With this information it can be assumed that there is an increased value of sea transportation in a scenario of a GMC.

By quantifying the impact on value of transportation, it can be assessed whether the expected increased cost of goods and passenger tickets is corresponding to the published premiums for sustainable transportation. The value of transportation can be analyzed by the difference between the current value and the expected value. This is done with the information on the average value of sold tickets for cargo and passengers during the time of one year. With this information the potential costs of the new green scenario, which are the additional fees to the tickets were assessed.

Table 12. Description on how impact on value of transportation is quantified.

Indicator	Unit	Key data input	Logic
Value of green transportation for passengers	EUR/year	• Annually sold tickets • Assumed price premiums for a carbon neutral transportation	Annually sold tickets * assumed price premiums
Value of green transportation for cargo owners	EUR/year	• Annual freight sales • Assumed price premiums for carbon neutral travel	Annual freight sales * Assumed price premiums

4.3.9 Impact on cost of transportation

The difference in the value of transportation in the new green scenario compared to the conventional version depends on the increased annual costs. The increased costs originate from the needed investments in shipbuilding with another propulsion system and batteries. The indicators chosen for these impacts are an increase of the passenger ticket price as well as the freight rate, both to illustrate the difference in the green scenario. The impact is quantified and can be assessed for different scenarios, depending on how big of a share of the costs are allocated to the passengers versus cargo.

The calculations of the potential price increase of the transported goods are based on cargo imported and exported, specifically loaded, and unloaded between Helsinki and Tallinn. Consequently, the specific calculations do not include cargo that is transported through the corridor and shipped further to other countries. A specific focus is applied on the change in the cost for high value goods (over 1,000 €/ton), as these are commonly transported with trucks. The calculations are based on four RoPax ships responsible for equal parts of the cargo shipping between the two countries, Viking XPRS, Tallink Silja MyStar, Tallink Silja Megastar and Eckerö Line M/s Finlanida.

Table 13. Description on how impact on cost of transportation quantified.

Indicator	Unit	Key data input	Logic
Increase passenger ticket price	%/ticket	• Annual increase of fuel cost • Investment in shipbuilding • Depreciation time of shipbuilding • Scrap value of the ship • Share of cost allocated to passengers • Share of cost allocated to cargo • Average number of annually transported passengers • Average ticket price • Average amount of annually transported cargo	Absolute increase of the ticket price = annual additional cost of the green scenario / number of annually transported passengers Relative increase of passenger tickets = Absolute increase of the ticket price / average ticket price
Increase freight rate	%/lane meter		Absolute increase of freight rate = annual additional cost of the green scenario / amount of annually transported cargo Relative increase of freight rate = Absolute increase of freight rate / average freight rate
Average price premium needed to cover the new/changed cost of the transportation	%	• Annual cost of the green scenario • Amount of cargo high value goods transported on the corridor • Customs value of cargo transported	Annual additional cost per goods / annual value of goods

4.3.10 Impact on safety of transportation

The safety of a new vessel is crucial both in regard to the passengers and the crew. It is possible that a new engine and propulsion systems brings safety risks, but with the switch of fuel and engine system there are risks that are removed. With an electric option, the risks with fuel spills would be completely reduced.

The safety risk that needs to be taken in account in the case of a new GMC is the change to a new electric engine. Different risks related to the onboard battery can be found compared to the conventional engine. The challenge with Li-ion batteries is that they need to be managed in the correct way to avoid the risk of battery fire. A battery fire can cause smoke inhalation damage due to the potent gases, which could be dangerous. There is also an increased risk of electrocution for the crew, a fact that must be met by proper safety education for the crew as the risks increase if the standards are compromised. To avoid these kinds of accidents the personnel should be given the needed information and training. In this specific case the ship would automatically connect to the battery charging system onshore, which reduces the risks for the crew compared to an alternative where the charging connection would be connected manually.

In this specific impact assessment for the Helsinki-Tallinn corridor this impact is not quantified as there is not data available on the safety. The information used is based on previous research on electric vessels. A possible way to quantify this impact would be to calculate the additional costs that are needed to mitigate the risks.

