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

Deliverable on Task 3.1:

Report on the outcome of Task 3.1
Measures from the Ro-Ro operator

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1 Executive Summary

Task 3.1 (entitled "Measures from the Ro-Ro operator") of the RoRoSECA project comprises of two main objectives:

- The definition of potential measures that the Ro-Ro operator can use to cope with the negative effects of the low-sulphur limits
- The use of the models developed in the context of WP2 to examine economic and environmental impacts of said measures

During the project's fourth Advisory Committee (AC) meeting that took place in September 2016, the DTU team presented a set of provisional Ro-Ro operator measures that would be examined during Task 3.1. The specifications of the proposed measures were subsequently fine-tuned in a per examined route basis, and agreed with DFDS Seaways. The measures consider the alteration of the service in terms of sailing time, sailing frequency, or fleet deployment. In addition, certain measures that do not affect the service but improve the route profitability are suggested. The effects of each measure on the ship operator and the shippers are estimated using the modelling framework developed in Work Package 2 (WP2), and the computational modules designed for Task 3.1. The measures are benchmarked against the actual 2015 situation for each route, and the report presents results for the three fuel case scenarios as defined in Task 2.2:

- Fuel Case 1, considering the actual average MGO and HFO fuel prices in 2015
- Fuel Case 2, considering high fuel prices as in early 2014
- Fuel Case 3, considering low fuel prices and that the regulation is not present (use HFO 2015 prices)

The outputs of the model include the new market share following any change in the schedule, the generated revenue, and the new fuel costs. Part of the deliverables in Task 3.1, was the design of a module that allows the estimation of the new fuel consumption for each trip at each activity phase following any alterations in sailing speed and frequency. The model takes into account the actual fuel consumption in the baseline case, and as input parameters that specify the changes in the route. The outputs include hourly fuel consumption for each activity, and the construction of a weekly fuel consumption for each ship on each route. The model additionally allows the estimation of the fuel consumption of a vessel should it be placed on a different route.

The models were run for various measures specification scenarios, considering the modal split model calibration conducted in the context of Task 2.2. The results show that the suggested measures have the potential to improve the profitability of the service, particularly for the high fuel price scenarios. The runs are illustrative, however the models allow the examination of any combination of measure specifications, routes examined, and cargo carried.

Task 3.1 was designed to have a duration of six months, and following its completion the last six months of the project will revolve around policy measures that can mitigate and reverse the negative effects of the new lower sulphur limits. The report on Task 3.1, shows that there are important liaisons

between Ro-Ro operator's and policy measures. Certain technological investments (e.g. scrubbers, LNG, cold ironing) require heavy capital costs from the ship owner, and the analyses show that due to the low fuel prices the return of these investments might be delayed. As a result, in the context of Task 3.2, the option of subsidising such investments for the involved stakeholders will be thoroughly examined using the results of the analyses in Task 3.1 as input.

2 Introduction: scope of the document and objectives of WP3

This report summarizes the main research findings of Task 3.1 (entitled "Measures from the Ro-Ro operator) of the RoRoSECA project. Task 3.1 falls under the umbrella of Work Package (WP) 3 (entitled "Measures to mitigate or reverse modal shifts"), whose main objective is to examine candidate measures from both the operator and the regulatory bodies, to protect the sector from the negative effects of the sulphur regulation. This Task is concerned with the operator's measures, and is building on the methodological background established during the first year of the project, and in particular on WP2. Task 2.2 showed that due to the very low fuel prices during the second half of 2014 and all of 2015, ship operators were able to cope with the lower sulphur limit, and in fact showed improved economic performances contrary to what was expected in the previous years before the new limit became effective. However, one of the key findings in WP2 was also that should fuel prices revert to their previous higher levels, modal backshifts would be anticipated and certain services might no longer be financially sustainable.
The document presents the methodologies developed in the context of WP3, in order to assess the efficacy of certain measures that the operator can utilize to help cope with environmental legislation. The examination is not limited to reversing the modal shift should this occur, but also to estimate the effects on the route profitability and the environmental balance of the system.

There are three quantitative main modules associated with Task 3.1:

- The interface with the modal split module developed in Task 2.2
- The KPI module that estimates key performance indicators for each route
- The fuel consumption modules that estimate operating costs under the new measures

The main objectives of WP2 were to create a methodological framework that could capture the effects of the sulphur regulation and other changes, in the shippers' decision making progress. The tools that were created in year 1, allow the thorough examination of introduced operational changes in the services as regards the environmental balance and profitability of the ship operators. In the context of Task 3.1, an interface was created to model the effects of certain proposed measures on mode choice. Particularly for measures that affect either the sailing speed (and thus total travel time), or the sailing frequency (and thus the available transport capacity, and waiting times between departures), these can also lead to a modal shift as they can affect the generalized cost of transport that the ship operator's option offers to the shipper. As a result, the modal split model has to be re-run each time a mitigating measure is applied.

As described in the report on the outcome of Task 2.2, data provided by DFDS allow the estimation of operating costs, and generated revenue from cargo, passenger fares, and on-board spending. However, several other cost components are harder to estimate due to either lack of data, or data confidentiality. To address this problem, a module is developed that estimates the new revenue and main operating costs following the implementation of each proposed measure. Key performance indicators (KPI) can be formulated to facilitate comparisons before and after the measure implementation. These KPIs can also be useful in comparing the efficacy of each measure for the different services examined in the RoRoSECA project. The KPIs stem from the route profitability and environmental balance modules developed during WP2.

The final module is concerned with the estimation of the new fuel consumption of each vessel following the implementation of each operator's measure. A condensed literature review reveals that the majority of existing models on fuel consumption are quite simplified, and to this end, the actual fuel consumption data of the DFDS fleet are used to create more realistic fuel consumption models.

The three previous modules will be subsequently adapted to be used also in Task 3.2 where policy measures will be considered as options to mitigate and reverse the negative effects of the regulation. In the ensuing report, a series of fuel case scenarios are used for each service and for each measure examined. It is envisioned that the wide range of the conceptual case studies can be useful for Ro-Ro operators in coping with the negative effects of environmental regulation that can increase their operating costs.

3 Summary of WP2 findings and methodology developed

During the first year of the RoRoSECA project, efforts were concentrated on defining the subset of the DFDS network where the case studies would be examined. Per the outcome of Task 2.1, it was decided to examine the following seven existing DFDS routes:

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

In addition, data for two more services were retrieved to further support the analysis of the effects of the regulation on short sea shipping. These services include:

- Marseille – Tunis; The only service of DFDS that was not affected by the SECA regulations
- Harwich – Esbjerg; a route that was shut down in 2014 ahead of the coming regulation, as it was already struggling financially.

Following the finalization of routes to be examined in the RoRoSECA project, research focused on the development of the enhanced modal split model, and its calibration based on data provided by DFDS, and data collected by statistical authorities. The majority of this work fell under the theme of Task 2.2 (entitled “Modal Split Development and Calibration”). Two main quantitative modules were developed during work for this task:

- the route profitability module
- the enhanced modal split module

The two modules are interconnected by providing input to each other. The route profitability module is taking as input the estimated market share of the ship operator, which can be used to estimate the annual revenue of the service given its frequency. Revenue from passenger fares (on Ro-Pax services) and their on-board spending were also incorporated into the model. Using data on actual fuel consumption, the route profitability module is also making an estimation of fuel consumption, and thus fuel costs (depending on which fuel price scenario is modelled). Other costs (including scrubber repayment) were also part of the model. Due to data confidentiality, certain other operating costs are considered fixed in terms of time (fixed cost per unit time at port, and at sea). The resulting revenue and operating cost balance can provide an estimate of the profitability of the service, and what are the effects of changes in the service as a result of the regulation. Certain changes in the revenue stemming from a drop or increase of the market share are modelled by the modal split model developed in Task 2.2.

The modal split model that was developed, allows a series of sensitivity analyses on the effects of fuel price, freight rate, and competing transport modes, on the shipper's choice. Inputs of the modal split module include:

- transported volumes for the competing modes in 2014 the year of calibration,
- the total travel time for each option
- the total cost for each option
- inter-departure times for the maritime options
- offered cargo capacity by the maritime options

The model was calibrated for all seven routes, considering the situation during year 2014; the last year before the implementation of the 0.1% limit. Based on the main data collected during year 1, and through the use of simulation for certain data that were not available. For such data, a software code was developed that performed a simulated calibration based on several combinations of input data (mainly market share information). Through each calibration, a set of scale parameters for each service were estimated, which can be used to predict the change in market shares when certain aspects of a service are altered (e.g. cost, or travel time). The enhanced modal split model follows a hierarchical (nested) logit structure assuming correlation between similar modes. When there are more than two options to a shipper, and there are two or more similar modes available (for example maritime), then there is a higher probability of switching to a similar mode than to a very different one. This model structure can collapse to a binary case when there are only two options available to the shipper. The main novelty of the developed methodological framework during WP2 can be summarized in the following observations:

- if a route becomes unprofitable it can be shut down and its traffic will be diverted to the alternative available modes
- the effects of possible speed reduction on transit time and modal shares can be modelled
- implications of a Ro/Ro freight rate surcharge are captured for either
    a. an increase of revenue for the cargo carried, or
    b. a decrease of quantity of cargo carried due to the surcharge.
- In the scrubber option effects of both capital and operational costs are included, while also considering the increased fuel consumption due to the scrubber energy demands
- The implication of cargo values and perishability can be considered through changes in the generalized cost of transport
- The model can easily be modified to include effects of changes in the sailing schedule including but not limited to:
    a. increasing utilization of the fleet and hence profitability,
    b. loss of cargo due to reduced throughput capacity,
    c. increased waiting time at port and hence increased total transport time

In addition, the modal split model takes as input the outputs of the route profitability module; in case there is a major setback, alternative options are considered that include changing key characteristics of the service, or a complete shutdown. The former event, is part of what WP3 is concerned with; what options exist for the ship operator and the regulatory bodies, so as to ensure that short-sea shipping services remain sustainable. Finally, during WP2 a road network model was also used to provide estimates on road transport costs and total travel times for virtually all possible O-D pairs in Northern Europe. Heat maps were plotted to show the implications of removing an existing ferry link for a set of case studies based on the selected scenarios.

For the case studies, three main fuel scenarios were selected for further analysis all considering what would have happened in 2015 for:

- Fuel Case 1 - for MGO 2015 prices
- Fuel Case 2 – for HFO (1% sulphur) 2015 prices
- Fuel Case 3 - for MGO 2014 prices

Fuel Case 1 is an attempt to compare the findings of the developed model in WP2, with the actual market situation as reported to the DTU team by DFDS. Fuel case 1 refers to the actual fuel price difference that the ship operators faced, and thus the change in freight rates that the shippers experienced. The comparisons facilitated the conclusion that the modal split methodology used was a reasonable approach.

Fuel Case 2 was a hypothetical scenario of what would have happened if the sulphur limit had remained at 1% and thus the only difference in operating costs would be the change in fuel prices as a result of the market. It has to be noted that in this case, the investments in scrubber systems would have not taken place, and thus the fuel consumption of the vessels was adjusted to account for this.

Finally, Fuel Case 3 was a hypothetical scenario to consider the impacts of the regulation, if the prices had not unexpectedly dropped to the point that it was actually cheaper to use MGO in 2015 as compared to HFO in 2014. For this reason, the MGO fuel prices in 2014 were used to simulate the effects of the regulation as anticipated in the ex-post market and research reports. Considering that fuel prices have started increasing during 2016, the results of Fuel Case 3 are very relevant for WP3.

The main findings of the first year of the project can be summarized to the following highlights:

- maritime shares increased due to the observed low prices
- maritime shares would have increased more if HFO was still allowed
- maritime shares would decrease if prices had not dropped unexpectedly
- Freight rate is the most dominant element governing the generalized cost of transport
- Time is not crucial, with the notable exception of perishable and expensive goods
- the profitability of the ship operators is masking the negative effects of the regulation

4 General background

In anticipation of the lower sulphur limits, most of the affected ship operators were expecting a negative outlook on their operations, with increased operating costs and a loss of market share due to the potential increase in freight rates. Ships were ordered during the boom years of the market, but were actually delivered at the time when the market had collapsed, which led to an overcapacity of ships. UNCTAD (2016) reports that the average age of the worldwide fleet reached 20.3 years in 2016. A great variation is observed across different vessel types. Figure 1 illustrates data from UNCTAD on the distribution of age of vessels clustered in groups.

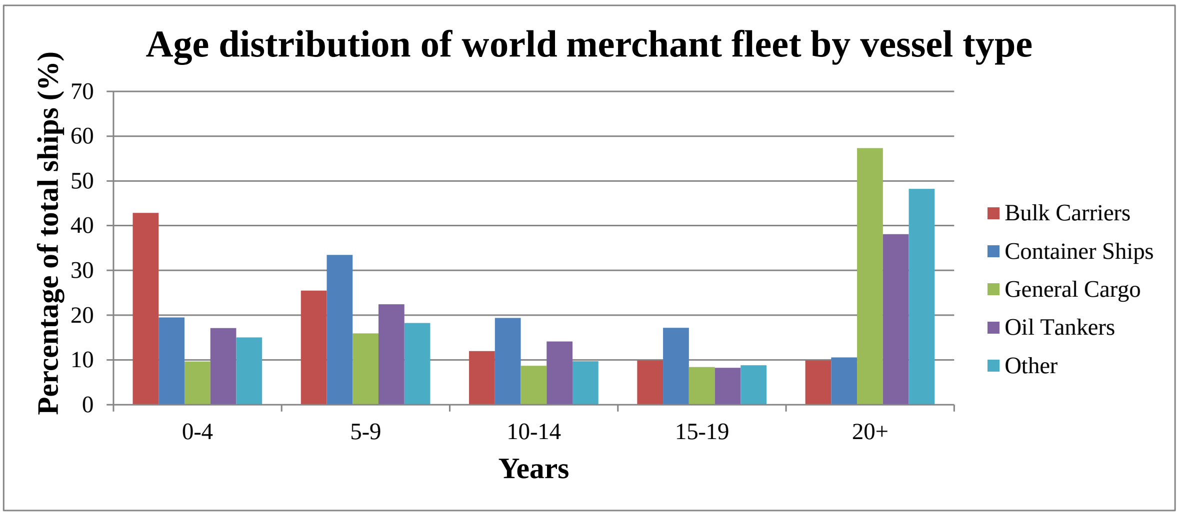

Figure 1: Age distribution of the world merchant fleet by vessel type. Data source: UNCTAD (2016)

Figure 1 shows that the bulk and oil carriers and containerships tend to be younger vessels in comparison to General Cargo vessels. The latter includes Ro-Ro and Ro-Pax ferries. This shows that in 2016 there have been less new ferry vessels delivered in comparison to other vessel types. For Ro-Ro vessels in particular, Stopford (2009) notes that in 2006 the average age of the Ro-Ro fleet was 20 years (considering a total fleet of 1109 vessels) something that suggests that the fleet is not being replaced. Stopford also provides an average sailing speed of 17.1 knots for Ro-Ro vessels. Typically, vessels after 25 to 30 years are recycled. Information for the age of 35 DFDS vessels was retrieved and the average age was 16.1 years as of 2016, with most services running at 18 knots with a few exceptions that will be discussed in section 7. A comparison of the age of the general cargo vessels worldwide with that of the DFDS fleet is shown in Figure 2.

