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An Emissions Analysis for Environmentally Sustainable Freight Transportation Modes: Distance and Capacity

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Transportation is one of the largest air pollutants as well as the Greenhouse Gas (GHGs) contributors. The inclusion of air pollutants in optimisation studies is less established than the use of CO_2 and/or GHGs which are often used as an indicator of environmental sustainability. This study aims to assess environmentally sustainable alternatives for freight transportation by considering both GHG and air pollutants. A case study identifying air emissions of different freight transport modes for moving goods from Rotterdam is presented. The assessed freight transports include articulated lorry, container ship, bulk carrier, and rail operated by diesel. The environmentally sustainable freight transport of the studied route based on the common practice (GHGs only) and the inclusion of air pollutants are discussed. Evaluation of the results shows that transport with lower GHG emissions does not result on PM and SO_x as well. A possibility of inappropriate decision making has been consequently highlighted. The impact of loaded capacity in moving the goods on the emission is assessed from the perspective of logistics service provider. A further comprehensive study which includes the entire life cycle is needed as this study only considers the tank to wheel emissions.

1. Introduction

The rapid growth in motorisation and the demand for transport has resulted in the need for a sustainable transport development. GHG emission in the transport sector is growing at a faster rate than other sectors. Various measurements and assessments have been proposed for a better transport system, in terms of performance, cost, and emission efficiency. Among the strategies proposed are fuel switching (biofuel etc.), modal shift, intermodal, logistics and demand management (time schedule, frequency, dry port and transferring station). Regmi and Hanaoko (2015) analysed the modal shift from road to rail transport between Laos and Thailand by considering CO_2 emission. A similar study was conducted by Tao et al. (2017) but extended by the assessment of the subsidies needed for shifting road to rail/water transport as a means to mitigate against CO_2 emission. Walmsley et al. (2015) applied carbon emission pinch analysis (CEPA) to identify possible strategies for reducing the CO_2 emission from freight and passenger transport. CEPA has also been applied by Ramli et al. (2017) in assessing electric vehicles. The CO_2 emission of intermodal and lorry only (single mode) freight transport systems has been compared by Kim and Wee (2015). This study (Kim and Wee, 2015) made use of semi-life cycle assessment and 7 issues (e.g. volume, door to door delivery, upstream emission, capacity), which are often underestimated in identifying the most sustainable transport mode.
The environmental factor can be further developed, as currently, the assessment is focused on minimising CO_2 or GHGs emission. Air pollutants emitted from transportation contribute to haze/smog formation and have a significant impact on human health. The EU target is to move 30 % of all road freight of over 300 km to other modes, such as rail or waterborne transportation (EU, 2016). Rail and water transportation appear to be more environmentally friendly than road freight especially in terms of lower GHGs emission and greater loading capacity. It allows the transportation of a larger amount of goods by a single entity and consequently a lower air

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emission per t of transported goods. However, the transport modes with lower GHGs emission do not necessary produce lower emission of air pollutants. The amount of goods to be transported and the capacity of the transportation mode also have a significant effect on the overall selection of transport mode. The environmental performance of a transport mode with large capacity (lower emission factor, g/tkm) decreases with the decreasing amount of goods to be transported. This study assesses the effect of air pollutants inclusion in the modal shift decision making through three scenarios study. It is important to minimise the possibility of footprint shifting and to support appropriate decision making. The second part of this study assesses the impact of amount of goods requiring transporting by different freight transport modes and the amount of emission produced. The assessment intends to contribute to the field of study by identifying the circumstance (distance and load limit value) which the transport mode is environmentally sustainable in terms of the air emission.

