Tuomo Kaivosoja

Assessment of the potential opportunities and limitations for intermodal transport

Case: Finland and the South Ostrobothnia region

School of Technology and Innovation Management
Master's thesis
Master's programme in Industrial Systems Analytics

Vaasa 2023

UNIVERSITY OF VAASA

School of Technology and Innovation Management

Author:	Tuomo Kaivosoja
Title of the Thesis:	Assessment of the potential opportunities and limitations for intermodal transport Case: Finland and the South Ostrobothnia region
Degree:	Master of Science in Technology
Programme:	Industrial Systems Analytics
Supervisor:	Hanne Ala-Harja
Year:	2023 **Pages:** 57

ABSTRACT:

Reducing CO_2-emissions across all industries has become a paramount objective for society. Rail-road transport has been proposed as a method to reduce emissions of the transportation sector. Intermodal transport is a major part of the European Union’s TEN-T transportation network policy.

Benchmarking intermodal transport is a method to assess the circumstances under which intermodal transport is most beneficial. Global transportation chains are complex and therefore benchmarking intermodal transport can be complex. Intermodal transport benchmarking can be done for a part of the transportation chain or the entire chain. Benchmarking should also focus on a perspective such as financial, environmental, or logistical.

This study analyses data from the Finnish transportation sector to assess the potential opportunities and limitations for rail-road intermodal transport in Finland and the South-Ostrobothnia region. It uses statistical data to assess the demand for intermodal transport as well as estimate the potential financial and environmental benefits intermodal transport could provide for the region. It also analyses statistics about various goods exported from South-Ostrobothnia as road freight to understand the potential logistical challenges of shifting those goods onto rails.

KEYWORDS: intermodal transport, combined transport, logistics

VAASAN YLIOPISTO

Tekniikan ja innovaatiojohtamisen yksikkö

Tekijä:	Tuomo Kaivosoja		
Tutkielman nimi:	Assessment of the potential opportunities and limitations for intermodal transport Case: Finland and the South Ostrobothnia region		
Tutkinto:	Master of Science in Technology		
Oppiaine:	Industrial Systems Analytics		
Valvoja:	Hanne Ala-Harja		
Vuosi:	2023	**Sivumäärä:**	57

TIIVISTELMÄ:

Hiilidioksidipäästöjen vähentämisestä kaikilla aloilla on tullut yksi yhteiskunnan tärkeimmistä tehtävistä. Kuorma-autojen ja junien yhdistettyjä kuljetuksia on ehdotettu ratkaisuksi tavaraliikenteen päästöjen vähentämiseksi. Yhdistetyt kuljetukset ovat keskeinen osa Euroopan Unionin TEN-T liikennejärjestelmää.

Benchmarking-analyysillä voidaan arvioida missä olosuhteissa yhdistetyt kuljetukset ovat kaikista hyödyllisimpiä. Globaalit kuljetusketjut ovat monimutkaisia ja siksi myös yhdistettyjen kuljetusten benchmark-analyysi voi olla monimutkaista. Benchmarking-analyysi voi tarkastella kuljetusketjun osaa tai koko kuljetusketjua. Benchmarkingissa tulisi myös valita näkökulma kuten taloudellinen näkökulma, ympäristönäkökulma tai logistinen näkökulma.

Tämä tutkimus analysoi dataa Suomen kuljetussektorilta arvioidakseen mahdollisuuksia kuorma-autojen ja junien yhdistetyille kuljetuksille Suomessa ja Etelä-Pohjanmaalla. Tilastotietoja käytetään maakunnan yhdistettyjen kuljetusten kysynnän sekä mahdollisten taloudellisten hyötyjen ja ilmastohyötyjen arvioimiseen. Tutkimus analysoi myös Etelä-Pohjanmaan viennin tieliikenteen tavarankuljetustilastoja tavaralajeittain arvioidakseen kuljetusten raiteille siirtämisessä mahdollisesti esiintyviä haasteita.

AVAINSANAT: yhdistetyt kuljetukset, logistiikka

Contents

Figures

Tables

Abbreviations

BSC	Balanced scorecard
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CT	Combined transportation
EEA	European Environment Agency
ERTMS	European Rail Traffic Management System
ETS	European Union Emission Trading System

EU	European Union
IEA	International Energy Agency
ITU	Intermodal transport unit
KPI	Key performance indicator
OECD	Organisation for Economic Co-operation and Development
TEN-T	Trans-European Transport Network
UIC	International Union of Railways
WRI	World Resources Institute

1 Introduction

The introduction of this thesis presents the background of this study, establishes the scope of research as well as presents the research questions and structure of the thesis. The background chapter explains why the topic of this thesis is important and relevant today. The research questions and scope of research are also specified to eliminate any ambiguity about the objectives of the thesis as much as possible. The structure of the thesis is explained in the introduction to give readers a piece of guidance beyond a simple table of contents.

1.1 Background

With the increasing amount of evidence of human-caused climate change and the global health risk it presents, there is also increasing demand for actions to limit greenhouse gas emissions caused by humans. Energy production and usage is the main contributor towards the emission of greenhouse gases worldwide. 73.2 % of global human greenhouse gas emissions measured in CO_2-equivalency come from energy usage of which 16.2 % is caused by the transportation sector (WRI, 2020 as cited in Ritchie & Roser, 2020). 11.9 % of the energy usage in the transportation sector originates from road transport.

Emissions in road transportation originate from the use of oil-based fuels to power cars and trucks. Today rail transport is largely electrified and contributes to only 0,4 % of the 16 % of emissions caused by the transportation sector (WRI, 2020 as cited in Ritchie & Roser, 2020). Comparing to the 11.9 % of road transport it is evident that rail transport causes far less greenhouse gas emissions globally than road transport. A major reason for this is the higher level of electrification of rail transport compared to road transport. Globally, 36.4 % of all rail traffic was electric in 2016 (IEA-UIC, 2016). In the European Union, 70 % of rail transportation energy was provided with electricity in 2013 (IEA-UIC, 2016).

Given the high electrification rate of railway transport in the European Union, increasing the amount of rail transportation relative to road transportation, is a method to reduce the emissions of the transportation sector in the European Union. A proposed method to increase rail transportation without sacrificing the quality of service of transportations by incorporating intermodal transportation. Intermodal transport is such transport where multiple modes of transport are used between the dispatch and delivery of the freight.

Intermodal transportation in the context of this thesis refers to the combination of railway transport and trucking. Intermodal transportation combining truck and rail transport is often referred to as combined transportation (CT), (Jahn et al., 2020). Intermodal transport with truck and train utilizes rail transport for longer distances inland while trucks complete the final portion of transportations in urban areas. Transporting most of the distance with rail reduces the total carbon emissions of the transport while trucks provide the flexibility for transportation in urban areas.

The EU’s Trans-European Transport Network (TEN-T) policy supports the building of an EU-wide multimodal transport network (European Commission, 2021b). Building more transhipment hubs and ensuring the ability to transport trucks on trains are listed as specific goals of the TEN-T network.

The infrastructure requirements for intermodal transport need to be studied for a successful multinational and multimodal transport network to be built. Currently, there are vast differences in the amount of intermodal transport between European nations. Understanding why certain countries have developed intermodal transport more successfully is crucial for the development of a homogenous network across Europe.

Finland has had very little intermodal transport compared to other European nations. One of the proposed reasons is that Finland’s state-owned railway operator VR Group had a monopoly in passenger traffic up to 2007 and in passenger traffic up to 2021. VR provided transport for trucks on rails between 1991-2014 but halted them due to low profitability and demand according to VR (2013). The breakup of VR’s monopolies and transformation of VR into a public company has increased the opportunities for the restart of intermodal transport in Finland.

1.2 Research questions and objectives

This thesis has three research questions, stated below. Answering these research questions is the main objective of this thesis. It also aims to educate the reader on the topic of intermodal transportation and the related terminology and concepts.

Q1: What are the key infrastructure requirements for intermodal transport globally and in Finland?

Q2: What are the key metrics to evaluate these infrastructural requirements?

Q3: What opportunities and limitations does South-Ostrobothnia present for an intermodal terminal?

As is evident from the research questions, this thesis does not aim to provide complete solutions on **how** to achieve the infrastructure requirements for intermodal transport, rather it aims to answer **what** infrastructure is required to support intermodal transport. Topics such as financing of intermodal terminals or technological solutions of locomotives are not part of the scope of this study, although related to intermodal transport.

1.3 Thesis structure

This thesis is split into five main sections. First the introduction familiarizes the reader with the topic and describes why it is relevant. It also establishes the research space for the thesis by describing what needs to be researched more and presents the research questions.

The introduction is followed by a theoretical background section. The theoretical background aims to find the answers to the research questions on a general and theoretical level. The theoretical background also explains terminology and concepts which are essential to grasp to fully understand the topic. It explains the process of benchmarking intermodal transport as well as presents various financial, environmental, and logistical key performance indicators for intermodal transport. Key indicators relating to specifically to intermodal terminals will also be presented. Features of the Finnish transportation system that affect intermodal transport will also be explored. This section of the thesis aims to answer primarily Q1 and Q2.

Following the theoretical background section, a methodology chapter explains the methodology used in this thesis to achieve and evaluate the results of this study. It explains the methodology of a benchmarking study and how benchmarking has been conducted in this thesis to evaluate the potential opportunities for intermodal transport in Finland and South-Ostrobothnia.

The results chapter expands on the achieved results of this study and elaborates on the important details of the achieved results. It presents various statistics about transportation in Finland and South-Ostrobothnia and evaluates the metrics against leading global examples. This produces a result that can be used to assess how well the infrastructure requirements of intermodal transport are met in Finland and South-Ostrobothnia. Primarily this section aims to answer Q3.

The conclusion chapter briefly summarizes the answers to the research questions. It also presents other significant findings of the thesis. Questions that have surfaced while conducting this thesis, that require future research outside the scope of this thesis will also be suggested as future research topics.

2 Theoretical background

This chapter explores the existing literature around intermodal transport to find out the key infrastructure requirements for intermodal transport. The infrastructure requirements and related key performance indicators (KPIs) are explored from literature around the globe and Finland to understand which infrastructure requirements are common for all intermodal transport development regardless of location, and whether there are requirements that are specific to Finland. This chapter aims to answer research questions 1 and 2.

Existing literature was searched for using the keyword “intermodal transport benchmarking” from various databases. The number of results returned from various databases is presented in Table 1.

Table 1. Number of search results returned for keyword “intermodal transport benchmarking” from various databases.

Database	Number of results
Scopus	490
Abi/Inform Collection	346
Web Of Science	223
Doaj Directory of Open Access Journals	201
Ebscohost Business Source Premier	163

The number of results returned by the keyword indicates the need for more research on the topic of intermodal transport benchmarking.

2.1 Challenges in benchmarking intermodal transport

Identifying KPIs for intermodal transport is difficult because of the complexity of intermodal transport chains (OECD, 2002). When benchmarking intermodal transportation chains, KPIs can be established either for the entire transportation chain or for parts of the transportation chain. For example, time from dispatch to delivery is a performance indicator for the whole transportation chain while CO_2-emissions per tonne-kilometre is an indicator that describes the efficiency of a single transportation mode in the transportation chain.

Comparing entire transportation chains can offer advantages when benchmarking global transportation chains (Islam et al., 2013). Global transportation chains stretch across multiple countries with differing regulations and technological capabilities. Therefore, it can be more reasonable to compare the performance of the entire transportation chain from dispatch to delivery than specific parts of the transportation chain. A global logistics service provider for example is more interested in the total transportation costs and delivery time than factors that can differ by region.

Benchmarking a single part of the transportation chain is useful when directly comparing it to an alternative transportation mode or comparing between two instances of the same transportation mode (OECD, 2002). For example, by comparing rail transportation with truck transportation for the same route, or by comparing it to another similar rail transportation route. Comparing alternative transportation modes highlights the advantages and disadvantages of each mode, while comparing with the same transportation mode is useful for evaluating performance against leading operators. For infrastructure operators benchmarking studies are a good way of evaluating performance against a selected benchmark facility once the KPIs have been identified (OECD, 2002).

When benchmarking intermodal transport infrastructure operators some performance indicators may be composed of multiple smaller indicators. Large-scale indicators such as annual tonne-kilometres can be useful for comparisons, but they do not express how the indicator has been formed through multiple contributing smaller factors (OECD, 2002). Therefore, benchmarking intermodal transport on an infrastructural level can give insight into what outcomes an intermodal transport system should achieve, but not necessarily how to achieve them.

To understand how an intermodal transport system can achieve its targeted outcomes, more detail-oriented research needs to be done across the various parts of the transport system. Often benchmarking studies are limited by the availability of data, especially data that has a standardized way of measurement, making benchmarking more difficult (OECD, 2002).

Establishing a set of macro-scale indicators that track the achieved outcomes and expected performance of transportation systems is important in the future development of transportation networks and policies (OECD, 2002). While different stakeholders in the transportation chain have different interests, modern transportation chains are globally connected, and stakeholders must adhere to international regulations. Therefore, identifying indicators that can be applied globally is important for future policymaking and sustainable development (Islam et al., 2013; OECD, 2002).