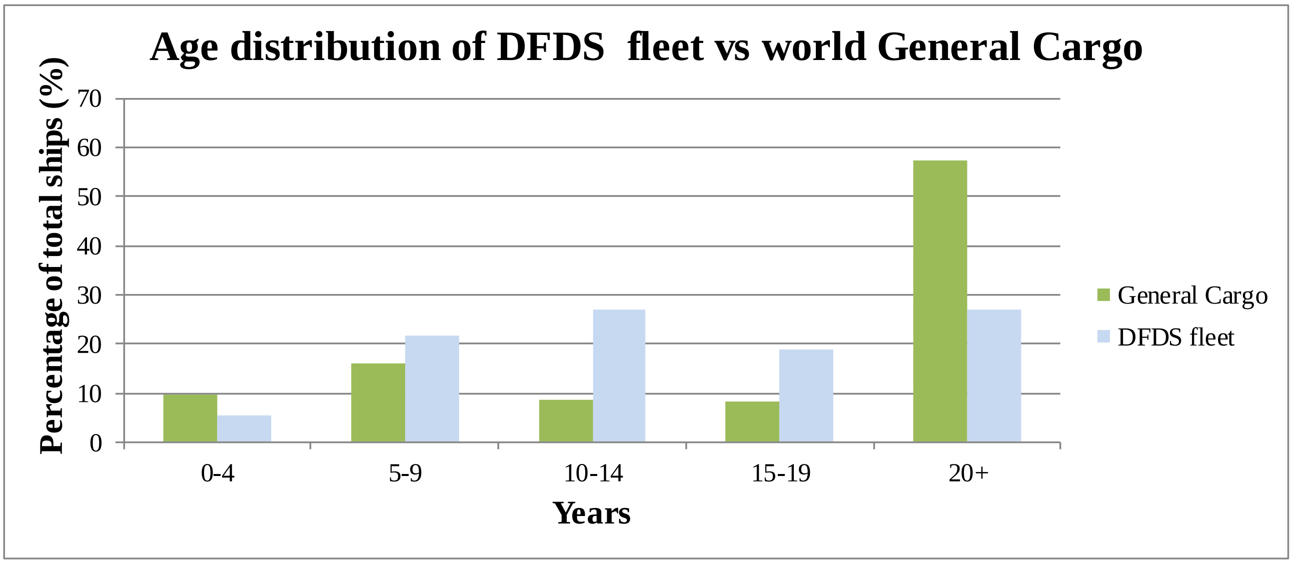

Figure 2: The age of the DFDS fleet compared with the age of the general cargo fleet. Data source: DFDS, UNCTAD (2016)

It can be seen that the DFDS fleet is more balanced in the different age groups with the two most recent new-builds Ark Germania and Ark Dania operating in the network. Considering the (in general) older fleet in Ro-Ro shipping, the technology of main and auxiliary engines is also older and as a result less fuel efficient. Therefore, operating measures can assist in closing the technological gap in order to improve efficiency of operations.

4.1 Implications of travel time and travel cost on shipper's choice

In the context of WP2, the enhanced modal split model that was developed considered the generalized cost of transport as the main utility (or rather disutility) function that the shipper is using to decide which of the available transportation modes to choose. This generalized cost in its simplest form is a function of the travel time and the total travel cost that the shipper is paying for each option. The travel time is converted to monetary units through the assumption that longer transit times lead to increased depreciation of the cargo transported, and consequently the generalized cost depends on the value of cargo transported. In the simulation runs that were conducted for Task 2.2, a wide range of depreciation rates and cargo values were used. The function for the calculation of the generalized cost is given in eq. 1

$$GC_{i.j}=P_{i,j}\cdot(1+s_j)+I_i\cdot(t_j+rel_j) \quad (1)$$

The cost of one additional hour of travel time can therefore be calculated for the various combinations used. A sensitivity analysis for the value of time was performed for various cargo values and depreciation rates in Task 2.2, which is shown below in Table 1

Table 1: Impacts of depreciation and cargo value, on value of time expressed in €/hr·lm

Cargo Value (€/lm)	Value of time (€/hr·lm)			
	r=1%	*r=10%*	*r=3%*	*r=20%*
100	0,000114155	0,001141553	0,000342466	0,002283105
1000	0,001141553	0,011415525	0,003424658	0,02283105
10000	0,011415525	0,114155251	0,034246575	0,228310502
100000	0,114155251	1,141552511	0,342465753	2,283105023

However, the question at hand is how would an extra hour of travel time affect the generalized cost of transport considering the freight rates as well. This can be calculated for all seven of the examined routes, and is presented in Table 2 for an indicative smaller set of cargo values. It has to be noted that the results of Table 2 are presented considering only the maritime leg and disregarding any additional landbased modes in the overall option (as this is assumed not to change in the event of an increase of sailing time).

Table 2: Percentage of 1 extra hour in the maritime generalized cost

Cargo Value (€/lm)	1 extra hour of transport			
	r=1%	***r=3%***	***r=10%***	***r=20%***
Gothenburg – Ghent				
1000	0,024	0,007	0,024	0,048
100000	0,241	0,718	2,354	4,6
Esbjerg – Immingham				
1000	0,003	0,008	0,028	0,056
100000	0,279	0,832	2,719	5,295
Rotterdam – Felixstowe				
1000	0,006	0,019	0,064	0,127
100000	0,631	1,871	5,975	11,275
Copenhagen – Oslo				
1000	0,004	0,013	0,042	0,084
100000	0,418	1,244	4,031	7,749
Klaipeda – Kiel				
1000	0,003	0,01	0,033	0,066
100000	0,327	0,976	3,179	6,163
Klaipeda – Karlshamn				
1000	0,003	0,009	0,031	0,063
100000	0,312	0,931	3,036	5,894
Dover – Calais				
1000	0,012	0,037	0,123	0,246
100000	1,218	3,567	10,978	19,783

It can be seen that for high depreciation rates, and for the relatively shorter journeys, the difference can be significant. For lower value cargoes travelling on longer routes, the one extra hour is relatively indifferent making up of less than 0,1% in certain cases. This is concurrent with the fact that shorter routes tend to have higher freight rates, and the increase in total travel time is relatively smaller for the same increase in absolute time. Raising the travel time from 1.5 hours to 2.5 in Dover - Calais (effectively reducing speed from 15.3 knots to 9.2) is a far more undesirable for a shipper than raising the travel time from 32 to 33 hours in Gothenburg – Ghent (reducing speed from 18 to 17.2 knots). Therefore, appropriate increases in sailing time need to be considered on a case-specific basis.

4.2 Effects of fuel price on operating costs for ship operator and travel cost on shipper

The fuel prices have a direct effect on both the operating costs of the shipping company, as well as on the freight rates imposed on the shippers. The fuel operating costs are proportional to the fuel price, when the service is not altered (sailing frequency and sailing speed). There may be a seasonal variation on the service frequency, or even lower sailing speeds on weekend sailings, however the schedule is not changing dynamically based on the fuel price. In the report on Task 2.2, the fuel costs as a share of total vessel operating costs were presented for 2014 and 2015. For all routes this contribution was drastically reduced (the reduction ranging from 7 to 15%) due to the much lower fuel prices in 2015. However, part of the fuel cost differential is passed on to shippers through changes in the freight rates, which were lower in 2015 (in certain routes nominally, in certain other when adjusted for inflation). The mechanism through which the freight rates are affected by the fuel prices is described in the next paragraph.

Shipping companies are adjusting their freight charges through the use of the so-called bunker adjustment factor (BAF), which represents surcharges due to changes in oil prices. Each operator has to set its own method for calculating the BAF, so as to avoid instances of collusion between ship operators. With regards to the RoRoSECA project, DFDS is using the price differential between MGO 0.1% and HFO 3.5% to set the BAF and thus the surcharges have increased since January 2015 in comparison to the previous years. It has to be noted that DFDS updates the BAF each month; the BAF on the current month is calculated based on the average price differential between the 20th of two months ago and the 20th of the last month. The actual level of the surcharge is also depending on the route characteristics, showing higher values for lengthier routes, and the sailing speed on the service that governs actual fuel consumption (faster services have higher BAF). Table 3 summarizes the BAF fluctuation from February 2016 until December 2016 as published by DFDS.

Table 3: 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			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	NA		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

The negative values refer to the fact that the MGO price that was used in this calculation was actually cheaper than the baseline HFO price (Oct-Nov 2014). However, it can be seen that as the price of MGO started increasing in mid-2016 the BAF has actually grown positive and could trigger a modal backshift to other modes.

4.3 Effects of fuel price on sailing speed and travel time

In times of high oil prices, a recurring practice has been to reduce sailing speed, commonly known as slow steaming, which has been used by ship operators to significantly reduce fuel consumption. Slow steaming is also used in times when excess capacity exists in the shipping market (Benford, 1981). In the aftermath of the 2008 recession, oil prices started increasing which led to the re-emergence of slow steaming to lower fuel costs (Psaraftis and Kontovas, 2010), especially in the liner shipping and oil trade. With regards to liner shipping in particular, Rodrigue et al. (2013) attributed the shift to lower sailing speeds in a combination of the effects of increased fuel prices, and the drop in demand for containerized shipping that coincided with the delivery of new-builds. Kontovas and Psaraftis (2011) summarize the following incentives for slow steaming:

- higher bunker prices and fuel costs
- Savings in other costs
- mandatory or voluntary regulations adapted by companies
- higher bunker costs due to the regulated use of more expensive fuel
- reduced freight rates

The relevance of the latter two incentives with the overall objectives of the RoRoSECA project is evident. As fuel prices have started increasing in 2016, it is possible that the initial fears of the negative repercussions of the lower sulphur limits are realized. In addition, the observed drop in freight rates in various shipping markets, can also act as a motivation to reduce sailing speeds in order to minimize fuel costs for the ship operator. However, the latter is more constrained for Ro-Ro operators due to the generally higher sailing speeds, but also higher frequency as these vessels tend to sail on single link services. Slow steaming in the context of Ro-Ro shipping has not been considered in the recent years, as the majority of research in slow steaming focuses on either tramp shipping, or liner shipping. This is due to the very high flexibility of containerships in adjusting their speed, and the potentially higher savings due to the nature of the trade. Similarly, tramp shipping allows the formulation of interesting problems as on the one hand a high fuel price is translated into the need to make as many trips as possible, but on the other hand this also increases the operating costs, and thus interesting speed optimization problems have been proposed (Ronen, 1982). Psaraftis et al. (2009) discussed the barriers for the implementation of slow steaming on high-speed craft of different types. For Ro-Ro ferries in Greece, they note that the at-port time can be reduced at no cost (as they tend to spend a lot of time idling), while for ferries carrying passengers, only small increases in time can be allowed so as not to lose desirability. However, when considering cut-off times for loading and unloading operations (e.g. the latest possible time that the cargo has to be at the port of departure), this opportunity to reduce at-port times can be further reduced.

5 The examined measures

The previous sections set the scene for the implications that a potential continuous increase of fuel prices may have on the short sea shipping sector. In the conceptual case studies presented in the context of WP2, it was shown that there could be modal shifts expected to other modes. Essentially the examined measures in the context of Task 3.1, are part of Step 5 in the overall modelling framework as seen in Figure 3.

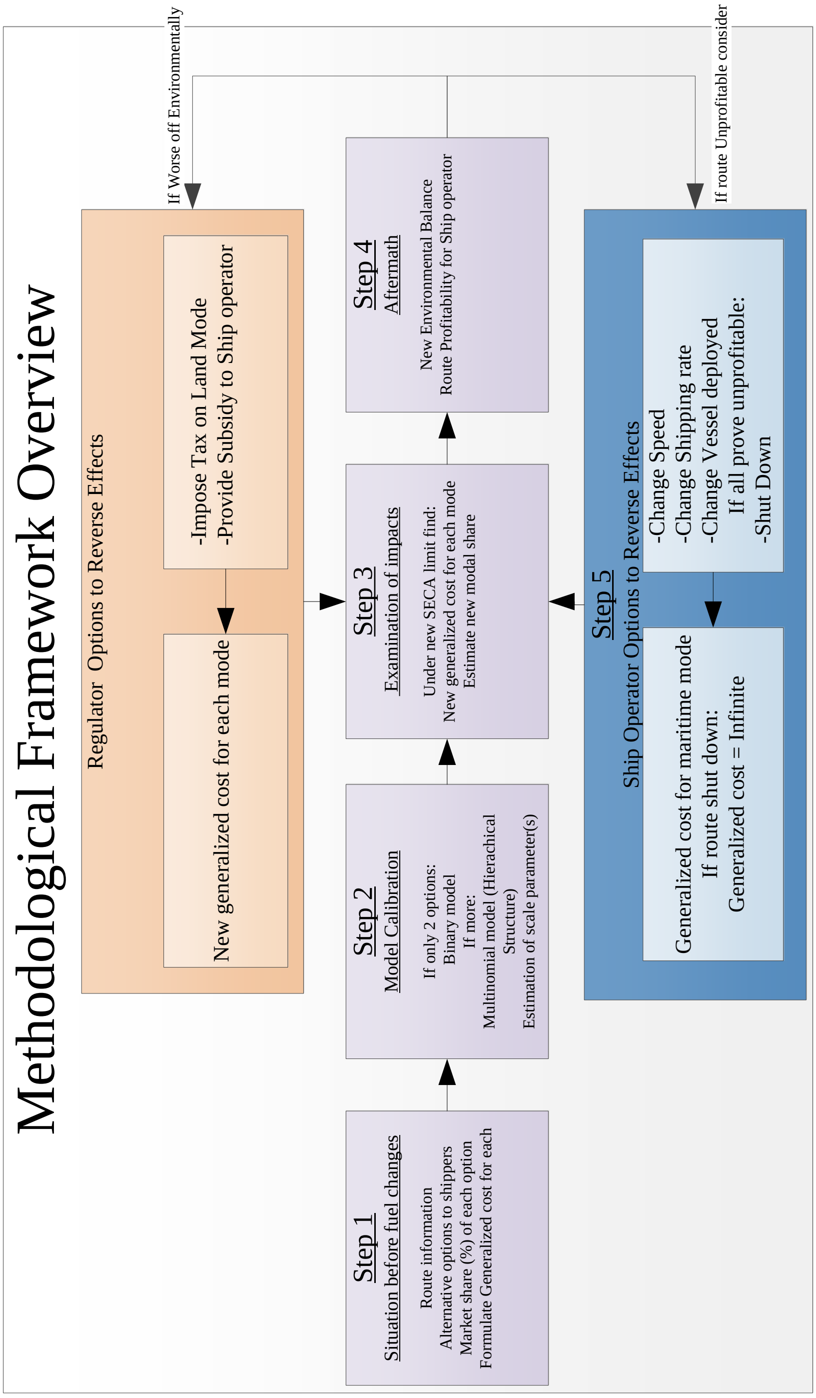

Figure 3: The modelling framework, and Step 5 corresponding to Task 3.1

This section will present a list of candidate measures that the Ro-Ro operator can consider to either cope with loss of market shares, or higher fuel costs. The presented measures were considered in a way to be transferable to other types of shipping and not limited to Ro-Ro operations.

5.1 Speed reduction

Lowering the sailing speed even by a small amount can lead to significant fuel consumption reductions in each journey. Therefore, for routes that are struggling with low traffic it may be an option to maintain a service financially viable. Unlike other types of shipping, Ro-Ro services are relatively fast and due to the high sailing frequency (multiple sailings per week, and in certain cases per day); there are additional constraints that do not allow very low sailing speeds. Due to the nature of the sector, most sailings last an integer number of hours, or integer multiples of 30minute periods, while also departures and arrivals of most DFDS sailings are at sharp or half-past times. This facilitates planning of cut-off times for the embarkation of goods and passengers.