2. Case study description and assessment methods

Three scenarios include Rotterdam (Netherland) to Antwerp (Belgium), to Gdansk (Poland) and to Genova (Italy) are considered in identifying the emission (g) of transporting 50 t of goods. The assessed freight transports include lorry, ship, and rail. Table 1 shows the transporting distance by different means of transports. The GHGs (CO_2eq) and the air pollutants (PM, NO_x, SO_x) from the different types of transportation mode were measured based on the emission factors reported in STREAM Freight Transport 2016 report (Boer et al., 2017). The emission factors are based on the freight transports in Netherland. The assessment results might not represent for other region such as Asia where the vehicle types, freight categories and fuel types are different. Table 2 shows the description of the transports (type, load capacity) and the emission factors (Boer et al., 2017) used in this study. This study only considering the direct emission (tank to wheel). Consequently, the transport run by electricity (e.g. electric rail) is excluded as the major emission is from the production of electricity instead of fuel combustion.

Table 1: Distance travelled by different transportation mode

Place	Distance (km)	Reference
Rotterdam to Antwerp		
• Road	101.690	NTMCalc Basic 4.0 and SeaRates LP (2018)
• Rail	96.985	NTMCalc Basic 4.0 and SeaRates LP (2018)
• Sea	200.060	SeaRates LP (2018)
Rotterdam to Gdansk		
• Road	1,253.310	NTMCalc Basic 4.0 and SeaRates LP (2018)
• Rail	1,270.005	NTMCalc Basic 4.0 and SeaRates LP (2018)
• Sea	1,187.910	SeaRates LP (2018)
Rotterdam to Genova		
• Road	1,181.62	NTMCalc Basic 4.0 and SeaRates LP (2018)
• Rail	1,353.72	NTMCalc Basic 4.0 and SeaRates LP (2018)
• Sea	4,092.82	SeaRates LP (2018)

Table 2: Emission factor of different transportation mode

Type of transportation	Load Capacity (t)	CO_2eq (g/tkm)	SO_x (g/tkm)	PM (g/tkm)	NO_x (g/tkm)
Articulated Lorry, light	15.7	195	0.0010	0.006	1.50
Articulated Lorry, heavy	29.2	91	0.0010	0.005	0.40
Rail container (Diesel)-Medium	70	27	0.0002	0.010	0.36
Ship (Container)-Medium	5,600	14	0.0090	0.007	0.31
Ship (Bulk carrier)-Medium	7,339	29	0.0180	0.013	0.60

As discussed in the Introduction, the load capacity of the transport mode plays a significant part to demonstrate the emission in transporting goods. The emission factor presented in g/ tkm is valid under the condition of the capacity of the transports are fully utilised/loaded. The emission per t of goods varies according to the loaded goods in the transport. The emission per t of goods will increase if the transport is not fully filled. Extra goods require extra transport. The circumstances (g of transported good) where the emission per t of goods are lower than the other transport mode was evaluated and compared. The calculation is based on Eq(1) and Eq(2) by using the data in Table 2. For example, if the articulated lorry (light) is fully utilised (15.7 t) the CO_2eq is 195 g/ tkm (see Table 2). If there is 12 t of goods (< 15.7 t), the emission per t of goods is 255.125 g, by applied Eq(1). If there is 29.2 t of goods (> 15.7 t), two tractors are needed, and the emission is 390 g/ tkm, applied in Eq(2).

The estimated results of this study provide a guideline to the logistics service provider for selecting the low emission transport mode based on the demand (the total order and weight of goods need to be transported) and the capacity of the transport mode.

$$[(EF_{table2})\ Load\ Capacity_{table2}]/\ Load_{transport} \quad (1)$$

$$(Load_{transport}/\ Load\ Capacity_{table2})\ EF_{table2} \quad (2)$$

The value of $Load_{transport}$ divided by Load $Capacity_{table2}$ equal to the number of transport needed, it has to be an integer. EF_{table2}= emission factor of transport as presented in Table 2; Load $Capacity_{table2}$ = Load capacity of the transport as presented in Table 2; $Load_{transported}$ = the total amount of transported goods.

