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# Low Emission Choices in Freight Transport: Comparing Land and Short Sea Shipping Alternatives

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**Abstract.** This study compares carbon dioxide (CO<sub>2</sub>) emissions in multimodal transport chains. Given the recent pressure towards responsible logistics, the International Maritime Organization (IMO) has given several resolutions aiming to decrease all emission types in sea transports. The study analyzes different combinations of alternative delivery chains of paper rolls from the production facility to the customer. The results show emissions originating from each transport leg. In the case of land transports, the greenhouse emissions from solely truck-based deliveries are two times higher than in intermodal solutions, i.e. different combinations of truck and rail. Electrified rail transportation lowers the overall emissions significantly. This indicates that a potential for electric trucks, particularly in the case of short distance deliveries.

**Keywords:** Multimodal Transport; Short Sea Shipping; Trucks; Emissions; Clean Shipping

## 1 Introduction

Global climate change agreements are trying to mitigate and limit atmospheric emissions, such as carbon dioxide (CO<sub>2</sub>). However, they have had limited impact on the environment thus far. As the situation deteriorates, global logistics operations and freights are still predominantly based on heavy-duty trucks (HDTs) and cargo ships that use non-renewable fuels (IPCC 2019). Land freight transports produce extensive volumes of emissions such as CO<sub>2</sub>; nitrogen oxides (NO<sub>x</sub>); black carbon (BC); polycyclic aromatic hydrocarbons (PAH); and particulate matter (PM) 0.5 and 2.5, which have significant health and global climate change impacts (IPCC 2019; Brunila et al. 2020). So far, 27% of Europe's CO<sub>2</sub> emissions originate from the transport sector (EEA 2019).

A typical international logistic chain covers land–port–maritime–port–land transport operations and uses multiple value streams from the point of dispatching, to storage, and up to consignees. Most land logistics chains and deliveries use light-duty trucks (LDT) and HDTs. They primarily use fossil fuels and in turn, produce large amounts of emissions that are detrimental to the environment and human health (Kuo et al. 2017). Mandal et al. (2020) explained that this “high mountain of technology hindrance” must be surmounted in order to find alternative solutions for the engine and fuel technology.

Moultak et al. (2017) argued that electric-technology vehicles could bring about emissions reductions (covering a whole life cycle) in diesel-dominated freight transportation, and heavy-duty electrical trucks (e-HDT) might provide a good option in the mitigation of CO<sub>2</sub> emissions (Sen et al. 2019). A case in point is China, a densely populated country with a vast logistics network plagued with increased combustion engine vehicles. Recently, China has experienced a significant increase in the total number of alternative new engine solutions, such as electrical, plug-in hybrid, fuel cell, and hydrogen fuel-cell vehicles to curb air pollution. The country has taken significant strides towards the utilization of alternative solutions to solve its environmental issues. Fortunately, the European market is catching up with China's usage of electric-driven busses. According to Transport & Environment (2018) in 2017, the number of electric bus orders in Europe increased from 400 (2016 figures) to over 1 000. Other remarkable development is seen from a spatial planning point of view from a Dutch study (Boogaard et al. 2012) that reveals that when HDTs operations were stopped in five residential areas in the Netherlands (Amsterdam, The Hague, Den Bosch, Tilburg, and Utrecht), environmental pollution decreased substantially. The coming years will certainly witness a shift from the regular fossil niche to mainstream and the beginning of a steep and necessary uptake curve of non-fossil options.

It is important to note that without the availability of necessary infrastructure for charging points for the smooth running of electrically powered trucks, low emissions technologies like e-HDTs remain expensive and rare. Even though e-HDT's operational range is shorter than the average HDTs or LDTs, the reduction of greenhouse gases and regional pollutants could be achieved by adopting cleaner vehicle technologies using a combination of electricity or non-fossil fuels (Kuo et al. 2017). These options indicate possibilities for successful transport policies that can reduce emissions significantly and improve air quality in densely populated areas.