Cut-off times depend on the efficiency of loading and unloading operations of the vessel at each port, and thus depend on the amount of cargo to be transported and the dimensions of the vessel. For this reason, the cut-off times as suggested by DFDS will be respected in the ensuing analysis thus limiting the number of available sailing times. This fact will be handled with a minimum berth duration time at each port, considering that the new sailing times will be the same for both directions of each sailing. For each of the examined routes, a number of different new sailing times will be considered based on the advertised schedule, and the modal shift potential identified in Task 2.2. The Gothenburg – Ghent route will be handled slightly differently due to the one weekly stop at the port of Brevik.

For each new sailing time, the generalized cost of transport for each service will be recalculated, and the modal split model will be re-run to redistribute cargo. Concerning Ro-Pax services, the assumption will be that the number of passengers will not change as a result of the change in sailing time. This rather crude assumption is necessary due to lack of data to accurately model passenger choice, which is also beyond the goals of the RoRoSECA project. However, the revenue from onboard passenger spending will be assumed as a function of travel time, using the data provided by DFDS to estimate this figure.

This speed reduction measure will be considered on its own, which means that no other changes will be introduced in:

- travel time of competing options (e.g. it is assumed that a competing maritime service will not follow the example and will retain its current sailing times),
- frequency (the comparison will be against the original number of sailings)
- cost (similarly the freight rates will not change on first instance for each of the options. The expected outputs will be drop in market share (for cases where sailing time is increased), and consequently a reduction in the generated revenue. These changes will then be compared with the decrease in operating costs due to the changes in the fuel consumption.

5.2 Sailing frequency

For certain services where the profitability may be hindered due to loss of cargo volumes, an option may be to reduce the number of weekly sailings. Companies tend to use this practice during the low season, but under this measure, a change in the peak season will also be examined. The measure will be targeted on routes that are facing the highest threat from a potential fuel price increase, or are showing very low utilization rates, which can increase through a reduction in the number of sailings (lowering the nominal capacity of cargo per week). Instead of shutting down a service completely, the sailing frequency may be adapted by either reducing the number of deployed vessels, or simply reducing the number of weekly sailings. While the market share will drop in such an event (as this is increasing the average travel times), it is expected that it will increase the utilization rate and thus improve the profitability of the route

Under this measure, no change will be considered in the sailing speed of the current schedule in orders to explicitly model the effects of the change in sailing frequency However, there are two ways in which a change in sailing frequency will change. In case only the number of deployed vessels is reduced (e.g. from three vessels down to two), then there may be some changes in the at-berth times to ensure satisfaction of all cut-off constraints and an adequate number of sailings. The target in this case will be to increase the utilization rate of the cargo capacity offered by the service.

In case only the number of sailings is reduced, but the number of vessels deployed will remain the same, then it can be assumed that there will not be any changes introduced on cut-off times for each journey, and the main berthing activities will not be altered. The only difference is that there will be certain idle times at berth where no activity is taking place (no loading/unloading), and thus the fuel consumption will be minimal at these times.

For each new sailing frequency in the examined services, the generalized cost of transport will also be recalculated by adding a waiting time between two successive departures. This will slightly increase the generalized cost as it is assumed that the lower sailing frequency is not desirable by shippers. As with the speed reduction measure, for the Ro-Pax services the assumption will be that the number of passengers will not change drastically. Two options will be examined:

- the number of total passengers remains the same
- the number of passengers per sailing remains the same

For both cases, the onboard spending is considered as a linear function of sailing time. The route profitability will be examined for all cases.

5.3 Fleet and network reconfiguration

This measure is essentially an adaptation of the sailing frequency option that the Ro-Ro operator has. Instead of altering the number of sailing frequency, the Ro-Ro operator can consider changing the fleet assignment between the different routes served by assigning vessels optimally according to their key technical characteristics in terms of capacity, speed, and fuel consumption. It has to be noted that DFDS is already using this measure, as the fleet deployment changes frequently each year among certain routes.

There are certain constraints for the implementation of this measure. Vessels are assigned to existing services based on their type (pure cargo, or cargo + passenger vessels) and thus vessels can be swapped only between similar type services. In addition, certain terminals require specific vessel design for ships calling and may not be able to receive certain other ships. The fact that DFDS received subsidies to retrofit vessels with scrubber systems, has made mandatory the use of certain retrofitted vessels on a specific service (e.g. in one of the Baltic routes) which must therefore always run on the existing service. Another softer constraint with this measure is that certain vessels are essentially sister ships, with very similar characteristics and thus the vessel swapping may only occur in case one of the vessels needs to be in layup for maintenance. However, there is still some flexibility in certain services to swap interchangeably ships to take advantage of differences in fuel consumption, and most importantly nominal capacity. This is what this measure will examine in this case, on a theoretical case study with a given transport demand between two services.

The target of this measure will be to increase the fuel efficiency of each service, in terms of kg of fuel consumed per NM-lm transported. This can be achieved by increasing the utilization capacity of each service; for example, if the market share prediction for a route is low, then a lower-capacity vessel may be preferable for this route, whereas for routes with very high market shares, a more fuel efficient vessel may be preferable.

5.4 Use of LNG as fuel

The use of liquefied natural gas (LNG) as fuel is an alternative option of complying with the SECA limits. LNG consists predominantly of methane (CH_4) and is cooled down to a temperature around -160º. This fuel has 0% sulphur content and it offers a permanent solution to the SO_x regulations. In addition, it offers significant savings in other pollutant gases, especially for PM and NO_x, while also offering good fuel economy thus reducing CO_2 emissions. LNG is also currently less expensive than bunker fuel; however, there are barriers to its further implementation. One concern is the so-called methane slip, whereby methane can be released in the atmosphere. This poses a serious environmental concern due to the much higher green-housing potential of methane compared to carbon dioxide. There is also a limited amount of bunkering ports for LNG globally, and thus fuel availability is necessary for ships sailing on Ro-Ro services. DFDS Seaways also has reservations about potential retrofits in their fleet.

This measure will be considered on a cost-benefit analysis (CBA) basis, on the option of using LNG as fuel. The measure requires high capital costs in cases of retrofitting an existing vessel with dual-fuel engines that allow the use of LNG, while there are additional concerns of reducing capacity to cater for the storage of LNG onboard the vessel. LNG as fuel is considered to reduce the operating costs due to the lower fuel price of LNG and lower fuel consumption, however there are financial risks associated with the volatility of the price of LNG. The potential environmental benefits for ships retrofitted to LNG may prove significant if the social costs of emissions are accounted for. This measure is not expected to affect the market shares of each service, as it is assumed that it will not have an effect on travel time or freight rates.

5.5 Use of scrubbers in more vessels

This option will explore the impact of additional investments n scrubber systems in the remaining fleet of DFDS. A recent paper of the DTU team (Zis et al., 2016) showed that due to the lower fuel prices, scrubber system investments would see an increased payback period, but the recent trends of increased fuel prices as experienced in early 2016 might stimulate additional interest in this option. Therefore, for certain vessels of the DFSD currently running on MGO, the option of retrofitting these in the very near future will be considered through a CBA on the net present value of such investments, for a variety of fuel price scenarios. Table 4 presents a summary of the recent history of investments in scrubber systems from DFDS, and the remaining vessels operating in the seven routes that are not retrofitted yet (and thus some of which could be considered for this measure).

Table 4: The DFDS scrubber equipped fleet, and DFDS vessels running on MGO in the seven examined routes

Year of installment	**Ship**	**Type**
2009	Ficaria	Ro-Ro
2013	Petunia	Ro-Ro
	Selandia	Ro-Ro
	Magnolia	Ro-Ro
2014	Victoria	Ro-Pax
	Primula	Ro-Ro
	Britannia	Ro-Ro
	Freesia	Ro-Ro
	Begonia	Ro-Ro
	Suecia	Ro-Ro
2015	Crown	Cruise
	Optima	Ro-Pax
	Sirena	Ro-Pax
	Ark Dania	Ro-Ro
	Ark Germania	Ro-Ro
	Regina	Ro-Pax
	Finlandia	Ro-Ro
2016	Athena	Ro-Pax
Current MGO vessels on examined routes	**Ship**	**Type**
Now	Anglia	Ro-Ro
	Flandria	Ro-Ro
	Jutlandia	Ro-Ro
	Ark Forwarder	Ro-Ro
	Pearl	Cruise
	Kaunas	Ro-Pax
	Malo	Ro-Pax
	Calais	Ro-Pax
	Dieppe	Ro-Pax

It can be seen that there are not many vessels in the examined network that can be retrofitted; however, a CBA will be useful to examine the implications of continuing the trend of DFDS Seaways to invest in scrubber systems.

5.6 Change in pricing policy

This measure will consider the option of DFDS absorbing the higher fuel costs completely by lowering freight rates in an effort to retain its market share in an event of higher fuel prices. Essentially, this measure will balance the increased operating costs with increased revenue due to higher transported volumes (considering that competing modes will not change their pricing policy, and thus lose market shares to DFDS). The purpose of this measure is to identify ranges of freight rates within which the shipping company can perform sustainably. This measure will be revisited in the context of Task 3.2, as the additional cost to the shipping company could also be provided by a regulatory body in the form of subsidies.

5.7 Cold Ironing for at-port compliance with sulphur limit

Similar to the previous measures which consider investments in technology (LNG or scrubber systems), one additional technological option that a ship operator has is the use of shorepower. In the recent past, DFDS had vessels able of receiving shorepower (calling at the port of Gothenburg); however, these vessels are no longer calling at these terminals. While cold ironing is not addressing the issue of SECAs, it poses an interesting option for vessels that are either relying on MGO, or have scrubbers that are not treating the exhaust gases of the auxiliary engines (which then requires the use of MGO at berth). In theory, this measure should also not affect market shares and shippers' choice.

6 Model Overview

This section of the report presents the modules developed in the context of Task 3.1, as well as the way that the modal split model of WP2 was used in the case studies for the Ro-Ro operators' measures.

6.1 Travel time and cost calculation post-Ro-Ro operator measure

The total travel time of the maritime leg using DFDS may change if a new sailing speed is selected. A straightforward calculation is used to estimate the new time. Figure 4 presents a snapshot of the model that estimates the new sailing speed following an increase of sailing time by a specific period, and the new total sailing and berthing hours per week. The run is conducted for an increase of the sailing time between Rotterdam and Felixstowe by half hour (equivalent to a speed reduction from 16.1 to 14.7 knots), and a reduction of weekly sailings by 1. The module also calculates the idle berth hours, e.g. the additional berth hours where no activity is taking place (no loading and unloading).

	SHIP	NEW Hours berth per week	New Sailing Hours		Distance per Week	New Average Speed	
Slow Steaming extra Hours	SUECIA	85.5	82.5		1210	14.66667	
0.5	SELANDIA	New Idle Berth Hours if freq change					
Ships Deployed	FLANDRIA	-2.5					
3	ANGLIA						
New Sailings per Week	BRITANNIA						
15	SHIP						

Figure 4: The new sailing speed and week berth/sailing hours calculation

The new sailing time is then fed to the modal split module, in order to calculate the new generalized cost of transport associated with the option using DFDS. This is further discussed in section 6.3. The new sailing speed and the change in hours of activity (sailing vs berth) has immediate implications on the total fuel consumption of the service. This is discussed in the next section.

6.2 New fuel consumption for each vessel and route

Most of the Ro-Ro operator measures described in section 5 will have a direct influence on the fuel consumption of each journey and subsequently the actual operating costs of the service. Fuel consumption modelling methodologies have been used in the past to estimate emissions and/or operating costs of ships during all vessel activities. These methodologies can be grouped into two main categories; bottom-up, and top-down approaches or occasionally a hybrid approach using elements of both of the latter. Deciding which strategy is more appropriate depends on the available data, and the purpose of the study. The data provided by DFDS, contain information on the monthly fuel consumption broken down by engine type (main engines, auxiliary engines, and auxiliary boilers) and fuel type (HFO or MGO), which were further processed through software code developed for the purposes of WP3. Coupled with information on sailing distance for each vessel at each month, and certain assumptions on the fuel used for each activity, it was possible to create accurate fuel consumption inventories for each vessel. A snapshot of data (white cells) for three months of activity of one of the vessels (name not disclosed due to confidentiality) is shown in Figure 5, where the purple cells are outputs of the software model.

Analysis complete	Jan-14	Feb-14
Distance [Nm]	8558.7	9731.1
ME HFO	xx	xx
ME MGO		
AUX E HFO	xx	xx
AUX E MGO	xx	xx
TOTAL AUX	xx	xx
total aux PER TRIP	xx	xx
Boilers HFO		
Boilers MGO	xx	xx
total boilers per trip	xx	xx
Boilers MGO/Aux MGO	xx	xx
Aux (propulsion over berth)		
No of trips	21	24
No of days	31	28
Fuel Consumption per NM ME	xx	xx
Fuel Consumption per NM AUX	xx	xx
Fuel Consumption per NM ME at port per T	xx	xx
Total HFO	xx	xx
Total MGO	xx	xx

Figure 5: Post-processing of fuel consumption data (confidential data marked as 'xx')

These data were further processed to estimate the hourly fuel consumption for each machinery, during each activity phase (sailing or berth hoteling). Data by DFDS were given for both 2014 and 2015, however there are certain implications for the fuel consumption estimates due to the low sulphur limit effective on 2015. Figure 6 shows the way fuel was consumed by machinery for vessels.

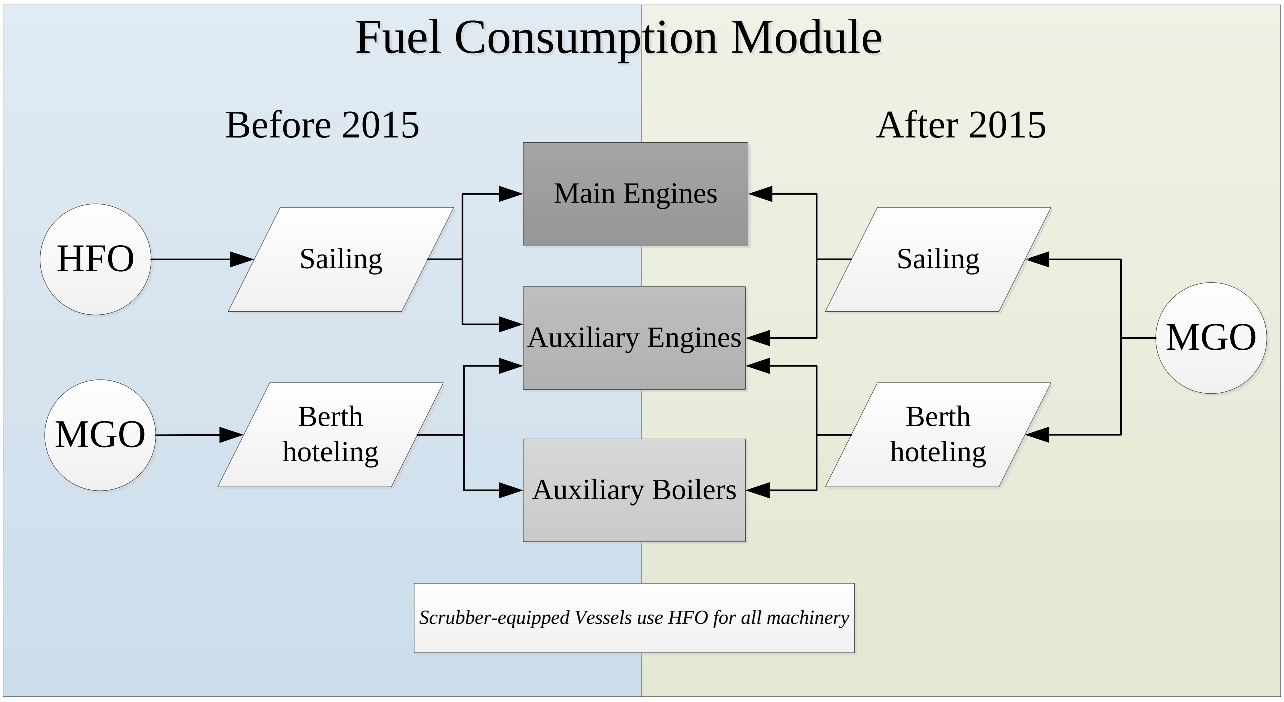

Figure 6: The use of fuel for each engine type in 2014 vs 2015

As seen in Figure 6, prior to 2015 the use of MGO was limited to the auxiliary engines and boilers while ships was hoteling at each port, to respect the rule set by the European Commission, that all ships must burn 0,1% sulphur content fuel while at berth (or when sailing in inland waterways). Therefore, it is possible to estimate the fuel consumption per hour at berth based on the MGO fuel consumption of each vessel during 2014. The HFO fuel consumption in turn, corresponds to only the propulsion activity. With regards to the fuel consumption during 2015, vessels are forced to either use MGO for all activities (so all machinery), or use HFO if they are equipped with scrubbers. It should be noted at this point, that the scrubber systems that DFDS is using allow for most of their vessels the treatment of exhaust gases of auxiliary engine activity as well. Analyzing the data based on year 2014, and considering the occasional vessel swapping that occurred between routes, a consistent fuel consumption performance was observed with a standard deviation of less than 8% of the average hourly fuel consumption for each activity.