3. Results and Discussion

Tables 3 - 5 shows the emission in transporting the goods (50 t) under different distances and transport modes. In general, rail container is the freight mode with the lowest emission. Rail has been commonly interpreted as the transport with low emission. This is especially for the rail that runs on electricity. The tailpipe emission is zero (Boer et al., 2017) however more study is needed by considering the entire lifecycle, including the generation of electricity. The CO_2eq emission of the rail run by diesel appears as the lowest in all the studied route except Rotterdam to Gdansk. This is due to the shorter distance of travelling by ship than rail. However, it should be noted that the emission considered when transporting by ship did not cover the loading and unloading as well as the additional distance from port to the destination, as stated in Section 2. The PM and/or NO_x emission of rail do not appear as the lowest in transporting from Rotterdam to Genova and Rotterdam to Gdansk. Air pollutants have an instantaneous impact on the environment and human health. They contribute to the formation of secondary pollutants in the atmosphere and cause the formation of haze or smog. It can impair visibility and produce acidification.
Road transport (lorry) which commonly view as the least environmental friendly mode does not show the highest emission in all the studied cases. The SO_x and PM performance are better, where the emission is lower than that of transport by ship. The presented results (Tables 3 - 5) highlight the contrasting interpretation of including the air pollutants in freight mode assessment/ selection. The relationship between the CO_2eq, SO_x, PM and NO_x, is not proportional. It proposes the current optimisation study should include air pollutants in claiming an alternative as a green solution. However, this remains a challenging as GHGs and air pollutants impact the environment differently. SO_x, PM, NO_x (clean air) or CO_2eq (climate change) should be rated as the priority (with highest weighting factors) and the compromise is yet to be identified.

Table 3: The emission of transporting goods from Rotterdam to Antwerp

Type of transportation	CO_2eq (g)	SO_x (g)	PM (g)	NO_x (g)
Articulated lorry, light	59,488.65	0.30507	1.8304	457.605
Articulated lorry, heavy	18,507.58	0.20338	1.0169	81.352
Rail container (Diesel)-Medium	2,618.60	0.01940	0.9699	34.915
Ship (Container)-Medium	2,800.84	1.80054	1.4004	62.019
Ship (Bulk carrier)-Medium	5,801.74	3.60108	2.6008	120.036

Table 4: The emission of transporting goods from Rotterdam to Genova

Type of transportation	CO_2eq (g)	SO_x (g)	PM (g)	NO_x (g)
Articulated lorry, light	691,247.70	3.54486	21.2692	5,317.290
Articulated lorry, heavy	215,054.84	2.36324	11.8162	945.296
Rail container (Diesel)-Medium	36,550.44	0.27074	13.5372	487.339
Ship (Container)-Medium	57,299.48	36.83538	28.6497	1,268.774
Ship (Bulk carrier)-Medium	118,691.78	73.67076	53.2067	2,455.692

Table 5: The emission of transporting goods from Rotterdam to Gdansk

Type of transportation	CO_2eq (g)	SO_x (g)	PM (g)	NO_x (g)
Articulated lorry, light	733,186.35	3.7599	22.5596	5,639.895
Articulated lorry, heavy	228,102.42	2.5066	12.5331	1,002.648
Rail container (Diesel)-Medium	34,290.14	0.2540	12.7001	457.202
Ship (Container)-Medium	16,630.74	10.6912	8.3154	368.252
Ship (Bulk carrier)-Medium	34,449.39	21.3824	15.4428	712.746

Other than distance, capacity also has to be considered in selecting the freight transport mode. The presented results in Tables 3, 4 and 5 assume that the transport mode is fully utilised. The calculation is based on the emission factor reported in g/ tkm (Table 2) with the specified load capacity. A half-loaded transport which underutilised could have a higher emission per t of transported goods.
Figures 1 - 4 illustrate the effect of the total amount of goods need to be transported on the GHGs, SO_x, PM and NO_x emission. In general, the emissions (g/ t) increase when the amount of goods is under and beyond the load capacity of the transport mode.

