



## Road and Maritime Transport Environmental Performance: Short Sea Shipping Vs Road Transport

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### ABSTRACT

Motorways of the Sea (MoS) are part of the European transport strategy towards an efficient, safe and environmentally friendly transport system. This paper develops a model for short sea shipping (SSS) and road transport environmental performance comparison, estimating direct emissions and quantifying their impacts due to air pollutant and greenhouse (GHG) gas emissions. Ultimately a case study is presented to analyse and value each transport alternative to design an action plan determining intervening actions favouring the rebalance of the current transport system.

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### 1. Introduction

Even though the actual economic crisis has partially released the European transport system from a sustained increase in transport demand, the current system suffers from capacity and flexibility problems. An acute imbalance in transport shares is the main reason of the inefficiencies of the current system. Almost half of the intra-European transport volumes are absorbed by road transport, followed by maritime transport and rail transport respectively as main means of transport (Eurostat Statistics, 2012).

In order to improve the current scenario, the European Union (EU) pursues a rebalancing of the transport system based on a modal shift from road to maritime means and to rail on a lesser extent (European Commission White paper, 2001). Maritime transport has always been pointed as an environmentally friendly mean of transport. However there is a common misconception in this appreciation, although maritime transport overall externalities are believed to be smaller than those of road (European Commission White Paper, 2001), maritime environmental performance

with regards to airborne emissions (air pollutants and greenhouse gases) it is not that advantageous (CE Delft, 2008).

As for road, in maritime transportation the main air pollutants are those generated from internal combustion engines. These are CO, VOC, NO<sub>x</sub> and PM: derived from soot and related to the engine technology being used; and on the other hand CO<sub>2</sub>, SO<sub>x</sub>, heavy metals and further PM: sulphate-derived and hence dependant on fuel type. The contribution of waterborne transportation means to airborne pollutant emissions is significant for SO<sub>2</sub>, NO<sub>x</sub>, CO<sub>2</sub>, CO, VOCs and PM. In some cases, as for SO<sub>2</sub>, the share of maritime airborne pollutant can be up to the 80% of total national emissions (EMEP /EEA, 2009).

This leads to the objective of this research that is to develop an environmental performance model for short sea shipping and road transport, estimating direct emissions and quantifying their impacts. Indirect emissions occurring upstream, from well to tank, are set aside (Schrooten, De Vliegcr, Int Panis, Chiffi, Pastori, 2009).

Proved airborne emissions as the weak point of maritime transport, it will definitely contribute to a discussion on an EU level on future emission legislation and the potential impact of increased co-modality.

Following the introduction, this paper presents in detail explanations of the proposed methodology, a breakdown of the developed emission estimation and impact model,

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an scenario analysis made by the model considering current and future scenarios based in already in place and scheduled future regulations, a comparative results assessment were all scenario results for each of the considered transportation modes come together and finally the conclusion to summarize the paper and identify future research and improvement areas.

## 2. Methodology

The environmental performance model, which is able to conduct analyses for six different scenarios for maritime transport and a year by year scenario analysis for road transport, is broke down into the following four major sections:

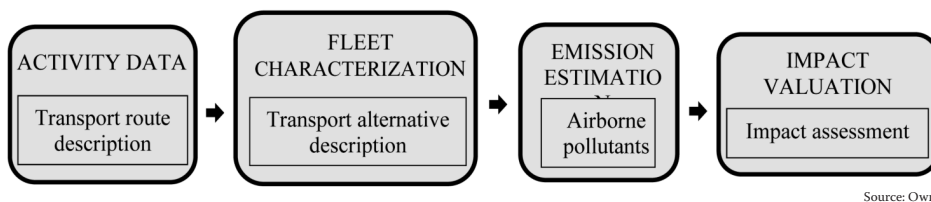


Figure 1. Generalized model breakdown.

In the first section, activity data, parameters describing the transport leg to be carried out are introduced, e.g.: origin; destination; length of the route to be followed; turn-around time for ships; route breakdown with regards to urban, rural and highway legs for road transport; average speed in each of the considered road legs; truck load factor.

