CHALMERS

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Comparing four routes through and around Panama from China to the US East Coast regarding emissions and time efficiency

Bachelor thesis for International Logistics Program

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DEPARTMENT OF MECHANICS AND MARITIME SCIENCES

CHALMERS UNIVERSITY OF TECHNOLOGY
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PREFACE

This thesis finalizes our bachelor studies at the International Logistics program at Chalmers University of Technology, it accounts for 15 of the total 180 credits. The program has provided us with knowledge ranging from insurances and legal advice to transport economy and supply chain logistics. We wish to express our gratitude to all lecturers and staff for making these three years rewarding, challenging, and making us prepared for not only this thesis but also future work.

In the making of this thesis, we have been able to dive deep into the interesting logistics solution that is the Panama Canal. A major part of this project has been focused on finding and validating alternative routes to it, a work that required great research and has broaden our perspective on the many different challenges of shipping. Whilst, shipping itself is not a new topic after three years of studies it has been incredible interesting to look at a current subject which faces legit consequences for the entire fleet. Additionally, our interest for green shipping and the development of such, has been further increased.

Finally, we would like to express our sincerest gratitude to our supervisor Kent Salo at Chalmers University of Technology, whose insights and guidance has been significant in the writing process of our work. Further, we would like to express our gratitude to Liza Nordfelt at the library of Chalmers University of Technology for answering our many questions regarding structure of the thesis.

Ella Jakobsson and Lisa Karlsson, Gothenburg, 2024

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SAMMANDRAG

Under 2023 upplevde de östra och centrala delarna av Stilla Havet den värsta torka någonsin registrerad vilket resulterade i låga vattennivåer i Panama Kanalen som i sin tur resulterade i minskade slottider för fartyg genom kanalen. Effekten av kanalens torka påverkade logistiska lösningar värden över och redare var därav tvungna att se över sina val av rutter. Syftet med studien är därmed att identifiera alternativa rutter till Panama Kanalen med fokus att hitta den rutt som är mest tidseffektiv och genererar lägst utsläpp för ett flöde av 4 700 twenty-foot equivalent unit (TEU) från till Shanghai, Kina till Jacksonville, FL, USA.
Scenario ett är baserat på rutten Shanghai, Kina till Jacksonville, FL, USA via Panama Kanalen och visade sig vara det mest tidseffektiva alternativet samt genererade näst minst utsläpp. Scenario två är baserat på rutten Shanghai, Kina till Jacksonville, FL, USA via Magellans sund och visade sig vara det näst minst tidseffektiva alternativet samt genererade mest utsläpp. Scenario tre är baserat på rutten Shanghai, Kina till Jacksonville, FL, USA med tåg genom Panama och visade sig vara det minst tidseffektiva alternativet samt genererade näst mest utsläpp. Scenario fyra är baserat på rutten Shanghai, Kina till Jacksonville, FL, USA med tåg genom Mexiko och visade sig vara det näst mest tidseffektiva alternativet samt genererade minst utsläpp. Studien visar på fungerande alternativa rutter genom och runt Panama men även på svårigheten att konkurrera med Panama Kanalen, huvudsakligen i förhållande till tidseffektivitet.

Studien fokuserar enbart på containertransport och tar inte hänsyn till utsläpp skapade vid omlastning. Inte heller utsläpp och tid skapade vid stopp i hamnar längst rutterna räknas med, utöver två hamnstopp för rutt två där utsläpp är inräknad. Om dessa faktorer skulle varit inräknade i studien hade möjligtvis ett annat resultat redovisats.

Nyckelord: Panama Kanalen, CO_2 utsläpp, sjöfart, tågtransport, intermodal, tidseffektivitet, CO_2, Mexiko, USA

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ABSTRACT

In 2023, the area around central and eastern Pacific Ocean experienced one of its worst droughts known which resulted in reduced slots through the Panama Canal, consequently, ship owners had to consider optional routes instead of the Panama Canal. Therefore, the aim of the study is to identify alternative routes and analyze time efficiency and emissions created by each rote. Moreover, the aim is to identify the most suitable route regarding both emissions and time efficiency for 4 700 TEUs. The first scenario is based on the route Shanghai, China to Jacksonville, FL, US through the Panama Canal and turned out to be the most time efficient whilst having the second lowest release of emissions. The second scenario is based on the route Shanghai, China to Jacksonville, FL, US around the strait of Magellan and turned out to be the second least time efficient whilst having the highest release of emissions. The third scenario is based on the route Shanghai, China to Jacksonville, FL, US passing Panama by railroad and turned out to be the least time efficient whilst having the third highest release of emissions. The fourth scenario is based on Shanghai, China to Jacksonville, FL, US through Mexico by train and turned out to be the second most time efficient whilst having the lowest release of emissions.
The study found functioning alternative routes through and around Panama, however, it was found difficult to compete with the Panama Canal especially regarding time efficiency.

The study only focuses on containers and does not take emissions created whilst reloading into account, further the time and emissions created for port stops along the route has not been considered for all routes. If these parameters were included the result might differ.

Keywords: Panama Canal, emission, shipping, railway, intermodal, time efficiency, CO_2 , Mexico, US

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ACRONYMS AND TERMINOLOGY

ARTF	The Regulatory Agency for Rail Transport
CIIT	Isthmus of Tehuantepec Interoceanic Corridor
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents
ECA	Emission Control Area
EEXI	Energy Efficiency Existing Ship Index
EF	Emission Factor
ENSO	El Niño-Southern Oscillation-cycle
ETF	Empty trip factor
ETW	EcoTransit World
EWI	EcoTransIT World Initiative
GHG	Green-house-gas
GTW	Gross Tonne Weight
HFO	Heavy fuel oil
IMO	International Maritime Organization
LNG	Liquified natural gas
MARPOL	The International Convention for the Prevention of Pollution from Ships
MDO	Marine diesel oil
MEPC	Marine Environment Protection Committee
MGO	Marine gas oil
NMHC	Non-Methane Hydrocarbone
NO_x	Nitrogen Oxide
PCRC	Panama Canal Railway Company
PM10	Particulate Matter
SO_2	Sulphur Dioxide
TEU	Twenty-foot-equivalent
TTW	Tank-to-Wake
UIC	International Union of Railways
WTT	Well-to-Tank
WTW	Well-to-Wake

1. INTRODUCTION

1.1 Background

Transporting goods has an impact on the environment, whether it is by road, shipping, or railroad. The different types of transport modes emit different types of pollution, including air pollution and emissions that emerge into water due to leakage, spillage, maintenance and washing as well as release of substances from anti fouling paints through everyday operation (Jonsson & Mattsson, 2016a). The main emissions from transport are carbon dioxide, nitrogen oxides, sulphur oxides, particles, hydrocarbons, and carbon oxides.

The International Maritime Organization (IMO), declared in their 2023 IMO Greenhouse Gas Strategy that the ambition is to reduce CO_2 emissions per transportation for international shipping with 40% by 2030 (IMO, 2023). The reduction requires different approaches such as renewable sources of energy, new technologies and vessels operating such that they release less emissions than currently. Although new vessels with renewable sources of energy would be an efficient solution concerning emissions it would require great investment to directly exchange the entire, current, fleet. Given the average lifespan of vessels, which is between 30 and 50 years according to SSI (n.d.) and assuming all further vessels ordered uses renewable fuels it could still take more than 30 years to ensure the world fleet is GHG net-zero. Therefore, the relevance for optimizing the current vessels, along with current fuels, is certain.

The greenhouse gases (GHG) released from shipping is significant due to maritime shipping being crucial to global trade making it an important factor for society to function, thus being used widely and non-replaceable. The shipping industry is estimated to make up for over 80% of the global trade, maritime shipping is both cost efficient and relatively reliable when it comes to delivery on time (Lister, 2015).

One essential factor of shipping regarding the efficiency and environmental effects is the chokehold point the Panama Canal (Rodrigue, 2017). In 1914, the canal was built and finalized by the United States and enabled vessels to transit from the Pacific Ocean to the Atlantic Ocean. The Panama Canal consists of two artificial lakes, artificial channels and twelve locks (Britannica, 2024). The two artificial lakes, Gatun Lake, and Alajuela Lake are crucial for the canal to be functional since the lakes provide the canal with water. The importance of the Panama Canal being well functioning becomes clear when learning that an estimate of 6% of the global trade passes through the canal yearly (Thalis P.V. Zis, 2023). It might be due to the connection between the Pacific- and Atlantic oceans the canal creates, which makes it possible to transit between the oceans in a shorter, safer, and more cost-effective way instead of going around the Cape Horn. Moreover, it enables the reduction of carbon emissions which results in a decrease of the impact on the environment. (McKinsey, n.d.).

During 2023, the area of central and eastern Pacific Ocean experienced one of the worst dry seasons since they first started to register the water levels, 73 years ago (Panama Canal Authority, 2023b). In October 2023 the area had the driest month with over 40% less rainfall because of the climate phenomenon El Niño which is a part of the El Niño-Southern Oscillation-cycle (ENSO). The climate cycle ENSO occurs in the Pacific Ocean and has two parts, the cold, La Niña and the warm El Niño and it occurs every three to seven years and it is a climate phenomenon that changes the climate pattern on many places around the world (SMHI, 2023). It causes a change in the wind patterns which results in warmer water. The warmer temperature in the Pacific Ocean will disrupt the usual pattern of rain and wind which increases the temperature. The consequences of the El Niño phenomena can differ, but it causes extreme rainfall and extreme drought (Karin Andersson et al., 2016). The low water level in the Panama Canal resulted in a decrease of the capacity. Under normal conditions, the canal has a capacity between 36-38 vessels per day and in October 2023, the Panama Canal Authority announced a reduced capacity with 24 vessels per day. The decrease resulted in congestions and a slot auction where slot prices were increased greatly and shipowners had to consider rerouting their vessels (Panama Canal Authority, 2023).

1.2 Aim of the study

In consideration to information mentioned in section 1.1 regarding the challenges that the Panama Canal are currently facing, the aim of this report is to identify alternatives routes through and around Panama. Moreover, these routes will be compared taking emissions and time efficiency for container shipping and rail transport into account. This thesis compares the routes releases of GHG, carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxide (NO_x), non-methane hydrocarbon (NMHC) and particulate matter (PM10).

1.3 Research questions

RQ1: Which route releases the lowest amount of emissions?

RQ2: Which route is the most time efficient?

RQ3: Which route would be the most suitable with consideration to emissions and time efficiency for a container ship carrying 4 700 TEUs from Shanghai, China to Jacksonville, FL, US?

1.4 Delimitations

This thesis only focuses on twenty-foot equivalent units (TEUs) transported by rail and sea, due to road routes not being confirmed for usage around the Panama Canal. Furthermore, the thesis limits the analysis by only using four different routes in calculations and focusing on the emission and time caused by those routes. Apart from scenario 2 which makes use of two port stops and the emissions for those are included, no other port stop for any other scenario is included. The ports stop in scenario 2 were necessary when calculating the emissions as the tool automatically would choose the shortest journey otherwise, thus passing through the Panama Canal. Emissions created when reloading containers on and off trains are not taken into consideration in this thesis. Neither are waiting time related to congestions linked to the Panama Canal and other port stops taken into consideration.

The rail route through Mexico is currently under construction which makes the data for transportations insufficient. This has resulted in assumptions regarding transit time, transportations per 24 hours, capacity per train, the manufacture year of locomotives and the fuel type.

Additionally, the tool for calculations, EcoTransIT, is not updated with all ports used in this thesis which has made it impossible to directly calculate all desired routes. The mentioned issue has been solved by using ports close to the desired destinations and calculating the emissions released per kilometer of that route multiplied with the actual distance of the desired route, which were derived from sea (Sea-Distances n.d.). As mentioned in 3.1.1 EcoTransIT has the ability to switch fuels used by vessels depending on the regulated Emission Control Areas (ECA), which affects all routes. The routes operating in ECA that are affected by the alternative solution for calculations, as mentioned above, does include the fuel change per kilometer although it is not consistent with the other calculations.

2. THEORY

The theory consists of concepts, previous research and theories that are valuable for this study.

2.1 Logistic

Logistic is a broad topic that can have different meanings but generally it could be described as the process of having the right goods or material at the right place and time. Logistics help streamline material flows so that companies can be competitive and economically efficient which is a part of a well-functioning and economically stable society. This is a significant part of a company since it does not only include the company itself but also producers, resellers, buyers, shippers, and consignees' etcetera. Logistics can be described as a system where every part of the system has its own system that fulfills a function that the logistic system needs to have a functioning material supply, production, and distribution (Jonsson & Mattsson, 2016).

The *Environmental Methodology and Data Update 2024* provided by EcoTransIT World (2024a) states that most important factors for environmental impact by transportation are the payload capacity, the size of vehicles and the utilization capacity. It is further explained that different transportation modes behave differently regarding the weight of goods, container vessels are described to be less sensitive to the weight of cargo in consideration to energy consumption and emissions released. Moreover, it is clarified that the lowered sensitivity is based on other factors such as physical resistance and ballast water being more relevant, whilst an increase of cargo weight has a more significant effect on rail and road transportation as it increases the consumption of fuels more.

2.2 Shipping related to the Panama Canal

Jonsson & Mattsson (2016) describe that shipping is the slowest transport mode whilst it is the transport mode with the lowest operating cost per ton km. However, in some scenarios shipowners still make use of a strategy called slow steaming which means that the vessels operate with slower speed to reduce the fuel consumption and operational costs. One could make the argument that a lower fuel consumption will lead to reduced emissions (Karountzos et al., 2023). Transport Geography (n.d.) states that the average speed for containerships is to be between 20-25 knots whilst slow steaming is stated to be between 18-20 knots and extra slow steaming is stated to be between 15-18 knots.

