IJEGEO

International Journal of Environment and Geoinformatics 10(2):048-060 (2023)

Review Article

Comparison of Maritime and Road Transportations in Emissions Perspective: A Review Article

Kevin Nusa[1,*], Gizem Kodak[2]

[1] University of Kyrenia, Institute of Graduate Studies, Department of Maritime Transportation and Management Engineering, Mersin TURKIYE
[2] University of Kyrenia, Faculty of Maritime Studies, Department of Maritime Transportation Management Engineering, Mersin TURKIYE

* Corresponding author: K.Nusa
* E-mail: k20201498@std.kyrenia.edu.tr

Received 21.01.2023
Accepted 16.04.2023

How to cite: Nusa and Kodak (2023). Comparison of Road and Maritime Transportations in Emissions Perspective. *International Journal of Environment and Geoinformatics (IJEGEO)*, 10(2): 048-060. doi. 10.30897/ijegeo.1254161

Abstract

The International Maritime Organization (IMO) in its attempt to avert the global environmental crisis continues to provide policies to mitigate anthropogenic emissions from the transport industry. The greenhouse gas emissions from the transport industry are relatively large, alarming, and continue to increase. Therefore, it is the focal point for the fight against global warming. This article reviews transport emissions with a focus limited to maritime and road transport. The purpose of this review article is to compare maritime and road transport from an emission perspective. Thus, it aims to create a source for future studies and to contribute to the existing literature. This study has used the PRISMA method to evaluate and review relevant scientific papers published. For this purpose, sixty-two articles published from 2012-2022 were found through the keywords search. After a screening of the full body text, eight articles were selected for the final review. The data and evidence across the articles reviewed have suggested that maritime transport contributes relatively little to the transport's CO2 emissions footprint, given the enormous volume of freight transported. This study presents a review that highlights the comparative advantage of maritime and road transport from an emission perspective. It supports the environmental superiority of maritime transport in terms of CO2 emission and presents an infrastructure for further scientific comparison.

Keywords: – Maritime emissions, Road emissions, GHG emissions, PRISMA, Systematic literature review

Introduction

Transportation modes are easily classified according to the medium they engage. Given this, land transportation, maritime transportation, and air transportation are easily identified from their engagement with the land, bodies of water, and air space respectively for the movement of freight and passengers both locally and across the globe. Land transportation is an umbrella name that encapsulates road, railway, and pipeline transportation. This article aims at comparing road emissions and maritime emissions; the motivation of this study is to draw attention to their environmental effects by reviewing studies comparing the two transportation systems in terms of emissions. Road transport, therefore, is that form of land transportation that engages the road network, facilitated by trucks, public buses, and private cars among others; it is regarded as the most dominant mode of transportation available to man today. This is due to its easy accessibility, reliability, flexibility, low capital cost, and low infrastructure cost. On the other hand, maritime transportation is the movement of freight or passengers, particularly in commercial volume via ships over a body of water. It could be on oceans, coasts, seas, lakes, rivers, or channels. It engages physical properties like buoyance and fluid friction to transport immensely large volume of freight economically and efficiently over significantly long distances on water. For this reason, it is regarded as the facilitator of international trade. Maritime infrastructures such as ports, ships, channels, waterways, and navigational locks are capital intensive, thereby creating a barrel for new investors due to the immense initial capital cost.

There is a continuous growing concern for the environment by world leaders and environmental experts due to the accelerating environmental deterioration. This is largely due to anthropogenic greenhouse gas emissions (GHG). Greenhouse gases are the gases in the earth's atmosphere that behave like a "blanket" covering the earth's surface, though they allow sunlight to pass through them, they prevent the heat radiated from the sun from leaving the earth's surface. Therefore, GHG is like a heat trap causing global temperature to rise (Fecht, 2021). Carbon dioxide (CO2), water vapor (H2O), methane (CH4), nitrous oxide (N2O), and ozone (O3) are the most important greenhouse gases in Earth's atmosphere. Globally, the transportation sector produced 7.0 gigatonnes (Gt) of carbon dioxide equivalent (CO2eq) of direct GHG emissions (including non-CO2 gases) in 2010 and hence was responsible for approximately 23 % of total energy-related CO2 emissions (Kontovas, and Psaraftis 2016). Exhaust carbon dioxide (CO2) from transportation and power generation could be regarded as a serious pollutant in terms of its global-warming potential (Votsmeier et al., 2019). Therefore, this will be the center point of our comparison.

Since the beginning of the industrial era, mankind has relied on the burning of fossil fuels for energy. Energy derived from fossil fuels is essentially used for power generation, transportation, agriculture, industry, and heating among which transportation accounts for the highest percentage. In the United States, transportation activities account for 27% of greenhouse gas (Johns Hopkins APL, 2022). While, in the European Union (EU) context, the transport sector accounts for almost one-third of total EU energy consumption, which generates high environmental costs (Vallejo-Pinto et al., 2019). This is not surprising, as a good percentage of the fuel used for transportation and transport-related activities is derived from fossil fuels. Therefore, with globalization, and increased freight demand, transportation accounts for a growing share of the total amount of energy spent for implementing, operating, and maintaining the international range and scope of human activities, which is today the consequence of the high percentage of greenhouse gas from the industry. This in its sense negates The United Nations (UN) definition and principle of sustainability, which is *"meeting the needs of the present without compromising the ability of future generations to meet their own needs."* (Patterson, 2022). In light of this definition, environmental sustainability is utilizing environmental resources in a way and manner that do not compromise the needs of the future generation. Hence, transportation, as it is today raising many sustainability concerns. However, efforts are already in place to combat the effect of greenhouse emissions, two of which are the Kyoto Protocol and the Paris international agreement of 1997 and 2015 respectively. While these agreements are critical steps toward achieving a safer environment, state enforcement remains a challenge.

In order to reduce total emissions and achieve the Kyoto Protocol or the Paris Agreement, policy maker must look at the sector with the highest percentage of emission contribution. Already, amidst power generation, transportation, agriculture, industry, and heating, research has shown that power generation and transportation are the highest contributors to anthropogenic greenhouse gas emissions (Ritchie et al., 2020). The focus of the article will be on transportation emissions (comparison between ship and road) since the energy intensity and GHG emissions in transport depend on the available transport infrastructure, choice of suitable vehicles, quantity and nature of the transported goods and the traction or fuel used (Skrúcaný, 2018). Transportation as earlier stated is a compound name that comprises land, maritime, and air transport. Road transportation and shipping are one of the largest global sources of GHGs and related pollutants. There has been great improvement in IC engines and exhaust control technology consequent to the continuous strict emission regulations. However, in 2014 transport as a whole was responsible for 23% of total CO_2 emissions from fuel combustion worldwide and road transport was responsible for 20% (Santos 2017). More so, amidst land transport, road is the mode mainly responsible for additional energy demands. Estimates for major economies show that road freight is responsible for 30–40% of all road transport emissions (ITF, 2010, as cited in Liimatainen et al., 2014). On the other hand, maritime transportation is one of the environmentally friendly modes of transport (European Environment Agency, 2023). However, with over 90 percent of world trade carried out via seas by 90,000 vessels (Kodak, 2022), it is an established source of GHG and air pollution. According to data from the International Maritime Organization (IMO), more than 3% of global carbon dioxide emissions could be attributed to ocean-going ships (Kodak, 2022). Although international organizations have formulated relevant environmental regulation programs and emission reduction measures, different ports have different resource endowments and are in development stages, and they lack clear technical standards and systematic green technology guidelines (Lin et al., 2022). In comparison to on-road vehicles, regulations for controlling ship emissions are new (IMO, 2005; Khan et al., 2013). Therefore, as seaborne shipping demand continues to grow because of its competitive freight and its capacity to move an enormous cargo volume in an eco-friendly and safe manner compared to other transport modes (Md Moshiul et al., 2021), ship emissions continue to grow and remain very much under-regulated. A tabular comparison of road transport and maritime transport is shown in Table 1 below. The comparison highlights several characteristics-feature, weaknesses, and strengths of each mode.