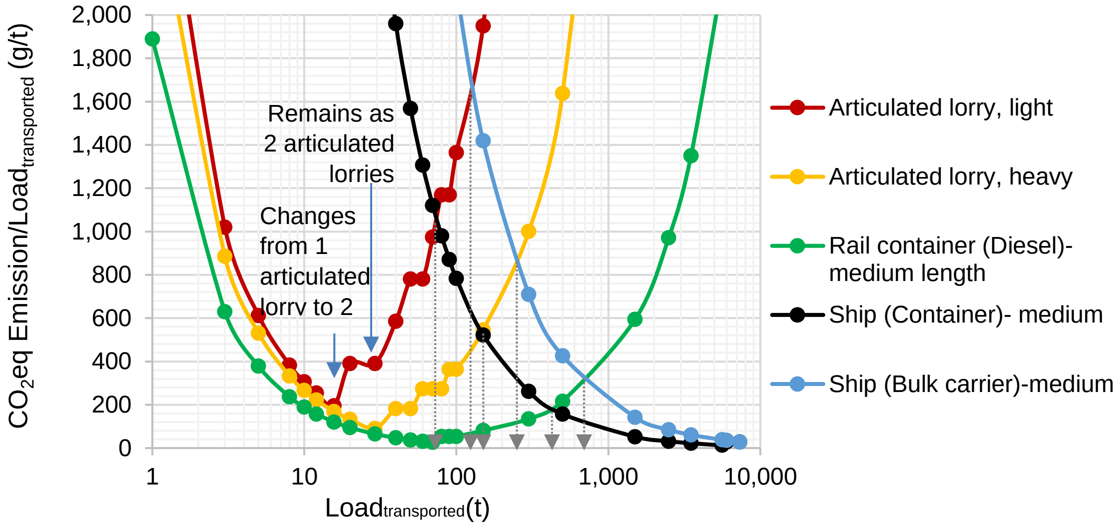

Figure 1: The effect of the total amount of goods need to be transported ($Load_{transpored}$, t) on the CO_2eq emission (g/ t), zoomed view

The zoomed view presented in Figures 1 - 4 highlighted the intersection/turning points of each transport modes. Based on Figure 1, although rail is the solution with lowest CO_2eq emission, ships serve as the better alternatives than rail when the total amount of goods need to be transported are approximately more than 500 t (container ship) and 800 t (Bulk carrier). Road transport (Articulated lorry, heavy) is feasible (low CO_2eq) than ship whenever the amount of goods to be transported is approximately lesser than 200 t. The estimation provides a guideline for transport mode selection, but it should be noted that weight is not the only concern of capacity. The volume and size which are not considered in this study could also impact on the capacity.

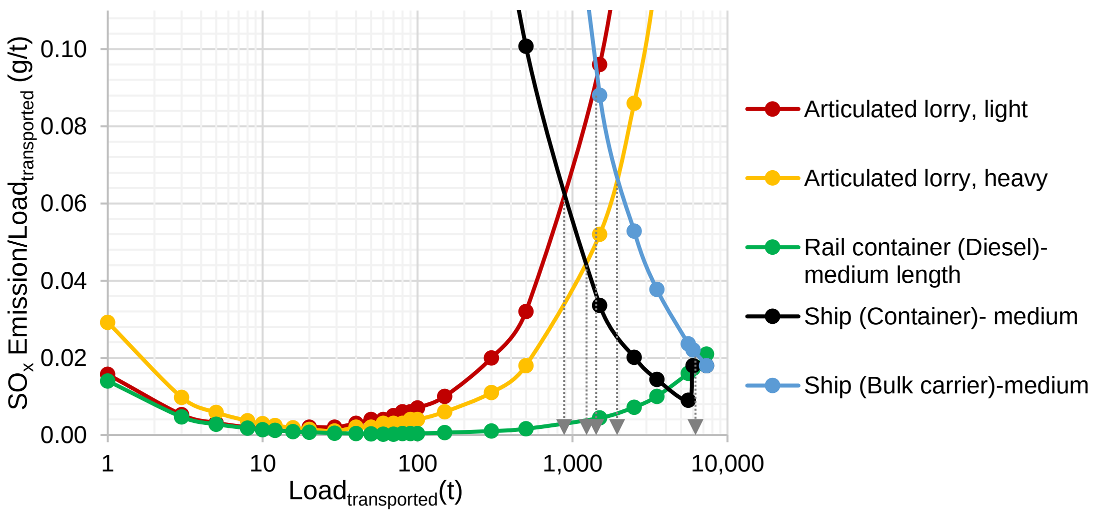

Figure 2: The effect of the total amount of goods need to be transported ($Load_{transpored}$, t) on the SO_x emission (g/ t), zoomed view