Shipping makes use of different fuel types which results in different emissions release. The majority of the world fleet vessels have historically been operating on heavy fuel oils, HFO, which are fossil fuels that have been derived from residual oil. It is estimated that every tonne of HFO consumed releases 3.15 tonnes of CO_2 emissions. Along with HFO, marine gas oil, MGO and marine diesel oil, MDO are commonly used fuel types, however they are both based on HFO (Nyári et al., 2024). The emissions derived from MGO and MDO are still significant however they have regulated sulphur levels of 0.5% sulphur content, therefore they are considered low sulphur fuel oils. However, improvements in the emissions released from fuel types are becoming more regulated and the require for renewable fuel types is increasing. A result of such requirements is Liquified natural gas, LNG, becoming more dominant on the fleet. LNG consists of cooled natural gas and whilst it is not considered a fossil fuel it still based on fossil materials and has high emissions when being produced. However, the low emissions whilst operating could still be viewed as a benefit (Nyári et al., 2024).

Since shipping is the slowest transportation mode, the Panama Canal plays a big role when it comes to enabling fast connections between the Pacific Ocean and the Atlantic Ocean. The canal enables a faster route from the US East Coast and the Gulf Coast to East Asia which results in lower emissions, time efficiency and costs (David Dierker et al., 2024). Moreover, Thalis P.V. Zis (2023) states that the canal operates about 60% of US cargo with origin or destination in the US and around 6% the global trade a year as mentioned in 1.1. Beyond mentioned advantages, the canal has had a good impact on the national security, diplomatic relations, security measures, efficiency, logistic strength and has resulted in good economic benefits (International Trade Administration, 2023).

When the Panama Canal was first built, it was mainly intended for military use (Luis Carral et al., 2018). Since the canal was built it has been reconstructed several times to improve its function due to the development of vessels getting larger. In 2023, the canal operated 14 080 transits, served 170 countries and connected 1920 port pairs. Panama Canal handle different type of vessels, from container ships to LNG tankers and cruise ships. Due to the capacity of the canal, there are limitations regarding the size of the ship for both width and height that vessels must fulfil when entering (Panama Canal Authority, 2022). According to Richard Joy (2014) the increase of vessels sizes is requested by the global market and has developed quickly in the last 40 years, increasing the demand of capacity in ports as well. Joy states that the original Panamax vessel has a capacity of 4 500 TEUs whilst EcoTransIT World (2024b) states that the maximum capacity of a Panamax vessel is 4 700 TEUs. It is further explained in the article *How Container Ship Sizes Have Grown Over Time* (CIE Manufacturing, n.d.) that a Panamax vessel vary in size from 3 000 to 5 100 TEUs. In the article it is also stated that the Panamax were introduced in 1914, when the canal was finalized, and became very important due to its ability to travel through the canal. However, both Post-Panamax and New Panamax have been introduced later, partly as a consequence of the canal allowing larger vessels.

Shipping is very sensitive to disruptions which refers to unexpected and sudden events that are unpredictable in advance as extreme weather, pirates, and cyber resilience (Thalis P.V. Zis, 2023). The low water levels in the Panama Canal are one of these incidents. As described in 1.1. the low water levels in the canal are an effect of extreme weather which could not be anticipated. The low water level became a problem for the supply chains depending on the canal to function. It can be interpretated that canals can help reduce the emissions due to lowered operating speed and shorter distances (Luis Carral et al., 2018), however, with reduced time slots and longer waiting time to enter the canal, shipowners must decide whether to wait or to reroute their vessels.

2.3 Rail transportation related to Panama

Rail transportation makes use of railways to transport shipments loaded onto trains and requires certain infrastructure to figure, mainly rails and transshipment possibilities. Therefore, it is mainly used to transport shipments between terminals. Transporting goods by train is well suited for larger volumes that require road transportation, as it has a larger capacity than trucks. Although rail has limitations in consideration to flexibility in changing routes the types of shipments railroad can transport ranges from container to bulk. Trains are considered an environmentally friendly option since they have the ability to operate without directly creating emissions, although indirect emissions are created when producing electricity. Trains are also the most energy efficient transport option (Jonsson & Mattsson, 2016b). Although trains operating on electricity or co-operating on electricity are becoming more dominant on the railway market, the usage of diesel engines on trains is still very much present (Dvořák & Chovančíková, 2019). Diesel trains consumptions results in CO_2, CO, NO_x, PM, and hydrocarbons emissions which consequently has a negative effect on the environment.

According to Logistics Cluster, founded by UNs world food hunger programme, the railway network in Panama consists of 18 locomotives which are all operating on diesel with the ability to provide electricity to passengers or reefer container (Logistics Cluster, n.d.). The trains operate on a single-line track and use double stacked rail cars which are in two sets of six, each set has the ability to, on average, accommodate 75 containers from the port of Colón to the port of Balboa and vice versa according to Panama Canal Railway Company (n.d.). Moreover, it can be read that the mentioned route can handle 10 transportations in each direction per 24 hours. Using double stacked containers enables more efficient handling at terminals, requires fewer locomotives, crew members, and lower fuels per container (Upadhyay et al., 2017).

Another, eventual, alternative route across the Panama Canal is the ongoing rail project in the Isthmus of Tehuantepec Interoceanic Corridor (CIIT) in Mexico (Railway Gazette International, 2024). The project aims to support the economic growth of Mexico and the railways are managed by the state-owned company Ferrocarril del Istmo de Tehuantepec which are part of the Mexican navy. The initiative creates three railway lines through Mexico with the aim to transport both goods and passengers according to the article *Historical Opportunity Isthmus of Tehuantepec Interoceanic Corridor (CIIT)* (Arias, 2024). It is further explained that one of the lines, line Z, consists of 308 km long tracks and will operate from the port of Coatzacoalcos to the port of Salina Cruz, thus being the only line that connects the Atlantic Ocean and the Pacific Ocean. To enable transportation of goods the article states that major modernisation steps for both ports have been put in motion, this includes container terminals with a capacity of 1.4 million TEUs annually.

The railways will enable transportation of 1.2 million TEUs yearly according to an article published by Railway Gazette International (2024). The article goes on to explain that the project was put into motion in 2020 and aim at fully operating mid-2024. Therefore, data concerning the project is currently limited, but it has been announced that their fleet will contain diesel driven locomotives in the previous article. It was also stated that InterCity 125 high-speed trains which are driven by diesel are currently used for the passenger trains which strengthens the assumption that their fleet will consist of diesel driven locomotives.

2.4 Intermodal transportation

Intermodal transportation makes use of more than one type of transportation by combining shipping, rail, road, or air. It requires the possibility to reload shipments, which is executed in the most efficient manner if shipments use standardized units such as containers. Intermodal solutions enable different types of transportation profitability, for instance railroad can be used to transport larger volumes over longer distances and then be reloaded onto road for the last mile transportation. It can therefore create a competitive supply chain but also create extra handling costs and time in terminals when reloading is required (Jonsson & Mattsson, 2016).

2.5 Emissions

Emissions generated by transportations.

2.5.1 Greenhouse gases (GHGs)

The atmosphere around the earth contains several gases that are important for all living species and the greenhouse gas effect is a crucial function on earth since it keeps the temperature around 30 ^{o}C higher than it would be without it (Naturskyddsföreningen, 2021). The characteristics of the GHGs is that they absorb wavelengths of some of the outgoing heat radiation. This results in a longer re-radiation which can continue to re-radiation more times after, which increases the temperature on earth since the thermal radiation stays within the atmosphere.

Karin Andersson et al. (2016) describes that the most important GHGs are (CO_2), nitrous oxide (N_2O) and methane (CH_4). They are emitted from combustion in engines, agriculture, deforestation, and use of energy. The effect of GHGs have a large impact on the climate as it sustains the temperature at reasonable levels on earth. In 2012, shipping accounted for 972 million tonnes of CO_2 and due to increased patterns of transportation needs, the GHGs will have an influence on the temperature on earth. Moreover, as mentioned before, CO_2 is the largest source of the GHGs, and it appears when the carbon in the fuel is combustion in the engine which is needed to get power onboard the vessel for driving force etcetera. Therefore, the consumption of a vessels fuel is directly connected to the CO_2 emissions.

The Swedish Nature Protection Association describes that GHGs has various climate impact and when comparing them to each other, carbon dioxide equivalents (CO_2e) can be used. The CO_2e compare the environmental impact CO_2 holds. The lifespan of the different gases varies and therefore also their impact on the environment if compared to CO_2, thus the equivalents are more often calculated for a span of 100 years (Naturskyddsföreningen. 2021).

When the amount of GHGs increases in the atmosphere, the global warming increases with a higher average temperature as result. As mentioned above, the global transportation plays a big role in the greenhouse gas effect, where the global warming and emissions from CO_2 created by combustion of fossil fuels are the biggest sources. When combustion creates CO_2 from fossil fuels, the plants have a hard time processing the big amount which creates an excess in the atmosphere (Naturskyddsföreningen, 2021).

Regulations regarding GHG emission in shipping is regulated by IMO as committers to the *Sustainable Development Goal 13* provided by the United Nations. Goal 13 states that action needs to be taken to decrease GHGs to restrain the global warming. The 2023 IMO Strategy includes ambitions and guidelines to reach net-zero GHG around 2050. In 2030, the ambition is to affect shipowners shifting to fuels with zero GHG (IMO, 2023).

The main goal of the strategy is to decrease the amount of carbon intensity of shipping, i.e. to reduce CO_2 emitted per transportation as a mean in shipping by approximately 40% in 2040 (IMO, 2020).To manage this, the strategy has presented *2023 GHG Candidate Mid-Term Measures* which consist of technical measures and economic measures. The technical measure refers to a standard for marine fuels where it aims to regulate the GHG intensity in fuels. The economic measures aim to determine a mechanism for pricing GHG emissions by shipping and the goal is to get the measures approved by the Marine Environment Protection Committee (MEPC) in 2025 (IMO, 2023).

According to The International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, in short term, vessels must improve its energy consumption to reduce their emitted GHG. Today, vessels must present their energy efficiency according to Energy Efficiency Existing Ship Index (EEXI) where each vessels receives a grade and ranking for its performance according to energy efficiency (IMO, 2023).

2.5.2 Sulphur dioxide SO_2

Sulphur dioxide (SO_2) is emitted from humans and natural sources worldwide, the biggest natural cause for SO_2 emissions are activities from volcanos however, one of the biggest causes created by humans are combustions from fossil fuels like carbon and oil. The environmental result from SO_2 are acidification of water and soil which results in a negative impact on potable water, animals, and plants (Naturvårdsverket. n.d.). The sulphur content in fuels is regulated by MARPOL Annex VI, regulation 14 and in 2020, a level of maximum 0.5% sulphur content in fuels were introduced as the new standard outside the Emission Control Areas (ECA). Inside ECA, the content of sulphur was regulated to an allowance of 0.1% to control sulphur emissions (IMO, n.d.-c).

2.5.3 Nitrogen oxide (NO_x)

Nitrogen oxide (NO_x) appears when nitrogen and oxygen react with each other at high temperature, i.e. combustion of fossil fuels etcetera (Naturvårdsverket, 2023). The biggest contributor is the road traffic; however, shipping is also a big contributor. The emissions of NO_x also have an acidification effect on the environment as SO_2. It lowers the pH-levels and affect the water and soil. NO_x contributes to eutrophication and can affect the human health (Naturvårdsverket, 2024a).

NO_x emitted by shipping are regulated by MARPOL Annex VI regulation 13 which is built on a tier system of three tiers where Tier I applies regulations on the engine for vessels built earlier than year 2000, Tier II regulates the emissions emitted outside of ECA and Tier III inside ECA. The regulations control the output power of the diesel engine and limits it to no lower that 130 kW. To control the output power of the engine, the engine must be certified according to basis provided by MARPOL Annex VI and the Tier limits (IMO, n.d.-a).

2.5.4 Non-Methane Hydrocarbon (NMHC)

Non-Methane Hydrocarbon (NMHC) is a collection of organic compounds in gas form i.e. alcohols as benzene, butane, and propane. It is emitted by varies actions but can be used as solvent in paint and anti- corrosion treatments. Moreover, it is being used in the procedure of making chemicals and degreasing. Today, the biggest contributor to emissions of NMHC are refineries, however incomplete combustion and worldwide transportation also contribute. However, emissions of NMHC by worldwide transportation has decreased significantly, mainly due to emissions from cars having become more regulated. NHMC can also be emitted by natural causes as terpenes from plants (Naturvårdsverket, n.d.-a).

The combination of sun, NMHC and NO_x creates ozone on ground levels which can result in negative effects for plants and humans. The Swedish Nature Protection Association also states that NMHC can have direct health effects (Naturvårdsverket, n.d.-a).

IMO do not provide any specific regulations to limit the emissions of NMHC, however, MARPOL Annex VI regulates other types of air pollutions, for example the regulation of sulphur content in fuels, therefore it can be interpretated the amount of NMHC are indirectly regulated as well.

