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ORIGINAL ARTICLE

# Evaluating the external costs of trailer transport: a comparison of sea and road

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**Abstract** The objective of this study is to deduce the comparative level of external costs per transported trailer within a context where an existing freight transport chain is replaced by one that includes greater use of shipping. Using both Sweden's national guidelines for cost–benefit analysis (ASEK) and the European guidelines (Ricardo), the external costs of two alternative options are evaluated. The external costs for a road and shipping option are estimated to be lower than for the direct shipping option under Swedish guidelines, but higher under the European guidelines. However, the results favour the road and shipping option in preference to the direct shipping option under both Swedish and European guidelines when internalizing taxes and fees are accounted for. This is the case even where the shipping mode is compliant with the most stringent environmental regulations. The paper concludes that the evaluation system employed can have a fundamental impact on the outcome of a CBA and that the Swedish guidelines (ASEK) could by improved by incorporating specific values for air pollution from ships (particularly $NO_x$ emissions) and a system for regularly updating emission factors.

**Keywords** Freight transport · Environment · CBA · Emissions · ro–ro · Ropax

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## Introduction

Incentivizing a modal switch for freight from road-based transport to both rail and water lies at the heart of EU transport policy, as embodied in its 2011 White Paper (European Commission 2011). The explicit target for this policy is that, assuming ‘business as usual’ conditions, a modal shift of 30% of road freight over 300 km by 2030 should be achieved, and more than 50% by 2050. It is this overarching policy objective which has invigorated and provided support to EU initiatives such as the Motorways of the Sea concept (European Commission 2004; Baird 2007; Paixão Casaca and Marlow 2007; Aperte and Baird 2013; Suárez-Alemán 2016; Morales-Fusco et al. 2017) and national initiatives, such as those in the UK, Norway and Sweden (U.K. Department for Transport 2015; Kystverket 2017; Trafikanalys 2017), even though the benefits of a modal switch from road to sea are not categorical in every case (Ng 2009; Baindur and Viegas 2011; Feo et al. 2011; Douet and Cappuccilli 2011; Hjelle 2014; Tzannatos et al. 2014). In general terms, the major identified benefits of increased shipping compared to other modes of transport are, *inter alia*, lower costs to shippers, the potential for lower emissions due to higher energy efficiency, less accidents and less congestion or capacity problems (López-Navarro 2013; Styhre et al. 2014).

The primary and generic objective of the analysis conducted in this paper is to identify and compare the external costs of freight traffic when there is a restructuring of an existing transport chain so that greater use is made of the shipping mode. The comparative level of external costs provides not only an obvious and valuable input into mode/route choice decisions, but also has the potential to inform transport policy with respect to relieving some of the intense demand on land infrastructure (Vanherle and Delhaye 2010). This may be achieved by replacing long land-based routes by shorter land-based routes, linked directly to the nearest port and then utilizing the sea mode. Despite our focus on a specific application to Sweden, similar circumstances often arise in many geographical contexts across the world (e.g. Janic 2007; Lee et al. 2010; Macharis et al. 2010; Lun et al. 2013), especially since environmental costs typically represent a very high share of the external costs of shipping and similar regulations for sea transport exist all over the world. Thus, there is an obvious and significant potential for the generalizability of our approach, results and conclusions.

The specific case investigated here is the movement of trailers originating from the Mälardalen region on the East coast of Sweden (represented by Stockholm) and destined for hubs in northern Germany (represented by Travemünde). There currently exists no frequent ro–ro link from Sweden’s East Coast ports. In consequence, the vast majority of trailers leaving the region are transported by truck to Trelleborg, a ferry port in southern Sweden, and from there to Travemünde in northern Germany using a ropax ferry. From Travemünde the trailers are transported by truck to their final destinations.

Daily departures of a ro–ro vessel are required in order to offer an attractive transport option for trailers to move by sea directly from the Mälardalen region of Sweden to northern Germany. To determine whether daily departures are justified,

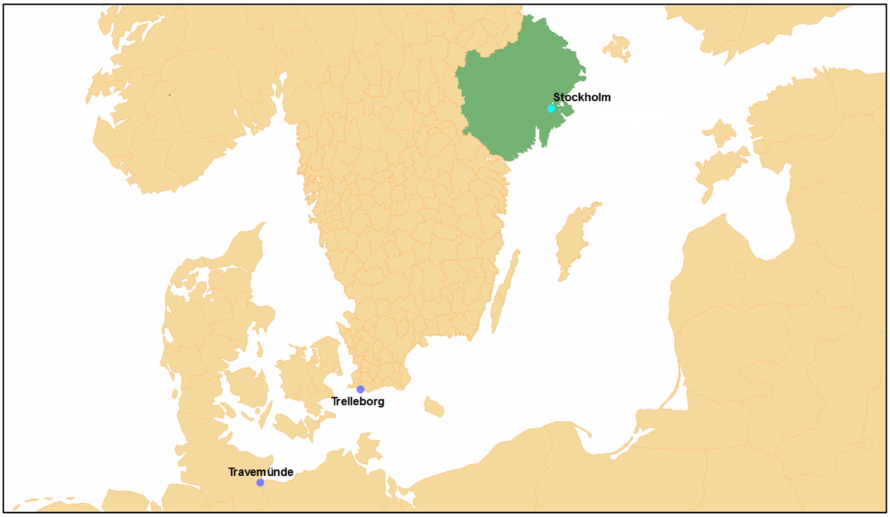



Illustration: Rune Karlsson

**Fig. 1** The assumed catchment area for trailer goods around Stockholm. Illustration: Rune Karlsson

**Table 1** Estimated import and export volumes to/from the Stockholm catchment area

| | Import | Export |
|---|---|---|
| Total tonnes (per year) | 9,640,168 | 4,850,103 |
| No. of trailers (per year) | 401,674 | 202,088 |
| No. of ships (per year) | 3062 | 1540 |
| Ship departures per day | 8.4 | 4.2 |

we have estimated imports and exports for the catchment area of the East coast port of Stockholm, strategically located mid-way along the coast of the Mälardalen region.[1] It is assumed that the catchment area of the port of Stockholm covers Stockholm County, Västmanland County, Uppland County and Södermanland County. This area is shown in Fig. 1.