While there is no universal standard on measuring the efficiency of transportation systems across multiple transportation modes, Lukinskiy et al. (2013) propose that logistics professionals can use the balanced scorecard (BSC) to evaluate transportation systems if it is adapted to the context of logistics.

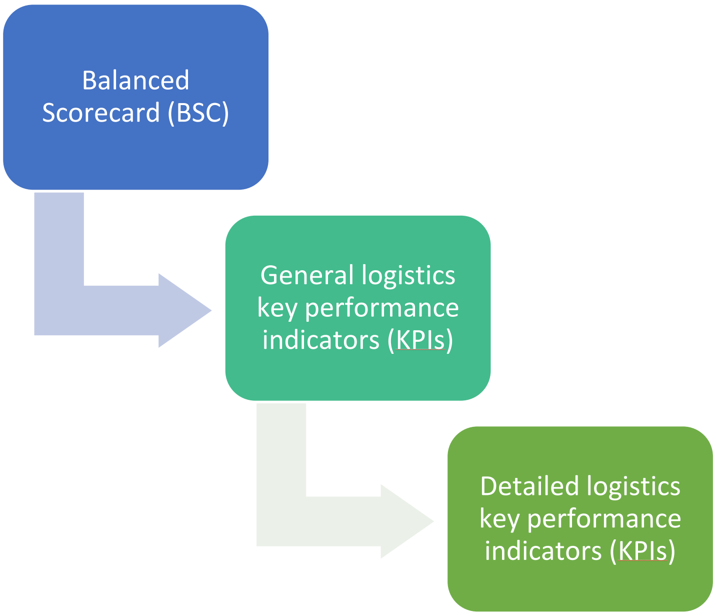

Figure 1. Process of applying the balanced scorecard to be used in logistics benchmarking (adapted from Lukinskiy et al., 2013).

Figure 1 presents the process of adapting the balanced scorecard to the context of logistics. Establishing the KPIs of logistical activities is crucial when adapting the BSC from the needs of the manufacturing industry to the needs of logistics. Also identifying the most relevant, more detailed KPIs for each part of the transportation chain is important for successful benchmarking (OECD, 2002).

2.2 Key performance indicator identification and selection

The logistics sector and transport chains can be evaluated by various performance indicators, evaluation criteria and stakeholder perspectives. When conducting benchmarking studies, choosing the most suitable indicator can be challenging (OECD, 2002). The indicator selection should reflect the stakeholder needs and the determined goals of the benchmarking study. Indicator selection can also be influenced by the availability of data.

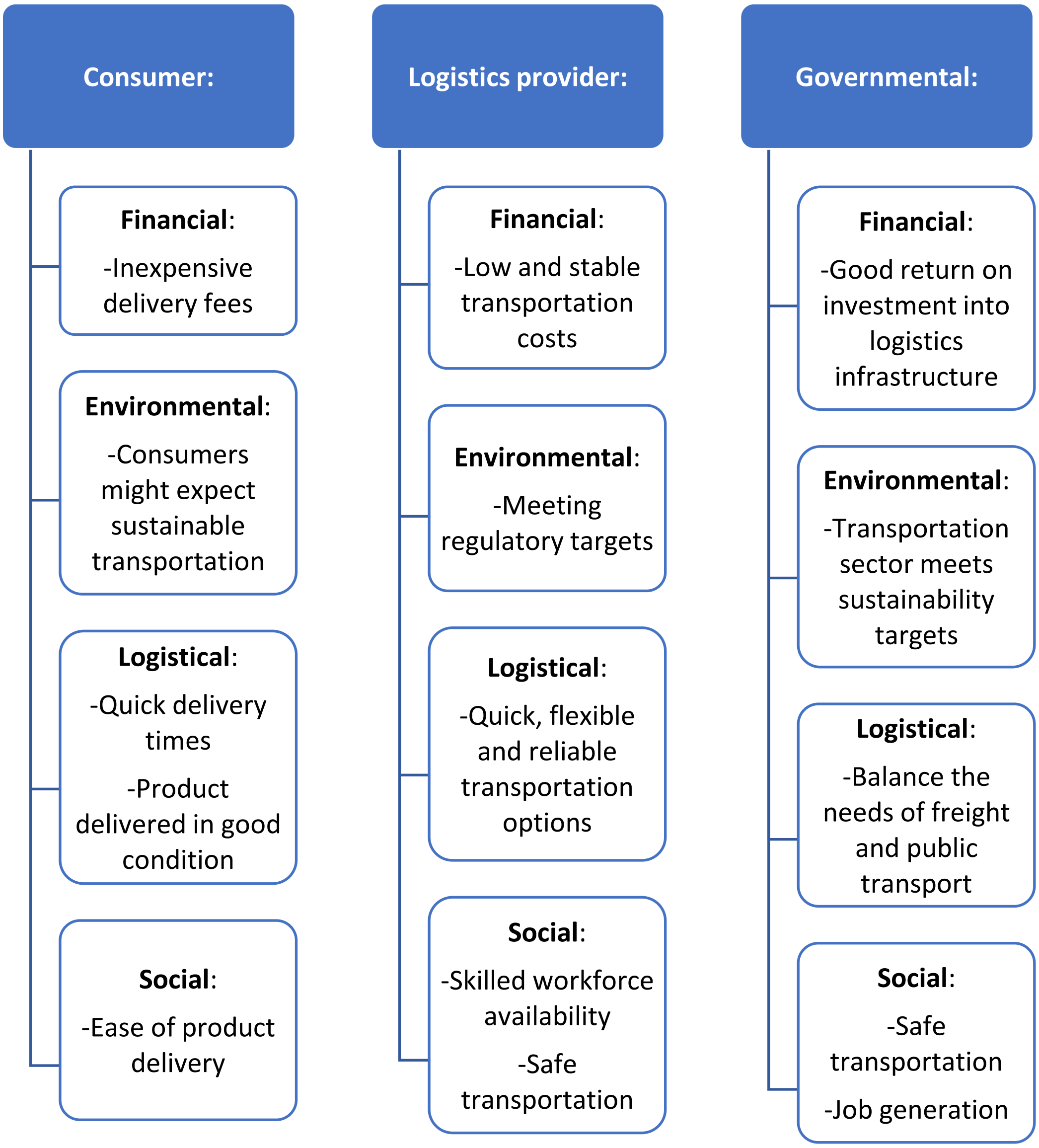

Figure 2. Key needs of transportation system stakeholders classified under evaluation criteria.

When studying the effectiveness of various transport methods for a certain good, transportation methods can be evaluated under three categories of evaluation criteria: environmental, logistical, and financial performance (Jahn et al., 2020). Stoilova and Kunchev (2017) list four major criteria for the evaluation of combined transport: environmental, economic, technological, and social criteria.

KPIs can also be classified by their respective stakeholders. Stakeholder perspectives can be classified into three categories: consumer perspective, logistics service providers' perspective, and government perspective (OECD, 2002).

Lukinskiy et al. (2013) list five KPIs for the efficiency of logistics systems: total logistical costs, quality of logistical service, logistical cycles duration, productive capacity, and return on the investments in logistical infrastructure. Islam et al. (2013) identified six KPIs for transport chains: transport cost, transport time, flexibility, reliability, quality, and sustainability.

The most important needs of the various stakeholders of the transportation system can be classified similarly to the KPIs. Four evaluation criteria can be used to group the needs of the three main stakeholders of transportation systems, as presented in Figure 2.

2.3 Financial key performance indicators

Organisations are often familiar with financial benchmarking because of the availability of financial data and the prevalence of using financial indicators to evaluate organisations' performance. Ideally, financial benchmarking for intermodal transport chain is done both from the perspective of the service provider as well as the service user (OECD, 2002).

Financial information availability in intermodal transport chains varies depending on the stakeholder (OECD, 2002). Information is generally more available from organizations that are often state-owned such as ports, terminals, and rail operators than the typically private or public companies such as road transport and shipping operators.
Transport costs are the largest cost of logistics service providers (OECD, 2002). Logistics costs includes transportation cost but also other logistics related costs like packaging

and warehousing costs. In Japan, 65 % of logistics costs were transportation costs in 1995.

It is important to note the relationship between logistics costs and transportation costs. Reducing transportation costs do not always result in reduced total logistics costs (OECD, 2002). Logistics costs are also influenced by the cost of storage, packaging, and sorting. It is possible that in some scenarios, the reduction of transportation costs is offset by an increase in other logistics costs.

Smaller shipments generally have more frequent orders and shorter lead times which creates a need for more transportation fleet and leads into an increase in transportation costs (OECD, 2002). On the contrary, larger shipments often have less frequent deliveries but longer lead times and increased storage costs.

2.3.1 Cost structure of combined transport

Rail-road intermodal transport chains have a variety of internal costs that occur between the dispatch and delivery of goods (Carboni & Dalla Chiara, 2018). Figure 3 presents the different costs occurring in combined transportation between the origin and destination of the transported goods.

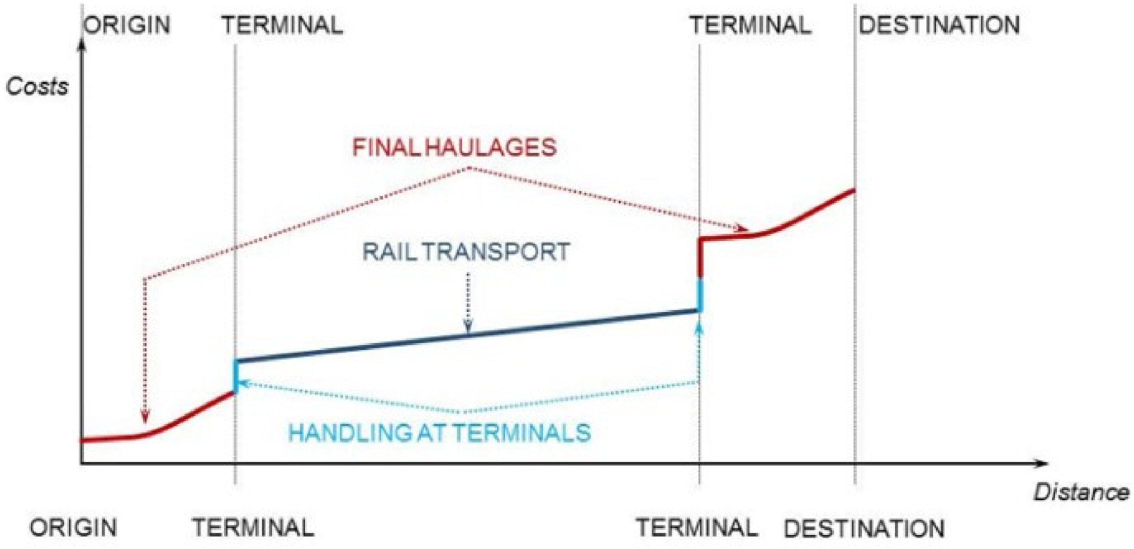

Figure 3. Cost scheme showing the structure of costs for combined transport (Carboni & Dalla Chiara, 2018, p. 5).

The first costs arise from the initial road transportation of goods from the dispatcher to the terminal, followed by terminal costs in the combined transport terminal (Carboni & Dalla Chiara, 2018). The initial road transport costs are mostly direct costs of the road transportation companies.

Rail transport costs take place after the initial road transport costs and terminal costs. Rail transport costs are generally the largest portion of total rail-road intermodal transport costs (Carboni & Dalla Chiara, 2018). Rail transport costs however are the least expensive transportation costs per kilometre and are significant in the profitability of combined transportation. The share of total costs is heavily influenced by the variations in terminal costs as well as the variation of distance in the road and rail transport legs.

After the rail transport leg, costs will still arise from the final road transport leg (Carboni & Dalla Chiara, 2018). The usage or rent costs of intermodal transport units (ITUs) and railway wagons also affect the total costs of intermodal transport. Finally, the administrative costs of the railway operator also influence the total operating costs of intermodal transportation.

2.3.2 Combined transport profitability

Intermodal transport becomes more profitable compared to road haulage when the length of the rail transport leg is longer (Carboni & Dalla Chiara, 2018). This is because the transportation costs of rail transport are lower than those of road transport. Rail transport is more cost efficient per km than road transport because of lower energy consumption and the higher capacities of trains relative to trucks. The average rail transport leg for domestic and international combined transportation in Europe is 480 km and 860 km, respectively (UIC, 2020).