2.5.5 Particulate matter (PM10)

Particulate Matter (PM10) is a type of particles with a diameter of no higher than 10 micrometers (Naturvårdsverket, 2024b). These particles can appear by natural causes as dust from the desert and waves meanwhile some of them are anthropogenic and created by combustion, tire, and break wear. The source of the emissions decides the size of the particle and the composition of the particles. Moreover, the particles effect on human health depends on the physical, and chemical qualities. PM10 and can be harmful to humans when inhaling the particles and can affect both lungs and heart. Long-term exposition of PM10 can lead to an early death, cancer, and breathing difficulties. PM10 especially affect children and can cause asthma and hinder lung development. PM10 is considered being indirect regulated by MARPOL Annex VI regulation 14.

2.5.6 Railway regulations

For rail transportation the information regarding regulations in Panama and Mexico has been unable to access, thus not being included in the separate emissions as shipping regulatiosn are. However, in recent organizations have focused on limiting emissions created by engine technology based on the manufacture year of the locomotives starting from 1973 according to EcoTransIT (2024). These organizations include international Union of Railways (UIC), which consists of 214 members in 95 different countries and operates worldwide as a support to railway and the development of rail transportation. In their work programme 2023-2025 they expressed an interest in Panama become a member although it has not been established (UIC, 2023). Therefore, it cannot be concluded that the Panama railway operates under the mentioned limitations in releasing emissions. The other organizations presented in the report from EcoTransIT (2024) are the European union and the U.S environmental protection agency, neither of them has expressed working with or regulating the area of Panama. For Mexico the Regulatory Agency for Rail Transport (ARTF) are part of UIC however as the CIIT are part of the Mexican navy this thesis has not managed to find a correlation between CIIT and ARTF in Mexico. The other organizations presented in the report from EcoTransIT (2024) are the

European union and the U.S environmental protection agency, neither of them has expressed working with or regulating Panama or Mexico.

2.6 EcoTransIT

The emission calculating tool EcoTransIT World (ETW) was created by EcoTransIT Wold Initiative (EWI) in 2012, the members of EWI represent various segments of the global transportation and provides ETW with necessary information for them to build the website. ETW provides emission calculations for global transportation and can be used to anyone who can access the internet. For one who wants to calculate emissions, it can be done in two ways, via the standard mode, where the user inserts transportation mode and destination, and the extended mode. The extended mode provides the user with different options to insert on the website, where the user can choose between transportation mode, vessel/train type, weight of shipment, transshipment, and type of shipment etcetera. After adjusting the tool after one’s preferences, it will calculate the emission and energy consumption. ETW has in past been EN 16258 certified which is the European standard for calculating emissions of GHGs, however, ETW in no longer EN 16258 certified due to transformation ratios of ISO 14083 which is a standard for calculating emissions created by transportation (EcoTransIT World, 2024b).

3. METHODS

This study will investigate the differences between four scenarios on transporting 4 700 TEUs through or around Panama and how it affects the emissions and time efficiency. The intended destinations are identical to all scenarios, despite how the passage through or around Panama differ, from Shanghai, China to Jacksonville, FL, USA.

Scenario 1: Shanghai, China to Jacksonville, FL, US through Panama Canal

Scenario 2: Shanghai, China to Jacksonville, FL, US around the Strait of Magellan

Scenario 3: Shanghai, China to Jacksonville, FL, US passing Panama by railroad

Scenario 4: Shanghai, China to Jacksonville, FL, US through Mexico by railroad

The four scenarios were selected as they could be confirmed as either currently being used or are likely to begin operating in the near future. Scenario 1 was chosen because of existing route collected from the shipping company Maersk Klicka eller tryck här för att ange text., scenario 2 as alternative route to scenario 1 if one would prefer to avoid intermodal solutions and scenario 3 because of existing seaway routes and railway used by the shipping company (Maersk, 2023). Moreover, scenario 4 was chosen because of the ongoing construction of CIIT railway and existing seaway routes between the chosen ports. However, since the CIIT railway is under construction, the railway leg in scenario 4 is made by assumptions collected from various websites and articles.

Furthermore, the decision to transport cargo from Shanghai, China to Jacksonville, FL, US is supported by the significantly larger volumes of cargo transported from China to the US. This becomes evident by looking at trading history for export from China to the US compared to the export from the US to China where the average export from China the last five years is $368.2 billion more (TRADING ECONOMICS, n.d). The ports were selected due to their establishment, Shanghai is rated as the number one port worldwide in consideration to volume (World Shipping Council, n.d.)whilst Jacksonville is rated top 34 in the US (Bureau of Transportation Statistics, n.d.). However, Jacksonville is well-suited for the routes in this thesis as it enables rather quick transit to both Panama and Mexico, therefore it is also likely to be used by companies.

3.1 Calculation strategy

The emissions will be calculated with the calculation tool EcoTransIT Emission calculator where vessels use either Heavy Fuel Oil (HFO) or Marine Diesel Oil (MDO) as energy source which is fossil fuels and not renewable since crude oil being raffinate and train transportations using diesel engines. All calculations are calculated as Well-to-Wake (WTW) which consider the emissions created by fuel production, bunkering, distribution, and emissions created onboard the transport mode. Where Well-to-Tank (WTT) represents emissions created by the fuel production to the tank onboard the transport mode and Tank-to-Wake (TTW) represent the emissions created whilst operating (Giorgio Zamboni et al., 2024). When choosing amount of TEUs, 4 700 was decided. This because it is the stated in the *Environmental Methodology and Data Update 2024* (EcoTransIT World, 2024a) that the total capacity of a Panamax Vessel is 4 700 TEUs and it is possible to choose Panamax as a vessel in the tool provided by EcoTransIT. Further it is stated in the methodology that the default values for load factor are based on the weight of cargo in relation to the vessel or vehicle. Which enables a maximum transportation of 4 700 TEUs, with a net weight of 10 tonnes, for Panamax whit a load factor of 70% for vessels. The cargo for this thesis is assumed to not be limited by volume nor weight, which would have affected the load factor. For rail transportation the load factor of either 75 or 110 TEUs with the weight of 10 tonnes becomes 47.8% by default in the tool. Further, an empty leg factor, ETF, of 20% is added by default.

Emissions created by operations in the port terminal has not been collected for this study, however, it can be interpretated those emissions emitted by operations in the terminal has a smaller share than emission created by transportation as shipping and railway etcetera which can be seen in the 2023 Sustainability Report provided by Maersk (2024).

3.1.1 Sea route calculation for energy consumption and emissions

When calculating the emissions for all sea routes, the extended mode in EcoTransIT has been used where 4 700 TEUs was chosen, weight type as container TEU, average goods as type of goods, 10 tonnes per TEU as weight in t/TEU because of average weight per container stated by (EcoTransIT World, 2024b), container as handling definition and avoid ferry routing to determine route priorities. The following modes were chosen when modifying the model, transport mode sea ship, ship class aggregated as standard ship class according to (EcoTransIT World, 2024b), ship type Panamax (3.5-4.7k TEUs), capacity of 4 700 TEUs and a load factor of 70% as standard for chosen ship type. Furthermore, a speed reduction of 20% as was manually put into the tool, by default a 36% speed reduction was given, however as stated in 2.2 the average speed for containerships is between 20-25 knots. With them assumption that the vessels operate on 25 knots a 36% speed reduction would generate a speed of 16 knots which is considered extra slow steaming. To avoid slow steaming, a 20% speed reduction was used instead which generated an average speed of 20 knots.

Scenario 1 only consists of one leg, directly from Shanghai to Jacksonville, FL. Scenario 2 also contain one leg, from Shanghai to Jacksonville, FL, US. However, the tool only provides the fastest and shortest route which means that the route alternative around Strait of Magellan did not come as an alternative. Therefore, the function *via* was used to receive the right route. After adding Zarate, Argentina and Santiago de Chile, the preferred route around the Stait of Magellan was shown. Moreover, this resulted in a slight difference in the distance which can affect the result of energy consumption and emissions. Scenario 3 was built on two sea legs, the first one from Shanghai, China to Balboa, Panama and the second one from Colón, Panama to Jacksonville, FL. Same as for the third scenario, the fourth scenario contains two sea legs. First from Shanghai, China to Salina Cruz, Mexico, and the second one from Coatzacoalcos, Mexico to Jacksonville, FL, US. There were some issues with both the port in Salina Cruz and in Coatzacoalcos due to updates in the model and therefore, they were not available as ports for shipping in the calculation tool. Therefore, Veracruz, Mexico was chosen as the closest port to Coatzacoalcos and Manzanillo as closest port to Salina Cruz. This resulted in a differ in distances, to calculate the emissions for the first sea leg, energy consumption and emissions were calculated per km, moreover, the real distance between the ports were collected from (Sea-Distances, n.d.). This made it possible to calculate total energy consumption, emissions times total km from Shanghai, China to Jacksonville, FL, US. The same method was used to calculate energy consumption and emissions for the second leg as well.

Power demand

In the *Environmental Methodology and Data Update 2024* provided by EcoTransIT, the calculation method for the emission factor for sea transport is based on equations from the study Fourth IMO Greenhouse Gas Study (EcoTransIT World, 2024b) and it calculates types of emissions and energy consumption for main engine, boiler, and auxiliary engine. Furthermore, different factors were considered such as vessel categories, fuel consumption, size of the vessels and emissions. However, vessels that uses LNG and LPG as main fuel has not been considered in the calculations. To calculate the emissions with higher accuracy, emissions that occur during operations in port and during the return voyage has been taken into consideration. The model for calculating emission factors and fuel consumption has taken load factor and speed optimization into consideration. Moreover, the model is adjusted after the limitations of sulphur content in the fuel outside and inside ECA (EcoTransIT World, 2024b).

The equation used to calculate the power demand for each vessel category and ship size are calculated as power demand in KWh/tkm and can be seen in Equation 1 collected from page 81 in *Environmental Methodology and Data Update 2024* (EcoTransIT, 2024)

$$W_{ME,Ship} = \frac{CF_{Ship} * W_{REF} * (t/t_{REF})^{0.66} * (v/v_{REF})^{3}}{CF_{Weather} * CF_{Fouling}} \qquad (1)$$

where $W_{ME,Ship}$ is the main engine power demand in kW, $W_{REF}$is the average power on the main engine in MCR in kW where the variable provided by (EcoTransIT, 2024) is based on Table 81 in MARPOL Annex N (IMO, 2020), t/t_{REF} is design draught and actual draught of the vessel where both design draught and actual draught as assumed to be 1. Furthermore, v, v_{REF} is design speed and actual speed of the vessel where the ratio is deiced to be 1 in Equation 1 to receive power demand at the vessels design speed to prepare for later calculation that take account for values modified by the user. CF_{Ship} is correction factor for the specific vessel type, $CF_{Weather}$is based on Table 44 in the Fourth IMO Greenhouse Gas Study (IMO, 2020) and is the correlation factor for weather and $CF_{Fouling}$ is the influence correction factor for hull roughness/hull fouling. (p.81)

The outcome of Equation 1 is separated by the speed of the vessel (km/h) to acquire kWh/km, and the freight weight to acquire kWh/tkm which are calculated with Equation 2 collected from page 82 in *Environmental Methodology and Data Update 2024* (EcoTransIT, 2024),

$$W_{ME,tkm} = \frac{\frac{W_{ME,Ship}}{v}}{(CC * CU)} \quad (2)$$

where $W_{Me/tkm}$ is the main engines propulsive power demand in kWh/tkm, CC is the vessels cargo capacity by default where deadweight tonnage is multiplied by 0.95, and CU is the cargo utilization on average for the vessel in % which EcoTransIT (2024) based on the Fourth IMO Greenhouse Gas Study (IMO, 2020).

Equation 3 calculate the power demand for the boiler and auxiliary engine in kWh/tkm and has been collected from page 82 in *Environmental Methodology and Data Update 2024* (EcoTransIT, 2024)

$$W_{A,B} = \frac{(\left((d_{sea} * 24 * L_{sea}) + \left(d_{port} * 24 * L_{port}\right)\right) * n)}{Dist\ * CC * CU} \quad (3)$$

where $W_{A,B}$ is the auxiliary engine/ boiler engine power demand in kWh/tkm, d_{sea} is amount of days spent at sea yearly where EcoTransIT has collected information from IMO (2020), L_{sea} is the load on the auxiliary engine/boiler at sea in kW where EcoTransIT has collected the information from IMO (2020), d_{port} is yearly number of days in port, L_{port} is the load on the auxiliary engine or boiler in port in kW where EcoTransit has collected the information from IMO (2020), n is how many numbers of auxiliary engines/boilers that has been collected from IMO (2020) and $Dist$ is the distance annual driven by the vessel, estimated as $dsea$ times 24 times v.

Fuel consumption

The published *Environmental Methodology and Data Update 2024* present various fuel mixes in the calculation tool that are taking account to ECA. The energy share for each fuel type is calculated with average consumption and emission variables for vessel type, size, and the chosen fuel type within and outside ECA.

The data in Table 1 has been collected from the *Environmental Methodology and Data Update 2024* provided by EcoTransIT and present sulphur content, CO_2e emission factor (EF), energy content and the energy share inside and outside ECA for the various fuel types in 2020. EcoTransIT based the energy share from data published by Clean Cargo Working Group (CCWG) which is a partnership between container shipping companies and other parties who are involved with container shipping. The CCWG represent around 85% of the trade and the data can only be considered for container vessels (BSR, 2014).

Table 1.
Emission factors for different types of fuel.