The volume of goods expected to be imported to, and exported from, this area is presented in Table 1. Data come from the demand matrix utilized in Sweden's national freight transport model (Samgods). Commodities that are not expected to be served by trailer transport via Germany have been removed from the original data set. All assumptions made in this respect have been established in consultation with Sweden's East Coast Ports Association.

Table 1 shows that enough goods are imported to fill 8.4 vessel arrivals per day and sufficient goods are exported to fill 4.2 vessel departures per day. The assumptions underpinning these calculations are that a trailer has a 24-tonne average load and that the ro–ro ships have a capacity of 164 trailers, with an 80% utilization

[1] Styhre (2009) provides some insights into the sort of considerations and strategies influencing the supply of short sea shipping services.

rate. To justify a single daily departure in either direction would require moving about 50,000 trailers per year. It would seem, therefore, that there is sufficient potential for goods movements by trailer in a direct roro-service within the area to suggest that the assumption of a single daily departure in either direction is indeed reasonable.

This study hypothesizes, therefore, the existence of an alternative routing, where these trailers are transported by ro–ro vessel directly to Travemünde from Stockholm. The assumed potential for such a wholesale modal switch reflects the all-or-nothing basis for the assignment of freight flows within Sweden's national freight model (Samgods). It is the predictive output of traffic flows from this model which would justify the design and implementation of appropriate policy measures, targeting environmental benefits, which would actually bring this scale of modal switch to fruition (Browne et al. 2012).

The focus of this study is to calculate and compare the external costs of direct shipments from Stockholm (as a nominal, but representative, East Coast port) to Travemünde (as a representative continental port), to the external costs of the existing transport chain, where road transport is used to Trelleborg and sea transport from there to Travemünde. IMO Tier 2 regulations are assumed for the maritime leg of both options, as this is what pertained at the time data were collected for the study and which, in any case, is still relevant for most ships. However, a sensitivity analysis is also conducted for vessels meeting the Tier 3 requirements for new vessels, which became mandatory from 2016 (see later).

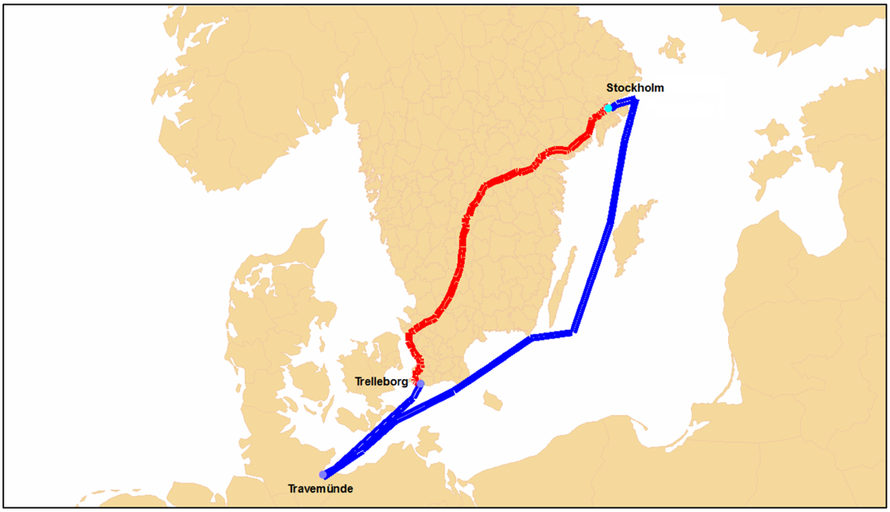
Thus, this study explicitly compares the external costs of the following two routing options:

- *Option 1* Road and shipping—from the Stockholm region to Trelleborg by truck. From Trelleborg to Travemünde with ropax ferry.
- *Option 2* Direct shipping—from the Stockholm region via the nominal port of 'Stockholm' directly to Travemünde using ro–ro vessels.

The routing options to be evaluated are shown graphically in Fig. 2.

Cost–benefit Analysis (CBA) can account for both internal costs (e.g. transport costs) and external costs (e.g. accidents). The analysis and results presented in this study, however, do not constitute a complete CBA; in that no account has been taken of internal costs. The focus of the study is on the short-term external costs that are not paid by transport operators and shippers and that, therefore, are not considered when choosing a transport solution. Instead, these costs are borne by society (Mostert et al. 2017). In the absence of reliable cost estimates, our analysis accounts only for the external costs that arise while trailers are being transported. In other words, although potentially important (Tichavska and Tovar 2017), the external costs incurred in ports and other terminals, as well as all internal costs, are not considered. Based on information from shippers, it is known that the two options for the trailer transport analysed here are priced at approximately the same level (Vierth and Sowa 2015).

The comparison of alternative transport chains which is undertaken in this study reveals which option imposes the least costs on entities other than transport




Notes: Light Line: Truck, Dark Line: Maritime. (Illustration: Rune Karlsson)

**Fig. 2** Illustration of transport routing options for trailers. *Notes* Light Line: Truck, Dark Line: Maritime. (Illustration: Rune Karlsson)

operators and shippers. It does not, however, reveal the option possessing the lowest economic costs overall. For this, all internal and external costs would need to be included in the analysis (Bickel and Friedrich 2013).

Various measures can be used to internalize external costs (i.e. to transfer the external costs into a firm's internal costs). Governments can introduce regulations that force firms to reduce external costs. For example, the Sulphur Directive of the EU prescribes the maximum permissible sulphur emissions from ships and the Tier regulations of the International Maritime Organization (IMO) prescribe maximum $NO_x$-emissions for new vessels. Governments can also introduce or adjust taxes or fees, in a way that companies offset social costs, and/or they can give incentives for reducing the external costs that transport gives rise to. Finally, companies can also take voluntary measures to reduce external costs. A further aspect of the analysis undertaken here is, therefore, to account for any internalization taxes or fees which may have been paid in each of the cases evaluated.

The next section outlines our broad methodology. This is elaborated in the following section where the external costs addressed here, as well as the range of taxes or fees applied for internalization, are categorized and examined. The penultimate section presents and discusses the results and, finally, conclusions are drawn.