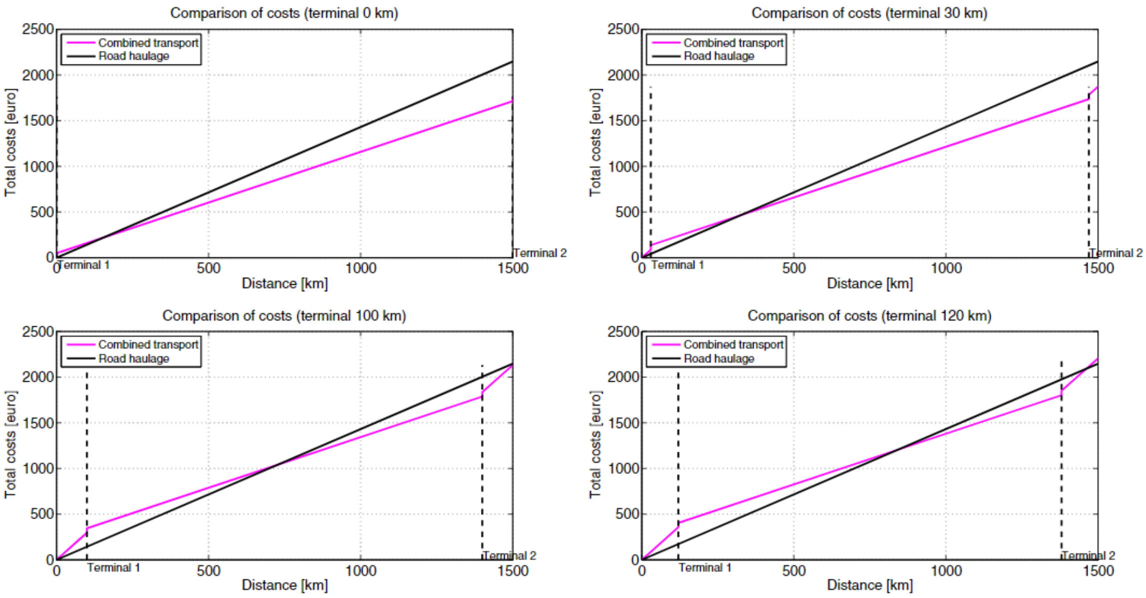

Figure 4. Comparison of the total costs for freight transport as a function of the terminal location (Carboni & Dalla Chiara, 2018, p. 9).

The profitability of combined transport compared to road haulage depends greatly on the length of the initial and final road transport legs as well as the length of the rail transport leg (Carboni & Dalla Chiara, 2018). Combined transport is cheaper than road transport when the CT terminals are sufficiently close to the dispatch and delivery sites and when the rail transport leg is sufficiently long. Figure 4 presents four different scenarios of total transportation costs over distance with different terminal locations.

Combined transport requires a long enough rail transport leg to offset the so called first mile and last mile costs associated with combined transport (Carboni & Dalla Chiara, 2018). Combined transportation requires transporting goods from the origin site to a CT terminal as well as transporting them from another CT terminal to the delivery site. This potentially involves more time spent in traffic congested areas increasing costs. This cost needs to be offset by the lower per km transport costs of railway transport relative to road haulage.

The costs of terminal operations also need to be offset by the rail transport leg. The combined terminal operating costs include goods handling, maintenance, energy, land, insurance, and staff salaries (Carboni & Dalla Chiara, 2018). CT terminals are also expensive investments and the capital expenditures like interest costs and depreciation need to be offset during the lifecycle of the terminal.

When building CT terminals, it is crucial to select locations which minimize the first mile and final mile transport distances of potential users (Carboni & Dalla Chiara, 2018). By selecting terminal locations carefully, the road transportation costs of combined transport can be minimized, resulting in a shorter required rail transportation leg to offset the cost disadvantage compared to pure road haulage.

A suboptimal terminal location can increase the first or final mile costs, increasing the distance required for the railway leg to offset the increased costs (Carboni & Dalla Chiara, 2018). This in turn increases the total transport distance required for combined transport to become more cost-efficient than pure road transport.

Therefore, countries which cover a smaller land area and have shorter rail transport distances might struggle to make intermodal transport competitive for domestic transport needs. To make combined transport competitive for smaller countries, combined transportation should be used for international transport needs or terminal density should be increased to provide terminals close enough to dispatch and delivery sites of goods.

Terminal density is a key factor in the development of combined transport (UIC, 2020). Increasing terminal density, however, also increases the expenditures related to terminal operations and investments into new terminals. New terminals should have a high utilization degree to shorten the payback period.

2.4 Environmental key performance indicators

Sustainability is one of the major proponents for combined transportation, making environmental indicators indispensable when evaluating the performance of combined transportation. Reducing greenhouse gas emissions is one of the key goals in sustainable development, including transportation.

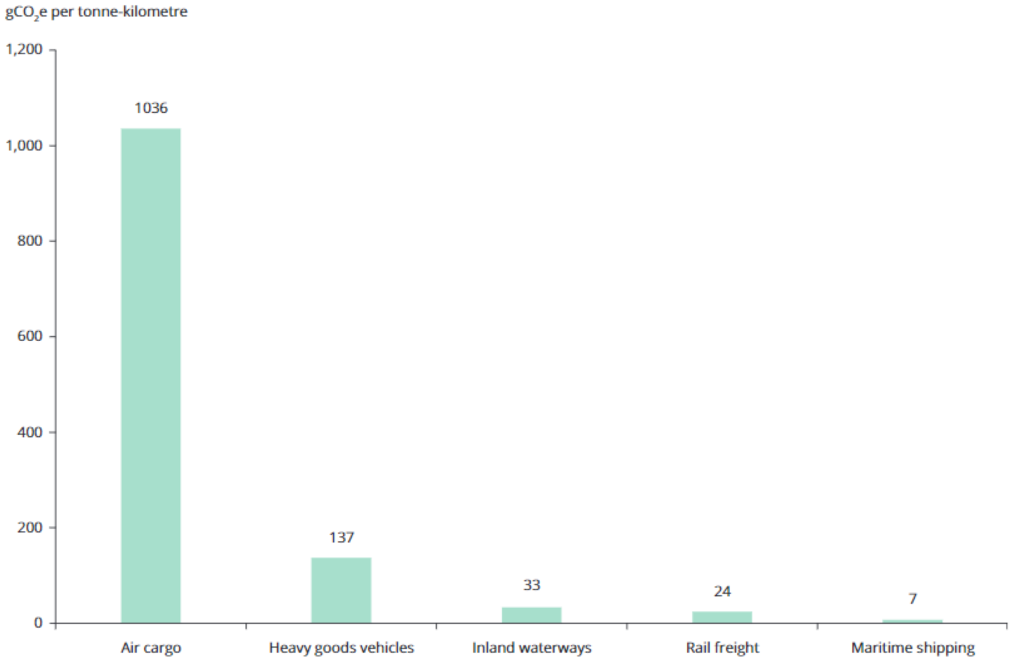

Figure 5. Average GHG emissions (gCO_2e per tonne-km), well-to-wheel, for freight transport in the EU-27, 2018 (EEA, 2022, p. 39).

2.4.1 Greenhouse gas emissions

Greenhouse gas emissions are often measured in CO_2-equivalent greenhouse gas emissions or by simply measuring CO_2-emissions. Combined transportation has the potential to reduce greenhouse gas emissions of the transportation sector under the right circumstances (Carboni & Dalla Chiara, 2018).

Rail transport produces less greenhouse gas emissions per tonne-kilometre of transported goods than road transport (EEA, 2022). Figure 5 presents the average well-to-wheel greenhouse gas emissions of various transport modes in grams of CO_2e per tonne-km in the EU in 2018. Well-to-wheel emissions calculations include all the emissions released in the entire process of sourcing energy, processing it as well as the final use of energy.

Carboni and Dalla Chiara (2018) refer to the environmental concerns of transport as external costs. Combined transportation has lower external costs than road transportation for two main reasons. Rail transport has a higher energy efficiency than road transport. The specific energy consumption of rail transport is lower than road transport because of the lower rolling resistance of trains.

Another reason for the lower emissions of road transport is that rail transport sources its energy from more diversified sources (Carboni & Dalla Chiara, 2018). While road transport moves largely on diesel sourced from oil, rail transport networks are much more electrified. Moving transportation from roads to rails reduces the emissions produced in transportation itself. If the energy used in rail transport is produced from renewable energy sources, the total greenhouse gas emission reduction potential becomes even greater.

Carboni and Dalla Chiara (2018) note that emissions and costs follow a similar trend for combined transport. The significance of this notion is that it implies that the cost benefits and emission benefits of combined transport are aligned. Under the circumstances where combined transport provides the greatest cost savings, it also provides the greatest emissions savings. Because road transport produces more emissions and costs than rail transport, short road transport legs and a long rail transport leg are beneficial both for profitability and emissions reduction.

The cost and emission reduction potentials of combined transportation become even more aligned if emissions trading is applied to road transport. The EU plans to expand its Emissions Trading System (ETS) to road transport from 2026 onwards (European Commission, 2021a). The ETS system places a price on the carbon intensity of the fuel used for transportation.

Given the high electrification rate of railways especially in the EU, the impact of a penalty targeted at the carbon intensity of the fuel used will be more significant for road transportation rather than rail transportation. Introduction of the ETS system to transportation would significantly improve the financial competitiveness of rail transportation.

2.4.2 Other environmental indicators

It is also important to monitor and understand other indicators about the transportation sector which influence greenhouse gas emissions of the transportation sector. The United Kingdom collects information on indicators such as freight transport by mode, energy consumption of road freight, and energy efficiency of road freight (OECD, 2002). Eurostat also collects information for European countries on indicators such as modal split and modal shift potential (Jahn et al., 2020).

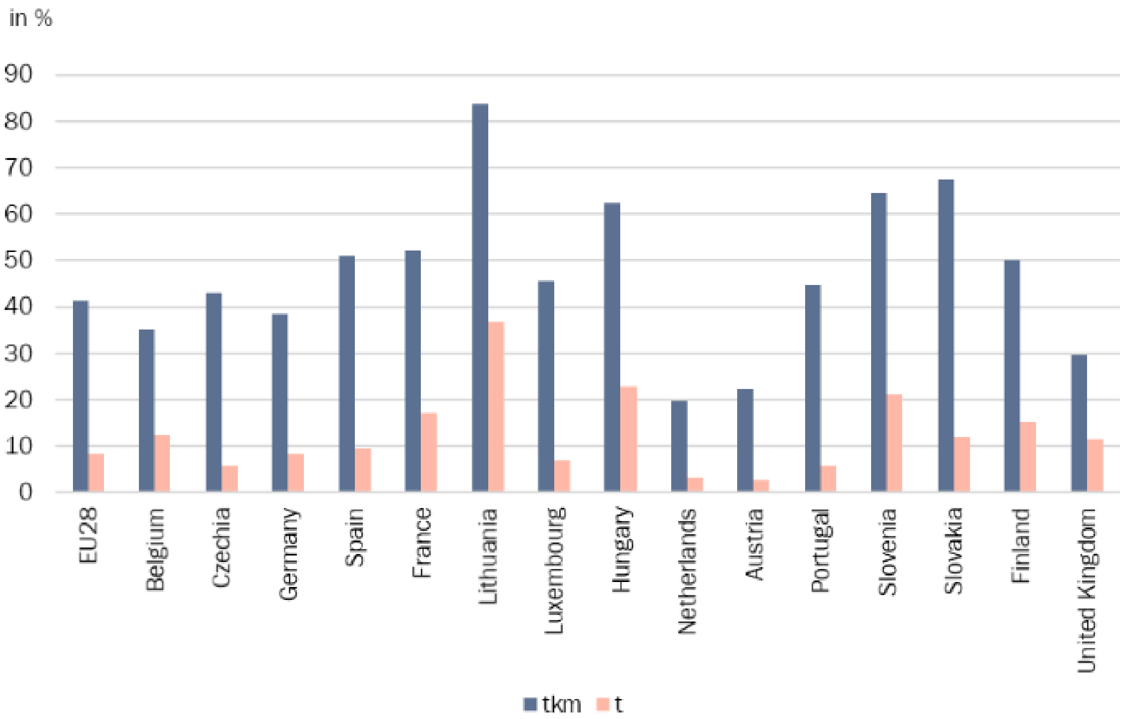

Figure 6. Modal shift potential of long-distance road freight in containers, 2017 (Eurostat 2020, as cited in Jahn et al., 2020, p. 18).

The “modal shift potential” indicator by Eurostat is a theoretical representation of the amount of road freight that could be moved to railways (Jahn et al., 2020). Modal shift potential expresses the share of containerised road freight that has travelled over 300 km. Eurostat uses 300 km as an estimated transport distance that would lead to a reduction in CO_2-emissions if shifted from road to rail. Figure 6 presents the modal shift potential for various European countries as a percentage of tonne-kilometres and tonnes of road freight falling under the modal shift potential criteria.

According to Carboni and Dalla Chiara (2018) the location of CT terminals on the transport route has a significant influence on the required transport distance to achieve emission and cost reductions. A transport distance of 300 km can provide a reduction of costs and emissions if CT terminals are within 30 km of the origin and destination sites. It is important to note that the modal shift potential indicator does not incorporate any information about railway networks (Jahn et al., 2020). Railway network capacity is a significant factor influencing how much road traffic can actually be shifted onto rails.

