Project No. 2014-122: Mitigating and reversing the side-effects of environmental legislation on Ro-Ro shipping in Northern Europe

Deliverable on Task 3.2:

Report on the outcome of Task 3.2
Measures from policy makers

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1 Executive Summary

This report summarizes the main research findings of Task 3.2 (entitled "Measures from policy makers") of the RoRoSECA project. Task 3.2 falls under the umbrella of Work Package (WP) 3 (entitled "Measures to mitigate or reverse modal shifts"). Task 3.2 is focusing on the policy makers' available options, and is using tools and models developed in Year 1 of the RoRoSECA project in order to quantify the implications of the examined measures. It is complementary to Task 3.1 ("Measures from the Ro-Ro operator") whose report has been delivered in month 19.

The following policies were examined in the context of Task 3.2:

- Full or partial internalization of external costs, all modes
- Easing of port dues/fairway dues/ ice dues for relevant shipping
- European-wide ECO bonus system based on the Italian system (no longer in operation) where freight haulers could get a refund for shipping cost. The level of such refund would depend on the specific route taken
- Public funding or subsidies from which shipping companies could get grants for environmental investments such as LNG conversions, scrubbers, and/or others.

To examine these policies, the following modules were developed:

- An interface with the modal split module developed in Task 2.2
- The KPI module that estimates key performance indicators for the Ro-Ro operator
- The BAF surcharge calculator
- The fuel consumption modules that estimate costs and emissions under the new measures
- The economy module for the policy measure that estimates the total cost
- The external cost calculator

The constructed modelling framework was tested for the aforementioned policy measures, that either increase the cost of competing land-based options, or reduce elements of the generalized cost of transport for the maritime options. The performed runs allow additionally the examination of the actual monetary cost that the low-sulphur requirement has on the shippers through the additional BAF surcharges due to the fuel price differentials. The examined policies that would provide a monetary incentive to the shipper that uses a maritime mode would require a significant capital investment from the policy maker, but would be successful in reversing the negative effects of the low-sulphur fuel requirements within SECAs. Other options could be a provision of certain subsidies to the affected (within SECAs) operators, either through a repayment of part of the port fees, or a partial payment towards retrofit costs. It has to be noted that the estimated policy costs for each of the available options, are calculated for each of the DFDS routes, and there would be a variability for the respective costs for policies targeting other ship operators. While some of these costs may seem low, ranging between a few million € annually, it has to be taken into account that there are numerous more Ro-Ro services that are affected in a similar manner. Therefore, the results of this work can be more useful if an actual available budget is known to the user of the developed methods. For example, the first implementation of the ECO-bonus system in Italy had an available budget of 230 million € for a two year period. The annual costs of the examined policies for only the seven DFDS routes range from 24, up to 103 million € (for a high fuel price scenario where the goal is increasing the modal share of maritime options). An important question for each of the examined measures is which body can (or should) provide the required funds for such policies. The necessary funds can of course be reduced, if ship operator’s measures are also deployed in cases of high fuel prices, as with the available options examined in Task 3.1. A combined effort by all of the affected stakeholders can ensure that the short sea shipping sector operating in SECAs will endure should fuel prices return to their previous high levels.

2 Introduction: scope of the document and objectives of WP3

This report summarizes the main research findings of Task 3.2 (entitled "Measures from policy makers") of the RoRoSECA project. Task 3.2 falls under the umbrella of Work Package (WP) 3 (entitled "Measures to mitigate or reverse modal shifts"). The primary objective of this WP is to propose and examine potential measures from the operator and regulatory bodies, in order to protect the Ro-Ro sector from the negative effects of the sulphur regulation. Task 3.2 is focusing on the policy makers' available options, and is using tools and models developed in Year 1 of the RoRoSECA project in order to quantify the implications of the examined measures. It is complementary to Task 3.1 ("Measures from the Ro-Ro operator") whose report has been delivered in month 19.

The first results of the RoRoSECA project showed that Ro-Ro operators have had very positive economic performances throughout 2015 and 2016, in contrast with what was expected prior to the 0.1% sulphur limit. This improvement was mainly attributed to the unexpectedly low fuel prices in the same period, that led to competitive freight rates offered to shippers, and as a result, higher transported volumes. However, findings suggested that if fuel prices return to higher levels, modal backshifts are to be expected with significant financial blows to certain services. From an environmental perspective, the comparison of the examined network in 2014 and 2015 showed a small increase in absolute CO_2 emissions (due to more trips being generated and potentially small increases in sailing speeds). In terms of carbon efficiency (per transported unit-nautical mile), a slight improvement was observed, mainly due to the higher load factors of the vessels (improved capacity utilization). The improvement in sulphur emissions was very significant as these emissions are proportional to the sulphur content of the fuel used, whereas for ships equipped with scrubbers the reduction can exceed 97%.

This document presents the final results of the RoRoSECA project, and the application of the methodologies developed in the context of WP3, on policy measures to revert and mitigate the negative effects of the lower limit. As with Task 3.1, the methodological framework is developed in a way to facilitate the estimation of economic effects for all involved stakeholders, and the system's environmental balance.

The following modules were developed in the context of Task 3.2:

- An interface with the modal split module developed in Task 2.2
- The KPI module that estimates key performance indicators for the Ro-Ro operator
- The BAF surcharge calculator
- The fuel consumption modules that estimate costs and emissions under the new measures
- The economy module for the policy measure that estimates the total cost
- The external cost calculator

The models developed in Year 1 allowed the estimation of the effects of the higher operating costs due to the new low sulphur limits. The effects modelled include the environmental balance of the system ex-post and ex-ante of the limit introduction. A new interface was constructed that enables the association of the effects of policies on the new balance between shippers opting for a maritime mode versus the available alternatives. These effects can be very significant if policies to internalize external costs are introduced, as such measures would have a direct effect on the total transport cost that the shippers would face.

The effects of the policy measures on the Ro-Ro operator's economy are examined through the changes in certain KPIs. These KPIs are based on the new revenue and operating costs balance, and signal a route facing closure in cases of high fuel prices. For the various policy interventions, one critical aspect is whether these can absorb the added cost of the low sulphur regulation on shippers. This added cost is in monetary terms the effect of the bunker adjustment factor (BAF) surcharge that the company is setting. Based on historical data of the DFDS BAF policy, as well as the current rules of the company (each operator has to set a unique BAF), a module has been constructed to predict the BAF as a function of fuel prices.

The fuel consumption modules developed in the context of Task 3.1 allow the estimation of the fuel consumption of the route in case of changes in the operating profile of the service (e.g. sailing speed changes, new sailing frequency, different vessel deployment), and subsequently the emissions generation per trip, per vessel, or per transported unit. In Task 3.2, the policy measures are not expected to affect directly the fuel consumption for a route, however the emissions per lane meter will be different as a consequence of changes in the modal choice of the shippers.

Arguably, the most important requirement for Task 3.2 is the economy module for the policy measure that estimates the cost of the measure for all stakeholders (regulator, shipper, ship operator). This cost can be compared with the benefits through the emissions reduction achieved as a result of the new sulphur limits. Finally, an important component of Task 3.2 is the development of a module that estimates the external costs for the movement of one unit of cargo from each of the available transportation modes. The values used in the calculator of this work are based on existing tools following a critical review of the available methodologies. These are discussed in Section 5 of this report.

The next sections of this report present analytically the examined measures, and how are these adapted for the various fuel price scenarios and routes examined. The wide range of the case studies examined are revealing the challenges in promoting policy measures that can revert modal backshifts in cases of high fuel prices, that are not desirable from the perspective of the European Union.

3 Summary of Task 3.1 findings

Task 3.1 examined measures that Ro-Ro operators could deploy in response to the new lower sulphur limits since January 2015. The selected measures for further analysis were the following:

- Change in sailing speed
- New sailing frequency
- Vessel swapping between compatible services
- Investments in abatement technologies versus the use of low-sulphur fuel
- Changes in pricing policy

These measures were adjusted for each of the examined services in terms of feasibility. For instance, a speed reduction beyond a certain threshold could be impossible, as there would be not enough time at the ports of call for the loading and unloading operations. Similarly, there were constraints on which vessels could be deployed at each service based on vessel type, policy requirements (subsidised scrubber-fit vessels are bound to specific route), and capacity considerations. The routes examined in Task 3.1 per the outcome of Task 2.1 are shown in Table 1.

Table 1: The examined services in Task 3.1

NORTH SEA	
Gothenburg – Ghent	Ro-Ro
Esbjerg – Immingham	Ro-Ro
Rotterdam – Felixstowe	Ro-Ro
Copenhagen – Oslo	Cruise
BALTIC SEA	
Klaipeda – Kiel	Ro-Pax
Klaipeda – Karlshamn	Ro-Pax
CROSS CHANNEL	
Dover – Calais	Ro-Pax

To assess the implications of the Ro-Ro measures on the profitability of each service, a fuel consumption module was developed taking as input actual fuel data provided by DFDS at the operating patterns used in the schedules of the company. In addition, data from the sea-trials of these vessels (at various sailing speeds) were used to model the impacts of changes in sailing speed in actual sailing conditions. It was therefore possible to estimate the fuel consumption at different combinations of sailing frequencies, speeds, vessels deployed, considering also the use of MGO or a scrubber retrofit. At the same time, certain of the examined measures would have an impact on the shippers in terms of increased (or in some rare cases of low fuel prices – reduced) sailing durations, waiting times (as a result of less frequent services), and capacity offered. To address this impact on the shipper, a computational module was created that was linking the effects of the new total travel time and cost on shippers' choice. This module was an enhancement on the modelling framework designed for WP2 and the modal split model in particular. Thus, the estimation of the new transport demand that the operator would have to satisfy was possible.

In WP3, the calibration results from WP2 were used to predict modal shifts as a result of the examined measures, and simulation was performed for three main fuel price scenarios. However, the models are developed in such a way that any potential fuel price combination (HFO vs MGO) can be readily examined. The calibration for each of the examined routes was based on data collection and simulation in the context of WP2 that concerned the year 2014 (the last year before the new sulphur limit was introduced). For each calibration, estimation of scale parameters was the main output that can be used to predict changes in market shares of each of the examined available options to the shipper. The modal split model is following a hierarchical (nested) structure that can collapse into a binary logit model in cases where only two options are available.

The models developed for Task 3.1 can be help ship operators to assess the economic and environmental impacts of any changes in their services, as well as to conduct feasibility studies for various fuel price scenarios. The route profitability module is using as input the estimated market shares of the ship operator based on work from Task 2.2. For Ro-Pax services, the passenger fares are considered to be unaffected by small changes in travel time (modal split models for passengers are beyond the scope of this project, and necessary data are not available for such a tool), and this revenue is treated as a function of the total number of trips. With regard to the on-board spending behaviour of passengers, this is considered as a function of sailing time (e.g. passengers are spending a little bit more if there is a small increase in the sailing time). The specifications of the examined measures were tailored according to the characteristics of each service and based on discussions that took place during project Advisory Committee (AC) meetings. The main findings of Task 3.1 can be summarized to the following key takeaways:

- The significant fuel savings through slow steaming (both during cruise, and at port; low speed - less hours at port) can help in times of high fuel prices with relatively small market share loss.
- The effect of time in the generalized cost of transport is far less important than the actual freight rate that the shipper is paying. Therefore, speed can play a very important role in case of very high fuel prices.
- The flexibility on changes in sailing duration is limited by the required loading/unloading times that pose operational constraints.
- It was observed that for very low fuel price scenarios it may be better to increase sailing speed, something that was observed in 2016 in one of the examined routes (Klaipeda – Kiel which is the examined service that competes more with landbased options)
- Changes in sailing frequency can be effective in improving the cargo loading utilization of the vessels, and would have a smaller effect on modal choice. In times of high fuel prices this could be a viable alternative to speed reductions particularly in services that have medium (e.g. 6-7 weekly services) or high frequencies (e.g. in routes such as Dover – Calais).

- A reduced sailing frequency could lead to undesirably high utilization rates (averages of 95% were observed in the analysis) that could compromise the reliability of the service (e.g. some cargoes would not be picked up).
- An increased sailing frequency (for low fuel price scenarios) could lead to lower utilization rates and thus higher emissions per transported unit than a small speed increase. Therefore, changes in sailing frequency require more cautious planning from the ship operators.
- Vessel swapping can also be effective in harmonizing the load factors at each route in case of a predicted change in transport demand. There are some constraints on which vessel is able of sailing which service, but for certain cases the differences in nominal cargo capacity for the different ships can prove useful in improving the load factors.
- Investing in scrubber systems is critically dependent on fuel prices and the relative differential between MGO and HFO. It was shown that following the unexpectedly low fuel prices, the payback period of such investments was significantly delayed in comparison to what was anticipated in 2013 and early 2014. However, the provision of subsidies for such investments can help with their economic feasibility.
- The role of scrubber systems is expected to change following the global sulphur cap coming in 2020, as more mature technologies are expected to be available at that time. This may have a more limited effect on Ro-Ro shipping that is already sailing within SECAs, but it is expected to change their payback period due to different fuel price differentials.
- The use of Liquefied Natural Gas (LNG) as fuel is more risky as an abatement investment in comparison to scrubber systems for Ro-Ro shipping. The main arguments are revolving around the uncertainty of LNG prices, the higher investment costs for LNG retrofits, and the lack of infrastructure at this stage (LNG bunkering ports).
- Technologies such as cold ironing are less relevant within SECAs as the ship operator must comply with low-sulphur requirements at all activity phases and not only at berth. In addition, due to the current low fuel prices the price differential between MGO and the electricity cost from the grid is smaller, constituting the payback period of cold ironing longer.

This section summarized the main findings of the implications of measures from the Ro-Ro operator. It also provided a condensed review of the main modules developed in WP2 and their extensions for Task 3.1. The next section will consider the main implications of the low-sulphur limits on the key stakeholders, and elaborate on how policies to reduce SO_x can have indirect negative effects.

4 Impacts of environmental policy on short sea shipping

The transportation sector is a significant contributor to the world CO2 emissions, with estimates placing this contribution between 15 and 24%, and in 2020 at 22% (IEA, 2012). The maritime sector alone was responsible for 2.7% in 2007 (IMO, 2009) and 2.2% in 2012 (IMO, 2014). This drop was largely attributed to the slow steaming as a consequence of the high fuel prices at the time. A similar picture is evident in Europe, with greenhouse gas emissions at 21.9% for the transportation sector, and an estimation of 4% for the maritime sector (European commission, 2013). The maritime sector is therefore more carbon efficient, and this may support the strategy of the European Union to promote maritime transportation.

However, ships are also emitting significant amounts of harmful pollutants, including SO_x, NO_x, and $PM_{2.5}$ emissions. From the perspective of local pollutants, the maritime sector is less efficient in comparison to other transportation modes. Environmental policies were therefore put in place, in order to address such impacts. For the sulphur and nitrogen emissions, the revised MARPOL Annex VI introduced limits on the emissions allowed by the sector, setting stricter limits in special emission control areas. Before the introduction of SECAs in the North and Baltic Sea, the EU had regulated the sulphur content of liquid fuels for all transport modes, ultimately setting a stricter limit of 0.1% sulphur content in fuels used during berth. The main rational behind the designation of SECAs was to limit the generation of SO_x emissions in these seas.

4.1 Implications of regulation on Ro-Ro operators

In the first year of the project, data collected from DFDS showed that the economic performance of the examined routes had improved. The main reason was attributed to the unexpectedly low fuel prices in 2015, to the point that the ultra-low sulphur fuel was cheaper than regular bunker oil in the previous year. A similar picture was reported on most Ro-Ro operators from press releases (more info on the report on Task 2.2).

However, the direct implication for the ship operators was a requirement for investments in abatement options (e.g. scrubber systems), or an additional operating cost through the use of low sulphur fuel. For the former, the average fuel price differential between HFO and MGO was $215 in 2015, or in other words 81% more expensive (in 2014 with higher overall fuel prices the respective numbers were $338 and 70.7%). For the latter, a typical scrubber installation for DFDS vessels would require a capital investment of three to four million € (https://shipandbunker.com/). For some of these investments a subsidy of 20% was provided from the EU. At the same time, while a scrubber allows the use of HFO, it also increases fuel consumption by 1.5 to 3% to cover its energy demands. It is evident that the environmental regulation can lead to significant expenditures to secure compliance. However, considering the very low fuel prices in 2015, this cost is not accurately depicted in the company's profitability. The relative fuel costs as a percentage of the operating costs were provided by the company for six of the seven routes, and are shown in Table 2.

Table 2: Fuel cost as share of operating costs (excluding hotel and stevedoring) and fuel prices 2014 vs 2015 (confidential data shown as 'xx')

Fuel cost as percentage of operating cost			**Fuel Price MGO**		**Fuel Price HFO**	
Route	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
Gothenburg – Ghent	xx%	xx%	816	478	533	269
Copenhagen – Oslo	xx%	xx%				
Esbjerg – Immingham	xx%	xx%				
Rotterdam - Felixstowe	xx%	xx%				
Klaipeda – Kiel	xx%	xx%				
Dover – Calais	xx%	xx%				

It can be seen that in 2015 the MGO was 10% cheaper than HFO was in 2014 which is also reflected in the significant drop of the share of fuel costs in the total operating costs. This is particularly evident in the Gothenburg – Ghent route, where all vessels were using scrubber systems and thus the fuel costs were reduced almost proportionally to the HFO fuel price drop. It could be argued, that a similar reduction in fuel costs could be anticipated in short sea shipping services outside SECAs. Naturally, the drop in fuel costs on other routes is smaller as certain vessels (non-retrofitted) would have to change fuel from HFO to MGO in 2015 during their sailing activities. Between the two years, the schedules of each service were relatively unchanged (in terms of frequency and sailing speeds). However, in certain routes in 2016 speed increases were introduced (e.g. Klaipeda – Kiel) taking advantage of the continuous low fuel prices and an increased demand for transportation.

The regulation also has an effect on the revenue of the company per transported unit, as it affects the freight rate through the BAF policy of the company. The lower fuel prices in 2015 led to small reductions in the freight rate of some routes, or very small increases taking into account the inflation, with a notable exception being the Dover – Calais route, which had an increase. In terms of total revenue (including passenger tickets and passenger spending on-board the Ro-Pax vessels), there were increases in most routes, due to the increased transport demand (more trips, more full vessels). The comparison of the two years is shown in Table 3.

Table 3: Comparison of 2014 and 2015 in the examined routes. Source: own analysis based on data provided by DFDS

Route	Year	Trips Total	Transported Cargo Volume change (%)	Cargo Rate change (%)	Revenue Change (%)	Annual Fuel Cost Change (%)
Gothenburg Ghent*	2014 2015	553 569	6.06	-5.62	0.09	-52.89
Esbjerg Immingham	2014 2015	512 580	19.46	-0.5	18.85	-15.29
Rotterdam Felixstowe	2014 2015	1514 1637	15.13	0.5	15.71	-24.34
Copenhagen Oslo	2014 2015	687 702	-5.82	1.58	4.28	-9.36
Klaipeda Kiel*	2014 2015	611 615	-4.64	-7.71	-8.89	-30.05
Klaipeda Karlshamn	2014 2015	717 710	3.64	-2.32	3.73	-22.99
Dover Calais	2014 2015	6210 4994	-17.66	9.36	-18.04	-50.35

Table 3 shows that either both the revenue increased and the fuel costs decreased, or that the revenue decreased at a lesser rate than the fuel cost savings (e.g. in Dover Calais, Klaipeda Kiel). The only route where all vessels were running on MGO in 2015 was Dover – Calais, and the lower fuel costs are a consequence of the reduced number of trips in 2015, and the very low fuel prices. The reduction is lesser in other routes due to some of the vessels switching to MGO which while still cheaper than HFO in 2014, it is more expensive than HFO (2015 prices). Overall, the profitability of routes has improved as the fuel costs have reduced at higher rates than revenue from freight transported (which has also increased for most routes). The profitability of the Ro-Pax services is also depending on passenger traffic, and while passenger traffic is not modelled in this work, the data from the Ro-Ro operator showed smaller fluctuations in passenger traffic. Modelling passenger demand before and after the new sulphur limit is a more difficult task, as stated preference methodologies should be used which is beyond the scope of this work.

The main conclusion on the impacts of the low sulphur regulation on the Ro-Ro operators was that because of the unexpectedly low fuel prices the operators were not harmed by it. Granted, the extent to which operators benefited by the low fuel prices was limited by the requirement to invest in scrubbers or use MGO. However, in case the fuel prices revert to previous levels, as shown in the deliverable report on Task 2.2, the Ro-Ro operators' profitability of these services will be severely affected by both a loss of market share, and a significant increase in fuel costs. Task 3.1 analyzed potential options that the operators can utilize in such an event.

4.2 Effects of regulation on emissions

The objective of the introduction of SECAs was to significantly reduce SO_x emissions in the nearby areas. From a research perspective, it is important to quantify how important was that decrease given some of the negative effects of the regulation on the short sea shipping sector. To this end, based on the actual fuel consumption for the vessels deployed in the examined routes, it is possible to estimate the generated emissions. The data were broken down by engine type (main engines, auxiliary units, boilers) and fuel type (HFO and MGO). The emissions inventory for each route is provided in Figure 1 in absolute terms.