Subsequently, the baseline fuel consumption inventory constructed through this approach was used to model the new fuel consumption when changes in the sailing schedule are introduced. For each new sailing scenario, the new weekly hours at berth and the new weekly sailing hours are considered for all vessels deployed on the examined route. For small changes, it can be assumed that the hourly hoteling fuel consumption will not change. The majority of fuel consumption during berth, occurs during the loading and unloading of vehicles, where it is necessary to provide ventilation in the lower decks/garages. Therefore, if the berth hours are marginally reduced to increase sailing time, the assumption is that the same requirements for ventilation will take place. Similarly, the auxiliary engines demand for fuel during sailing is assumed not to change despite any alterations in vessel sailing speed. However, the main engines will have a vastly different fuel consumption when sailing speed is altered. To address this, data from DFDS on sea-trials fuel consumption was provided for most of the vessels. These data, contain information on fuel consumption for certain different sailing speeds, and it is therefore possible to fit a curve that follows the propeller law as suggested in the literature. The exponent used that better captured the fuel consumption at different speeds ranged from 3 to 3.5 depending on vessel type and speeds. There is a significant difference between the sea trials fuel consumption and the actual fuel consumption, with the latter being higher by up to 20% in certain cases. This is an unsurprising fact, as the sea trials are performed in calm waters so the weather effect is not accounted for. Based on this methodology, the quantitative module developed can provide the new fuel consumption for each vessel at each new sailing configuration (sailing speed and sailing frequency). A snapshot of the module is shown in Figure 7 for vessels on the Gothenburg – Ghent route.

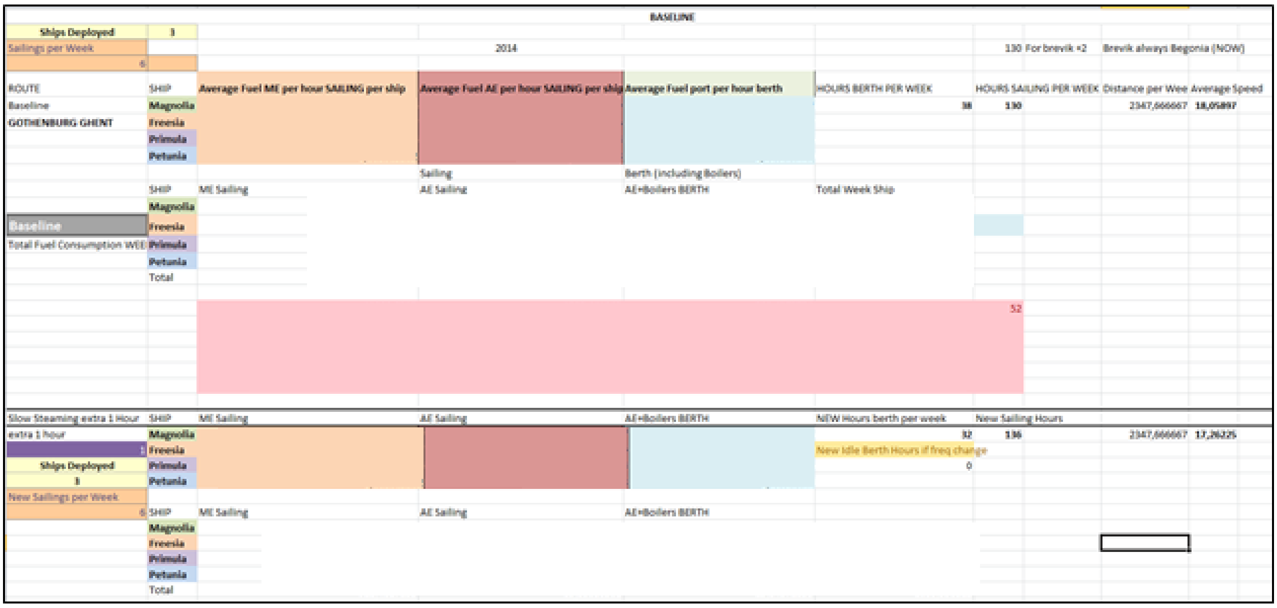

Figure 7: The module estimating new fuel consumption for all activities under the new sailing schedule (confidential data not shown)

In the run presented in Figure 7, the schedule is assumed to change by introducing an additional hour of sailing time at each trip on the Gothenburg – Ghent service, assuming that the once a week Gothenburg – Brevik link is unaffected, while the Brevik – Ghent link is also increased by 1 hour (sailing speed reduced from 18.1 to 17.3 knots). The module estimates the new berth and sailing hours, the necessary sailing speed to achieve this schedule, and then calculates the hourly fuel consumption for all ships, for all different activities, and the new weekly fuel consumption. The module allows introduction of multiple changes in the sailing schedule, including the swapping of vessels, the addition/removal of weekly sailings, as well as more slow (or even fast) steaming scenarios.

6.3 Modal split module post-Ro-ro operator measure

The modal split model that was developed in WP2, was using the generalized cost of transport as the function of disutility associated with each available travel option. This was calibrated based on data for 2014, for a wide variety of scenarios representing different cargo values, depreciation rates, and different O-D pairs. The results of this calibration was the estimation of the respective scale parameters λ for each service. The logic of the developed methodology, is that using these scale parameters, but for different generalized costs of the available transport options, it is possible to estimate the new market share for each option. In fact, the model is set up in such a way to model the new probability of choice for each option. Figure 8 presents a snapshot of the modal split model where the new generalized costs have to be entered to retrieve the new market shares.

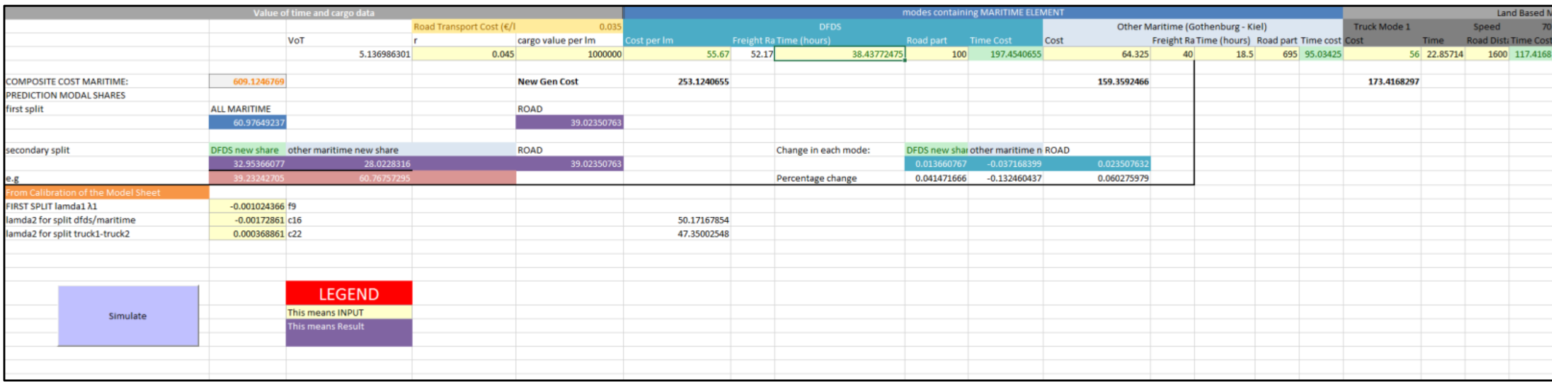

Figure 8: Simulation post-Ro-Ro operators' measure

The only requirement is that the user enters either the new travel time and travel cost information for the DFDS mode (as the other options are assumed not to change as a consequence of the Ro-Ro operator's measures), or simply directly plugin the new generalized cost at once. The new market shares can then be retrieved, as well as the loss/gain in percentage terms. This can then be used in conjunction with the transport demand in the base year, to estimate the revenue of the service.

6.4 New Environmental Balance and Route profitability

As seen in Figure 2, the introduction of changes in the service can affect both the environmental and economic performance of the fleet. Considering the new fuel consumption as estimated by the module presented in section 6.2, it is possible to calculate the new emissions generation from the service. In conjunction with the new market shares, it is possible to estimate the emissions per lm-NM of cargo transported, and compare with the situation prior to the measure. At the same time, given the fuel prices in the examined scenario, it is possible to estimate the new fuel costs, and the new revenue based on the new transport demand for the shipping company. 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.

7 The examined measures tailored for each Route (where applicable)

In section 5 measures that are at the disposal of the ship operator were presented in qualitative terms to justify the rationale behind their selection. This section shows the format under which these measures were considered for each of the seven routes examined in the context of the RoRoSECA project. The measures are presented in a matrix form where each row depicts each of the seven services, and each column represents the examined measure. The matrix was presented to DFDS and the suggested measures were agreed as reasonable options that the company could potentially consider, and as interesting for further examination. Table 5 contrasts the current status of each service, (actually the status in year 2014, just prior to the implementation of the 0.1 % limit). A short description of the ex-post measure is given in the matrix, and a more detailed description ensues.

Table 5: The Route-Measure Matrix with a short summary of the specifications examined for each measure at each service

<table>
<tr><th rowspan="2">Measure / Route</th><th colspan="2">Speed Reduction</th><th colspan="2">Sailing Frequency</th><th rowspan="2">Fleet and network reconfiguration</th><th rowspan="2">Use of LNG as fuel (CBA, no change in schedule)</th><th rowspan="2">Use of scrubbers in more vessels (CBA, no change in schedule)</th><th rowspan="2">Change in pricing policy</th><th rowspan="2">Cold ironing</th></tr>
<tr><th>Current (hours)</th><th>New (hours)</th><th>Current (#/week)</th><th>New (#/week)</th></tr>
<tr><td>Gothenburg – Ghent</td><td>32</td><td>+ 1, 2,3</td><td colspan="2">Not relevant as doing well</td><td>Swap vessel with Goth-Immingham based on capacity or abatement technology. No change at schedule, or demand</td><td rowspan="7">Not route specific. Feasibility and CBA to be conducted on different vessel type (Ro-Ro/Ro-Pax/Pax) and size, assuming new-build.</td><td>All vessels have scrubbers</td><td rowspan="7">Not route specific. Either absorb BAF 0.1/1% sulphur differential Alternatively, lower cost to obtain same market share, or same revenue. Policy changes for each fuel case scenario</td><td rowspan="7">Not route specific. First assumption: 1 port offers facility, or both ports offer facility. Always available. CBA for one vessel will be conducted, external costs will be contrasted</td></tr>
<tr><td>Esbjerg – Immingham</td><td>18.5</td><td>+0.5,1, 2</td><td>6</td><td>5 (cut Saturday)</td><td rowspan="2">Swap vessels between these two routes</td><td>Now both have scrubbers (not in the past)</td></tr>
<tr><td>Rotterdam – Felixstowe</td><td>7.5</td><td>+0.5,1</td><td>16</td><td>Not relevant (3/weekday fixed schedule)</td><td>All vessels now have scrubbers (Anglia Seaways was the last to be retrofitted)</td></tr>
<tr><td>Copenhagen – Oslo</td><td>17</td><td>+0.5,1, 2 (more revenue onboard)</td><td colspan="2">Not relevant as doing well</td><td>Not relevant, could swap with AMS-NEW</td><td>Crown has scrubber-
Fit scrubber on Pearl was ruled out by DFDS</td></tr>
<tr><td>Klaipeda – Kiel</td><td>20</td><td>-1.5 (actually happened) +0.5</td><td>7</td><td>6</td><td rowspan="2">Swap vessels between these two routes</td><td>All vessels have scrubbers</td></tr>
<tr><td>Klaipeda – Karlshamn</td><td>12/13-15</td><td>+1,2</td><td>7</td><td>6</td><td>Athena was the last vessel that was retrofitted</td></tr>
<tr><td>Dover – Calais</td><td colspan="2">Not relevant due to low sailing time</td><td>75 weekday
13 Saturday
11 Sunday</td><td>75</td><td>Not relevant due to loading/unloading uniqueness of vessels</td><td>Current deployed have scrubbers (not in the past)</td></tr>
</table>

Gothenburg – Ghent

This is one of the most important routes of DFDS, and due to contracts with Volvo the sailing frequency is something that will not change. Due to cut-off times for different cargoes, there is relatively small flexibility on reducing berth hours to prolong sailing time. However, reducing the total sailing time by 1, 2, or 3 hours will be examined as a means to reduce fuel consumption at each sailing, which can be interesting, should fuel prices increase again. Currently vessels sail on an average speed of 18,1 knots which is relatively fast. All vessels in this route, as well as on Gothenburg – Immingham (one of the DFDS routes that are not examined in the RoRoSECA project) are sister ships of the same class knows as the flower-class, with small differences in carrying capacity. All vessels in these two routes are already equipped with scrubber systems so this measure will not be examined for this route. Finally, it should be noted at this point that DFDS has lengthened some of the vessels on this route, so as to increase their carrying capacity by up to 20%, as a means of adapting to the new higher demand that was observed in the last two years. Finally, a case study of DFDS internalizing part of the BAF surcharges by lowering the freight rates will be considered, to contrast the impacts on profitability and market share.

Esbjerg – Immingham

This North Sea service is one of the most improved during 2015 served by two Ro-Ro vessels. The number of six sailings per week has not changed from 2014, and the sailing time is requiring approximately 18.5 hours and on fast sailing speeds of 18.1 knots. According to schedule, each vessel stays at the port for 6 hours from the moment of arrival, to the next departure. Considering the cut-off times that require a minimum arrival at the port of 3 hours ahead of vessel departure for most vehicles, and 4 hours for certain lift units, there is little slack for reducing sailing time. Therefore, only a small reduction by 0.5, 1, or 2 hours will be considered, even though the latter time may be unrealistic to ensure that there are no delays at the port (a sailing speed decrease to 16.3 knots). With regards to changing the sailing frequency, this is only considered in the event of a very high increase in fuel prices, where it will be changed to 5 weekly sailings, effectively shutting down one weekend sailing. Vessels sailing in this route are occasionally swapped with vessels on the Rotterdam – Felixstowe service, so this will be considered here on the basis of vessel capacity. The current vessels on this route are both equipped with scrubber systems and therefore this measure is no longer relevant in this route.