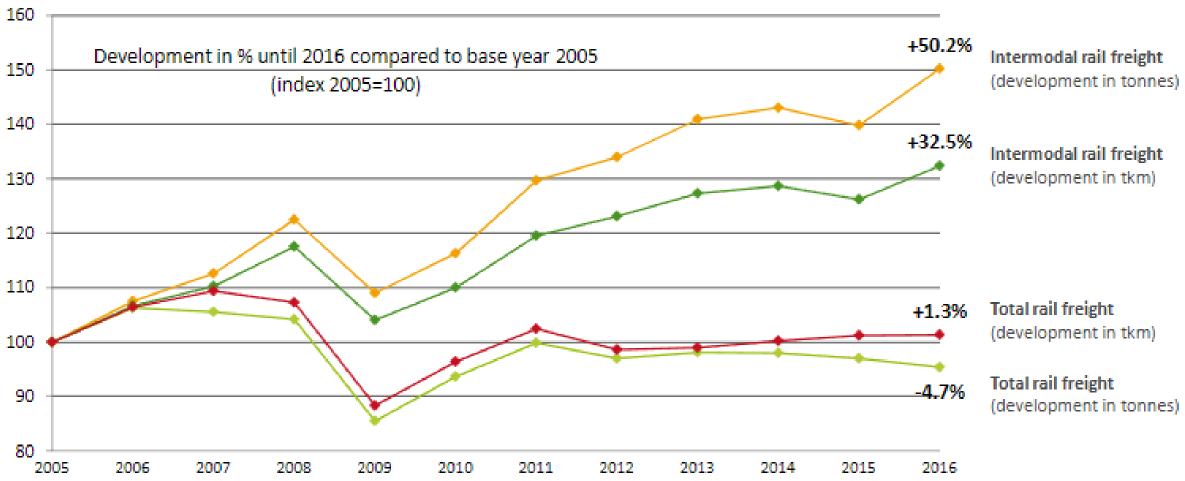

Figure 7. Development of total rail freight performance vs. rail transport of goods in intermodal transport units in Europe (UIC, 2019, p. 13).

Intermodal rail transport has grown continuously in Europe since 2005 (UIC, 2019). Figure 7 presents the percentage development of total rail freight and intermodal rail freight tonnes and tonne-kilometres. Development is shown relative to the year 2005 baseline represented as 100 %.

This graph includes data for the transport of containers and swap bodies from major European countries, as there is less data available for the transport of semitrailers and tractor unit accompanied transport. A dataset from only those European countries that have Eurostat figures available, shows a similar growth trend for semitrailers while accompanied transport has been declining (UIC, 2019).

The growth of intermodal rail transport is significant especially as total rail transport has remained almost constant (UIC, 2019). In fact, intermodal transport is the only rail transport market segment currently growing in Europe.

2.5 Logistical key performance indicators

Logistical performance indicators such as the time and flexibility of delivery are also relevant in the assessment of different transportation modes. Different transportation modes have their respective advantages and disadvantages (Jahn et al., 2020). Nature can also impose limitations on the selection of transportation mode. Some locations can only be reached with a certain transportation mode.

Road transportation is often the only transportation mode capable of door-to-door deliveries because rail and inland waterways require a more developed infrastructure (Jahn et al., 2020). Road transport is also considered to be the transportation mode most capable of dealing with natural obstacles such as significant elevation changes.

Comparing to rail transportation, road transportation is considered to offer higher compatibility (Reis et al., 2013). Trucks can use roads in any country and the regulations of trucking are highly uniform, especially in the EU. With rail transport, unfortunately multiple track widths are present, even in the EU. Railway wagons are therefore not as interchangeable as trucks and their trailers.

One logistical advantage of trains is their capability of transporting high capacities with good efficiency. Heavy bulk cargo such as coal or oil can be transported in much larger amounts with trains (Reis et al., 2013). Transporting large shipments with road is more likely to cause congestion and disrupt road traffic (Jahn et al., 2020).

Improving the speed and flexibility of rain transportation are important for the attractiveness of rail transport (Reis et al., 2013). Currently rail transport involves more stationary time for the delivered goods, and often longer lead times which is considered a disadvantage by transportation customers. This becomes especially important with time-sensitive industries such as food transportation and transportation of expensive items.

There are multiple reasons why rail transport has slower lead times than road transport. Rail transport often incorporates a modal shift between road and rail unless trains directly from industrial sites or ports are available (Carboni & Dalla Chiara, 2018). In most cases, road transport must be used to collect items and deliver them to the final destination.

Road transportation must often be used for first and final mile solutions because of the broader capillarity of road networks (Carboni & Dalla Chiara, 2018). Capillarity in logistics refers to the ability of the logistic system to deliver the product as close as possible to its destination. A network with a higher capillarity covers more destinations within a given area and therefore can be used to deliver goods closer to the destination.

Rail transport is also inherently compromised by its flexibility (Carboni & Dalla Chiara, 2018). While roads can become congested, railways are even more susceptible to congestion because in many instances two points are only connected by a single track. This implies that rail transport schedules must be carefully planned as overtaking same-direction traffic and passing by oncoming traffic is more difficult on tracks than on roads.

Modern signalling systems such as the European Rail Traffic Management System (ERTMS) can improve the scheduling of trains and help achieve a higher utilization rate of railway capacity (Islam et al., 2016). ERTMS provides live web-based tracking for operators and thus a higher number of trains can be flexibly managed without changes to the railway infrastructure itself.

Planning transportation schedules early can be difficult for some transportation customers. Volatile industries where supply and demand fluctuate quickly, might be unable or unwilling to commit to transportation schedules earlier than what is deemed necessary. Also, industries that deliver expensive but physically small goods tend to value flexibility and speed over other factors (Reis et al., 2013).

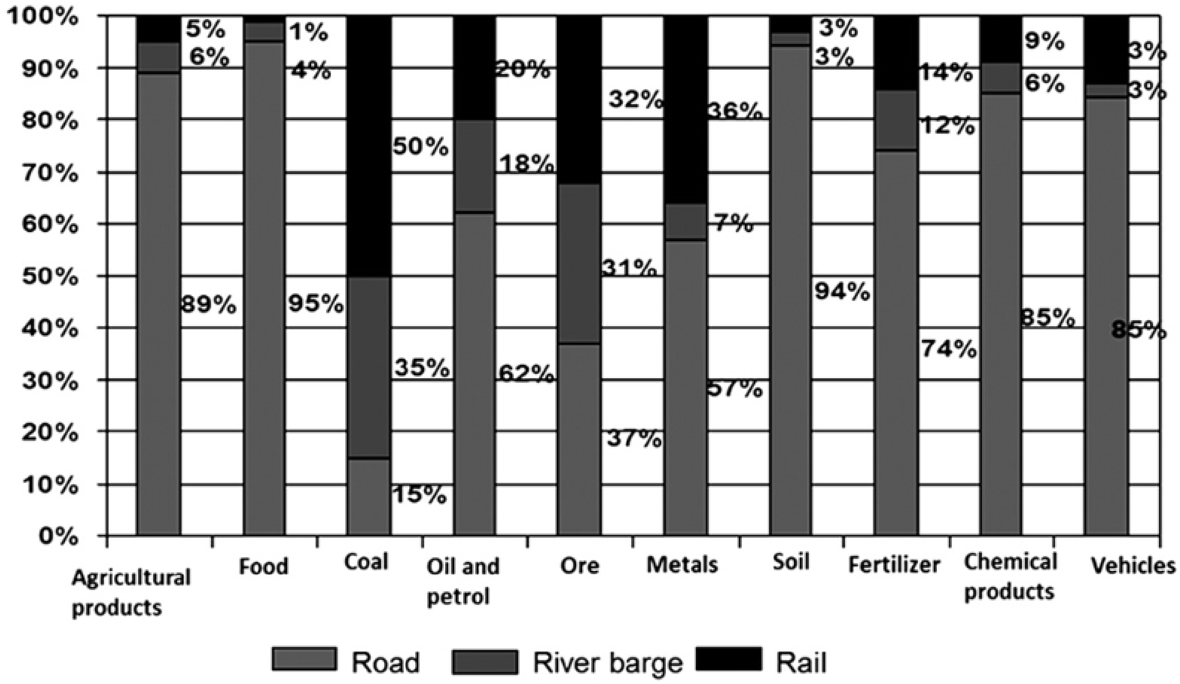

Figure 8. Modal share of different goods (Reis et al., 2013, p. 22).

Figure 8 presents the modal share of different types of goods transported. The logistical aspects of rail transportation and combined transportation make it most suitable for heavy cargo which is less time-sensitive and demands less of flexibility (Reis et al., 2013). Most heavy goods such as coal, oil or metals are not particularly time sensitive since they do not degrade quickly and are relatively cheap per kilogram, meaning they do not bind excessive amounts of capital.

Considering the financial, environmental, and logistical aspects of combined transportation, the most suitable scenario for combined transportation in its current state seems to be long-distance heavy cargo. To make combined transportation better suited for other industries, the lead times of combined transportation need to be reduced (Reis et al., 2013).

Combined transportation lead times can be reduced mainly with two methods. CT terminal operations can be sped up by investing into terminals and optimizing the loading and unloading of intermodal transport units (Reis et al., 2013). Rail transportation can also be made faster by using high-speed rail in freight transport, however high-speed rail connections are often prioritized for passenger traffic (Carboni & Dalla Chiara, 2018).

2.6 Terminal benchmarking

Terminals or dry ports are a key part of the combined transportation infrastructure contributing to the success of combined transportation. Especially terminal density is important for successful combined transportation (UIC, 2020). This is because a higher terminal density helps shorten the road leg of combined transport, lowering the total costs and greenhouse gas emissions of combined transportation (Carboni & Dalla Chiara, 2018).

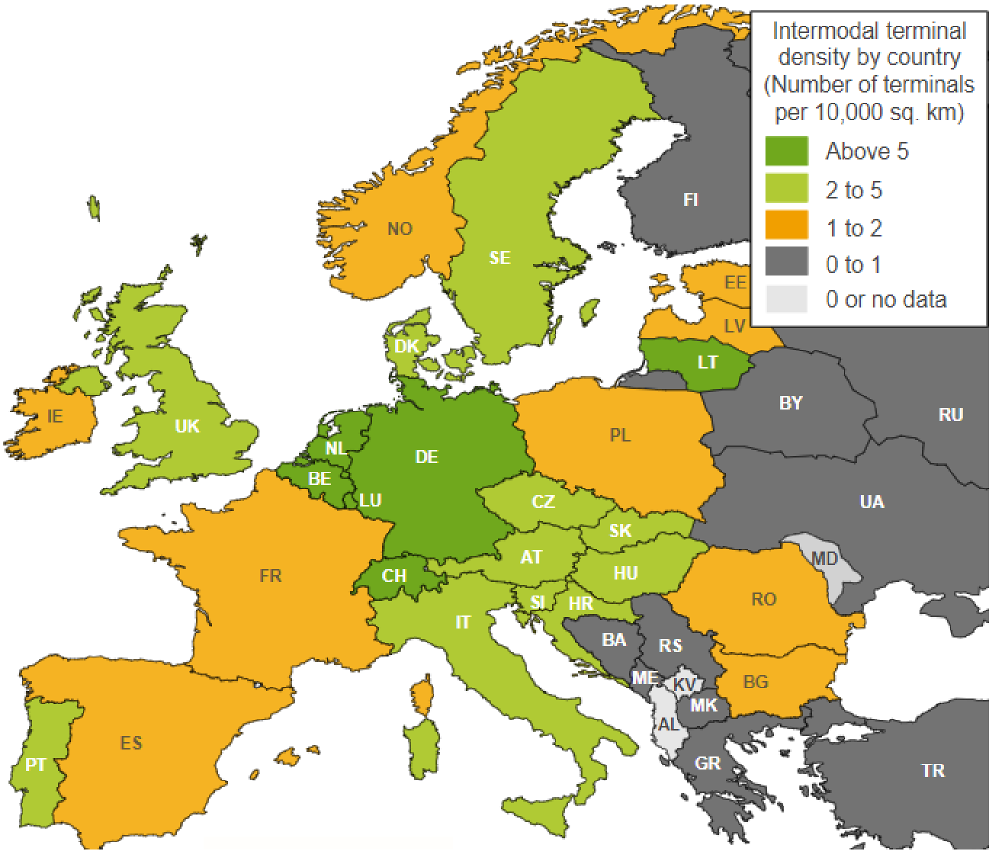

Figure 9. Terminal density in European countries (UIC, 2020, p. 23).

Figure 9 is a map of the intermodal terminal density of various European countries. Data is presented as the number of terminals per 10 000 square kilometres. Sufficient terminal density is a key infrastructural requirement for combined transportation. UIC (2019) lists congestion at terminals for certain wagon types as one of the challenges for combined transportation fleet currently. Insufficient capacity at terminals is also listed as a future challenge for combined transportation fleet.