On the other hand in the second section and regarding maritime transport, the type of ship between those usually engaged in short sea shipping activities (container, RoRo, RoPax and ConRo) is selected. With regards to road transport a configuration of a road tractor coupled to a semi-trailer is used, with a maximum permissible weight between 40 to 50 tonnes. For emission estimation purposes the engine type needs to be selected (Euro I-V). In case this is unknown the fleet average option can be chosen, which depending on the presence of the different engine technologies (Euro I-V) in the European truck fleet, adjusts and calculates emission factors.

The third section leads us to an emission index for each of the alternatives, road or maritime transport, and scenarios selected. Once main emission drivers are known, introduced in sections 1 and 2, the tier 3 methodology described in the *EMEP/EEA emission inventory guidebook 2009* is used for both alternatives (European Environment Agency, 2009). Emission factors are updated for each of the considered scenarios, following the methodology presented by Entec in its 2002, 2005 and 2007 emission studies. Emissions for NO<sub>x</sub>, SO<sub>2</sub>, CO<sub>2</sub>, VOCs and PM are calculated, as these are considered as the most significant airborne pollutants. In the case of road transport NH<sub>3</sub> emissions are also estimated.

Finally the fourth section, using main emission and impact drivers introduced in the first two sections of the

model, assesses and quantifies the impact of the estimated emissions. With regards to emission impact assessment two are the projects used in the model as reference, the “Benefits Table Database: Estimates of the Marginal External Costs of Air Pollution in Europe (BETA)” project for air pollutant local impact (Holland and Watkiss, 2002) and “Clean Air For Europe Program (CAFE)” for rural or trans-boundary impact (European Commission, 2001).

Once airborne pollutant emissions have been estimated and their impact has been quantified for each of the considered alternatives and scenarios; a comparative analysis is carried out trying to identify the best of the alternatives, and the strengths and weaknesses of each.

Finally conclusions from the conducted research are drawn pointing out the relevant findings and identifying areas for further research and improvement of the model.

## 3. Model breakdown

In order to understand maritime and road transport environmental performance with regards to air pollution, it is important to identify and describe emission drivers giving rise to air pollutant emissions, as well as cost drivers determining the sensitivity of the emission area and hence the extent of the produced impact. It is in the activity data and fleet characterization sections where these factors are introduced.

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### 3.1. Maritime transport model

The maritime transport model is built up based on ship types and average ship sizes derived from the analysis of the SSS ships calling at Spanish harbours during the second half of 2011. The user will have to introduce relevant parameters with regards to ship activity. Moreover for air pollutant emission estimation the tier 3 methodology, described in the *EMEP/EEA emission inventory guidebook 2009*, for navigation is used. Finally CAFE and BETA projects are used for the emission impact assessment.

### 3.2. Activity data

Parameters describing the route being considered as well as the ship type being used need to be selected by the model user in order to be able to perform consequent calculations with regards to the environmental performance of maritime transport in that particular route, ship type and sailing scenario.

#### Ship movement data

In this section the user describes the route being considered, establishing the origin and destination ports and hence considering the inhabitants around the ports; which indeed result's critical for the local impact assessment. At this first stage the sea area in which the sailing is carried

out is also considered, as the area where the pollutants are emitted is relevant for the emissions rural impact. Finally the distance of the considered route is also introduced as this will determine the sailing time and hence the emissions at the cruising phase.

### 3.3. Fleet characterization

For the maritime alternative the fleet characterization is very important, as depending on the considered ship types and their main characteristics the emission values differ significantly. A bottom up approach has been conducted to provide the research with the consistency given by the consideration of different and detailed input variables. For this purpose the Lineport database (Fundación ValenciaPort, 2012), which records all ships engaged in SSS services competitive with road transport, is used. Once all these ships are identified, using the Fairplay Seaweb database all relevant factors that give rise to airborne emissions from ships are found and introduced into the model's database.