Rotterdam – Felixstowe

The shorter North Sea service has also seen significant improvement in terms of transported cargo during 2015. Three Ro-Ro vessels were deployed with a total of 16 sailings per week each lasting approximately 7.5 hours on a sailing speed of 16knots. The average berth time on a normal weekday is 4.5 hours per call, but is much higher on weekends due to the less frequent sailings. The cut-off times for drivers are just 1 hour, and 2 hours for hazardous material, which can allow for a small change in sailing speed. An increase of 0.5 and 1 hour will be considered in this route, due to the competition it faces from other maritime modes, and the available slack time at berth. Changing the sailing frequency will not be considered in this measure, due to the number of vessels deployed in the route. As stated in the previous section, vessel swapping with Esbjerg – Immingham is a practice that DFDS already is using, and its merits will be examined in this report. All vessels in this route are equipped with scrubber systems, with the last vessel that was using MGO (Anglia Seaways) having been retrofitted within the previous year.

Copenhagen – Oslo
The only cruise service examined in RoRoSECA project, is one of the more stable services in the network. The number of vessels deployed and the sailing frequency are not subject to change for the foreseeable future considering the nature of the service. One minor change that will be considered is the prolongation of sailing time, in an effort to increase the on-board revenue from passenger spending. This will assume that the on-board revenue is a direct function of time for small incremental increases. The current average sailing speed is at 15.5 knots. An extension of ½, 1, and 2 hours will be considered. Vessel swapping is not feasible for this route, as there are only 4 DFDS cruise vessels (the other two on Amsterdam – Newcastle), but the option of swapping vessels with the other cruise route has been deemed as not possible by DFDS. Finally, Crown Seaways is already equipped with scrubbers, while Pearl Seaways has been ruled out by DFDS for a possible conversion.

Klaipeda – Kiel
This Baltic Sea service is the second longest in terms of sailing time of the ones examined in the RoRoSECA project. Two Ro-Pax vessels serve this route on 21-22-hour long voyages at 18.4 knots approximately, offering seven sailings per week each way. This speed was the published speed for 2014 and 2015, but interestingly the current sailing speed has been increased by effectively reducing the travel time to 19.5-20 hours. The repercussions of this decision will be examined, along with the impacts of a potential increase of sailing time, should fuel prices increase. Considering the very tight space for adjustments (cut-off times of 2 hours for self-drives and trailers, 3 hours for hazardous units) and the limited berth hours per call in the original schedule (4 hours at each port from arrival to departure), an increase of 1 hour in sailing time will be examined. Vessels used to be swapped occasionally by DFDS between the Klaipeda – Kiel and the Klaipeda – Karlshamn routes due to small differences in available cargo capacity, and the occasional lay-up for maintenance. However, as DFDS received a subsidy from the EU to install scrubber systems on certain vessels, these have to sail on specific routes only; thus this measure will not be examined further for these two routes. Currently, all vessels in this service have scrubbers.

Klaipeda – Karlshamn
The second Baltic Sea service examined in RoRoSECA, is a shorter service where two Ro-Pax vessels sail daily each way at around 17.2 knots over 13 hours. The very high berth times (11 hours per day) allow for some flexibility in the sailing speed, which DFDS is already taking advantage of by increasing the sailing time up to 15 hours outside peak seasons. The option of changing the sailing frequency to a lower number will be considered for a very high fuel price case. Increasing the sailing frequency would actually require either a significant increase of sailing speed, or the deployment of a third vessel on the route, something that in the current status of the service seems unlikely. Vessel swapping with Klaipeda – Kiel is limited due to the scrubber subsidies by the EU. Finally, in this route both deployed vessels are equipped with scrubbers.

Dover – Calais

The shorter service in the DFDS network, is currently served by two Ro-Pax vessels, sailing a maximum of 75 times each way per week, with a slightly less frequent service during the weekend. The sailing takes approximately 1.5 hours, and the sailing speed is on average 15.3 knots (though this depends on the actual distance sailed, which varies according to different estimates). Due to the competing nature of the service with Eurotunnel, and other ferry operators (especially in the past), it is not realistic to reduce the sailing speed by 0.5 hours. While a smaller increase could be feasible, the timetable of the service would be perplexed. Altering the number of weekly sailings will be considered instead. The vessels in this route cannot be swapped with other Ro-Pax services, due to the unique design of vessels calling at these two ports. Finally, the current vessels deployed in this route are running on scrubbers, however it is noteworthy that the vessels deployed in the Route during 2014 and 2015 were running on MGO. The current vessels are still using MGO to cover their auxiliary engines demands at berth.

8 Simulation of modal changes and analysis of Route performance

This section will present a summary of runs performed for the measures described in section 5, for each service with the specifications described in section 7. As with Task 2.2, three main fuel price scenarios are used for each implementation of a measure, and each measure is considered on its own. It should be noted that the models have been created in a way where any combination of measure specification, fuel price (MGO and HFO), and fleet deployment can be readily tested for its implications on route performance. The simulation process for each measure is depicted schematically in Figure 9.

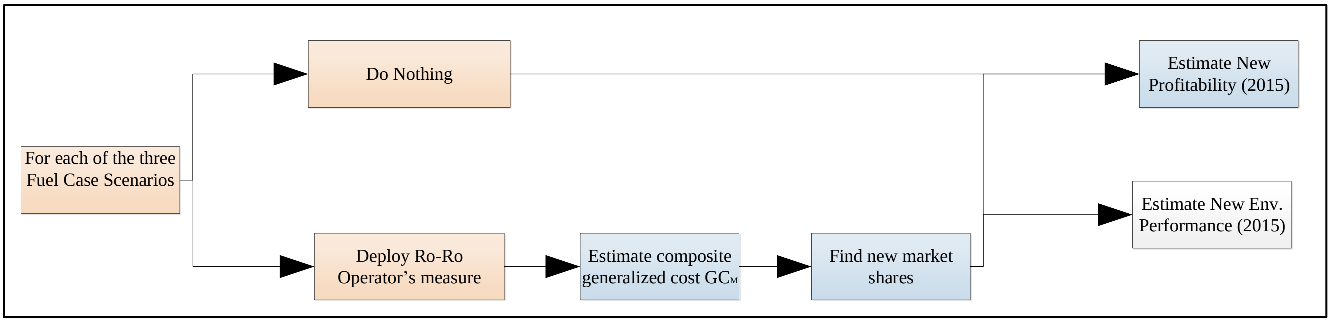

Figure 9: The simulation process used in the analysis of the Ro-Ro measures

The three fuel case scenarios in the ensuing analysis are the same as the ones considered in Task 2.2, and Table 6 below shows the average fuel prices for HFO and MGO for each scenario. For the sake of simplicity, the calculations on revenue and costs are conducted for one week in each scenario, assuming the peak season with the highest number of sailings and sailing speeds

Table 6: The Fuel Case Scenarios

Scenario	HFO Price ($/ton)	MGO Price ($/ton)	Comment
Fuel Case 1	263	478	These are the actual fuel prices in 2015
Fuel Case 2	533	816	These are using the fuel prices in 2014, which were higher. This is a pessimistic scenario.
Fuel Case 3	263	(Not used)	These are using the HFO prices in 2015, so represent an optimistic scenario of very low fuel prices (or lack of regulation)

8.1 Gothenburg – Ghent

For this route, the options of increasing sailing time by 1, 2, or 3 hours will be considered. From the six ships that are sharing this route with the Gothenburg – Immingham service, only one vessel is slightly smaller (and currently deployed in the other route). The implication of swapping this vessel will be examined in terms of capacity utilization and operating costs.

8.1.1 Baseline

For the baseline case, the assumption is that for all fuel case scenarios the sailing speed and sailing frequency are not changing and that the deployed vessels were Magnolia, Freesia, and Primula Seaways.

Table 7: The Baseline fleet deployment for all Fuel Cases

Sailing Speed 18.06 knots - Sailing Frequency 6 per week				
	Transported lm	Capacity Utilization (%)	Revenue (€)	Cost of Fuel (€)
Fuel Case 1	42331	85.95	2004373	206147
Fuel Case 2	39533	79.8	2043591	417780
Fuel Case 3	43724	89.01	1972660	200142

In accordance with the findings in Task 2.2, it can be seen that in the second fuel case scenario (MGO 2014 prices); there is a loss of cargo due to the higher freight rates charged. The total revenue is slightly higher as the freight rates increase is higher than the loss of cargo. However, the fuel cost is more than double and this is considering that the vessels are running on scrubbers. There is also a reduction in the capacity utilization factor, however this remains within acceptable values. For Fuel Case 3 scenario, the number of transported lanemeters is increasing due to the lower freight rate, the capacity utilization is further improved, while the revenue shows a small decrease in comparison to FC1. The fuel cost is slightly lower than FC1, because the assumption is that the vessels would not have a need for scrubber systems, and thus the fuel consumption is slightly lower.

8.1.2 Slow steaming

As discussed in section 7, there are three tiers of slow steaming that will be examined that consider an increase in sailing time by 1, 2, or 3 hours. The implications of such changes in the fuel consumption of the deployed vessels are summarized in Table 8.

Table 8: The effects of a new sailing speed on fuel consumption per hour (confidential data marked as 'xx')

Ship	Average Fuel ME (tonnes per hour)	Average AE (tonnes per hour, cruise)	Average Fuel port (tonnes per hour, berth)
Baseline Sailing Speed 18.06 knots			
Magnolia	**xx**	**xx**	**xx**
Freesia	**xx**	**xx**	**xx**
Primula	**xx**	**xx**	**xx**
Petunia	**xx**	**xx**	**xx**
Increase Trip by 1 hour, New Sailing Speed 17.26			
Magnolia	**xx**	**xx**	**xx**
Freesia	**xx**	**xx**	**xx**
Primula	**xx**	**xx**	**xx**

Petunia	**xx**	**xx**	**xx**
Increase Trip by 2 hours, New Sailing Speed 16.53			
Magnolia	**xx**	**xx**	**xx**
Freesia	**xx**	**xx**	**xx**
Primula	**xx**	**xx**	**xx**
Petunia	**xx**	**xx**	**xx**
Increase Trip by 3 hours, New Sailing Speed 15.86			
Magnolia	**xx**	**xx**	**xx**
Freesia	**xx**	**xx**	**xx**
Primula	**xx**	**xx**	**xx**
Petunia	**xx**	**xx**	**xx**

It can be observed that the hourly consumption of the main engine is significantly reduced for all slow steaming scenarios, and can almost be halved with an increase of sailing time by three hours. The other fuel consumptions are assumed not to change, as the electrical demands during cruise and at berth are assumed not to change as a consequence of the new sailing speed (and new berthing hours). With the new sailing speeds, the weekly distribution of sailing hours vs hours at berth is changing, and the resulting total fuel consumption is shown in Table 9.

Table 9: Effects of slow steaming on weekly fuel consumption for ships on Gothenburg – Ghent

Ship	Hours at berth	Hours sailing	Weekly fuel consumption (tonnes)	Reduction (%)
Baseline Sailing Speed 18.06 knots				
Magnolia	38	130	**xx**	NA
Freesia			**xx**	
Primula			**xx**	
Petunia			**xx**	
Increase Trip by 1 hour, New Sailing Speed 17.26				
Magnolia	32	136	**xx**	-10.11
Freesia			**xx**	-10.51
Primula			**xx**	-9.26
Petunia			**xx**	-8.52
Increase Trip by 2 hours, New Sailing Speed 16.53				
Magnolia	26	142	**xx**	-18.36
Freesia			**xx**	-18.96
Primula			**xx**	-17.55
Petunia			**xx**	-16.67
Increase Trip by 3 hours, New Sailing Speed 15.86				
Magnolia	20	148	**xx**	-34.86
Freesia			**xx**	-35.80
Primula			**xx**	-34.23
Petunia			**xx**	-33.24

It has to be noted that in the estimation of the fuel consumption at different sailing speeds, the assumption is that any changes in cargo volumes loaded are not considered. In reality, if due to the lower sailing speed the demand for the route drops, this will result in a slightly lower fuel consumption due to the lower deadweight. The next step of the analysis is to understand the effect of the lower sailing speed into modal choice, considering that no other change is introduced (e.g. the freight rates are remaining the same for all three Fuel Case scenarios as in the baseline). The runs are performed for average cargo values and depreciation rates as defined in Task 2.2.

Table 10: Effects of slow steaming on transported cargo, revenue of service, and cost of fuel consumed per week

Increase Trip by 1 hour, New Sailing Speed 17.26				
	Transported lm	Capacity Utilization (%)	Revenue (€)	Cost of Fuel (€)
Fuel Case 1	42309	**xx**	**xx**	**xx**
Fuel Case 2	39389	**xx**	**xx**	**xx**
Fuel Case 3	43815	**xx**	**xx**	**xx**
Increase Trip by 2 hours, New Sailing Speed 16.53				
Fuel Case 1	42287	**xx**	**xx**	**xx**
Fuel Case 2	39255	**xx**	**xx**	**xx**
Fuel Case 3	43793	**xx**	**xx**	**xx**
Increase Trip by 3 hours, New Sailing Speed 15.86				
Fuel Case 1	42265	**xx**	**xx**	**xx**
Fuel Case 2	39232	**xx**	**xx**	**xx**
Fuel Case 3	43772	**xx**	**xx**	**xx**

Table 10 shows that for all speed reduction scenarios a minor loss of cargo is observed, which is due to the very low effect that the extra time has on the generalized cost of transport. However, it must be stressed that if a very high depreciation rate is used and/or cargoes of very high values, then the loss due to slow steaming would be higher. It can also be seen that the revenue is relatively unchanged, whereas the cost of fuel is changing dramatically for lower speeds for all fuel case scenarios. The capacity utilization remains within the target levels of DFDS, not surpassing 90% where it could lead to certain trips being completely full, and not dropping below 79%.

8.1.3 Fleet reconfiguration

In this scenario the option could be the deployment of Petunia Seaways (lower fuel consumption) instead of Freesia (largest nominal capacity and highest fuel consumption as evidenced by data from DFDS). Such a swap would only make sense if there were a drop of transportation demand, due to for instance a high increase in freight rates. As seen in section 8.1.2, even for the high price FC2, the loss of cargo was minimal however; there was a reduction in utilization capacity observed. Table 11 compares for all scenarios the effects of such a swap.

Table 11: Effects of swapping Freesia Seaways with smaller Petunia Seaways during a peak week

	Capacity utilization	ΔFuel Cost (€)
Fuel Case 1	**xx**	4662
Fuel Case 2	**xx**	9447
Fuel Case 3	**xx**	4526

Table 11 suggests that the fuel cost benefit per week is relatively small from this swap. For the high fuel price scenario where there is also an important drop in demand (due to the higher freight rates), the fuel benefit is approximately €10000 per week, while the capacity utilization remains at near-optimal level (as defined by DFDS). For low fuel price scenarios, the fuel cost benefit is very small while the vessels are loaded very close to the maximum capacity, which is undesirable from the shipping company. Therefore, this measure would make sense if fuel prices increase and for external reasons the Gothenburg – Immingham service increases its transport demand.

8.2 Esbjerg – Immingham

For this route, the options of increasing sailing time by 0.5, 1, or 2 hours will be considered. For FC2, the option of reducing the number of weekly sailings from 6 to 5 will be considered (shutting down a weekend voyage).

8.2.1 Baseline

For the baseline case, the assumption is that for all fuel case scenarios the sailing speed and sailing frequency are not changing and that the deployed vessels were Ark Dania and Ark Germania as these were used for the majority of 2015 in this service by DFDS. Both vessels were using scrubbers as of 2015.