Terminal operations are one of the cost elements of combined transportation together with road transportation and rail transportation. Carboni and Dalla Chiara (2018) argue that while terminal operations are the smallest operating cost of combined transportation, they are significant because the cost is unrelated to the transportation distance. Terminal costs are also not present in road-only transportation. Therefore, making terminal costs lower is important in the competitiveness of combined transportation.

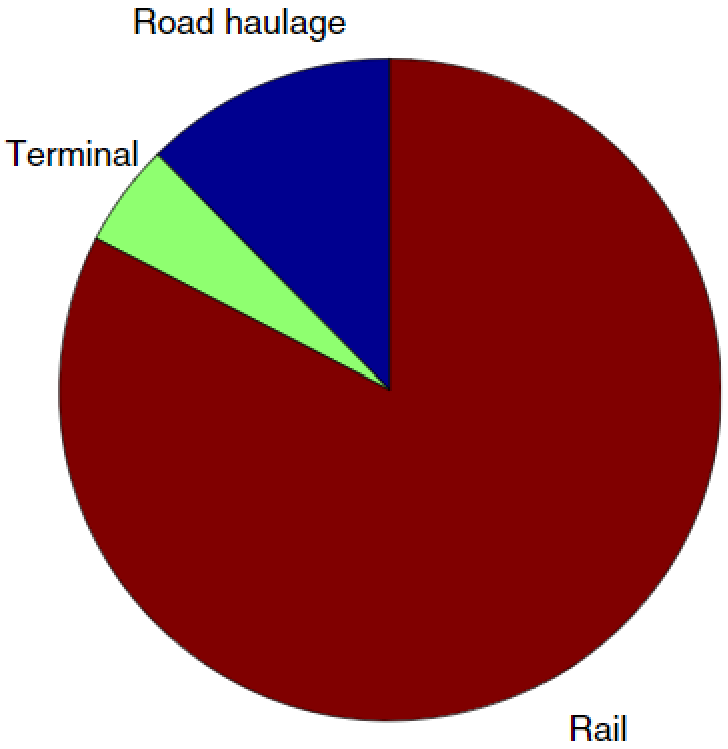

Figure 10. Influence of each cost item on the final combined transport price (Carboni & Dalla Chiara, 2018, p. 10).

Figure 10 presents how the total costs of combined transportation are typically distributed between road, rail, and terminal operations. The share of terminal costs becomes proportionally higher when transporting over shorter distances, as terminal costs are independent of distance (Carboni & Dalla Chiara, 2018).

Islam et al. (2016) argue that terminal operations should be made both faster and cheaper to make combined transportation more attractive. This can be done by designing terminals with modern loading equipment and using the best loading and unloading practices. With horizontal transfer technology, stoppage times of 20 to 30 minutes can be achieved for trains.

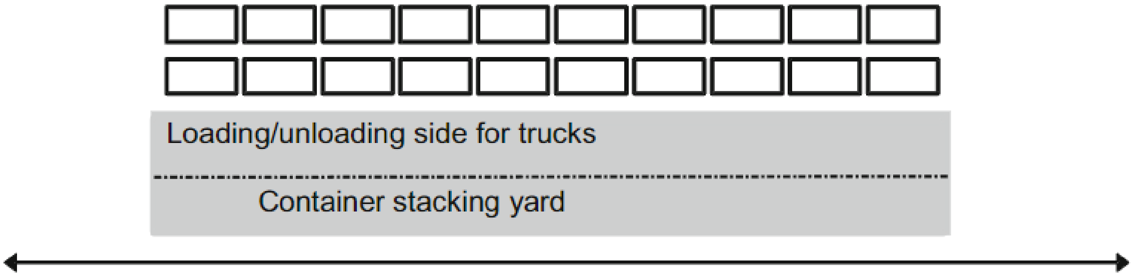

Figure 11. Typical trackside low-cost loading/unloading facility (SPECTRUM Consortium, as cited in Islam et al., 2016, p. 12).

Figure 11 presents a typical small terminal with horizontal loading capability of intermodal transport units. At modern terminals with horizontal loading capability, trucks and trains can load or unload their cargo independent of each other. This enables trucks to leave the terminal or pick up new cargo immediately after unloading their cargo.

Trucks often unload their intermodal transport unit on a parking space or at a storage site from where it will be moved next to the rail track. ITUs are placed parallel with the rail track and wagons, ready to be loaded onto the train. Various technological solutions have been developed for the horizontal handling of ITUs at the terminal sites (Islam et al., 2016).

OECD (2002) list multiple performance metrics for combined transportation terminals. Performance metrics for can be divided into road-related metrics and rail-related metrics. Road-related metrics include metrics such as truck turnaround times, entry waiting times, container dwell time, and shipment tracing capabilities. Rail-related metrics include metrics such as on-time departures, shunting times, container dwell time, and shipment tracing capabilities.

2.7 Combined transportation in Finland

This chapter will expand on the recent history and current state of combined transportation in Finland, as well as highlight features of the Finnish transportation system that affect the potential of combined transportation in Finland. Understanding these features will provide a more precise understanding of the viability of combined transportation in Finland.

Finland’s state-owned railway operator VR Group provided a combined transport service between 1991 and 2014 (VR, 2013). Declining demand and low profitability were stated as the reasons for discontinuation, but VR also stated it was willing to restart the service if a sufficient customer base was found and other preconditions supported restarting of the service.

The combined transport provided by VR was tractor unit accompanied transport (Salanne et al., 2021). It is noteworthy that accompanied transport has been the only declining form of combined transport across Europe while transport of semitrailers, swap bodies, and containers has been increasing (UIC, 2019).

Salanne et al. (2021) state that declining demand for combined transport was affected by poor reliability of service caused by high traffic on the Kokkola-Ylivieska railway line as well as maintenance work on the Seinäjoki-Oulu line. Completion of the Seinäjoki-Oulu line maintenance work and concerns about truck emissions has sparked conversation about restarting combined transport in Finland. A line between the Turku harbour and Oulu has been considered.

Legislative changes might also have affected the declining demand of combined transport in Finland (Salanne et al., 2021). The maximum permitted length of trucks was increased in 2019, which has enabled transporting two 40-feet containers simultaneously, resulting in an increase of High-Capacity Transport (HCT) trucks on Finnish roads.

Also, the maximum height for tractor-trailers was increased in 2013 from 4.2 metres to 4.4 metres (Salanne et al., 2021). The higher 4.4 metre trailers were too high to transport with existing wagons whilst complying with safety regulations. Transporting the higher trailers would breach the required safety margins to the overhead lines on electrified railways.

The electrification rate of Finnish railways, like many other European countries, is very high. 94 % of passenger traffic and 79 % of freight transport is moved with electric-powered locomotives (Andersson et al., 2020). A high electrification rate of rail transport increases the possible emission reduction that can be achieved by moving transport from road to rail.

Available railway capacity is one of the most important factors that needs to be considered before restarting combined transport in Finland (Salanne et al., 2021). Insufficient capacity will lead to delays and unreliability which will negatively affect the perception of combined transport. The Helsinki-Riihimäki and Ylivieska-Oulu railway lines are of particular concern in terms of available capacity.

According to Salanne et al. (2021) new wagons should be purchased if combined transport is to be restarted in Finland. While existing wagons can transport 4.2 metres high trailers and with minor modifications 4.3 metres high trailers, the 4.4 metre trailers have become common in Finland, and thus wagons capable of accommodating them would be beneficial. New wagons should also take into consideration the increased size and mass of modern Finnish trucks. The use of innovative solutions in wagons should also be researched. The availability of used options might be limited because the Finnish track gauge of 1524 mm differs from the standard or European 1435 mm track gauge.

3 Methodology

This chapter presents how the results of this study have been achieved. This thesis is a benchmarking study intended to assess the potential of intermodal transport in Finland and the South-Ostrobothnia region. The results chapter is aiming to answer Q3 “What opportunities and limitations does South-Ostrobothnia present for an intermodal terminal?”, while the theoretical background chapter of this study aims to answer Q1 and Q2.

The theoretical background chapter established an understanding of the basics of combined transport, transport infrastructure and key metrics of combined transport. It also discussed benchmarking studies and challenges in benchmarking intermodal transport. With the knowledge established in the theoretical background, the results chapter will try to evaluate data about the Finnish transportation sector and benchmark it against leading global examples.

It is important to note that all data is secondary data, this thesis does not involve primary data collection. The reasoning for only incorporating secondary data is straightforward. As the research questions focus on combined transportation infrastructure and the viability of combined transportation in Finland and South-Ostrobothnia, these questions are best answered by analysing official statistics from the Finnish transportation sector.

Data has been gathered from Finnish government agencies such as Tilastokeskus and is publicly available. Calculations using data from multiple sources is the primary method to create results that can be used to evaluate the potential of combined transport in Finland and South-Ostrobothnia.

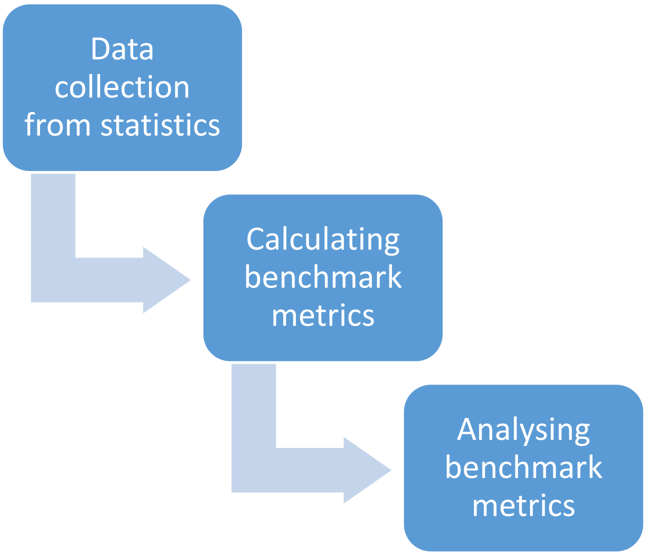

Figure 12. Simplified benchmarking process of this study.

Figure 12 presents the simplified steps of this benchmarking study. Once relevant data has been collected from statistics sources, the benchmarking metrics will be calculated. Data might not be readily available for benchmarking but combining data from different statistics can be used to make estimations and projections about combined transportation in Finland and South-Ostrobothnia. Analysing the estimations and projections will complete the benchmarking.

This study aims to evaluate the potential benefits of intermodal rail-road transport in South-Ostrobothnia by estimating the demand for intermodal transport and by evaluating the feasibility of moving road freight to rails. Due to the limited availability of data about the true railway capacity, the study focused largely on evaluating the theoretical benefits of moving freight to rail in the South-Ostrobothnia region. The theoretical benefits are evaluated using data from the road freight transportation sector, compiled by Tilastokeskus. This framework of this study does not try to replicate a specific previous study but it can be classified as a benchmarking study.

4 Results and discussion

This chapter will analyse data from the transportation sector in Finland and South-Ostrobothnia to estimate the viability of intermodal transport in South-Ostrobothnia. This chapter will also estimate the potential financial and environmental benefits intermodal transport could provide for the transportation sector in the region as well as analyse factors potentially limiting the opportunities for intermodal transport in South-Ostrobothnia. This chapter aims to answer research question 3.

4.1 Transportation volumes and terminal demand

VR (2013) stated that it was willing to restart intermodal transport in Finland if a sufficient customer base was for the service was found and other preconditions supported the restarting of intermodal transport in Finland. To understand whether an intermodal terminal in South-Ostrobothnia would be viable, the volume of road freight transport in South-Ostrobothnia needs to be analysed. This will help determine the modal shift potential of South-Ostrobothnia and thus the demand for an intermodal transport terminal in South-Ostrobothnia.

Table 2. Road freight transportation volume from and to South-Ostrobothnia in 2017 in tonnes (Tilastokeskus, 2017).

Transportation volume (tonnes)	Departing	Arriving	Total
Road freight	2 959 000	2 658 000	5 617 000

Table 2 presents the volume of road freight from and to South-Ostrobothnia in 2017 in tonnes. Road freight transport inside South-Ostrobothnia is not included in the figures. Road transport within the region is not taken into consideration here, because transport distances within the region are short and it is not useful to consider them when estimating the volume of transport that could be shifted onto rails.