Materials and Methods

Literature reviews provide a comprehensive consolidation and evaluation of literature in a specific field of knowledge, as well as identify gaps in the field's body of knowledge that should be filled to further develop the field (Tranfield et al., 2003, as cited in Raza et al., 2020). In this review article, the research tries to align itself with the method of systematic literature review and reporting. More specifically, it uses the Preferred Reporting Items for Systematic Reviews and Meta-Analyses, otherwise known as PRISMA for reporting and evaluation of the literature review. The process to identify the relevant keywords for the literature review is fundamental to the success of the study since the study is geared towards an emission comparison alone roads and maritime transport. The keywords were chosen within the scope of the topic and intended findings. The keywords are as follows: maritime emissions, road emissions, and GHG emissions. This study used a dataset generated by keyword filtering on the google scholar and semantic scholar portals to evaluate emissions comparison of maritime and road transport. PRISMA, the review method for this study, avoids the complexity that may occur during research. With this method, the boundaries of which are drawn with keywords, a systematic review is provided. Accordingly, the study only took into account the articles that examine or compare maritime and road transport in terms of emissions.

Table 1. Comparative analysis of Road and Maritime Transport.

Parameters	Road Transport	Maritime Transport
Distance	Suitable for short	Suitable for long distance
Door-to-door delivery	It promotes door-to-door services	Due to the limitation imposed by Coastline door-to-door delivery is hindered
Cargo capacity	Limited to truck size, government regulation, and available traction	Except for container size limitation, it could support a wide range of goods across various sizes, shapes, and weights.
Hazard substance	It is not the most suitable for hazardous material	It is highly recommended for hazardous materials with a 99.99% success in delivery (Seaspace, n.d.)
Cost Australian interstate freight rates, 2016)	8.38 cents per net tonne-kilometer (Bureau of Infrastructure, Transport and Regional Economics 2017)	2.90 cents per net tonne-kilometer (Bureau of Infrastructure, Transport and Regional Economics 2017)
Speed	Suitable for small goods and are usually delivered within a day	Very slow, freight could take days or weeks
Uncontrollable circumstance/limitations	It is easily affected by weather and traffic. Container size and weight impose a drawback to trucking	Could be affected by adverse weather conditions and unavoidable delays in port. It has a vast load capacity and multiple container sizes are available
Loading and unloading time	This could range from a few minutes to hours depending on the size of the truck and the nature of the goods	This can take container loading / unloading in hours several days
International trade	Trucks move goods to and from the port, and from the warehouses. So they facilitate distribution while ensuring door-to-door delivery	Shipping is the backbone of international trade.
Carbon footprint	The European Automobile Manufacturers Association reports 56.5g/t.kg as the average CO2 emission for heavy-duty trucks (ACEA, 2020)	They have low CO2 emissions compared to other modes emitting between 10 to 40 grams of CO2 per nm (Kennemer, 2020)

In addition, articles examining greenhouse gas emissions and environmental/transport sustainability related to ships and road vehicles were also evaluated within the research. The study is limited to emission from maritime and road transportation, therefore emissions from aircraft were not considered. The literature review was carried out as of December 2022. Only studies in English between 2012 – 2022 were included in the study. The review also considered synonyms of the keywords such as road emissions could be reported as vehicle emissions, GHG emissions could be reported as CO2 emissions or air pollution, and environmental sustainability could be reported as climate change or emission performance. The use of Boolean operators was particularly useful to include or exclude search keywords. The snowball method was also used twice to avoid the risk of excluding important articles. The literature review was carried out Google Scholar and Sematic Scholar databases, due to their robustness in scientific research papers and their user-friendliness. In addition, the reports prepared by National Geography, Our World in Data and the European Environment Agency (EEA) were included in the research as it is directly related to the subject.

Articles that over-emphasized modal shifts due to monetary and social considerations at the expanse of the environment or without adequate consideration for environmental sustainability were excluded. It this context, it is possible to say that the comparison aims to identify the most environmentally sustainable transport mode.

Studies that narrowed down its review to emissions from public buses, trucks, and passenger vehicles only were excluded. Similarly, studies examining only maritime emissions were excluded. Lastly, studies that review transportation emissions and GHG gasses without specific reference to transportation mode or emissions generated from transportation mode were equally excluded. As a result of the research, 8 articles that met the eligibility criteria were obtained.

Thus, the profile of the studies obtained after the filtering process can be explained as follows.

i. Articles that analyzed maritime and road emissions.
ii. Articles that draw technical comparisons between maritime and road emissions with a view to highlighting possible mode shifts.
iii. Those articles that made their analysis within the context of social, economic, and environmental considerations.
iv. In addition, the articles that analyze transport sustainability especially as it relates to the environment.

Keywords are decisive in this study and Table 2 shows the number of articles carrying each keyword.

The studies obtained as a result of the literature review are given in Table 3 with the title, author and keyword information. The research method is given in Figure 1 below.

Table 2: Number of articles showing the keywords

Keywords	Number of articles
GHG/CO2 emissions	44
Road emission/transport	14
Ship transport/short-sea shipping	18
Environmental Performance/sustainability	29
Transport Mode	14
Mode shift	7
Freight Transport	7

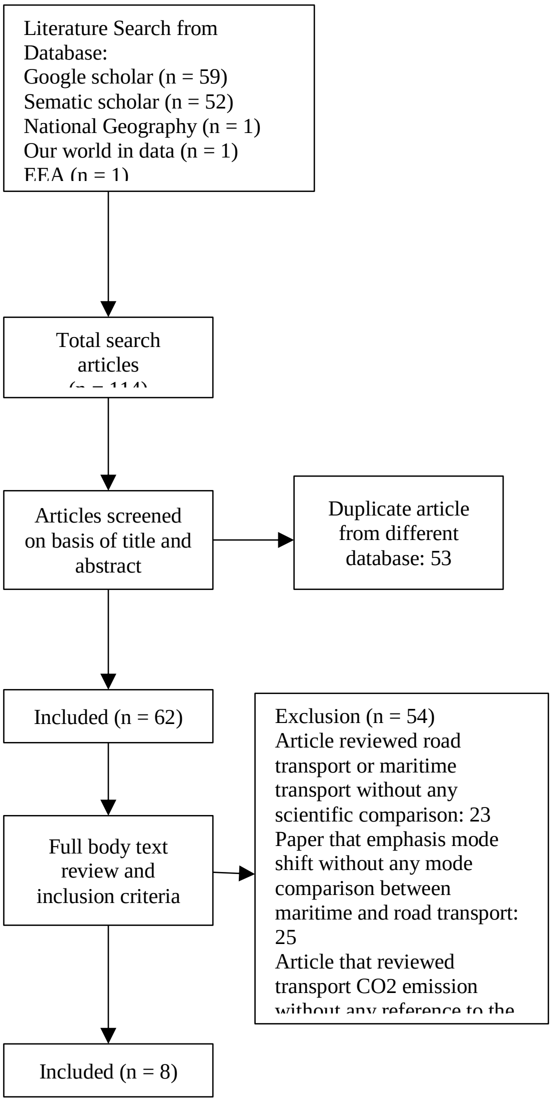

Fig. 1. Application of the PRISMA method to the study

Results and Discussions

From a holistic point of view, all transport mode offers some form of merits and demerits. Comparison only helps us to understand which is best for each circumstance. The first aim in today's fight against transport GHG emissions is not a total elimination of anthropogenic transport emissions sources but a reduction of these sources such that environmental sustainability is assured initially. Today, maritime transport is on its way to being the transport system that contributes the least to atmospheric emissions, especially in terms of unit cargo volume transported, in line with IMO's targets and regulations. Thanks to the improvements made within the scope of energy efficiency, CO2 emissions per ton have been significantly improved. However, according to the IMO Conventions, ships are to be constructed with an immediate reduction in greenhouse gas (GHG) emissions of 15%, then 20% by 2020, and 30% by 2025 (Lee and Nam, 2017). The reason is that the enormous scale of the industry means that it is nevertheless a significant contributor to the world's total greenhouse gas emissions, which is around 3% of total global CO2 emissions (ICS, n.d.). Therefore, International organizations continue to tighten regulations on ship emissions toward the realization of their ambitions, which will further strengthen the maritime sector as the friendliest mode of transportation.