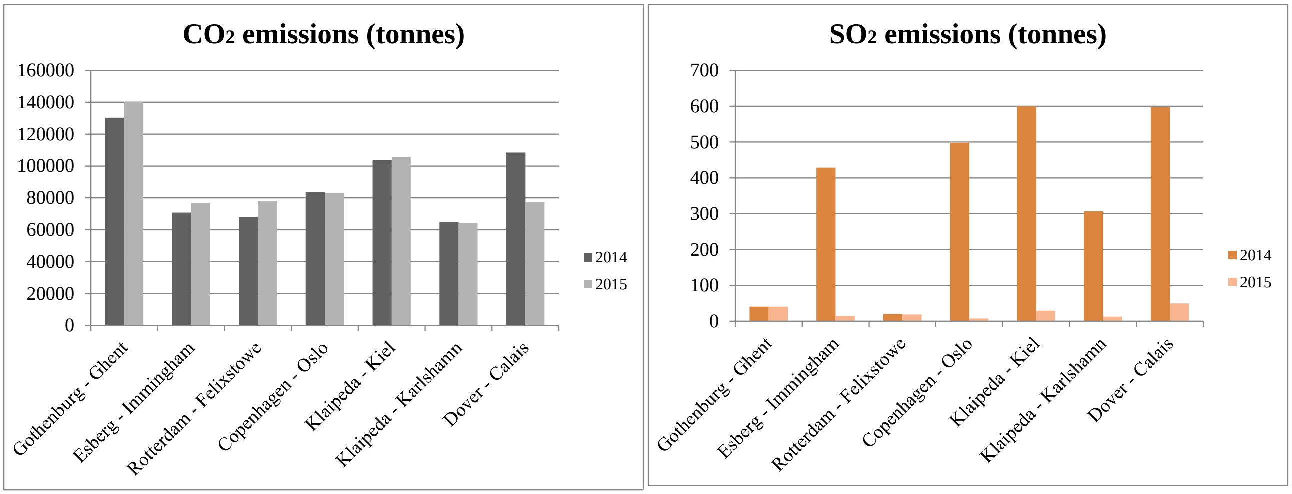


Figure 1: CO_2 and SO_2 emissions (tonnes) in the examined routes. Source: own calculation based on data provided by DFDS

The results show that the CO_2 emissions have not changed dramatically in comparison with 2014. For most routes there is a slight increase, which can be attributed to a similar increase of trips, a potential increase of sailing speed due to the low fuel prices, the use of MGO which has a higher CO_2 emission factor, and the use of scrubbers that are also increasing the fuel demand. A notable decrease can be observed for the Dover-Calais route which is attributed to the significant reduction of sailings due to external events. In terms of SO_2 emissions it can be seen that for most routes there has been a detrimental reduction due to the lowered sulphur limit. The only route that does not show a reduction is the Gothenburg Ghent, where all vessels were equipped with scrubbers since the end of 2013, and the assumption is that the vessels were using the systems from the time of installation.

However, it is also important to contrast the emissions intensity of transporting a unit of cargo (a lane meter of cargo in this case- lm) for one nautical mile (NM), as these routes are not comparable otherwise. Typically, emissions intensity is measured in terms of transported ton-km to facilitate comparisons with different transport modes. As Ro-Ro shipping companies are charging based on the lane meters that shipments take onboard their vessels, they do not keep track of the weight of each shipment. The MEPC is using an assumption of a 2 ton per lm in a Ro-Ro vessel (Hjelle and Fridell, 2012) that leads to a CO_2 emissions intensity of 49.5g/tonne-km which translates into 45.8

g/lm-NM -lm. These numbers are dependent on the load factor of both the vessel, as well as the cargo transported and the load factor of unaccompanied trailers. Figure 2 presents the actual emissions per NM-lm based on the fuel consumption of the vessels in each service, and the number of lane meter-NM transported.

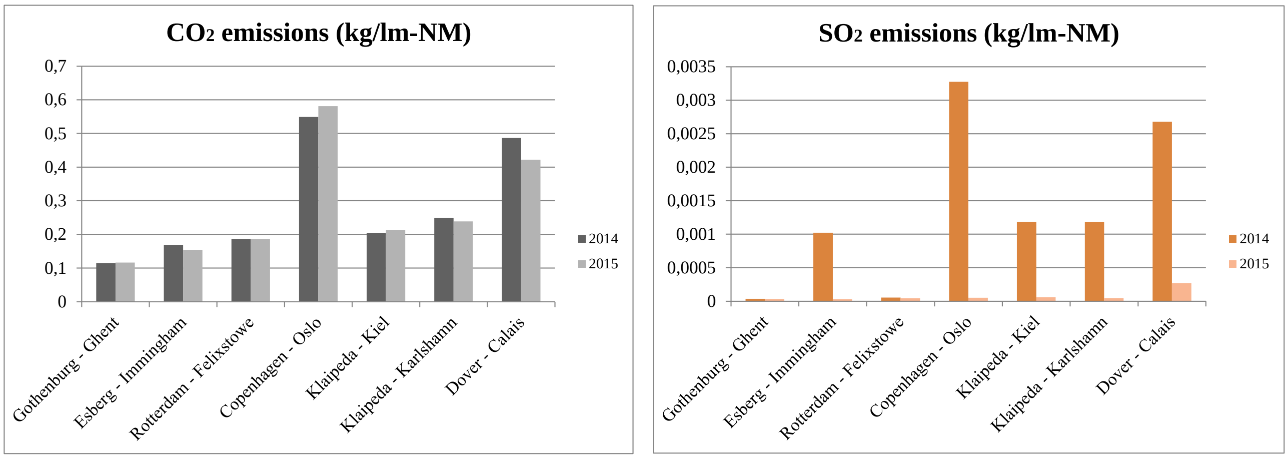


Figure 2: Emissions intensity (kg/lm-NM) for CO_2 and SO_2 in the examined routes. Source: own calculation based on data provided by DFDS

It has to be noted that for four of the routes, the vessels are also carrying passengers and therefore the emissions allocation should be different. Particularly for Ro-Pax ferries, it is very difficult to allocate emissions among cargo and passengers. Figure 2 shows that the carbon emissions intensity has decreased for most routes; except for Klaipeda – Kiel and Copenhagen – Oslo (however this assumes a full allocation of emissions on cargo, on a route that is predominantly passenger-oriented). This result is a consequence of improved utilization of the vessels' capacity. In terms of SO_2 emissions intensity, the picture is very similar to the absolute levels of SO_2 emissions, as the regulation is clearly a success in reducing this type of pollutant. The results in Figure 2 do not allow a direct comparison with other modes as there is no concrete information on the actual average weight carried in one lane meter of cargo for each of these routes. What can be deduced from this analysis is that the regulation has been a considerable success for reducing SO_2 emissions, with a relatively small penalty of increased CO_2 emissions, which is halted by the improved vessel deployment in that year. This penalty could however be higher if the energy (and associated CO_2 emissions) of producing low-sulphur fuel were considered in the calculations. However, both abatement options (MGO or scrubbers) are also successful in reducing PM emissions, and therefore there are more health benefits associated with the regulation. These benefits could be quantified in monetary terms, if converted to the reduction of external costs brought by the new sulphur limit. However, the analysis of WP2 has showed that a fuel price increase can lead to significant losses of market shares, and as a result decreased utilization rates for the vessels, which can be translated in a higher emissions intensity.

4.3 Implications for early adopters

The previous sections presented the first implications of the low-sulphur regulation on ship operators, shippers, and their effects on the environmental balance. The focus has been the lower limit within SECAs since 2015. Similar regulations that are targeting environmental impacts of the sector, can be expected to affect key stakeholders in various ways. Indeed, the introduction of the EEDI, the potential expansion of emission trading schemes (ETS) to cover emissions from the shipping sector, as well as the introduction of the global 0.5% sulphur cap, can all have the potential of being game changers. In the context of the SECA limit and the findings of the RoRoSECA project, one significant observation is that occasionally the early adopter of a new situation, may 'pay' for it. In the deliverable report on Task 3.1, a cost benefit analysis was presented where it was argued that the payback period of scrubber systems was delayed as a consequence of the very low fuel prices in 2015. Considering the relatively young age of DFDS vessels (16.1 years in comparison to an average of 20 years for the global Ro-Ro fleet) and the fact that most vessels are recycled after 25 to 30 years, one could argue that the delay in the payback period for scrubbers was not a major setback to DFDS.

The provision of subsidies under the Motorways of the Sea Programme covered approximately 20% of each installation, awarding about €9 million to DFDS among other short sea shipping operators. Such policies are rewarding early adopters and promote investments in newer emissions abating technologies. The US Coast Guard has committed to assist operators using scrubbers in optimizing the design of the system, transferring knowledge on operating the scrubber, while also working with manufacturers (source: http://www.mpropulsion.com). However, new regulations may constitute the existing scrubber systems as non-compliant, or simply require additional significant capital costs for the abatement of different pollutant species (for example Black Carbon). As a result, the option of not investing in 'one-off' solutions, but instead relying on pricier low-sulphur fuel, may offer higher flexibility on ship operators. Particularly for scrubber systems, the coming of the global sulphur cap in 2020 is expected to raise the demand for such technologies, especially if the low-sulphur fuel availability is not enough to cover the necessary demand. However, a turn of the industry to scrubber technologies may in turn potentially increase the demand for HFO in contrast to what is anticipated, and thus raise its price and reduce the fuel price differential with 0.5% fuel (and thus the benefit of investing in scrubber systems). Therefore, the impacts of environmental policies are much more complicated and difficult to predict, as it has been shown with the lowering of sulphur limits within SECAs. It is therefore vital to propose policies that mitigate the possible negative impacts of such regulations.

5 Internalization of external costs

Transport generates negative externalities that involve a cost to society and the economy. Seen from the welfare economics point of view, internalising these external costs aims at efficiency gains through conveying the right price signal to economic actors. The right prices would encourage the use of safer, more silent and environmentally friendly vehicles and, the planning of trips according to expected traffic conditions.

The internalisation of transport related external costs is a haunted issue in the EU transport policy. Raised in 1995 with the 'Green Book on fair and efficient pricing,' it was brought forward by the 2001 White Paper and was reaffirmed by the 2006 Mid-term review, which proposed an EU methodology for smart infrastructure charging. With the latest release of the White Paper, the European Commission sets year 2020 as the deadline for the full and mandatory internalisation of external costs for all modes with emphasis on road and rail transport (EC, 2011).

In view of this requirement, the present section aims at investigating the potential impact of a full or partial internalisation strategy on mitigating the side effects of the stricter environmental legislation on the Ro-Ro shipping in Northern Europe. It supports earlier results on Task 2.3 (Kristensen, 2016) by quantifying the external costs of all transport modes and introducing them in the general cost structure of the model presented in Section 7, to estimate their impact on the shares and profitability of Ro-Ro services on all seven routes examined by the project. This will also enable the examination of price sensitivity as a determinant of the effectiveness of internalisation. Sometimes, this is hindered for reasons like the lack of credible alternatives, insufficient competition with regard to a particular mode of transport, insufficient incentive to switch to clean vehicles, etc.

5.1 Quantification of external costs

As part of its 'Greening Transport' package, the European Commission proposed in 2008 a revision of Directive 1999/62/EC enabling Member States to integrate the traffic-related cost of air and noise pollution into tolls levied on heavy goods vehicles (HGVs). During peak periods, it also allows tolls to be calculated on the basis of the cost of congestion imposed upon other vehicles. In the rail sector, the Commission suggested the introduction of differentiated track access charges, based on noise emissions (EC, 2008).

To support its internalisation strategy and upon insistence by the European Parliament, the Commission ordered a generally applicable, transparent and comprehensible model for the assessment of all transport-related external costs by all modes (Maibach et al., 2008). Later on, this 2008 Handbook was updated to take into consideration the new developments in research and policy (Ricardo-AEA, 2014). Reflecting the state of the art and best practice on external cost estimation in the EU, this updated Handbook will be the primary source of information for this chapter.

This information will be supplemented by the results of the latest update of the COWI/DTU study on transport unit prices that is undertaken on behalf of the Danish Ministry of Transport, Building and Housing to provide estimates of the input values required for relevant socio-economic analyses (COWI/DTU, 2016).

All types of external costs that are both relevant to the present project and sufficiently quantified by these two studies are included in our analysis. Six types of external costs meet these criteria; those related to climate change, air pollution, noise, accidents, congestion and infrastructure. They are presented separately in the following headings, which provide information at three levels: (a) methodology (methods used to produce external cost figures), (b) input values (values needed for the estimation), and (c) output values (external cost estimates).

5.2 Climate change

Climate change or global warming impacts of surface transport are mainly caused by emissions of the greenhouse gases (GHG) CO_2, N_2O and CH_4. To a smaller extent emission of refrigerants (hydrofluorocarbons) from mobile air-conditioners also contribute to global warming. The related social costs should reflect impacts on energy use, agriculture, water supply, health, ecosystems and biodiversity, as well as impacts due to extreme weather events, sea level rise and major - potentially catastrophic - events.

The general approach for quantifying total external climate change costs for the transport sector involves the following steps:

1. assess total vehicle kilometres by type of vehicles of different categories for the area of interest,
2. multiply vehicle kilometres by emission factors (in g/km) for the various GHGs,
3. add various GHG emissions to a total CO_2 equivalent GHG emission using Global Warming Potentials, and
4. multiply total tonnes of CO_2 equivalent emissions by an external cost factor expressed in €/tonne.

The formula expressing this approach is:

*External climate change costs = Specific GHG emissions * External cost factor of CO_2 equivalent*

The most critical parameter in quantifying external climate change costs is the external cost factor of CO_2 equivalent. The **avoidance cost approach** is generally accepted as the best practice for estimating the external cost factor. It results from a cost-effectiveness analysis that determines the least-cost option to achieve a pre-set target of GHG emission reduction. Based on a meta-study that looked into a wide range (26 models) of available estimates of abatement costs, the 2014 Handbook arrives at a bandwidth of €48 - €168, with a central value €90 per tonne of CO_2

equivalent (in 2010 prices).[2] Apparently reflecting a shorter-term view, the COWI/DTU study suggests the value of 82.1 DKK/tonne, while a DKK 54.2 value is proposed as a low estimate (in 2016 prices). Table 4 transforms these values into 2015 prices. According to the 2014 Handbook, a 3% discount rate has been used for the intertemporal movements, while the GDP deflator for the Eurozone has been used to correct for inflation. For comparison purposes, it is mentioned that on 6 June 2017 the future (Dec. 2017) contract for one tonne of carbon emissions was traded at €4.97 at the EU Emissions Trading System (ETS). The end 2015 price was €8.29/tonne.

Table 4. Unit values of CO_2 equivalent by different sources

Source	Suggested value	Range	Suggested value	Range
2014 Handbook	90	48 - 168	110.43	58.90 – 206.14
	(€/tonne, 2010)		(€/tonne, 2015)	
COWI/DTU	82.1	54.2 - 82.1	10.59	6.99 – 10.59
	(DKK/tonne, 2016)		(€/tonne, 2015)	

Source: Own compilation

By multiplying the tank-to-wheel CO_2 emissions per unit of fuel with the suggested value of €90 per tonne, the 2014 Handbook derives climate change costs per unit of fuel consumed (Table 5).

Table 5. Climate change costs per unit of fuel consumed (2010 prices)

Fuel	kg CO_2 per litre of fuel	g CH_4 per litre of fuel	g N_2O per litre of fuel	Climate change cost, €ct per litre of fuel
Gasoline	2.25	0.81	0.26	21.1
Diesel (road and rail)	2.66	0.14	0.14	24.3
Marine diesel oil	2.99	0.27	0.08	27.2
Jet kerosene	2.86	0.02	0.08	26.0
LPG (50% propane + 50% butane)	1.77	1.74	0.01	16.3
CNG (methane)	1.57	2.58	0.08	14.9

Source: Ricardo-AEA (2014)

The 2014 Handbook further transforms these figures into unit costs per vehicle-kilometre (vkm) based on examples for different types and sizes of vehicles. Table 6 summarizes the factors that determine unit external costs per mode and provides the minimum and maximum values that define the range of variation. It is worth noting that no Ro-Ro ship appears in the analysis. Furthermore, the definition of urban areas is country-specific but in most cases they refer to conurbations of more than 50,000 inhabitants.

[2] This is a substantial change in comparison to the 2008 Handbook, where the central value steadily increases from 25 €/tonne in 2010 to 85 €/tonne in 2050.

Table 6. Marginal external climate change costs per unit of transport work produced (2010 prices)

Mode	Determinants	Min value	Max value
Road (€ct/vkm)	• Vehicle type (LDV petrol, LDV diesel, HGVs) • Size (<=7.5t, 7.5-16t, 16-32t, >32t) • EURO-class (0 to V) • Road type (urban, rural, motorway)	2.3 [HGV, <=7.5t, EURO V, rural]	13.2 [HGV, >32t, EURO 0, urban]
Rail (€ct/locomotive-km)	• Type of train (diesel, electric) • Region (urban, non-urban)	0.0 [electric, urban]	126.31 [diesel, non-urban]
Maritime (€/1000 tkm)	• Type of ship (crude oil tanker, product tanker, general cargo, bulk carrier) • Size of ship (feeder, handysize, handymax)	0.5 [crude oil tanker, 80-120 kt] & [bulk carrier, handymax]	4.1 [product tanker, 0-5 kt]

Source: Own compilation

The same determinants enter the estimations of the COWI/DTU study, which are presented together with all other external costs in Tables 4-6 for the low, medium and high scenarios respectively. It is worth noting that while the 2014 Handbook recommends no external climate change costs for electric trains, the COWI/DTU study provides an estimate which, however, is related to non-propulsion emissions.

Additional external climate change costs are associated with up- and downstream processes due to energy production (pre-combustion) and the production, maintenance and disposal of transport vehicles. However, it is important to consider that these costs occur in other than the transport market and for some of them certain level of internalisation already exists. A good share of these costs, which concern carbon emissions related to pre-combustion processes (well-to-tank), are already accounted for through the participation of the European energy production industry in the ETS scheme. As such, it was decided to exclude them from the present analysis despite the fact that the 2014 Handbook provides relevant estimates.

Table 7. Illustrative marginal external costs in DKK per Km – Low values (2016 prices)

Marginal external costs (2016 prices)								LOW VALUES		
DKK/Km		**Capacity**	**Air pollution**	**Climate change**	**Noise**	**Accidents**	**Congestion**	**Infrastructure**	**Health**	**TOTAL**
Bicycle (only urban)		1 pers	0.0000	0.0000	0.0000	0.4386	0.0000	0.0000	-1.2859	-0.8473
Passenger car	Gasoline	4 pers	0.0010	0.0098	0.0267	0.1764	0.0863	0.0027		0.3028
	Diesel	4 pers	0.0046	0.0082	0.0267	0.1764	0.0863	0.0027		0.3049
	Electrical	4 pers	0.0004	0.0040	0.0100	0.1764	0.0863	0.0027		0.2797
Van	Gasoline	1.5 t	0.0021	0.0177	0.0371	0.1093	0.1192	0.0044		0.2896
	Diesel	1.5 t	0.0102	0.0149	0.0371	0.1093	0.1192	0.0044		0.2949
Truck	Diesel	23.2 t	0.0180	0.0536	0.0543	0.3034	0.1468	0.2824		0.8586
Bus	Diesel	46 pers	0.0905	0.0584	0.1179	0.3966	0.1495	0.1550		0.9678
Passenger train	Electrical	481 pers	0.0337	0.3276	0.1164	1.3829				1.8606
	Diesel	270 pers	0.0945	0.2381	0.1164	1.3829				1.8319
Freight train	Electrical	659 t	0.0650	0.5891	0.6685	0.5927				1.9152
	Diesel	496 t	0.4425	0.6672	0.6685	0.5927				2.3708
Passenger plane	Jet	120 pers	0.0307	1.4032						1.4339
	Turboprop	60 pers	0.0052	0.3066						0.3118
Coastal vessel		2,000 t	7.2789	1.4192						8.6981
Containership		3,500 t	18.7326	3.6525						22.3851

Source: COWI/DTU (2016)

Table 8. Illustrative marginal external costs in DKK per Km – Medium values (2016 prices)

Marginal external costs (2016 prices)								MEDIUM VALUES		
DKK/Km		**Capacity**	**Air pollution**	**Climate change**	**Noise**	**Accidents**	**Congestion**	**Infrastructure**	**Health**	**TOTAL**
Bicycle (only urban)		1 pers	0.0000	0.0000	0.0000	0.8771	0.0000	0.0000	-2.5717	-1.6946
Passenger car	Gasoline	4 pers	0.0124	0.0149	0.0534	0.2320	0.3762	0.0108		0.6998
	Diesel	4 pers	0.0498	0.0124	0.0534	0.2320	0.3762	0.0108		0.7347
	Electrical	4 pers	0.0107	0.0060	0.0200	0.2320	0.3762	0.0108		0.6558
Van	Gasoline	1.5 t	0.0249	0.0268	0.0741	0.1831	0.5223	0.0174		0.8486
	Diesel	1.5 t	0.1183	0.0226	0.0741	0.1831	0.5223	0.0174		0.9378
Truck	Diesel	23.2 t	0.5102	0.0813	0.1087	1.3852	0.6445	1.1296		3.8595
Bus	Diesel	46 pers	0.9537	0.0886	0.2358	0.5154	0.7034	0.6199		3.1167
Passenger train	Electrical	481 pers	0.8272	0.4967	0.3492	2.5603				4.2334
	Diesel	270 pers	3.0057	0.3610	0.3492	2.5603				6.2762
Freight train	Electrical	659 t	1.5972	0.8931	2.0054	2.9633				7.4590
	Diesel	496 t	13.7206	1.0116	2.0054	2.9633				19.7008
Passenger plane	Jet	120 pers	6.6564	2.1276						8.7840
	Turboprop	60 pers	1.0563	0.4649						1.5212
Coastal vessel		2,000 t	147.6309	2.1518						149.7828
Containership		3,500 t	379.9367	5.5379						385.4746

Source: COWI/DTU (2016)

Table 9. Illustrative marginal external costs in DKK per Km – High values (2016 prices)

Marginal external costs (2016 prices)								HIGH VALUES		
DKK/Km		**Capacity**	**Air pollution**	**Climate change**	**Noise**	**Accidents**	**Congestion**	**Infrastructure**	**Health**	**TOTAL**
Bicycle (only urban)		1 pers	0.0000	0.0000	0.0000	1.7543	0.0000	0.0000	-5.1434	-3.3892
Passenger car	Gasoline	4 pers	0.0875	0.0149	0.1068	0.3096	1.0639	0.0217		1.6044
	Diesel	4 pers	0.3483	0.0124	0.1068	0.3096	1.0639	0.0217		1.8627
	Electrical	4 pers	0.0696	0.0060	0.0399	0.3096	1.0639	0.0217		1.5106
Van	Gasoline	1.5 t	0.1745	0.0268	0.1483	0.2909	1.4895	0.0348		2.1648
	Diesel	1.5 t	0.8260	0.0226	0.1483	0.2909	1.4895	0.0348		2.8121
Truck	Diesel	23.2 t	3.6045	0.0813	0.2174	1.8234	1.8931	1.6944		9.3142
Bus	Diesel	46 pers	6.8396	0.0886	0.4715	0.6582	1.9798	0.9298		10.9675
Passenger train	Electrical	481 pers	5.3769	0.4967	1.0476	4.7413				11.6625
	Diesel	270 pers	21.0689	0.3610	1.0476	4.7413				27.2188
Freight train	Electrical	659 t	10.3818	0.8931	6.0161	7.6058				24.8969
	Diesel	496 t	96.7266	1.0116	6.0161	7.6058				111.3601
Passenger plane	Jet	120 pers	46.5454	2.1276						48.6730
	Turboprop	60 pers	7.3712	0.4649						7.8361
Coastal vessel		2,000 t	935.9007	2.1518						938.0525
Containership		3,500 t	2,408.5941	5.5379						2,414.1320

Source: COWI/DTU (2016)

5.3 Air pollution

This type of costs are caused by the emission of air pollutants such as particulate matter (PM), nitrogen oxides (NOx), sulphur dioxide (SO_2), ozone (O_3) and volatile organic compounds (VOC). They consist of health costs, building/material damages, crop losses and costs of further damages to the ecosystem (biosphere, soil, water). Most important are the costs for $PM_{2.5}$ and NOx. They are calculated by the formula:

*External air pollution costs = Specific emission * Cost factor per pollutant*

The cost factor is estimated by differentiated damage cost curves based on the **impact pathway approach**, which is broadly acknowledged as the preferred approach for estimating air pollution costs. Important input value is the Value of Statistical Life (VSL), which is estimated at € 1.65 million (in 2010 prices). Other input values include population densities, country specific meteorological conditions and traffic patterns (distribution of exhaust emissions).