**Table 1.** Average ships engaged in SSS services.

	Container ships	Ro-Ro ships	Ro-Pax ships	Con-Ro
Length Over All	178	184,1	197	168
Breadth	25	25	27	24
Draft	10	7	7	7
GT	20205	27486	34052	17330
DWT	24592	9393	6933	10537
ME type	MSD	MSD	MSD	MSD
ME power	16837	17775	29352	11427
EA type	MSDHSD	MSDHSD	MSDHSD	MSDHSD
EA power	3704	5333	10273	3428
Average service speed	20	21	24	18
Capacity (TEU-s)	1820	na	na	658
Capacity (line meters)	na	3196	2319	2131
Capacity (trailer or CEU-s)	na	213	155	142
Capacity per TEU(tm)	21,5	na	na	21,5
Capacity per trailer (tm)	na	24	24	24
Total capacity (tm)	24592	5114	3710	10537

Source: Own, based in Seaweb and Lineport database

### 3.4. Main engine type and power

Under the main engine (ME) tab, the engine type and its power are described. In the marine industry diesel engines are the predominant form of power for both main and auxiliary engines (Trozzi, 2010). Emissions are engine type dependent; therefore it is important to identify the engine types for the considered typical ship types in SSS services. Diesel engines are categorised into slow (up to 300 rpm), medium (300-900 rpm) and high (more than 900 rpm) speed diesel engines (SSD, MSD, HSD) depending on their rated speed.

As a result of the carried out SSS ships survey, the developed model considers MSD engines as predominant in the SSS fleet, and hence uses emission factors for this type of engines in the emission estimation phase.

Moreover airborne pollutant emissions are proportional to the fuel consumption or engine power; therefore

besides the engine type, the average power for the different typical SSS ship types is also identified.

#### *Auxiliary engine type and power*

Auxiliary engines, used to provide power and services within the vessels, also contribute to ship emissions. Therefore these also need to be characterized.

The auxiliary engine (AE) tab is defined by the type, power and number of AEs installed on-board. However this information is not usually available for all ships, even in the most complete ship databases.

Following assumptions done in the Entec study for the Department for Environment, Food and Rural Affairs (DEFRA) of the British government (Entec, 2010) with regards to AE engine types, MSD and HSD engines are considered to be evenly distributed among the fleet. As the number and power of AEs are also unknown, the model also follows Entec 2010 assumptions with regards to the AE/ME power ratio per vessel type.

#### *Service speed and engine load factor*

The ship service speed and the engine load factors at each of the considered phases (sailing, manoeuvring and at berth) are also relevant for emission estimation. The service speed for each of the considered ship types is the average value obtained from the SSS fleet survey carried out. It is a significant parameter since it determines the time spent at sea.

On the other hand engine load factors are directly obtained from the study carried out by the Entec for the European Commission regarding emissions from ships associated with ship movements between ports in the European Community, in 2002 (Entec, 2002). As well as the service speed the engine load factor is also an important parameter since emissions are proportional to it.

#### *Sailing, manoeuvring and at berth times*

The tier 3 methodology estimates emissions for three well differentiated phases in the maritime transport leg: sailing, manoeuvring and at berth.

Therefore it is needed to know the time that the vessel undergoes in each of the phases as the emissions will be proportional to the time spent. In the case of the sailing phase this is calculated dividing the distance between ports by the service speed. On the other hand the manoeuvring and at berth times are taken either from existing projects (Entec 2002, 2010) or from surveys carried out to certain SSS lines in previous research studies (Usabiaga et al., 2011).

#### *Capacity*

The capacity tab together with the covered distance will enable the model to show results (emissions or impacts) in transport work units (per tonne kilometre). The capacity for each of the considered ship types is the result of the average value obtained from the ship survey carried out. Depending on the ship type the capacity is given in units such as twenty feet equivalent unit container (TEU) for container ships and line meters for RoRo and RoPax ships. However following

the assumptions illustrated in Table 1, capacities in tonnes are calculated for the considered ship types.

### 3.5. Emission estimation

The methodology quoted as Tier 3 in the EMEP/EEA air pollutant emission inventory guidebook 2009 is used for the estimation of airborne emissions from ships. This methodology requires detailed ship movement data besides technical information on ships being considered.