Table 3. Literature review.

Title of study	**Authors**	**Keywords**
A comparative CO2 emissions analysis and mitigation strategies of short-sea shipping and road transport in the Marmara Region	Ulker et al., 2021	CO2 emissions; road transport; short-sea transport; Sea of Marmara
Road and Maritime Transport Environmental Performance: Short Sea Shipping Vs Road Transport	Castells et al., 2012	Maritime Transport, Short Sea Shipping, Road Transport, Environmental performance
Emphasis on Occupancy Rates in Carbon Emission Comparison for Maritime and Road Passenger Transportation Modes	Dujmovic et al., 2022	carbon emissions; occupancy rates; passenger mobility; transportation mode choice; maritime transportation; road transportation
Iso-emission map: A proposal to compare the environmental friendliness of short sea shipping *vs* road transport	Vallejo-Pinto et al., 2019	Greenhouse gas emissions Iso-emission map Motorway of the sea Road transport Short sea shipping
Environmental Comparison of Different Transport Modes	Skrucany el al., 2018	Energy consumption; GHG production; road transport; rail transport; water transport
Mode shift as a measure to reduce greenhouse emissions	Nelldal el al., 2012	Mode shift; greenhouse gas; GHG; rail; passenger transport; freight transport; infrastructure investment; EC white paper.
Comparison of Inland Ship Emission Results from a Real-World Test and an AIS-Based Model	Han el al., 2021	Inland ship emission; AIS-based emission model; real-world test; PEMS
Driving Factors behind Energy-Related Carbon Emissions in the U.S. Road Transport Sector: A Decomposition Analysis	Rui et al., 2022	carbon emissions; carbon neutrality; renewable energy; electric vehicles
Greenhouse gas emissions from global shipping, 2013-2015	Olmer et al., 2017	-
Measuring in-use ship emissions with international and U.S. federal methods	Sindhuja et al., 2013	-
Reducing Greenhouse Gas Emissions from Ships through Analyzing Marginal Abatement Cost (MAC) Curves	Tien, 2017	Greenhouse gas emission; marginal abatement cost; climate changes.
The impacts of CO2 emissions from maritime transport on the environment and climate change	Veysel et al., 2018	Climate Change CO2 Emissions Environment Maritime Transport
The Role of International Maritime Traffic on PM10 Pollutants in the Strait of Istanbul (Bosphorus)	Kodak, 2022	Ship Emissions; PM10; Strait of Istanbul; Maritime Transportation
Impact of a Telemedicine Program on the Reduction in the Emission of Atmospheric Pollutants and Journeys by Road	Vidal-Alaball et al., 2019	Telemedicine; carbon dioxide; air pollutants; vehicle emissions; primary care
Impact of maritime transport emissions on coastal air quality in Europe	Viana et al., 2014	Source apportionment Vessels; Mitigation strategies; Harbour operations; Shore power
Quantification of carbon emissions of the transport service sector in China by using streamlined life cycle assessment	Duan et al., 2015	Transport service sector; Carbon dioxide emissions; Streamlined life cycle assessment; China
Quantifying Emissions in the European Maritime Sector	Robert et al.,2022	Technical reports; Energy and transport; Environment and climate change
Review of the studies on emission evaluation approaches for operating vehicles	Lyu et al., 2021	Traffic engineering; Operating vehicles; Vehicle emissions; Emission measurements;

		Emission models; Vehicle emission evaluation
Measurements of the Emissions of a "Golden" Vehicle at Seven Laboratories with Portable Emission Measurement Systems (PEMS)	Giechaskiel, et al., 2021	Vehicle emissions; real-driving emissions (RDE); portable emissions measurement systems (PEMS); validation test; round robin; repeatability; reproducibility
Impact of a Telemedicine Program on the Reduction in the Emission of Atmospheric Pollutants and Journeys by Road	Vidal-Alaball et al., 2019	Telemedicine; carbon dioxide; air pollutants; vehicle emissions; primary care
Impact of maritime transport emissions on coastal air quality in Europe	Viana et al., 2014	Source apportionment Vessels; Mitigation strategies; Harbour operations; Shore power
Quantification of carbon emissions of the transport service sector in China by using streamlined life cycle assessment	Duan et al., 2015	Transport service sector; Carbon dioxide emissions; Streamlined life cycle assessment; China
Quantifying Emissions in the European Maritime Sector	Robert et al.,2022	Technical reports; Energy and transport; Environment and climate change
Review of the studies on emission evaluation approaches for operating vehicles	Lyu et al., 2021	Traffic engineering; Operating vehicles; Vehicle emissions; Emission measurements; Emission models; Vehicle emission evaluation
Measurements of the Emissions of a "Golden" Vehicle at Seven Laboratories with Portable Emission Measurement Systems (PEMS)	Giechaskiel, et al., 2021	Vehicle emissions; real-driving emissions (RDE); portable emissions measurement systems (PEMS); validation test; round robin; repeatability; reproducibility
A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018	Lamb et al., 2021	Greenhouse gas emissions; energy systems; industry; buildings; transport; AFOLU; trends and drivers
Prioritizing Environmental Justice and Equality: Diesel Emissions in Southern California	Marshall et al., 2014	-
Intermediate Volatility Organic Compound Emissions from a Large Cargo Vessel Operated under Real-World Conditions	Huang et al., 2018	-
Primary Particulate Matter Emitted from Heavy Fuel and Diesel Oil Combustion in a Typical Container Ship: Characteristics and Toxicity	Wu et al., 2018	-
Numerical Modeling of Air Pollutants and Greenhouse Gases Emissions in Intermodal Transport Chains	Ramalho et al., 2019	freight transport emissions; short sea shipping emissions; modal shift; greenhouse gas emissions; sustainable transport
A review on air emissions assessment: Transportation	Fan et at., 2018	Transportation; Greenhouse gas; Air pollutants; Emissions assessment; Transportation mode choice
A Study on Emissions from Drayage Trucks in the Port City-Focusing on the Port of Incheon	Lee et al., 2019	urban freight transport; drayage truck; port city; emission; sustainability
EU shipping's climate record Maritime CO2 emissions and real-world ship efficiency performance	Abbasov et al., 2019	-
A freight transport demand, energy and emission model with technological choices	Shiyu et al., 2020	Freight transport; CO2 emission; Energy consumption; Carbon tax; CO2 emission performance standard; goods vehicle
The comparative CO2 efficiency of short sea container transport	Svindland et al., 2019	short sea shipping; environmental sustainability; emission; cost efficiency
Easy Ride: why the EU truck CO2 targets are unfit for the 2020s	Suzan., 2021	Transport & Environment
A review on regulations, current status, effects and reduction strategies of emissions for marine diesel engines	Ni et al., 2022	Marine diesel engines; Emissions; Alternative fuel; Exhaust gas after-treatment
State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review	Bouman et al., 2017	Maritime transport; Shipping and the environment; Greenhouse gases; Abatement options; Emission reductions
Comparative Analysis of Long-Distance Transportation with the Example of Sea and Rail Transport	Neumann., 2021	Maritime transportation; railway transportation; multi-criteria analysis
Modelling of Ship Originated Exhaust Gas Emissions in the Strait of Istanbul (Bosphorus)	Bayırhan et. al, 2019	The Strait of Istanbul, Emission, Air pollution, Vessel Traffic, CO2
Factors affecting the emission of pollutants in different types of transportation: A literature review	Aminzadegan et al., 2022	Greenhouse gases; Emission; Railway transport; Road transport; Marine transport; Air transport
Natural gas fuel and greenhouse gas emissions	Speirs et al., 2020	Ships; trucks; natural gas; greenhouse gas;