Table 10. Unit values of main pollutants from transport, in € per tonne (2010 prices)

	$PM_{2.5}$			NO_x	NMVOC	SO_2
Country	Rural	Suburban	Urban			
Austria	37766	67839	215079	17285	2025	12659
Belgium	34788	60407	207647	10927	3228	13622
Bulgaria	34862	65635	212875	14454	756	12598
Croatia	31649	61539	208779	15149	1819	12317
Cyprus	25040	51200	198440	6465	1122	12594
Czech Republic	43028	68427	215667	15788	1648	14112
Germany	48583	73221	220461	17039	1858	14516
Denmark	13275	40760	188000	6703	1531	7286
Estonia	15359	49948	197188	5221	1115	8441
Spain	14429	48012	195252	4964	1135	7052
Finland	8292	43997	191237	3328	781	4507
France	33303	64555	211795	13052	1695	12312
Greece	19329	50605	197845	3851	854	8210
Hungary	47205	74641	221881	19580	1569	14348
Ireland	16512	47420	194660	5688	1398	6959
Italy	24562	50121	197361	10824	1242	9875
Lithuania	23068	55535	202775	10790	1511	10945
Luxembourg	45688	71308	218548	18612	3506	15103
Latvia	19528	53638	200878	8109	1499	10000
Malta	NA	NA	98132	1983	1007	6420
Netherlands	29456	48352	195592	11574	2755	16738
Poland	47491	74215	221455	13434	1678	14435
Portugal	18371	49095	196335	1957	1048	4950
Romania	56405	84380	231620	22893	1796	17524
Sweden	14578	50210	197450	5247	974	5389
Slovenia	39633	67670	214910	16067	1975	12422
Slovakia	54030	79270	226510	21491	1709	17134
United Kingdom	14026	47511	194751	6576	1780	9192
EU average	**28108**	**70258**	**270178**	**10640**	**1566**	**10241**

Source: Ricardo-AEA (2014)

The 2014 Handbook recommends the unit values of Table 10 for air pollutants emitted from land-based transport (per country). They are based on average population exposure numbers per country.[3] Given that all health impacts are evaluated at average EU values, these numbers do not reflect

[3] The EU average $PM_{2.5}$ figures for suburban and urban areas are reference values corresponding to population densities of 300 and 1,500 inhabitants/km^2 respectively.

differences in income levels across countries. The values recommended by the 2014 Handbook for maritime transport are shown (per sea region) in Table 11.

These figures are further transformed into external costs per vehicle-km through the use of models taking into account the different modes and vehicle categories engaged in transport services in each country. The factors determining unit external costs per mode and the ranges of variation are shown in Table 12.

Table 11. Unit values of main pollutants in sea areas, in € per tonne (2010 prices)

Sea region	NMVOC	NOx	$PM_{2.5}$	SO_2
Baltic Sea	1100	4700	13800	5250
Black Sea	500	4200	22550	7950
Mediterranean Sea	750	1850	18500	6700
North Sea	2100	5950	25800	7600
Remaining North-East Atlantic	700	2250	5550	2900

Source: Ricardo-AEA (2014)

Table 12. Marginal external air pollution costs per unit of transport work produced (2010 prices)

Mode	Determinants	Min value	Max value
Road (€ct/vkm)	• Country • Vehicle type (LDV petrol, LDV diesel, rigid truck, articulated truck) • Size (<=7.5t, 7.5-12t, 12-14t, 14-20t, 20-26t, 26-28t, 28-32t, >32t) • EURO-class (0 to VI) • Road type (urban, suburban, interurban, motorway)	0.1 [FI, rigid HGV, <=7.5t, EURO VI, motorway]	52.1 [NL, articulated truck, 50-60t, EURO 0, urban]
Rail (€ct/locomotive-km)	• Country • Type of train (diesel, electric) • Region (urban, suburban, rural)	12.4 [FI, electric, rural]	506.5 [DE, diesel, rural]
Maritime (€/1000 tkm)	• Type of ship (crude oil tanker, product tanker, general cargo, bulk carrier) • Size of ship (feeder, handysize, handymax) • Region (Baltic Sea, Black Sea, North Sea, Mediterranean Sea, Remaining North-East Atlantic)	0.45 [crude oil tanker, 80-120 kt, N-E Atlantic]	9.09 [product tanker, 0-5 kt, North Sea]

Source: Own compilation

Note that the determinants of Table 12 differ from those of the climate change costs only by a geographic parameter, reflecting the local character of the air pollutants. Emissions of air pollutants vary considerably depending on average speed (figures are based on certain assumptions regarding speed for each vehicle size and type of network). Once again, no Ro-Ro ship appears in the analysis.

Table 13. Unit values of main air pollutants in DKK per kg (2016 prices)

Unit value of emissions (2016 prices)						
DKK/kg	**Urban**			**Rural**		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
$PM_{2.5}$	250.6315	1,748.8991	11,812.8500	34.9406	243.8143	1,646.8316
NOx	4.5318	53.2263	408.8154	0.0326	53.2263	375.3265
SO_2	57.2518	241.1759	1,146.5725	10.6948	208.5430	1,259.7542
CO	0.0045	0.0242	3.0998	0.0000	0.0087	1.1089
HC	0.5841	2.9200	16.7287	0.5220	2.4788	14.5675

Source: COWI/DTU (2016)

The unit values that the COWI/DTU study recommends appear in Table 13, while the corresponding indicative external costs are presented in Tables 4-6. A discussion on how these values compare to those of the Handbook is provided in Section 5.8.

5.4 Noise

Annoyance and health impacts caused by transport-related noise emissions generate the relevant external costs. The annoyance costs concern social disturbances like discomfort or inconvenience and are usually estimated on the basis of **stated or revealed preferences** of individuals. **Hedonic pricing** quantifying amenity losses due to noise has been used extensively in the past. On the other hand, health costs (especially due to cardiovascular diseases) are quantified through the **impact pathway approach** presented in Section 5.3.

Marginal noise costs are defined as the additional costs of noise caused by adding one vehicle to the existing traffic flow. Due to the background traffic noise, marginal costs follow a decreasing function leading to marginal costs lower than average costs in the case of medium to high traffic volumes. Furthermore, the logarithmic nature of the noise/traffic relationship makes marginal noise costs very sensitive to existing traffic flows and the related noise. Other cost drivers include the time of the day (noise disturbances at night lead to higher marginal costs than at other times of the day), population density close to the emission source and a number of technical characteristics of the infrastructure and vehicles used, including the presence of noise walls.

The formula used for estimating external noise costs is:

*External noise costs = Specific noise emission * number of people affected * damage per dB(A)*

There are no well-defined thresholds above which noise is considered a nuisance. Usually 50 dB(A) is considered a reasonable level of noise. Furthermore, empirical evidence shows that for a given decibel output, noise nuisance due to rail transport is experienced as less of a nuisance than road traffic noise. To correct for this effect, rail transport is often given a 5 dB 'discount' (rail bonus).

The 2014 Handbook provides estimates of marginal noise costs for road and rail transport. The EU average figures are shown in Table 14. For the purposes of noise costs, urban areas are defined by a population density of 3,000 inhabitants per km of road length, suburban areas by 700 inhabitants per km and rural areas by 500 inhabitants per km of road length.

Table 14. Illustrative marginal noise costs for the EU in € per 1000 vkm (2010 prices)

Mode	Time of day	Traffic type	Urban	Suburban	Rural
Car	Day	Dense	8.8	0.5	0.1
		Thin	21.4	1.4	0.2
	Night	Dense	16.1	0.9	0.1
		Thin	38.9	2.5	0.4
Motorcycle	Day	Dense	17.7	1.1	0.1
		Thin	42.7	2.7	0.4
	Night	Dense	32.1	1.9	0.2
		Thin	77.9	5.1	0.6
Bus	Day	Dense	44.0	2.4	0.4
		Thin	107.0	6.8	0.8
	Night	Dense	80.3	4.5	0.7
		Thin	194.7	12.7	1.5
LCV	Day	Dense	44.0	2.4	0.4
		Thin	107.0	6.8	0.8
	Night	Dense	80.3	4.5	0.7
		Thin	194.7	12.7	1.5
HGV	Day	Dense	81.0	4.5	0.7
		Thin	196.6	12.7	1.5
	Night	Dense	147.8	8.3	1.3
		Thin	358.2	23.1	2.6
Passenger train	Day	Dense	273.4	12.1	15.0
		Thin	540.2	23.8	29.7
	Night		901.6	39.8	49.6
Freight train	Day	Dense	484.8	23.9	29.9
		Thin	1,169.6	46.3	57.8
	Night		1,977.6	78.3	97.7

Source: Ricardo-AEA (2014)

The factors determining the external noise costs per mode and the ranges of variation are shown in Table 15. The unit values recommended by the COWI/DTU are shown in Tables 7-9.

Marginal noise costs due to maritime transport are assumed to be negligible, because emission factors are comparably low and most of the activities occur outside densely populated areas.

Table 15. Marginal external noise costs per unit of transport work produced (2010 prices)

Mode	Determinants	Min value	Max value
Road (€/1000 vkm)	• Country • Vehicle type (LDV, HGV) • Time of day (day, night) • Traffic type (dense, thin) • Region (urban, suburban, rural)	0.4 [LV, HGV, day, dense, rural]	477.1 [NL, HGV, night, thin, urban]
Rail (€/1000 vkm)	• Country • Type of train (passenger, freight) • Time of day (day, night) • Traffic type (dense, thin) • Region (urban, suburban, rural)	13.1 [LV, freight, day, dense, suburban]	2634.1 [NL, freight, night, urban]

Source: Own compilation

5.5 Accidents

External accident costs consist of the social costs of traffic accidents that are not covered by risk oriented insurance premiums. They include the following cost categories:

- expected cost (of death and injury) due to an accident for the person exposed to risk,
- expected cost for the relatives and friends of the person exposed to risk,
- accident cost for the rest of the society (output loss, material costs, police and medical costs).

Accident costs can be estimated by the formula:

*External accident costs = Traffic volume * Risk elasticity * Unit cost per accident * External part,*

where risk elasticity is the risk of an additional accident at the actual level of traffic volume. In calculating the unit cost per accident, the Value of Statistical Life (VSL) is once again needed. It is assumed that VSL also includes the cost for the relatives and friends. The EU-wide VSL is taken at an average value of € 1.7 million per fatality (in 2010 prices).[4] Values for severe injuries are derived as 13% of VSL, and for slight injuries as 1% of VSL. The various direct and indirect economic costs (of the third category listed above) are assumed to be in the order of 10% of these values.

The percentage of the resulting accident costs internalised (θ) depends on the approach applied and the national insurance system. The Handbook distinguishes three approaches:

- The average accident risk is internalised by transport users (θ=1),
- The average accident risk is not internalised (θ=0);

[4] This figure is slightly higher than the VSL used in estimating air pollution costs. This is due to the different design of the willingness-to-pay surveys employed to estimate health and accident costs. Another contributing reason is the fact that accident risk perception (sudden fatalities) is different to air pollution related long-term mortality risks (loss of life years).

- The accident risk of the causer is internal, while the risk of the non-responsible victim is external (causation principle - Swiss approach).

The causation principle is assumed by the Handbook, leading to θ values of 0.76 for cars, 0.22 for LDVs and HGVs, and 0.16 for buses.

Table 16. Marginal accident cost estimates in €ct/vkm (2010 prices)

	Car			HGV			Motorcycle		
State/Type	Motor-way	Other non-urban road	Urban road	Motor-way	Other non-urban road	Urban road	Motor-way	Other non-urban road	Urban road
Austria	0.5	0.4	0.9	5.8	1.8	3.8	0.4	5.6	12.1
Belgium	0.3	0.3	0.4	3.0	1.5	0.9	1.6	3.0	6.0
Bulgaria	0.1	0.1	0.3	0.5	0.5	1.1	0.0	0.0	0.1
Croatia	0.3	0.2	2.9	0.9	0.6	16.4	0.0	0.2	1.6
Cyprus	0.8	0.1	2.1	2.0	0.3	46.2	0.3	0.1	5.6
Czech Republic	0.1	0.2	0.2	1.1	0.6	1.0	0.0	0.2	0.2
Denmark	0.1	0.1	0.1	1.1	1.0	0.7	0.3	1.2	3.8
Estonia		0.4	0.2		0.5	0.8		0.2	0.2
Finland	0.1	0.1	0.1	0.2	0.5	0.3	0.3	1.1	2.1
France	0.1	0.2	0.2	0.4	0.5	0.7	0.9	2.3	7.8
Germany	0.2	0.4	0.6	2.4	1.3	1.5	0.6	3.3	8.5
Greece	0.2	0.2	0.2	0.9	1.3	1.3	0.1	0.1	0.4
Hungary	0.1	0.3	1.3	0.8	1.2	6.8	0.0	0.1	2.4
Ireland	0.1	0.2	0.1	1.7	1.4	0.6	0.2	0.4	0.3
Italy	0.1	0.2	0.6	2.1	1.0	4.0	0.1	0.2	1.5
Latvia		0.3	0.2		0.4	0.5		0.1	0.3
Lithuania		0.2	0.3		0.3	0.9		0.2	0.2
Luxembourg	0.9		0.1	1.8		0.1	23.8		3.5
Malta			3.6			17.3			0.7
Netherlands	0.0	0.1	0.1	0.3	2.3	1.2	0.2	4.5	11.6
Poland	0.1	0.2	0.5	0.6	0.6	1.9	0.0	0.1	0.4
Portugal	0.1	0.1	0.3	2.1	2.7	9.3	0.1	0.2	0.9
Romania	0.0	0.2	2.1	0.1	0.6	12.0	0.0	0.0	1.5
Slovakia	0.1	0.3	0.5	0.8	0.7	12.2	0.0	0.2	0.5
Slovenia	0.1	0.2	0.2	0.5	0.7	1.7	0.0	0.3	0.1
Spain	0.2	0.1	0.1	1.8	0.9	0.3	1.0	0.8	1.6
Sweden	0.3	0.3	0.3	1.2	1.0	0.9	1.0	3.4	8.1
Great Britain	0.1	0.1	0.2	0.9	0.5	0.3	0.4	1.3	2.1
EU average	**0.1**	**0.2**	**0.3**	**1.2**	**0.8**	**1.1**	**0.2**	**0.5**	**1.9**

Source: Ricardo-AEA (2014)

The accident cost estimates produced under these assumptions appear by country in Table 16 and are summarised in Table 17 together with the corresponding rail transport figure. The latter is generally lower than the road-related costs due to differences in the insurance systems applied in each mode. In the case of freight trains, all accident costs are considered external, rendering the marginal equal to average costs. An estimate of €0.2 per 1,000 vkm is recommended for freight trains. Illustrative accident costs for road and rail transport produced by the COWI/DTU study are presented in Tables 4-6.

Table 17. Marginal external accident costs per unit of transport work produced (2010 prices)

Mode	Determinants	Min value	Max value
Road (€ct/vkm)	• Country • Vehicle type (car, HGV, motorcycle) • Road type (motorway, other non-urban, urban)	0.2 [FI, HGV, motorway]	3.0 [BE, HGV, motorway]
Rail (€/1000 vkm)	N/A	0.2	

Source: Own compilation

5.6 Congestion

The external congestion costs are experienced by all other infrastructure users due to the entrance of an additional operator into the system. They include primarily travel time increases and additional fuel costs, while secondary effects are additional vehicle provision and operating costs and higher valuation of delay times compared to standard in-vehicle time due to the unreliability of travel time (particularly important for freight transport).

Estimation is based on the difference between average and marginal costs at optimal traffic levels through the formula:

*External congestion costs = Increased journey time * Value of time * Traffic volume*

Important input values are speed-flow relations and the value of time. **Willingness-to-pay** (WTP) is the best practice approach for the estimation of the value of time (based on stated preference approaches).

Furthermore, as levying the external costs to transport users will affect the level of demand and thus the level of congestion itself, price-relevant marginal social congestion costs need to be computed for the equilibrium of demand and supply. Demand elasticity figures are then also needed as input values.

Based on the FORGE model used in the National Transport Model of the UK, the 2014 Handbook recommends for road transport in the EU the marginal costs of Table 18. ‘Free flow’ in this table is defined as the situation where the volume of the actual traffic flow is less than 25% of capacity of the road, while the ‘near capacity’ conditions refer to traffic volumes between 75 and 100% of the nominal capacity.

Table 18. Marginal congestion costs for the EU in €ct per vkm (2010 prices)

Vehicle	Region	Road type	Free flow (€ct/vkm)	Near capacity (€ct/vkm)	Over capacity (€ct/vkm)
Car	Metropolitan	Motorway	0.0	26.8	61.5
		Main roads	0.9	141.3	181.3
		Other roads	2.5	159.5	242.6
	Urban	Main roads	0.6	48.7	75.8
		Other roads	2.5	139.4	230.5
	Rural	Motorway	0.0	13.4	30.8
		Main roads	0.4	18.3	60.7
		Other roads	0.2	42.0	139.2
Rigid truck	Metropolitan	Motorway	0.0	50.9	116.9
		Main roads	1.8	268.5	344.4
		Other roads	4.7	303.0	460.9
	Urban	Main roads	1.2	92.5	144.1
		Other roads	4.7	264.9	438.0
	Rural	Motorway	0.0	25.4	58.4
		Main roads	0.8	34.8	115.3
		Other roads	0.4	79.8	264.5
Articulated truck	Metropolitan	Motorway	0.0	77.6	178.4
		Main roads	2.7	409.8	525.6
		Other roads	7.2	462.5	703.5
	Urban	Main roads	1.8	141.1	219.9
		Other roads	7.2	404.4	668.6
	Rural	Motorway	0.0	38.8	89.2
		Main roads	1.2	53.1	176.0
		Other roads	0.6	121.9	403.8
Bus	Metropolitan	Motorway	0.0	66.9	153.8
		Main roads	2.3	353.3	453.1
		Other roads	6.2	398.7	606.4
	Urban	Main roads	1.6	121.7	189.6
		Other roads	6.2	348.6	576.3
	Rural	Motorway	0.0	33.5	76.9
		Main roads	1.0	45.8	151.7
		Other roads	0.5	105.0	348.1

Source: Ricardo-AEA (2014)

For rail transport, external costs of this category include opportunity costs (slot allocation) and delay costs (operative deficits). A figure of €0.20 per 1,000 tkm is suggested based on the Marco Polo calculator.

Although capacity in some North American and European ports is approaching its limits and congestion at cargo handling and storage facilities is becoming an issue, no marginal external congestion costs have been estimated for the maritime transport due to lack of data.

Table 19 summarises the results of the 2014 Handbook, while the estimates of the COWI/DTU study are shown in Tables 7-9.

Table 19. Marginal external congestion costs per unit of transport work produced (2010 prices)

Mode	Determinants	Min value	Max value
Road (€ct/vkm)	• Country • Vehicle type (rigid truck, articulated truck) • Region (metropolitan, urban, rural) • Road type (motorway, main road, other road) • Flow conditions (free flow, near capacity, over capacity)	0.0 [all countries, rigid truck, metropolitan, motorway, free flow]	937.0 [NL, articulated truck, metropolitan, other road, over capacity]
Rail (€/1000 tkm)	N/A	0.2	

Source: Own compilation

5.7 Infrastructure

Marginal infrastructure costs refer to the increase in infrastructure maintenance and repair expenditures induced by higher traffic levels. They differ by country, type of infrastructure and vehicle class. Differences across countries are often attributed to differing quality of the infrastructure. Higher quality requiring higher initial investments usually has longer lifespan and is less prone to damage from increased traffic. Heavier vehicles tend to cause more damage to the infrastructure. In fact, it has been found that the weight/damage relationship follows a power law.

Due to difficulties in assessing traffic elasticities of costs by vehicle type, the 2014 Handbook suggests approximating marginal costs by the **average variable costs**, which include the routine maintenance and large repair works that ensure the original required infrastructure conditions (part of capital costs), as well as the operational maintenance works that ensure proper functionality (part of running costs).

Based on the latest German road accounts, the 2014 Handbook differentiates average variable costs by vehicle and road types.[5] Adjusted to reflect the civil engineering price indices of each country, these estimates lead to illustrative country-specific unit costs. The corresponding EU averages are shown in Table 20, while Table 21 exhibits the range of variation. It is interesting to note that the heavy (44t) 5-axle trucks running on Swedish roads of low freight traffic are associated with a significant cost (€1.64/vkm) which, however, drops drastically (to €0.90/vkm) when a 6th axle is added.

[5] According to the German road accounts, 'motorways' are defined as federal or municipal roads with freight traffic share greater than 6%, 'other trunk roads' as federal or municipal roads with freight traffic share between 3 and 6%, and 'other roads' as municipal and district roads with freight traffic share less than or equal to 3%.