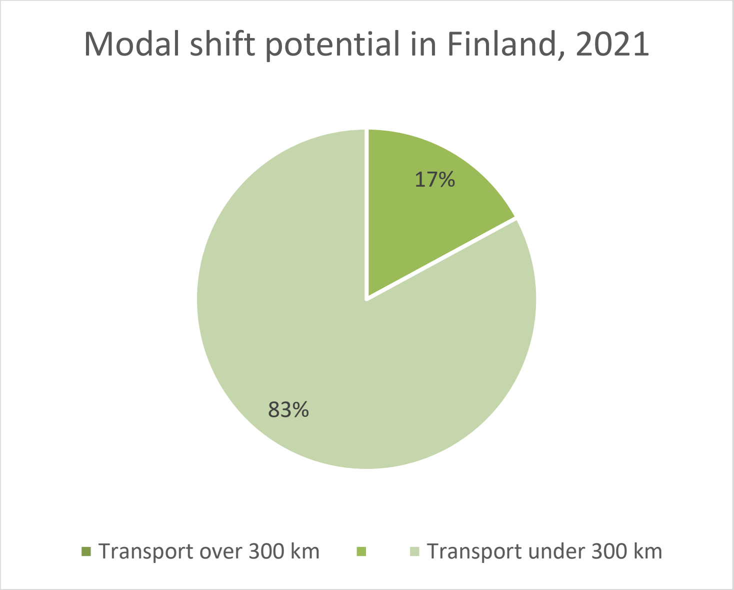

Figure 13. Modal shift potential of road freight tonnes in Finland in 2021 (Tilastokeskus, 2022a).

Based on the Eurostat indicator modal shift potential, 15 % of road transport volume measured in tonnes could be shifted onto rails in Finland (Jahn et al., 2020). Figure 13 presents the modal shift potential in Finland in 2021 based on nationwide road freight transport data by Tilastokeskus (2022a). In 2021 road freight transport in Finland that travelled over 300 km was 17 % of all road transport volume measured in tonnes. This result is similar to the 15 % figure by Eurostat (Jahn et al., 2020).

It is important to note that there are two variables of modal shift potential. The first way to measure modal shift potential is to measure the percentage of tonnes that were transported over 300 km. The second way is to measure the percentage of tonne-kilometres that were transported over 300 km.

Modal shift potential measured as a percentage of tonne-kilometres is generally greater than as a percentage of tonnes. This is because long-distance transportations that exceed 300 km are less frequent but measuring transportation in tonne-kilometres emphasizes long-distance transportations while measuring in tonnes does not (Jahn et al., 2020).

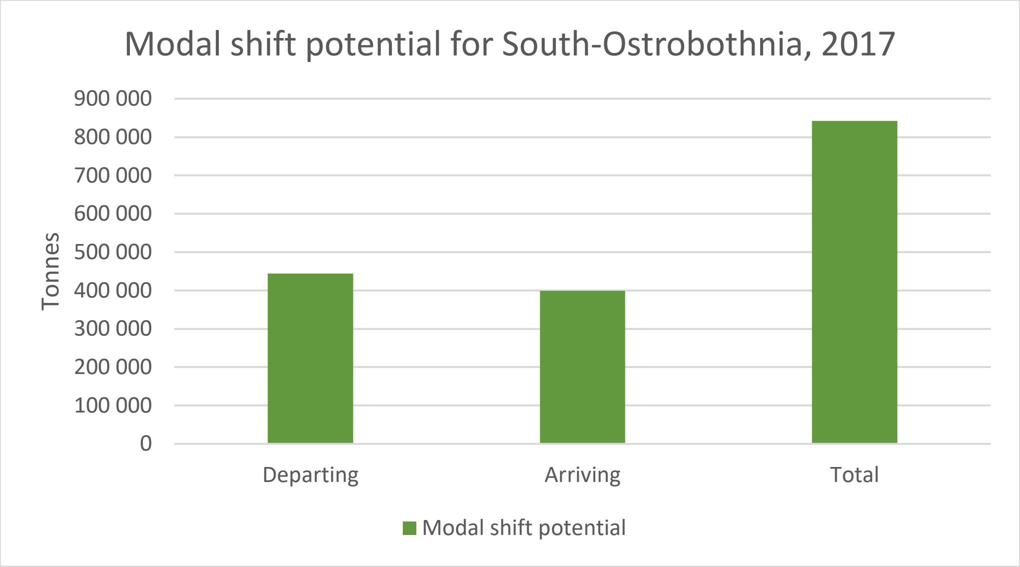

Figure 14. A 15 % modal shift potential for South-Ostrobothnia based on 2017 road transportation volumes in tonnes.

Figure 14 presents the yearly modal shift potential for South-Ostrobothnia in tonnes. The estimation is calculated using the road freight transportation volume in tonnes, presented in Table 1. It assumes a 15 % modal shift potential of road freight transportation volume measured in tonnes. The total yearly modal shift potential for South-Ostrobothnia is 842 550 tonnes.

A modal shift potential of 842 550 tonnes yearly would equate to 4 trains per day, assuming a typical train size of 525 tonnes, containing 30 ITUs and with terminal operations performed 365 days per year. This volume would equal 43 800 ITUs per year which would place an intermodal terminal of this volume to the medium sized terminal category by Bielenia et al. (2020).

It is unlikely however that the realized modal shift of South-Ostrobothnia would be this great, as the observed modal shift in many European countries has been significantly smaller than the theoretical modal shift potential (Jahn et al., 2020). The observed modal shift in Finland was 0.6 % between 2006 and 2017.

Observed modal shift is smaller than the modal shift potential likely due to the railway network not being able to handle such large volumes. However, that is difficult to estimate in the case of the Finnish railway network because regular statistics have not been collected about the actual utilization rate of railways and the unused capacity (Räty et al., 2020). Nevertheless, the volume of transport is sufficient for intermodal transport.

4.2 Financial and environmental benefits estimation

Under the right circumstances, combined transportation can provide both financial and environmental benefits compared to pure road transportation. This chapter will estimate the financial and environmental benefits combined transportation could provide for the South-Ostrobothnia region transportation sector.

Table 3. Road freight transportation volume from and to South-Ostrobothnia in 2017 in millions of tonne-kilometres (Tilastokeskus, 2017).

Transportation volume (millions of tonne-kilometres)	Departing	Arriving	Total
Road freight	669	558	1227

Table 3 presents the volume of road freight transportation in South-Ostrobothnia in 2017, in millions of tonne-kilometres. Road freight transportation within the region is not included. The data from this table can be used to estimate the greenhouse gas emission reduction potential of implementing intermodal transport in South-Ostrobothnia. The tonne-kilometre based modal shift potential for Finland, published by Eurostat is 50 % (Jahn et al., 2020).

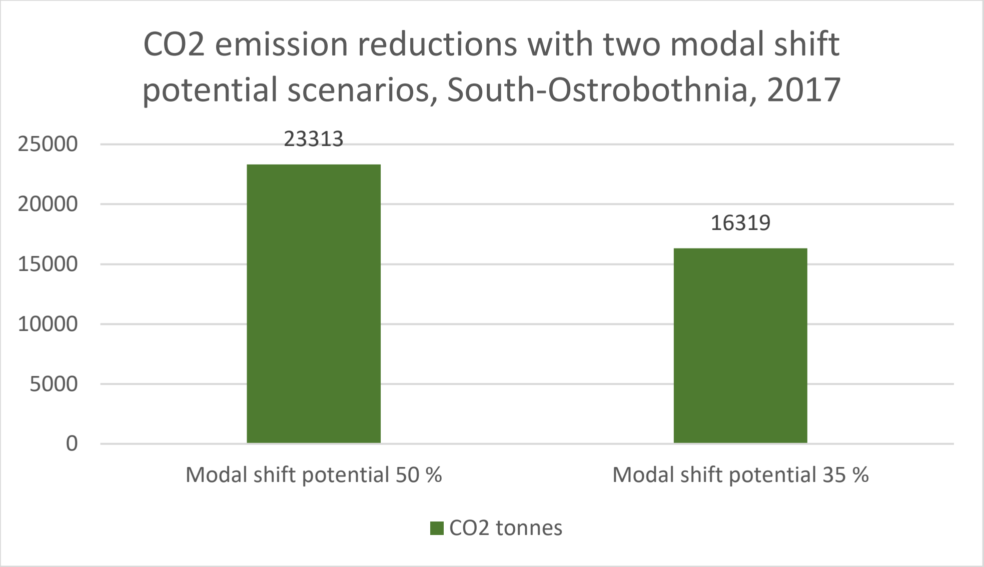

Figure 15. Yearly CO_2-emission reduction potential of two modal shift potential scenarios based on road freight tonne-kilometres to and from South-Ostrobothnia in 2017.

Figure 15 presents two scenarios of yearly emission reduction potential of combined transportation in South-Ostrobothnia. A 50 % modal shift potential based on the Eurostat figure and a pessimistic 35 % scenario are used to calculate CO_2-emission reductions achieved with the modal shift. The modal shift potential scenarios are calculated based on road freight transportation tonne-kilometres from and to South-Ostrobothnia presented in Table 2.

Figures are calculated using an estimation of 38 grams of CO_2 emitted tank-to-wheel per one tonne-kilometre of road freight transport (VTT, 2017). Rail transport is assumed to be electric and thus emission free in the transportation stage.

A 50 % modal shift potential for South-Ostrobothnia results in a CO_2-emissions decrease of 23 313 tonnes yearly. The 35 % modal shift potential scenario results in yearly emissions decrease of 16 319 tonnes.

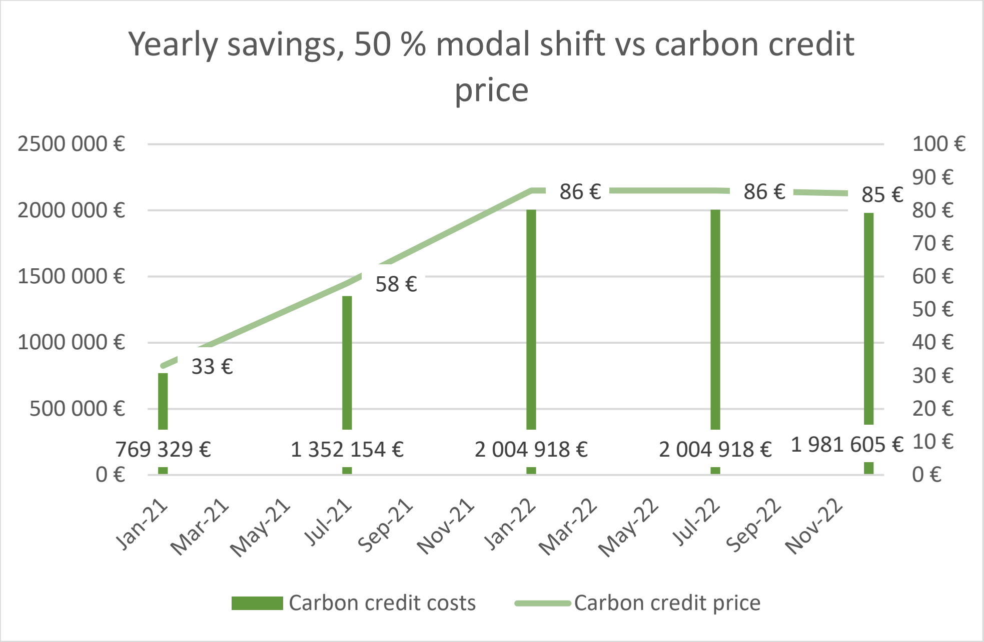

Figure 16. Yearly cost savings in EU emissions trading versus the price of carbon credits, based on the 50 % modal shift for 2017 tonne-kilometres.

Figure 16 presents how much the transportation sector in South-Ostrobothnia would save yearly in the EU Emissions Trading System if it were to be applied to road freight transportation, and how the savings are affected by the price of carbon credits. Figure 16 uses the 50 % modal shift scenario-based emission reduction potential, first presented in Figure 15, based on the road freight transportation tonne-kilometres volume presented in Table 2.

Savings are calculated using the emission decrease potential of 23 313 tonnes and the price development of the official EU Emissions Trading System imposed penalty for releasing one tonne of CO_2-emissions. Yearly savings in the EU ETS would result into 1 981 605 € for the South-Ostrobothnia transportation sector with the December 2022 price of EU ETS carbon credits. The development of savings increases greatly with the price increase of one tonne of CO_2-emissions.

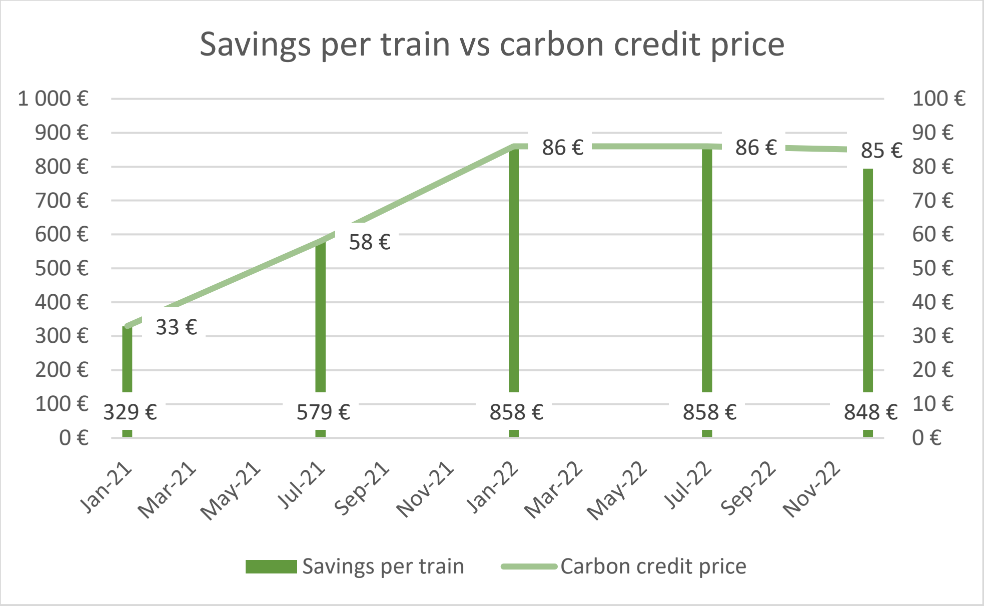

Figure 17. The emissions trading-based cost savings of moving road freight to rail per a 525-tonne train travelling 500 km in relation to the price of EU ETS carbon credits.