Further focusing on the emissions estimation methodology uncovers that this work follows the procedure using data on installed main and auxiliary engine power, engine load factors and total time spent on each navigation phase. The Tier 3 method also employs specific emission factors depending on the engine type, fuel used and navigational phase.

$$E_{trip} = E_{sailing} + E_{manoeuvring} + E_{atberth} \quad (1)$$

$$E_{trip,s,i} = \sum_p \left( T_p \sum_e (P_e \times LF_e \times EF_{e,i,s,m,p}) \right) \quad (2)$$

E <sub>trip</sub>	emissions per trip (tons)
EF	emissions factor (tons/kWh)
LF	engine load factor (%)
P	nominal engine power (kW)
T	time (hours)
e	engine (main, auxiliary)
i	pollutant (PM <sub>2.5</sub> , SO <sub>2</sub> , NO <sub>x</sub> , VOC, CO <sub>2</sub> )
s	ship type (Container, RoRo, RoPax, ConRo)
m	fuel type (Bunker Fuel Oil, Marine Diesel Oil, Marine Gas Oil)
p	trip phase (sailing, manoeuvring, at berth)

Moreover emission factors are different in each of the considered scenarios: as fuel properties, regarding sulphur content, and engine technology, with regards to NO<sub>x</sub> emissions, vary from one to the other.

The emission factor update is made following the methodology and assumptions described in Entec 2010, study developed for the DEFRA. Five air pollutants emissions are estimated for maritime transport: NO<sub>x</sub>, VOCs, PM<sub>2.5</sub>, SO<sub>2</sub> and CO<sub>2</sub>.

## 4. Impact valuation

Once emissions for each of the navigation phases are known, the impact of these must be quantified. Two types of impacts are distinguished for marine airborne pollutants emissions: a site, seaport, specific local impact and a sea or country specific rural impact. Both local and rural impacts are quantified for manoeuvring and at berth phases. However in the sailing phase only rural impact is present.

The local impact is produced just after the pollutants, PM and SO<sub>x</sub> primarily, have been released. Local impact

estimations need of great emission site detail; therefore, a bottom-up approach has been chosen for emissions' geographical characterization (Miola et al, 2010). On the other hand the rural impact is country or sea specific, and for impact quantification purposes that much information is not needed.

For local impact quantification purposes the methodology provided in "Benefits Table Database: Estimates of the Marginal External Costs of Air Pollution in Europe (BETA)" study is used.

The rural impact quantification in each of the navigation phases is a straight forward process as the Clean Air For Europe Program (CAFE) 2005, contains emissions costs for the considered airborne pollutants, and the EU27 countries and surrounding seas.

Moreover the BETA project provides a straightforward estimation of air pollution's overall external costs, putting together both urban and rural externalities. Therefore this is the methodology being used for manoeuvring and at berth phases.

This paper maintains the methodology given by BETA to list urban and rural external costs, but takes updated rural external costs provided by the CAFE program. The cost estimation done under the CAFE program considers human exposure to PM<sub>2.5</sub>, human exposure to ozone, and exposure of crops to ozone. Although more impacts are known, there is not sufficient information to evaluate them with guarantee.

Moreover, in an attempt to achieve comprehensive results, the valuation done by the CAFE program considers four different sensitivity scenarios that lead to four different results for each geographical areas and scenarios being considered.

The resulting maritime environmental performance assessment model is composed of a top-down approach with regards to fleet characterization and a bottom-up approach regarding geographical characterization. In this manner, the model achieves a comprehensive assessment, taking into account the specifics of each emission point as well as the details of the emitting vessel type.

$$I_{trip,i} = \sum_p (Irt_{s,p,m,i} + Ilt_{port,s,p,m,i}) \quad (3)$$

$$Irt_{s,p,m,i} = E_{s,p,m,i} \times Ir_{p,i} \quad (4)$$

$$Ilt_{port,s,p,m,i} = E_{port,s,p,m,i} \times (Is_i \times P_{f_{port}}) \quad (5)$$

I <sub>trip</sub>	impact per trip (€)
I <sub>rt</sub>	total rural impact per country or sea area (€/tm)
I <sub>lt</sub>	total local impact per port (€/tm)
I <sub>r</sub>	rural impact per country or sea area (€/tm)
I <sub>l</sub>	local impact per port (€/tm)
E	airborne pollutant emissions (tm)
I <sub>s</sub>	standard local impact for 100.000 inhabitants' city (€/tm)



