Green Distribution – A Comparative Study of Sea and Road Transport Modes for a Norwegian Manufacturing Company

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Abstract. This paper presents a case study comparing sea and road transport modes for a Norwegian producer of plastic pipes for the construction industry. The study is based on three cases in which CO_2e emissions and transport costs were calculated and compared. The main research problem was to analyze whether sea transport is more environmentally friendly than road transport in terms of emissions of greenhouse gases (GHG) and cost-effectiveness. The results from the three analyzed cases show that sea transport is not always the most environmentally friendly and cost-effective mode. We suggest that in order to evaluate the environmental impact and cost-effectiveness of sea transport as an alternative to road transport, such factors as transport distances, load weight/volume ratios, ship load factors, number of port calls, ship sizes, and ship fuel types for each specific case need to be analyzed.

Keywords: SCM, distribution, sustainability

1 Introduction

The global economic growth in the last century has led to huge increases in the consumption of goods. However, the production, transportation, storage, and consumption of these goods have created environmental problems. Global warming is now a major environmental concern and there is consensus among most climate scientists that this is mainly caused by large-scale emissions of GHG [1].

According to Crum et al. [2], supply chain managers are in an advantageous position to impact environmental and social performance, both positively and negatively, through such means as supplier selection and supplier development, modal and carrier selection, vehicle routing, location decisions, and packaging choices. According to Hjelle [3], the issue of global warming receives wide attention on the global political agenda, mainly related to direct emissions of GHG from vessels and vehicles, but also to emissions related to the manufacturing of these means of transport.

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Molde, along with four industrial partners. One of the industrial partners was interested in analyzing whether changing from road to sea transport mode would reduce GHG emissions and simultaneously reduce its distribution costs. The case company is an international manufacturer of plastic pipes and fittings. The cases presented in this paper are related to delivery of pipes to road construction projects in Norway. Hjelle [3] pointed out that the efficiency of short sea shipping in a setting with small consignments and frequent port calls needs to be demonstrated relative to road transport alternatives.

The purpose of this study was to find out whether a manufacturer can reduce GHG emissions and transport costs by switching from road to sea transport.

2 Theoretical background

Environmental issues related to road and sea transport are traditionally divided into environmental hazards that have local, regional, or global impacts [4]. Locally, the most severe effects are related to poor air quality from emissions of SO_2, NO_X, and particles. At the regional level, the concerns are emissions of SO_2 and NO_X, oil spills, and disposal of waste products such as ballast water. On the global scale, the issue of global warming has received the greatest attention, mainly related to emissions of GHG from vessels and vehicles [5]. International shipping contributes approximately 2.4 percent of global GHG emissions and this share is expected to increase in the future [6].

GHG emissions are defined as the total mass of a GHG released to the atmosphere over a specified period of time. GHG include such gases as carbon dioxide (CO_2), methane (CH_4), and nitrous oxides (NO_x). Each type of GHG has a different global warming potential and GHG emissions are usually reported in carbon dioxide equivalents (CO_2e). CO_2e is a unit used for comparing the radiative forcing of a GHG to that of carbon dioxide [4].

The CO_2e emissions can be calculated based on fuel consumption. The emission factors for different fuel types are presented in Table 1 [7], [8] .

Table 1. CO_2e emission factors

Fuel type	Density (kg/l)	kg CO_2e/kg	kg CO_2e/l
Diesel	0.832	3.21	2.67
Marine diesel oil	0.9	3.24	2.92
Marine gas oil	0.89	3.24	2.88
Liquefied natural gas	0.42	2.83	1.18

Several factors affect the performance of sea and road transport mode with regard to fuel consumption. According to Hjelle [5], key performance indicators for sea transport are vessel types and operating speed, load factors, fuel, and engine types. In road transport, such factors as operating speed, road gradient, congestion, driver behavior, and vehicle characteristics affect the fuel consumption and GHG emissions [9].

The globalization of trade has resulted in the creation of worldwide shipping networks that make use of a limited number of large ports. This concentration of flows has produced a division between deep-sea shipping (DSS) and short-sea shipping (SSS) [10]. SSS is typically defined as the movement of cargo and passengers by sea between ports that does not involve an ocean crossing [11]. According to Hjelle [3], deep-sea and bulk operations are superior to other transport modes in terms of GHG emissions, while the superiority of SSS needs to be demonstrated relative to road transport alternatives.

3 Research methodology

This paper presents a case study comparing sea and road transport modes for distribution of plastic pipes for road construction projects in Norway. The main focus has been to calculate GHG emissions and distribution costs for three cases. To collect the data needed for our analysis, such as price, fuel consumption, and number of port calls, we contacted a shipping agent, which provided us with information from three ship-owners.