## Methodology

The analysis revolves around a comparison of the external costs of two alternative freight transport chains. The first is the currently existing base-case solution (Option 1: road and shipping) which has a significant land-based element. The other alternative is a theoretical solution which offers a greater use of shipping (Option 2: direct shipping). Option 2 assumes that the freight movements take place by sea between the port of Stockholm on the East Coast of Sweden and Travemünde in northern Germany. The comparison comprises only the external costs that occur during the transport, and not external costs in ports or terminals. For Option 2, the external costs related to the relatively local connecting road transport to and from the port of Stockholm are also not included.

**Assumptions on vehicles**

The assumptions on the vehicles and loading factors are based on information from shippers and transport operators within the Mälardalen region (Vierth and Sowa 2015). As a road transport vehicle, a long-haul 40-tonne truck is assumed, with a maximum load capacity of 28 tonnes and an average load of 24 tonnes of freight. The truck is assumed to have an average annual mileage of 125,000 km (Såcalc 2015) and to consume 45 L of diesel per 100 km. The truck is assumed to belong to the environmental class Euro 5[2] and every truck is expected to be able to ship a trailer. Empty transport is not included in the calculations. (Resa-mellan.se (2017) is the source of data for the relevant truck distance calculations).

For ferry services from Trelleborg to Travemünde, it is assumed that the Nils Dacke ropax ferry that currently sails this route is representative of ferry traffic between these destinations. Nils Dacke is 6600 dwt and has a gross weight of 26,800 tonnes, with a maximum load capacity of 160 trailers (Unifeeder 2015). For ro–ro transport between Stockholm and Travemünde, a ro–ro vessel with a maximum capacity of 164 trailers, a dwt of 7910 tonnes and a gross tonnage of 25,518 is assumed. Both vessels are expected to have a utilization rate of 80%. It is assumed that four vessels are used. (Sailing distances are based on data from sea-distances.org 2017).

As of 1 January 2015, sulphur emissions from ships have been reduced to a permitted maximum of 0.1% within the sulphur emission control area (SECA) in the Baltic Sea, North Sea and English Channel. The owners/operators of vessels have reduced their sulphur emissions either by using low-sulphur fuel or technology for sulphur removal. The level of a vessel's $NO_x$ emissions is largely dependent on its engine. The IMO has developed regulations to reduce $NO_x$ emissions from ships and categorized them as Tiers 0, 1, 2 and 3, with each tier specifying the requirements that the engine must meet. Determining which Tier requirements are applicable depends on the year the vessel was constructed. It is assumed that both the ropax and ro–ro vessels considered in our analysis meet the Tier 2 requirements, which means that they are built in 2011 or later. For the ro–ro vessel, a sensitivity analysis is also conducted under the assumption that ships meet Tier 3 requirements, which new vessels built after 2016 must meet.

[2] Directive 91/542/EWG defined Euro 1 and Euro 2, which were compulsory from 10/1993 and 10/1996, respectively. Euro 3 became compulsory from 10/2001 and Euro 4 from 10/2006, regulated by 1999/96/EWG updated by 2001/27/EWG. Three years later, Euro 5 was required, described in Directive 2006/81/EWG and modified in 2008/74/EWG. Euro 6 became compulsory in 01/2014. New Euro classes are usually on the market one or more years before they become compulsory (Dieselnet 2017).

### Calculating the amount of emissions

The calculation tool, NTM Calc, was used to compute the amount of emissions from the two options (NTM 2016). However, following detailed discussions with the NTM developers, it was concluded that the tool was overestimating shipping emissions. This was due to the fact that certain parameters embedded in the tool were based on values from 8 to 15 years earlier. In more recent years, the operating speeds of ships have been reduced in order to achieve better fuel economy in depressed shipping markets. Also, more modern ships are more fuel efficient than their predecessors. Across all ship types used within NTM Calc, contemporary fuel efficiency levels were estimated to be, on average, about 80% of the assumed levels embedded within the model. Based on this, the emission estimates that have been used in this study are 20% lower than those produced by NTM Calc.

### Calculating the external costs

The monetary valuation of the external effects of both transport chains is determined using Sweden's national CBA guidelines, ASEK (Trafikverket 2015), which have been applied in the evaluation of virtually all Sweden's major national transport investments since the 1990s (Eliasson 2013). In parallel, the European guidelines on external costs of transport (Ricardo 2014) are also applied to facilitate a comparison of outcomes. The method for calculating the external costs associated with each of the two options is in principle the same as applied in Vierth (2013) and Mellin (2013). However, some updating of these works has been implemented in relation to both the Swedish and European guidelines and this has had an impact on some of the estimates of external costs. These updates relate particularly to assumptions about the characteristics of the vehicles/vessels and fuels used, and the fuel consumption per vehicle-km.

Various types of external costs can be identified, some of which are more relevant to certain modes of transport than to others: infrastructure costs, accidents, congestion or scarcity of capacity, noise, air pollution (mainly in the form of nitrogen oxides ($NO_x$), sulphur dioxide ($SO_2$) and particulate matter (PM)), climate change impacts in the form of carbon dioxide emissions ($CO_2$) and the specific impact of other emissions (including noise), on the land, coastal areas, rivers, seas and the sea bottom. Due to limited knowledge neither the European nor the Swedish guidelines include unit values for water pollution and the impact on the coast and sea bottom.

Road traffic congestion generally exists in Sweden, but only in major metropolitan areas during peak hours and hardly at all on the motorway network which links cities. Therefore, external costs of congestion on the road are assumed to be zero. In other words, changing the routing option from the current version to one where greater shipping is involved is assumed to have zero impact upon network congestion. This analysis also assumes, as does ASEK, that there are no congestion problems related to shipping in Sweden (Trafikanalys 2015).

The external costs arising from transport are dependent, *inter alia*, upon the vehicles or vessels used, on the routes taken, speeds, as well as on how the overall

**Table 2** The external costs of road and shipping considered in the analysis

| | Road | Shipping |
|---|---|---|
| Infrastructure costs/wear and tear | X | |
| Accidents | X | |
| Noise | X | |
| Air pollution | X | X |
| $CO_2$ emissions | X | X |

effects per kilometre are measured in monetary terms. In particular, for the land-based modes, the values for air and noise pollution vary, depending on whether the shipment is carried through rural or urban environments. Table 2 summarizes the external costs that are included in our analysis.

The external infrastructure costs depend solely upon the amount of wear and tear that results from the use of roads. In accordance with both the Swedish and European guidelines, the cost of wear and tear is assumed to be zero for shipping. Thus, external infrastructure costs are relevant only to Option 1—the Stockholm/Trelleborg route.