4.3.11 Impact on sustainable tourism

With the change from a conventional combustion system to an electric system, the emissions from the vessel would decrease as already ascertained in impact 4.3.1. This implies that the emissions and carbon footprint per passenger would decrease. There are different possibilities to show how the emissions of tourism would be affected by a GMC. In this case the chosen method is visualized in Figure 12. The figure shows the different amounts of CO_2 emissions emitted per passenger from different transportation modes in general for an 82 km route. The different modes of transportation that are included are aviation, Viking XPRS, diesel car, and an electric vessel running on renewable electricity. The calculations for the emitted emissions of aviation and diesel car were based on estimations and possible emission factors. It is to be noted that the calculations can differ depending on the exact models of vehicle and other factors. The calculations assume that the number of travelling passengers is at full capacity. It is assumed that the passengers on the Viking XPRS accounts for half of its CO_2 emissions, and cargo for the rest.

In Figure 12, it is presented that the travel mode with the least amount of emissions is the electric vessel, followed by the diesel car. The conventional Viking XPRS emits around double the amount of CO_2 per passenger for the same travel distance as a diesel car. Whereas for aviation, CO_2 per passenger is three times higher than for the passengers on the conventional Viking XPRS.

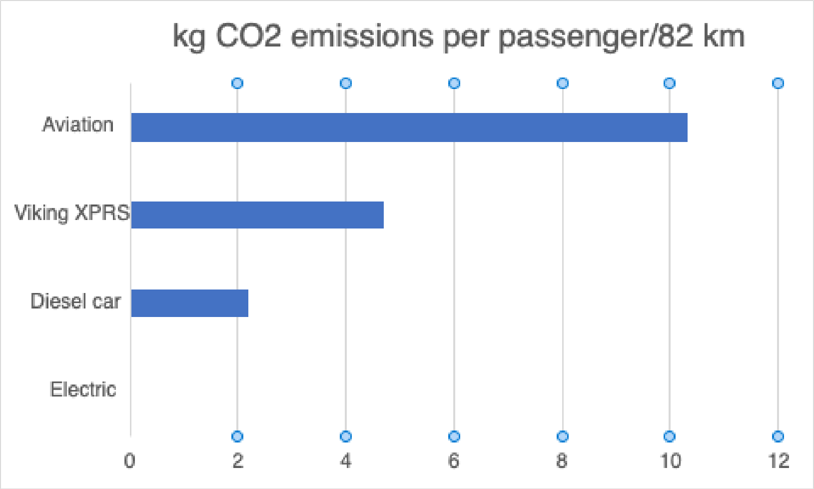


Figure 12. The tank-to-wake CO_2 emissions per passengers for different transportation modes.

Table 14. Description on how impact on sustainable tourism is quantified.

Indicator	**Unit**	**Key data input**	**Logic**
CO_2 emissions per passenger for 82 km route	Kg CO_2/82 km	• Route length • Fuel burned/km • Production of CO_2/kg fuel burned • Passenger capacity	CO_2 emissions/passenger= [(Fuel burned/km* route length*CO_2/kg fuel burned)/(route length* passenger capacity)]*route length

4.3.12 Impact on green manufacturing

With a change to an electric vessel transporting goods there is an indirect impact on green manufacturing, but the outcome is not transparent. The change does not necessarily mean that the producers will alter their goods to more sustainable options. But on the other hand, if the producers want to market their products as carbon neutral the transportation plays a crucial role in it. Carbon neutral transportation can be the key for products to be known to the customers as fully sustainable. So, for producers that already sell somewhat green products this can help them to brand their products as even more sustainable and environmentally friendly.

During 2021, the biggest part of Estonia's export is to Finland, over 12%. In comparison just over 3% of Finland's exports has the end destination of Estonia (OEC, 2021). This implies that the number does not show is the export volume of freight that is transported from Finland, through Estonia towards to other destinations. Most freight transported from Finland through Estonia, is distributed throughout Europe via Baltic routes. This entails that the GMC would involve a big part of the exports from Finland.

This impact is partly quantified as it cannot be assumed how much of the products transported would be transformed into greener products or how much this would affect the companies whose products are transported.

Table 15. Description on how impact on sustainable manufacturing is quantified.

Indicator	**Unit**	**Key data input**	**Logic**
The share of products that can be transported on the carbon-neutral route	%	• Tons of cargo transported annually on the route • Tons of cargo the green corridor has capacity for	Share of cargo = The green capacity of cargo / cargo transported annually

4.3.13 Impact on new renewable energy

As already mentioned in subchapter 4.3.4 security of supply, there is a need and a potential for a growth in the renewable energy industry in both Finland and Estonia. Both involved countries could theoretically already today run the potential electric vessel individually based on their production of renewable fuel. For the last few years Finland has had a greater production of renewable energy than Estonia. For Estonia to fuel the electric vessel by itself, the vessel would use up around 9% of the country's yearly renewable energy production. For Finland to power the vessel by itself the vessel would use up under 1% of the country's yearly renewable energy production. These values will decrease as the renewable energy production grows.