In each of the cases, the calculations were based on the real-world data provided by the case company, ship owners, and shipping agents. GHG emissions were calculated using a method based on the European standard [7].

4 Case Study Analysis

4.1 Case description

The case company, a manufacturer of plastic pipes, was interested in identifying whether it could reduce its GHG emissions and transportation costs by switching from road transport to sea transport.

In this context the sea and road transport costs and GHG emissions on three specific cases were calculated. Case 1 is a delivery to a road construction project in the North of Norway (Tromsø), Case 2 is a delivery to a project in the South-East of Norway (Fredrikstad), and Case 3 is a delivery to a project on the West coast of Norway (Haugesund).

The road mode includes transportation from the factory directly to the construction site. The sea mode includes transportation from the port closest to the factory to the port closest to the road construction site, as well as transportation by truck from the factory to the port of origin and from the destination port to the road construction site, assumed to be 10 km each way.

Table 2. Approximate transport distances from the factory to destination (km)

	Sea	**Road**
Case 1a, b – Tromsø	977	1272
Case 2 – Fredrikstad	1064	610

Case 3 – Haugesund	574	760

Table 2 shows the approximate distances for both sea and road transport modes for the three cases.

According to CEN [7], the CO_2 emissions from different fuel types are based on the fuel consumption. The trucks in road transport mode use diesel fuel, which has an emission factor of 3.21 kg CO_2e per kg fuel used. In our study, in sea transport mode, three types of fuel are used: marine diesel oil (MDO), marine gas oil (MGO), and liquefied natural gas (LNG). The fuels have different densities, but the emission factor for MDO and MGO is 3.24 kg CO_2e per kg fuel used, while for LNG the emission factor is 2.83 kg CO_2e per kg fuel used.

Plastic pipes have a high volume/weight ratio. Several methods can be used to calculate the share of GHG emissions that are caused by transportation of a specific load (plastic pipes in our case), which utilizes only a part of the ship's capacity. One of the methods is based on the ratio between the weight of the transported goods and the dead weight tonnage of the ship. However, in our case, because of large volume and relatively light weight of plastic pipes we chose to base the calculations on the ratio between the volume of the transported goods and the total utilized load capacity of the ship.

Cargo ships usually have a load factor of 50–70 percent [12], [3]. The load factor will have a significant impact on the final result of the CO_2e emissions that a specific load accounts for.

Fuel Consumption

The ships used in our study vary in terms of their size, fuel type, and load capacity. All of these factors influence actual fuel consumption.

The estimated fuel consumption in our cases is provided by the ship-owners and relates to a "normal" load for the ship. In Case 1, we look at two alternatives: transportation by a MDO-fueled ship and transportation by a LNG-fueled ship. In this case, for a direct route from Surnadal to Tromsø, ca. 11,700 kg of MDO will be used, while MDO consumption for the same route with 15–20 port calls is ca. 18,000 kg. In the other alternative, a LNG-fueled ship will use 40,800 kg of LNG from Surnadal to Tromsø with several port calls. In Case 2, the estimated fuel consumption for a route from Surnadal to Fredrikstad is ca. 13,350 kg of MGO. In Case 3, the estimated fuel consumption for a route from Surnadal to Haugesund is 9000 kg MGO.

For the road transport mode, we have calculated three different alternatives. The actual truck fuel consumption will vary, based on the weight of the cargo, the geography, driver behavior, etc. According to the case company's transport provider, the average fuel consumption is 0.45 liters of diesel per kilometer. To be able to see the effects of these variations we have also calculated the GHG emissions based on an average consumption of 0.4 and 0.5 liters of diesel per kilometer.

Load factor

Load factors have a large impact when calculating GHG emissions in sea transport. A number of sources show varying load factors for short-sea shipping in Norway. A study by Hjelle [3] shows that there is a large difference in load factors between southbound and northbound transport routes in Norway. Southbound routes had a load factor of 66 percent, while northbound routes had a load factor of 47 percent. Oterhals et al. [12] found that an average load factor for ships operating on the Norwegian coast was 67 percent.

4.2 Results of the analysis

Because of the variation in load factors, we chose to analyze the influence that different load factors (namely, 50 percent, 60 percent, and 70 percent) had on the GHG emissions a company will need to "pay" for. We also looked at different values for average fuel consumption for the road transport mode. The results of this analysis are presented in Table 4.