European maritime sector came up with stringent rules to promote good sustainable environmental practices. Because of various shipping regulations, there are already different options for ship owners to consider how to reach desired emission reductions. These options include (but are not limited to) the use of scrubber technologies, waste heat recovery systems, alternative fuels, and the use of batteries and solar energy. Recently, many newly built container ships are using liquefied natural gas (LNG) that significantly reduces CO<sub>2</sub> emissions when compared to diesel. However, LNG emissions have issues related to methane that makes it a controversial fuel type in overall emission reduction.

Environmental regulation is important for eco-innovations as Makkonen and Inkinen (2018) addressed. Their study depicted maritime scrubber – a system that removes excess sulphur from ships – as an example of incremental innovation. It is also a response to stricter emission regulations. So far, emissions have reduced in the EU, although the level is debatable: CO<sub>2</sub> emissions have reduced approximately 20% during the last decade (Olaniyi & Viirmäe 2016). SO<sub>x</sub> and fine particles have reduced to almost 99% and NO<sub>x</sub> emissions decreased to some 85% (Prause & Olaniyi 2019).

The creation of the Sulphur emission control area (SECA) legislation brought about lowered SO<sub>x</sub> values in the atmosphere dramatically in the EU, especially in the port

areas connoting that international binding legislation has a significant impact on emissions levels (Lähteemäki-Uutela et al. 2019). It emphasizes the significance of policy-making and environmentally driven international cooperation as a key factor in (technological) environmental improvement. Although, Hämäläinen and Inkinen (2019a) explain that many of these technological solutions present only acute (short-term) solutions that may not be applicable in longer periods. In the end, a sustainable transport chain should be through a complete transformation from the existing diesel engine-based technique to low or zero emission techniques (Hämäläinen & Inkinen 2019b).

Responsible industrial operations should continuously consider environmental consequences contrasted with economic gains. Particularly, transport emitted pollution and environmental stress should be accounted for, especially, in value and efficiency. Wu et al. (2016) argue that air pollution problems link to all types of vehicle emissions and the success or failure of export-oriented long-distance logistics is dependent on a secured and efficient functioning of the logistics chains. A responsible transport chain begins from several information flows (e.g. finance, transport, and location data). They have to be integrated into secure and reliable (physical) freight transportation. All organizations in the chain should be committed to contemporary requirements and regulations striving to achieve low emissions objectives.

The objective of this work is to determine the most suitable land–sea–land transportation combination with the lowest CO<sub>2</sub> emissions generation for a Nordic paper company's product. Using the analyses of different combinations of alternative delivery chains of paper rolls from the production site until the end-users, the study calculates possible CO<sub>2</sub> emissions generated by each delivery logistics mix. These combinations include the use of trucks, trains, and ships. The result from the study is intended for policy interpretations towards emissions reduction in the land–sea–land transports.

This paper has a following structure: The section 2 shows the methodology and the data analyses of the study. The third section highlights the results. The fourth section discusses the results and their implications. The last section 5 concludes the work.

## **2 Methodology**

There are three major logistics challenges that are dependent on transportation mode, port operation efficiency, and shipping processes. The first step is the cargo transfer from the warehouse to the port (land process with either trucks or trains). The second step is the sea process (from the port A to port B with ships). The final third step is the destination land process (the final trip to delivery address using trucks or trains and short distance transport options, e.g. e-trucks or other low emission vehicles). This process is clearly visible in our case study: the paper rolls are transported from the warehouse to ports by HDTs. The cargo is stored in the ports for a while, and then loaded into ships. Sea process is done with short sea shipping (SSS). On arrival at the new port, the rolls are stored and transported by trucks or train onwards to the consignees.

McKinnon and Piecyk (2010: 2012) recommended in their (widely used) report that “the average CO<sub>2</sub> emission factor for road transport operations should be 62 g CO<sub>2</sub> ton-km. This value is based on an average load factor of 80% of the maximum vehicle

payload and 25% of empty running.” On the other hand, the corresponding figure for rail transport operations is 22 grams per transported freight ton. The value is based on the following components from the updated EcoTransIT (2020):

- The average split between diesel and electric haulage,
- The average carbon intensity of electrical power sources,
- The average energy efficiency of the locomotive,
- Assumptions on average train load factors.