The production of locally produced energy in Finland was around 67 TWh the year 2022. Out of that 42% (Ministery of Agriculture and Forestry of Finland, 2022), more than 28 TWh, came from renewable energy sources. These calculations are the base estimations of how much of Finland's renewable energy would be used by the electric vessel. Finland's renewable energy sources mainly consist of bioenergy (from biomass), hydropower, wind power and geothermal heat. The Finnish renewable energy industry is expected to have a CAGR at 8% until 2025 (Mordor Intelligence, 2023). As the EU has a specific goal to increase the production of renewable energy this will encourage the future growth and strengthen the possibility to have an electric vessel charged in the port of Helsinki with renewable energy.

Table 16. Description on how impact on renewable energy is quantified.

Indicator	Unit	Key data input	Logic
The share of the locally produced electricity needed to power the vessel	%	• The yearly production of renewable energy (2022) • The estimated amount of renewable energy produced 2025 • The yearly electricity needed to power the electric vessel	The annual amount of energy needed to power the electric vessel / the amount of locally produced energy
The renewable energy availability in Finland and Estonia	%	• Electricity consumption of the potential green corridor • Renewable energy production in Finland and Estonia	The % of the involved countries renewable energy would be needed to power the vessel= The yearly electricity needed to power the vessel / the countries' renewable energy production

4.3.14 Impact on shipbuilding

The change to an electric powered vessel on one shipping corridor would have an impact on the shipbuilding industry because this technology is still rather new to the maritime context. If proved technically and economically feasible in the focal corridor, it can be an attractive alternative for decarbonization on other corridors with similar operating conditions, which would impact the number of electric ship newbuilds. Since in this scenario, it is assumed that a local Finnish shipyard would develop the technology and process for building electric vessels, this would create export potential for the focal shipyard. While it is difficult to quantify the impact of electrifying one corridor on the overall shipbuilding industry, it is expected that the changes will be drastic due to the significant differences between currently prevailing marine propulsion systems based on ICEs and fully electric ships. Quantification of these impacts is beyond the scope of this thesis, however the types of impacts on shipbuilding are discussed qualitatively below.

The transformation in shipbuilding from conventional vessels to electric ones would possibly transform the industry, as the technologies behind the two are dissimilar. As it can be seen on previous industries that have experiences drastic technology shifts, such as car manufacturing industry, the changes in the industry can be drastic. In particulate, it is a significantly bigger number of moving parts in cars' ICEs compared to electric cars, which has meant that the manufacturing process and cost are also different.

The impact on shipbuilding is a comprehensive concept and a big potential impact that is closely connected previous impacts in this study. It is difficult to assess exactly how the possible indicators would be affected and how the industry would evolve as it would be part of a technology shift. Possible relevant indicators of shipbuilding in the context of a green vessel could thus concern the following:

- Export potential – if the feasibility of the new (for the maritime industry) technology is demonstrated by the first-mover shipyard, the export potential can be high due to the lack of competition during the early phases of transformation.

- R&D in shipbuilding technology – due to the novelty of electric ship technology, higher impact on R&D can be expected in terms of the related technologies, but also in terms of process innovation in shipbuilding industry.
- Jobs created – it is challenging to assess the immediate and long-term impact on jobs: new jobs may be created, while others could cease: the decreased complexity of electric propulsion compared to ICE-based propulsion can also have an impact on the labor intensity of shipbuilding.
- Shipbuilding lead time – similarly, the duration of constructing an electric vessel might be shorter than conventional ships when higher learning effect is achieved.
- Cost of ship construction – given the differences discussed above, the cost of constructing an electric ship may differ from that of conventional ships, and the difference is likely to change over time as more know-how is generated.
- Maintenance concepts – electric vessels provide opportunities for new maintenance concepts, which will also affect some key characteristics of shipbuilding industry such as the frequency of maintenance checks, docking duration, *etc*.

If the industry of electric vessels would grow, a learning effect could be expected. The learning effect describes the increase of productivity of repetitive tasks. It will be of interest to see how fast the capacity grows in contrast to how the cost will decrease over time. The more electric ships that are built the faster they will be constructed and the cheaper they will become as the digitalization is evolved (Sender et al., 2021). The logistic chain of the shipbuilding industry is most likely affected of the change, including shipbuilding, alternative energy, ship operations, port operations, land logistics, cargo owners, and consumers. This entails that the whole value chain is involved and will experience a difference of the change.