Table 20. Illustrative marginal road infrastructure costs for the EU in €ct per vkm (2010 prices)

Vehicle category	All roads	Motorways	Other trunk roads	Other roads
Motorcycles and mopeds	0.2	0.1	0.1	0.3
Cars	0.5	0.2	0.3	0.8
Buses	2.0	0.8	1.4	2.7
LDV < 3.5 t	0.7	0.3	0.5	1.2
HGV 3.5 - 7.5 t, 2 axles	0.1	0.0	0.0	0.4
HGV 7.5 - 12 t, 2 axles	1.5	0.6	1.0	8.2
HGV 12 - 18 t, 2 axles	3.9	1.6	2.7	21.5
HGV 18 - 26 t, 3 axles	5.2	2.2	3.6	28.9
HGV 26 - 32 t, 4 axles	6.6	2.8	4.6	36.7
HGV 26 - 32 t, 5 axles	3.6	1.5	2.5	20.1
HGV 32 - 40 t, 5 axles	8.0	3.3	5.6	44.6
HGV 32 - 40 t, 6 axles	4.8	2.0	3.3	26.7
HGV 40 - 50 t, 8 axles	5.0	2.1	3.5	28.1
HGV 40 - 50 t, 9 axles	3.8	1.6	2.7	21.5
HGV 50 - 60 t, 8 axles	10.6	4.4	7.4	59.3
HGV 50 - 60 t, 9 axles	7.6	3.2	5.3	42.3
HGV 40 t, 8 axles	3.5	1.5	2.4	19.4
HGV 40 t, 9 axles	2.8	1.2	2.0	15.6
HGV 44 t, 5 axles	18.8	7.9	13.1	105.0
HGV 44 t, 6 axles	10.3	4.3	7.2	57.7

Source: Ricardo-AEA (2014)

Table 21. Marginal external infrastructure costs per unit of transport work produced (2010 prices)

Mode	Determinants	Min value	Max value
Road (€ct/vkm)	• Country • Vehicle type (LDV, HGV) • Size (<=3.5t, 3.5-7.5t, 7.5-12t, 12-18t, 18-26t, 26-32t, 32-40t, 40-50t, 50-60t, 44t) • Number of axles (2, 3, 4, 5, 6, 8, 9) • Road type (motorways, other trunk roads, other roads)	0.0 [all countries, HGV, 3.5-7.5t, 2 axles, motorways]	163.7 [SE, HGV, 44t, 5 axles, other roads]
Rail (€/vkm)	N/A	0.2 – 0.7 (indicative only)	

Source: Own compilation

In terms of rail transport, the 2014 Handbook suggests estimation based on the formula:

$$\textit{Marginal cost} = \textit{Average cost} * \textit{Cost elasticity}$$

Although cost elasticity figures are provided, no average cost estimates are readily available, constraining the applicability of the method. A figure of €0.2 to €0.7 per train-km has been suggested for freight trains, which however, cannot be used for internalisation purposes.

Indicative external infrastructure costs are provided by the COWI/DTU study only for the road sector. They are presented in Tables 4-6. No reference to marginal infrastructure costs associated with maritime transport is made by any of the two sources examined.

5.8 External cost estimates for the present study

The purpose of this section is to select the external cost values that will be used in Section 8.1 to investigate the effectiveness of internalising external costs as a policy instrument. A comparison of the estimates produced by the two sources used is a prerequisite for this selection.

According to both sources, the only external costs pertaining to maritime transport are those of climate change and air pollution. However, none of these sources provides Ro-Ro specific estimates. Therefore, these costs will have to be calculated on the basis of the fuel consumption data obtained directly from the vessels employed and the unit values (€ per kg) of the pollutants that the two sources provide. For comparison purposes, the Denmark-specific values of the air pollutants appearing in both sources are presented Table 22 after having been recalculated to reflect 2015 prices. The CO_2 values have been added to the table.

Table 22. Unit values of global and local pollutants in € per kg (Denmark, 2015 prices)

Pollutant	2014 Handbook			COWI/DTU study		
	Low	Medium	High	Low	Medium	High
CO_2	0.0589	0.1104	0.2061	0.0070	0.0106	0.0106
$PM_{2.5}$		34.7875		4.6390	52.3539	1,568.3829
NOx		7.5837		0.0043	7.0668	54.2781
SO_2		8.2433		1.4199	28.1214	167.2566

Source: Own compilation

As mentioned in Section 5.2, the CO_2 values exhibit differences of one order of magnitude, apparently reflecting the shorter-term perspective of the COWI/DTU study. Among the air pollutants, the only values that converge are those of NOx. There are significant differences in the $PM_{2.5}$ and SO_2 values, albeit within the same order of magnitude. The COWI/DTU results are considered more accurate in the sense that they build on those of the 2014 Handbook by incorporating more detailed country-specific data. Unfortunately, though, their coverage is restricted to Denmark, which is insufficient for analysing the routes of the present study. In addition, the extensive width of the variation range emphasises the need for consistency, even at the expense of accuracy. Therefore, we decided to use the 2014 Handbook central values as the default ones, and extend the range of variation to accommodate the extreme values of the COWI/DTU study. The values that will be used in the subsequent sections appear in Table 23. The corresponding values for the sea areas are shown in Table 24.

Table 23. Unit values of global and local pollutants in € per kg (EU, 2015 prices)

Pollutant	2014 Handbook (EU)			COWI/DTU study (DK)			Present study (EU)		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
CO_2	0.0589	0.1104	0.2061	0.0070	0.0106	0.0106	0.0070	0.1104	0.2061
$PM_{2.5}$		50.1542		4.6390	52.3539	1,568.3829	4.6390	50.1542	1,568.3829
NOx		13.4744		0.0043	7.0668	54.2781	0.0043	13.4744	54.2781
SO_2		12.9691		1.4199	28.1214	167.2566	1.4199	12.9691	167.2566

Source: Own compilation

Table 24. Unit values of main pollutants in sea areas, in € per kg (2015 prices)

Sea region	$PM_{2.5}$	NOx	SO_2
Baltic Sea	17.4762	5.9520	6.6486
Black Sea	28.5572	5.3189	10.0678
Mediterranean Sea	23.4283	2.3428	8.4848
North Sea	32.6730	7.5350	9.6246
North-East Atlantic	7.0285	2.8494	3.6725

Source: Own compilation

In relation to the other modes, the marginal costs derived from the two sources are compared to each other on the basis of the reference vehicles used by the COWI/DTU study: a diesel 23.2 t EURO IV rigid truck (Table 25), an electric 659 t train (Table 26) and a diesel 496 t train (Table 27). Note that train costs refer to one locomotive per train. Furthermore, only the EU Member States with access to the Baltic or the North Sea have been considered in setting the 2014 Handbook minimum and maximum values, with the exception of the climate change costs, where the upper and lower limits reflect the bandwidth of the CO_2 values (refer to Table 4).

Table 25. Illustrative marginal costs for a diesel 23.2 t rigid truck in € per vkm (EU, 2015 prices)

External cost	2014 Handbook (EU)			COWI/DTU study (DK)			Present study (EU)		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Climate change	0.0360	0.0859	0.2428	0.0069	0.0105	0.0105	0.0069	0.0859	0.2428
Air Pollution	0.0013	0.0899	0.4850	0.0024	0.0677	0.4786	0.0013	0.0899	0.4850
Noise	0.0005	0.1026	0.6042	0.0072	0.0144	0.0289	0.0005	0.1026	0.6042
Accidents	0.0025	0.0152	0.0380	0.0403	0.1839	0.2421	0.0025	0.0152	0.2421
Congestion	0.0000	0.5138	7.7744	0.0195	0.0856	0.2513	0.0000	0.5138	7.7744
Infrastructure	0.0190	0.0659	0.5711	0.0375	0.1500	0.2250	0.0190	0.0659	0.5711
Total	0.0593	0.8732	9.7155	0.1138	0.5121	1.2363	0.0302	0.8732	9.9196

Source: Own compilation

Table 26. Illustrative marginal costs for an electric 659 t train in € per vkm (EU, 2015 prices)

External cost	2014 Handbook (EU)			COWI/DTU study (DK)			Present study (EU)		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Climate change	0.0000	0.0000	0.0000	0.0760	0.1152	0.1152	0.0760	0.1152	0.1152
Air Pollution	0.1570	0.5344	0.9232	0.0086	0.2121	1.3784	0.0086	0.5344	1.3784
Noise	0.0166	0.6139	3.3358	0.0888	0.2663	0.7988	0.0166	0.6139	3.3358
Accidents	0.0003	0.0003	0.0003	0.0787	0.3934	1.0098	0.0003	0.0003	1.0098
Total	0.1739	1.1486	4.2593	0.2521	0.9870	3.3022	0.1015	1.2638	5.8392

Source: Own compilation

Table 27. Illustrative marginal costs for a diesel 496 t train in € per vkm (EU, 2015 prices)

External cost	2014 Handbook (EU)			COWI/DTU study (DK)			Present study (EU)		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Climate change	0.8266	1.5499	2.8931	0.0861	0.1305	0.1305	0.0861	1.5499	2.8931
Air Pollution	0.1232	3.9575	6.4143	0.0588	1.8217	12.8423	0.0588	3.9575	12.8423
Noise	0.0166	0.6139	3.3358	0.0888	0.2663	0.7988	0.0166	0.6139	3.3358
Accidents	0.0003	0.0003	0.0003	0.0787	0.3934	1.0098	0.0003	0.0003	1.0098
Total	0.9667	6.1215	12.6434	0.3123	2.6119	14.7814	0.1617	6.1215	20.0810

Source: Own compilation

All costs are expressed in € per vkm to enable comparison and have been adjusted to reflect 2015 prices to be compatible with other (internal) costs entering the generalised cost function of Section 7.1. The general observation is that only air pollution and infrastructure costs are of comparable magnitude (same order). The 2014 Handbook recommends much higher central values for the climate change, noise and congestion costs, while the opposite is true for accident costs. For consistency purposes, we use the 2014 Handbook central values as the default ones, and extend the range of variation to accommodate the extreme values of both studies. The only exception to this rule is the climate change costs for electric trains, where, in the absence of a Handbook figure, the COWI/DTU suggested values are taken as default.

Expressed on a per vehicle-km basis, the truck exhibits 31% lower external costs than the electric train, which, however, has about 25 times the carrying capacity of a truck. The impact of railway electrification on marginal costs is also impressive. The external costs of our reference electric train comprise less than 21% of the corresponding figure of the diesel one despite the fact that it is about 33% larger in mass.

This section analysed the different methods of calculating external costs of transportation for the various modes, and the significant variations in the actual values. The next section of this report will present the proposed policies, (including a partial of full internalization of external costs) that can revert the negative impacts of the low-sulphur fuel on short sea shipping operators.

6 The examined policy measures

The previous sections discussed the main findings of the project so far, and the main implications that new environmental policy can have on the main stakeholders affected by it. In Task 3.1 the main options that an operator has to cope with the new situation were examined. Such measures may prove critical in the survival of certain services in the event of a re-emergence of high fuel prices in the near future. Even in the event that fuel prices remain at low levels, the operators may also need to fine-tune their services in order to maximize the financial performance of a route. This section of the report presents the policy measures that could be used to offset the potential modal backshifts that could result from an increase in fuel prices.

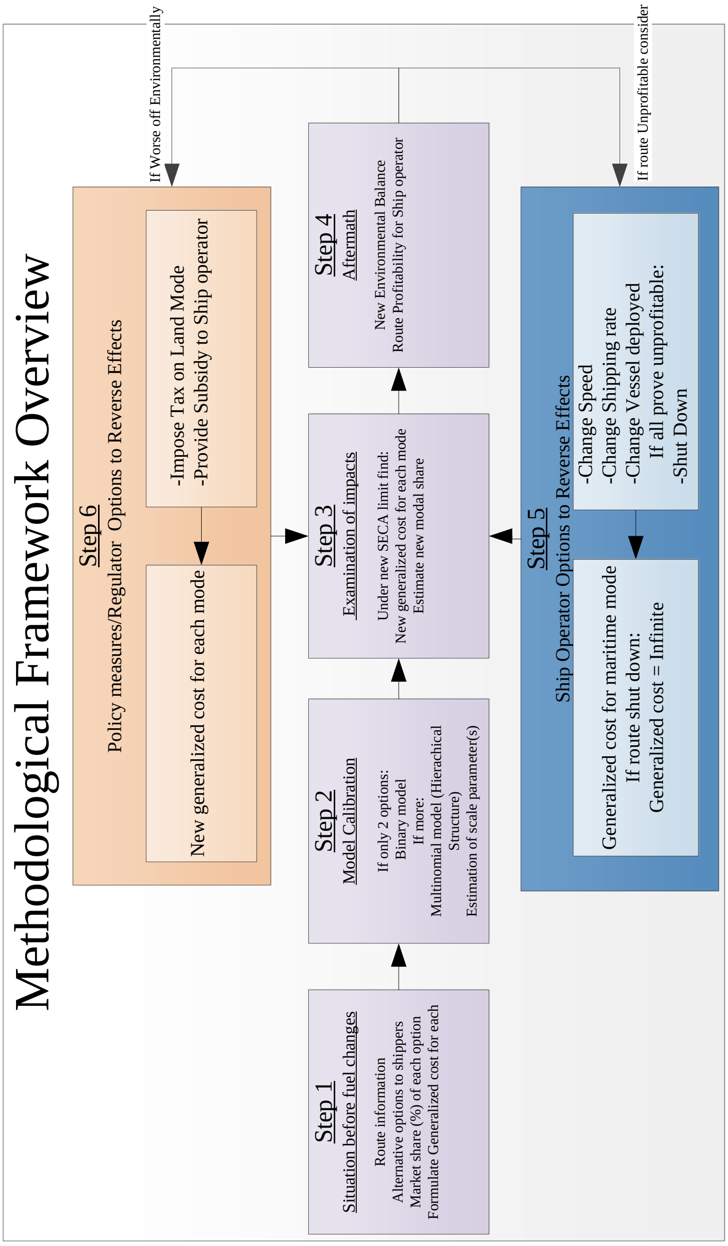


Figure 3: The modelling framework, and Step 6 corresponding to Task 3.2

The internalization of external costs is of particular focus, as it has a very significant effect to the generalized cost of transport for all modes and users. The policy measures are part of the modelling framework, and Step 6 that is corresponding to Task 3.2.

6.1 Internalization of external costs

This measure considers the full or partial internalization of external costs associated with the transportation of the examined routes and the various modes used. In the examined case studies, the external costs will be added to the transport cost element in the generalized cost formulation used in the modal shift models. Various different specifications will be considered for the internalization process, based on the derived costs from Section 5 of this report. The effects of the added costs on the final generalized cost of transport for the different routes, as well as on the new modal balance will be discussed. Figure 4 presents the process of examining the impacts of a potential internalization of external costs, as a measure to combat the negative effects of the low sulphur fuel requirements.

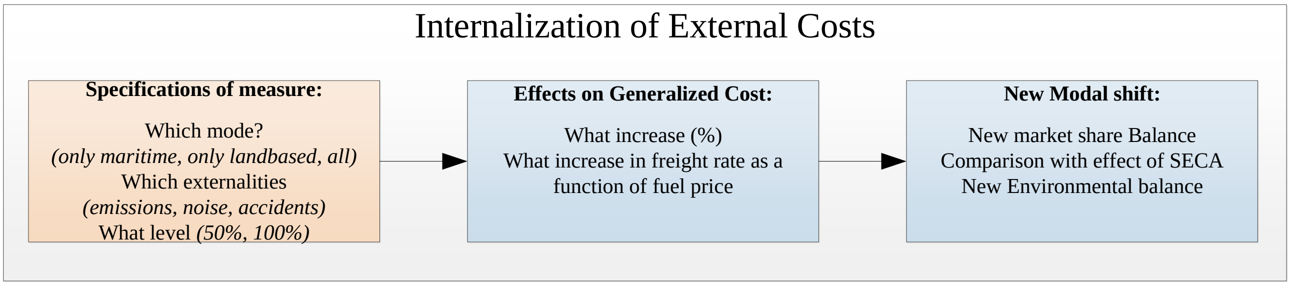


Figure 4: The internalization of external costs as a potential policy measure

At the first step, the specifications of the policy measure need to be decided. As presented in section 5 of this report, the external costs of transport comprise of the negative effects to society of pollutant emissions, greenhouse gas generation, noise, and accidents associated with the transportation mode. A potential internalization of external costs may include all of these externalities, or merely a sub-set of them, and the effects of a partial (50%) or full internalization will be considered. The second step will consider the actual monetary effect of such a measure to the generalized cost of transportation for one unit of transport, in the different routes and for the different project specifications. The third and final step, would be the use of the modal shift model developed in the context of WP2, to estimate the new market shares of the competing transportation modes. The effects of this measure will be compared with the effects of the 0.1 sulphur limit on the short sea shipping sector, and the impacts on emissions generation will be considered.

A critical decision in such measures is who would actually be responsible for the payment of the additional cost. Within this project, it is envisaged that in the process of internalizing some (or all) of these externalities, the shipper would have to pay an additional fare that is to be decided as a function of the allocated emissions for the transportation of the cargo. It can be argued that in such a measure, the ship/freight operator would have to pay according to the emissions and transport work produced. These costs will be examined, but it can be anticipated that if the operator is paying for the externalities, these additional costs would in some manner be passed on to the shipper. Finally, considering the values for the various external costs as presented in section 5, it can be observed that there is a wide variation in the different studies. There can also be an expected volatility in the values of these costs, and a significant increase in the transportation costs for each mode. Consequently, it can be anticipated that such a measure could lead in an overall reduction in transport demand from an economics perspective. The models developed in the RoRoSECA project are useful in estimating the market share of each competing mode as a percentage, and not the overall transport demand. Therefore, the internalization of external costs as a policy measure will be examined concerning its effects on the probability of choosing one of the available modes, and not considering the option of not transporting some cargo as an option.

6.2 Easing of port dues

This measure is considering the option of subsidising part of the port dues that the affected ship operators have to pay during their vessel calls. The rationale behind this measure is that since there are lower emissions as a consequence of the regulation (during the approach/departure phases) it may be reasonable to reduce the port fees by a certain extent. Retrieving information on the actual port fees for each vessel call is possible through the websites of the respective port authorities. However, it is quickly evident that the information on the tariffs are referring to a typical port call, and information on the actual tariffs for recurring vessels is not available. For this reason, the actual port dues that DFDS has paid were collected, and an analysis to their effect in the profitability of each service will be analysed, considering different fuel price scenarios.

6.3 ECO-bonus system

The first ECO-bonus system was authorized by the European Commission as a temporary state aid scheme in Italy for freight operators moving from road to sea. The main objective of ECO-bonus was to establish a mechanism to promote short sea shipping, and in particular the Italian Motorways of the Sea network (Tsamboulas et al., 2015). The first implementation of the scheme, considered the provision of 20% towards the seaway tariffs of existing (at the time) services (up to 30% for new services), while setting certain minimum limits (in terms of annual trips by the benefited operator). Due to limited resources and the ensuing recession, this scheme was operational only for a little bit over two years. More recently, there are new efforts attempting to implement similar schemes.

In Norway, shipping lines that seek to establish new cargo services in the country can apply for grants from the Norwegian Coastal Administration (www.shiptonorway.no , 2017). To be eligible for the grant, the shipowner needs to propose a service

- between Norwegian ports (or a Norwegian and one port within the EEA)
- that leads to environmental benefits in comparison to the road transport option,
- that would otherwise be not commercially viable (without the grant)
- that will be viable after the support period

While this scheme is targeting new services, there is some flexibility to support existing services under exceptional circumstances, and in case these services are facing closure without the help. Finally, it is noteworrh that for this scehme, the aid goes directly to the shipoperator and can be either the environmental benefit of the modal shift, the 30% of the operating costs of the service, or a 10% of the transhipment equipment costs.

In Italy, two additional state aid schemes were approved from the European Commission targeting modal shifts towards rail and sea. The maritime scheme is called Marebonus, and will have a budget of €138 million that will be used for the introduction of new services, or upgrades to existing sea routes (European Commission, 2017). Finally, work on an ECO-bonus like system is currently conducted by the MED-Atlantic ecobonus project (co-funded by the EC) that seeks to increase the use of MoS in the Western Mediterranean and Atlantic markets. There are synergies between RoRoSECA and the MED-Atlantic projects, however at this stage the specifications of the system have not yet been finalized by the project partners.

In the previous examples of systems similar to ECO-bonus there are different ways of providing subsidies towards moves from road to sea. In the context of Task 3.2, the annual costs for such schemes are estimated for certain routes examined in the RoRoSECA project, along with the new modal shift that can be anticipated by the lowering of the generalized cost of maritime transport options, as well as the environmental benefits of the system.

6.4 Subsidies for environmental investments

In the deliverable report on Task 3.1, one of the operators' measures that was examined was the investments in abatement technologies such as scrubbers or LNG engines. From the operator's perspective, the main question in such investments is the net present value and the length of the payback period. DFDS has invested heavily in scrubbers, which has had several implications as the company can be considered as an early adapter to the technology in terms of size of investment (number of vessels). For five of its vessels, DFDS had secured subsidies amounting to 6.3M€ from the European Commission, under the Motorways of the Sea (MoS) programme. In Task 3.2, the cost implications for the policy maker will be considered and compared to the emissions savings achieved by this measure. This measure will not have a direct influence on modal shift, as the freight rates are not affected by it. However, in the future such measures may reduce the payback period of such environmental investments by effectively reducing the size of initial capital requirements.

6.5 Tax on land-based modes

This measure considers the identification of the necessary increase in the landbased freight rates that a shipper must pay, in order to negate the modal shift loss that is triggered by the low sulphur fuel requirement. It is evident that this is a very case specific measure, as the necessary increase per landbased transport work (in lm-NM units) will depend on the relative weight of the maritime costs in the generalized cost of the shipper. In Section 7 of this report, a theoretical model is developed that facilitates the calculation of this tax levy on a case specific basis. Subsequently, in Section 8 with the case studies this measure is examined in a more straightforward way whereby the freight rates per km for the land-based options are increased, and the effects of such increases in the market shares are considered.

7 Model Overview

This section will briefly present the new computational modules developed to estimate the effects of the examined measures for Task 3.2 for each stakeholder (shipper, policy maker, ship operator). The synergies of the new modules with the modal split model developed in WP2 are also discussed.