Table 12: The Baseline fleet deployment for all Fuel Cases

Sailing Speed 18.06 knots - Sailing Frequency 6 per week				
	Transported lm	Capacity Utilization (%)	Revenue (€)	Cost of Fuel (€)
Fuel Case 1	32663	**xx**	**xx**	**xx**
Fuel Case 2	31671	**xx**	**xx**	**xx**
Fuel Case 3	33452	**xx**	**xx**	**xx**

Using the calibration results obtained in Task 2.2, it can be seen that in the second fuel case scenario (MGO 2014 prices); there is a notable loss of cargo due to the higher freight rates charged. The total revenue is slightly higher as the freight rates increase is higher than the loss of cargo. The cost of fuel is increasing proportionally to the fuel price, and is very high for FC2. Finally, for FC3 the assumption is that the fuel consumption would be slightly reduced, as scrubbers would not be required, while the transported cargo increases due to the lower freight rates. The capacity utilization in FC3 is increasing to almost 93%, which may require using a larger vessel to ensure that no cargoes are left unloaded.

8.2.2 Slow steaming

The effects of considering slow steaming in Esbjerg – Immingham are summarized in Table 13.

Table 13: Effects of new sailing speed on fuel consumption per hour

Ship	Average Fuel ME (tonnes per hour)	Average AE (tonnes per hour, cruise)	Average Fuel port (tonnes per hour, berth)
Baseline Sailing Speed 18.11 knots			
Ark Germania	**xx**	**Included in ME**	**xx**
Ark Dania	**xx**		**xx**
Increase Trip by 0.5 hour, New Sailing Speed 17.62			
Ark Germania	**xx**	**Included in ME**	**xx**
Ark Dania	**xx**		**xx**
Increase Trip by 1 hour, New Sailing Speed 17.16			
Ark Germania	**xx**	**Included in ME**	**xx**

Ark Dania	**xx**		**xx**
Increase Trip by 2 hours, New Sailing Speed 16.3			
Ark Germania	**xx**	**Included in ME**	**xx**
Ark Dania	**xx**		**xx**

The hourly consumption during sailing is reduced to a lesser extent in comparison with other services, due to the very small extent of the speed reduction. However, the fuel savings are still noteworthy. The resulting total fuel consumption is shown in Table 14 including information on the new distribution of berthing and sailing hours.

Table 14: Effects of slow steaming on weekly fuel consumption for ships on Esbjerg – Immingham

Ship	Hours at berth	Hours sailing	Weekly fuel consumption (tonnes)	Reduction (%)
Baseline Sailing Speed 18.11 knots				
Ark Germania	60	108	**xx**	NA
Ark Dania			**xx**	
Increase Trip by 0.5 hour, New Sailing Speed 17.62				
Ark Germania	57	111	**xx**	-6.47
Ark Dania			**xx**	-14.19
Increase Trip by 1 hour, New Sailing Speed 16.53				
Ark Germania	54	114	**xx**	-12.40
Ark Dania			**xx**	-19.72
Increase Trip by 2 hours, New Sailing Speed 15.86				
Ark Germania	48	120	**xx**	-22.87
Ark Dania			**xx**	-29.38

The effects of a potential speed reduction to the probability of the shipper choosing DFDS is shown in Table 15 considering that nothing else is changed. The runs are performed for average cargo values and depreciation rates as defined in Task 2.2.

Table 15: Effects of slow steaming on transported cargo, revenue of service, and cost of fuel consumed per week

Increase Trip by 0.5 hour, New Sailing Speed 17.62				
	Transported lm	Capacity Utilization (%)	Revenue (€)	Cost of Fuel (€)
Fuel Case 1	31479	**xx**	**xx**	**xx**
Fuel Case 2	30409	**xx**	**xx**	**xx**
Fuel Case 3	32335	**xx**	**xx**	**xx**
Increase Trip by 1 hour, New Sailing Speed 17.16				
Fuel Case 1	30203	**xx**	**xx**	**xx**
Fuel Case 2	29060	**xx**	**xx**	**xx**
Fuel Case 3	31124	**xx**	**xx**	**xx**
Increase Trip by 2 hours, New Sailing Speed 16.3				
Fuel Case 1	27400	**xx**	**xx**	**xx**
Fuel Case 2	26134	**xx**	**xx**	**xx**
Fuel Case 3	28437	**xx**	**xx**	**xx**

Table 15 shows that for all speed reduction scenarios a notable loss of cargo is observed. It can also be seen that for certain high fuel price scenarios, an increase in sailing time could drastically reduce the utilization factor of the service. During 2015, DFDS reported utilization rates of up to 90.73% on this route. This means that should the transport demand increase further, an option could be to increase the sailing frequency of the service, by adding an additional weekend service. From another perspective, an increase in transport demand that may increase the risk of overcapacity (and thus cargoes not being loaded in the intended sailing), could be offset by increasing the sailing time to lower the utilization rates to the desired levels.

8.2.3 New sailing frequency

The sailing frequency of 6 sailings each way per week could easily be modified in times of low transport to 5 (by removing the weekend service) or 7 if the transport demand keeps on increasing. The first is examined for FC2 (high fuel prices) and the latter for FC3 (low fuel prices). The results on capacity utilization, new market share, and fuel costs are summarized in Table 16. No other changes are introduced.

Table 16: The effects of a new sailing frequency on the service

	New sailing frequency	New Transported lm	New capacity utilization	ΔRevenue (€)	ΔFuel Cost (€)
Fuel Case 2	5	**xx**	**xx**	**xx**	-33579
Fuel Case 3	7	**xx**	**xx**	**xx**	16569

It can be seen that the drop in demand as a consequence of the increased freight rates and the reduced frequency, is not enough to reduce the capacity utilization to a reasonable range. The reduction in revenue is higher than the reduction in fuel costs, and unless the reduction in other costs (salary, port fees, and depreciation of vessel) is higher than this difference the company will be worse off by reducing the service. Thus, it can be concluded that the reduction of sailing frequency should be used for an extreme drop in demand in this route. For the optimistic case where an additional sailing is launched, the capacity utilization is lowered to a more robust level (82%), while the transport demand is also increased. The net difference between the additional revenue and the additional fuel costs is approximately €23000 per week, which needs to be higher than the extra salary costs, port fees, and wear of the vessel.

8.2.4 Fleet reconfiguration

In this scenario, the option examined is swapping Ark Dania (higher fuel consumption) with Britannia Seaways (lower fuel consumption and slightly lower capacity). This swap could be considered if there is a drop in transport demand as it reduces that available transport capacity. As discussed in section 8.2.2, a lower sailing speed would also result in a reduction in transport demand and it could be combined with the deployment of a smaller vessel. Table 17 shows the effects of the vessel swap for the three fuel case scenarios, while maintaining the sailing speed of the schedule.

Table 17: Effects of swapping Ark Dania with Britannia Seaways during a peak week

	Capacity utilization	ΔFuel Cost (€)
Fuel Case 1	**xx**	-11033
Fuel Case 2	**xx**	-22358
Fuel Case 3	**xx**	-10711

Table 17 suggests that the fuel cost benefit per week is slightly higher in comparison to the Gothenburg – Ghent swap. For the high fuel price scenario where there is also an important drop in demand (due to the higher freight rates), the fuel benefit is approximately €22000 per week, while the capacity utilization remains a very good level. For low fuel price scenarios, the fuel cost benefit is smaller while the vessels are loaded extremely close to the maximum capacity and therefore it would not make any sense to use this measure.

8.3 Rotterdam – Felixstowe

For this route, the options of increasing sailing time by 0.5, or 1 hour will be considered. A vessel swap with a less fuel demanding ship will also be presented.

8.3.1 Baseline

For the baseline case, the vessels deployed were Selandia, Suecia, and Anglia that were mostly used in 2015 by DFDS on this route.

Table 18: The Baseline fleet deployment for all Fuel Cases

Sailing Speed 16.13 knots - Sailing Frequency 16 per week				
	Transported lm	Capacity Utilization (%)	Revenue (€)	Cost of Fuel (€)
Fuel Case 1	70538	xx	xx	xx
Fuel Case 2	67216	xx	xx	xx
Fuel Case 3	73493	xx	xx	xx

For FC2, there is an important loss of cargo due to the higher freight rates charged. The total revenue is slightly lower as the freight rates increase is not great in this simulation scenario. There is also a reduction in the capacity utilization factor, which now falls under 90% and closer to the DFDS target. For Fuel Case 3 scenario, the number of transported lanemeters has increased while the revenue is also increased in comparison to the FC1. The cost of fuel shows significant variation due to its dependence with fuel price, while the revenue is relatively stable due to the low impact of the fuel price on the freight rates on this route.

8.3.1 Slow steaming

As discussed in section 7, two tiers of slow steaming consider an increase in sailing time by 0.5 or 1 3 hour. Their effects are shown in Table 19.

Table 19: The effects of a new sailing speed on fuel consumption per hour

Ship	Average Fuel ME (tonnes per hour)	Average AE (tonnes per hour, cruise)	Average Fuel port (tonnes per hour, berth)
Baseline Sailing Speed 16.11 knots			
Suecia	xx	xx	xx
Selandia	xx	xx	xx
Anglia	xx	xx	xx
Increase Trip by 0.5 hour, New Sailing Speed 14.67 knots			
Suecia	xx	xx	xx
Selandia	xx	xx	xx
Anglia	xx	xx	xx
Increase Trip by 1 hour, New Sailing Speed 13.44 knots			
Suecia	xx	xx	xx
Selandia	xx	xx	xx
Anglia	xx	xx	xx

It can be observed that the hourly consumption of the main engine is significantly reduced for all slow steaming scenarios due to the fact that even a small increase in sailing time results in an important reduction in speed. The new weekly distribution of sailing hours vs hours at berth is also altered, and the resulting total fuel consumption is shown in Table 20.

Table 20: Effects of slow steaming on weekly fuel consumption for ships on Rotterdam – Felixstowe

Ship	Hours at berth	Hours sailing	Weekly fuel consumption (tonnes)	Reduction (%)
Baseline Sailing Speed 16.11 knots				
Suecia	88	80	**xx**	NA
Selandia			**xx**	
Anglia			**xx**	
Increase Trip by 0.5 hour, New Sailing Speed 14.67				
Suecia	80	88	**xx**	-18.05
Selandia			**xx**	-17.33
Anglia			**xx**	-18.23
Increase Trip by 1 hour, New Sailing Speed 13.44				
Suecia	72	96	**xx**	-31.42
Selandia			**xx**	-30.16
Anglia			**xx**	-32.08

The weekly fuel cost shows an important decrease as expected due to the much lower sailing speeds. The effects of the additional voyage time on shipper's choice, and thus revenue and capacity utilization are shown in Table 21, based on the average depreciation rates and cargo values as defined in Task 2.2.

Table 21: Effects of slow steaming on transported cargo, revenue of service, and cost of fuel consumed per week

Increase Trip by 0.5 hour, New Sailing Speed 14.67				
	Transported lm	Capacity Utilization (%)	Revenue (€)	Cost of Fuel (€)
Fuel Case 1	69822	**xx**	**xx**	**xx**
Fuel Case 2	66517	**xx**	**xx**	**xx**
Fuel Case 3	72764	**xx**	**xx**	**xx**
Increase Trip by 1 hour, New Sailing Speed 13.44				
Fuel Case 1	69109	**xx**	**xx**	**xx**
Fuel Case 2	65821	**xx**	**xx**	**xx**
Fuel Case 3	72037	**xx**	**xx**	**xx**

Table 21 shows that for all speed reduction scenarios there is a significant loss of cargo observed, which is due to the important effect that the extra time has on the generalized cost of transport. It can also be seen that the revenue is relatively unchanged, whereas the cost of fuel is changing dramatically for lower speeds for all fuel case scenarios. The capacity utilization remains at very high levels while for the low fuel price scenarios it is extremely high, to the point where the deployment of a larger vessel could provide a solution.

8.3.2 Fleet reconfiguration

In this scenario, the option examined is substituting Anglia Seaways with the larger Britannia Seaways. This would be a reasonable option if the transportation demand is increased, and the operator would want to ensure that the utilization factor is at reasonable levels. The results are summarized in Table 22.

Table 22: Effects of swapping Anglia Seaways with Britannia Seaways during a peak week

	Capacity utilization (%)	ΔFuel Cost (€)
Fuel Case 1	**xx**	10331
Fuel Case 2	**xx**	20938
Fuel Case 3	**xx**	10030

Table 22 suggests that the fuel cost penalty per week is relatively small from this swap. The capacity utilization for all scenarios drops at more reasonable levels that offer higher service reliability to the shippers. This measure could be useful in case there is an increase in transport demand to the point that the capacity utilization reaches higher than 90% values. Alternatively, instead of swapping vessels one option could be to increase the capacity via vessel lengthening.

8.4 Copenhagen – Oslo

In the only cruise service examined in this project, only the option of prolonging the sailing time will be considered, about its repercussions on revenue generation.

8.4.1 Baseline

For the baseline case, the vessels deployed were Crown and Pearl Seaways. The cargo and passengers transported in a week are summarized in Table 23. The assumption is that the number of passengers is not changing as a result of the fuel price, due to the nature of the service and the lack of data for the proper modelling of passenger's choice of transport. Modelling the transport choice of passengers, which depends on many additional factors besides price, is beyond the scope of the RoRoSECA project.

Table 23: The Baseline fleet deployment for all Fuel Cases

Sailing Speed 15.54 knots - Sailing Frequency 7 per week						
	Transported lm	Capacity Utilization (%)	Revenue (€)	Passenger Revenue	On-board Revenue	Cost of Fuel (€)
Fuel Case 1	10505	xx	xx	xx	xx	xx
Fuel Case 2	8918	xx	xx	xx		xx
Fuel Case 3	11640	xx	xx	xx		xx

For all scenarios, the transported cargo is a very small fraction of the overall revenue of the service, as the most important component is the on-board spending of passengers, followed by the passengers' fares. There is a significant variation of transported cargo for the three fuel case scenarios, and for FC2 it can be observed that the capacity utilization falls at very low levels. For FC3, the utilization factor surpasses 70%, and the cost of fuel is much lower than FC2.

8.4.2 Slow steaming

Speed reduction in this route could be considered as a means to prolong the on-board spending of passengers, as the cost of fuel is very low in comparison to the generated revenue of the service. The effects of slow steaming on fuel consumption for the two cruise ships are shown in Table 24.

Table 24: The effects of a new sailing speed on fuel consumption per hour

Ship	Average Fuel ME (tonnes per hour)	Average AE (tonnes per hour, cruise)	Average Fuel port (tonnes per hour, berth)
Baseline Sailing Speed 15.54 knots			
Crown Seaways	xx	xx	xx
Pearl Seaways	xx	xx	xx
Increase Trip by 0.5 hour, New Sailing Speed 15.11			
Crown Seaways	xx	xx	xx
Pearl Seaways	xx		xx
Increase Trip by 1 hour, New Sailing Speed 14.70			
Crown Seaways	xx	xx	xx
Pearl Seaways	xx		xx

The hourly consumption of the main engine during sailing is only slightly reduced due to the very small extent of the speed reduction. The resulting weekly fuel consumption is shown in Table 25 including information on the new distribution of berthing and sailing hours.

Table 25: Effects of slow steaming on weekly fuel consumption for ships on Copenhagen – Oslo

Ship	Hours at berth	Hours sailing	Fuel consumption (tonnes)	Reduction (%)
Baseline Sailing Speed 15.54 knots				
Crown Seaways	45.5	122.5	**xx**	NA
Pearl Seaways			**xx**	
Increase Trip by 0.5 hour, New Sailing Speed 15.11				
Crown Seaways	42	126	**xx**	-5.03
Pearl Seaways			**xx**	-4.78
Increase Trip by 1 hour, New Sailing Speed 14.70				
Crown Seaways	38.5	129.5	**xx**	-9.59
Pearl Seaways			**xx**	-9.10

It can be observed that the fuel savings for an additional hour of sailing can reach almost 10%. The effects of a potential speed reduction to the probability of the shipper choosing DFDS is shown in Table 26 considering that nothing else is changed. The runs are performed for average cargo values and depreciation rates as defined in Task 2.2. The revenue from passenger fares is assumed that the number passengers is fixed at all fuel cases, while on-board spending is proportional to sailing time.