4.4 Results of the impact assessment

The impact assessment for one electric vessel on the Helsinki-Tallinn corridor included both direct and indirect impacts. The impact assessment framework is made for a scenario where the current vessel Viking XPRS is replaced with an electric vessel. The impacts were carefully chosen for this specific corridor, even though the base for the impact assessment framework originated from the DECATRIP project. The change to an electric vessel would bring significant advantages in various aspects, as the reduction in GHG emissions. This specific reduction is essential when it comes to achieving the desired environmental goals and enabling a greener future. The focal GMC would be possible to be replicated onto other corridors and encourage the green transition. A summary of the results of all the impacts included in this impact assessment is visualized in Table 17.

Table 17. Summary of impacts, indicators, and result values.

Impact #	**Impact**	**Indicator**	**Unit**	**Year 1/ per year**	**During 2024-2030**
1	Impact on GHG, pollutant emissions and noise pollution	Absolute reduction of GHG emissions	Tons CO_2 emitted/year	38,100	266,700
		Relative reduction of GHG emissions	%	100%	100%
		Reduction of NOx emissions	Tons per ship/year	847	5,929
		Reduction of SOx emissions	Tons per ship/year	21.8	152.6
		Reduction in noise level in port	dB	N/A	N/A
		Reduction in noise level at sea	dB	N/A	N/A
2	Impact on health	Reduction of health impacts, noise, and vibration	€ per electric ship/year	18,293,245	128,052,714
3	Impact on GDP	Change of GDP	Total/year	55,030,000	2,495,030,000
4	Impact on the security of supply	Decrease of the costs of imported fossil marine fuel	€	7,200,000	50,400,000
		Relative decrease in imported fossil marine fuel	%		-
5	Impact on export potential	Export potential for renewable energy until 2030	€	-	1,600,000,000
		Export potential for vessel newbuilds	€	-	600,000,000

6	Impact on jobs	Jobs created in renewable energy production	Job-years	446	3,098
		Jobs created in shipbuilding	Job-years	180	4,394
7	Impact on R&D	Number of patents	#	N/A	N/A
		Number of scientific publications	#	13	-
		R&D investments	€	2,400,000	-
8	Impact on the value of transportation	Value of green transportation for passengers/year	€	4,920,000	-
		Value of green transportation for cargo/year	€	27,880,000	-
9	Impact on the cost of transportation	Relative increase in price for passenger ticket	%/ticket	36%	-
		Relative increase in freight rate	%/lane meter	252%	-
		Average price premiums to cover the change in cost of transportation, import for high value goods	%	0.52	-
		Average price premiums to cover the change in cost of transportation, export for high value goods	%	0.41	-
10	Impact on the safety of transportation	Difference in safety regulations		N/A	N/A
11	Impact on sustainable tourism	The amount of CO_2 emissions per passenger for 82 km travel by aviation	Kg CO_2	10.33	-
		The amount of CO_2 emissions	Kg CO_2	2.22	-

		per passenger for 82 km travel by diesel car			
		The amount of CO_2 emissions per passenger for 82 km travel by conventional vessel car	Kg CO_2	4.73	-
		The amount of CO_2 emissions per passenger for 82 km travel b electric vessel	Kg CO_2	0	-
12	Impact on sustainable manufacturing	The share of goods to be exported with green RoPax	%	1.5	-
		The share of goods to be imported with green RoPax	%	1.2	-
13	Impact on renewable energy	The needed amount of renewable energy to power the green electric RoPax	TW	0.2	-
14	Impact on shipbuilding	Increase of local shipbuilding		N/A	N/A

5 Discussion

5.1 Research contribution

This study investigates and analyzes the impacts of a potential GMC, using an electric vessel between Helsinki and Tallinn. With supporting previous research, this study has brought more clarity on how decarbonized corridors can be assessed.

As previously discussed in the literature review, different goals are set that drive the green maritime transformation forward, *e.g.*, the Paris Agreement (International Maritime Organization, 2018). This study's main focus is on RoPax shipping and the technical measure of utilizing alternative energy sources. There are various renewable fuel options, most are still under development (Schwartz et al., 2020). By utilizing renewable electricity as the energy source for the vessel the emissions would be significantly lowered. For this to be possible there is a need for in infrastructure to be further developed, *e.g.*, the needed electrical charging possibilities in ports for electrical vessels (Serra & Fancello, 2020).