As shown in Figure 2, the SO_x emission of rail exceeds the emission by ship when the amount of transport is approximately higher than 4,000 t. Under 1,500 t of goods to be transported, road transport (Articulated lorry, heavy) remains as a preferable option than sea transport (ship container) in term of SO_x emission.

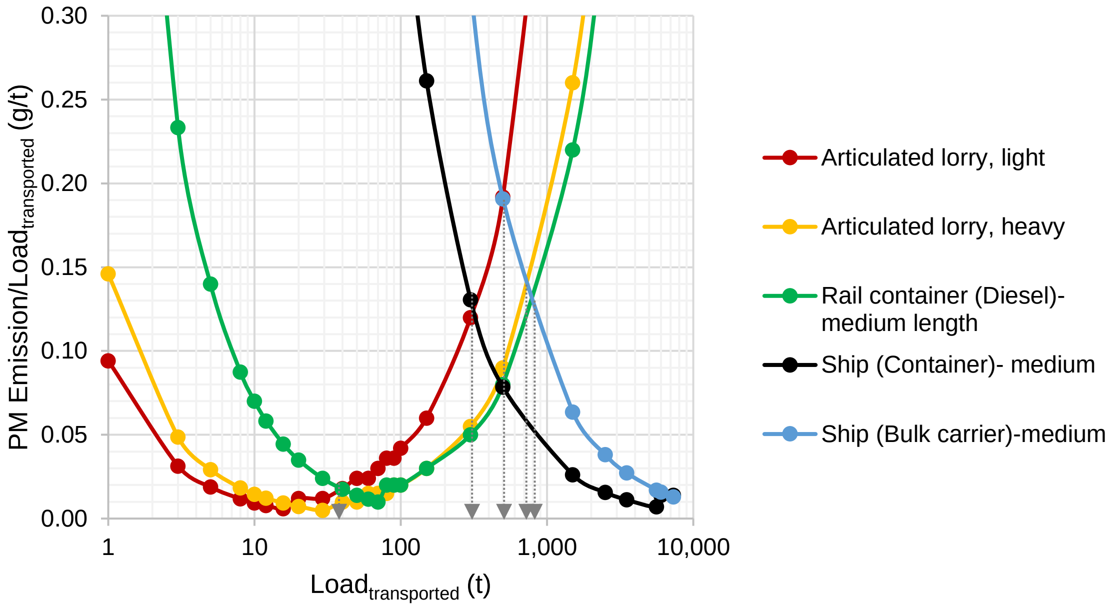

Figure 3: (a) The effect of the total amount of goods need to be transported ($Load_{transpored}$, t) on the PM emission (g/ t), zoomed view