The external costs of road accidents include inter alia, health care costs, lost productivity and the costs associated with loss of life and health. In accordance with both the Swedish and European guidelines, the cost of accidents is assumed to be zero for shipping.

The external cost of noise is calculated in accordance with how many people are affected by that noise, and it depends on vehicle size, speed and technical characteristics. Noise costs for road (and rail) are a relatively new component of the Swedish guidelines and, in consequence, were not considered in previous studies such as those reported in Vierth (2013) or Mellin (2013). The European unit values depend on several factors: day/night operation, dense/sparse traffic and operation in urban/suburban/rural areas. The figure used here is, a function of all these factors, where 15% of all road traffic is assumed to go through urban areas, with the remaining 85% operating in rural areas. It is also assumed that 50% of the traffic moves during the day and that this is only relatively light traffic. As only underway costs are considered, noise impacts from berthing, loading and unloading in ports and narrow inlets are not included. In parallel with both the Swedish and European guidelines, the impact of noise from shipping while at sea is assumed to be zero. Due to limited knowledge, neither the European nor the Swedish guidelines include unit values for noise in water.

The Swedish guidelines contain recommendations for the external costs of air pollution and $CO_2$ emissions based on both per vehicle-kilometre and per kilogram emissions. This study uses the cost per kilogram of emission, since it facilitates a more precise specification of the specific truck and vessels used. This will then yield more precise estimates of the external costs of air pollution and $CO_2$ emissions. The external costs of one kilogram of air pollution and $CO_2$ emissions are presented in Table 3. The calculation is undertaken in two steps: The first step is to use the 'NTM Calc' tool to calculate how many tonnes of $NO_x$, $SO_2$, PM and $CO_2$ emissions different vehicles or vessels emit per vehicle-/vessel-kilometre (NTM

Table 3 External costs of road and shipping under Swedish and European guidelines *Source* Trafikverket (2015), Ricardo (2014) and own calculations (exchange rate 8.83 SEK/EURO)

| | Swedish guidelines | | European guidelines | |
|---|---|---|---|---|
| | Road | Shipping | Road | Shipping |
| € per vehicle-km | | | | |
| Wear and tear | 0.042 | – | 0.068 | – |
| Accidents | 0.035 | – | 0.011 | – |
| Noise | Reg. 0.043, loc. 0.308 | – | 0.045 | – |
| € per kg of emission | | | | |
| $NO_x$ | Reg. 9.06, loc. 1.59 | Reg. 9.06 | 5.25 | 5.21 |
| $SO_2$ | Reg. 3.06, loc. 13.93 | Reg. 3.06 | 5.39 | 5.44 |
| PM | Reg. 0, loc. 476.22 | Reg. 0 | Reg.14.58, loc. 197.54 | 14.50 |
| $CO_2$ | 0.12 | 0.12 | 0.11 | 0.09 |

2016). In the second step, these emissions are valued using the Swedish and European guidelines, respectively. For the air pollution cost, it is necessary to differentiate between local and regional emissions. This is not needed for $CO_2$ emissions that have global impacts. As discussed earlier, the total amount of $CO_2$ emissions from ships is dependent on their actual speeds.

For sea transport, the Swedish regional values have been applied, as local air pollution is assumed not to exist. The European guidelines recommend separate valuations for land and sea transport and different sea transport costs for different sea areas. In this study, the average of the values for the North Sea and the Baltic Sea has been used.

As revealed through a comparison of the content of Table 3, there are sometimes large differences between the valuations provided by the Swedish and European guidelines. For certain items, the variation can be more than a factor of three (e.g. for accidents). Such differences can be caused by different circumstances.

For air pollution, the Swedish guidelines differentiate between local and regional impacts for road (and rail) but, with respect to sea transport, the same values are applied to emissions in port and at sea. For shipping, it should also be noted that the Swedish values for $NO_x$ and $CO_2$ are higher than the European values, while they are lower for $SO_2$ and PM.

## Calculating the taxes and fees

As previously alluded to, governments and international organizations can introduce or adjust regulations as well as taxes and fees, amongst other things, to convert external costs into internal costs. For a complete analysis of external costs, it is important to consider the effect of such taxes and fees. Therefore, we also calculate the external costs that remain uninternalized (i.e. external costs after taxes and fees have been deducted) and the internalization rate (taxes and fees divided by the total external costs).

## Analysis and discussion of results

### External cost calculations

In accordance with all the assumptions made, Table 4 shows the amount of emissions that trucks, ropax vessels and ro–ro vessels that fulfil the Tier 2 requirements (base case) and Tier 3 requirements (sensitivity analysis), are estimated to cause on each of the specified routes.

The external costs of the two options for evaluation are calculated on the basis of (1) our assumptions with respect to the trucks and vessels used, as outlined earlier; (2) the calculated amount of emissions under the two options, as shown in Table 4; and (3) the unit values for the external costs, as shown in Table 3 for both the Swedish and European guidelines. The results of these external cost calculations are shown in Tables 5 and 6, for the Swedish and European guidelines, respectively.

Previous studies have found similar results to those shown in Tables 5 and 6. The fact that the ro–ro vessel has a higher external cost than the truck is also what Vanherle and Delhaye (2010) found in their study of ships sailing in Swedish waters. In comparing the costs of road and ro–ro transport in Greece, Tzannatos et al. (2014) also found that a ro–ro vessel has lower internal costs, but higher external costs than a road vehicle. These studies, however, do not consider vessels which meet Tier 3 requirements.

In comparing the outcomes of the two sets of guidelines, both Option 1 and Option 2 show significantly lower costs when Ricardo is used. The reason for this is almost exclusively due to the different values of $NO_x$ for shipping (€ 5.21 in Ricardo versus € 9.06 in ASEK, see Table 3). The $NO_x$, in turn, represents 98% of the total external cost of air pollution from shipping, and if Tier 2 is assumed, then more than 50% of the external costs of shipping are related to air pollution. When the ro–ro vessel complies with Tier 2 requirements, the ranking of the options differs depending on the valuation guidelines applied (ASEK or Ricardo). When the ro–ro vessel complies with Tier 3 requirements, the *direct shipping* option has lower external costs than the combined road/shipping option, independently of valuation. For road transport, $CO_2$ is the largest item, representing over 40% of its total external costs.