The impact assessment for the possible electric vessel implies that there are significant advantages of this specific GMC. Previous studies have come to the same conclusion regarding the advantages as this impact assessment, most prominently the decrease of GHG emissions (Bouman et al., 2017) and reduction of health issues connected to air pollution (Blonsky et al., 2019). The increase of electric vessels running on renewable energy is likely to drive the local renewable energy industry forward (Mordor Intelligence, 2023), as well as evolve the shipbuilding industry, both scenarios increasing the number of jobs. A new GMC with zero emissions would make Finland a precursor for the shipping industry, not just on a national level but also globally, as it is a new futuristic concept.

5.2 Implications of decarbonizing the corridor

The constantly rising level of global emissions is alarming and actions are required to minimize the escalating greenhouse effect. This requires fields and sectors to act, among which the shipping industry is a major contributor of GHG emissions.

When striving to create a decarbonized GMC, there are several options of decarbonization to be considered and the outcome may vary depending on the chosen decarbonization method. However, they all share the common goal to decarbonize and decrease emissions. This study focuses on a GMC operated by an electric running vessel running on 100% renewable energy.

Some of this study's findings on impacts of the GMC differ considerably from the DECATRIP project's impact assessment. This assessment focuses on building a new electric ship running on renewable fuel, whereas the assessment for DECATRIP focuses on a retrofit. The two potential projects have different energy sources, as well as costs and infrastructure. The electric option would need a newbuild vessel, as retrofitting of an existing conventional vessel would nor be a profitable or suitable option.

The major impacts that have been discussed in this thesis are the impact on GHG and pollutant emissions, as the electric option would implicate close to no emissions released. With one corridor choosing this green option, it could help others to make the transition as well. In the future, this could make a huge difference on a national level and globally lowering the GHG emissions in the world. A decrease of pollutant emissions would be followed by a decrease in the health problems caused by the pollutants. With a change to a fully electric vessel, different industries are implicated. The change requires more resources from them and encourages them to grow, *e.g.*, the shipbuilding industry and the renewable energy production, also opening up more job opportunities. This demonstrates that impacts can be closely connected to each other, even though they appear as individuals. The economic side of the project, as the cost of fuel, hull *etc.,* will affect the prices of passenger tickets and the cost of transported cargo. However, environmentally conscious consumers are willing to pay for the green service and a sustainable way of travel and shipping. The next possible step towards GMCs is with the help of the impact assessment frameworks assess other corridors, make the calculations into reality and a step closer to a greener future.

5.3 Implications of the impact assessment framework

When adapting the DECATRIP project's impact assessment framework to the case of the GMC between Helsinki and Tallinn, there were a few challenges on the way. One of the most prominent ones is the lack of research on the concept of fully electric vessels. A reason behind this is that fully electric vessels powerful enough have not been a lucrative alternative until recently because of the rather new technologies used in the vessels. Certain impacts could not be quantified as the values were not possible to be assumed as there were no values available for certain impacts. This required some minor modifications to be made to the framework in order to apply it to the case of this study. In this study the framework also uses a color-coding system to show if the values used come from previous calculations from the DECATRIP project or are new variables.

The revised framework is shown in Table 6, showing the new impacts with indicators and impacts that have been modified to fit the new Helsinki-Tallinn corridor. It also shows the impacts not applicable to the modified framework. The possibility to quantify the specific impacts is also included in the table. In the modified framework, the impact of GHG, pollutant emissions and noise pollution have been composed into one impact as they all fall under the same category as different pollutions. The added impact of shipbuilding discusses the potential impact on the Finnish shipbuilding industry, and its potential. The impact on electrification of road vehicles is not applicable in this assessment as the vessel does not offer a charging possibility for the vehicles onboard. For future projects and studies on the topic of GMCs, this modified impact assessment framework can be used, only requiring case specific values to be inserted in the calculations. Depending on the route and specific services that the vessel offers the outcome will differ as the individual impacts may change.

Table 18. The revised framework, showing new impacts, indicators and impacts that have been modified and the ones that are not applicable for the corridor.