Type of fuel	Sulphur reduction tool	Sulphur level	CO_2e EF [g/MJ]*	Energy content [MJ/kg]	Energy share 2020	
HFO	Scrubber	2.6%	77.1	41.2	Inside ECA	Outside ECA
	No scrubber	2.6%	77.1	41.2	0.0%	29.0%
Hybrid fuels	Not available	0.5%	79.0	41.3	13.4%	15.0%
MDO	Not available	0.07%	78.9	41.1	0.4%	31.2%
LNG	Not available	n/a	74.3	49.1	84.9%	24.8%
LNG					1.3%	0.0%

Note. Table 1. Collected from page 83 in the Environmental Methodology and Data Update 2024 (EcoTransIT, 2024).

Moreover, EcoTransIT World (2024b) states that fuel types are determined by ECA, inside these areas vessels operates on Marine Diesel Oil (MDO), instead of HFO, due to regulations as described in 2.5.2 which makes Table 1. invalid regards the sulphur content in HFO. The calculations carried out in this thesis all operate on the US East Coast, which is a part of the North American ECA (IMO, n.d.-b), therefore affected by the change in fuel.

In the calculation tool, fuel consumption calculations are divided into two categories, fuel-based and energy-based. When calculating the fuel-based emissions, the quality of the chosen fuel is significant. The emission factor for the fuel-based category is presented as g/g fuel where fuel- and energy consumption, SO_x, and CO_2 are taken into consideration. For the second category, energy-based emissions depend on the engine and the combustion process which is highly dependent on the load factor. The energy-based emissions are presented as g/kWh and includes NMHC, PM and NO_x (EcoTransIT, 2024).

The factors for average energy and emission consumption are computed with Equation 4 where vessel type and fuel-based factors are considered. Equation 4 and explanations about the variables has been collected from page 84 in *Environmental Methodology and Data Update 2024* (EcoTransIT, 2024)

$$EF_{p,MT,a} = \sum_{FT,AG} SH_{FT,a} * Sh_{AG} * W_{MT,OA} * SFC_{FT,AG,MT,ET} * EF_{p,FT,ET,MT} \quad (4)$$

where $EF_{p,MT,area}$ is the consumption/emission factor in g/tkm for pollutant p and all the engines mentioned and type of area, a is specified (outside and inside ECA). FT is type of fuel and technology which can be found in Table 39 in the *Environmental Methodology and Data Update 2024* by EcoTransIT World (2024b), OA is the area where the vessel is supposed to operate and consider both ports and sea. AG stands for age group and the efficiency of the engine depending on age of the vessel since it differ, the age groups has been divided into three groups, engines built before 1983, engines built between 1984–2000 and engines built from 2001 onwards. ET is type of the engine considering diesel engines with low, medium, and high-speed diesel. Furthermore, $Sh_{FT,a}$ is the share of the fuel and technology in area a which can be found in Table 39 (EcoTransIT World, 2024b)

Moreover, Sh_{AG} is the share of ships in each age group (AG). Where the share is computed based on the year the vessel was built assuming a length of life up to 50 years for vessels with deadweight over 50 000, a length of life up to 30 for vessels with deadweight less or equal to 50 000 where EcoTransIT collected this information from (Foen, 2015). $W_{MT,OA}$ is representing the power demand in OA of the machine type in kWh/tkm. $SF_{CFT,AG,MT,ET}$ is the specific fuel consumption for the engine type and machine type with FT and AG that has been collected by EcoTransIT from IMO (2020). $EF_{p,FT,ET,MT}$ is the emission factor for pollutant p, engine type, machine type and, when PM is considered, AG. EcoTransIT based the CO_2, energy consumption and SO_x on Table 39 and sulphur contet transformed to g/g from Equaion 15 in the Fourth Greenhouse Gas Study by IMO (2020). When operation on HFO with scrubber EcoTransIT assumed a 96% reduction of SO_x emissions compared to not using a scrubber based on (Yang et al., 2017).

Moreover, the calculation to calculate energy-based pollutants as NOx, NMVOC and PM is computed with Equation 5. The equation and further explanations about the variables have been collected from page 85 in *Environmental Methodology and Data Update 2024 (*EcoTransIT, 2024),

$$EF_{p,MT,a} \sum_{FT,AG} Sh_{FT,a} * Sh_{AG} * W_{MT,OA} * EF_{p,FT,ET,MT,AG} \tag{5}$$

where AG represent the age group of the vessels, when looking at PM, emission factors are varying in the same way as for specific fuel consumption. When looking age group for NO_x emissions, three different tiers has been provided by IMO with different age gaps. Furthermore, $EF_{p,FT,ET,MT,AG}$ is the emission factor for pollutant p, machine type, engine type, furthermore, PM and NO_x are considered. The variable AG is also included in this variable. Information regarding NO_x has been collected from Table 23 (IMO, 2020) by EcoTransIT, furthermore, information about NMVOC has been collected from Table 61 and 62 in Annex M (IMO, 2020), and information regarding PM has been collected from Tables 52-54 in Annex M (IMO, 2020) by EcoTransIT.

The emission factors and fuel consumption take account for the various trade lanes and are computed as an average of tkm-weight of the vessels that operates on the chosen trade and size. When computing the different values in EcoTransIT extended mode, the tool takes capacity, milage and total capacity onboard into consideration. The emission factors on the various trades varying, this because of capacity. In the container segment, the size of the vessel can vary since different trades have various size limitation because of the routing (EcoTransIT World, 2024b).

Speed adjustments and cargo utilization

The operation speed of the vessel is crucial when calculation the emissions and fuel consumption. During the last couple of years, slow seaming has been commonly used in the shipping industry as mentioned in 2.2. However, the total capacity onboard is sensitive because the calculation tool is built on emissions emitted by specific vessel. It will vary depending on the total amount being loaded onboard, the more cargo, the lower emissions. The vessels design speed affects the adjustment of speed and is expressed as reduction in percent in relation to the vessels design speed meanwhile cargo utilization is described as percent of the vessel’s capacity (EcoTransIT World, 2024b).

The adjustment of speed is computed with Equation 6 which calculate the workload on the main engine when reducing the speed according to vessels deign speed (EcoTransIT World, 2024b). Equation 6 and explanations about the variables have been collected from page 90 in *Environmental Methodology and Data Update 2024* (EcoTransIT, 2024)

$$LF_{act} = \frac{CF_{Ship} * \left(\frac{v}{v_{REF}}\right)^3}{CF_{Weather} * CF_{Fouling}} \tag{6}$$

where LF_{act} the main engine load factor when the tool is modified with speed settings by a user and v,v_{REF} which is the speed design and actual speed of the vessel (EcoTransIT World, 2024b).

When the workload on the main engine has been identified during the acutal speed of the vessel, emission factors and fuel consumption can be adjusted and calculated with Equation 7 which sums up emissions or fuel consumption of the auxiliary engine, boiler and the main engine and takes air pollution emission factor into consideration for a not fully loaded vessel and the total voyage time when operation in slower speed (EcoTransIT World, 2024b). Equation 7 and explanations about the meanings of the variables has been collected from page 90-91in *Environmental Methodology and Data Update 2024* (EcoTransIT, 2024)

$$EF_{adj} = (EF_M * LF_{act} * LAF) + \left(EF_{A.Sea} + EF_{B,Sea}\right) * (1/(1 - v/v_{REF})) + (EF_{A,Port} + EF_{B,Port}) \tag{7}$$

Where EF_{adj} is emission factor or fuel consumption by speed adjustments, EF_M is the emission factor and fuel consumption for the main engine, LAF is adjustment factor for low-load air pollutants, based on load points and pollutants in Table 20 in the Fourth Greenhouse Gas Study (IMO, 2020) which is the base for this equation by (EcoTransIT World, 2024b). Furthermore, $EF_{A.Sea}$ is the emission factor and fuel consumption for the auxiliary engine when at sea in g/tkm, $EF_{B.Sea}$ is the emission factor and fuel consumption for the boiler when at sea in g/tkm, $EF_{A.Port}$ is the emission factor and fuel consumption for the auxiliary engine in port in g/tkm, and $EF_{B,Port}$ is the emission factor and fuel consumption for the boiler in port in g/tkm (EcoTransIT World, 2024b).

Moreover, adjustments for cargo utilization by default are made with Equation 8 where emission factors and speed-adapted fuel consumption are adapted for variance of the cargo utilization. The equation and meanings of the variables has been collected from page 91 in *Environmental Methodology and Data Update 2024* (EcoTransIT, 2024)

$$EF_{final} = EF_{adj} * (CU_{Def}/CU_{act}) \tag{8}$$

where EF_{final} is final emission factor and fuel consumption adjusted by cargo utilization in g/tkm, CU_{Def} is the default cargo utilization which was collected by EcoTransIT from the Second IMO GHG Study (IMO, 2009), with an average of tkm-weighted in the respective trade or vessel size and type provided by (EcoTransIT, 2024) and CU_{act} is the real cargo utilization in %.

3.1.2 Railway route calculation for energy consumption and emissions

To calculate the emissions for one rail route in scenario 3, the extended mode in EcoTransIT has been used where *75 TEUs* was chosen because of the capacity of the Panama Canal railway, weight type as container TEU, average goods as type of goods, *10 tonnes per TEU* as weight in t/TEU because of average weight per container stated by (EcoTransIT World, 2024b).

When calculating the emissions for one rail route for scenario 4, the extended mode in EcoTransIT has been used where the following values have been decided, firstly an assumed capacity *110 TEUs* was chosen. Due to the information regarding the Mexican railway being insufficient, however it is known that the three railway lines can transport 1.2 million TEUs per year. In this thesis the assumption that the quantity of containers is even for all three lines and that they operate 365 days per year was made. The mentioned assumptions result in 1096 TEUs per day for each of the three lines. To enable a fair comparison the assumption that line Z can manage 10 transportations per day were made, the same amount as the Panama railway, which results in 110 TEUs per transportation. Therefore, 110 TEUs per train transportation through CIIT are used in the EcoTransIT calculations. The other values used were weight type as container TEU, average goods as type of goods, 10 tonnes per TEU as weight in t/TEU because of average weight per container stated by (EcoTransIT World, 2024b).

Furthermore, transport mode *train*, train type *double stacked container*, train weight *2 500 tonnes*, emissions standard *EPA NR* and traction *diesel* where chosen. Whilst an empty trip factor of *20%* and a load factor of *47.8%* were given by default from the calculation tool for both scenario 3 and 4. The 20% empty trip factor results in more transportations being carried out, as it is assumed that the trains are only loaded with 80% of the TEUs. Resulting in 88 transportations of 60 TEUs each for 3 and 78 transportations of 88 TEUs each for scenario 4. Moreover, the ferry routing option has been avoided due to route preferences.

Calculation method

To calculate rail emissions EcoTransIT makes use of seven different regions where countries with the highest transport performance were identified and considered due to all countries not having sufficient data available. Other countries within the regions were in some extent used for default values. The regions used are Africa, Asia and Pacific, Australia, Central and South America, Europe, Russia and former Soviet Union and North America.

It is important to note that the used version of ETW for rail might include differences in energy consumption for freight trains depending on locomotives and train configurations used by different companies. Although, these could not be established with enough certainty. Furthermore, they could not be established for specific countries, therefore a differentiation in energy consumption per country were not carried out by ETW(EcoTransIT World, 2024a).

Generally, ETW base many calculations on the European standard EN 16258 for calculations performed in their tool, even though they are longer EN 16258 certified as explained in 2.6. Certain parameters are determined by the tool itself ex distance, weather conditions and traffic jam whilst others can be determined by the user ex vehicle type and load factor. However, ETW supply default values for all parameters within the tool that still are in line with the EN 16258 standard. This report makes use of such default values for load factor of 75 TEU's with the weight of 10 tonne which calculates to 47.8% and an empty trip factor of 20%.

The payload capacity for container wagons differs depending on their size and can be relocated in the *Environment Methodology and Data Update 2024* by EcoTransIT (2024) in table 7 on page 30. The payload capacity for double stacked container wagons are 100 tonnes. The container rail transport calculations for load factor are based on Equation 9 collected from page 31 in the *Environmental Methodology and Data Update 2024* (EcoTransIT, 2024)

$$LF_{Container\ train} = \frac{(Container_{brutto} * Container\ amount_{wagon})}{Payload\ capacity_{container\ wagon}} \qquad (9)$$

where LF*container train* is the load factor for container trains. Further $Container_{brutto}$ represents the brutto weight of the container and is multiplied by the container amount in wagons, $Container\ amount_{wagon}$ and divided by the $Payload\ capacity_{container\ wagon}$.

The gross tonne weight for rail transportation in this thesis is 2500 tonnes per train for the Panama railway and the Mexico railway line Z, which is derived from ETW's average on gross weight for double containers which is further based on statistics from railway companies. The engine technology used by locomotives is also described as a parameter which has a large effect on the emissions release when operating on rail. Therefore, it is possible to choose from a range of different regulations in the calculation tool based on the manufacture year of the locomotive. However, as mentioned in 2.5.6 it cannot be concluded that the Panama railway operates under the limitations presented by UIC in releasing emissions, consequently the calculations executed in this report have not considered such limitations. Similarly, there could not be any relation to the rail route through Mexico, thus it is not regulated in the calculations. Furthermore, the manufacture year for locomotives used on both railway solutions are unknown which strengthens the assumption to not include regulations in the calculations. Therefore, in the calculation tool EPA NR has been chosen under emissions standard as it is the only option for non-regulated trains. Even though EPA is the United States environmental protection agency which does not regulate Panama nor Mexico, however it does not make any differences in the results as the remain unregulated.