Pf	population factor for local impact projection purposes
i	pollutant (PM <sub>2,5</sub> , SO <sub>2</sub> , NO <sub>x</sub> , VOC,)
s	ship type (Container, RoRo, RoPax, ConRo)
m	fuel type (Bunker Fuel Oil, Marine Diesel Oil, Marine Gas Oil)
p	trip phase (sailing, manoeuvring, at berth)
port	considered port

$$GW_{trip} = E_{s,p,m,CO_2} \times Ig_{CO_2} \quad (6)$$

GW	global warming impact per trip (€)
E	greenhouse gas (CO <sub>2</sub> ) emissions (tm)
Ig	Global impact per CO <sub>2</sub> tonne emitted (€/tm)

## 5. Road transport model

The road transport model has been built up following the same method as for the maritime model. The methodologies used for airborne emissions estimation (EMEP/EEA tier 3) and their impact assessment (BETA and CAFE projects) are the same for both maritime and road models, therefore the differences between models lie in specific activity data and fleet characterization parameters basically.

## 6. Activity data

In this section the inputs are the parameters describing the considered road transport leg. These parameters are some of the drivers needed to calculate emissions and impact.

### 6.1. Truck movement data

Under this tab two are the main inputs: distance covered under each of the considered stages for road transport (urban, rural, highway) and the average people affected under the urban stage.

These inputs are significant and they will permit to estimate, together with the average speed, the amount of emissions in each of the stages and the impact produced on them.

### 6.2. Load factor

Road transport emissions are proportional to the fuel consumption, and as the latter increases together with the load factor (Madre et al., 2010), this parameter is important within the road transport model.

### 6.3. Route type

Under this tab roads vertical geometry is described, enabling us to distinguish between flat, average and highland profiles. Once again the fuel consumption is significantly affected by this parameter.

### 6.4. Average speed

To finish with the activity data section, the last relevant parameter when it comes to airborne emission estimation, is average speed. This parameter will be necessary to determine both the time spent and the quantity of emitted pollutants in each of the road leg's stages (urban, rural, highway).

## 7. Fleet characterization

Under this section the European truck fleet engaged in freight services is characterized. More in detail, the vehicle park engaged in international freight services and competing with SSS services. The typical truck class engaged in international haulage, the fleet's engine technology (Euro I-V) and capacity are reviewed (AEA, 2011).

### 7.1. Truck class

Under this tab the truck class considered by the model to simulate the road transport environmental performance is described. The European truck fleet is formed by rigid trucks, articulated trucks and road trains. For calculation purposes the articulated truck, i.e. a road tractor coupled to a semi-trailer, is considered representative of the truck fleet Eurostat statistics for 2008, apportion the 73,9% of the total intraeuropean road freight transport in tm.km to articulated trucks.

### 7.2. Engine type

Under this tab the engine technology of the considered truck fleet segment is characterized. For this purpose data given by the Eurostat database (2012), with regards to lorries and road tractors age categories, for the year 2008 is used. Once the truck fleet is characterised in percentages according to age categories, engine technologies present in the current fleet are extrapolated.

### 7.3. Capacity

The EMEP/EEA tier 3 emission estimation methodology, besides the truck class, needs the identification of truck capacity parameter in order to be able to estimate airborne pollutants emissions. In order to achieve a realistic fleet characterization a review of allowed gross vehicle weights in the EU27 is conducted, identifying articulated trucks with maximum gross weights between 40 to 50 tonnes as the most representative category among the ones considered by the tier 3 methodology (AEA, 2011).

## 8. Emission estimation

In the road transport model the emission estimation is also carried out according to the EMEP/EEA emission inven-

tory guidebook 2009, although this time the tier 3 methodology described in the road chapter is followed.

Once all relevant emission drivers have been introduced into the model, the latter will calculate emission results for each of the considered road transport stages and air pollutants. In the road transport model NH<sub>3</sub> emissions are also estimated besides those already estimated for maritime transport.

SO<sub>2</sub> and CO<sub>2</sub> emissions are proportional to the fuel consumption; however emissions for the rest of the pollutants are calculated according to empirical formulas presented on the EMEP/EEA study for the considered truck class and capacity.

### 9. Impact valuation

The impact assessment for road transport is conducted just as for maritime transport following same projects and methodologies. Only a few different considerations are taking into account: in this case the local impact is only considered for the urban stage, taking into account the average inhabitants living in the crossed urban areas; on the other hand the rural impact will be quantified in the three of the road leg stages, depending on which are the crossed countries.