Table 26: Effects of slow steaming on transported cargo, revenue of service, and cost of fuel consumed per week

	Transported lm	Capacity Utilization (%)	Revenue (€)	Passenger Revenue	On-board Revenue	Cost of Fuel (€)
Increase Trip by 0.5 hour, New Sailing Speed 15.11						
Fuel Case 1	10191	**xx**	**xx**	**xx**	**xx**	**xx**
Fuel Case 2	8642	**xx**	**xx**	**xx**		**xx**
Fuel Case 3	11302	**xx**	**xx**	**xx**		**xx**
Increase Trip by 1 hour, New Sailing Speed 14.70						
Fuel Case 1	9885	**xx**	**xx**	**xx**	**xx**	**xx**
Fuel Case 2	8372	**xx**	**xx**	**xx**		**xx**
Fuel Case 3	10971	**xx**	**xx**	**xx**		**xx**

Table 26 shows that there is a loss of cargo (and thus revenue from cargo) due to the slow steaming, and that the capacity utilization remains at low levels for all scenarios, particularly for the high fuel prices case. Considering that the passenger fare would not change as a result of the extra time, the passenger revenue is assumed unaffected by this Ro-Ro operator measure. Under the assumption of proportionality between sailing time, and passenger spending, which is of course an approximation, it is obvious that the on-board revenue more than makes up for the loss in revenue from cargo transported. Combined with the lower fuel bill it is evident that this measure would increase the profit of the service, though this benefit should be compared with the possible additional staff salaries on-board the vessel and any other operating costs that are not considered here.

8.5 Klaipeda – Kiel

In the first Baltic Sea route, the options of slow steaming will be examined, as well as the recent development in 2016 where actually the service has increased sailing speed. The option of reducing the number of weekly sailings by 1 will be examined for fuel case 2.

8.5.1 Baseline

For the baseline case, the vessels deployed were Victoria and Optima that were used for the majority of 2015 on this service. The cargo and passengers transported in a week are shown in Table 27.

Table 27: The Baseline fleet deployment for all Fuel Cases

Sailing Speed 15.54 knots - Sailing Frequency 7 per week						
	Transported lm	Capacity Utilization (%)	Revenue (€)	Passenger Revenue	On-board Revenue	Cost of Fuel (€)
Fuel Case 1	27761	xx	xx	xx	xx	xx
Fuel Case 2	26580	xx	xx	xx		xx
Fuel Case 3	28600	xx	xx	xx		xx

For all scenarios, the transported cargo is the major contributor in the revenue of the service while the on-board revenue is almost insignificant in comparison to the other revenue sources. There is some variation of transported cargo for the three fuel case scenarios; however, the utilization factor is at very good levels for all three fuel cases. For FC2 it can be observed that the cost of fuel is far higher than the passenger revenue.

8.5.1 Change of sailing speed

Speed reduction in this route could be considered for high fuel price scenarios. The option of increasing sailing time by 0.5 hour will be examined, as well as the repercussions of speeding up to reduce the total sailing time by 1.5 hours. The latter, is something that DFDS has been doing in 2016 (from a sailing time of 21.5 hours it was reduced to 20) and therefore interesting comparisons can be made. The effects of changing the sailing speed on fuel consumption for the two vessels are estimated in Table 28.

Table 28: Effects of a new sailing speed on fuel consumption per hour

Ship	Average Fuel ME (tonnes per hour)	Average AE (tonnes per hour, cruise)	Average Fuel port (tonnes per hour, berth)
Baseline Sailing Speed 18.39 knots			
Victoria Seaways	xx	xx	xx
Optima Seaways	xx	xx	xx
Increase Trip by 0.5 hour, New Sailing Speed 17.98			
Victoria Seaways	xx	xx	xx
Optima Seaways	xx		xx
Decrease Trip by 1.5 hour, New Sailing Speed 19.77			
Victoria Seaways	xx	xx	xx
Optima Seaways	xx		xx

The hourly consumption of the main engine during sailing is significantly increased in the faster steaming scenario. The resulting weekly fuel consumption is shown in Table 29 including information on the new distribution of berthing and sailing hours.

Table 29: Effects of slow steaming on weekly fuel consumption for ships on Klaipeda – Kiel

Ship	Hours at berth	Hours sailing	Fuel consumption (tonnes)	Change (%)
Baseline Sailing Speed 18.39 knots				
Victoria Seaways	17	151	**xx**	NA
Optima Seaways			**xx**	
Increase Trip by 0.5 hour, New Sailing Speed 17.98				
Victoria Seaways	13.4	154.6	**xx**	**xx**
Optima Seaways			**xx**	**xx**
Decrease Trip by 1.5 hour, New Sailing Speed 19.77				
Victoria Seaways	27.4	140.6	**xx**	**xx**
Optima Seaways			**xx**	**xx**

It is evident that the decision to cut the sailing time in 2016 would require a significant increase in fuel consumption that perhaps will not be sustainable if fuel prices continue increasing. The effects of the change in sailing time on shippers' choice are shown in Table 30

Table 30: Effects of slow steaming on transported cargo, revenue of service, and cost of fuel consumed per week

Increase Trip by 0.5 hour, New Sailing Speed 17.98						
	Transported lm	Capacity Utilization (%)	Revenue (€)	Passenger Revenue	On-board Revenue	Cost of Fuel (€)
Fuel Case 1	27729	**xx**	**xx**	**xx**	**xx**	**xx**
Fuel Case 2	26548	**xx**	**xx**	**xx**		**xx**
Fuel Case 3	28568	**xx**	**xx**	**xx**		**xx**
Decrease Trip by 1.5 hour, New Sailing Speed 19.77						
Fuel Case 1	27857	**xx**	**xx**	**xx**	**xx**	**xx**
Fuel Case 2	26677	**xx**	**xx**	**xx**		**xx**
Fuel Case 3	28695	**xx**	**xx**	**xx**		**xx**

Table 30 shows that there is not much variation in cargo units transported as a consequence of the change in sailing speeds. It must be stressed however that this is due to the assumptions used on cargo values and depreciation rates. As DFDS in 2016 had increased the sailing speed, it may be an indication of more time-sensitive cargoes. Comparing the two cases, it is evident that the fuel bill is increasing significantly for FC2 with the faster sailing speed. Finally, for all scenarios the revenue from passengers and their on-board spending is not as a great contributor as in the cruise service between Copenhagen and Oslo. As with the latter service, it is important to compare the difference in cost of fuel and revenue, with the necessary adjustment of other operating costs (staff salary, port tariffs, vessel maintenance).

8.5.1 New sailing frequency

The sailing frequency of 7 sailings each way per week could easily be modified in times of low transport to 6 (by removing one of the two weekend services) as was the case in the recent past. This is examined for FC2 (high fuel prices) and FC1. The results on capacity utilization, new market share, and fuel costs are summarized in Table 31, considering the sailing speed of 2015 to facilitate comparisons.

Table 31: The effects of a new sailing frequency on the service

	New sailing frequency	New Transported lm	New capacity utilization	ΔRevenue	ΔFuel Cost
Fuel Case 1	6	**xx**	**xx**	**xx**	-28172
Fuel Case 2	6	**xx**	**xx**	**xx**	-57093

The reduced demand because of the reduced frequency, fails to reduce the capacity utilization to an acceptable figure. Thus, a larger vessel should be deployed so as to ensure that the capacity offered by the service always satisfies demand. The reduction in revenue is higher than the reduction in fuel costs for FC1, while for FC2 the savings in fuel costs are higher than the loss of revenue. Thus, for FC1 there would have to be significant other savings to justify the reduction of service frequency. For FC2 however, the company will save more money from its fuel bill than the loss of cargo revenue. The revenue from passengers should also be considered in such a scenario; however, more information is required to model the new passenger demand following a reduction of sailing frequency.

8.6 Klaipeda – Karlshamn

In the second Baltic Sea route, the options of slow steaming for all fuel cases (1 and 2 hours extra sailing time per voyage), and the reduction of the number of weekly sailings by 1 will be examined for fuel case 2.

8.6.1 Baseline

For the baseline case, the vessels that were mostly deployed on the Klaipeda – Karlshamn route were Regina and Athena Seaways. The cargo and passengers transported in a week are shown in Table 32.

Table 32: The Baseline fleet deployment for all Fuel Cases

Sailing Speed 17.15 knots - Sailing Frequency 7 per week						
	Transported lm	Capacity Utilization (%)	Revenue (€)	Passenger Revenue	On-board Revenue	Cost of Fuel (€)
Fuel Case 1	26267	**xx**	**xx**	**xx**	**xx**	**xx**
Fuel Case 2	24606	**xx**	**xx**	**xx**		**xx**
Fuel Case 3	27149	**xx**	**xx**	**xx**		**xx**

For all scenarios the major source of revenue is stemming from the transported cargo, while the on-board revenue is very small. The variation of transported cargo for the different fuel cases is significant, while the utilization factor is for all cases within 70 and 80%. It should be noted that in this route, the main competition is a different maritime service from Stena, and in the simulations performed for Task 2.2, the assumption was that the competitor is less elastic in changing their tariff. Finally, the cost of fuel for FC2 is very high, close to the revenue of passengers.

8.6.2 Change of sailing speed

Speed reduction in this route is considered for all three FC scenarios. The options of increasing sailing time by 1 or 2 hours are examined. The new weekly fuel consumption broken down by activity and machinery type is shown in Table 33.

Table 33: Effects of a new sailing speed on fuel consumption per hour

Ship	Average Fuel ME (tonnes per hour)	Average AE (tonnes per hour, cruise)	Average Fuel port (tonnes per hour, berth)
Baseline Sailing Speed 17.15 knots			
Athena Seaways	**xx**	**xx**	**xx**
Regina Seaways	**xx**	**xx**	**xx**
Increase Trip by 1 hour, New Sailing Speed 15.93			
Athena Seaways	**xx**	**xx**	**xx**
Regina Seaways	**xx**		**xx**
Increase Trip by 2 hour, New Sailing Speed 14.87			
Athena Seaways	**xx**	**xx**	**xx**
Regina Seaways	**xx**		**xx**

The hourly consumption of the main engine during sailing is lowered by a considerable amount due to the much lower sailing speeds. The weekly fuel consumption and the new distribution of berthing and sailing hours are shown in Table 34.

Table 34: Effects of slow steaming on weekly fuel consumption for ships on Klaipeda – Karlshamn

Ship	Hours at berth	Hours sailing	Fuel consumption (tonnes)	Change (%)
Baseline Sailing Speed 17.15 knots				
Athena Seaways	77	91	**xx**	NA
Regina Seaways			**xx**	
Increase Trip by 1 hour, New Sailing Speed 15.93				
Athena Seaways	70	98	**xx**	**xx**
Regina Seaways			**xx**	**xx**
Increase Trip by 2 hour, New Sailing Speed 14.87				
Athena Seaways	63	105	**xx**	**xx**
Regina Seaways			**xx**	**xx**

The fuel savings are considerable for both cases as the sailing speed is reduced drastically. The effects of the change in sailing speed on the transported cargo and the overall economy of the service are summarized in Table 35.

Table 35: Effects of slow steaming on transported cargo, revenue of service, and cost of fuel consumed per week

Increase Trip by 1 hour, New Sailing Speed 15.93						
	Transported lm	Capacity Utilization (%)	Revenue (€)	Passenger Revenue	On-board Revenue	Cost of Fuel (€)
Fuel Case 1	26014	**xx**	**xx**	**xx**	**xx**	**xx**
Fuel Case 2	24313	**xx**	**xx**	**xx**		**xx**
Fuel Case 3	26912	**xx**	**xx**	**xx**		**xx**
Increase Trip by 2 hour, New Sailing Speed 14.87						
Fuel Case 1	25758	**xx**	**xx**	**xx**	**xx**	**xx**
Fuel Case 2	24032	**xx**	**xx**	**xx**		**xx**
Fuel Case 3	26671	**xx**	**xx**	**xx**		**xx**

Table 35 shows that there is some variation in the cargo units transported for each fuel case scenario and slow steaming scenario. The variation in the revenue is much lesser, while the cost of fuel changes much more due to its linear dependence with fuel prices. Therefore, slow steaming could be an option for very high fuel price scenarios, especially considering that the route is practically unrivalled by fully landbased modes, and the competing maritime service would also change its freight rates according to fuel prices. Thus, the loss of cargo predicted here might be too conservative.

8.6.3 New sailing frequency

As with Klaipeda – Kiel, the option of reducing the sailing frequency from 7 to 6 per week will be examined for FC2 and FC1.The summary of their effects on capacity utilization, and difference in revenue and fuel cost with the baseline is shown in Table 36.

Table 36: The effects of a new sailing frequency on the service

	New sailing frequency	New Transported lm	New capacity utilization	ΔRevenue	ΔFuel Cost
Fuel Case 1	6	**xx**	**xx**	**xx**	-13169
Fuel Case 2	6	**xx**	**xx**	**xx**	-26688

The reduced demand increases the capacity utilization to a range between 82 and 90% for both fuel cases. Therefore, there is no need to alter the vessel deployment as these levels have a low risk of overcapacity in certain voyages. The reduction in fuel cost is higher than the reduction in revenue, and thus the economy of the route is improving. As with the other services, it is necessary to take into account the effects on passenger demand following the change in the sailing frequency, as well as to include other operating costs (staff salary, maintenance of vessel, port fees etc.).

8.7 Dover – Calais

In the shortest route examined in the project, the only option that will be considered is reducing the sailing frequency.

8.7.1 Baseline

In 2015, the vessels deployed were Calais and Malo Seaways though in the first four months there was only one vessel due to external events that limited the service. In the ensuing analysis, the baseline case will consider the use of Calais and Dieppe Seaways (deployed in the majority of 2014) as there is not enough fuel consumption data for the vessels deployed in 2016 (Cote de Flandres, and Cote de Dues). Information on passengers and cargo transported in a week are summarized in Table 37

Table 37: The Baseline fleet deployment for all Fuel Cases

Sailing Speed 15.33 knots - Sailing Frequency 99 per week						
	Transported lm	Capacity Utilization (%)	Revenue (€)	Passenger Revenue	On-board Revenue	Cost of Fuel (€)
Fuel Case 1	139196	**xx**	**xx**	**xx**	**xx**	**xx**
Fuel Case 2	138218	**xx**	**xx**	**xx**		**xx**
Fuel Case 3	141517	**xx**	**xx**	**xx**		**xx**

For all scenarios the revenue of freight cargo and passengers is much higher in comparison to the cost of fuel. The variation in cargo is relatively small due to the assumptions associated with the calibration of the model, and the fact that the total travel time is fixed for all three fuel case scenarios. The utilization factor is also showing very little fluctuation because of the change in freight rates for the different fuel price scenarios.

8.7.2 New sailing frequency

The option of reducing the sailing frequency from 99 to 75 per week will be examined for FC2 and FC1.Their on capacity utilization, and difference in revenue and fuel cost with the baseline are shown in Table 38.