ETW group trains into three categories based on their gross tonne weight (GTW), when calculating the final energy consumption (TTW), the categories are less than 1000 GTW, in-between 1000 & 2000 GTW and above 2000 GTW. For the relevance of this paper Equation 10 obtained from the *Environmental Methodology and Data Update 2024* (EcoTransIT, 2024) page 60 have been used in the calculations. It represents the calculation for trains with a GTW higher than 2000 tonnes

≥ 2000 GTW (linear function):

$$EC_{spec} = [WH/Gtkm] = -0.0007 * GTW + 10.577. \qquad (10)$$

where EC*spec* is the specific energy consumption and *Gtkm* is the energy consumption for trains. Further -0.0007 is the rate in which the energy consumption changes in regards to the GTW and 10.577 is the intercept of the linear function.

3.1.3 Time efficiency

Time efficiency will be calculated by comparing the time it takes to pass the Panama Canal, travel around the Panama Canal and how long it would take to transport the same number of containers by train including average time spent on loading from vessel to train and from train to vessel.

For calculating time consumption and distances for sea roues the website Sea-Distances will be used for collecting the data. A tool where origin, destination and speed are modified. As mentioned in 3.1, the average speed of a container vessel with capacity of 4 000-5 000 TEU is 20 knots and with an assumption that a speed reduction of 20% results in 20 knots, it was the chosen speed when calculation the voyage time at sea. However, since the preferred route around the Strait of Magellan did not show in EcoTransIT and two extra ports in South America was added, the calculations for time consumption could be affected.

It is important to note that the destinations derived from Sea-Distances are not in exact accordance with those derived from EcoTransIT. A slight difference in distance appear in scenario 1, scenario 2 and scenario 3, a different distance would affect the emissions released. The emissions for scenario 4 were manually calculated from the distances derived from Sea-Distances, as explained in 3.1.1 which results in the emissions and distance being in complete aligns.

Time consumption for the Panama railway has been collected from the website Logistics Cluster (n.d.) and thereafter manually calculated the total time consumption by multiplying total capacity collected from Panama Canal Railway Company (n.d.-b). When calculating the time consumption for the rail route in Mexico, capacity and time consumption has been collected from the International Railway Journal (2024) and then manually calculating the total time consumption for the 4 700 TEUs by multiplying capacity and time.

Information regarding reloading time and emissions created in the process of loading and unloading cargo for the ports included in this thesis were unavailable. Therefore, reloading time from a Swedish container terminal has been applied to the scenarios that make use of the intermodal solutions. The terminal used is to remain anonymous however it is generally known and considered a reliable and relevant source for this thesis. The information provides regarding time for reloading containers from a vessel onto train and vice versa. The information provided consists of an average of each weekday ranging from November 2023 to May 2024. The daily average of the total period for vessel to train results in 5.2 days and for train to vessel 4.8 days.

4. RESULTS

This chapter provides the result of the intended research questions.

4.1 Emission calculations for each scenario

Results collected from EcoTransIT emission calculator for each scenario are presented in tables, however they are not further discussed in this chapter. Instead, a discussion and a decomposition of every fuel can be found in chapter 5.

4.1.1 Scenario 1

Scenario 1 consist of one sea leg directly from Shanghai, China to Jacksonville, FL, US via the Panama Canal, and the result of calculating energy consumption and emissions for scenario 1 can be seen in Table 2.

Table 2.
Result for scenario 1.

Scenario	Route	Distance (km)	Cargo weight (t/TEU)	Speed reduction	Load factor
1	Shanghai, China – Jacksonville, FL, US via Panama Canal	18 757.53 km	4 700 teu /t/TEU: 10	20%	70%

Energy consumption	
WTW (Megajoule)	**171 361 104**
TTW (Megajoule)	**135 501 984**
GHG emissions (CO_2e)	
WTW (Tonnes)	**11 876**
TTW (Tonnes)	**10 357**
Carbon dioxide (CO_2)	
WTW (Tonnes)	**11 632**
TTW (Tonnes)	**10 267**
Sulphur dioxide (SO_2)	
WTW (Kilogram)	**68 792**
TTW (Kilogram)	**57 915**
Nitrogen oxides (NO_x)	
WTW (Kilogram)	**233 943**
TTW (Kilogram)	**227 946**
Non-methane hydrocarbon (NMHC)	
WTW (Kilogram)	**14 976**
TTW (Kilogram)	**11 236**
Particulate matter (PM10)	
WTW (Kilogram)	**17 259**
TTW (Kilogram)	**16 419**

Note. Table 2. Shows values chosen and default values for each category (port pairs, cargo weight in tonnes per TEU, speed reduction and load factor) and results received from EcoTransIT emission calculator.

4.1.2 Scenario 2

Scenario 2 consist of one sea leg directly from Shanghai, China to Jacksonville, FL, US via the Strait of Magellan, and the result of calculating energy consumption and emissions for scenario 2 can be seen in Table 3.

Table *3*.

Result for scenario 2.

Scenario	Route	Distance (km)	Cargo weight (t/TEU)	Speed reduction	Load factor
2	Shanghai, China – Jacksonville, FL, US via Strait of Magellan	34 603.87 km	4 700 teu /t/TEU: 10	20%	70%

Energy consumption	
WTW (Megajoule)	**317 224 160**
TTW (Megajoule)	**251 117 152**
GHG emissions (CO_2e)	
WTW (Tonnes)	**22 010**
TTW (Tonnes)	**19 205**
Carbon dioxide (CO_2)	
WTW (Tonnes)	**21 558**
TTW (Tonnes)	**19 040**
Sulphur dioxide (SO_2)	
WTW (Kilogram)	**130 563**
TTW (Kilogram)	**110 472**
Nitrogen oxides (NO_x)	
WTW (Kilogram)	**433 741**
TTW (Kilogram)	**422 646**
Non-methane hydrocarbon (NMHC)	
WTW (Kilogram)	**27 750**
TTW (Kilogram)	**20 828**
Particulate matter (PM10)	
WTW (Kilogram)	**32 568**
TTW (Kilogram)	**31 016**

Note. Table 3. Shows the values chosen in each category (port pairs, cargo weight in tonnes per TEU, speed reduction and load factor) and results received from EcoTransIT emission calculator.

4.1.3 Scenario 3

Scenario 3 has been separated into five different calculations due to the calculations not being able to be carried out as one in the tool by EcoTransIT, as explained in 1.4. Table 4 to 7 present the result for each leg and Table 8 present the total result of energy consumption and emissions.

Table 4.

Results for the first leg in scenario 3 from Shanghai, China to Balboa, Panama.

Scenario	Route	Distance (km)	Cargo weight (t/TEU)	Speed reduction	Load factor
3	Shanghai, China to Balboa, Panama	15 847.99 km	4 700 teu /t/TEU: 10	20%	70%

Energy consumption	
WTW (Megajoule)	**144 506 720**
TTW (Megajoule)	**114 459 064**
GHG emissions (CO_2e)	
WTW (Tonnes)	**10 032**
TTW (Tonnes)	**8 757**
Carbon dioxide (CO_2)	
WTW (Tonnes)	**9 826**
TTW (Tonnes)	**8 681**
Sulphur dioxide (SO_2)	
WTW (Kilogram)	**60 250**
TTW (Kilogram)	**51 110**
Nitrogen oxides (NO_x)	
WTW (Kilogram)	**197 744**
TTW (Kilogram)	**192 692**
Non-methane hydrocarbon (NMHC)	
WTW (Kilogram)	**12 648**
TTW (Kilogram)	**9 494**
Particulate matter (PM10)	
WTW (Kilogram)	**14 985**
TTW (Kilogram)	**14 278**

Note. Table 4 Shows values chosen and default values for each category (port pairs, cargo weight in tonnes per TEU, speed reduction and load factor) and results received from EcoTransIT emission calculator.

Table 5.

Results for the second leg in scenario 3 from Balboa, Panama to Colón, Panama via Panama Canal railway for one way transportation.

Scenario	Route	Distance (km)	Cargo weight (t/TEU)	Empty trip factor (ETF)	Load factor
3	Balboa, Panama to Colón, Panama via Panama railway, one transportation.	76 km	75 teu /t/TEU: 10	20%	47.80%

Energy consumption	
WTW (Megajoule)	Per km 111 009/587.61 = 188.916 x 76 = **14 357.63**
TTW (Megajoule)	Per km 83 672/587.61=142.393 x 76 = **10 821.93**
GHG emissions (CO_2e)	
WTW (Tonnes)	Per km (7 /587.61) x 76= **0.905**
TTW (Tonnes)	Per km (6 /587.61) x 76= **0.776**
Carbon dioxide (CO_2)	
WTW (Tonnes)	Per km (7 /587.61) x 76= **0.905**
TTW (Tonnes)	Per km (6 /587.61) x 76= **0.776**
Sulphur dioxide (SO_2)	
WTW (Kilogram)	Per km (27 /587.61) x 76= **3.492**
TTW (Kilogram)	Per km (20 /587.61) x 76= **2.587**
Nitrogen oxides (NO_x)	
WTW (Kilogram)	Per km (102 /587.61) x 76= **13.192**
TTW (Kilogram)	Per km (98/587.61) x 76= **12.675**
Non-methane hydrocarbon (NMHC)	
WTW (Kilogram)	Per km (6 /587.61) x 76= **0.776**
TTW (Kilogram)	Per km (4 /587.61) x 76= **0.517**
Particulate matter (PM10)	
WTW (Kilogram)	Per km (3 /587.61) x 76= **0.388**
TTW (Kilogram)	Per km (2 /587.61) x 76= **0.259**

Note. Table 5. Shows values chosen and default values for each category (port pairs, cargo weight in tonnes per TEU, empty trip factor and load factor). The desired route was not possible to perform due to the ports not existing in the database as explained in 1.4. Therefore, the emissions from EcoTransIT have been calculated from the results given, dived per kilometer then multiplied with the number of kilometers for the actual route.

Table 6.

Results for the second leg in scenario 3 from Balboa, Panama to Colón, Panama via Panama Canal railway for 4 700 TEUs.

Scenario	Route	Distance (km)	Cargo weight (t/TEU)	Empty trip factor (ETF)	Load factor
3	Balboa, Panama to Colón, Panama via Panama railway, 78 transportations.	5 928 km	4 700 teu /t/TEU: 10	20%	47.80%

Energy consumption	
WTW (Megajoule)	14 357.63 x 78 = **1 119 895.14**
TTW (Megajoule)	10 821.93 x 78 = **844 110.54**
GHG emissions (CO_2e)	
WTW (Tonnes)	0.905 x 78 = **70.59**
TTW (Tonnes)	0.776 x 78 = **60.528**
Carbon dioxide (CO_2)	
WTW (Tonnes)	0.905 x 78 = **70.59**
TTW (Tonnes)	0.776 x 78 = **60.528**
Sulphur dioxide (SO_2)	
WTW (Kilogram)	3.492 x 78 = **272.376**
TTW (Kilogram)	2.587 x 78 = **201.786**
Nitrogen oxides (NO_x)	
WTW (Kilogram)	13.192 x 78 = **1 028.976**
TTW (Kilogram)	12.675 x 78 = **988.572**
Non-methane hydrocarbon (NMHC)	
WTW (Kilogram)	0.776 x 78 = **60.528**
TTW (Kilogram)	0.517 x 78 = **40.326**
Particulate matter (PM10)	
WTW (Kilogram)	0.388 x 78 = **30.264**
TTW (Kilogram)	0.259 x 78 = **20.202**

Note. Table 6. Shows values chosen and default values for each category (port pairs, cargo weight in tonnes per TEU, empty trip factor and load factor) in EcoTransIT to receive the result. Numbers received from EcoTransIT when above values are chosen, although the desired route was not possible to perform due to the ports not existing in the database as explained in 1.4. Therefore, the emissions have been multiplied with 78 which is the number of transportations it would require to transport 4 700 TEUs with ETF of 20% as described in 3.1.2.

Table 7.

Results for the third leg in scenario 3 from Colón, Panama to Jacksonville, FL, US.

Scenario	Route	Distance (km)	Cargo weight (t/TEU)	Speed reduction	Load factor
3	Colón, Panama to Jacksonville, FL, US	2 845.37 km	4 700 teu /t/TEU: 10	20%	70 %

Energy consumption	
WTW (Megajoule)	**26 269 228**
TTW (Megajoule)	**20 579 442**
GHG emissions (CO2e)	
WTW (Tonnes)	**1 803**
TTW (Tonnes)	**1 564**
Carbon dioxide (CO_2)	
WTW (Tonnes)	**1 766**
TTW (Tonnes)	**1 551**
Sulphur dioxide (SO_2)	
WTW (Kilogram)	**8 298**
TTW (Kilogram)	**6 598**
Nitrogen oxides (NO_x)	
WTW (Kilogram)	**35 398**
TTW (Kilogram)	**34 474**
Non-methane hydrocarbon (NMHC)	
WTW (Kilogram)	**2 277**
TTW (Kilogram)	**1 703**
Particulate matter (PM10)	
WTW (Kilogram)	**2 213**
TTW (Kilogram)	**2 082**

Note. Table 7. Shows values chosen and default values for each category (port pairs, cargo weight in tonnes per TEU, speed reduction and load factor) in EcoTransIT to receive the result. Numbers are collected from EcoTransIT calculation tool.

Table 8.
Shows values for the result for all three legs in scenario 3 added together as total emissions.