	Impact: Helsinki - Tallinn	**Indicator**	**Unit**
1	Impact of GHG, pollutant emissions and noise emissions (Modified)	Reduction of CO_2, NOx, SOx and PM 2.5 emissions per ship Reduction of noise and vibration during voyage and at ports	Metric tons dB
2	Impact on health (Modified)	Reduction in health impacts, noise, and vibration	EUR
3	Impact on GDP (Modified)	Impact on GDP	EUR
4	Impact on the security of supply (Modified)	Decreased dependency on imported fossil maritime fuels in the involved countries of the corridor	% and metric tons
5	Impact on export potential (Modified)	Export potential for renewable energy Export potential for renewable fuels Export potential for vessel newbuilds Export potential for retrofitting Export potential for ship related clean technologies	EUR

6	Impact on jobs (Modified)	Jobs created in renewable energy production Jobs created in shipbuilding Jobs created in ship retrofitting	Job-years
7	Impact on R&D (Modified)	Number of new patents Number of scientific articles R&D investments in clean fuel and maritime clean tech	EUR
8	Impact on the value of transportation (Modified)	Price premiums on passenger and cargo transport on ships	EUR/ year
9	Impact on the cost of transportation (Modified)	Increased cost for passenger and cargo transport due to higher cost of renewable fuel and required retrofits	%/ticket %/lane-meter %
10	Impact on the safety of transportation (Modified)	Impact on safety of transportation and related costs (*e.g.*, onboard energy handling)	N/A
11	Impact on sustainable tourism (Modified)	Carbon footprint for different transportation modes	Kg CO_2
12	Impact on sustainable manufacturing	The share of goods likely to be exported and imported by green ship	%
13	Impact on renewable energy (Modified)	The required power for producing the energy needed	%
14	Impact on shipbuilding (New)	Increase of the market size of shipbuilding	EUR
15	Impact on electrification of road vehicles (Not applicable)	Additional number of EV trucks utilizing the GMC thanks to onboard charging possibility	#

Most of the impacts have been modified for this specific corridor. The impact on electrification of road vehicles could be included in an assessment for an electric RoPax if the vessel in question would include a charging possibility for onboard vehicles. The charging possibility would make travelling more convenient for EVs and encourage them to choose the green option when travelling overseas. Retrofitting of ships was also included in different indicators for multiple impacts for the DECATRIP-project. Retrofitting could be included in this framework if the corridor would be based on existing vessels that would require retrofitting to be transformed into less emitting vessels. However, in this scenario the vessel is not retrofitted but newbuilt. Hence, the impact of retrofitting has not been taken into account. However, the impact of shipbuilding is discussed as an individual impact as this could result in growth and development of the electric vessel shipbuilding industry. Depending on the specific energy source used the construction of the vessel may differ. For a potential future corridor that could potentially include charging of EVs, retrofitting and renewable fuels a describing figure is shown in Figure 13. These impacts are highlighted with yellow. The figure demonstrates the impacts from the centre as most direct further out to more indirect.

By combining the impacts and information from the Turku-Stockholm corridor and the Helsinki-Tallinn corridor, impacts of future GMCs can be more easily assessed as the characteristics and impacts of the specific corridor can be more easily picked out. Every potential GMC is different and is based on individual data, resulting in specific outcomes of the impacts. With further research about GMC, the knowledge will grow and more information about the subject will appear. This could potentially result in more precise information about the impacts.