We acknowledge that emission data on freight transport may have significant variations depending on the data collection site and time. There are differences between countries and regions in terms of energy policies, supported means of transport, and technological progression. It is highly difficult to create universal (or even European) emission indicators (or factors). Still, according to McKinnon and Piecyk (2010; 2012), the estimation of the CO<sub>2</sub> emissions may be built on two main freight transport operations: energy consumption and the level of transport activity. McKinnon and Piecyk brought to light the energy-based approach for CO<sub>2</sub> emissions for all freight transport and the transport activity approach as an indication of transport operation volume.

(1) *Energy-based approach:*

The application of emission factors and the conversion of energy values to CO<sub>2</sub> are as follows:

- Liters (L) of fuel (unit of energy) for trucks, diesel-hauled trains, barges, and ships
- Kilowatt-hours (kW/h) for electric rail and pipeline.

(2) *Activity-based approach:*

Used if there are no available energy data, it uses carbon footprint as an alternative to estimate transport operations where CO<sub>2</sub>/grams is calculated as:

$$\text{Tones transported} \times \text{average distance traveled} \times \text{CO}_2 \text{ emissions factor/ton} - \text{km} \quad (1)$$

Estimation of emissions is based on system boundaries (SB) integrated data, which are differentiated into five levels (Table 1) by the Swedish environmental organization (NTM; Erixon et al. 2003; updated 2006). These levels are cumulative, starting from the SB1 and going up to SB5 covering all emissions from the transportation sector.

**Table 1.** The system boundaries in the environmental calculation. Adapted from Erixon et al. (2003; 2006).

<b>SB1:</b> Confines to the calculation of emissions from actual transport operation, most of which emanate from vehicle exhaust. In the case of electrified rail freight operations, it includes emissions from the electrical power source.
<b>SB2:</b> Takes account of the extraction, production, refining, generation, and distribution of energy, using a "well-to-tank" perspective.
<b>SB3:</b> Includes the servicing and maintenance of vehicles and transport infrastructure
<b>SB4:</b> Includes emissions from the manufacturing of the vehicles, construction of transport infrastructure, including their subsequent scrappage and dismantling.
<b>SB5:</b> Includes emissions associated with the management of transport operations, mainly of-fice functions and activities of staff.

This study focuses on SB1, thus calculating the direct carbon emissions from freight transport from the paper mill to two different countries in Europe. We use the total life cycle emission calculations with complete and reliable data storages (data is obtained from the mill and it is continuously updated in daily operations). Electrically powered trucks are classified under SB1 and they produce low or zero emissions in daily use. As a reference, Özsalih et al. (2009) made an empirical analysis with a company level case data (from Unilever) and concluded that intermodal transport (road/water or train/water) is probably greener than pure road transports.

### 3 Results

#### 3.1. Conditions, Factors, and Variables

Peripherally located large bulk industrial site requires a well-functioning transportation chain to deliver their products to their primary markets. Usually, annual production volumes may start from 350 000 tons to one million tons of high-quality pulp and paper products. Nearly 100% of this product category are delivered to international and global markets. If the site is located inland (requiring long-distance land transport), as in the case company, the intermodal transport chain includes several phases. It starts from the production site to the port, loading the freight (or containerization), SSS, port operations, and finally inland transportation to customers. The delivery (order sizes) tons may vary according to each buyer, making delivery and route planning a complex problem (Hämäläinen 2011). Estimations have the following assumptions:

- (1) From industrial site to outward port (40 km): There are two options: truck (diesel) or train (two-way electricity production is estimated) transportation.
- (2) SSS transport to the destination country (1 800 km): All paper products are inside containers and transported by container ships that comply with the required maritime bunker and emissions regulations.
- (3) From import port to customers behind various export routes (100 km per 200 000 tons and 300 km per 150 000 tons): Options are either truck or intermodal (rail and truck).