7.1 Calculation of the new generalized cost of transport

In order to reverse the negative effects of the low sulphur limits, it was first necessary to identify them. In WP2 it was shown that while the ship operators seem to have enjoyed a very positive economic performance in 2015, this was mainly due to the low fuel prices, and thus the regulation had a negative effect by halting the potential growth of the sector due to these prices. WP2 also showed that in the event of higher fuel prices, the regulation would have an actual negative effect through market share losses to other sectors. Most of the examined policy measures are either aiming to increase the generalized cost (GC) of transport of competing modes, or to decrease the GC of the maritime options. Alternatively, some policies are considering offering a subsidy towards environmental investments (thus reducing operating costs), or impose the internalization of external costs to all modes. The shipper will notice a difference if it leads into a lower GC (or higher GC in a competing mode). The GC formulation in the RoRoSECA project depends on three key elements:

- The monetary cost for the transportation
- The total travel time including any transhipment times
- The value of the cargo modelled, all shown in the following equation

$$GC_i = TC_i + a \cdot TT_i \tag{1}$$

where TC_i (€/lane meter-lm) is the monetary travel cost for mode i and TT_i (hours) is the total travel time. The cost is expressed in € per lane meters as this is the unit in which Ro-Ro operators are setting freight rates. Parameter α(€/lm·hour) represents the monetary value of time that links the previous two as formulated by Psaraftis and Kontovas (2010) and Zis and Psaraftis (2017). The value of time is a function of the cargo value CV(€/lm) and its opportunity cost of capital r (%) as in:

$$a = \frac{CV \cdot r}{365 \cdot 24} \tag{2}$$

To account for any additional policy-driven cost (or reduced cost), eq. 1 can be reformulated as:

$$GC_i = TC_i + a \cdot TT_i + TP_i \tag{3}$$

Where TP_i refers to the new cost (or benefit) for transport mode i under the new policy scheme examined. The value of TPi is a straight forward calculation for the following measures:

- a percentage increase in the freight rate for the landbased options in case of a levy,
- An addition of the external cost as a estimated in Section 6
- A reduction in the freight rate by the equivalent increase of the BAF due to the low limit

Calculating the new generalized cost for each of the available options can be used in conjunction with the calibration results of WP2, to predict the new market share as follows:

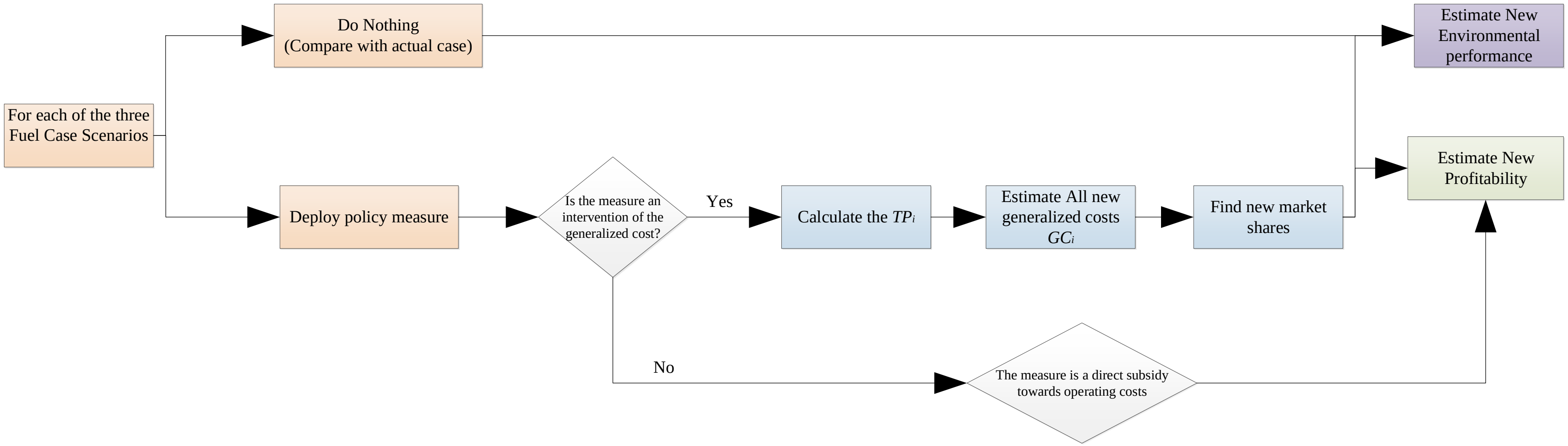


Figure 5: The modelling process of the effects of new policy measures examined in Task 3.2

7.2 Modal split module post-policy maker measure

For the binary case between a maritime *m* and a land-based *l* option, let GC_m and GC_l be the respective generalized costs of transport used in the calibration. As stated in the report on Task 2.2, the scale parameter λ can be calibrated if the market shares of each option x_m and x_l respectively are known. Let now GC_m' and GC_l' to denote the new generalized cost for each option following a change in the cost or travel time (or both). The objective in this case is to estimate the required increase in the generalized cost of the competing mode, so that the new market shares x_m' and x_l' are the same as before, considering though that GC_m' will have increased due to the BAF It is possible to eliminate the unknown scale parameter l if equation 4 is used for both cases (before and after the introduction of changes) considering the following system:

$$
\begin{cases}
x_m = \dfrac{e^{-\lambda \cdot GC_m}}{e^{-\lambda \cdot GC_m} + e^{-\lambda \cdot GC_l}} & (4) \\[2ex]
x_l = \dfrac{e^{-\lambda \cdot GC_l}}{e^{-\lambda \cdot GC_m} + e^{-\lambda \cdot GC_l}} & (5) \\[2ex]
x_m' = \dfrac{e^{-\lambda \cdot GC_m}}{e^{-\lambda \cdot GC_m'} + e^{-\lambda \cdot GC_l'}} & (6) \\[2ex]
x_l' = \dfrac{e^{-\lambda \cdot GC_l'}}{e^{-\lambda \cdot GC_m'} + e^{-\lambda \cdot GC_l'}} & (7)
\end{cases}
$$

Dividing equation 4 over 5 and equation 6 over 7, and taking logarithms for each new equation gives:

$$
\begin{cases}
\ln\left(\dfrac{x_m}{x_l}\right) = -\lambda(GC_m - GC_l) & (8) \\[2ex]
\ln\left(\dfrac{x_m'}{x_l'}\right) = -\lambda\left(GC_m' - GC_l'\right) & (9)
\end{cases}
$$

Finally, dividing 6.5 over 6.6 allows the elimination of the scale parameter, and thus the expression of the new market shares as a function of the generalized cost differentials ΔGC and $\Delta GC'$, leading to equation 7:

$$\frac{x_m'}{x_l'} = \left(\frac{x_m}{x_l}\right)^{\frac{\Delta GC'}{\Delta GC}} \qquad (10)$$

Considering that the market shares x_m and x_l add up to the total transported volumes (or to 1 if these are treated as probability of choosing a mode), it is possible to estimate the impacts of the new changes in the probability of selecting each of the affected modes. This theoretical approach can also be used in cases where more than two options are available, and accurate information on the market shares is not retrieved. Thus, bypassing the need to calibrate the scale parameters.

From equation (10), it is evident that the necessary TP_i to fully reverse any negative impacts of the low sulphur regulation, has to be equal to the effect of the regulation on ΔGC. Assuming that the initial effect of the regulation was only affecting the freight rate (through the bunker ardjustment factor), it is obvious that the TP_i should aim at reverting this change. While this can be straightforward in the case of a policy subsidy towards the shipper (e.g. the policy maker pays the difference), it is harder to calculate for other options. In the case of providing a tax levy on landbased modes, an additional step is required where the tax levy per km needs to be equal to the total BAF increase (per shipment), taking into account all landbased steps (also in the maritime mode). This calculation is explained further in section 8.3.

7.3 Calculation of costs to policy makers

There may be some direct costs (or benefit) that the policy maker would have to cover. For example,

- Provision of financial assistance towards the retrofit of a vessel with abatement technology (e.g. scrubber system)
- A subsidy towards the shipper in the form of an ECO-bonus initiative
- Covering the BAF or part of it for the shipper
- A difference in the total external costs generated by modal shifts that is therefore a society cost or benefit
- A revenue source by the implementation of some additional tax on landbased options

These costs will lead to a change in emissions, and thus the cost per abated ton of pollutant through a policy measure can be retrieved, and compared to the value of the external cost of each of the modelled pollutant species. For each measure, these costs or benefits are calculated as a function of the affected units of transport as follows:

- The total cost for the subsidy of one retrofitted vessel, based on estimated technology costs
- The number of lane meters on-board a vessel multiplied with the subsidy per unit offered in an ECO-bonus system or BAF
- The net difference in external costs as a result of modal shifts due to a regulation

For all of the examined measures, one critical question will be who would be responsible for covering the necessary costs, while there should also be an estimation of secondary costs for the policy (monitoring of transported volumes that can qualify for a subsidy, ensuring commitment of beneficiaries to using the technology as in MoS. However, answering these questions is beyond the scope of this project.

7.4 New Environmental Balance and Route profitability

Figure 5 illustrates that the introduction of changes in the service through a policy measure, can affect both the environmental and economic performance of the fleet. Considering that the fuel consumption per trip can be calculated from the models developed in Task 3.1, and given that the modal split model will estimate the new transport demand, it is possible to calculate the new emissions generation from the service per transported unit. At the same time, given the fuel prices in each scenario, it is possible to estimate the new fuel costs, and the new revenue based on the new transport demand for the shipping company, also taking into account any subsidy from the policy maker (particularly if there is a direct subsidy towards abatement investments). This analytical calculation allows a good approximation of the effects of the proposed measures to each route examined in the context of Task 3.1. Outputs of the model for the new environmental and economic performance of each route are shown in a screenshot of the model, in Figure 6.

BASELINE 2014																					
Option 1												Option 2									
GC	Freight Rate	of which I	Road Co:	Road Distance	Cargo Value	Depreciation R:	Total Tim	CO2 (tota	SO2 (port pe	NOx (port per lm)	Transported lm per trip	GC		Road Co:	Road Dis	Cargo Va	Deprecia	Total Tim	CO2	SO2	NOx
42.388	37.66723411	0	0.0333	100	10000	0.045	27.012	76.666	0.0141755	0.040400169	2029.50069	54.508		0.0333	1600	10000	0.045	22.857			
2015 what happened																					
Option 1												Option 2									
39.484	34.76279655	0.3291	0.0333	100	10000	0.045	27.012	75.397	0.013941	0.039731773	2063.642341	54.508		0.0333	1600	10000	0.045	22.857			
MITIGATE MODAL SHIFT VIA POLICY																					
39.155	34.76279655	0.3291	0.0333	100	10000	0.045	27.012	75.196	0.0139037	0.039625506	2069.176627	54.508		0.0333	1600	10000	0.045	22.857			
lamda	0.019				Initial Utilization Rate																
	SHARE 1	0.5573			84.69%																
	SHARE 2	0.4427																			
				Change Share																	
	SHARE 1	0.5709		1.36%	86%																
	SHARE 2	0.4291		-1.36%																	
	SHARE 1 NEW	0.5724		1.51%	86.35%																
	SHARE 2 NEW	0.4276		-1.51%																	

Choose Policy Measure and specs

Figure 6: The aftermath of the policy measure on emissions and profitability

7.5 Selection of policy measures

In section 8, a series of representative case studies for each of the examined policy measures will be presented to illustrate their effects. The examined measures can however be altered to examine their sensitivity to changes in key parameters such as the level of a tax levy, a partial repayment of the BAF to the shipper, an inclusion of external costs for only the maritime sector, or to go as far as the introduction of alternative options (e.g. a conceptual introduction of road speed limits). In the case studies, this measures are examined individually. However, the model is set up in a way where a combination of policy measures can be tested for each of the seven existing DFDS routes. A user-interface has been created which prompts the user to select a combination of policy measures as shown in Figure 7.

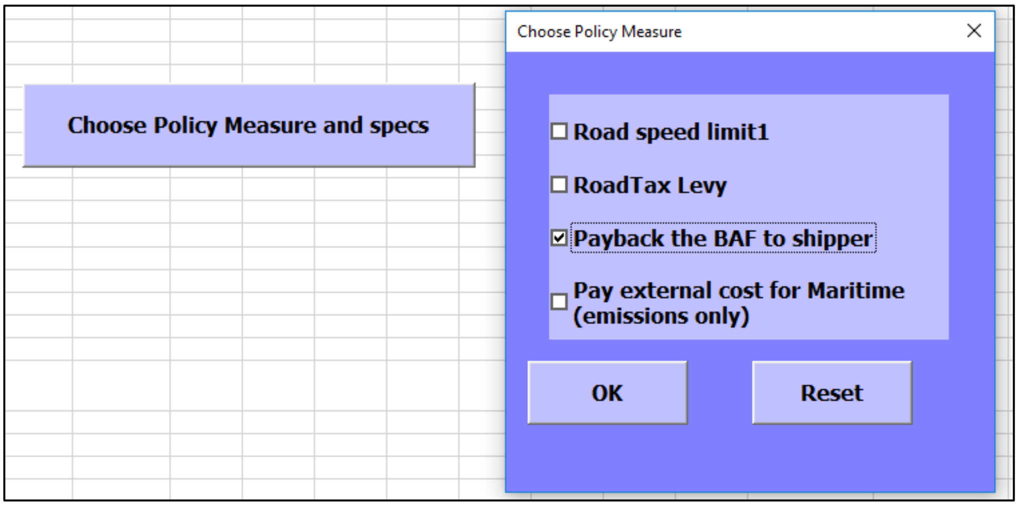


Figure 7: Selection of policy measures to be tested

Subsequently, for measures that require an additional specification (e.g. what levy, what speed limit), the user will have to provide this argument as in Figure 8.

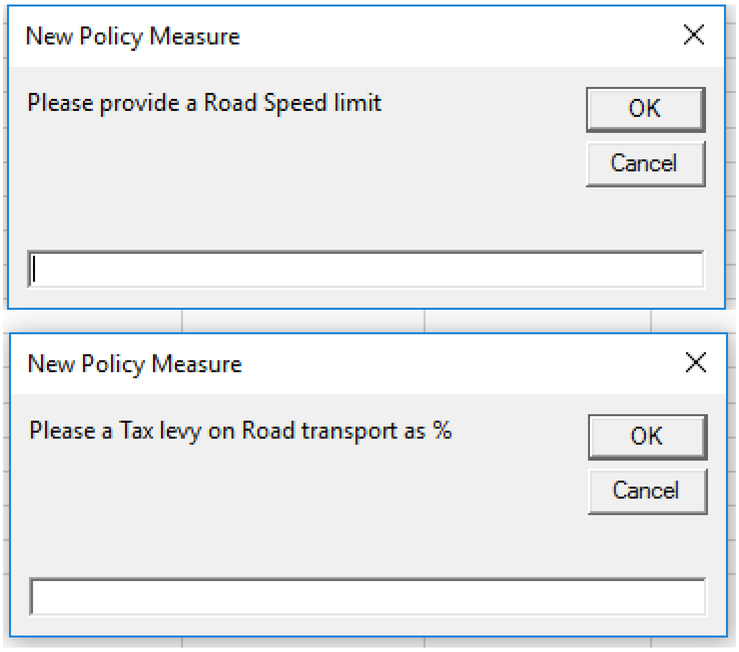


Figure 8: Entry request for specification of policy measure

The output of these measures are the new modal balance, the new revenue of the ship operator, and the new environmental balance of the system. In future versions of the developed tools, the option of combining these policy measures with a change in sailing speed from the Ro-Ro operator will be possible. This section of the report presented the new modelling tools developed for the examination of the impact of the proposed policy measures, for each of the examined routes. The next section will present illustrative results for each of the proposed measures.

8 Simulation of modal changes, and relevant policy costs

This section will present a summary of runs performed for the measures described in section 6, for each service. As with previous tasks, three main fuel price scenarios are used for each implementation of a measure, and each measure is considered individual. For each route and measure examined, the changes in market shares are compared to the change in market share as a consequence of the lower sulphur limit (e.g. the modal shift because of the regulation for each fuel price scenario).

8.1 Impacts of internalization of external costs in the examined routes

The internalization of external costs in the examined services would lead to significant increases in the transportation costs for each service, as well as an increased cost for the landbased legs. This section uses the values suggested in Section 5, and presents the resulting increases in freight rates for each mode at each route. For the maritime modes, it is expected that an internalization of the external costs would result in higher freight rates as the emissions of the voyage could be allocated to the units transported. As in the case of Task 2.2, for services that also carry passengers the way the emissions would be allocated between cargo and passengers is not standard, and there can be great variability. For the sake of comparison across the routes, the next section assumes that all emissions are always attributed to the cargo even though that would not be realistic in an internalization scenario. For the maritime modes, the emissions at the port are considered for CO_2, SO_x,NO_x and $PM_{2.5}$ emissions, while at the sailing phases only the CO_2 emissions are internalized. For the first route more analytical results will be presented using different combinations of scenarios (full internalization of CO2 only, or of all emissions, in combination with the different levels of the external cost values – low, medium, high).

- Gothenburg – Ghent

This cargo service is the longest route of the ones examined. Based on the fuel consumption of all trips during 2015, as well as the actual number of transported units it is possible to estimate what is the external cost per unit of transportation. Figure 9 shows the external cost if only the CO_2 emissions are internalized, for all estimates (low, medium, high) of the two studies in 2015 prices as shown in Table 22.

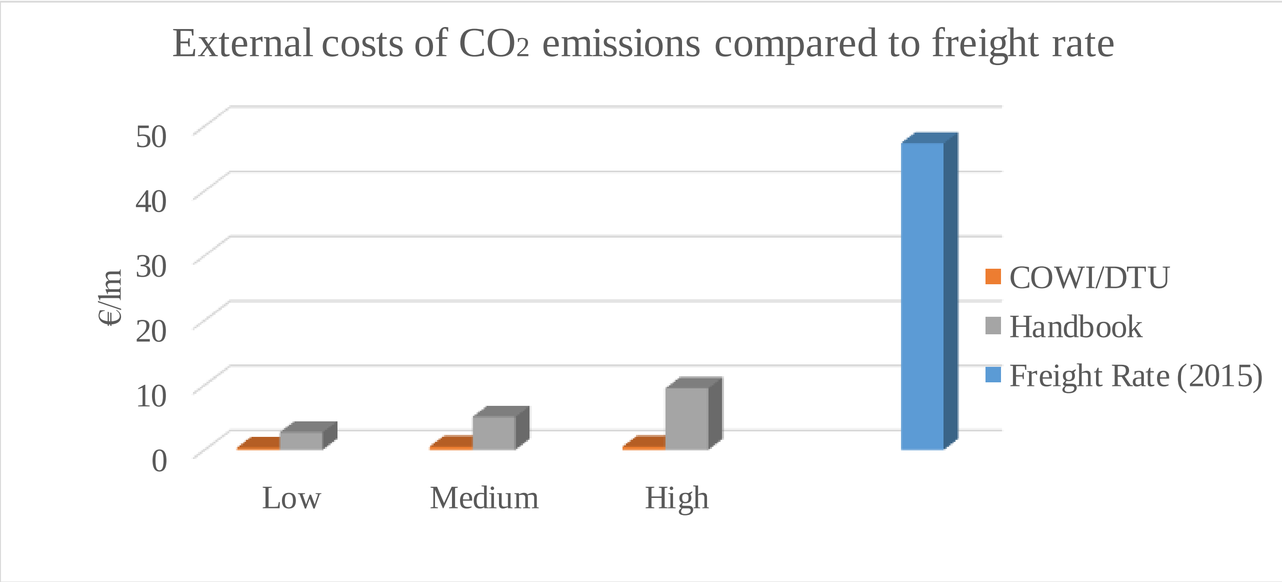


Figure 9: Comparison of external costs of emissions per lane meter with the freight rate

It is evident that a full internalization would be a significant cost only in case the suggested values from the Handbook are used. The inclusion of harmful pollutants at the port would increase the external costs as shown in Figure 10.

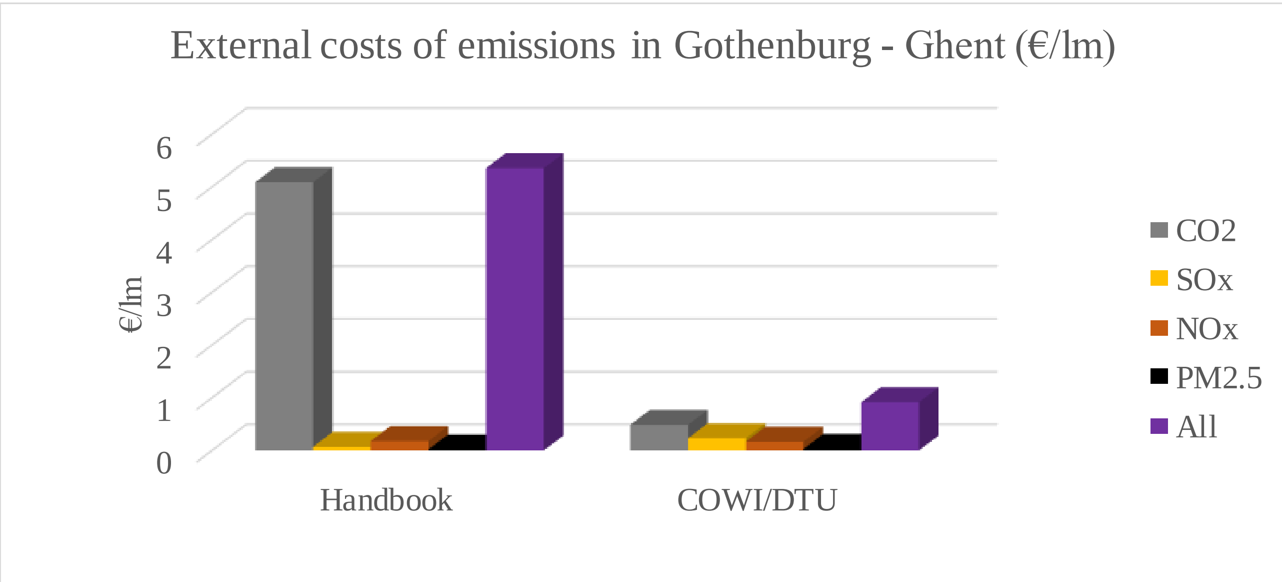


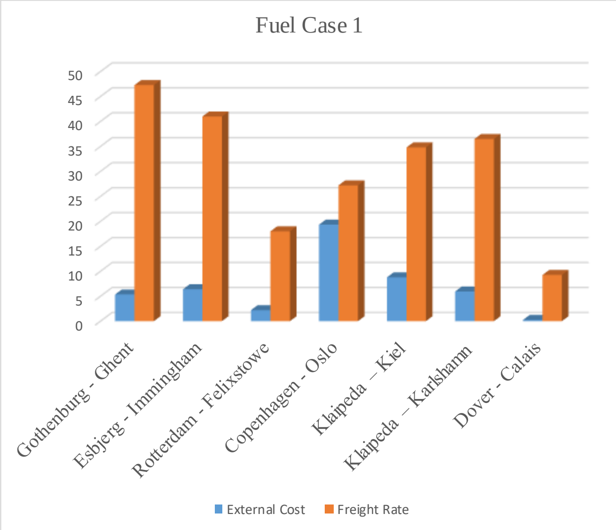
Figure 10: Comparison of contribution of different pollutants to the external costs for one transported lamenter in Gothenburg – Ghent

Figure 10 shows that the main difference for both methodologies is due to the cost of carbon emissions. If all pollutants external costs are internalized, there is a significant increase in the total external cost per lane meter at this route. The next table summarizes the impacts of internalizing these costs on the market shares of each mode.