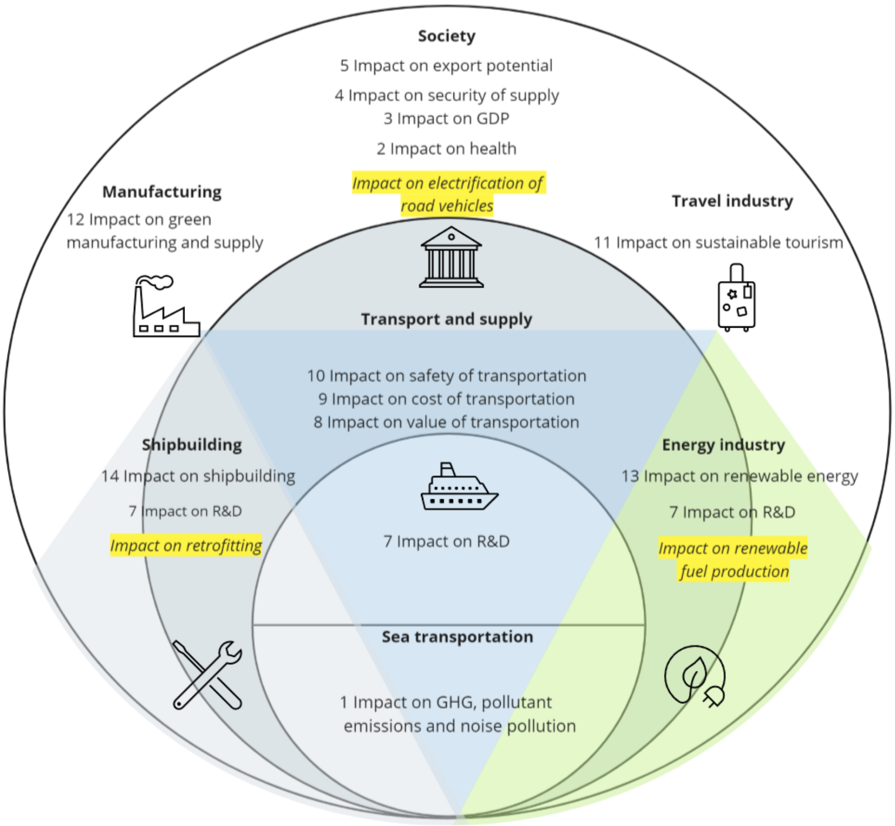


Figure 13. Potential impacts for a future GMC.

6 Conclusions

To slow down climate change the GHG emissions need to be drastically reduced. In order to reach this goal, all industries need to take direct actions. Pressure for action is also added by new legislation and regulations set by governments and intergovernmental organizations. These direct actions also call for cooperative efforts within and across different industries. The transport industry is a massive contributor of GHG emission, and the industry will be forced to develop over the coming years in order to work in line with both current and future regulations and legislations. As a major share of global trade is at some point transported overseas, decarbonizing the shipping industry would have a major impact on the decrease of the global GHG emissions. This study focuses on GMCs, which is one possible way of decarbonizing the maritime industry. The establishment and running GMCs require cooperation between various actors in the whole value chain. To gain an understanding of how prospective GMCs would impact the current situation and emissions, it is necessary to assess all the specific impacts of the individual corridor.

The purpose of this study is to conduct an empirical assessment of the potential impacts of a potential GMC and create a useful impact assessment framework for a potential green RoPax corridor between Helsinki and Tallinn. The vessel working the route today for Viking Line is Viking XPRS. The currently fossil fuel-driven vessel would be replaced with a new electrically powered vessel. The previous DECATRIP project developed an impact assessment framework for a GMC between Turku and Stockholm. The impact assessment framework was modified and is now used as a base for the specific case. The two separate cases on the two corridors differ from each other, as one would be a retrofit project and the other a newbuild ship. The forms of the chosen energy are different, as well as the route and the access to EV-charging onboard. The impact assessment includes different fields that are affected by the GMC both directly and indirectly. The modified impact assessment framework is possible to be further modified in order to suit future GMCs.

7 Swedish summary – Svensk sammanfattning

Konsekvensbedömning av gröna RoPax transportkorridorer – Fallet med avkarbonisering av Helsingfors-Tallinn-korridoren

För att bromsa den negativa klimatförändringen behöver utsläppen av växthusgaser minskas. Detta kräver att olika branscher måste vidta direkta åtgärder och vara villiga att samarbeta. Nya lagar och regler av såväl länder som interstatliga organisationer behövs för att styra mot en minskning av växthusgasutsläpp. Transportindustrin är en av de industrierna som bidrar till de globala utsläppen. Av all handel transporteras över 80 % i något skede över sjövägen (European Commission, 2015). Av de totala växthusgaserna i världen härstammar 3 % från sjöfartsindustrin (Gillingham & Huang, 2020). Detta innebär att en minskning av utsläppen från sjöfartsindustrin skulle minska de globala utsälppen av växthusgaser. Ett möjligt sätt att minska på sjöfartsindustrins utsläpp är att etablera gröna maritima korridorer. Gröna maritima korridorer är sjöfartsrutter med reducerade växhusgasutsläpp. Lösningen med gröna korridorer kräver dock ett samarbete mellan flera aktörer genom hela värdekedjan. För att skapa en insikt i hur en potentiell grön maritim korridor skulle fungera i praktiken är det nödvändigt att utvärdera alla de specifika effekterna av den aktuella korridoren (C40 cities, 2023).