Emission factors taken from Hämäläinen (2011) explored how different modes of transport produce CO<sub>2</sub> (grams per ton-km). The authors recognize a considerable variation between the calculated factors (even in the same logistic model), and used the following three factors (routes and phases) to create several intermodal combinations:

- The emission values are dependent on the engine technology. The selected combinations indicate the largest variety in calculated emission levels for each transport option.
- It is important to recognize that a single large mill (such as the case here) may have thousands of customers in different locations.
- The average delivery (i.e. order) may range from a few tons up to hundreds of tons. This again results in hundreds of transports that vary considerably in their lengths.

### 3.2. Case study: CO<sub>2</sub> emissions per ton-km from the mill to port

The case mill operates annually for around 8 000 hours (corresponding approx. 91% of the production efficiency). Inside the mill, one large paper machine produces approximately 44 tons of paper per hour, and daily production can reach around 956 tons. The mill runs typically around the clock, suggesting that the logistic chain must operate continuously from mill warehouse to export port (intermediate storage); otherwise, the central warehouse would become overstocked without storage for the new incoming and newly produced products. Usually, there are online store orders as all products are manufactured on-demand basis (by customer orders).

Table 2 presents CO<sub>2</sub> emissions per ton-km from the mill to port with two transport modes. Transportation by diesel truck is the first option, and the second one is electrified freight train.

**Table 2.** Data from the mill to port – production volumes

Export of heavy freight (paper rolls)	Production and Volumes
Mill/machine h	8000
Tons/hour (91% efficiency)	43.75
Daily production (round)	955.5
Heavy Duty Truck 60% utilization	59
Volume (ex-mill tons)	350000
Distance from a port (km)	40

We assume (from the company's document review) that trucks are fully loaded from the mill to the port and that they are only partially loaded from the port back to the mill. Therefore, the assumption is that the trucks run on average approximately with 60% utility. The annual paper transportation from the paper mill to port by diesel trucks produces about 826 tons of CO<sub>2</sub> greenhouse emissions. It is further assumed that the electricity used in the trains is produced either by fully renewable natural resources (hydro or solar power). Thus, the direct CO<sub>2</sub> footprint remains low (around 0.003 CO<sub>2</sub> grams per ton-km) used in Table 3.

### 3.3. Transportation combinations and their total CO<sub>2</sub> emissions

We make an assumption that 22 CO<sub>2</sub> grams per ton-km emission level are reached. In a comparison of motor and fuel technologies, it is detectable that the total CO<sub>2</sub> emission level varies significantly. In other words, diesel trucks are estimated to reach 826 tons, electronic train with a combination of non-renewable and renewable energy production ends up to 308 tons, and finally, renewable electricity production operated trains reach only 0.042 tons. Electrified trains (with renewable electric power) may be considered highly scalable technology with nearly zero usage emissions (comparative figures in Table 3).

**Table 3.** CO<sub>2</sub> (tons) production with different transport means. Adapted from McKinnon and Piecyk (2010).

Export of heavy freight (paper rolls)	Option 1	Option 2
	Diesel	Electric Train
Transport g CO <sub>2</sub> /ton-km either diesel trucks (60 % utility) or Electrified rail freight service from 0.003 g CO <sub>2</sub> /ton-km for electricity generated by renewables	59	0.003
Electrified trains (el is produced by a mix of different sources gCO <sub>2</sub> /ton-km)		22
Total CO <sub>2</sub> emissions (tons) el train renewables and non-renewables		308
Total CO <sub>2</sub> emissions (tons) el train renewables		0.042
Total CO <sub>2</sub> emissions (tons)	826	308.042

An example is calculated for 1 800 km long SSS container line. It is further assumed that everything is transported to the central market. In real life, the variety of transportation options from a Nordic country to the main (European) markets, is large and both container ship types and distances vary extensively (see Hämäläinen 2011). The transport volumes are very high so that the total CO<sub>2</sub> footprint of 350 000 tons of paper transported 1 800 km by SSS rises to 10 080 tons. Overall, 1 800 km distance is considered a typical sea route from a Nordic country to several main European ports like Poland, Germany, or the Netherlands. This is important as the applied distance has a fundamental impact on the CO<sub>2</sub> levels in these calculations. The different bunkering fuel cargo ships use are mainly LNG, MGO, methanol, and HFO (with scrubbers by regulation). All these bunkers produce different amounts of CO<sub>2</sub>.