in trucks and ships		emissions
Speed correlation and emission of truck vehicles on dynamic conditions	Lutfie et al., 2018	-
Impact of congestion on greenhouse gas emissions for road transport in Mumbai metropolitan region	Bharadwaj et al., 2017	Mumbai;
Simulation of Air Pollutants Emission by Trucks and Their Health Effects	Posada-Henao et al., 2022	Emissions; trucks; off-hours; human health; Acute Respiratory Infections (ARI)
How and why we travel – Mobility demand and emissions from passenger transport	O'Riordan et al., 2022	-
European road transport policy assessment: a case study for Germany	Schulthof et al., 2022	Transport policy; Evaluation; Environmental policy instruments; Road transportation; Regulation; Policy assessment
Health benefits of decreases in on-road transportation emissions in the United States from 2008 to 2017	Choma et al., 2021	particulate matter; transportation; air pollution; public health; climate change
Emissions from a Modern Euro 6d Diesel Plug-In Hybrid	Selleri et al., 2022	regulated pollutants; unregulated pollutants; greenhouse gas emissions; on-road vehicle testing; laboratory vehicle testing
CO2 Emissions and The Transport Sector in Malaysia	Solaymani., 2022	Transport CO2 emissions; energy intensity; urbanization, ARDL; impulse response; Environmental Kuznets Curve
The emission reduction potential of electric transport modes in Finland	Jenu et al., 2021	Modal shift; electric transport modes; electric aviation; greenhouse gas emissions; travel time
Urban Transportation Mode Choice and Carbon Emissions in Southeast Asia	Wei-Shiuen Ng., 2018	-
Transport and environment report 2021 Decarbonising road transport — the role of vehicles, fuels and transport demand	European Environment Agency (EEA)., 2022	-
Cars, planes, trains: where do CO2 emissions from transport come from?	Ritchie., 2020	-
Health benefits of on-road transportation pollution control programs in China	Wang et al., 2020	traffic pollution control scenario analysis air quality mortality impact China
Transportation, Pollution and the Environment	Semakula et al., 2018	Environmental Degradation; Transport Industry; Urban Pollution; Modes of Transport
Transportation noise pollution and cardiovascular disease	Thomas et al., 2021	-
Air Pollution due to Road Transportation In India: A Review on assessment and reduction Strategies	Shrivastava et al., 2013	Air pollution; Road traffic; Transport modeling; Vehicle emission; Pollution Standard; PM10 (Particulate Matter with diameters less than 10 micron.)
Fuel demand, road transport pollution emissions, and residents' health losses in transitional China	Yang., et al 2016	Road transport fuel demand system; Air pollution emissions; Health losses; Demand price elasticities; Pollution emissions elasticities
Personal Vehicles Evaluated against Climate Change Mitigation Targets	Miotti et al., 2016	-
The environmental impacts of cars, explained	National Geographic Staff 2019	-
The potential role of hydrogen as a sustainable transportation fuel to combat global warming	Acar et al., 2018	Hydrogen; Fuel; Sustainability; Internal combustion engine; Transportation; Energy
An overview on global warming in Southeast Asia: CO2 emission status, efforts done, and barriers	Lee et al., 2013	Southeast Asia; Global warming; Carbon dioxide; ASEAN
Modal shift from road haulage to short sea shipping: a systematic literature review and research directions	Raza et al., 2020	Modal shift; freight transport; road haulage; short sea shipping (SSS); literature review; research directions
Analysis of Modal Shift to Support MRT-Based Urban Transportation in Jakarta	Febriani et al., 2019	-
Joint Model of Sustainable Mode Choice for Commute, Shift Potential and Alternative Mode Chosen	Ramakrishnan et al., 2021	-
How to make modal shift from road to rail possible in the European transport market, as aspired to in the EU Transport White Paper 2011	Islam et al., 2016	Rail freight; Customer requirements; Improvements; Modal shift; White paper 2011; 2050; Europe
A comparative analysis of COx emissions by road and sea transport	Srinivasan., et al 2017	Comparitive; Green house; Emission & Logistics.
How to make modal shift from road to rail possible in the European transport market, as aspired to in the EU Transport White Paper 2011	Islam et al., 2016	Rail freight; Customer requirements; Improvements; Modal shift; White paper 2011; 2050; Europe

As for the present, studies based on the instantaneous monitoring of ships have gained importance for the calculation of ship traffic emissions. At this point, one of the most important and current studies carried out is the instant measurement of harmful emissions of ships passing through the Strait of Istanbul. The Istanbul University and the South Korean National Research Foundation (NRF) are working in collaboration to carry out the project. The project is called Air Emission Inventory Analysis from Ships Passing the Strait and it aims to measure the emission of ships passing through the strait with the aid of sensors installed at three locations (Daily Sabah, 2022).

In a study by Ülker et al. (2021), the highway emissions of a particular route in the Marmara Region of Turkey were compared with the corresponding seaway distance. The study measured and compared the ship-generated CO2 emission of 13 ro-ro and ferry lines (RFLs) in the Sea of Marmara when it been used to transport vehicles to the CO2 emission generated if the vehicles were to move by road themselves. From the article, the CO2 emission generated by the RFLs in moving the vehicles is 204,470.99 and 170,459.85 t/year, using the Entec UK Ltd, Trozzi, and Vaccaro methods respectively. While on the other hand, the potential CO2 emission generated by road vehicles in 2017, 2018, and 2019 are 121,690.54, 106,844.89, and 100,921.95 t/year respectively. The CO2 emission of RFLs varies according to the traveling distance, speed, number of voyages, available engine power, as well as the method of emission calculation. To this end, the CO2 emission varies across the 13 RFLs. From the available data, it is a matter of little consideration that the number favours road vehicle over RFLs. It is also evidence from the result, that the RFLs do not portray the environmental superiority of ship transport. The superiority of ship transport could have been appreciated if the comparison were made with the bulk carriers as against RFLs. They have more cargo carrying capacity and move at low speed. The study therefore recommends proper evaluation of load carried, the sea advantage factor, and the engine power so as to obtain environmental and economic sustainability.

Emissions were calculated using the Tier 1 method. The research has that the road emission budget surpassed that of the shipping budget. In emission comparison, it is concluded from the article that the annual CO2 emission budget can be reduced if the road truck is shifted to the sea route.

In a study by Dujmovic et al. (2022), carbon emissions comparisons were made between maritime and road transport on selected routes between Italy and Croatia in the Adriatic regions. The selected routes were Venice–Pula–Poreč (R1), Ancona–Zadar (R2), and Bari–Dubrovnik (R3). The article utilized the engine fuel consumption of the reference vessel for the corresponding engine power on the particular route and timetable to calculate the ship emission. The route timetables were based on 2019 data. On the other hand, publicly available emission factors for average personal cars and public buses were used as the standpoint to calculate road CO2 emissions. Therefore, 135.7 gCO2/vehicle-km, which is the average emission for newly registered cars in 2011, was used to compute the average road CO2 emission. Thus, the article made a detailed comparison between the occupancy rate and the selected mode in relation to carbon emission efficiency. The occupancy rate in this context is a relationship between the number of passengers in a given transport system to the maximum number of passengers the transport system can support or move on a given trip through a given route. Table 4 shows the CO2 emission of the different modes of transportation through the different routes.