As for the maritime model, the impact quantification is achieved following BETA and CAFE projects. The BETA project is relevant for local impact quantification and for the joining of both rural and local impacts in the urban stage; and on the other hand, the CAFE project is relevant as it provides costs per emitted pollutant for each of the EU27 countries.

$$I_{trip,i} = \sum_s (Irt_{t,s,i} + Ilt_{urban,t,s,i}) \quad (7)$$

$$Irt_{t,s,i} = E_{t,s,i} \times Ir_{s,i} \quad (8)$$

$$Ilt_{urban,t,s,i} = E_{urban,t,s,i} \times (Is_i \times Pf_{urban}) \quad (9)$$

I <sub>trip</sub>	impact per trip (€)
I <sub>rt</sub>	total rural impact for crossed countries (€/tm)
I <sub>lt</sub>	total local impact for crossed urban areas (€/tm)
I <sub>r</sub>	rural impact per country (€/tm)
I <sub>l</sub>	local impact per urban area (€/tm)
E	airborne pollutant emissions (tm)
I <sub>s</sub>	standard local impact for 100.000 inhabitants' city (€/tm)
P <sub>f</sub>	population factor for local impact projection purposes
i	pollutant (PM <sub>2,5</sub> , SO <sub>2</sub> , NO <sub>x</sub> , VOC, NH <sub>3</sub> )
t	truck type (Container, RoRo, RoPax, ConRo)
s	road leg stage (urban, rural, highway)
urban	crossed urban areas

$$GW_{trip} = E_{s,p,m,CO_2} \times Ig_{CO_2} \quad (10)$$

GW	global warming impact per trip (€)
E	greenhouse gas (CO <sub>2</sub> ) emissions (tm)
Ig	Global impact per CO <sub>2</sub> tonne emitted (€/tm)

### 10. Scenario analysis

Once the general environmental performance model have been developed, scenarios simulating the real performance of both trucks and ships currently and in the future are built up. These scenarios will enable the model to conduct comparative performance analysis not only for current scenarios, but for future ones; providing the model with forecasting and in advance policy measure testing abilities.

This section describes each of the built up scenarios, which are based on environmental policies applicable to trades and transportation modes considered in the paper.

With regards to maritime airborne emissions the regulatory framework applicable to SSS is basically formed by the MARPOL 1973/1978 convention and the so-called EU sulphur directives (Directive 2005/33/EC, Directive 1999/32/EC, Directive 1993/12/EEC).

Baseline scenarios are based in the regulatory framework currently in place and future scenarios are built up taking into account the scheduled development of the regulatory framework which is increasingly stringent.

Table 2. Maritime regulatory framework together with key implementation years.

Construction year	NOx emissions limits	Area	Period	Max fuel sulphur content
Pre 1990	None	Port	Post January 1, 2010	0,10 %
1990-1999	Tier 0	SECA-s	July 1, 2010-2015	1,00 %
2000-2010	Tier I		Post January 1, 2015	0,10 %
2011-2015	Tier II	Global	Pre January 1, 2012	4,50 %
Post 2016	Tier III		January 1, 2012-2020	3,50 %
			Post January 1, 2020	0,50 %

Source: Own

Moreover depending on the concerned sea area and ship type some additional scenarios come up, as the regulatory framework varies for certain ship types and especially sensitive sea areas known as emission control areas (ECAs).

Finally NO<sub>x</sub> emission factors will also vary from current to future scenarios as the engine technology on-board varies together with the ship recycling cycle. Years 2000 (Tier I), 2011 (Tier II) and 2016 (Tier III) are considered key years in this respect, as correspond to new regulation implementing years with regards to NO<sub>x</sub> emissions (MARPOL, Annex VI, regulation 13). These new regulations forced ships to be built with new engine technologies further reducing NO<sub>x</sub> emissions. For the purpose of projecting forward 2012, a 25 year ship life cycle is assumed, which is equivalent to a 4% annual fleet renewal rate.

Scenarios considered in Maritime transport model are:

**Baseline 2012.** Among all the considered scenarios the less stringent and therefore the one chosen as baseline, is that representing the 2012 scenario; with no special characteristics with regards to sensitive areas or specially regulated ship types.