Scenario	Route	Distance (km)	Cargo weight (t/TEU)
3	Shanghai, China to Jacksonville, FL, US through Panama by train, total emissions	24 621.36 km	4 700 teu /t/TEU: 10

Energy consumption	
WTW (Megajoule)	**171 895 843**
TTW (Megajoule)	**135 882 617**
GHG emissions (CO_2e)	
WTW (Tonnes)	**11 905.59**
TTW (Tonnes)	**10 381.53**
Carbon dioxide (CO_2)	
WTW (Tonnes)	**11 662.59**
TTW (Tonnes)	**10 292.53**
Sulphur dioxide (SO_2)	
WTW (Kilogram)	**68 820.38**
TTW (Kilogram)	**57 909.78**
Nitrogen oxides (NO_x)	
WTW (Kilogram)	**234 170.98**
TTW (Kilogram)	**228 154.57**
Non-methane hydrocarbon (NMHC)	
WTW (Kilogram)	**14 985.53**
TTW (Kilogram)	**11 237.33**
Particulate matter (PM10)	
WTW (Kilogram)	**17 228.26**
TTW (Kilogram)	**16 380.2**

Note. Table 8 shows total distance, total amount of TEU and cargo weight used when calculating the total emissions. The total emissions for scenario 3 are based on the results for the three legs presented in table 7, 6 and 4.

4.1.4 Scenario 4

Scenario 4 has been separated into five different calculations due to the calculations not being able to be carried out as one in the tool by EcoTransIT, as explained in 1.4.

Table 9.

Results for the first leg in scenario 4 from Shanghai, China to Salina Cruz, Mexico.

Scenario	Route	Distance (km)	Cargo weight (t/TEU)	Speed reduction	Load factor
4	Shanghai, China to Salina Cruz, Mexico	13 784.436 km	4 700 teu /t/TEU: 10	20%	47.8%

Energy consumption	
WTW (Megajoule)	Per km 115 409 704/12 656.93 = 9 118.3 x 13 784.436 = **125 690 644**
TTW (Megajoule)	Per km 91 412 264/12 656.93 = 7 222.3 x 13 784.436 = **99 555 461.1**
GHG emissions (CO_2e)	
WTW (Tonnes)	Per km 8 012/12 656.93 = 0.633 x 13 784.436 = **8 725.73**
TTW (Tonnes)	Per km 6 993/12 656.93 = 0.552 x 13 784.436 = **7 615.95**
Carbon dioxide (CO_2)	
WTW (Tonnes)	Per km 7 848/12 656.93 = 0.62 x 13 784.436 = **8 547.12**
TTW (Tonnes)	Per km 6 933/12 656.93 = 0.547 x 13 784.436 = **7 550.61**
Sulphur dioxide (SO_2)	
WTW (Kilogram)	Per km 48 119/12 656.93 = 3.801 x 13 784.436 = **52 405.54**
TTW (Kilogram)	Per km 40 818/12 656.93 = 3.224 x 13 784.436 = **44 454.15**
Nitrogen oxides (NO_x)	
WTW (Kilogram)	Per km 157 928/12 656.93 = 12.477 x 13 784.436 = **171 996.56**
TTW (Kilogram)	Per km 153 893/12 656.93 = 12.158 x 13 784.436 = **167 602.11**
Non-methane hydrocarbon (NMHC)	
WTW (Kilogram)	Per km 10 101/12 656.93 = 0.798 x 13 784.436 = **11 000.82**
TTW (Kilogram)	Per km 7 583/12 656.93 = 0.599 x 13 784.436 = **8 258.51**
Particulate matter (PM10)	
WTW (Kilogram)	Per km 11 968/12 656.93 = 0.945 x 13 784.436 = **13 034.13**
TTW (Kilogram)	Per km 11 403/12 656.93 = 0.9 x 13 784.436 = **12 418.8**

Note. Table 9. Shows values chosen and default values for each category (port pairs, cargo weight in tonnes per TEU, speed reduction and load factor), Although the desired route was not possible to perform due to the ports not existing in the database as explained in 1.4. Therefore, the emissions from EcoTransIT have been calculated from the results given, dived per kilometer then multiplied with the number of kilometers for the actual route. All numbers are calculated in Megajoule.

Table 10.

Results for the second leg in scenario 4 from Salina Cruz, Mexico to Coatzacoalcos, Mexico via CIIT railway for one way transportation.

Scenario	Route	Distance (km)	Cargo weight (t/TEU)	Empty trip factor (ETF)	Load factor
4	Salina Cruz, Mexico to Coatzacoalcos, Mexico by train, one transportation.	286.03 km	110 teu /t/TEU: 10	20%	47.8%

Energy consumption	
WTW (Megajoule)	**79 252**
TTW (Megajoule)	**59 736**
GHG emissions (CO_2e)	
WTW (Tonnes)	**5**
TTW (Tonnes)	**4**
Carbon dioxide (CO_2)	
WTW (Tonnes)	**5**
TTW (Tonnes)	**4**
Sulphur dioxide (SO_2)	
WTW (Kilogram)	**7**
TTW (Kilogram)	**1**
Nitrogen oxides (NO_x)	
WTW (Kilogram)	**73**
TTW (Kilogram)	**70**
Non-methane hydrocarbon (NMHC)	
WTW (Kilogram)	**4**
TTW (Kilogram)	**3**
Particulate matter (PM10)	
WTW (Kilogram)	**2**
TTW (Kilogram)	**2**

Note. Table 10. Shows values chosen and default values for each category (port pairs, cargo weight in tonnes per TEU, empty trip factor and load factor), numbers received from EcoTransIT when the values are chosen.

Table 11.
Results for the thrid leg in scenario 4 from Salina Cruz, Mexico to Coatzacoalcos, Mexico via CIIT railway for 4 700 TEUs.

Scenario	Route	Distance (km)	Cargo weight (t/TEU)	Empty trip factor (ETF)	Load factor
4	Salina Cruz, Mexico to Coatzacoalcos, Mexico by train, 53 transportations.	15 159.59 km	110 teu /t/TEU: 10	20%	47.8%

Energy consumption	
WTW (Megajoule)	79 252 x 53 **= 4 200 356**
TTW (Megajoule)	59 736 x 53 **= 3 166 008**
GHG emissions (CO_2e)	
WTW (Tonnes)	5 x 53 = **265**
TTW (Tonnes)	4 x 53 = **212**
Carbon dioxide (CO_2)	
WTW (Tonnes)	5 x 53 = **265**
TTW (Tonnes)	4 x 53 = **212**
Sulphur dioxide (SO_2)	
WTW (Kilogram)	7 x 53 = **371**
TTW (Kilogram)	1 x 53 = **53**
Nitrogen oxides (NO_x)	
WTW (Kilogram)	73 x 53 = **3 869**
TTW (Kilogram)	70 x 53 = **3 710**
Non-methane hydrocarbon (NMHC)	
WTW (Kilogram)	4 x 53 = **212**
TTW (Kilogram)	3 x 53 = **159**
Particulate matter (PM10)	
WTW (Kilogram)	2 x 53 = **106**
TTW (Kilogram)	2 x 53 = **106**

Note. Table 11. Shows values chosen and default values for each category (port pairs, cargo weight in tonnes per TEU, empty trip factor and load factor). The emissions from table 10 have been multiplied with 53 which is the number of transportations it would require to transport 4 700 TEUs.

Table 12.

Results for the third leg in scenario 4 from Coatzacoalcos, Mexico to Jacksonville, FL, US by sea.

Scenario	Route	Distance (km)	Cargo weight (t/TEU)	Speed reduction	Load factor
4	Coatzacoalcos, Mexico to Jacksonville, FL, US	2 353.892 km	4 700 teu /t/TEU: 10	20%	70%

Energy consumption	
WTW (Megajoule)	Per km 23 032 772/2 489.38 = 9 252.41 x 2 353.892 = **21 779 181.1**
TTW (Megajoule)	Per km 18 009 234/2 489.38 = 7 234.425 x 2 353.892 = **17 029 056.2**
GHG emissions (CO_2e)	
WTW (Tonnes)	Per km 1 578/2 489.38 = 0.634 x 2 353.892 = **1 429.12**
TTW (Tonnes)	Per km 1 368/2 489.38 = 0.549 x 2 353.892 = **1 293.54**
Carbon dioxide (CO_2)	
WTW (Tonnes)	Per km 1 545/2 489.38 = 0.621 x 2 353.892 = **1 460.91**
TTW (Tonnes)	Per km 1 356/2 489.38 = 0.544 x 2 353.892 = **1 282.19**
Sulphur dioxide (SO_2)	
WTW (Kilogram)	Per km 6 870/2 489.38 = 2.759 x 2 353.892 = **6 496.09**
TTW (Kilogram)	Per km 5 374/2 489.38 = 2.158 x 2 353.892 = **5 081.51**
Nitrogen oxides (NO_x)	
WTW (Kilogram)	Per km 30 952/2 489.38 = 12.433 x 2 353.892 = **29 267.39**
TTW (Kilogram)	Per km 30 142/2 489.38 = 12.108 x 2 353.892 = **28 501.47**
Non-methane hydrocarbon (NMHC)	
WTW (Kilogram)	Per km 1 993/2 489.38 = 0.801 x 2 353.892 = **1 884.52**
TTW (Kilogram)	Per km 1 490/2 489.38 = 0.598 x 2 353.892 = **1 408.9**
Particulate matter (PM10)	
WTW (Kilogram)	Per km 1 862/2 489.38 = 0.748 x 2 353.892 = **1 760.66**
TTW (Kilogram)	Per km 1 747/2 489.38 = 0.702 x 2 353.892 = **1 651.92**

Note. Table 12. Shows values chosen and default values for each category (port pairs, cargo weight in tonnes per TEU, numbers of TEUs, speed reduction and load factor) in EcoTransIT. The solution presented in 3.1.1 has been adapted on this route, as the desired ports were not available in the tool provided på EcoTransIT.

Table *13*.

Shows values for the result for all three legs in scenario 4 added together as total emissions.

Scenario	Route	Distance (km)	Cargo weight (t/TEU)
4	Shanghai, China to Jacksonville; FL, US through Mexico by train, total emissions.	31 297.918 km	4 700 teu /t/TEU: 10

Energy consumption	
WTW (Megajoule)	**151 670 181**
TTW (Megajoule)	**119 750 525**
GHG emissions (CO_2e)	
WTW (Tonnes)	**10 419.85**
TTW (Tonnes)	**9 121.49**
Carbon dioxide (CO_2)	
WTW (Tonnes)	**10 273.03**
TTW (Tonnes)	**9 044.8**
Sulphur dioxide (SO_2)	
WTW (Kilogram)	**59 272.63**
TTW (Kilogram)	**49 558.66**
Nitrogen oxides (NO_x)	
WTW (Kilogram)	**205 132.95**
TTW (Kilogram)	**199 813.58**
Non-methane hydrocarbon (NMHC)	
WTW (Kilogram)	**13 097.34**
TTW (Kilogram)	**9 826.41**
Particulate matter (PM10)	
WTW (Kilogram)	**14 900.79**
TTW (Kilogram)	**14 176.72**

Note. Table 13. Shows values for the total distances, cargo and cargo weight used when calculating the total emissions, The total emission based on the results in table 9, 11 and 12 that were furthered based on calculations from EcoTransIT.

4.2 Time efficiency for each scenario

The following chapter provides the result for time consumption for each scenario.

4.2.1 Scenario 1

The distance of scenario 1 is 18 757.53 km between Shanghai, China and Jacksonville, FL, US (EcoTransIT, n.d.). However, when computing the modes in Sea-Distances, a distance of 18 733 km was received. Since the distance only differ by 24 km, the distance and time consumption are based on numbers received from Sea-Distances. When computing the calculation tool provided by Sea-Distances (n.d.) with 20 knots, the voyage takes 21 days.

4.2.2 Scenario 2

For scenario 2, the total distance between Shanghai, China and Jacksonville, FL, US via Strait of Magellan with two added ports has a range of 34 603.87 km (EcoTransIT, n.d.). As mentioned in 3.1.3, the preferred route did not show when calculation emissions in EcoTransIT because of the model only showing the fastest route. Since two ports were added, it affects the calculations for time consumption in scenario 2. However, the data collected from Sea-Distances has been used when calculation time consumption for this scenario. The distances provided by EcoTransIT and Sea-Distances differ by around 3 800 km but since the intended route only focuses on the route between Shanghai, China and Jacksonville, FL, US, the distance for calculation time consumption were collected from Sea-Distances (n.d.) and resulted in a total voyage time of 34.5 days.

4.2.3 Scenario 3

For the third scenario, the route has been divided into three separate legs. From Shanghai, China to Balboa, Panama by sea, Balboa, Panama to Colón, Panama by railway and from Colón, Panama to Jacksonville, FL, US by sea. The first leg is 15 848 kilometers and takes approximately 18 days (Sea-Distances, n.d.). For the second leg from Balboa, Panama to Colón, Panama by train, the distance is 76 km and takes 1.5 hours per departure (Logistics Cluster, n.d.). Moreover, the Panama Canal Railway Company (n.d.-b) states that they only operate 10 departures day with a capacity of 75 TEUs. However, the empty trip factor in the calculation tool is by default 20% which reduce the capacity to 60 TEUs per departure which results in approximately 8 days to transport 4 700 containers by train. Furthermore, the total time for reloading cargo from vessel to train and then from train to vessels adds another 10 days to this leg of the route. The last leg is 2 845.37 km (EcoTransIT World, 2024b). However, when computing the modes in Sea-Distances, a distance of 2 787 km was received. Since the distance only differ by around 58 km, the distance for calculating time consumption is based on numbers received from Sea-Distances (n.d) which results in a total transit time of approximately 3 days when operation on 20 knots. The total operation for scenario 3 takes approximately 39 days.