**Table 4** Estimated amount of emissions for truck, ropax and ro–ro vessels Source: Based on NTM (2016) and our own calculations based on IMO (2014)

| | $NO_x$ (g) | $SO_2$ (g) | PM (g) | $CO_2$ (kg) |
|---|---|---|---|---|
| Truck: Stockholm–Trelleborg (649 km) | 2247 | 426 | 32 | 851 |
| Ropax: Trelleborg–Travemünde (222 km) | 710,700 | 46,980 | 6890 | 43,680 |
| Roro: Stockholm–Travemünde (898 km) (Tier 2) | 2,682,000 | 177,300 | 26,040 | 164,800 |
| Roro: Stockholm –Travemünde (898 km) (Tier 3) | 692,800 | 177,300 | 26,040 | 164,800 |

**Table 5** External costs in € according to ASEK

| | Wear and tear | Accidents | Noise | Air pollution | $CO_2$ | Total per truck/vessel | Total per trailer |
|---|---|---|---|---|---|---|---|
| Option 1: road and shipping | | | | | | | |
| Road | 28 (12%) | 23 (10%) | 54 (23%) | 20 (9%) | 104 (45%) | 229 | 229 |
| Ropax | | | | 6583 (55%) | 534 (45%) | 11,925 | 93 |
| Total | | | | | | | 322 |
| Option 2: shipping direct | | | | | | | |
| Roro (Tier 2) | | | | 24,841 (55%) | 20,157 (45%) | 44,998 | 343 |
| Roro (Tier 3) | | | | 6,819 (25%) | 20,157 (75%) | 26,976 | 206 |

**Table 6** External costs in € according to Ricardo

| | Wear and tear | Accidents | Noise | Air pollution | $CO_2$ | Total per truck/vessel | Total per trailer |
|---|---|---|---|---|---|---|---|
| Option 1: road and shipping | | | | | | | |
| Road | 45 (24%) | 7 (4%) | 30 (16%) | 27 (14%) | 77 (42%) | 185 | 185 |
| Ropax (Tier 2) | | | | 4448 (60%) | 3008 (40%) | 7455 | 58 |
| Total | | | | | | | 243 |
| Option 2: shipping direct | | | | | | | |
| Roro (Tier 2) | | | | 16,785 (53%) | 14,931 (47%) | 31,716 | 242 |
| Roro (Tier 3) | | | | 4950 (25%) | 14,931 (75%) | 19,881 | 152 |

Remembering that the ropax vessel is consistently assumed to meet Tier 2 requirements, under the sensitivity analysis when the ro–ro vessel complies with Tier 3 requirements, Option 2 (Direct Shipping) is the choice that involves the lowest external costs. This result is consistent, irrespective of which of the two valuation guidelines is used.

It is important to emphasize that neither the results achieved under the Swedish nor the European guidelines say anything about which of the two options is more expensive for society. This is because internal costs also need to be taken into account for a full CBA. What can be inferred from our results, however, is that, for the road mode, $CO_2$ accounts for the largest proportion of external costs (about 46% under ASEK and 42% under Ricardo). For sea transport, under the assumption of Tier 2 compliance, air pollution is the largest external cost, accounting for between 53 and 60% of total external costs depending upon the vessel and the valuation guidelines used. Given that $NO_x$ emissions account for approximately 94% of the air pollution from vessels, when Tier 3 compliance is assumed, the proportion of total external costs accounted for by air pollution falls to 25%, with CO2 emissions now accounting for 75% of the total external cost.

**Accounting for the internalization of external costs**

Information on applicable taxes and fees for the two options is derived from the responsible state agencies. Internalizing fees are fuel taxes and other applicable fees for the road mode and fairway dues for shipping. Fees of *nautical-technical services* (pilotage, towage, line-handling) are not included as internalizing fees, as no accident costs are assumed. The inclusion of such fees would lead to double counting, as the external costs of accidents at sea are assumed to be zero. This assumption is a simplification, as the relevant regulations do not remove the possibility of an accident occurring.

Fairway dues are mandatory for ships sailing in Swedish waters and are levied by the Swedish Maritime Administration (Sjöfartsverket 2017). They consist of two parts: a GT charge (based on the vessel's gross tonnage) and a cargo fee (depending on the amount of cargo loaded or unloaded). These fees are € 0.29 per GT and € 0.31 per tonne of cargo (the level of the fairway dues payable in Options 1 and 2 have been calculated with the help of the Swedish Maritime Administration).

Taxes and/or fees internalizing external costs are significantly higher for road transport than shipping. Referring to Table 7, the fees paid by the firms are € 197 per trailer in Option 1: Road and shipping and € 22 per trailer in Option 2: Direct shipping. Due to the relatively long trucking leg from the Mälardalen region to Trelleborg, the combined fuel taxes in Option 1 are much higher than in Option 2. Table 7 also reveals that the fees payable for transiting between Trelleborg and Travemünde in Option 1 are higher compared to those applicable to the Stockholm-Travemünde transit in Option 2. This is largely explained by the fact that the ropax vessel sailing the Trelleborg-Travemünde route also transports passengers and, because of other regulations, the gross amount of the passenger fare charged will

**Table 7** Taxes and fees for both options

| | € per vehicle | € per trailer |
|---|---|---|
| Option 1: road and shipping | | |
| Truck | 170 | 170 |
| Ropax-vessel | 3439 | 27 |
| Total | | 197 |
| Option 2: shipping direct | | |
| Roro-vessel | 2919 | 22 |

**Table 8** External costs after internalization and degree of internalization according to ASEK

| | € per trailer | Degree of internalization (%) |
|---|---|---|
| Option 1: road and shipping | | |
| Truck | 59 | 75 |
| Ropax | 53 | 29 |
| Total | 112 | 61 |
| Option 2: shipping direct | | |
| Roro (Tier 2) | 321 | 6 |
| Roro (Tier 3) | 183 | 11 |

'€ per trailer' External costs—taxes and fees, 'Degree of Internalisation' Taxes and Fees/External costs

**Table 9** External costs after internalization and degree of internalization according to Ricardo

| | € per trailer | Degree of internalization (%) |
|---|---|---|
| Option 1: road and shipping | | |
| Truck | 15 | 92 |
| Ropax-vessel | 40 | 40 |
| Total | 57 | 83 |
| Option 2: shipping | | |
| Roro-vessel (Tier 2) | 220 | 9 |
| Roro-vessel (Tier 3) | 129 | 15 |

apply in determining fee charges. In addition, for passenger traffic, the vessel pays for the first five calls per month instead of the first two calls which applies for pure freight vessels.