Table 4 approaches transport emissions through both truck and intermodal options and yields the following interpretations as it presents transportation from import harbor to the customers with the CO<sub>2</sub> factor per tonnage. Customers are businesses with varying order sizes and delivery times (see Hämäläinen et al. 2017).

**Table 4.** Transportation options in the export country from port to end customers. Source: Authors.

CO <sub>2</sub> (g) factor/ton-km		Truck	Intermodal road/train
		59	26
Av. distance from the port	Delivered tons	CO <sub>2</sub> tons	CO <sub>2</sub> tons
100	200 000	1 180	520
300	150 000	2 655	1 170
Cumulative total in the port country (CO <sub>2</sub> tons)		3 835	1 690

Two average scenarios are used to include the final transport leg from ports to customers: If all consignments are transported by trucks (59 CO<sub>2</sub> grams per ton-km), the total CO<sub>2</sub> footprint of deliveries (in the importing country) would be approximately 3 835 tons. Second, if deliveries are transported by intermodal transport chain (rail and road),

the total CO<sub>2</sub> emissions are less than half (1 690 tons) in comparison to truck deliveries only. Truck (diesel) is a two times higher greenhouse gas emitter when compared to intermodal option because CO<sub>2</sub> emission factor in rail transportation is considerably lower. Table 5 captures the CO<sub>2</sub> emissions from different transportation modes outside and within the importing country.

**Table 5.** Total CO<sub>2</sub> tonnages by different transport modes from the paper mill to end-customers. Source: Authors.

Transport option	Total CO <sub>2</sub> emissions with 350 000 tons	Context
Truck diesel	826	Export country
El. Train 100% renewables	0.042	Export country
Non-renewables + renewables train	308	Export country
Diesel (MGO) ship	10 080	SSS
Truck diesel	3 835	Import country
Intermodal road/ electrified rail	1 690	Import country

Table 5 distinguished the substantive and pertinent question of how to mitigate CO<sub>2</sub> emissions produced especially in SSS, and this is because long-distance heavy industry deliveries are often dependent on long sea journeys. This connotes high CO<sub>2</sub> grams per ton-km factor.

Table 6 presents different transport means combinations and their total CO<sub>2</sub> emissions. There are six choices where the lowest greenhouse footprint (combination 1) is produced by electrified rail service (Renewable electricity production) + SSS + intermodal road and electrified rail service together.

**Table 6.** Summary of the 350 000 tons transport (mill to markets). Source: Authors.

Comparing emissions	First	2nd	Third	Total CO <sub>2</sub>	CO <sub>2</sub> (tons)	%
Renew Train + SSS + Intermodal road/rail	0.042	10080	1690	11770	0	0
Ren+non ren El train + SSS + Intermodal road/rail	308	10080	1690	12078	308	2.616
Truck + SSS + Intermodal road/rail	826	10080	1690	12596	826	7.017
Ren+non ren El train + SSS + Truck	308	10080	3835	14223	2453	20.84
Renew Train + SSS + Truck	0.042	10080	3835	13915.042	2145	18.22
Truck + SSS + Truck	826	10080	3835	14741	2971	25.24

The example logistics chain produces 11 770 tons of CO<sub>2</sub> emissions. Note that the significant contribution of emissions is by maritime transportation (95–98%) because there is no viable alternative to replace SSS. However, at the same time, while a long sea journey creates a significant amount of CO<sub>2</sub> footprint, there are more alternatives available for inland logistics. Calculated combinations in Table 6 do not include diesel-only rail emissions because diesel locomotives are no longer widely used by the case mill.

## 4 Discussion

A plausible choice an export company for decreasing CO<sub>2</sub> footprint is to focus on electrified land transportation and the lowest (i.e. the most environmentally friendly) CO<sub>2</sub> maritime transport. These options offer a scalable solution to decrease airborne transport emissions. In the nearest future, electrified trucks will gain more popularity in short-distance final deliveries, but currently they are not extensively available in the array of logistics suppliers.