4.2.4 Scenario 4

Scenario 4 includes 3 legs, from Shanghai, China to Salina Cruz, Mexico by sea then with train from Salina Cruz, Mexico to Coatzacoalcos, Mexico finishing with a sea route from Coatzacoalcos, Mexico to Jacksonville, FL, US. The first leg between Shanghai, China to Salina Cruz, Mexico is 13 784.436 km (EcoTransIT, n.d.) and when operating the vessel in 20 knots, the total voyage time is around 15.5 days (Sea-Distances, n.d.). The second route between Salina Cruz and Coatzacoalcos, Mexico by railway is 286 km long (EcoTransIT, n.d.) and takes approximately 7h (International Railway Journal, 2024), however, the identified time consumption for this route is only based on passenger trains since they have not yet started the cargo operation and therefore not confirmed time for cargo yet (International Railway Journal, 2024). The train is assumed to have a capacity of 110 containers per transportation, this means that for this number of containers, a total of 10 departures a day results in a total transit time of 5.4 days for transporting 4 700 TEUs. Furthermore, the total time for reloading cargo from vessel to train and then from train to vessels adds another 10 days to this leg of the route. For the third leg in scenario 4, the sea route between the port of Coatzacoalcos, Mexico and the port of Jacksonville, FL, US has a distance of 2 353.892 km (EcoTransIT, n.d.) which takes approximately 3 days (Sea-Distances, n.d.). This results in a total transit of for scenario 4 is approximately 34 days.

5. DISCUSSION

This study presents the emissions generated by four different routes using shipping and/or railway transportation to transport 4 700 TEUs from Shanghai, China to Jacksonville, FL, US through or around Panama, which are presented in 4.1. Furthermore, the time efficiency for each route has been calculated, which is presented in 4.2. With the current challenges that the Panama Canal are facing, the study provided some interesting results regarding the most effective alternative route when analyzing total emissions and time spent per route.

5.1 Total emissions for each route

All emissions are discussed separately.

5.1.1 Energy consumption

Table 14.

WTW and TTW energy consumption for all scenarios.

Scenario 1 (sea route Panama Canal)	
WTW (Megajoule)	**171 361 104**
TTW (Megajoule)	**135 501 984**
Scenario 2 (sea route Strait of Magellan)	
WTW (Megajoule)	**317 224 160**
TTW (Megajoule)	**251 117 152**
Scenario 3 (intermodal route Panama rail)	
WTW (Megajoule)	**171 895 843**
TTW (Megajoule)	**135 882 617**
Scenario 4 (intermodal route CIIT rail)	
WTW (Megajoule)	**151 670 181**
TTW (Megajoule)	**119 750 525**

When analyzing the energy consumption WTW for 4 700 TEUs for each scenario it becomes evident that the distance is a major factor for routes solely based on shipping, which are scenario 1 and scenario 2. The WTW energy consumption for scenario 2, Shanghai, China to Jacksonville, FL, US around the strait of Magellan is 145 863 056 megajoule more than scenario 1, Shanghai, China to Jacksonville, FL, US through the Panama Canal, it is also 15 846.34 kilometers longer. A similar correlation cannot be found between energy consumption for the scenarios that make use of both rail and sea transportation. The clearest examples being scenario 2 and scenario 4, Shanghai, China to Jacksonville, FL, US through Mexico by train, which only differs 3 305.952 kilometers whilst the WTW energy consumption from scenario 2 is 165 553 979 megajoule higher than scenario 4. Scenario 3, Shanghai, China to Jacksonville, FL, US through the Panama railway, which also make use of rail show of similar results, it is 9 982.51 kilometers shorter than scenario 2 but still manages to create 145 328 317 megajoule less of WTW energy consumption.

With these results it is likely to believe that the rail transportations create less WTW and TTW energy consumption which is further strengthen if one were to take a closer look at scenario 3 and scenario 4. In order to enable transportations of 4 700 TEUs with an ETF of 20%, scenario 3 requires 78 transportations with 60 TEUs which adds up to 5 928 kilometers of rail transportation whilst scenario 4 requires 53 transportations with 88 TEUs which adds up to 15 159.59 kilometers of rail transportation. Scenario 4, which consists of longer rail transportations, create 20 225 662 megajoule less in WTW energy consumption than scenario 3. Which is interesting because although the entire route is more than 9 000 kilometers longer than scenario 3, the WTW energy consumption still manages to be lower.

Another interesting perspective to look at is the emissions created for one single rail route, although the research question for this thesis focuses on 4 700 TEU's it would also be possible to use the rail routes for smaller amounts of cargo. Scenario 3 results in 14 357.63 megajoule whilst scenario 4 results in 79 252 megajoule WTW energy consumption, the large differences can be explained by the lengths of the routes and the capacity of containers they are able to carry. It instantly becomes apparent that scenario 3 would be the favorable alternative for a batch of 60 containers with an ETF of 20% in regard to WTW energy consumption, once again TTW energy consumption display the same pattern. However, if one were to exclusively look at the energy consumptions created it would take more than five routes with scenario 3 to reach the same levels created by scenario 4 which results in 300 TEUs transported. The CO_2e, CO_2, NO_x, NMHC and PM10 show a similar pattern of scenario 3 being able to carry out 5 transportations to reach the emissions created by one rail route by scenario 4. The only exception is SO_2 WTW where it would require two trips for scenario 3 to reach the level of scenario 4, however scenario 4 still creates more SO_2 TTW than scenario 3 in only one trip.

5.1.2 GHG emissions (CO_2e) and Carbon dioxide (CO_2)

Table 15.

WTW and TTW GHG emissions (CO_2e) for all scenarios.

Scenario 1 (sea route Panama Canal)	
WTW (Tonnes)	**11 876**
TTW (Tonnes)	**10 357**
Scenario 2 (sea route Strait of Magellan)	
WTW (Tonnes)	**22 010**
TTW (Tonnes)	**19 205**
Scenario 3 (intermodal route Panama rail)	
WTW (Tonnes)	**11 905.59**
TTW (Tonnes)	**10 381.53**
Scenario 4 (intermodal route CIIT rail)	
WTW (Tonnes)	**10 419.85**
TTW (Tonnes)	**9 121.49**

To keep the discussion concise CO_2 and CO_2e will not be discussed separately, instead CO_2e will be used to cover both emissions. In all scenarios the release of CO_2 and CO_2e are similar, with the amount of CO_2 being slightly smaller, which is to no surprise considering that CO_2e depends on the CO_2. The consistency of the pattern supports the choice to refrain from closer examinations of both results.

In the results it can be found that scenario 2 has a significantly larger release of $CO2_e$ in both WTW and TTW when transporting 4 700 TEUs, it nearly doubles the amount of all the other scenarios. Once again scenario 2 and scenario 4 differ greatly, whilst the distance of the scenarios is similar both the release of WTW CO_2e and TTW CO_2e is more than 10 000 tonnes larger. Another interesting result is the similarity in CO_2e between scenario 1 and scenario 3 even though they differ 5 863.83 kilometers, with the rail route on scenario 3 lasting 5 928 kilometers of the total route.

Furthermore, the result of one rail route in scenario 3 generating less CO_2e than one rail route in scenario 4 as found in table 5 and table 10 cannot be directly related to the CO_2e emissions for the entire routes. Various factors could impact the total emissions of CO_2e, scenario 4 has the ability to transport more containers in one transportation which requires less trips however the route for one rail trip for scenario 4 is significantly longer than for scenario 3 along with the total weight of the train being heavier due to more containers. Therefore, the higher CO_2 emissions seem to emerge from the shipping part of the routes. Coatzacoalcos is north to Colón which enable a shorter route to Jacksonville, FL, US as well as Salina Cruz being north to Balboa which could enable a shorter route from Shanghai, China. This reasoning is supported by comparing table 4 with table 9 and table 7 with table 12 where it is clear that sea distances for scenario 4 are shorter than scenario 3.

It is important to note that the El Niño climate phenomenon is linked to warmer water levels meaning that if the water temperature increases so does the effects of El Niño. When CO_2 is released the GHG is affected which, an increase of GHG, as explained in 2.5.1, would lead to higher temperatures within the atmosphere thus also increased water temperature. This means that the continuing release of CO_2 negatively affect the already existing issue faced by the Panama Canal.

5.1.3 Sulphur dioxide (SO_2)

Table 16.

WTW and TTW sulphur dioxide (SO_2) for all scenarios.

Scenario 1 (sea route Panama Canal)	
WTW (Kilogram)	**68 792**
TTW (Kilogram)	**57 915**
Scenario 2 (sea route Strait of Magellan)	
WTW (Kilogram)	**130 563**
TTW (Kilogram)	**110 472**
Scenario 3 (intermodal route Panama rail)	
WTW (Kilogram)	**68 820.38**
TTW (Kilogram)	**57 909.78**
Scenario 4 (intermodal route CIIT rail)	
WTW (Kilogram)	**59 272.63**
TTW (Kilogram)	**49 558.66**

The results of sulphur dioxide generally follow the above pattern with scenario 2 generating a significantly larger amount. Whilst scenario 4 continues to generate the lowest release of emission, 9 519.37 kilograms less of WTW SO_2 than the second least which is scenario 1. Scenario 3 also releases higher amounts of WTW SO_2 than scenario 4 when transporting 4 700 TEUs, which aligns with the SO_2 released from one train transport as explained in 5.1.1. If stricter regulations regarding SO_2 emissions would be implemented outside ECA, it can be interpretated that emissions of SO_2 would decrease. A similar result would be found if the trains were under regulations, the higher release of SO_2 for scenario 4 per train route is explained by the length of the route. If there were information regarding scenario 4 making use of electrified locomotives instead of diesel it would have been interesting to compare the emissions of scenario 3 and scenario 4 as it would display the impact the type of train has on the emissions released. It could be interpreted that it would result in lower emissions for scenario 4 which could make it an even stronger competitor to the Panama Canal railway.

5.1.4 Nitrogen oxides (NO_x)

Table 17.

WTW and TTW nitrogen oxides (NO_x) for all scenarios.

Scenario 1 (sea route Panama Canal)	
WTW (Kilogram)	**233 943**
TTW (Kilogram)	**227 946**
Scenario 2 (sea route Strait of Magellan)	
WTW (Kilogram)	**433 741**
TTW (Kilogram)	**422 646**
Scenario 3 (intermodal route Panama rail)	
WTW (Kilogram)	**234 170.98**
TTW (Kilogram)	**228 154.57**
Scenario 4 (intermodal route CIIT rail)	
WTW (Kilogram)	**205 132.95**
TTW (Kilogram)	**199 813.58**

The NO_x emissions released are nearly identical for scenario 1 and scenario 3 which both operate on sea for the same distances outside the Panama Canal. Whilst scenario 2 and scenario 4 continue to differ, the NO_x emissions released from scenario 2 are 228 608.05 kilograms WTW and 222 832.42 TTW higher than those from scenario 4. The relation between scenario 3 and scenario 4 is similar to the one found in 5.1.2, with scenario 4 generating less NO_x emissions for the total route when transporting 4 700 TEUs.

5.1.5 Non-methane hydrocarbon (NMHC)

Table 18.

WTW and TTW non-methane hydrocarbon (NMHC) for all scenarios.

Scenario 1 (sea route Panama Canal)	
WTW (Kilogram)	**14 976**
TTW (Kilogram)	**11 236**
Scenario 2 (sea route Strait of Magellan)	
WTW (Kilogram)	**27 750**
TTW (Kilogram)	**20 828**
Scenario 3 (intermodal route Panama rail)	
WTW (Kilogram)	**14 985.53**
TTW (Kilogram)	**11 237.33**
Scenario 4 (intermodal route CIIT rail)	
WTW (Kilogram)	**13 097.34**

TTW (Kilogram)	**9 826.41**

Scenario 1, 3 and 4 display very similar results in regards to the WTW release of NMHC, however scenario 4 generates almost 12 770 kilograms more of TTW NMHC than both scenario 1 and 3. Knowing that large parts of the calculations for scenario 4 are based on rail transportation and that one route of scenario 4's rail trip generates more NMHC than one rail trip of scenario 3, it could be assumed that the higher volumes of TTW NMHC were created by rail transportation. However, if one were to take a closer at table 11 and 21 it would become apparent that both WTW and TTW NMHC emissions from the train routes are almost insignificant to the entire routes. Scenario 2 continues to generate the largest emissions in both WTW and TTW NMHC emissions.

5.1.6 Particulate matter (PM10)

Table 19.

WTW and TTW particulate matter (PM10) for all scenarios.

Scenario 1 (sea route Panama Canal)	
WTW (Kilogram)	**17 259**
TTW (Kilogram)	**16 419**
Scenario 2 (sea route Strait of Magellan)	
WTW (Kilogram)	**32 658**
TTW (Kilogram)	**21 016**
Scenario 3 (intermodal route Panama rail)	
WTW (Kilogram)	**17 228.26**
TTW (Kilogram)	**16 380.2**
Scenario 4 (intermodal route CIIT rail)	
WTW (Kilogram)	**14 900.79**
TTW (Kilogram)	**14 176.72**

PM10 shows of similar results as NMHC emissions, where scenario 2 generates the largest amount in WTW and TTW and scenarios 1 and 3 continue to be almost identical in both WTW and TTW. However, scenario 4 generates a smaller amount by 2 300 kilograms in WTW and by 2 200 kilograms in TTW.