Figure 17 presents the cost savings potential of one 525-tonne train travelling 500 km in relation to the price of EU ETS carbon credits. Using the 38 grams of CO_2-emissions per tonne-kilometre of transport we can calculate the emissions of the equivalent amount of road freight transported. Then by using the emissions of the equivalent amount of road freight, we can calculate the cost savings based on the cost of emitting one tonne of CO_2 according to the EU ETS prices.

With December 2022 prices of EU ETS carbon credits, the cost savings a 525-tonne train would provide in emissions trading compared to an equivalent amount of road transportation equals 848 €. Again, the emissions trading-based cost saving potential of intermodal transport is highly dependent on the price of carbon credits.

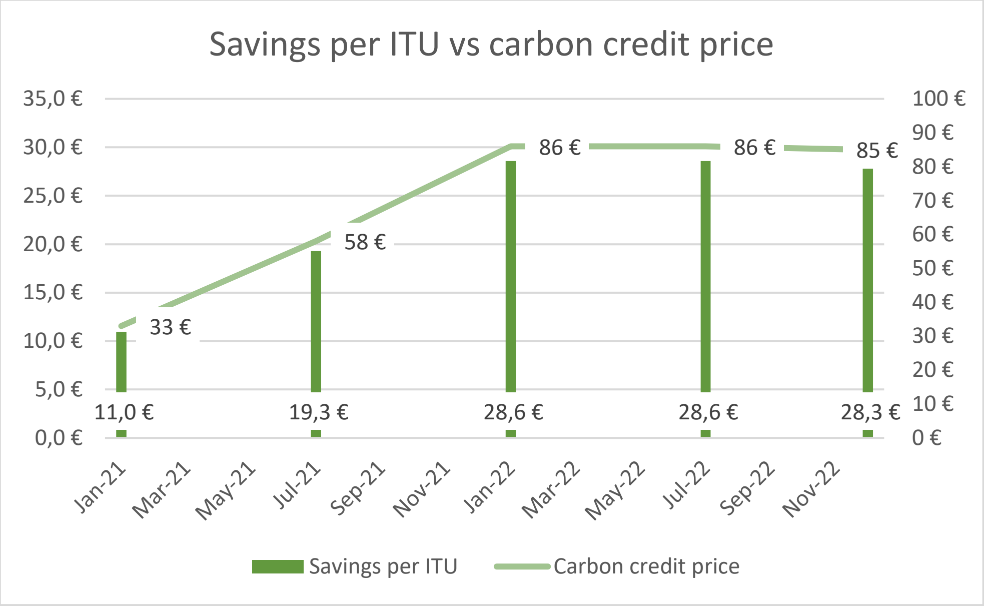

Figure 18. The emissions trading-based cost savings of moving road freight to rail per one ITU travelling 500 km in relation to the price of EU ETS carbon credits.

Figure 18 presents the emissions trading-based savings as a value per one intermodal transport unit travelling 500 km, in relation to the price of EU ETS carbon credits. Using the savings per train value presented in Figure 17, and assuming 30 ITUs per train we calculate the savings achieved per ITU on a 500 km distance when moving freight transportation from road to rail.

Cost savings in EU ETS emissions trading per ITU for a 500 km transportation distance equals 28.3 € with the December 2022 prices of EU ETS carbon credits. Increasing the penalty for emitting CO_2 would also greatly increase the cost savings of intermodal transport should EU ETS be implemented to road freight transportation.

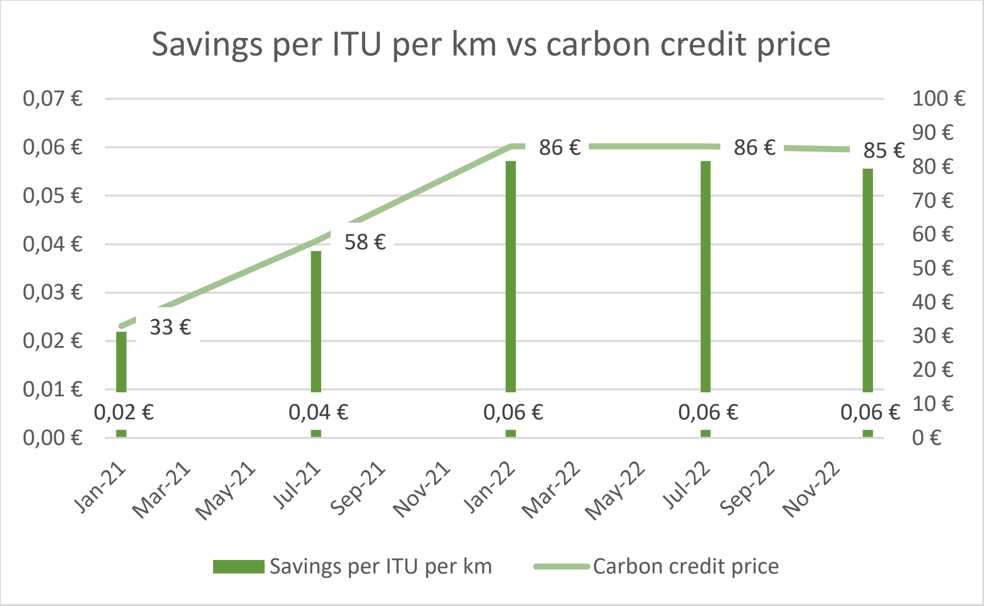

Figure 19. The emissions trading-based cost savings of moving road freight to rail per one ITU per km in relation to the price of EU ETS carbon credits.

Figure 19 presents the emissions trading-based savings as a value per one intermodal transport unit per km, in relation to the price of EU ETS carbon credits. Using the savings per ITU value on a 500 km transportation distance, presented in Figure 18, we can calculate the savings per ITU per km, that can be achieved by moving freight transportation from road to rail.

The cost savings per ITU per km with the December 2022 price of EU ETS carbon credits amounts to 0.06 €. Carboni and Dalla Chiara (2018) state that the total cost of transporting one ITU one km on the road is 0.58 – 1.37 €. Therefore, should EU ETS be implemented to road freight transportation, it would directly increase transportation costs of road freight by 4 – 10 %.

While the price of carbon credits in EU ETS can still be considered inexpensive, implementing it to road freight transportation would result in a significant relative increase of costs, because road freight transportation itself is also inexpensive.

4.3 Logistical opportunities and limitations

This chapter will consider the opportunities and limitations for intermodal transport in South-Ostrobothnia, from a logistical perspective. Intermodal transport is better suited for certain types of goods than others. Goods that are less time-sensitive and demand less flexibility are better suited for intermodal transport than other goods. The containerization of goods is another point of consideration. While bulk goods are less time-sensitive, they can be difficult for intermodal transport if they are not containerized.

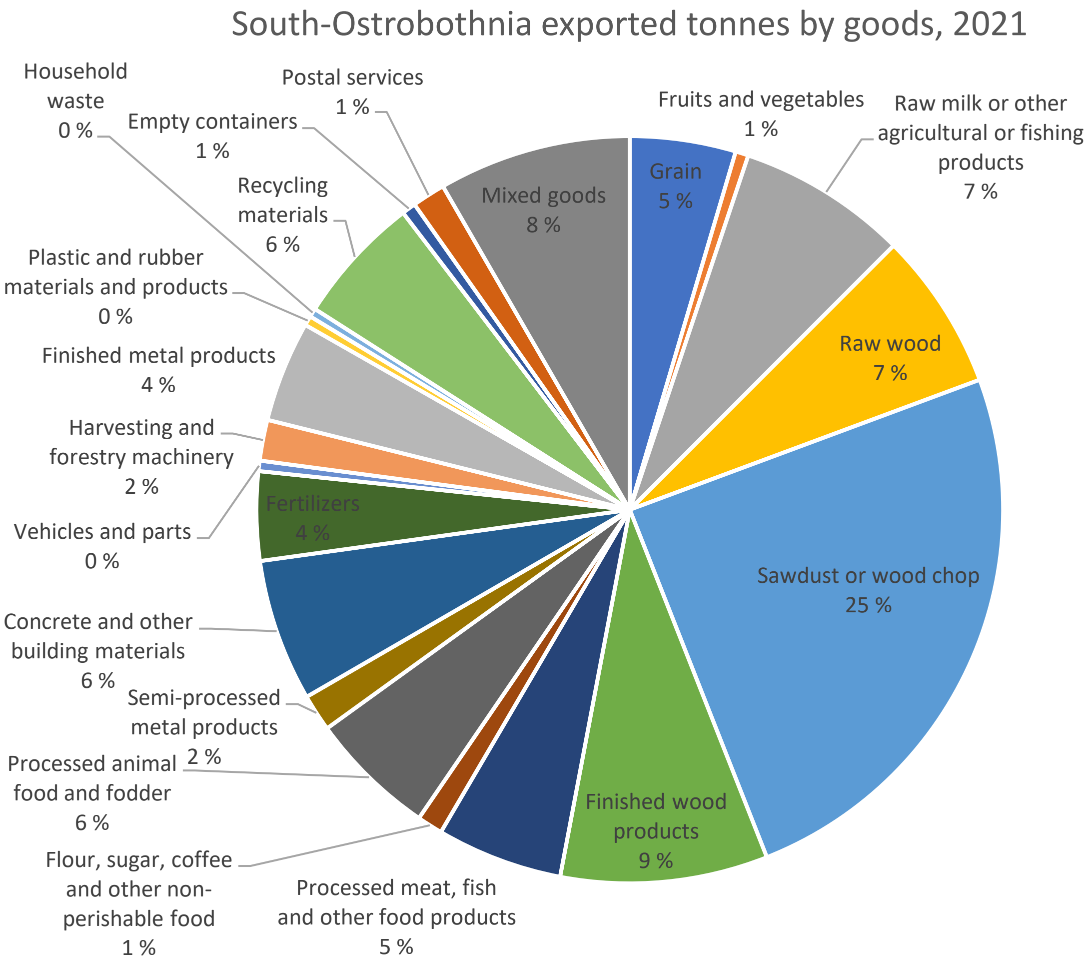

Figure 20. Road freight export tonnes from South-Ostrobothnia by types of goods in 2021 (Tilastokeskus, 2022b).

Figure 20 presents the road freight exported from South-Ostrobothnia to elsewhere in Finland as a percentage of exported tonnes in 2021 by types of goods. Data is from Tilastokeskus (2022b). The figure shows the large share of wood products and agricultural products exported from the South-Ostrobothnia region.

Wood products are suitable for intermodal transport because of their low time-sensitivity and low value per kilogram. Wood products however are often not containerized unless they are heavily processed or finished products. Raw wood is transported in open trailers and wagons, and because of its extremely low time-sensitivity and value per kilogram, should be moved between road and rail with conventional equipment directly from trailers to wagons without need to load trailers onto wagons.

Agricultural products are much more time-sensitive and in some cases require refrigeration during transport. Transporting agricultural products intermodally requires quick lead times, enabled by quick terminal operations and a reliable railway service. The high electrification rate of Finnish railways could in theory provide inexpensive and sustainable refrigeration, but technological solutions that allow reefers to be powered while the train is moving, are uncommon in the EU.