Table 4. CO2 emission of the modes at 100% occupancy rate. (Dujmovic et al. 2022)

Route	Public bus (kgCO2/trip)	Personal car (kgCO2/trip)	Vessel (wCI) (kgCO2/trip)	Vessel (woCI) (kgCO2/trip)
R1S1	1,191	2,534	2,098	2,934
R1S2	236	502	863	924
R1S3	1,052	2,239	1,281	2,347
R2	14020	30482	12550	32,680
R3	26,499	57,616	28,753	43,753

Note: Adapted from "Emphasis on Occupancy Rates in Carbon Emission Comparison for Maritime and Road Passenger Transportation Modes" by Dujmovic et al. 2022, Carbon Management. Copyright 2017 by Taylor and Francis Group.

R1 contains three segments (see Table 4). Venice–Pula (*R*1*S*1), Pula–Poreˇc (*R*1*S*2), and Poreˇc–Venice (*R*1*S*3). In reality, occupancy rates are mostly below 100 percent. From the above table, it is clear that the public bus produces the least CO2 emission with the marine vessel only having a slightly better CO2 emission at R2 (Zadar–Ancona) and this is largely due to the considerable long distance. Again, the article shows that as the occupancy rate reduces the CO2 emission produced increases. Table 5 below shows the on-read and on-sea distance of each route.

Table 5. Distance on each route (Dujmovic et al. (2022)

Route	Sea distance (Nm)	Highway distance (km)
R1S1	76.2	283
R1S2	30.4	56
R1S3	60.7	250
R2	864	91.4
R3	108.9	1633

Note: Adapted from "Emphasis on Occupancy Rates in Carbon Emission Comparison for Maritime and Road Passenger Transportation Modes" by Dujmovic et al. 2022, Carbon Management. Copyright 2017 by Taylor and Francis Group.

The occupancy rate and passenger demand are recipes for an optimal transportation mode choice in terms of carbon emission efficiency (Dujmovic et al., 2022).

In another study by (Vallejo-Pinto et al., 2019) the need to focus on the main objective of a possible reduction in global greenhouse gas emissions as against a mere mode shift was emphasized. To that effect, the article proposed the Iso-emission map, which is a systematic tool that compares road transport (only road) and maritime transport alternatives. It emphasizes that the comparison should not be geared solely towards financial and time efficiency but also within the geographical scope of identifying the best alternative in terms of emissions. He, therefore, concluded that a reduction in emission could be achieved for many origin-destination pairs by simply continuously shifting traffic from road to Motorway of the sea (MoS), and vice versa.

A comparison between maritime and road transport as it relates to the total monetary cost of environmental externalities was reported by Castells et al. (2012). The Container ship, RoRo, ConRo, and RoPax were the four ships type considered under three baseline scenarios. These four ships were placed in a side-by-side comparison and their environmental ranking was tabulated as shown in Table 6 below.

Table 6. Environmental performance summary (Castells et al., 2012).

Measurement baseline	Road transport (€/tm.km)	Maritime transport Container Ship (€/tm.km)	ConRO (€/tm.km)	RoRo (€/tm.km)	Ropax (€/tm.km)
Baseline 2012	0.0029	0.0008	0.0015	0.0016	-
RoPax 2012	0.0029	-	-	-	0.0073
Baseline 2020	0.0015	0.00052	0.0009	0.0027	0.0058

According to mentioned study results, maritime transport was considered one of the most environmentally friendly modes of transport. However, results from this model show that it is still a significant source of air pollution with RoRo and RoPax as major contributors to ship emissions. In this context, the study points out that it is already difficult for ships to comply with the already approve strict emission regulations. Therefore, it is recommended to use newly developed greening technology to reduce emissions and ensure sustainability in the system.

Svindland and Hjelle, H.M. (2019) made an attempt to challenge the environmental superiority of maritime transport over road haulage. Their report aims at reviewing the emission level of ocean-going vessels by collecting empirical data on current real-life ship emissions and comparing them with previously reported data. Therefore, it is possible to say that the report focused on comparing ship emissions to road emissions with an intention to challenge and investigate the environmental supremacy of maritime transport. The report categorized shipping freight into smaller feeder vessel SFV (323 TEU, 4544 DWT), medium feeder vessel MFV (458 TEU, 7750 DWT), and largest feeder vessel LFV (679 TEU, 8199 DWT), with average CO2 efficiency of 718 g/TEU-km, 582 g per TEU-km and 654 g CO2 per TEU-km respectively. The CO2 efficiency of road transport at 0%, 50%, and 100% backhaul load factors was compared across the three categories of shipping freight. Obtained results show that even the worst CO2 efficiency of ship freight surpasses the best road haulage thought by only a margin. Therefore, the report confirms and further strengthens the environmental superiority of maritime transport.

Freight Routing and Emissions Analysis Tool (FREAT) is a spreadsheet tool developed by James J. Corbett and focus on the tradeoff between land base transportation (trucking routes) and maritime transportation (short sea routes). The FREAT is a multimodal transportation system developed to achieve three objectives, one of which is to select a chain of routes suitable with the desired modal combination with a view of an overall reduction in travel emissions alongside an increase in financial and time efficiency. In this study, it is reported that shipping and trucking could be compared based on several perimeters or constraints. If time is the constraint at an instance, then trucking is considered. On the other hand, if emission and cost are to be considered where time is not a constraint, shipping takes the lead. Results from the study further indicated that for the same traveling route, shipping requires a third of the energy required by trucks.

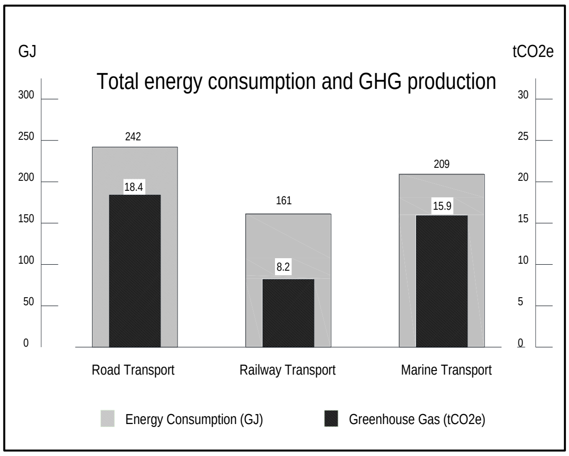

Fig. 2. Total energy consumption and GHG production (Skrúcaný et al., 2018).

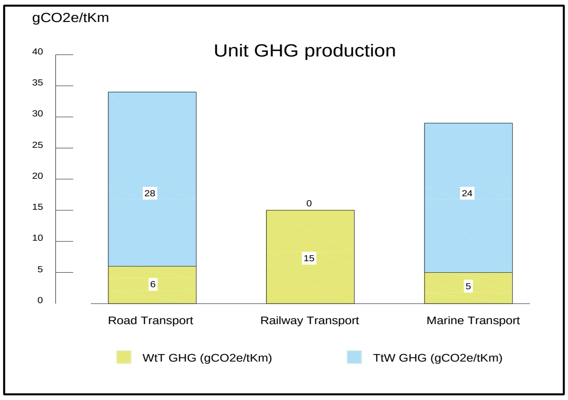

Fig. 3. Unit of GHG production (Skrúcaný et al., 2018).

In another study by Skrúcaný et al (2018), road, rail and maritime transport were compared in terms of transportation, energy requirements, energy consumption and greenhouse gas emissions. The study was able to group the energy consumption and the GHG emission of transportation into two sections namely, well-to-tank-(WtT), which is the energy required to produce and distribute the needed energy in the first place. These are referred to as secondary energy consumption sources.