As shown in Tables 8 and 9, when the taxes and fees are subtracted from the external costs, Option 1 (road and shipping) looks more beneficial than Option 2 (direct shipping) under both the Swedish and European guidelines. The external costs of trucking are internalized by about 75% under ASEK and 92% under Ricardo, if it is assumed that all diesel used in Sweden is taxed.[3] This means that the external cost that is not internalized is higher for Option 2 than for Option 1. In addition, the shipping part of Option 1 (Trelleborg-Travemünde) has a higher degree of internalization than Option 2 (Stockholm-Travemünde). This is due *inter alia* to the difference in discounts which apply to ropax ferries and ro–ro vessels and to the fact that fees are not distance-dependent. The fact the fairway dues are not distance-dependent, unlike most of the fees for other transport modes, means that the internalization rate for sea transport decreases as distance increases. Regardless of which guideline is used (ASEK or Ricardo) or if the ro–ro ships meet the

[3] In undertaking this analysis, it is not entirely certain that all diesel fuel consumed by trucks on the Stockholm-Trelleborg route is taxed in Sweden. The reason is that foreign trucks carry a large part of the freight moved to and from Sweden and fuel taxes differ across Europe. Luxembourg, for example, has one of the lowest diesel taxes in Europe; standing at about 40% lower than that in Sweden. There is, therefore, reason to believe that the degree of internalization presented is slightly overestimated. As an extreme case, if only diesel purchased in Luxembourg is used, the internalization rate decreases from 75 to 44% under ASEK values.

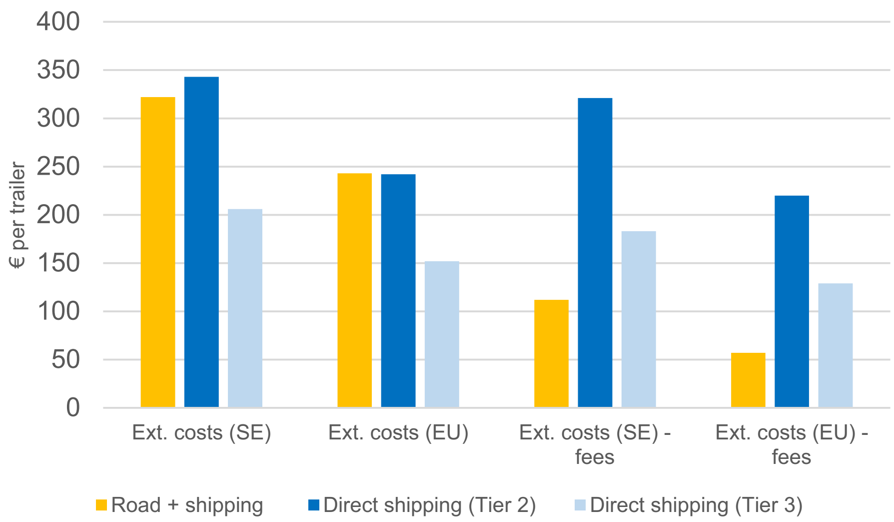



**Fig. 3** Comparison of the options

requirements for Tier 3 or not, Option 2 yields higher external costs after taxes and fees.

## Summary comparison

Based on the Swedish national guidelines (ASEK), total external costs for Option 1: Road and shipping via Trelleborg are estimated to be € 322 per trailer compared to € 343 per trailer (Tier 2) and € 206 per trailer (Tier 3) for Option 2: Direct shipping via Stockholm (See Table 5). When using values from the European guidelines, however, the external costs of Option 1 are found to be € 243 per trailer, compared to € 242 per trailer (Tier 2) and € 152 per trailer (Tier 3) for Option 2 (see Table 6).

Figure 3 shows that, under the assumption solely of Tier 2 compliance, the external costs of the two options are close to each other in value, irrespective of the guidelines used. However, because the road mode has higher internalizing fees than the sea mode, when internalizing fees are subtracted from the total external costs, the result favours Option 1: Road and shipping, under both Swedish and European guidelines, and even under the more stringent environmental compliance regime of Tier 3 regulations.

Given an assumed annual trailer number of 50,000 trailers, the results mean that the annual external costs amount to about € 16 million for Option 1: Road and shipping and about € 17 million and € 10 million for Option 2: Direct shipping, Tier 2 and Tier 3, respectively. After accounting for internalizing fees and applying the Swedish guidelines, Option 1: Road and shipping yields external costs of € 6 million per year and Option 2: Direct shipping yields € 16 million per year (Tier 2) and € 9 million per year (Tier 3). The difference between the results for the net external costs of the two options is largely because higher fees are paid for the use of the road mode than for the sea mode.

## Conclusions

The objective of this study was to ascertain how the external costs of a trailer-based freight transport chain between the Mälardalen region of East Sweden (represented by Stockholm) and hubs in Northern Germany (represented by Travemünde) would change following a modal shift in which greater use is made of shipping. The external costs of two options (a road and shipping option and a direct shipping one) have been estimated as external costs per trailer. The ambition was to include the external costs of wear and tear, accidents, noise, air pollution and $CO_2$ emissions. It was assumed that a change of transport chain would not have any impact on network congestion. The internalizing fees have then been taken into account to arrive at figures for the uninternalized external costs and the internalization rate. The calculations were based on (1) information from shippers and transport operators regarding the type of truck and vessels used, their capacity utilization and the routes deployed (Vierth 2015); (2) the NTM calculation tool regarding emission factors and; (3) the Swedish and European guidelines, respectively, on the unit values of external costs.

Based on the Swedish guidelines, external costs for the road and shipping option are estimated to be lower than for the direct shipping option under Tier 2 compliance, but not when Tier 3 compliance is assumed. When using values from the European guidelines, however, the external costs of the road and shipping option are found to be higher than the direct shipping option under both Tier 2 and Tier 3 compliance. When the internalizing fees that are paid are subtracted from the external costs, the result favours the road and shipping option, using either Swedish or European guidelines.