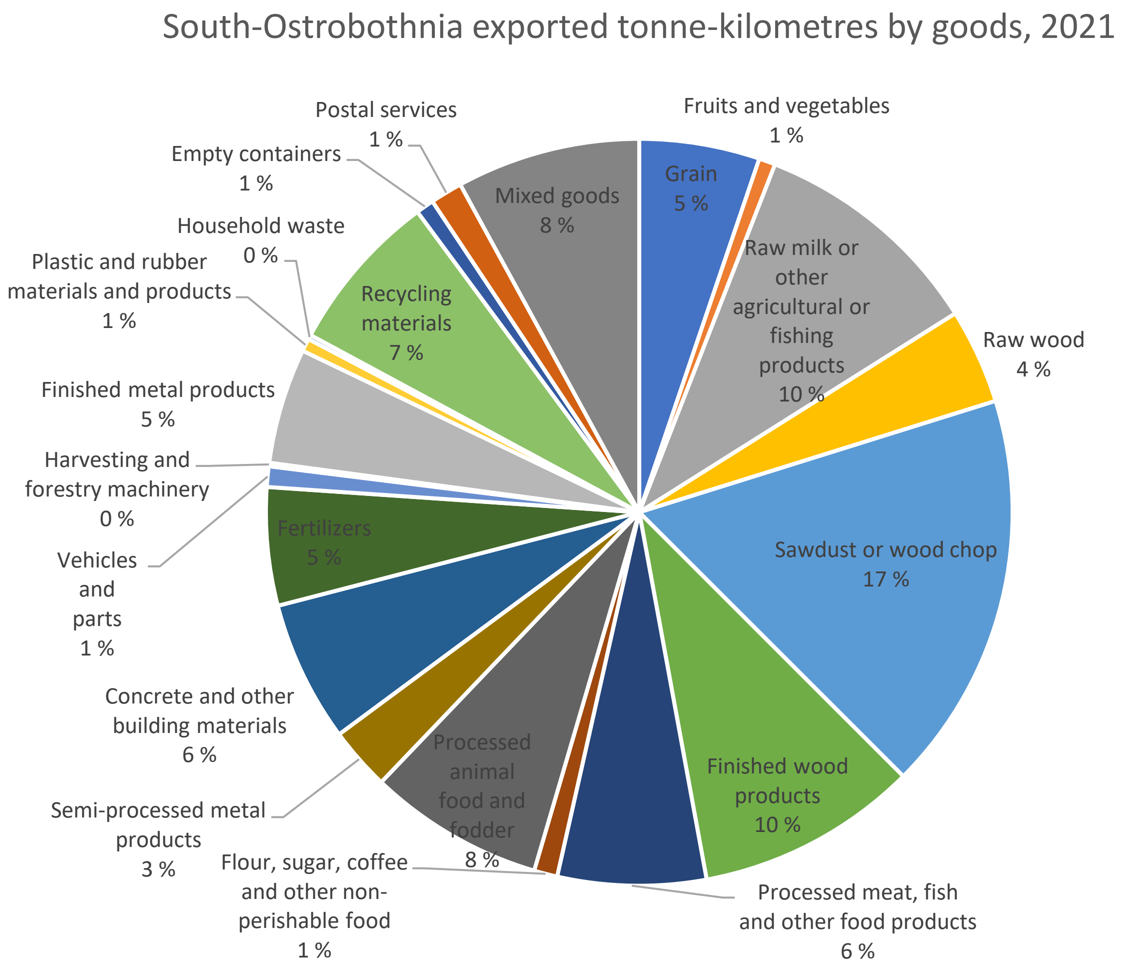

Figure 21. Road freight export tonne-kilometres from South-Ostrobothnia by types of goods in 2021 (Tilastokeskus, 2022b).

Figure 21 presents the road freight exported from South-Ostrobothnia to elsewhere in Finland as a percentage of exported tonne-kilometres in 2021 by types of goods. Data is from Tilastokeskus (2022b). Compared to Figure 20 presenting the exported road freight as tonnes, the share of agricultural products is increased, and the share of wood products is decreased when measuring exports in tonne-kilometres.

Agricultural products contribute more to tonne-kilometres than tonnes because they are lighter but are transported over a longer distance, while wood products contribute more to tonnes than tonne-kilometres because of their heavier weight but shorter transportation distances. As intermodal transport provides the greatest benefits when the rail transport leg is long enough relative to the road transport leg, agricultural products are better suited for intermodal transport regarding transportation distance. However, agricultural products provide a challenge for intermodal transport with their high time-sensitivity and refrigeration demands.

5 Conclusions

Increasing rail-road intermodal transport is one of the proposed solutions to reduce the greenhouse gas emissions of the transportation sector. The European Union states that it wants to shift transportation from road to rail. It also emphasizes intermodal transport as a major part of its future TEN-T transportation network policy, with clear goals such as building more transhipment hubs and ensuring the ability to transport trucks on trains.

Benchmarking intermodal transport can be used as a method to understand what is required from intermodal transport so that it can be financially competitive and environmentally beneficial. Benchmarking intermodal transport also helps understand the logistical challenges of intermodal transport.

Benchmarking intermodal transport is a complex issue and benchmarking exercises should focus on a certain perspective, such as financial, environmental, or logistical. Benchmarking exercises should also benchmark either the entire transportation chain or a part of it, depending on the circumstances.

The financial and environmental benefits of rail-road intermodal transport are aligned. Intermodal transport provides the greatest financial and environmental benefits when the distance covered by rail is maximized relative to the distance covered by road on a given transportation distance.

Intermodal transport can reduce CO_2-emissions compared to pure road transport because of the lower emissions per tonne-kilometre of rail transport compared to road transport. The primary reasons for this are the better energy efficiency of trains and the larger share of renewable energy in the energy sources of rail transport compared to road transport.

For intermodal transport to be environmentally beneficial, it requires that the rail transport leg is long enough to offset the emissions caused by terminal operations as well as the initial and final road haulages. Intermodal transport can lead to more truck traffic in urban areas compared to road-only transport, and therefore a long rail transport leg is needed to offset the emissions caused by the increased amount of highly polluting urban area truck transport.

Intermodal transport also requires a dense terminal network to be able to achieve the circumstances where it is financially viable and environmentally beneficial. Modern horizontal loading technology can also speed up terminal operations, making the lead times of intermodal transport more competitive, together with modern signalling systems such as ERTMS. Rail-road intermodal transport is, however, still best suited for goods that are less time-sensitive and demand less flexibility from the transportation process.

The Finnish transportation network provides opportunities for intermodal transport, with the high electrification rate of Finnish railways and the hydropower-sourced renewable energy used for rail transport. Limiting factors include the availability of data about unused railway capacity as well as the prioritization of passenger traffic on railways. Therefore, estimating how much road transport can be shifted onto rails is difficult.

The South-Ostrobothnia region has enough road freight transport, to support building an intermodal terminal according to the theoretical modal shift potential scenarios. More research needs to be done to understand the available railway capacity to better estimate if sufficient demand exists for an intermodal transport in South-Ostrobothnia. Researching the suitable terminal loading technologies for South-Ostrobothnia is also suggested as a future research topic.

Shifting road freight onto rails would provide environmental benefits for the South-Ostrobothnia region. A modal shift would also provide financial benefits, should the EU ETS be applied to road freight transportation in 2026, as planned by the European Commission.

The share of various goods exported from South-Ostrobothnia presents a challenge for intermodal transport. South-Ostrobothnia is a major exporter of raw wood, wood products and agricultural products. Wood products are not time-sensitive, which is beneficial for intermodal transport, but they are often transported over shorter distances, limiting the environmental and financial benefits. Wood products also might not be containerized, which complicates loading operations and does not benefit from modern loading equipment of trailers.

Agricultural products are transported over longer distances, which is better suited for intermodal transport. However, agricultural products are time-sensitive and can require refrigeration. Currently in the EU, the opportunities for powering reefer containers while the train is moving are limited, despite a high electrification rate of railways. Agricultural products would also require fast terminal operations and a reliable railway service for intermodal transport to be able to compete with road-only transport.

The results of this study are reliable and repeatable as the data is almost entirely public and therefore results are repeatable. The results of the study are reliable because the large amount of data gathered by Tilastokeskus allows a small margin of error. Tilastokeskus surveys 10 000 truck owners from the 94 771 registered trucks in Finland as of 2021. The confidence interval for national statistics is 95 % and the margin of error is under 1 %. The results of the data were limited by the availability of data about the true available railway capacity in Finland.

References

Andersson, A., Jääskeläinen, S., Saarinen, N., Mänttäri, J., & Hokkanen, E. (2020). *Fossiilittoman liikenteen tiekartta -työryhmän loppuraportti*. (2020:17). Liikenne- ja viestintäministeriö. http://urn.fi/URN:ISBN:978-952-243-598-9

Bielenia, M., Borodo, A., Cirella, G. T., Czermański, E., Czuba, T., Jankiewicz, J., Oniszczuk-Jastrząbek, A., Sidorowicz, M., & Wiśnicki, B. (2020, November 30). *Combined transport terminals benchmark analysis*. University of Gdansk. https://www.combine-project.com/sites/default/files/content/resource/files/combine_3_1_report_final.pdf

Carboni, A., & Dalla Chiara, B. (2018). Range of technical-economic competitiveness of rail-road combined transport. *European Transport Research Review*, *10*(2). https://doi.org/10.1186/s12544-018-0319-3

EEA. (2022, February). *Transport and environment report 2021 | Decarbonising road transport – the role of vehicles, fuels and transport demand*. European Union. https://www.eea.europa.eu/publications/transport-and-environment-report-2021/download

European Commission. (2021a, July 14). *Questions and Answers - Emissions Trading – Putting a Price on carbon*. https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3542

European Commission. (2021b, December 14). *Questions and Answers: The revision of the TEN-T Regulation*. https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_6725

IEA-UIC. (2016). *IEA-UIC Energy and CO2 Railway Handbook 2016*. https://uic.org/IMG/pdf/iea-uic_railway_handbook_2016.pdf

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*(3). https://doi.org/10.1007/s12544-016-0204-x

Islam, D. M. Z., Zunder, T. H., & Jorna, R. (2013). Performance evaluation of an online benchmarking tool for European freight transport chains. *Benchmarking: An International Journal*, 20(2), 233–250. https://doi.org/10.1108/14635771311307696

Jahn, M., Schumacher, P., Wedemeier, J., & Wolf, A. (2020). *Combined Transport in Europe: Scenario-based Projections of Emission Saving Potentials*. (HWWI Research Paper 192). HWWI. https://www.combine-project.com/sites/default/files/content/bilder/hwwi_researchpaper_192.pdf

Lukinskiy, V. S., Pimonenko, M. M., Paajanen, M., & Shulzhenko, T. G. (2013). Development of Methodology and Tools for Comparative Assessment of Operational Efficiency of Kpi-Based Logistical Infrastructure Facilities. *Transport and Telecommunication Journal*, *14*(3), 223–229. https://doi.org/10.2478/ttj-2013-0019

OECD. (2002). *Benchmarking Intermodal Freight Transport*. https://www.itf-oecd.org/sites/default/files/docs/02benchmarkinge.pdf

Reis, V., Fabian Meier, J., Pace, G., & Palacin, R. (2013). Rail and multi-modal transport. *Research in Transportation Economics*, *41*(1), 17–30. https://doi.org/10.1016/j.retrec.2012.10.005

Ritchie, H., & Roser, M. (2020). *Emissions by sector*. Our World in Data. https://ourworldindata.org/emissions-by-sector#citation

Räty, L., Musto, M., Lautela, A., & Aitolehti, L. (2020). *Rautateiden aikataulusuunnittelu ja ratakapasiteetin hallinta*. (28/2020). Väylävirasto. https://urn.fi/URN:ISBN:978-952-317-780-2

Salanne, I., Tikkanen, M., Herneoja, A., Kaartinen, K., & Valli, R. (2021). *Yhdistettyjen kuljetusten hiilidioksidipäästöjen vähennyspotentiaali Suomessa*. (2021:24). Liikenne- ja viestintäministeriö. http://urn.fi/URN:ISBN:978-952-243-670-2

Stoilova, S., & Kunchev, L. (2017). Study of criteria for evaluation of transportation with intermodal transport. *Engineering for Rural Development*. https://doi.org/10.22616/erdev2017.16.n070

Tilastokeskus. (2017, April 26). *Liitetaulukko 6. Tavaramäärä ja kuljetussuorite maakunnittain vuonna 2017*. Tieliikenteen tavarakuljetukset. http://www.stat.fi/til/kttav/2017/kttav_2017_2018-04-26_tau_006_fi.html

Tilastokeskus. (2022a, April 20). *Kotimaan kuorma-autoliikenteen suoritteet kuljetusetäisyyden mukaan, ilman maa-aineksia, 2011-2021*. Tieliikenteen tavarakuljetukset. https://pxdata.stat.fi/PxWeb/pxweb/fi/StatFin/StatFin__kttav/statfin_kttav_pxt_117a.px/

Tilastokeskus. (2022b). *Maakuntatason tiedot kotimaan tieliikenteen tavarakuljetuksista 2012-2021.* [Unpublished raw data].

UIC. (2019, January). *2018 Report on Combined Transport in Europe*. https://uic.org/IMG/pdf/2018_report_on_combined_transport_in_europe.pdf

UIC. (2020, October 28). *2020 Report on Combined Transport (CT) – Press conference*. https://uic.org/IMG/pdf/2020_combined_transport_report_press_conference_202010230.pdf

VR. (2013, November 1). *Rekkojen kuljetus junissa päättyy.* https://www.vrgroup.fi/fi/vrgroup/uutiset/rekkojen-kuljetus-junissa-paattyy-011120130828/

VTT. (2017, July 6). *LIPASTO yksikköpäästöt -tietokanta*. Teknologian tutkimuskeskus VTT Oy. http://lipasto.vtt.fi/yksikkopaastot/