The other is the Tank-to-wheel (TtW) – this represents the energy directly connected to the transportation of freight and passengers, otherwise referred to as the primary energy consumption sources. Both sources could be fossil fuel or electricity sources. Electric-powered vehicles are considered zero-emission during TtW, in this stage; the vehicle literally produces no emission. However, secondary energy consumption requires electric energy whose production could most likely not be zero-emission, especially if the primary energy source of electricity is the coal power plant. Emissions are therefore intensive contributing immensely to greenhouse emissions and by extension global warming even though the final products are zero emission. This is just the case with electric vehicles. Other fossil fuel-powered engine used across the road and maritime transport consumes energy and produce GHG emission. The result can therefore be summarized in Figure 2 and Figure 3 below.

The findings of the study showed that although environmental sustainability is taken into account, rail transport takes the lead. Another result that the study draws attention to is that considering the amount of cargo carried, maritime transportation has the least energy requirement and minimum greenhouse gas emissions to the environment.

Finally, Srinivasan and Poongavanam (2017) made a mathematical analysis, comparing emissions between road and maritime transportation. The study focused on the comparative COx analysis of road and maritime transport between Hyundai (Chennai OEM) and Gandhidham (Gujarat) as a way to understudy the eco-friendliness of each mode. The study results have shown that the COx emission of road transport surpasses ship transport. Furthermore, it affirms that ship transports are much more eco-friendly in terms of their Cox footprint, although it is still a significant source of Sulphur oxide and Nitrous oxide pollution. Therefore study, recommends an expansion of ship transport infrastructure and an increase in government incentives toward the support of coastal shipping.

Conclusion

Our natural environment contains essential resources meant for the survival and sustainability of life. These resources are naturally occurring and available in abundance. In recent times, human's drive towards development and advancement in technology has guaranteed the depletion of these resources and undermined the environment's ability to sustain life. Clean air, water, natural vegetation, and wildlife are natural environmental resources under continuous attack by the present-day civilization. By burning fossil fuels to develop energy to drive the transport sector, the transportation emission footprint continues to increase over the years. Therefore, to achieve the ambition of international organizations the resources used for transportation must be significantly reduced to a point where environmental sustainability is guaranteed and resources are utilized in a manner that does not compromise the needs of the future generation.

Transportation helps to drive business and promote civilization. However, it is a major contributor to anthropogenic GHG. There is therefore an urgent need to decarbonize the transport sector.

This study uses the PRISMA method to evaluate and review emissions from the maritime and road transport sector. The review compares and summarize scientific publications on transport emissions between 2012 and 2022 by reviewing journal publications during this period. As a result of the literature review, 62 scientific publications were accessed. From the review, maritime transportation could provide leading steps towards reduction of transportation GHG. If maritime transport could be operated as close to 100 percent occupancy rate, it will provide a valid means to reduce transportation GHG when used for significantly long distance and for large volume of freight. On the other hand, public bus provides a sustainable means of transport over short and medium distance even with a moderate occupancy rate. Again, if we consider the CO2 emission along with the load factor and energy requirement between maritime and road transport. The review shows that even at 0%, 50% and 100% backhaul load factors, maritime transport appears to be more superior to road transport. Although, it is difficult to make a direct comparison of maritime and road transport since they differ in capacity and volume of freight transported. Nevertheless, they could be compared using their emission rate or base on the gram of CO2 emitted per tonne of freight per kilometer traveled. It difficult to isolate a particular mode for excellent environmental performance, international trade, door-to-door delivery, timely delivery and sustainability. Maritime transport is the backbone of international trade and the most eco-friendly. It emits the least tonne of CO2 per unit load transported per unit distance of travelled. In other words, it has the least gram of CO2 per tonne-kilometre (gCO2/tkm). Nevertheless, it significantly slow, not suitable for short distance and capital intensive. Road transport on the other hand offers speedy transportation of moderate volume of freight over short distance. Since maritime transport is limited to the sea and ocean, road transport is essential to move freight from the factory to the port and from the port the warehouse. Therefore, it is quite difficult to isolate one for the other especially in light of their role in international trade. Therefore, there must be infrastructural development that supports continuous mode shift.

References

Acar, C., Dincer, I. (2020). The potential role of hydrogen as a sustainable transportation fuel to combat global warming. *International journal of hydrogen energy, 45*(5), 3396-3406.

ACEA (Ed.). (2020, March). *CO2 emissions from heavy‐duty vehicles Preliminary CO2 baseline (Q3‐Q4 2019) estimate*. The European Automobile Manufacturers' Association.

Ambi Ramakrishnan, G., Srinivasan, K. K., Mondal, A., Bhat, C. R. (2021). Joint Model of Sustainable Mode Choice for Commute, Shift Potential, and Alternative Mode Chosen. *Transportation Research Record*, *2675*(7), 377–391.

Aminzadegan, S., Shahriari, M., Mehranfar, F., Abramović, B. (2022). Factors affecting the emission of pollutants in different types of transportation: A literature review. DOAJ: Directory of Open Access Journals

Bayırhan, İ., Mersin, K., Tokuşlu, A., Gazioğlu, C. (2019). Modelling of Ship Originated Exhaust Gas Emissions in the Strait of Istanbul (Bosphorus). International Journal of Environment and Geoinformatics, 6(3), 238-243.

Bharadwaj, S., Ballare, S., Rohit, Chandel, M.K. (2017). Impact of congestion on greenhouse gas emissions for road transport in Mumbai metropolitan region. *Transportation research procedia*, 25, 3538-3551.

Bouman, E. A., Lindstad, E., Rialland, A. I., Strømman, A. H., Rialland, A. I. (2017). *State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review.* Elsevier, 52, 408-421.

Brand, C., Brand, C., Anable, J. L., Morton, C. (2019). Lifestyle, efficiency and limits: Modelling transport energy and emissions using a socio-technical approach. *Springer*, *12*(1), 187-207.

Bureau of Infrastructure, Transport and Regional Economics (2017), Freight Rates in Australia BITRE, Canberra

Castells, M., Usabiaga, J. J., Martínez, F. (2012). Road and maritime transport environmental performance: Short sea shipping vs road transport. *Journal of Maritime Research*, *9*(1697-4840), 45-53.

Choma, E. F., Evans, J. S., Gómez-Ibáñez, J. A., Spengler, J. D. (2021). Health benefits of decreases in on-road transportation emissions in the United States from 2008 to 2017. PNAS, 118(51), 01-10.

Corbett, J. J., Winebrake, J. J. (n.d.). Emissions Analysis of Freight Transport Comparing Land-Side and Water-Side Short-Sea Routes: Development and Demonstration of a Freight Routing and Emissions Analysis Tool (FREAT). The United States Department of Transportation Research and Special Programs Administration.

Daily Sabah (Jan 09, 2023). New project to analyze emissions from vessels in Bosporus, by daily sabah with AA, Accessed 15 Jan, 2023, Retrieved from https://www.dailysabah.com/doi.10.30897/ijegeo.641397

Duan, H., Hu, M., Zhang, Y., Wang, J., Jiang, W., Huang, Q., Li, J. (2015). Quantification of carbon emissions of the transport service sector in China by using streamlined life cycle assessment. *Elsevier*, *95*(16), 109-116.

Dujmovic, J., Krljan, T., Lopac, N., Žuškin, S. (2022). Emphasis on occupancy rates in carbon emission comparison for maritime and road passenger transportation modes. Journal of Marin Science and Engineering, 10(4), 1-31.

Elangovan, R., Kanwhen, O., Dong, Z., Mohamed, A., Rojas-Cessa, R. (2021). Comparative Analysis of Energy Use and Greenhouse Gas Emission of Diesel and Electric Trucks for Food Distribution in Gowanus District of New York City. Frontiers in big data, 4, 693820.

European Environment Agency (2022). Decarbonising road transport — the role of vehicles, fuels and transport demand. Transport and Environment Report 2021, 01-87.