Table 28: Effects of internalization of external costs on modal share

	Fuel Case 1			Fuel Case 2		
	Maritime external cost (extra €/lm)					
Landbased external cost	5.35			5.84		
0.8732 €/vkm	Internalization level (%)			Internalization level (%)		
Mode	0	50	100	Baseline	50% internalization	Full internalization
Maritime (DFDS)	32.1	47.0	61.2	28.4	43.8	58.1
Maritime (other)	29.8	29.5	25.9	31.5	31.2	27.9
Landbased	38.1	23.5	12.9	40.1	24.9	14.0
Total Policy Revenue (€)	NA	0.959	1.465M	NA	1.009	1.561M

Table 28 shows the effects of a hypothetical internalization of external costs in the Gothenburg – Ghent service. It is noteworthy that for the high fuel price scenario, the external cost of the maritime leg is increasing due to the lower load factor that is arising as a result of the market loss. In both the partial (50%) and full internalization, it is evident that the maritime option with the least road distance involved (DFDS at 100 km on average, vs 500 on the competing maritime option at Gothenburg – Kiel) would actually increase its transport demand, mainly due to the much higher external costs for the road option used in this work. In such a scenario, there would actually be a need to deploy more vessels in this route. It should also be mentioned that such an internalization would significantly increase the freight rates for all options, and as a result there would be a reduction in the total transportation demand, which cannot be calculated with the developed models. Figure 11 summarizes the cost of internalization per unit transport compared to the freight rate of each route for the two fuel case scenarios, assuming full emissions allocation to the cargoes.



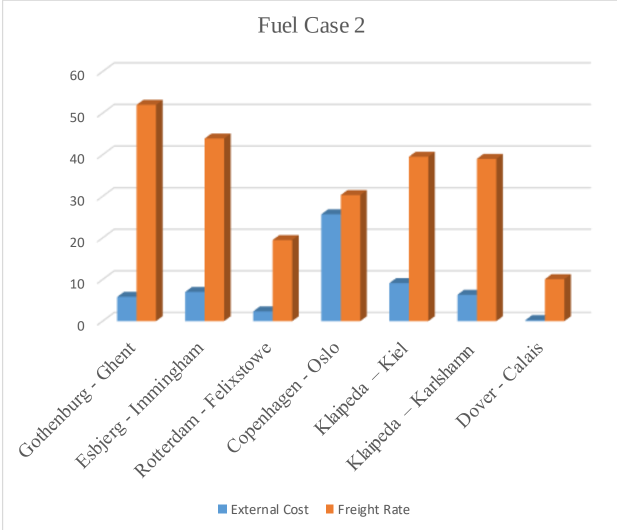


Figure 11: Cost of internalization of emissions for each route

It is evident that for the cargo routes the external costs are between 10 and 16% of the freight rate for both fuel case scenarios. The impacts of internalizing the external costs of transport are revisited in section 9 of this report, with visual representation of the impacts of such a policy in the road network model.

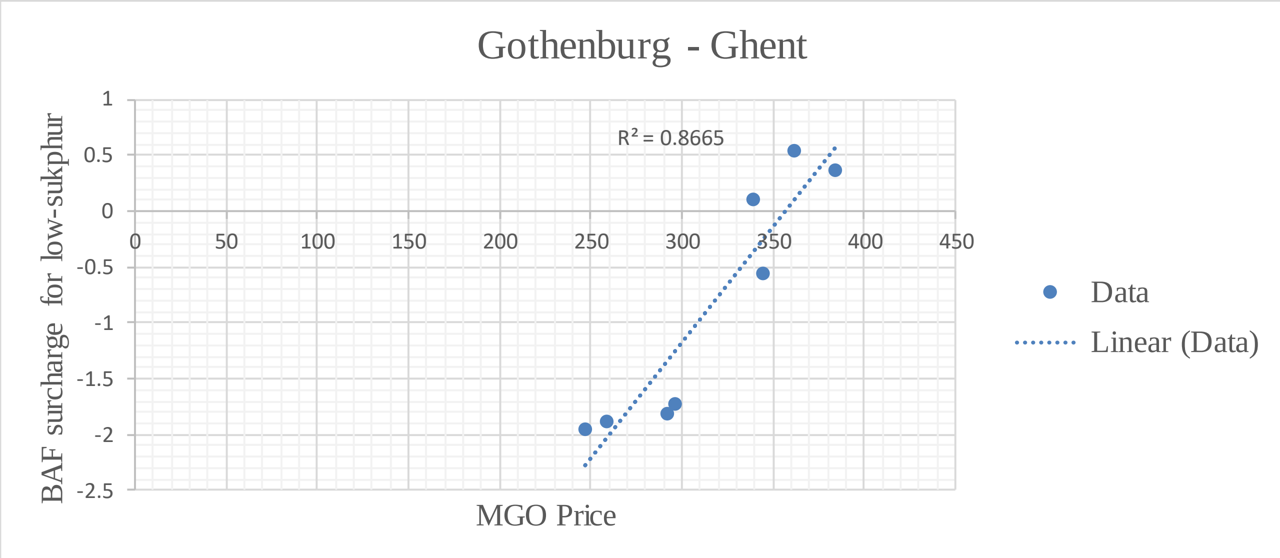
8.2 Providing monetary assistance to shippers to negate the BAF surcharges

This measure considers that a policy body will cover the additional surcharges that shippers have to pay for the use of low-sulphur fuel. Shipping companies are adjusting their freight rates through the use of the bunker adjustment factor (BAF). Each operator is required to set its own method for calculating the exact amount that the shipper has to pay, and is a function of the fuel price, typically at the time of purchase. Since the 1st of January 2015, DFDS has included the price differential between ultra-low sulphur fuel and HFO in the calculation, thus effectively increasing the freight rates for shippers due to the regulation. The calculation is always conducted based on the fuel price differential between the MGO 0.1% price from Rotterdam, and the HFO (1%) price during October-November 2014. The exact final amount depends on various service characteristics, including the length, frequency, sailing speed, and ship type. In Table 29, the actual fluctuations of the BAF are shown for the seven routes for most months of 2015.

Table 29: Fluctuations of the BAF with the respective 0.1% MGO price that defined it

Route	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fuel Price 0,1% MGO	258	247	291	295	344	NA		338	361	384	377
Gothenburg/Brevik - Ghent	-1,89	-1,95	-1,81	-1,73	-0,56			0,11	0,55	0,37	0,92
Esbjerg - Immingham	-1,47	-1,52	-1,41	-1,34	-0,44			0,09	0,43	0,29	0,71
Rotterdam - Felixstowe	-0,54	-0,56	-0,52	-0,49	-0,16			0,03	0,16	0,11	0,26
Copenhagen - Oslo	-1,47	-1,52	-1,41	-1,34	-0,44			0,09	0,07	0,29	0,71
Klaipeda – Kiel	-2,17	-2,24	-2,08	-1,97	-0,64			0,13	0,63	0,43	1,05
Klaipeda – Karlshamn	-1,25	-1,29	-1,19	-1,13	-0,37			0,07	0,36	0,25	0,6
Dover - Calais	-0,43	-0,44	-0,41	-0,39	-0,13			0,02	0,02	0,08	0,21

Where the negative values indicate a reduction in the BAF surcharge in comparison to the baseline HFO value (October and November 2014). If the low sulphur requirement was not present, the reduction would be greater. In order to model the effect of the BAF on each of the examined routes, a model was constructed that predicts the additional BAF surcharge for each of the routes, as a function of fuel price for MGO 0.1% only. This was achieved through fitting a linear regression model using the least square method for each of the examined routes. An example is shown for Gothenburg – Ghent, with an R^2 value of 0.8665.



In this section the resulting market shares from a policy instrument covering the BAF due to the low sulphur requirement are calculated, for fuel case scenarios 1 and 2. It is assumed that the BAF is covered only for the DFDS routes, due to lack of information on the BAF policy and values of other operators. For all scenarios and for the sake of facilitating comparisons, it is assumed that the number of trips in the year will be the same as the actual trips in 2015

- Gothenburg – Ghent

Table 30: Impacts of subsidizing the BAF premium on Gothenburg – Ghent

	Fuel Case 1		Fuel Case 2	
BAF cost (extra €/lm)	1.37		5.13	
Mode	Baseline	Pay BAF	Baseline	Pay BAF
Maritime (DFDS)	32.1	32.9	28.4	31.3
Maritime (other)	29.8	29.5	31.5	30.2
Landbased	38.1	37.6	40.1	38.5
DFDS Utilization Rate	Confidential	+2.5%	NA	
Total Policy Cost (€)	2502557		10063542	

Table 30 shows that the total policy cost for this service will heavily depend on the fuel prices. For FC1, which is the actual fuel prices observed in 2015, it can be seen that approximately 2.5 million €

would be required to offset the effect of the low sulphur fuel on the freight rates. This would result in an additional 0.8% of the market to be captured by DFDS, more than 60% of it will be a shift from the landbased option. For FC2, it is evident that the cost is much larger at around 10 million €, and the increased share (0.9%) will come mostly from the competing maritime mode, due to the assumption that this BAF would only be paid for the DFDS route.

- Esbjerg – Immingham

Table 31: Impacts of subsidizing the BAF premium on Esbjerg – Immingham

	Fuel Case 1		Fuel Case 2	
BAF cost (extra €/lm)	1.19		4.30	
Mode	Baseline	Pay BAF	Baseline	Pay BAF
Maritime (DFDS)	64.5	66.7	58.4	66.7
Landbased	35.5	33.3	41.6	33.3
DFDS Utilization Rate	Confidential	+3.5%	NA	
Total Policy Cost (€)	1963015		7817635	

Table 31 shows the variability in the cost of such a policy with different fuel prices. Considering that the service characteristics would not change (ie. Service time and frequency), at times of high fuel prices reimbursing the BAF can be costly for this service (almost 8 million €). In such an event, the revenue of the operator would not be reduced due to a loss of cargoes; however, the fuel costs of the service would still increase.

- Rotterdam – Felixstowe

Table 32: Impacts of subsidizing the BAF premium on Rotterdam – Felixstowe

	Fuel Case 1		Fuel Case 2	
BAF cost (extra €/lm)	0.44		1.58	
Mode	Baseline	Pay BAF	Baseline	Pay BAF
Maritime (DFDS)	26.1	27.3	23.1	27.3
Landbased	73.9	72.7	76.9	72.7
DFDS Utilization Rate	Confidential	+4.7%	NA	
Total Policy Cost (€)	1595017		6491124	

As with the previous route, reverting the modal shifts that result from the low sulphur regulation can be significantly costly in times of high fuel prices.

- Copenhagen – Oslo

Table 33: Impacts of subsidizing the BAF premium on Copenhagen – Oslo

	Fuel Case 1		Fuel Case 2	
BAF cost (extra €/lm)	1.19		4.30	
Mode	Baseline	Pay BAF	Baseline	Pay BAF
Maritime (DFDS)	18.7	20.8	14.1	20.8
Landbased	81.3	79.2	85.9	79.2
DFDS Utilization Rate	Confidential	+10.9%	NA	
Total Policy Cost (€)	696241		3328295	

This route is very interesting as it is predominantly a passenger service, however the BAF surcharge per lane meter is the same as in Esbjerg – Immingham. It is interesting to note the significant increase in market share and utilization rate in comparison to the other services. This is due to the very low utilization observed in the baseline (actual) case, and sensitivity to the freight rate. The total costs of this measure are lower, due to the fact that this is a service targeting passengers, the decision patterns of whom are not modelled in this measure.

- Klaipeda – Kiel

Table 34: Impacts of subsidizing the BAF premium on Klaipeda – Kiel

	Fuel Case 1		Fuel Case 2	
BAF cost (extra €/lm)	1.76		6.34	
Mode	Baseline	Pay BAF	Baseline	Pay BAF
Maritime (DFDS)	57.1	57.9	54.9	57.9
Landbased	42.9	42.1	45.1	42.1
DFDS Utilization Rate	Confidential	+1.43	NA	
Total Policy Cost (€)	2270397		8480922	

This route has the highest BAF surcharge and as a result the highest costs as a policy. It is interesting to note that in 2015 Klaipeda – Kiel was the route (of the ones examined in RoRoSECA) that had the highest drop in transport demand and revenue (9%) excluding Dover – Calais for exogenous reasons. In 2016, there were increased sailing speeds observed that took advantage of the low fuel prices. As discussed in the deliverable report on Task 3.1, this service could benefit from a change in the sailing speed of the vessels, with significant reductions in case of high fuel prices. If a policy intervention is used instead, in the form of covering the BAF, it would cost approximately 8.5 million.

- Klaipeda – Karlshamn

Table 35: Impacts of subsidizing the BAF premium on Klaipeda – Karlshamn

	Fuel Case 1		Fuel Case 2	
BAF cost (extra €/lm)				
Mode	Baseline	Pay BAF	Baseline	Pay BAF
Maritime (DFDS)	71.5	73.1	66.9	73.1
Landbased	28.5	26.9	33.1	26.9
DFDS Utilization Rate	Confidential	+2.3%	NA	
Total Policy Cost (€)	1379728		5312740	

The second Baltic service that is also carrying passengers, is the examined route with the least competition due to the geographical advantages it has. However, there is significant transport loss at high fuel prices, that can be averted with approximately 5.3 million €. The policy cost is lower in this route than most services, due to the smaller distance, and shows a better value for money in mitigating potential modal backshifts.

- Dover – Calais

Table 36: Impacts of subsidizing the BAF premium on Dover – Calais

	Fuel Case 1		Fuel Case 2	
BAF cost (extra €/lm)	0.33		1.2	
Mode	Baseline	Pay BAF	Baseline	Pay BAF
Maritime (DFDS)	42.8	43.5	41.0	43.5
Landbased	57.2	56.5	59.0	56.5
DFDS Utilization Rate	Confidential	+1.6%	NA	
Total Policy Cost (€)	2347834		8946668	

The final examined route is the service with the highest frequency and lowest sailing distance. It has to be noted that the results refer to the number of voyages in 2015 which was smaller due to external events. Table 36 shows that if in 2015, a policy body would repay the BAF surcharges, a sum of 2.3 million € would be necessary, and would result in a full reversion of the direct effects of the regulation. At higher fuel prices, this cost would rise to almost 9 million €.

This section estimated the costs of BAF surcharge repayment as a policy option, for the two fuel case scenarios. Essentially, this is a combination of the added monetary cost that shippers paid in this year due to the regulation (the ones that did not switch or stop transportation), and of the loss of cargoes. The next section will examine what is the necessary increase in the landbased options, to result in a similar mitigation of the negative effects of the regulation.

8.3 Introduction of tax levies on land-based options

This section conducts an exploratory analysis where the objective is to identify what percentage increase in the total monetary cost of landbased transport options will result in absorbing the modal backshift attributed to the low sulphur fuel requirement. It is an application of the theory presented in section 7.2. The necessary percentage increases are summarized in Table 37, for the two fuel price scenarios. For the Dover – Calais service, the percentage increase refers to the Eurotunnel cost. For Klaipeda – Karlshamn this measure was not considered due to the lack of competition with other options (in WP2 this route was considered illustratively to compete with a Stena line between Gdynia and Karlskrona, with very similar road distances to Klaipeda – Karlshamn).

Table 37: Tax levy to reverse negative effects of low sulphur limits

Route	Fuel Case 1	Fuel Case 2
Gothenburg - Ghent	3.83	14.48
Esbjerg – Immingham	2.48	8.95
Rotterdam – Felixstowe	3.3	11.88
Copenhagen – Oslo	7.15	25.8
Klaipeda – Kiel	3.52	12.68
Dover – Calais (Eurotunnel)	2.12	7.74

Table 37 clearly shows that the examined Ro-Ro services would be at considerable risk for high fuel prices. The necessary increase in the landbased option to offset the effects of the higher BAF is increasing significantly in FC2. The wide variance of the necessary landbased tax levy is evidence of the sensitivity of the total road lengths in the shippers' decision making process. Therefore, suggesting a flat levy at 10% (e.g. in the form of an additional tax on petrol) would lead to net modal shifts towards maritime services for most of the examined routes (net in the sense that it would overcome the negative effects of the low-sulphur requirements).

8.4 Easing the port dues of a ship operator

The port dues for ship operators are typically depending on the vessel size, and the length of stay at the port. For example, the port of Esbjerg charges 7.95 DKK per GT per month for a visiting vessel, that in the case of the two DFDS vessels accounts for approximately 0.85 million € a year. Esbjerg is then providing a 90% refund of this cost in the next year if the vessel is a Ro-Ro ship (source: http://portesbjerg.dk). In contrast, the port of Immingham has a tariff of £3.98 per NT just for the port fees (http://www.humber.com) and the DFDS vessels have a net tonnage of approximately 10000. In addition, different ports have additional costs for mooring, waste charges, dock rents, fairway dues in certain countries etc. While most of these costs are available online, the actual costs paid by frequent callers (as in the case of Ro-Ro services) are not public. It is therefore very difficult to construct a one-fits-all policy for the easement of such fees. In the case of DFDS, data were retrieved on the percentage cost of the port fees, in the annual costs of each service during 2015. These are given in comparison to the fuel costs in Table 38

Table 38: Port fees vs fuel costs as % of operating costs

Route	Port cost as % of operating costs	Fuel costs as % of operating costs
Gothenburg - Ghent	4.6	30
Esbjerg – Immingham	4.2	39
Rotterdam – Felixstowe	4.5	30
Copenhagen – Oslo	4.7	21
Klaipeda – Kiel	6.8	NA
Klaipeda – Karlshamn	4.9	21
Dover – Calais	14.7	23

Table 38 shows that the port costs in the year are a very small component of the overall operating cost for each service, with the exception of Dover Calais with a very high number of port calls a year. An interesting comparison can be made if the percentage towards the operating costs due to the use of MGO instead of HFO is estimated. While some vessels have been using scrubbers and therefore are still using HFO, for a ship operator with a similar cost structure, the MGO-HFO differential price would amount between 8 and 15% of the total operating costs, which is higher than the port fees.

If a subsidy is provided to the ship operators towards their port dues, this could amount (for a full refund) to between 1.2 and 8 million € per year, which is similar for most routes to the cost of simply covering the BAF surcharges as seen in section 8.2.

8.5 Effects of an ECO-bonus scheme in the examined routes

As discussed in section 6.3, the ECO-bonus systems have various different specifications, where some incentive is provided to shippers switching from landbased options to a maritime leg. This section considers the annual costs of providing a subsidy of 20% of the freight rate paid in each service for all customers (new and old) during 2015, and the impact this would have on the market shares of the examined service (additional %share captured).

Table 39: Cost and impacts on market share of a 20% subsidy to shippers

Route	Fuel Case 1	Fuel Case 2
Gothenburg – Ghent	+5.93%	+6.18%
Total Policy Cost (€)	21M	23M
Esbjerg – Immingham	+13.6%	+16%
Total Policy Cost (€)	14.6M	14.9M
Rotterdam – Felixstowe	+10.92%	+10.95%
Total Policy Cost (€)	17.6M	19.5M
Copenhagen – Oslo	+10.63	+9.97
Total Policy Cost (€)	4.5M	5.4M
Klaipeda – Kiel	+3.2%	+3.67%
Total Policy Cost (€)	9.3M	10.7M
Klaipeda – Karlshamn	+10.55	+12.4%
Total Policy Cost (€)	11.1M	12.4M
Dover – Calais	+3.9%	+4.24%
Total Policy Cost (€)	14.2M	15.7M

The results indicate that such as scheme would be very successful in attracting additional customers using the Ro-Ro links, however the cost would be particularly high if it was applied to all users. In case a pilot implementation was considered, whereby the refund would be provided only to new users of the link, the cost would be proportionally lower. It is clear that such a policy would have an objective of increasing the users of maritime services, and not simply to reverse the negative effects of the low-sulphur regulation, as the monetary incentive exceeds the actual surcharge imposed on shippers because of low-sulphur fuel use. A subsidy of a different level could also be considered as a potential measure.

8.6 Policy cost of subsidies towards retrofits for abatement technology

This section considers providing a subsidy for the installation of scrubber systems as an alternative policy option. DFDS has already received support of up to 20% for the retrofits of vessels with certain constraints only with regards to the services in which the retrofitted vessels are allowed to operate. Table 40 presents the total cost that such a policy would incur, for the retrofit of the vessels deployed in each of the examined routes (considering no vessel swapping, and that only the maximum number of vessels deployed in a peak-week are retrofitted).

Table 40: Costs towards scrubber retrofits

Route	Number of vessels	Retrofit subsidy for scrubbers (M€)
Gothenburg – Ghent	3	2.4-4.8
Esbjerg – Immingham	2	1.6-3.1
Rotterdam – Felixstowe	3	2.6-5.2
Copenhagen – Oslo	2	1.9-3.8
Klaipeda – Kiel	2	1.9-3.8
Klaipeda – Karlshamn	2	1.7-3.4
Dover – Calais	2	1.8-3.5

The variations are due to the different estimates on the cost for a retrofit per installed power (see report on Task 2.1). It can be seen that such a policy would require significant funds for the installation of scrubbers on all the available vessels. However, these costs are one-off (unlike other policies that could be annual) and in theory could be combined with a requirement that the benefitted ship operators would reduce the BAF surcharge since they could still use HFO.