The interesting relation between scenario 2 and scenario 4 is sustained by scenario 2 generating more than double the amount of PM10 in WTW compared to scenario 4 even though the distances for both scenarios are similar. Seemingly the sea route generates more PM10 which can be strengthen if one were to look at table 11, where it is evident that the train routes of scenario 4 only generate 106 WTW and TTW kilograms of PM10.

5.2 Time efficiency for each scenario

Table 20.

Total days spent on each route.

Scenario 1 (sea route Panama Canal)	21 days
Scenario 2 (sea route Strait of Magellan)	34.5 days
Scenario 3 (intermodal route Panama rail)	39
Scenario 4 (intermodal route CIIT rail)	34 days

When comparing the time efficiency for the four scenarios, it becomes clear that scenario 1 from Shanghai, China to Jacksonville, FL, US is the fastest alternative with a voyage time of 21 days. This becomes reasonable if one were to look on the length of the different scenarios, where scenario 1 is the shortest by 5 863.83 kilometer at the least, and the fact that it does not make use of any intermodal solutions. However, the calculations do not consider the current challenges with the Panama Canal as presented in 1.1. With this information in mind the short transaction time of scenario 1 might not be as attractive of a choice, as the time cannot always be certain. As mentioned in 1.2 El Niño reoccurs whit a couple of years in-between which furthers the reasoning that this route is uncertain in time efficient, at least to an extent. Further the continued releases of CO_2 could increase the issue, as explained in 5.1.2, which would make the route even more uncertain.

In the result, it can be seen that scenario 2 and 4 is almost identical when it comes to time efficiency. Scenario 2 is the longest route by kilometer followed by scenario 4 which is the second longest route, however, the distance only differs by 3 306 kilometers. It is an interesting result because looking at 4.2.4, it is obvious that scenario 4 is significantly less time consuming when excluding 10 extra days for handling in terminal when loading and onloading from vessel to train. It is important to note that the distance is even longer when calculated in sea routes than in EcoTransIT, as explained in 4.2, for scenario 2 which could make the time more even. With the assumption that the train can operate 10 times daily with 110 TEUs per transportation it would not be unlikely that the relative short transit time is partly due to the capacity of the trains but instead due to the shipping part. Along with the argument that scenario 4 has a shorter distance between the ports by sea transportation, as presented in 5.1.2, it is not surprising that it has a slightly shorter transit time.

Scenario 3 is the most time-consuming route from Shanghai, China to Jacksonville, FL, US with a railway solution through Panama with a time of 39 days including time for loading and unloading the train. The Panama railway solution has the ability to carry out 10 transport of 75 TEUs daily which results in more train trips than scenario 4. However, the total distances for containers on train remains shorter than scenario 4, as the rail route of scenario 3 is less than a third of the rail route in scenario 4. Therefore, the longer transit time could not be explained by the capacity of TEUs per train but rather by the number of trips the railway can handle daily. Along with the slightly longer sea route than scenario 4.

It is important to note that the time calculations for both scenarios that make use of an intermodal solution, 3 and 4, includes time for transshipment provided by a Swedish terminal. Therefore, it could affect the result if time of transshipment was collected from the actual port terminals used in the various scenarios. It must also be noted that none of the scenarios, except scenario 2, takes port stops along the way into consideration which also can affect the result.

Moreover, it can be stated that the railway between the ports in Mexico has not yet been established for cargo capacity and the connected ports are being adjusted for the expected volume of cargo. Scenario 4 can therefore not be considered an established route at this moment.

5.3 Most suitable route for 4 700 containers

The final research question of this thesis requires a trade-off between emissions and time for a route to qualify as most suitable for 4 700 TEUs. One could argue for the sake of scenario 1 due to its time efficiency and, in relation to the other scenarios, relatively low release of emissions. However, it would include the risk of El Niño occurring which, as presented in 1.1, lowers the capacity of the Panama Canal and could result in heavily delayed vessels.

As stated in 2.1 marine container vessels have a significantly smaller reaction to the weight of containers in regard to emissions and energy consumption than other transport modes. Therefore, one could argue that scenario 1 would be well suited for heavier containers as it does not make use of intermodal solutions, which would have a larger effect on the emissions and energy consumption. The quantity of 4 700 TEUs is based on the maximum capacity of a Panamax vessel according to EcoTransIT. However, as stated in 2.2 vessels have increased in size since Panamax was originally introduced, meaning that the container vessels passing through the Panama Canal in scenario 1 are not limited to 4 700 TEUs in regard to transit time. If a vessel were to have the capacity of 10 000 TEUs instead the transit time would remain the same and it is likely that it would be more profitable. However, the loading and reloading time in port would increase along with the emissions. As explained in 3.1.1 an increase of cargo results in lower emissions for vessels, which is reasonable considering that the weight of cargo does not affect the emissions extensively. Therefore, a larger vessel with an increased amount of TEUs would most likely result in lower emissions per TEU, if it has a similar percentage of load factor as the Panamax used in this thesis. However, as explained in 5.1.2 the effects of increased GHG released the climate phenomena El Niño could increase, thus resulting in even fewer slot times available or the canal being unable to operate at all during periods. This would further increase the demand of the other routes which could lead to increased speed during sea transportation which results in higher emissions released.

Scenario 2 is proven to have the thirds longest transit time together with the largest amount of emission released. Furthermore, the time efficiency differs greatly compared to scenario 1. Therefore, both results are most likely heavily dependent on the length of scenario 2, it is the longest route and only operates by sea. It is important to note that the emissions released include two port stops along the way, as explained in 3.1.1. Although, the gap between scenario 2 and the scenario which releases the second most emissions is so significant that it cannot solely be explained by the port stops. All together the option remains safe from current challenges that the Panama Canal are facing and does not require an intermodal solution. Due to emissions created when reloading containers on the intermodal solutions being excluded from this thesis and the possible waiting time for the Panama Canal during El Niño not being included in the time calculations, one could argue that the result for scenario 2 are the most accurate. Although, it is very unlikely that adding the reloading emissions for scenarios 3 and 4 would make them reach the same amount as scenario 2, as explained in 3.1, and that the waiting time for scenario 1 would be almost 2 weeks. Scenario 2 seems like a more reliable option than scenario 1 and scenario 4, due to it not depending on water levels and is proven to be functioning. If one wanted to make use of scenario 2 but is hesitant due to the large amount of emission released, a possible solution would be to make use of even more slow steaming as explained in 2.2. This would increase the transit time but also lower the emissions created. This strategy could be included in all scenarios, however as scenario 2 creates a significantly larger amount of emissions it would be the best suited for this route.

Scenario 3 provides an intermodal solution which seemingly works well. However, the relatively small amount of cargo, 60 TEUs per train with an ETF of 20% and the train only being able to carry out 10 transportations daily increases the time and capacity for the route. Even in the best-case scenario, with 75 TEUs with an ETF of 0% transported, scenario 4 remains a competitive solution for rail. As mentioned, scenario 3 has a very similar result in emissions released as scenario 1, even though it is 5 863.83 kilometers longer than scenario 1. The scenario provides a stable solution for passing the Panama even though it has a longer transit time than scenario 1. It can be assumed that the differences in transit time heavily depend on the usage of railroad and the added time for reloading the containers in port. Further, the trains are not mainly restricted by the capacity of them but instead, of the number of daily transportations they are able to carry out. If the transportations were to double to 20 per day the transit time would decrease by four days resulting in 35 days which is the almost the same as scenario 2.

Scenario 4 display the lowest emissions released when transporting 4 700 TEUs whilst being the second most time efficient alternative. However, the results in this thesis are strictly theoretical for scenario 4 and with several assumptions which affects both transit time and emissions released.

Both scenario 3 and 4 would be well suited for transporting cargo from the US East coast to the US West coast, although this is noting the chosen route it is still an interesting perspective. This solution would enable transportation of cargo whilst completely avoiding option of the canal or the option to travel around Cape Horn. It could make use of smaller containerships on both sides of Panama and Mexico and use the railway to transport TEUs onto the other side where they again would be loaded onto smaller containerships to carry them to the final ports. This route would not be as suitable for scenario 1 and scenario 2 as it would result in longer transit times and higher emissions released. Therefore, it can be interpreted that scenario 1 and scenario 2 are mainly suited for longer routes whilst the railway solutions in scenario 3 and scenario 4 could benefit different routes with different distances.

It is important to note that the fuel types used for all scenarios have a significant effect on the emissions released, if they were to change the results would differ. As presented in 2.2 LNG is an established fuel type which could reduce certain emissions, however one could assume that if all the routes were to switch to LNG a similar percentage in emission could be assumed for the sea routes. Similarly, a change in locomotives would generate different results, it could be used as a benefit for themselves if only one of scenario 3 or scenario 4 were to switch to electrified locomotives, which would make them a more attractive option.

5.4 Method discussion

The various method used for this study can be discussed. Calculating energy consumption and emissions with EcoTransIT were suitable for the railway stations and ports available at the website, however, there were two ports and two train stations that were not available for the desired transport mode. This resulted in manual calculations for Scenario 3 regarding the two chosen railway stations and the ports selected in Mexico in Scenario 4 which could influence the result because the actual calculation tool takes factors as speed, fuel consumption, weather and hull fouling in consideration for each route. An improvement to future research regarding emission calculations would be to collect fuel and energy consumption data from vessels sailing these routes which could lead to a more accurate result. To collect data about time consumption for each sea route, Sea-Distances were used. It was noted that the distances from EcoTransIT and Sea-Distances had some differences as explained in 5.2. The website does not share any information about who made the website nor how they calculate/collect data regarding the distances therefore, an analyze about the creditability of the website cannot be done. However, serval reports that make use of Sea-Distances as a reference to calculate distances has been found, which improve the credibility. For future research, using data collected from vessels would be suitable for analyzing time consumption per route.

To improve the method of this study and the result, taking port stops, loading, and unloading in ports along the way should have been taken into consideration since it is not likely that a vessel does not have any port stops between the origin and destination. Moreover, improvements can be done regarding the method for calculating the emissions and energy consumption for each route that includes intermodal solutions, this method did not take emissions created when reloading from vessel to train and vice versa into consideration which effect the result.

6. CONCLUSION

Decreased capacity in the Panama Canal has led to disruption in the logistic chain and forced ship owners to find suitable alternative routes. The aim of the study was to find the most suitable route through and around Panama from Shanghai, China to Jacksonville, FL, US. In order to investigate emission released and transit time four routes were identified and analyzed.

If one were to solely look at the emission released, CO_2e, CO_2, SO_2, NO_x, NMHC and PM10, it becomes evident that scenario 4 is the favorable route. Secondly, scenario 1 and 3 display similar amounts of emissions released, with scenario 3 releasing a slightly higher amount. However, emissions created when reloading cargo is not included in either scenario 4 or scenario 3, which would increase their emissions released. Therefore scenario 1 becomes the second most favorable route and scenario 3 the third in regards of emissions. Lastly, scenario 2 generates the highest emissions released in all results, thus it is the least favorable route in regards of emissions.

If analyzing the time consumption for each scenario, it is clear that scenario 1 is the most time efficient route followed by Scenario 4, Scenario 2 and Scenario 3. The explanation behind Scenario 1 will be that it only includes one leg and includes the chokehold point the Panama Canal, which enables a shorter transit through Panama. The second most time efficient route, scenario 4, includes an intermodal solution with train through Mexico instead of using the Panama Canal which enable shorter sea legs from both Jacksonville, FL, US and Salina Cruz, Mexico. However, the train ride in Mexico takes around 7 hours which adds significant time, especially considering reloading time. Meanwhile, the third most time efficient route, scenario 2, could be explained by the lack of using intermodal solutions, therefore not requiring extra time for reloading, but still being the longest route. The length of the route along with the two port stops are concluded to be the reason behind the long transit time.

Scenario 3 is the least time efficient route, and it can be explained by longer sea leg from Jacksonville, FL, US and Balboa, Panama, however the ride of 1.5 hours it becomes evident that the transit times of the railways is not the main factor as mentioned in 5.2. Instead, the long transit time could be explained by reloading time and the number of transportations that the railway is able to handle daily. The slowest route turned out to be scenario 2 which can be explained by it representing the longest distance and the two port stops it includes.

The conclusion for transporting 4 700 TEUs from China, Shanghai to Jacksonville, FL, US becomes that scenario 1 is the most time efficient and has the second lowest emissions released, thus making it the most favorable. However, the uncertainty in security regarding time related to El Niño must be considered, ultimately it depends on how sensitive the cargo transported is in regards of arriving on time. Theoretically scenario 4 have a good trade-off between transit time and emissions released making it an attractive solution for transporting 4 700 TEUs from the destinations in this thesis, even if it cannot be confirmed. Therefore, in the results of this thesis scenario 4 would be considered relatively suitable in regard to both emissions and time efficiency. Scenario 3 provides longer transit times and slightly higher releases of emissions than scenario 1. Lastly, scenario 2 would be the least favorable option in regard to emissions for transporting 4 700 TEUs although it has a competitive transit time. As mentioned in 5.3 a suitable strategy for scenario 2 would be to make use of slow steaming whilst operating however this would increase the transit time, thus scenario 2 is still the least favorable scenario.

7. RECOMMENDATIONS FOR FURTHER RESEARCH

If future research were to be conducted it would be recommended to include reloading emissions and time added for more accurate results on scenarios that make use of intermodal solutions. Another interesting angle would be to add profitability of the four routes into the comparison which would give a broader understanding of which route would be the most beneficial. Additionally, other fuel types would generate different results and could give an interesting perspective on how renewable sources of energy and fuel types affects the emissions created.

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