European Environment Agency (2023). Motorlu taşımacılık: tren, uçak, karayolu veya gemi- hangisi en yeşil?, Accessed 18.02.2023, Retrieved from https://www.eea.europa.eu/tr/highlights/motorlu-tasimacilik-tren-ucak-karayolu

Fan, Y.V., Perry, S., Klemeš, J.J., Lee, C. (2018). A review on air emissions assessment: Transportation. *Journal of Cleaner Production*. *194*, 673-684.

Febriani, D., Olivia, M. C., Sholilah, S. A., Hidajat, M. (2019). Analysis of modal shift to support MRT-based urban transportation in jakarta. *Journal of Physics: Conference Series*, 01-08.

Fecht, S. (2021, February 25). How exactly does carbon dioxide cause global warming? [Fact sheet]. State of the Planet. Retrieved February 19, 2023, from https://news.climate.columbia.edu/2021/02/25/carbon-dioxide-cause-global-warming/

Giechaskiel, B., Casadei, S., Rossi, T., Forloni, F., Di Domenico, A. (2021). Measurements of the Emissions of a “Golden” Vehicle at Seven Laboratories with Portable Emission Measurement Systems (PEMS). *Sustainability*, *13*(16), 8762.

Gutiérrez, J. M., Grados, C. V. D. (2021). Numerical modeling of air pollutants and greenhouse gases emissions in intermodal transport chains. Journal of Marine Science and Engineering, 9(679), 01-24.

Hoen, K.M., Tan, T., Fransoo, J.C., Houtum, G.J. (2014). Effect of carbon emission regulations on transport mode selection under stochastic demand. Flexible Services and Manufacturing Journal, 26, 170-195.

Huang, C., Hu, Q., Li, Y., Tian, J., Ma, Y., Zhao, Y., Feng, J., An, J., Qiao, L., Wang, H., Jing, S., Huang, D., Lou, S., Zhou, M., Zhu, S., Tao, S., Li, L. (2018). Intermediate Volatility Organic Compound Emissions from a Large Cargo Vessel Operated under Real-World Conditions. Environmental science & technology, 52(21), 12934–12942.

International Maritime Organization. (2005). The protocol of 1997 (MARPOL Annex VI). http://www.imo.org

Islam, D.M.Z., Ricci, S., Nelldal, B.L. (2016). How to make modal shift from road to rail possible in the European transport market, as aspired to in the EU Transport White Paper 2011. *European Transport Research Review* 8(18), 01-11.

Istrate, I.R., Iribarren, D., Dufour, J., Ortiz Cebolla, R., Arrigoni, A., Moretto, P., Dolci, F. (2022)

Quantifying emissions in the European maritime sector, EUR 31050 EN, Publications Office of the European Union, ISBN 978-92-76-51975-.

ITF (2010). Reducing transport greenhouse gas emissions—Trends and data 2010. International Transport

Jenu, S., Baumeister, S., Pippuri-Mäkeläinen, J., Manninen, A., Paakkinen, M. (2021). The emission reduction potential of electric transport modes in Finland. Environmental Research Letters, 16(10), 01-11.

Jiang, H., Peng, D., Wang, Y., Fu, M. (2021). Comparison of inland ship emission results from a real-world test and an AIS-based model. *MDPI*, *12*(12), 01-13.

Jiang, R., Wu, P., Wu, C. (2022). Driving factors behind energy-related carbon emissions in the U.S. road transport sector: A decomposition analysis. *International Journal of Environmental Research and Public Health*, *19*(4), 01-17.

Johns Hopkins APL. (2022, November 9). *Johns Hopkins APL uses AI, satellite images to track greenhouse emissions*

Kennemer, J. (2020, May 12). Airfreight vs. sea freight carbon footprint // environmental impact of shipping [Fact sheet]. Sourcing Hub.

Khan, M. Y., Ranganathan, S., Agrawal, H., Welch, W. A., Cocker III, D. R. (2012). Measuring in-use ship emissions with international and U.S. federal methods. *Journal of the Air & Waste Management Association*, *63*(3), 284-291.

Khan, M. Y., Ranganathan, S., Agrawal, H., Welch, W. A., Laroo, C., Miller, J. W., Cocker III, D. R. (2013). Measuring in-use ship emissions with international and U.S. federal methods. Journal of the Air & Waste Management Association, 63(3), 284-291.

Kodak, G. (2022). The role of international maritime traffic on PM10 pollutant in the strait of Istanbul (Bosphorus). *International Journal of Environment and Geoinformatics (IJEGEO)*,*9*(3), 036-047.

Koffi, B. L., Szopa, S., Cozic, A., Velthoven, P. Van. (2010). Present and future impact of aircraft, road traffic and shipping emissions on global tropospheric ozone. Copernicus Publications, 10(23), 11681-11705.

Kontovas, C. A., Psaraftis, H. N. (2016). Transportation emissions: Some basics. *Green Transportation Logistics: The Quest for Win-Win Solutions*, 41-79.

Lamb, W. F., Wiedmann, T., Pongratz, J., Minx, J. C. (2021). A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018. *IOP Publishing Ltd*, *16*(7), 01-31.

Lee, H., Pham, H., Kim, C., Lee, K.D. (2019). A study on emissions from drayage trucks in the port city focusing on the port of Incheon. Sustainability, 11(19), 01-15

Lee, T., Nam, H. (2017). A study on green shipping in major countries: In the view of shipyards, shipping companies, ports, and policies. Elsevier, 33(4), 253-262.

Lee, Z. H., Sethupathi, S., Lee, K. T., Bhatia, S., Mohamed, A. R. (2013). An overview on global warming in Southeast Asia: CO2 emission status, efforts done, and barriers. *Elsevier*, *28*(8), 71-81.

Liimatainen, H., Arvidsson, N., Hovi, I. B., Jensen, T. C., Nykänen, L. (2014). Road freight energy efficiency and CO2 emissions in the Nordic countries. *Research in Transportation Business & Management*, *12*, 11-19.

Lin, C.-Y., Dai, G.-L., Wang, S., Fu, X.-M. (2022). the evolution of green port research: A knowledge mapping analysis. MDPI, 14(19), 01-25.

Marshall, J. D., Swor, K. R., Nguyen, N. P. (2014). Prioritizing environmental justice and equality: diesel emissions in Southern California. Environmental Science and Technology, 48(7), 4063-4038.

Md Moshiul, A., Mohammad, R., Anjum, H. F., Yesmin, A., Chelliapan, S. (2021). The evolution of green shipping practices adoption in the international maritime industry. UIKTEN, 10(03), 1112-1121.

Miotti, M., Supran, G. J., Kim, E. J., Trancik, J. E. (2016). Personal Vehicles Evaluated against Climate Change Mitigation Targets. *Environmental science & technology*, *50*(20), 10795–10804.

Morabia, A., Amstislavski, P. N., Mirer, F. E., Amstislavski, T. M., Eisl, H., Wolff, M. S., Markowitz, S. B. (2009). Air pollution and activity during transportation by car, subway, and walking. American journal of preventive medicine, 37(1), 72–77.

Münzel, T., Sørensen, M., Daiber, A. (2021). Transportation noise pollution and cardiovascular disease. Nature reviews. Cardiology, 18(9), 619–636.

National geography (Ed.). (2019, September 4). *The environmental impacts of cars, explained* [Fact sheet]. National Geography. Retrieved November 7, 2022.

Neeta, S., Geeta, G. (2013). Air pollution due to road transportation in India: A review on assessment and reduction strategies. Journal of Environmental Research and Development, 8(1), 69-77.

Neumann, T. (2021). Comparative analysis of long-distance transportation with the example of sea and rail transport. *MDPI*, *14*(6), 01-13.

Ng, W. (2018). Urban Transportation Mode Choice and Carbon Emissions in Southeast Asia. Transportation Research Record, 2672(2), 54 - 67.