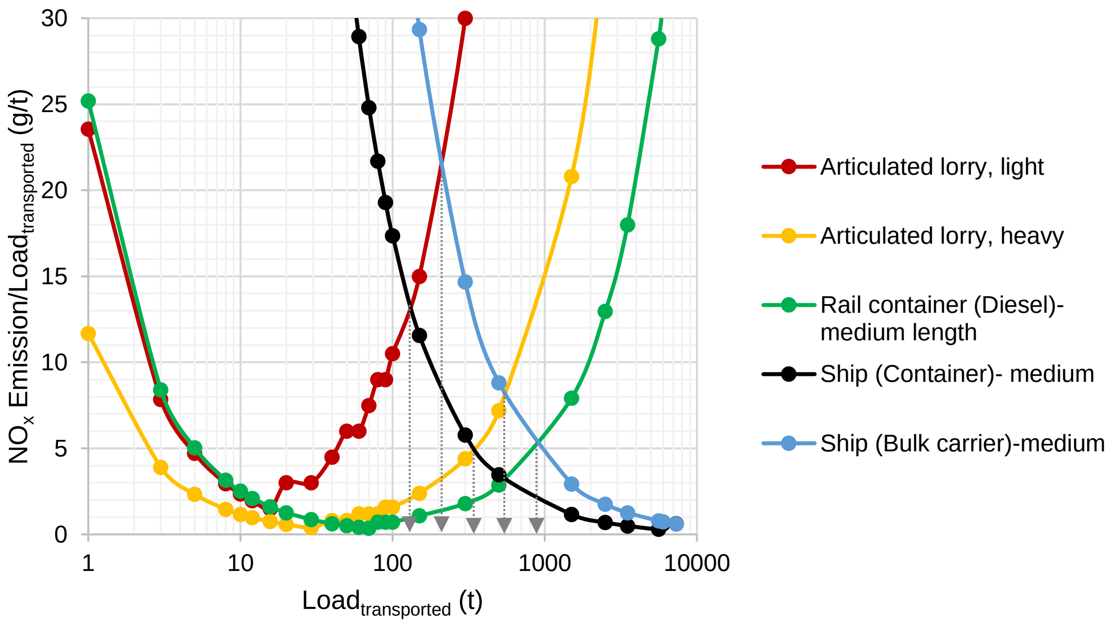

Figure 4: (a) The effect of the total amount of goods need to be transported ($Load_{transpored}$, t) on the NO_x emission (g/t), zoomed view

Figure 3 and 4 show the impact of the amount of goods need to be transported on the PM and NO_x emissions. When the amount of goods is more than ~ 300 - 700 t, ship and rail represent the better freight options than road transport in term of PM emission. The load amount lower than 40 t is less feasible to transport by rail than a tractor. However, more studies are needed for further validation as unlike the other transport mode, the capacity of rail is comparatively flexible where the length of the train can be adjusted. Figure 4 suggests the NO_x emission of road transport is lower when the amount of goods need to be transported is not more than 150 - 550 t. In general, similar trends are presented in Figures 1 - 4. However, the decisive values (the amount of goods) suggesting the need for a modal shift towards the lower emission alternatives are different. The presented results provide a general view of the relationship between the impact of goods amount and the emission. However, it is having a limited function for the final decision making as a different type of emissions are not presented under one integrated picture.

4. Conclusions

This study has contributed to the overall field of study by highlighting the roles of air pollutants in the selection of freight transport. The circumstances (amount of goods) where the freight transport mode is feasible (low emission) are identified. Road transport by articulated lorry, which is commonly viewed as the least environmental friendly mode does not show the highest emission in all the studied cases. The PM and SO_x emissions are lower than ship in moving goods from Rotterdam to Antwerp (PM= 3.6 g, SO_x= 2.6 g) and Genoa (PM= 73.67 g, SO_x= 53.21 g). Road transport (Articulated lorry) is more feasible than ship in term of GHGs, SO_x, PM, NO_x when amount of goods has to be transported are less than 80 - 200 t, 1,500 – 2,000 t, 300 t - 700 t and 150 - 550 t. However, the presented results are not able to show the complete picture. The freight mode selection is depended on one element only (e.g. refer to GHGs or PM or SO_x or NO_x). Future studies are needed to have a representative weighting factor and quantification unit for evaluating the air emission (GHGs and air pollutants) as a whole. The next step of this study is to identify the equation in defining the relationship between air emission and the amount of goods to be transported by different transport modes. Distance parameters should also be incorporated into the equation. A more comprehensive study involving footprint perspective (entire life cycle), travelled time, cost and the intermodal system needs to be conducted. It should be noted that the total weight of the loaded transport is also has an impact on the transport emission. The fuel consumption of empty and loaded transport is different.

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