When electric trains (operating in countries with low CO<sub>2</sub> emission power plants) are in use, or when container ships operate SSS, intermodal transportation will bring clear environmental benefits. However, this is not the case in all situations. When intermodal transport uses Ro-Ro cargo and Ro-Pax ships, lowering carbon emissions might be challenging because the easiest way to reduce emissions from shipping activities without compromising demand is to reduce emitted CO<sub>2</sub> (aggregate) per unit. (ICCT 2017).

Transport sector needs environmental innovations. This is critical because blue and green innovations can resolve several of the challenges associated with the climate crisis (OECD/ITF 2016). However, implementation must be economically viable and they require holistic understanding, e.g. of the production of electricity. Nordic countries, such as Sweden and Finland, have a significant production volume of hydrological, wind, and in some cases nuclear power that offers (after plant construction and dismissing fuel transport and power cell/grid production in other countries) nearly CO<sub>2</sub> free electricity for rail transport. Yet, some of the generated electricity is produced by coal power or other non-renewable power solutions. Consequently, the generated emissions (in electricity production) are quite high. They correspond approximately one-third of total diesel truck CO<sub>2</sub> emissions.

Maritime sector has been able to build industry-level structures to achieve emissions reductions for a long time (Anner et al. 2006). Even though water transportation is a relatively simple way to move freight between countries (emissions per transported unit is the lowest among transport modes), globally the maritime transportation sector produces between 2–3% of total CO<sub>2</sub> emissions (EU 2019). This is a significant amount of airborne emissions. It also explains why IMO (2009) started already a decade ago numerous policies aiming to lower all maritime emissions. In terms of transport volumes, sea transportation remains the most environmentally friendly way (per unit or capita)

to move passengers and freight between geographical locations. However, the downside is that emission particles are spread several miles to coastal areas. Evidently, reduction of emissions to the barest minimum remains the most preferred choice.

Conversely, and from the climate point of view, it does matter what transport modes are employed by heavy industries in their long-leg transports, as they are sea transported in any case. Modal shifts from road to rail have essential impacts. Last-mile logistics especially in inner-city regions should be done with electrified trucks, and while this may be expedient, the replacement of the whole truck fleet from diesel technology to electrified ones remains an expensive investment. This results in the fact that industry-level changes may likely take a long time. Moreover, the transport range (of e-trucks) is still short. The transport chain needs to be carefully planned from an environmental perspective.

Lastly, inter-, trans-, and supranational regulatory structures can only be strengthened when unified across sectors and most importantly across countries (Olaniyi 2016). The current mismatched and expensive cyclicity and capital utilization currently witnessed in the marmite industry, for example, can only be resolved through transnational coordination, which may take years to achieve. In particular, the environmental innovations and blue/green technologies stem from various compliance activities that may establish new key drivers for the future economic growth and social wealth.

## **5 Summary**

This study scrutinized the seeming complexity of multimodal transport emissions. The case dealt with the transportation and delivery process of products from a large paper production company to their end customers. The goal was to illustrate with different combinations of transport modes the total levels of generated greenhouse emissions. This is needed to determine the best-combined transport means for the low generation of CO<sub>2</sub>.

The result shows that typical transportation of bulky material from the production site to the end-users amounts to close to a million (826) tons of CO<sub>2</sub> greenhouse emissions. The bulk of the emissions are coming from shipping. Intercity CO<sub>2</sub> emissions from all truck deliveries are also high when compared to rail transports. The paper presented several example calculations to illustrate the emission effect of intermodal transport on emissions. The results indicate that the greenhouse emissions from all truck (diesel) inland deliveries are two times higher than in the case of inland intermodal logistics (i.e. a combination of truck-rail). This is because CO<sub>2</sub> emission factors in rail transportation are comparably low when the renewably produced electricity is used.

Focusing on electrified land transportation and low CO<sub>2</sub> maritime transportation is a conceivable solution to lower emissions and to create a satisfactory low pollution (or even pollution-free) environment. Logistics companies need to work harder in focusing on intermodal transport or a combination of different means of transport for goods deliveries. Policymakers would need to use stringent regulations to enforce successful joint efforts from all actors to achieve this change.

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