At the same time, from the ship operators perspective the payback period of such an investment will be drastically reduced. Zis et al. (2016) showed that due to the very low fuel prices in recent years, the payback period of scrubber investments has doubled in certain cases. In a scenario where a subsidy is provided towards the capital investment costs, the payback period will be reduced by the percentage amount covered by the subsidy.

This section presented a summary of the runs performed in the context of Task 3.2, and the anticipated impacts of such policies in an effort to reverse modal backshifts towards landbased modes, as well as to ensure the sustainability of short sea shipping services. The next section will illustrate the effects of a potential internalization of external costs of transport, through the use of the road network model developed in the context of Task 2.2, and enhanced for Task 3.2.

9 Visualization of external costs of transport in the road network

This section describes the calculation of the external cost maps for the RORO SECA project. In Task 2.2 of the RORO SECA project a tool was developed for calculation, visualisation and assessment of transport costs and competitive relations within freight transport. The tool can model the supply (or performance) of an intermodal transport system and visualise competitive relations between different modes. This section describes how the RORO SECA tool has been extended to visualize the effect of internalising the external cost of transport.

9.1 Background

The RORO SECA tool that can model the cost of freight transport within an intermodal transport system. In this case the model has been extended not only to include the user cost but also to include the external cost of transport. The external cost values shown in table below were compiled in the Section 5 of this report.

Table 41: Illustrative marginal costs for a diesel 23.2 t rigid truck in € per vkm (EU, 2015 prices)

External cost	2014 Handbook (EU)			COWI/DTU study (DK)			Present study (EU)		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Climate change	0.0360	0.0859	0.2428	0.0069	0.0105	0.0105	0.0069	0.0859	0.2428
Air Pollution	0.0013	0.0899	0.4850	0.0024	0.0677	0.4786	0.0013	0.0899	0.4850
Noise	0.0005	0.1026	0.6042	0.0072	0.0144	0.0289	0.0005	0.1026	0.6042
Accidents	0.0025	0.0152	0.0380	0.0403	0.1839	0.2421	0.0025	0.0152	0.2421
Congestion	0.0000	0.5138	7.7744	0.0195	0.0856	0.2513	0.0000	0.5138	7.7744
Infrastructure	0.0190	0.0659	0.5711	0.0375	0.1500	0.2250	0.0190	0.0659	0.5711
Total	0.0593	0.8732	9.7155	0.1138	0.5121	1.2363	0.0302	0.8732	9.9196

The user cost for a diesel 23.3 t rigid truck is calculated to 1 EUR/vKm. This means that a full internalisation of the external cost for this kind of truck will increase the user cost with app. 87%.The shipping lines shown in the table below are the one included in the intermodal network. For each of the shipping lines both the user and external costs are shown.

Table 42: Marginal external costs for using RORO lines to transport a diesel 23.2 t rigid truck in € per trip (EU, 2015 prices)

RoRo line	User Cost (€/trip)	External Cost (€/trip)
Gothenburg – Ghent	758	72
Esbjerg – Immingham	653	100
Rotterdam – Felixstowe	287	33
Copenhagen – Oslo	435	267
Klaipeda – Kiel	556	118
Klaipeda – Karlshamn	583	82
Dover - Calais	148	4

In order to illustrate some of the effects of internalising the external costs a full internalisation of the marginal external cost for sea transport are calculated.

9.2 Generating the thematic maps

The output of the RORO SECA tool are two types of thematic maps:

- Isocost maps
- Differential maps

Each type is calculated for making the external cost maps and are briefly described in the following sections.

Isocost maps

Isocost maps are showing different cost levels for the accumulated cost of transport from a given origin using the least expensive route. The accumulated transport costs is illustrated as uniform bands of isocosts. The calculated isocost map for a land (truck) based transport chain from Gothenburg in Sweden to destinations around the SECA area using the previous mentioned user costs are shown in Figure 12.

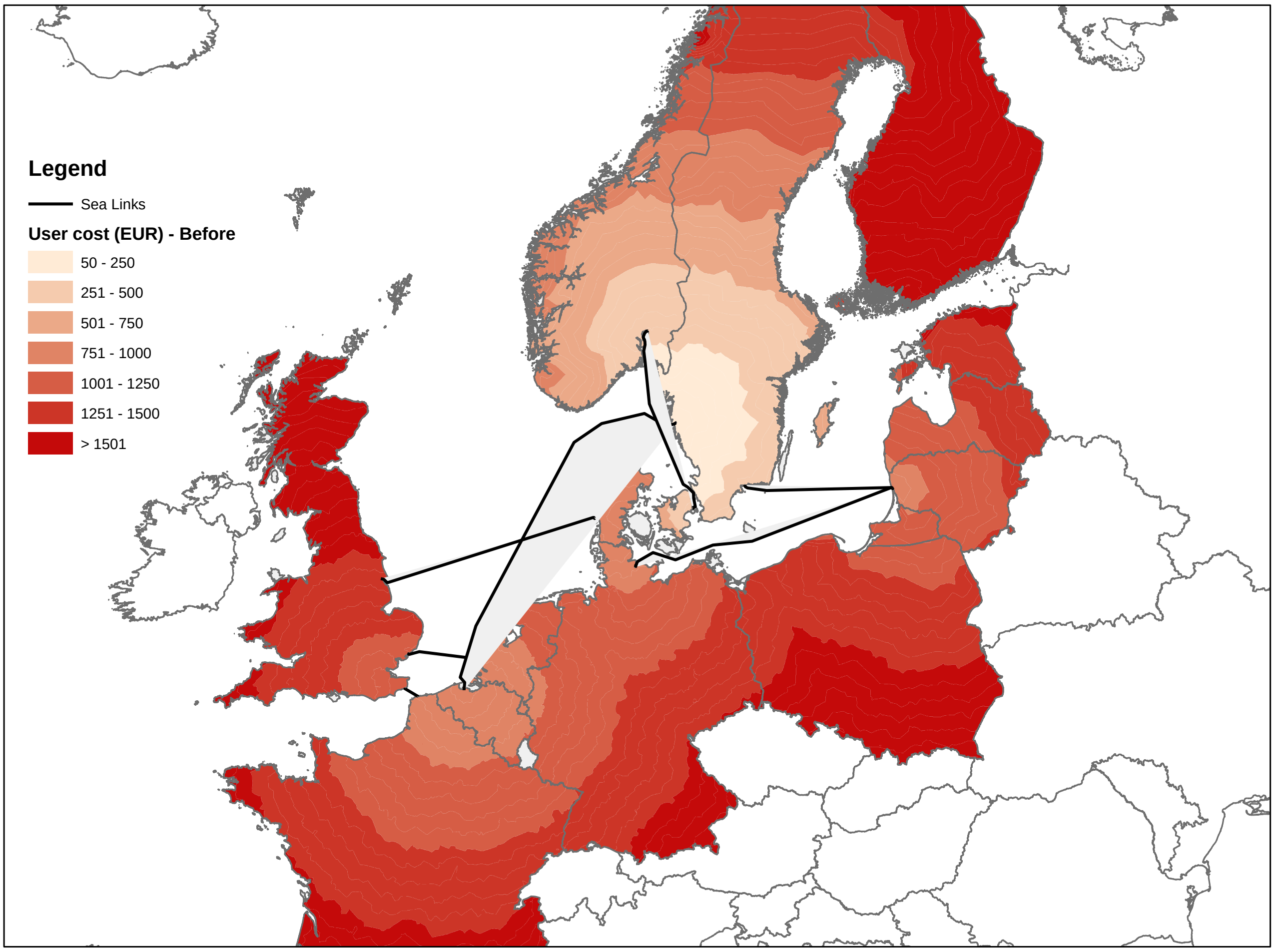


Figure 12: Isocost map with Gothenburg as origin

Figure 12 shows how the Gothenburg – Ghent and the Karlshamn - Klaipeda sea links is competitive to the land based trucking solution as they “beachhead” a lower user cost at both Ghent and Klaipeda. The map also gives an indication of the competitive boarder between the transport chains using the sea links and the land based truck transport. This are seen as peaks in the isocost bands just east of the German/Polish border and a bit less clear in the central part for Germany towards Northwest.

Following this calculation, the transport cost in the network is updated by internalising the external cost on all the sea links and the isocost calculation was repeated. The isocost map for the least cost transport chain after internalising the external cost on the sea links are shown in Figure 13.

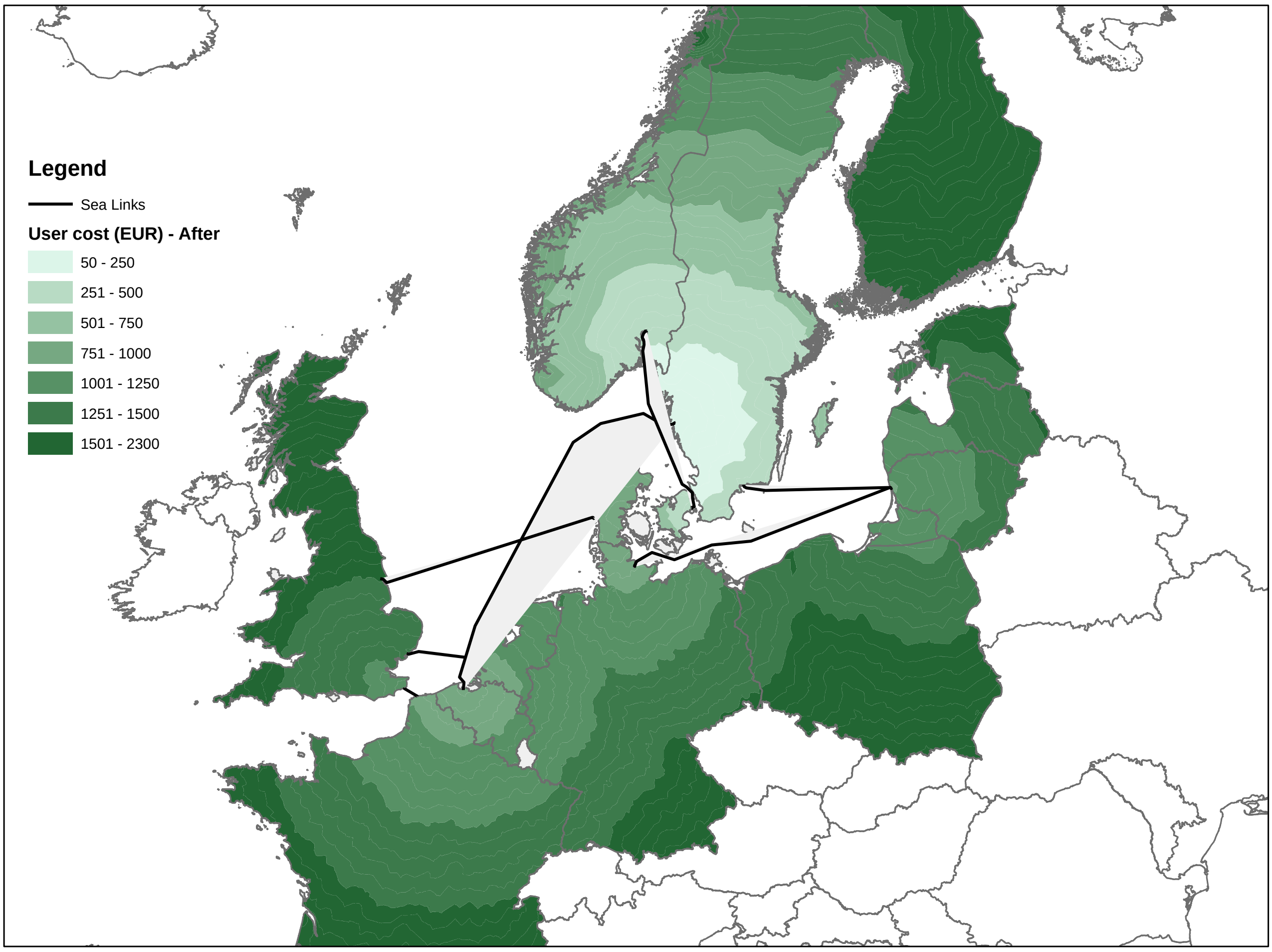


Figure 13: Isocost map with Gothenburg as origin after internilization

The influence of the internalization can be seen on the figure where the extent of the sea link “beachheads” in both Ghent and Klaipeda is diminished. This effect also spreads to the UK and France. Whereas there is no change in Sweden and Norway since road based transport from Gothenburg both before and after the internalisation of the external cost is the most economical competitive solution.

The location of the competitive borders between the land based only transport and the intermodal transport using the sea links becomes much clearer when looking at a differential map.

9.3 Differential maps

A differential map is basically two isocost maps that are subtracted. The differential map in Figure 14 is the result of a "subtraction" between the two previous maps.

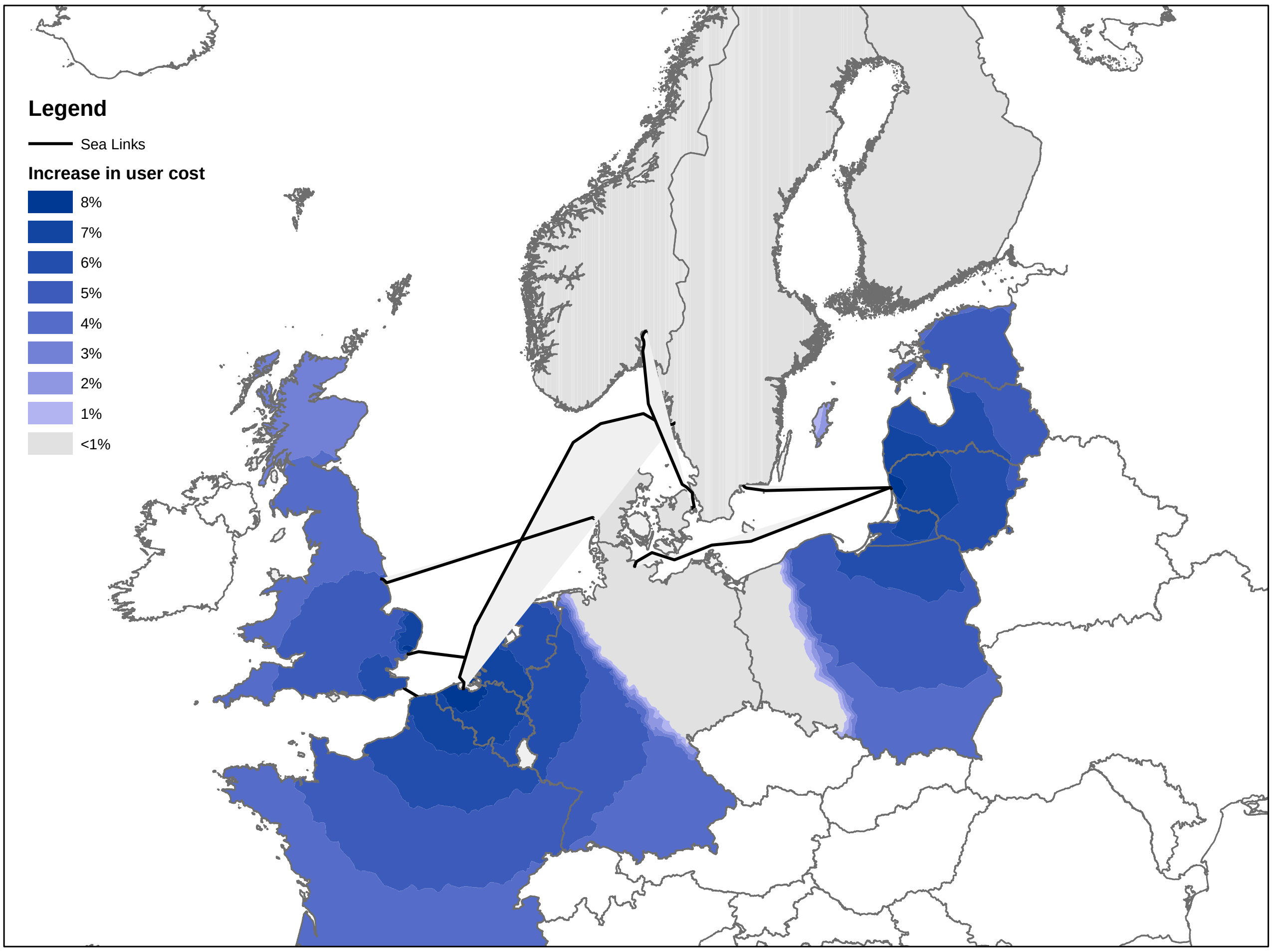


Figure 14: Differential map with Gothenburg as origin

The figure illustrates not only the areas where the intermodal transport chain from Gothenburg using the sea links is competitive but also gives an indication on how the competitiveness changes when the external cost are internalised. The different intervals correspond to the relative increase in total user cost due to the internalisation of all external costs for the sea links.

The grey areas are the areas where land based truck transport is most competitive both before and after the internalisation of the external cost. In the blue areas, the intermodal transport chain is still competitive, but the relative user cost of the transport increases from 1-8% making intermodal transport less competitive.

9.4 Mapping the effect of a full internalisation of external cost for sea transport

The following sections describes the results of mapping the effect of a full internalisation of the external cost for sea transport for transports to and from the following cities:

Hamburg
Antwerp
Klaipeda
London

9.4.1 Hamburg

The following map shows the change in transport costs (in %) when all external cost for the RORO links are internalised for transport to and from Hamburg.

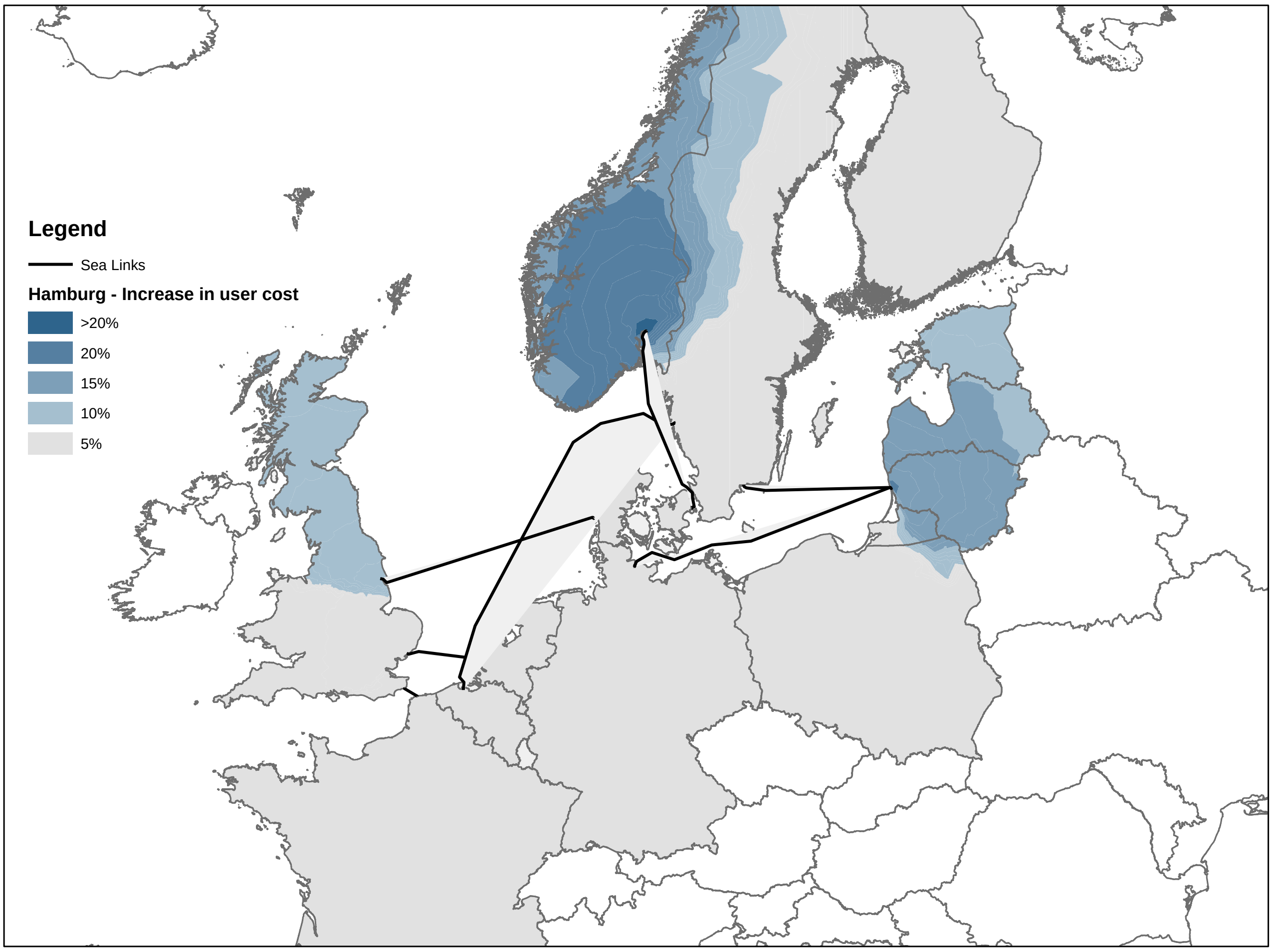


Figure 15: Effects of full internalization of external costs with Hamburg as origin

The light grey areas indicates where the transport cost increases with less than 5%. In these areas the truck based land transport are the most competitive both before and after the internalisation of the external cost for sea transport.

In the northern part of the UK, the transport cost increases with 5-10%. This means that the intermodal route to and from Hamburg using the Esbjerg – Immingham sea link is still competitive having the lowest total user cost. However the increase in transport cost makes the intermodal solution less competitive and might lead to a modal shift. The same pattern shows for the Oslo area in Norway (using the Copenhagen – Oslo sea link) and the area around Klaipeda in Lithuania (using the Kiel – Klaipeda sea link).

9.4.2 Antwerp

The following map shows the change in transport costs (in %) when all external cost for the RORO links are internalised for transport to and from Antwerp.