Table 3. Influence of different load factors on GHG emissions that transport of different volumes of plastic pipes accounts for

	Sea transport mode GHG emissions, kg CO_2e			**Road transport mode GHG emissions, kg CO_2e**		
	LF 50%	**LF 60%**	**LF 70%**	**FC 0.4 l/km**	**FC 0.45 l/km**	**FC 0.5 l/km**
Case 1a, Tromsø (MDO), 2253 m^3	45,913	38,261	32,795	33,972	38,218	42,464
Case 1b, Tromsø (LNG), 2253 m^3	32,068	26,723	22,906	33,972	38,218	42,464
Case 2, Fredrikstad (MGO), 1366 m^3	19,700	16,417	14,072	16,291	18,328	20,364
Case 3, Haugesund (MGO), 2253 m^3	17,037	14,197	12,169	20,297	22,835	25,372

Legend: LF – load factor, FC – fuel consumption

Table 4. Sea transport GHG emissions and costs as a percentage of road transport GHG emissions and costs on respective routes (LF 60%, FC 0.45 l/km)

	GHG emissions	**Transport costs**
Case 1a – Tromsø (MDO)	100.1%	69.6%
Case 1b – Tromsø (LNG)	69.9%	77.7%
Case 2 – Fredrikstad (MGO)	89.6%	176.4%
Case 3 – Haugesund (MGO)	62.2%	105.7%

Table 5 shows the results of the cost and GHG emissions calculations for the three cases. Case 1a (MDO) shows almost equal GHG emissions for sea and road transport modes, while the sea transport mode is ca. 30 percent cheaper than the road transport mode. In Case 1b (LNG) the GHG emissions are ca. 30 percent lower for sea transport mode than for the road transport mode, and at the same time sea transport mode is ca. 22 percent cheaper than the road mode. Case 2 shows approximately 10 percent lower GHG emissions for sea transport mode compared to the road transport mode, but the cost of sea transport mode is significantly higher (ca. 76 percent) than the road mode. The third case shows substantially lower GHG emissions (almost 40 percent) for the sea transport mode compared to the road transport mode, while the costs are only slightly (ca. 6 percent) higher for sea transport mode than for the road mode.

5 Discussion

As this study is based only on three cases, its results are not generalizable. However, the findings create a background for discussion around the efficiency of sea and road transport modes in terms of GHG emissions and distribution costs.

Several sources present sea transport as a "by default" greener alternative in terms of emissions of GHG compared to road transport [5]. However, the results of the study presented in this paper show that this is not always correct when different factors are taken into consideration. Below we provide a discussion about the influence of such factors as number of port calls and load factors on GHG emissions and costs connected to transport of loads on relatively short distances. In addition, such factors as ship size and fuel type also influence the level of GHG emissions in each specific case. For instance, according to Hjelle [5], larger ships are more fuel efficient than smaller ones. According to a study by Burel et al. [13] conducted for a 33,000 DWT tanker ship, usage of LNG leads to a 35 percent reduction of operational costs and a 25 percent reduction of CO_2 emissions compared to usage of heavy fuel oil.

Port Calls

An example from Case 1a shows that the fuel consumption for a direct route between the factory and Tromsø is 13,000 kg MDO; however, for a more realistic route with 15–20 stops, the estimated fuel consumption is 18,000 kg MDO. Because the ship in this case is relatively small, the GHG emissions the case company accounts for would be lower if the company chartered the whole ship and shipped its goods directly. Although many ships run on regular routes up and down the coast, many ships make additional calls to other ports, and several ships only make port calls if they are notified of available goods.

Because of these variations, it can be difficult for companies to choose the "greenest" transport alternative.

Load factors

Several sources show that load factors in short-sea shipping in Norway vary from 50 percent to 70 percent. The actual load factors are very important for concluding whether the sea transport mode is "greener" than road transport, as shown in Table 4. The achieved load factors will vary between northbound and southbound routes, between ship-owners, and will depend on the origin and destination of the transported goods.

The results of the present study show that there is no simple answer to the question of whether sea or road transport is more cost-efficient and environmentally friendly over relatively short distances. In order to determine this, each specific case has to be analyzed by comparing the alternatives while considering such factors as transport distance, number of stops, weight/volume ratio of load, load factors, fuel types, and ship sizes.

6 Conclusion

This paper has presented an analysis of GHG emissions and costs connected to distribution of plastic pipes by sea and road transport modes in Norway. The objective of the study has been to find out whether sea transport is more environmentally friendly in terms of GHG emissions and more cost-efficient than road transport, based on three specific cases. In each case, the calculations were based on the real-world data provided by the case company, ship-owners, and shipping agents. The results from the study show that the widespread opinion that sea transport is "greener" than road transport is not always correct when considering transportation of loads to relatively short distances. For example, loads have different weight/volume ratios; ships on different routes have different average load factors and use different types of fuels; road distances can be longer or shorter than sea distances in each specific case; and ships often have different number of stops on each route. All of these factors need to be taken into consideration in order to create a more realistic picture of which transport mode is cheaper and more environmentally friendly for each specific case.

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