It is important to point out that the results should not be interpreted as a measure of socio-economic costs or socio-economic efficiency. External costs are only part of the total socio-economic cost and, therefore, it should be borne in mind that these estimates do not provide a comprehensive picture of which transport options are the least costly for society.

The main sources for the valuation of external effects were Swedish Transport Administration's ASEK recommendations and the European Commission's Ricardo report. An important difference between the Swedish and the European guidelines is that the $NO_x$ valuations are significantly lower in the European guidelines (€ 5.21 per tonne) than in the Swedish guidelines (€ 9.06 per tonne). Unlike the Swedish guidelines, the European guidelines provide specific costs for sea transport. This gives reason to believe that the true external cost values for shipping are closer to the European guidelines than to the Swedish guidelines. Another difference is that Ricardo differentiates between air pollution on land and at sea (as well as between different seas). To increase the quality of CBAs within the Swedish context, ASEK needs to develop values which are specifically adapted to maritime transport, at least

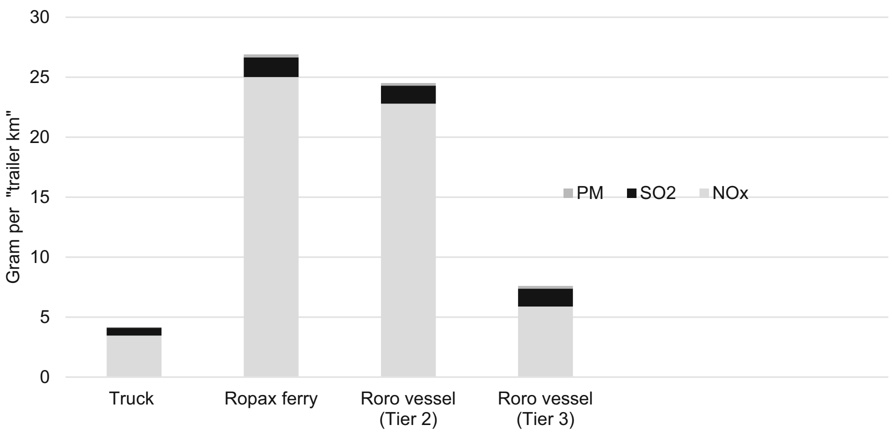



**Fig. 4** Air pollution per vehicle kilometre

for those seas on the coast of Sweden. Alternatively, the use of European (Ricardo) unit values for air pollution is recommended.

The external costs of sea transport largely depend on vessel engines and speed, in that these directly affect fuel consumption, air pollution and $CO_2$ emissions. However, the optimal speed of ships is largely determined as a function of fuel prices and the economic situation in specific shipping markets (Tichavska and Tovar 2017). As such, vessel speeds will vary over time and this means that the external costs of shipping will also vary over time. Hence, as illustrated when applying the NTM Calc tool in this analysis for estimating the emissions, it is desirable that continuous updates of emission factors for sea transport are undertaken.

Relative to other transport modes, $NO_x$ emissions represent a large part of the external costs of maritime transport. Figure 4 clearly shows, however, that the ropax ferry and ro–ro vessel engines that meet Tier 2 compliance requirements still have the highest $NO_x$ emissions of all vehicles and ships. This is due to a low loading capacity relative to their size and the relative inefficiency of Tier-2 engines. The picture changes with the introduction of Tier 3 engine technology, which became mandatory for new vessels from 2016, as the amount of $NO_x$ emissions is estimated to decrease by about 75%. Since compliance with Tier 3 regulations applies only to new vessels, the change will filter through rather slowly into shipping markets. In this context, it is important to study the type of instruments that can be used to reduce ship emissions of $NO_x$, $SO_2$, PM etc. during the transitional period. In this aspect, perhaps shipping has much to learn from the road sector where, through the introduction of the euro-class system in the early 1990s (i.e. minimum requirements for air pollution for new heavy trucks), it has been possible to significantly reduce emissions of $NO_x$, $SO_2$, PM etc.[4] Against a potential backdrop of impending higher

[4] The EU Directive 8/77/EWG regulates the emissions of carbon oxide (CO), hydrocarbon (HC), nitrogen oxide ($NO_x$), particulate matter (PM) and smoke. From Euro 1 to Euro 6, CO emissions have been reduced by 67%, HC emissions by 88%, NO$x$ emissions by 95% and PM emissions by 97% (Dieselnet 2017).

rail transport charges and the introduction of distance-based infrastructure charges for heavy trucks in Sweden, both of which will increase the level of internalization of land-based external costs, the regulation of shipping emissions needs to continue apace if policies of promoting modal shift from land to sea are to prove meaningful and effective.

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## References

Aperte, X.G., and A.J. Baird. 2013. Motorways of the sea policy in Europe. *Maritime Policy & Management* 40 (1): 10–26.

Baindur, D., and J. Viegas. 2011. Challenges to implementing motorways of the sea concept—lessons from the past. *Maritime Policy & Management* 38 (7): 673–690.

Baird, A.J. 2007. The economics of Motorways of the Sea. *Maritime Policy & Management* 34 (4): 287–310.

Bickel, P., and R. Friedrich (eds.). 2013. *Environmental external costs of transport*. Berlin: Springer.

Browne, D., B. Caulfield, and M. O'Mahony. 2012. Assessing the barriers to greener fiscal measures and ecological tax reform in the transport sector. In *Sustainable systems and energy management at the regional level: Comparative approaches*, ed. M. Tortora, 19–37. Information Science Reference: Hershey PA.

DieselNet. 2017. Emission standards. Heavy-duty diesel truck and bus engines. http://www.dieselnet.com/standards/eu/hd.php, accessed 10/09/17.

Douet, M., and J.F. Cappuccilli. 2011. A review of short Sea Shipping policy in the European Union. *Journal of Transport Geography* 19 (4): 968–976.

Eliasson, J. 2013. Project appraisal in Sweden. In *International comparisons of transport appraisal practice: Overview report*, ed. P. Mackie, and T. Worsley. Leeds: Institute for Transport Studies, University of Leeds.

European Commission. 2004. Motorways of the Sea, Implementation through Article 12a TEN-T. Consultation, Document dated 30 July, Brussels: Commission of the European Communities.