Syftet med denna studie är att bygga upp en empirisk bedömning av de potentiella effekter som ett projekt med målsättning att minska koldioxidutsläpp har. Tillika är syftet att skapa ett användbart verktyg för en konsekvensbedömning av en potentiell RoPax-korridor mellan Helsingfors och Tallinn. Det fartyg som idag kör rutten Helsingfors-Tallinn för Viking Line är fartyget Viking XPRS. Detta fartyg drivs med fossilt bränsle och skulle i denna studie ersättas med ett nytt eldrivet fartyg. DECATRIP-projektet har utvecklat grunden för det verktyg som används vid konsekvensbedömning. DECATRIP-projektet behandlar en grön korridor mellan Åbo och Stockholm. Genom att modifiera konsekvensbedömningen från DECATRIP-projektet kunde bedömningen anpassas till rutten mellan Helsingfors och Tallinn. De två korridorerna skiljer sig från varandra på olika sätt. Den ena behandlar eftermontering på fartyget medan den andra handlar om ett nybyggt fartyg. Med beaktande av olikheterna byggdes tabell 4 upp. Tabellen beskriver de olika områdena som behandlas i konsekvensbedömningen. Konsekvensbedömningen omfattar olika områden som berörs av den gröna korridoren, både direkt och indirekt. Den modifierade konsekvensbedömningen är möjlig att vidareutveckla med tanke på andra framtida gröna maritima korridorer.

Konceptet gröna maritima korridorer är relativt nytt och har trätt fram i samband med olika regleverk och politiska mål som ställs bland annat av Europeiska unionen och Internationella sjöfartsindustrin. Avtal som drivit konceptet av gröna korridorer framåt är bland annat Paris-avtalet från 2016, med målet att minska på den globala uppvärmingen och motverka klimatförändringen (International Maritime Organization, 2018). Under Förenta nationernas klimatkonferens år 2021 skrev över 20 länder under dokumentet ”Clydebank Declaration”, vars mål är att skapa sex stycken gröna maritima korridorer innan år 2025 (PierNext, 2022; Procter, 2022).

Det finns olika alternativ när det kommer till skapandet av gröna maritima korridorer, även om alla har det gemensamma målet att minska utsläppen från sjöfartsindustrin. Denna studie fokuserar på en grön korridor med ett potentiellt eldrivet fartyg som drivs med förnybar energi. Bränslen som är producerade från förnybara källor utgör ett alternativ för gröna maritima korridorer. Tabell 2 beskriver olika alternativ bland förnybara bränslen och utmaningar de förknippas med under sin livscykel.

Beräkningarna bakom konsekvensbedömningen bygger på data från tidigare forskning och data direkt från företag. Även sekundärdata från det tidigare DECATRIP-projektet användes i specifika beräkningar. Det finns olika tillvägagångssätt som är möjliga då det gäller att beräkna effekterna av en grön maritim corridor. De indikatorer som används i detta fall presenteras i tabell 4. Hur de enskilda beräkningarna utförs förklaras i tabell 6- tabell 16. Mer praktisk information om den specifika rutten som behandlas och det potentiella elektriska fartget framställs i tabell 5.

De olika områdena som behandlas i konsekvensanalysen för Helsingfors-Tallinn-korridoren är påverkan på:

- Utsläpp av växthusgaser, föroreningar och buller
- Hälsan
- BNP
- Försörjningstrygghet
- Exportpotential
- Jobb

- Forskning och utveckling
- Transportens värde
- Transpoertkostnader
- Transportsäkerhet
- Hållbar turism
- Hållbar produktion
- Förnybar energi
- Varvsindustrin.

Alla dessa effekter behandlas enskilt men flera har samband som kopplar dem till varandra. Figur 11 illustrerar hur dessa effekter påverkas av en potentiell elektrisk grön korridor med de mest centrala effekterna i mitten av figuren mot mera indirekta i kanterna. Resultaten av beräkningarna för de enskilda områdena presenteras i tabell 17. Flera områden påverkas direkt, när projektet kommer igång och fartyget börjar traffikera en rutt, därinbland t.ex. minskning av växthusgasutsläpp, föroreningar och buller. Även de förändrade kostnaderna kommer att synas direkt på varor som fraktas på rutten och även på biljettpriset för passagerare. Effekterna på vissa andra områden blir synliga först efter en längre tid, såsom påverkan på BNP och de hälsorelterade aspekterna.

I processen av att bygga upp koncekvensbedömningen fanns det vissa utmaningar. Eftersom konceptet gröna maritima korridorer är relativt nytt var inte alla konsekvensområden möjliga att kvantifieras då nödvändig information inte fanns tillgänglig. För att genomföra beräkningar och fastställa resultat av konsekvensbedömningen krävdes därmed vissa antagna värden. Särskild vikt lades vid fastställandet av dessa antagna värden för att uppnå en konsekvensbedömning som motsvarar den framtida sanningen så väl som möjligt. Målet med den slutliga konsekvensbedömningen är att den kan återanvändas som ett anpassbart ramverk för konsekvensbedömning för framtida gröna maritima korridorer.

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