Ni, P., Wang, X., Li, H. (2020). A review on regulations, current status, effects, and reduction strategies of emissions for marine diesel engines. *Elsevier*, *279*, 01-16.

Olmer, N., Comer, B., Roy, B., Mao, X., Rutherford, D. (2017, October). *Greenhouse gas emissions from global shipping, 2013–2015* [Fact sheet]. ICCT.

O'Riordan, V., Rogan, F., Uidhir, T. M., Ó Gallachóir, B., Daly, H. (2022). Passenger transport demand, fuel consumption, and emissions data for the Irish Passenger Transport Emissions and Mobility (IPTEM) model. Data in brief, 42, 108154

Patterson, N. (2022, April 22). What is Environmental Sustainability? Goals with Examples [Lecture notes]. Southern New Hampshire University.

Posada-Henao, J. J., Restrepo-Peña, H. M., Gonzalez-Calderon, C. A. (2022). Simulation of air pollutants emission by trucks and their health effects. Atmosphere, 13(10), 01-16.

Raza, Z., Svanberg, M., Wiegmans, B. (2020). Modal shift from road haulage to short sea shipping: a systematic literature review and research directions. Transport Reviews, 40(3), 382-406.

Ritchie, H. (2020, October 6). Cars, planes, trains: where do CO2 emissions from transport come from? Our World in Data.

Ritchie, H., Rosado, P. R., Roser, M. (2020). CO_2 and Greenhouse gas emissions. Our World in Data. https://ourworldindata.org/emissions-by-sector#energy-electricity-heat-and-transport-73-2

Samang, L., Adisasmita, S. A., Ramli, M. I. (2018). Speed correlation and emission of truck vehicles on dynamic conditions. IOP Publishing, 140(1), 01-06.

Santos, G. (2017). Road transport and CO2 emissions: What are the challenges?. *Transport Policy*, *59*, 71-74.

Schrooten, L., De Vlieger, I., Int Panis, L., Chiffi, C., Pastori, E. (2009). Emissions of maritime transport: A reference system [Abstract]. *Journal of Maritime Research (JMR)*, *408*(9), 318-323.

Schulthoff, M., Kaltschmitt, M., Balzer, C., Wilbrand, K., Pomrehn, M. (2022). European road transport policy assessment: a case study for Germany. Environmental sciences Europe, 34(1), 92, 01-16.

Schwartz, H., Gustafsson, M., Spohr, J. (2020). Emission abatement in shipping – is it possible to reduce carbon dioxide emissions profitably? *Elsevier*, *241*, 01-21.

Seaspace (Ed.). (n.d.). *Sea vs Air vs Land freight – what is the best method of transport for you?* Seaspace International Forwarder.

Selleri, T., Melas, A., Ferrarese, C., Franzetti, J., Giechaskiel, B., Suarez-Bertoa, R. (2022).Emissions from a modern euro 6d diesel plug-In hybrid. Atmosphere, 13(8), 01-21.

Semakula, M., Inambao, F. (2018). Transportation, pollution and the environment. International Journal of Applied Engineering Research, 13(6), 3187-3199.

Skrúcaný, T., Kendra, M., Kalina, T., Jurković, M., Vojtek, M., Synák, F. (2018). Environmental Comparison of Different Transport Modes. Naše more.

Solaymani, S. (2022). CO2 emissions and the transport sector in Malaysia. Frontiers, 9(774164), 01-11.

Speirs, J., Balcombe, P., Blomerus, P., Hawkes, A. (2020). Natural gas fuel and greenhouse gas emissions in trucks and ships. IOP Publishing, 2(1), 01-25.

Srinivasan, R., Poongavanam, S. (2017). A Comparative Analysis of Cox Emissions by Road and Sea Transport, International Journal of Mechanical Engineering and Technology 8(11), 2017, pp. 1095 – 1102.

Svindland, M., Hjelle, H. M. (2019). The comparative CO2 efficiency of short sea container transport. *Elsevier*, *77*, 11-20.

Szkutnik-Rogoż, J., Ziółkowski, J., Małachowski, J., Oszczypała, M. (2021). Mathematical Programming and Solution Approaches for Transportation Optimisation in Supply Network. Energies, 14(21), 7010.

Tatar, V., and Ozer, M. B. (2018). The impacts of CO2 emissions from maritime transport on the environment and climate change. Int. J. Environ. Trends 2 (1), 5–24.

The International Chamber of Shipping (Ed.). (n.d.). Environmental performance: Reduction in the quantity of spilled oil [Fact sheet]. ICS. Retrieved January 19, 2023, from https://www.ics-shipping.org/shipping-fact/environmental-performance-reduction-in-the-quantity-of-spilled-oil/

Tien A.T., (2017). Reducing Greenhouse Gas Emissions From Ships through Analyzing of Marginal Abatement Cost (MAC) Curves. *Global Journal of Science Frontier Research*, *17*(E1), 15–22.

Tranfield, D., Denyer, D., Smart, P. (2003). Towards a methodology for developing evidence‐ informed management knowledge by means of systematic review. *British journal of management*, *14*(3), 207-222.

Transport and Environment (2021). Easy Ride: why the EU truck CO2 targets are unfit for the 2020s

Ulker, D., Bayırhan, I., Mersin, K., Gazioglu, C. (2021). A comparative CO2 emissions analysis and mitigation strategies of short-sea shipping and road transport in the Marmara Region. Carbon Management,12,1-12.

Vallejo-Pinto, J. A., Garcia-Alonso, L., Fernández, R. Á., Mateo-Mantecón, I. (2019). Iso-emission map: A proposal to compare the environmental friendliness of short sea shipping vs road transport. *Elsevier*,*69*,*597*-609.

Viana, M., Hammingh, P., Colette, A., Colette, A., Querol, X., Degraeuwe, B., de Vlieger, I., Aardenne, J. Van. (2014). Impact of maritime transport emissions on coastal air quality in Europe. *Elsevier*, *90*, 96-105.

Vidal-Alaball, J., Franch-Parella, J., Lopez Seguí, F., Garcia Cuyàs, F., Mendioroz Peña, J. (2019). Impact of a Telemedicine Program on the Reduction in the Emission of Atmospheric Pollutants and Journeys by Road. *International journal of environmental research and public health*, *16*(22), 4366.

Votsmeier, M., Kreuzer, T., Gieshoff, J., Lepperhoff, G., Elvers, B. (2019). Automobile exhaust control. *Wiley-VCH*, 01-15.

Wang, H., He, X., Liang, X., Choma, E. F., Liu, Y., Shan, L., ... and Evans, J. S. (2020). Health benefits of on-road transportation pollution control programs in China. *Proceedings of the National Academy of Sciences*, *117*(41), 25370-25377.

Wang, P. S., Liu, Y., Wang, Y. (2021). Review of the studies on emission evaluation approaches for operating vehicles. *Journal of Traffic and Transportation Engineering (English Edition)*, *8*(4), 493-509.

Wiłkomirski, B., Sudnik-Wójcikowska, B., Galera, H., Wierzbicka, M., Malawska, M. (2011). Railway transportation as a serious source of organic and inorganic pollution. Water, air, and soil pollution, 218(1-4), 333–345.

Wu, D., Li, Q., Ding, X., Sun, J., Li, D., Fu, H., Teich, M., Ye, X., Chen, J. (2018). Primary Particulate Matter Emitted from Heavy Fuel and Diesel Oil Combustion in a Typical Container Ship: Characteristics and Toxicity. *Environmental science & technology*, *52*(21), 12943–12951.

Yan, S., de Bruin, K., Dennehy, E., Curtis, J. (2020). A freight transport demand, energy, and emission model with technological choices. The Economic and Social Research Institute (ESRI), 669, 01-57.

Yan, X., Crookes, R. J. (2010). Energy demand and emissions from road transportation vehicles in China. Progress in Energy and Combustion Science, 36(6), 651-676.