European Commission. 2011. White paper: Roadmap to a single European transport area—towards a competitive and resource efficient transport system. COM(2011) 144. Brussels: Commission of the European Communities.

Feo, M., R. Espino, and L. Garcia. 2011. A stated preference analysis of Spanish freight forwarders modal choice on the south-west Europe Motorway of the Sea. *Transport Policy* 18 (1): 60–67.

Hjelle, H. 2014. Atmospheric emissions of short sea shipping compared to road transport through the peaks and troughs of short-term market cycles. *Transport Reviews* 34 (3): 379–395.

IMO. 2014. *Third IMO GHG Study 2014*. London: International Maritime Oraganisation.

Janic, M. 2007. Modelling the full costs of an intermodal and road freight transport network. *Transportation Research Part D: Transport and Environment* 12 (1): 33–44.

Kystverket. 2017. Kystverkets veileder for tilskudd til overføring av gods fra veg til sjø. http://kystverket.no/link/68d44d9f645f4d4b83c3e9ccc9cfb726.aspx. Accessed 05 Sept 17.

Lee, P.T.W., K.C. Hu, and T. Chen. 2010. External costs of domestic container transportation: Short-sea shipping versus trucking in Taiwan. *Transport Reviews* 30 (3): 315–335.

López-Navarro, M.A. 2013. Unaccompanied transport as a strategy for international road hauliers in Ro-Ro short sea shipping. *Maritime Economics & Logistics* 15 (3): 374–394.

Lun, Y.V., K.H. Lai, and T.E. Cheng. 2013. An evaluation of green shipping networks to minimize external cost in the Pearl River Delta region. *Technological Forecasting and Social Change* 80 (2): 320–328.

Macharis, C., E. Van Hoeck, E. Pekin, and T. Van Lier. 2010. A decision analysis framework for intermodal transport: Comparing fuel price increases and the internalisation of external costs. *Transportation Research Part A: Policy and Practice* 44 (7): 550–561.

Mellin, A., Wikberg, Å., Karlsson, R., and Vierth, I. 2013. Internalization of external effects in European freight corridors. CTS Working Paper 2013:2, Stockholm: Center for Transport Sttudies.

Morales-Fusco, P., M. Grau, and S. Sauri. 2017. Effects of RoPax shipping line strategies on freight price and transporter's choice, Policy Implications for promoting MoS. *Transport Policy*. https://doi.org/10.1016/j.tranpol.2017.03.021.

Mostert, M., A. Caris, and S. Limbourg. 2017. Road and intermodal transport performance: the impact of operational costs and air pollution external costs. *Research in Transportation Business and Management.* 23: 75–85.

Ng, A.K.Y. 2009. Competitiveness of short sea shipping and the role of port: the case of North Europe. *Maritime Policy & Management* 36 (4): 337–352.

NTM. 2016. NTM Calc 4.0. https://www.transportmeasures.org/ntmcalc/v4/basic/index.html#/. Accessed 10 Apr 2017.

Paixão Casaca, A.C., and P.B. Marlow. 2007. The impact of the trans-european transport networks on the development of short sea shipping. *Maritime Economics & Logistics* 9 (4): 302–323.

Resa-mellan.se. 2017. Truck distance and fuel calculator. http://www.resa-mellan.se/. Accessed 4 Sept 2017.

Ricardo. 2014. Update of the handbook on external costs of transport (Final Report), London: Ricardo-AEA.

Sea-distances.org. 2017. Sea distance calculator. https://sea-distances.org/. Accessed 04 Sept 2017.

Sjöfartsverket. 2017. *Fairway Dues.* http://www.sjofartsverket.se/en/About-us/Finances/Fairway-Dues/. Accessed 04 Sept 2017.

SåCalc. 2015. Verktyg från Sveriges Åkeriföretag. Årlig körsträcka för lastbil. http://www.akeri.se/transportindex/sacalc-basic. Accessed 04 Sept 2017.

Styhre, L. 2009. Strategies for capacity utilisation in short sea shipping. *Maritime Economics & Logistics* 11 (4): 418–437.

Styhre, L., V. Roso, R. Bergqvist, J. Woxenius, and K. Lumsden. 2014. *Development of the short sea shuttle concept*. Gothenburg: IVL Swedish Environmental Research Institute Ltd.

Suárez-Alemán, A. 2016. Short sea shipping in today's Europe: A critical review of maritime transport policy. *Maritime Economics & Logistics* 18 (3): 331–351.

Tichavska, M., and B. Tovar. 2017. External costs from vessel emissions at port: A review of the methodological and empirical state of the art. *Transport Reviews* 37 (3): 383–402.

Trafikanalys. 2015. *Transportsektorns samhällsekonomiska kostnader 2015: Rapport 2015*. Stcokholm: Trafikanalys.

Trafikanalys. 2017. Eco-bonus för sjöfart: slutredovisning, Rapport 2017:11, Stcokholm: Trafikanalys. http://www.trafa.se/globalassets/rapporter/2017/rapport-2017_11-ecobonus-for-sjofart—slutredovisning.pdf. Accessed 14 Sept 2017.

Trafikverket. 2015. Samhällsekonomiska principer och kalkylvärden för transportsektorn: ASEK 5.2. Version 2015-04-01. Borlänge: Trafikverket.

Tzannatos, E., S. Papadimitriou, and A. Katsouli. 2014. The cost of modal shift: a short sea shipping service compared to its road alternative in Greece: European. *Transport* 56 (2): 1–20.

U.K. Department for Transport. 2015. Guide to the Waterborne Freight Grant scheme. https://www.gov.uk/government/publications/waterborne-freight-grantscheme-guide-2015-to-2020. Accessed 09 Apr 2017.

Unifeeder. 2015. Vessels and vessel tracking. http://www.unifeeder.com. Accessed 17 Apr 2017.

Vanherle, K., and Delhaye, E. 2010. Road versus short sea shipping: comparing emissions and external costs. Proceedings of the International Association of Maritime Economists, Lisbon, Portugal, 7–9.

Vierth, I. Mellin, A., and Karlsson, R. 2013. Externa kostnader och avgifter för fem svenska, gränsöverskridande godstransporter. Notat 10-2013Stockholm: VTI.

Vierth, I., and Sowa, V. 2015. Externa kostnader i transportscenarier med utökad användning av sjöfart. Report 848. Stockholm: VTI.