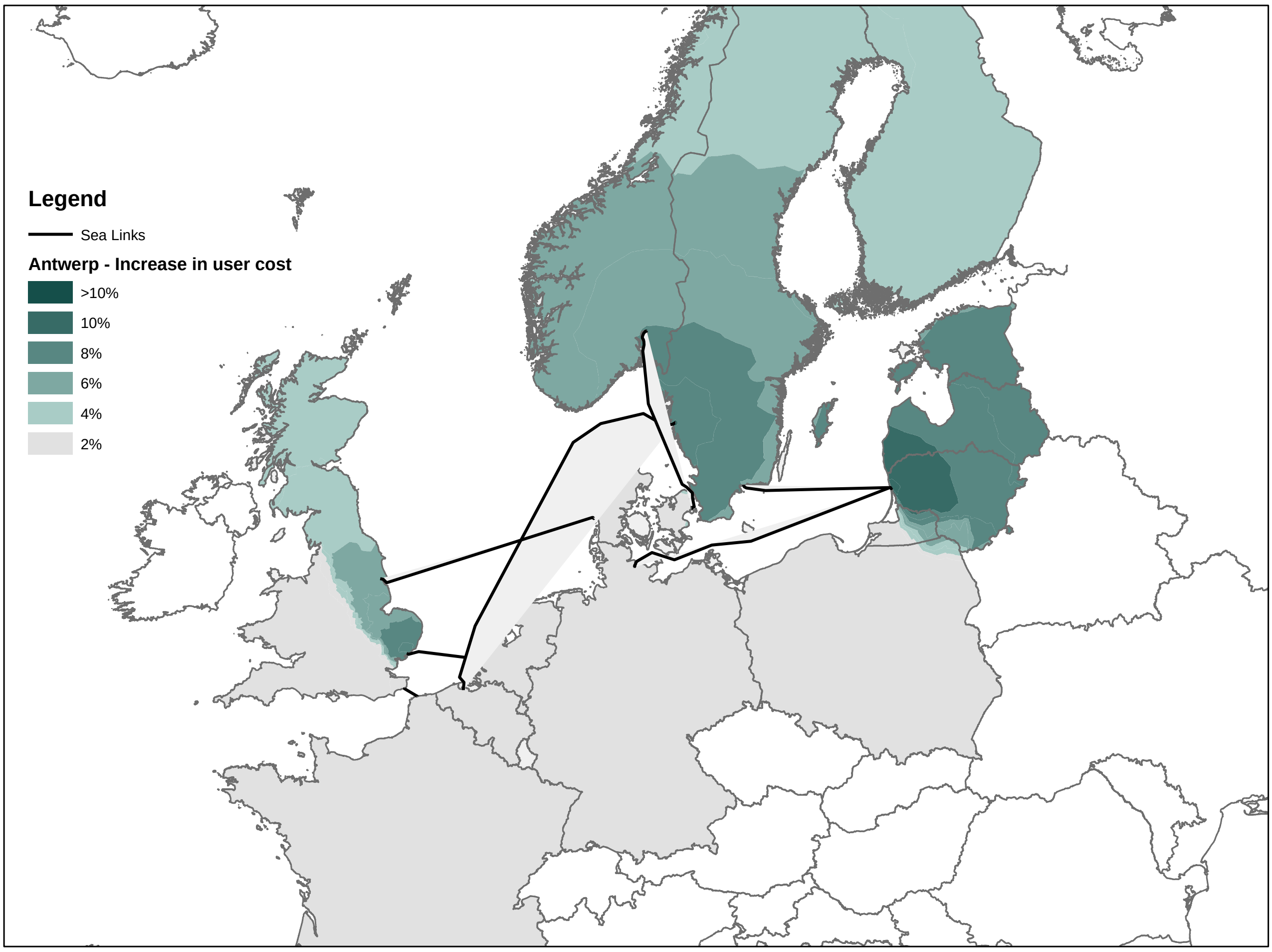


Figure 16: Effects of full internalization of external costs with Antwerp as origin

The light grey areas indicates where the transport cost increases with less than 2%. In these areas the truck based land transport are the most competitive both before and after the internalisation of the external cost for sea transport.

In the eastern parts of the UK, the transport cost increases with 2-8%. This means that the intermodal route to and from Antwerp using the Rotterdam – Felixstowe sea link is still competitive having the lowest total user cost. However (as for the transport to and from Hamburg) the increase in transport cost makes the intermodal solution less competitive and might lead to a modal shift. The same pattern shows for the Gothenburg area in Sweden (using the Gothenburg - Ghent sea link) and the area around Klaipeda in Lithuania (using the Kiel – Klaipeda sea link). The increase in transport cost are highest around the ports as the relative change in the total transport cost by the internalisation on the sea links diminish the further the transport goes into the hinterlands of the ports.

9.4.3 Klaipeda

The following map shows the change in transport cost (in %) when all external cost for the RORO links are internalised for transport to and from Klaipeda.

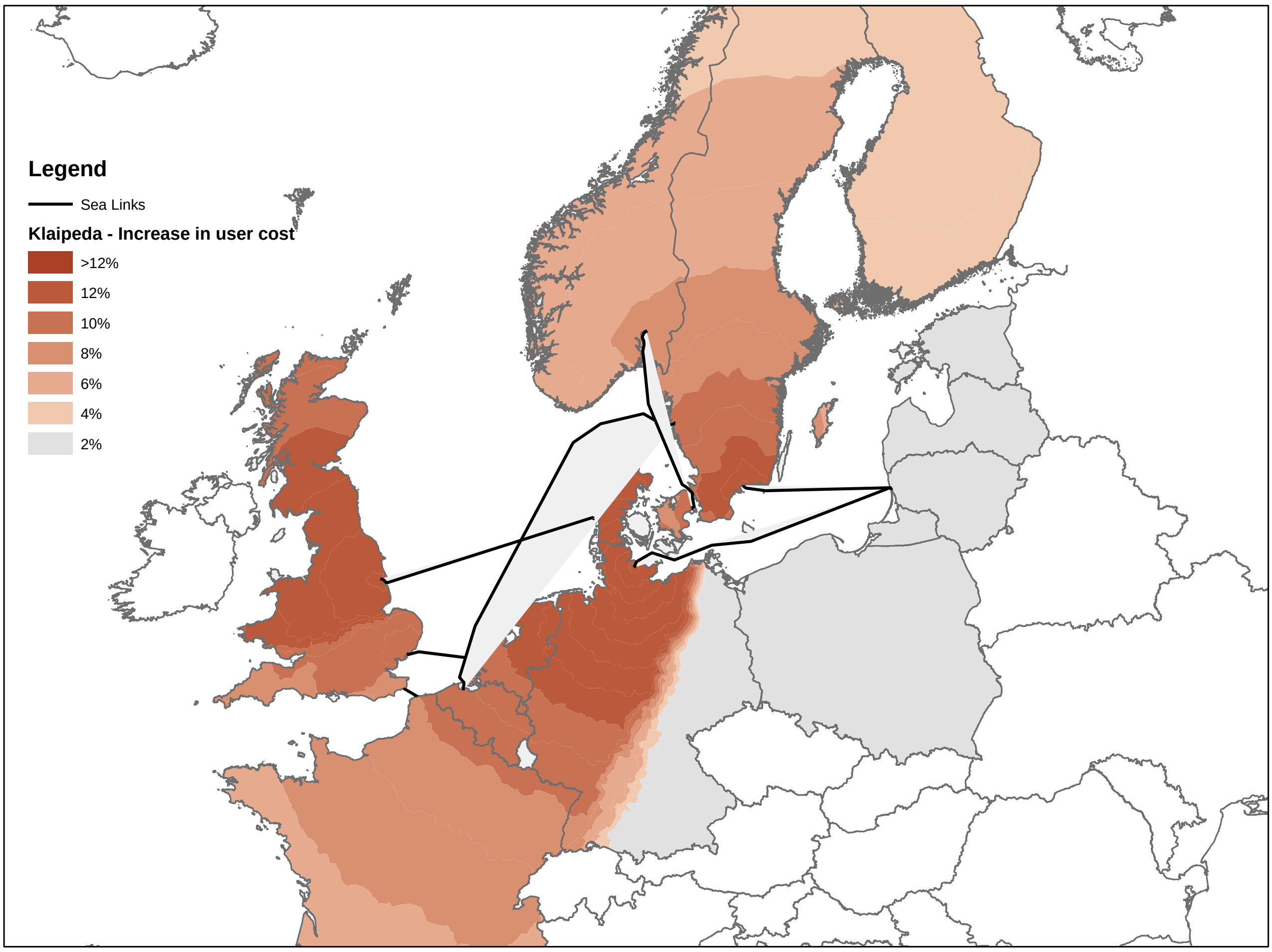


Figure 17: Effects of full internalization of external costs with Klaipeda as origin

The light grey areas indicates where the transport cost increases with less than 2%. In these areas the truck based land transport are the most competitive both before and after the internalisation of the external cost for sea transport.

In the southern part of Sweden, the transport cost increases with 6-12%. However even thought this is a substantial increase in the transport cost the intermodal transport chain is still competitive, as the land-based alternative has to drive a substantial distance around the Baltic Sea. The map also shows that the intermodal transport chain using the Klaipeda – Kiel sea link are still competitive for trips to and from the western part of Germany and the UK.

9.4.4 London

The following map shows the change in transport cost (in %) when all external cost for the RORO links are internalised for transport to and from London.

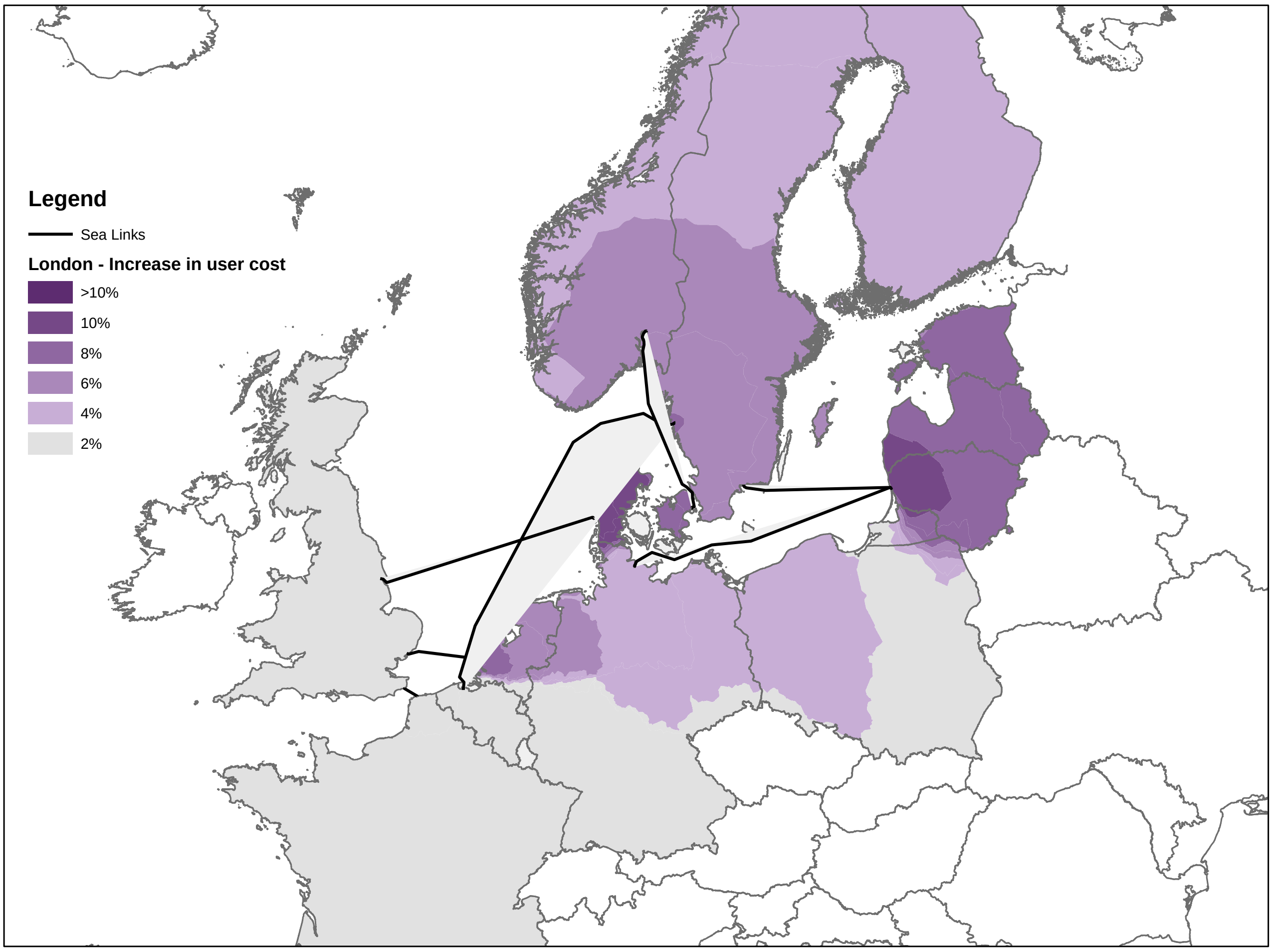


Figure 18: effects of full internalization of external costs with London as origin

The light grey areas indicates where the transport cost increases with less than 2%. In these areas the truck based land transport are the most competitive both before and after the internalisation of the external cost for sea transport. Around Rotterdam, the transport cost increases with 2-8%. This means that the intermodal route to and from London using the Rotterdam – Felixstowe sea link is still competitive having the lowest total user cost. However again the increase in transport cost makes the intermodal solution less competitive and might lead to a modal shift. The same pattern shows for Denmark (using the Immingham - Esbjerg sea link), the Gothenburg area in Sweden (using the Gothenburg - Ghent sea link) and the area around Klaipeda in Lithuania (using the Kiel – Klaipeda sea link). As for the Antwerp map the increase in transport cost i highest around the ports as the relative change in the total transport cost by the internalisation on the sea links diminishes the further the transport goes into the hinterland.

10 Conclusions and key findings

This document presented the main findings of work related to the final Task of WP3, on the potential policy options to mitigate and reverse the negative effects of the low-sulphur limit on the short sea shipping sector. This final section will summarize the findings on the examined policy measures, and the implications of a potential increase in fuel prices and the need for such measures.

10.1 Discussion of findings

The modelling framework designed for WP2 has been enhanced with the addition of quantitative that allow the introduction of additional cost elements or subsidies, allocated to either the shipper or the ship operator depending on the policy specification. The output of the constructed modules is the estimation of the resulting transportation demand through the use of the modal split model developed in WP2. Policy makers could utilize the produced tools to examine the potential impacts of their instruments. The model can also be useful to ship operators, as it can allow the estimation of the effects of new policies on the service profitability in the affected routes.

The constructed modelling framework was tested for a variety of policy measures, that either increase the cost of competing land-based options, or reduce elements of the generalized cost of transport for the maritime options. The performed runs allow additionally the examination of the actual monetary cost that the low-sulphur requirement has on the shippers through the additional BAF surcharges due to the fuel price differentials. The examined policies that would provide a monetary incentive to the shipper that uses a maritime mode would require a significant capital investment from the policy maker, but would be successful in reversing the negative effects of the low-sulphur fuel requirements within SECAs. Other options could be a provision of certain subsidies to the affected (within SECAs) operators, either through a repayment of part of the port fees, or a partial payment towards retrofit costs. It has to be noted that the estimated policy costs for each of the available options, are calculated for each of the DFDS routes, and there would be a variability for the respective costs for policies targeting other ship operators. While some of these costs may seem low, ranging between a few million € annually, it has to be taken into account that there are numerous more Ro-Ro services that are affected in a similar manner. Therefore, the results of this work can be more useful if an actual available budget is known to the user of the developed methods. For example, the first implementation of the ECO-bonus system in Italy had an available budget of 230 million € for a two year period. The annual costs of the examined policies for only the seven DFDS routes range from 24, up to 103 million € (for a high fuel price scenario where the goal is increasing the modal share of maritime options). An important question for each of the examined measures is which body can (or should) provide the required funds for such policies. The necessary funds can of course be reduced, if ship operator's measures are also deployed in cases of high fuel prices, as with the available options examined in Task 3.1. A combined effort by all of the affected stakeholders can ensure that the short sea shipping sector operating in SECAs will endure should fuel prices return to their previous high levels.

10.2 Overall conclusions and transferability of the developed tools

The RoRoSECA project sought to answer the question of whether it is possible, through the use of operational practices or policy instruments, to mitigate and revert the negative effects of the low-sulphur fuel requirements within SECAs. Prior to the introduction of the sulphur limit, a rather gloomy picture was portrayed by the industry and the media with anticipated losses of market shares to the point that certain services would be shut down. This was particularly crucial for short sea shipping, due to the higher level of competition with alternative transport modes (primarily road). This would be against the EU policies that seek to move traffic from land to sea in order to reduce congestion and emissions. However, the record low fuel prices observed in the end of 2014 and until today resulted in a completely different outcome. As a result, the low fuel prices led to record breaking revenues for ship operators, and largely masked the negative effects of the regulation.

The models developed in the RoRoSECA project constituted possible the dissection of the effects of the regulation from the very low fuel prices observed in 2015. This would not have been possible without the inputs of DFDS, and the provision of very important (and frequently highly confidential) data, that facilitated the understanding of their impacts of the regulation. The models developed can answer the following questions:

- What is the economic impact of the new legislation?
- What is the environmental impact of the new legislation?
- What may be possible modal shifts?
- What measures can the Ro-Ro operator take to mitigate and reverse the situation?
- What policy measures are deemed the most appropriate?

This project has been the first attempt to examine in detail the impacts of the new limits, and the main conclusions of WP2 and WP3 can be summarized in the following key takeaways:

- Maritime shares increased due to the unexpectedly low fuel prices
- Maritime shares would have increased further if HFO were still allowed
- Maritime shares would drop if fuel levels returned to 2014 levels
- The freight rate is the most important component for the shipper, as opposed to transit time, which was deemed not so important

On operators measures to reverse the negative effects of the regulation, the following options are relevant

- Slow steaming reduces fuel consumption and hence emissions, but reducing speed is limited by logistical constraints. At high fuel prices it can help with balancing costs and revenue for the severely affected services that heavily compete with landbased options. In 2016 certain routes actually sped up.
- Frequency of sailing service can be used to improve load factors of a vessel, mainly on very frequent services. On 6/7 sailings per week, some flexibility can be achieved through changes in the number of sailings.

- Vessel swapping can also be used to help with load factors, taking advantage of the variability of nominal capacities offered in the (usually) diverse fleet of a Ro-Ro operator.
- Investing in scrubbers critically depends on fuel prices, and level of subsidies

The previous measures examined in Task 3.1 show that the operator has some options to adjust in the new setting, particularly in case of fuel prices returning at previous levels. However, this may not be sufficient, and policy measures may be required to mitigate potential modal shifts. For a policy measure to be successfully, essentially it is a question of how to mitigate the effects of the BAF surcharges due to the low sulphur requirements. In summary for Task 3.2:

- There is a requirement for policy measures to mitigate potential modal shifts
- For a policy measure to be successful, the BAF effect needs to be mitigated
- Typical annual costs for full mitigation is 2M€ per route, but can increase fast for high fuel prices scenarios as policies are sensitive to fuel price.
- Repayment of the BAF, ECO-bonus like systems, and internalization of external costs have similar effects.
- If policy and operators' measures are combined, it is possible to cause a modal shift from landbased options to maritime.

Potential users of the models developed by DTU include Ro-Ro operators, intermodal operators, other short sea shipping companies operating in ECAs, and maritime policy makers including the EU. Possible uses of these models include:

- Estimation of emissions and external costs
- Evaluation of possible modal shifts in ECAs
- Evaluation of possible modal shifts when 0.5% global S cap applies in 2020
- Assessment of the merits of alternative mitigation measures
- Assessment of the merits of alternative mitigation policies
- Identification of routes that exhibit risk of being non-viable
- Assistance of operators and policy makers to perform "what if" analyses of alternative scenarios
- Assistance of operators and policy makers to select among alternatives

The tools are transferable in the sense that additional policies that have effects on the economic and environmental balance of the short sea shipping sector can be readily tested, provided their effects are identifiable. For example, the impacts of the global sulphur cap on affected services can also be tested through the enhanced modal split model, provided that predictions on fuel prices are generated. The model can also be used in case a similar intervention on landbased modes is imposed (for example through speed limits, or banning lorries in certain areas).

11 References

COWI/DTU (2016). Transport Economic Unit Prices for use in socio-economic analyses – Version 1.6 (in Danish). (Accessed 14/2/2017).

European Commission (2011). WHITE PAPER. Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. COM(2011) 144, Brussels, 28.3.2011.

European Commission (2008). Strategy for the internalisation of external costs. COM(2008) 435, Brussels, 8.7.2008.

Investing (2017). Carbon Emissions Futures Historical Prices – Investing.com. https://www.investing.com/commodities/carbon-emissions-historical-data (Accessed 8/6/2017).

Kristensen H.O. (2016). External cost calculator for the SHIP-DESMO model. RoRoSECA report No.6. Kongens Lyngby, Denmark.

Maibach M., Schreyer C., Sutter D., van Essen H.P., Boon B.H., Smokers R., Schroten A., Doll C., Pawlowska B. and Bak M. (2008). Handbook on estimation of external costs in the transport sector. IMPACT study. Delft, CE.

Psaraftis, H. N., & Kontovas, C. A. (2010). Balancing the economic and environmental performance of maritime transportation. *Transportation Research Part D: Transport and Environment*, *15*(8), 458-462.

Ricardo-AEA (2014). Update of the Handbook on External Costs of Transport. Report for the European Commission DG MOVE, London.

Tsamboulas, D., Chiappetta, A., Moraiti, P., & Karousos, I. (2015). Could Subsidies for Maritime Freight Transportation Achieve Social and Environmental Benefits? The Case of Ecobonus. *Transportation Research Record: Journal of the Transportation Research Board*, (2479), 78-85.

Zis, T., Angeloudis, P., Bell, M. G., & Psaraftis, H. N. (2016). Payback Period for Emissions Abatement Alternatives: Role of Regulation and Fuel Prices. *Transportation Research Record: Journal of the Transportation Research Board*, (2549), 37-44.

Zis, T., & Psaraftis, H. N. (2017). The implications of the new sulphur limits on the European Ro-Ro sector. *Transportation Research Part D: Transport and Environment*, *52*, 185-201.