Table 38: The effects of a new sailing frequency on the service

	New sailing frequency	New Transported lm	New capacity utilization	ΔRevenue	ΔFuel Cost
Fuel Case 1	75	**xx**	**xx**	**xx**	-58844
Fuel Case 2	75	**xx**	**xx**	**xx**	-119255

The reduced demand increases the capacity utilization to a risky 95% for FC1 while for FC2 this value reaches 88%, which is adequate. Due to the high sailing frequency of the service, there may be increased tolerance to high capacity utilization. The reduction of fuel costs is much higher than the reduction in revenue in FC2, while in FC1 it is almost the same. Therefore, it can be concluded that a reduction in sailing frequency can be a viable solution for very high fuel prices. However, it must be stressed that this will also depend on the freight rates from Eurotunnel in times of high oil prices, which is currently the main competitor to the service. Technically, ferries are carrying the capacity that the Eurotunnel cannot satisfy, so actually, the transport demand is more complicated to estimate and perhaps the modal split model is less reliable for this route (particularly given the external events affecting this route). As with all other Ro-Pax routes, a change in the sailing frequency has to take into consideration the effects of passenger demand, and the staff, port, and maintenance costs associated with the introduction of the new change.

8.8 General measures not tied to specific service

This section will present the implications of using three policy measures in terms of a Cost Benefit Analysis without considering a specific DFDS service.

8.8.1 Installing of a scrubber in more vessels

DFDS Seaways has invested heavily in scrubber systems since 2010 to retrofit their fleet, and continued to do so in 2016. In the routes examined within the RoRoSECA project, there is a strong presence of scrubber-equipped vessels and for various reasons most of the non-retrofitted vessels deployed in the seven routes will continue to use low sulphur fuel. Recently DFDS has started using hybrid low-sulphur HFO fuel for some of their services as it is slightly cheaper than MGO, and has some additional benefits when it comes to the lubrication requirements of the engine. Essentially the two options can be decomposed as follows:

- Invest heavily upfront in order to reduce operating costs through the use of cheaper fuel
- Do not invest, and buy more expensive fuel that increases operating costs

Zis et al. (2016), considered a CBA of the options of using scrubber systems versus the use of low sulphur fuel, given the very low fuel prices observed in 2015. They considered case studies of vessels that are spending all or part of their sailing time within regulated waters (SECA), and conducted a sensitivity analysis on fuel prices for MGO and HFO for the payback period of an investment in scrubber systems. Unsurprisingly, their analysis showed that for vessels that are operating at all times within SECA, the payback period is shorter due to the higher fuel bill. The results also reveal that considering the very low fuel prices in 2015 (as compared to the baseline of fuel prices in 2013, the year that some operators decided to retrofit their vessels), the payback period has increased and actually doubled in some cases. This section will use the same modelling framework for a retrofit case study of a DFDS vessel.

The payback period of return of an investment can be defined as the time necessary to reach a break-even point. It can be considered as the time at which the Net Present Value (NPV) of the investment is zero. The NPV is the sum of outgoing and incoming cash flows over a period of time, where all cash flows are discounted back to present values. Considering that outgoing cash flows are negative and incoming are positive, the NPV of an investment *i* is given by:

$$NPV^i = CAPEX^i + \sum_{i=0}^{N} \frac{B_t^i - OPEX_t^i}{(1+r)^t}$$

Where:

$CAPEX^i$ is the capital investment costs

$OPEX_t^i$ are the operating and maintenance expenses in period *t* for the scrubber investment.

r is the discount rate

B_t^i are the annual benefits of the investment. In the context of scrubbers, the benefits are the fuel cost savings per year due to the use of HFO. Benefits could potentially include social costs associated with emissions from the use of scrubbers, but this will not be considered in the context of Task 3.1, as the inclusion of social costs falls under the scope of Task 3.2.

Jutlandia Seaways is a vessel currently deployed in Esbjerg – Immingham that is relying on the use of low-sulphur fuel to comply with the SECA regulation. Based on data provided by DFDS, it has the highest fuel consumption of the non-scrubber fleet of the company due to a combination of higher sailing speed and vessel and engine size. Using an estimated retrofit cost of €250 per kW of installed main engine power, the capital cost of investment would be in the region of 4.8 M€. Under the current schedule of the service, the total weekly fuel consumption for the vessel reaches 303 tons. Following an installation of scrubbers, the additional fuel consumption is assumed to be 3% to cover the scrubber's energy requirements as discussed in the project deliverable report on Task 2.1. The operating cost savings will depend on the fuel price differential of HFO and MGO. Considering several fuel prices as a benchmark, the payback period of the investment is estimated in Table 39

Table 39: Payback period of investing in a scrubber for Jutlandia Seaways

Fuel prices	*HFO (€/ton)*	*MGO (€/ton)*	*Annual Savings (M€)*	*Payback period (years)*
December 2015	135	304	1.21	4.3
October 2015	237	480	1.731	2.9
November 2014	590	880	1.998	2.4
February 2014	803	1212	2.825	1.3

It can observed that assuming a constant fuel price differential (which is a crude assumption to facilitate comparisons) for the calculation, there is a significant variation in the payback period of the scrubber. Therefore, at the highest fuel prices observed in the two years between 2014 and 2015, the investment in scrubber systems would seem as very promising. However, taking into account the lowest fuel prices observed in the end of 2015, the payback period increases to 4.3 years e.g. 2020. At that point in time, the global sulphur cap will be enforced and potentially new technologies would be available that would constitute investing in scrubbers in 2016 less appealing. Considering these simplistic calculations, the age of the vessel should also be taken into account as if the particular vessel has less than 5 years of remaining service, investing in scrubbers may not make sense.

Finally, it should be noted that DFDS is using for some of its non-retrofitted vessels a hybrid low-sulphur HFO fuel that is currently cheaper than MGO. Therefore, the fuel price differential in that case would be smaller and the NPV of the investment lower (with a higher payback period). The analysis in this case study assumed that the vessel would remain in the same service with no changes in schedule (slow steaming, sailing frequency). In reality, the vessel may be often change deployment and the fuel price differential will also vary in the future, and thus the results in this section are only illustrative. In addition, the same analysis for other non-retrofitted vessels would reveal higher payback periods, as the fuel consumption is lower for other vessels in their current deployment.

8.8.2 Using LNG as fuel

The use of LNG as fuel has been considered in recent years as a potential alternative to low-sulphur fuel or use of scrubber systems, due to the zero content of sulphur in LNG, as well as the better fuel economy offered by LNG engines and the lower carbon emission factors. There is however, some scepticism concerning LNG on both environmental grounds due to the potential methane slip, as well as techno-economics due to the limited number of LNG bunkering ports. Holden (2014) notes that as of 2014, very few ports within ECAs offered LNG bunkering facilities.

The Danish Maritime Authority (DMA) conducted a feasibility study on LNG as a potential solution for new-builds and retrofits. The DMA considers that the funds required to retrofit an engine to use LNG on a Ro-Ro vessel with a main engine of installed power of 21000 kW would require an investment €339/kW and an additional installation cost €150/kW (main and auxiliary engine). The total capital investment costs can therefore reach 10.5 million Euros. Unlike a scrubber investment that allows the use of HFO instead of MGO, the price of LNG is not guaranteed to be much lower than MGO. However, the specific fuel oil consumption (SFOC, g of fuel per kWh) is lower for gas turbines in comparison to internal combustion engines. Kristensen (2012) suggests that LNG powered turbines have a SFOC that is typically 18%. This figure will be used in the case study for Jutlandia Seaways (on Esbjerg – Immingham to facilitate comparisons with the scrubber case).

The DMA considered three scenarios for the price of LNG, while fixing the price of MGO and HFO in their analysis. In all of their scenarios LNG (485, 610, or €740/ton of LNG) was cheaper to MGO (€885/ton) while HFO (€530/ton) was cheaper in two of the scenarios. Using a similar simplified analysis as in section 8.8.1, the payback period for Jutlandia Seaways is estimated in Table 40 for indicative fuel price scenarios:

Table 40: Payback period of investing in a scrubber for Jutlandia Seaways

HFO (€/ton)	*MGO (€/ton)*	*LNG (€/ton)*	*Annual LNG Savings (M€)*	*LNG Payback period (years)*
135	304	250	727121	23
237	480	485	605132	35
590	880	610	2788661	4.9
803	1212	740	4443090	2.5

As with the analysis in section 8.8.1, the results vary depending on the fuel price differential between LNG and MGO. However, due to the emissions reduction of various pollutant species and not only SO_x, the use of LNG may provide a faster return of investment should external costs be included in the benefits calculation. This will be further examined in the context of Task 3.2.

8.8.3 Change in pricing policy

The analysis in sections 8.1 to 8.7 revealed that the implications of the change in freight rates because of the different fuel price scenarios used, are important on shippers' choice. In the deliverable report for Task 2.2, a summary of the change in freight rates between 2014 and 2015 was provided for all seven routes, and it was noteworthy that despite the lower fuel prices, there was a significant variation between the two years. DFDS is currently revising their BAF policy in an effort to simplify its structure and reduce the number of key parameters for its estimation. As stated in section 5.6, this measure can also be considered as a policy measure whereby subsidies are provided to shippers that cover the increase in freight rates as a result of the sulphur regulation. Therefore, it will be thoroughly examined in the context of Task 3.2.

8.8.4 Cold Ironing

Cold ironing refers to the process of providing shorepower to vessels at berth in order to cover their electricity demand (hoteling activities). Vessels using cold ironing (also known as 'alternative maritime power' – AMP) may switch off their auxiliary engines. For cold ironing vessels, the only source of emissions at the port is stemming from the ship boilers that are used to maintain the temperature of fuel and heating of the vessel in general. Within the EU, cold ironing can be an alternative to the EC (2005) fuel regulation that dictates the use of 0.1 sulphur content fuel while at port. While the provision of shorepower can significantly reduce emissions generation at the port, there are certain environmental and economic aspects that must be taken into account. Environmentally, there are induced emissions generated at the power source that depend on the energy mixture powering the cold ironing unit at the port (Zis et al., 2014). There are also additional transmission and energy conversion losses that are associated with cold ironing, estimated at 2% and 8% respectively on average.

In economic terms, the shipowner must invest heavily to retrofit an older vessel to be able to receive shorepower. The costs depend on the size and type of the vessel and range between $300000 and $2 million. At the same time, the port operators face significant costs to install cold ironing units at the port. The payback period for the stakeholders will depend on the price of fuel, the price of electricity, and the time spent at the port. Within SECAs, the option of cold ironing may be less attractive as the ship operator must comply with the low-sulphur requirements at all activity phases (sailing, manoeuvring, and hoteling). Coupled with the current low fuel prices, a ship operator could prefer the use of MGO even if the option of plugging in is available (e.g. port and vessel are able to use cold ironing). Therefore, investments in scrubber systems may be more appropriate at this time. Cold ironing will be considered as a policy measure in Task 3.2, through the provision of subsidies to ports for the necessary infrastructure.

9 Conclusions and plan ahead for the end of the project

This document presented the main findings of work undertaken in the context of Task 3.1. This section will summarize the findings on the examined Ro-Ro operators' measures, the implications of a potential increase in fuel prices and the need for such measures, and the final steps of the RoRoSECA project.

9.1 Main findings

The modelling framework designed for WP2 has been enhanced with the addition of quantitative modules that facilitate the assessment of potential measures that the Ro-Ro operator can use to affect its economic balance on the routes served. The modules allow the estimation of the new transport demand that the operator will have to satisfy following any changes in the sailing schedule of its service. In addition, the model provides estimations of the new fuel costs and the new revenue following the introduction of the changes. Therefore, ship operators can utilize the model to assess the economic and environmental impacts of any new changes in their services. The model currently only estimates the new revenue and the new fuel cost, as due to data confidentiality, there was no information on the port fees, maintenance costs, stevedoring, and staff costs that DFDS has to cover. However, ship operators can readily utilize the developed model in the context of Task 3.1, and compare the outputs with the aforementioned operating costs (that the model does not consider) and conclude whether changes in the schedule are in order.

The modelling framework was tested for certain Ro-Ro operator's measures as defined during the last six months following the fourth AC meeting and discussions with DFDS. The runs considered changes in the sailing speed of the vessels at each of the examined routes (where a change in sailing speed would be reasonable) for the three fuel case scenarios that were used in Task 2.2. Slow steaming should be performed for high fuel prices, as the cargo losses would be minimal, while the hours at the port would also be reduced. However, the latter fact may require additional resources in order to ensure the efficiency of loading/unloading operations and the on time departure of the vessel to the next port. The model was tested for changes in the sailing frequency of the vessels for routes where DFDS considers this as a viable option. Swapping vessels between routes was also examined under the assumption that the schedule in that case would not be altered, and thus the transport demand would stay fixed. The results illustrated that the impacts of increased sailing time would not result in major transport losses, and thus these measures could be used should fuel prices increase. For these scenarios, the fuel savings are higher that the loss of revenue. However, the utilization factor of the vessel may be reduced. Changes in sailing frequency have important impacts on the utilization factor. The Ro-Ro operator can use this measure as a mechanism to cope with either

- too high utilization factors (that pose the threat of transport demand exceeding the capacity of the vessel and thus cargoes left at the port for the next sailing)
- too low (with negative environmental impacts due to the resulting high emissions per transported NM-lm).

Finally, the option of further investing in scrubbers was considered for a conceptual retrofit scenario in one of the most fuel demanding vessels. The analysis showed that the current low fuel prices constitute the investment less appealing in comparison to the previous years. The payback period of the investment in scrubbers is shown to have doubled in comparison to what it would have been in 2014. It would be even higher for other vessels that have a lower fuel consumption. The analysis section finished off with a discussion on the use of LNG as fuel, and the options of introducing changes in the pricing policy. The latter will be explored thoroughly in Task 3.2 in conjunction with the option of internalizing external costs.

9.2 Links with Task 3.2 and the global sulphur cap in 2020

The enhanced modelling framework enables the examination of impacts to any change that affects the key stakeholders (Ro-Ro operator, shipper). The computational modules will be adapted to consider external changes from policy makers that will include:

- the provision of subsidies to the shipper (e.g. covering the BAF surcharges)
- the provision of subsidies to the shipowner (e.g. for retrofits)
- the provision of subsidies to the port for cold ironing
- the introduction of additional taxes to landbased modes
- the introduction of an Eco-bonus like system
- the facilitation of LNG bunkering

Task 3.2 will assume the perspective of the policy operator where the objective is the improvement of the environmental performance of the transport operations. For this reason, the option of internalizing external costs will be considered for its effects on shippers' choice, and the overall environmental balance. Within Task 3.2, the implications of the last tier in the SECA regulations (global cap) will be examined. Following a debate on low sulphur fuel availability, in October 2016 during the 70^{th} session of IMO's Marine Environment Protection Committee (MEPC 70) the global (e.g. outside ECAs) limit of sulphur content was decided to be reduced to 0.5% as of 2020 and not postponed to 2025. The implications of this decision may not have a direct effect on the routes served by DFDS (with the exception of the Marseille-Tunis route); however, there may be indirect influences to the fuel price of 0.1% sulphur content fuel as well. In addition, the new global limit may be the driver for technological innovation to provide alternative abatement options, not limited to the development of more efficient scrubber systems, but also promote the use of LNG as fuel.

9.3 The next steps in the RoRoSECA project

The modelling framework designed under WP2 has been the backbone of the project, and the basis for the work undertaken in WP3. With the conclusion of Task 3.1 and the examination of potential measures that the Ro-Ro operators have at their disposal, the RoRoSECA project is closing in to the final milestone on Task 3.2, the policy measures. In the remaining months of the project, efforts will revolve around WP4 (project dissemination) and Task 3.2. It is expected that at least one journal paper will be submitted in the work of Task 3.1, essentially a shorter and more academic version of this report. Work on Task 3.2 will also be presented in academic conferences, and subsequently will be sent for review in academic journals after the end of the project.

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