**2012 SECA.** The difference of this scenario comparing it with the baseline scenario is the sulphur emissions allowed during the sailing phase. The ship is supposed to sail in a SOx ECA and therefore must comply with special regulations. Under this scenario the emission factors for the sailing phase are calculated considering the ship to use MDO with 1% sulphur content.

**2012 Ro-Pax services.** EU sulphur directives besides limiting the sulphur content of principal fuels used at ports, also limit this content for passenger ships during the sailing leg; and establish it in 1,5%.

**2015 SECA.** Comparing it with the already described 2012 scenario, the projection of the 2015 scenario is made based on the following assumptions. Regarding sulphur content derived emissions, for the sailing phase a maximum sulphur content of 0,1% in the marine fuel used is considered, considering as principal fuel MGO. On the other, when it comes to NOx emission factors the average fleet emission factors are calculated assuming a 4% yearly fleet renewal, representing a significant NOx emission reduction as old tier 0 engines are replaced by far more eco-friendly tier 2 engines.

**2016 SECA + NECA.** The unique and main change for this scenario comparing in it with the previous one, is given by the condition of sailing in a NOx ECA, which means that all ships engines must comply with Tier 3 emission standards.

**Baseline 2020.** Finally under the 2020 scenario the change in the global sulphur cap scheduled by the MARPOL convention is the main feature when comparing it with the rest of the scenarios. This cap is planned to be placed at a maximum sulphur content of 0,5%. The model simulates it using 0,5% sulphur MDO during the sailing phase.

Same scenarios are considered for road transport for comparison purposes. However these are only characterized by the engine technology in place within the fleet, as fuel composition is similar in all countries and it is not the driving factor for emission factor compliance.

## 11. Results comparison and discussion

In this section the Barcelona – Civitavecchia case study is presented. Both road's and Maritime's environmental performances have been calculated applying the introduced model. The following table shows the considered variables:

Parameters describing the route being considered as well as the ship and truck type being used need to be selected by the model user in order to be able to perform consequent calculations with regards to the environmental performance of maritime and road transport. Table 4 and Table 5 show data input sheets of ship and truck activity and fleet characterization.

Table 3. Case study main parameters.

<b>Route</b>	Barcelona (Spain)-Civitavecchia (Italy)
<b>Maritime Distance (nm)</b>	450 (833 km)
<b>Road Distance (km)</b>	1282
<b>Ship Types</b>	All (Containership, RoRo, RoPax and ConRo)
<b>Engine type ship</b>	Fleet average
<b>Scenario</b>	Baseline (2012), Baseline (Ro-Pax) and Baseline (2020)
<b>Sensitivity scenario</b>	1
<b>Urban (Road)</b>	Average speed 40 km/h
<b>Highway (Road)</b>	Average speed 80 km/h
<b>Load factor</b>	100%
<b>Route type</b>	Medium
<b>Engine type truck</b>	Fleet average

Source: Own

Table 4. Ship activity and fleet characterization data input sheet.

<b>Ship type</b>	RoRo
<b>Engine type</b>	Fleet average
<b>Route distance (nm)</b>	450
<b>Scenario</b>	Baseline (2012)
<b>Sea</b>	Mediterranean sea
<b>Port of origin</b>	Barcelona
<b>Country</b>	Spain
<b>Inhabitants in the port city</b>	1.600.000
<b>Port of destination</b>	Civitavecchia
<b>Country</b>	Italy
<b>Inhabitants in the port city</b>	50.000

Source: Own

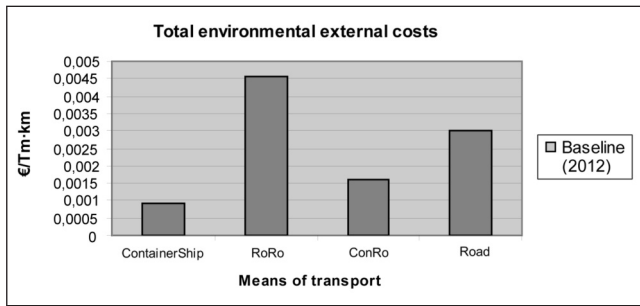
Table 5. Truck activity and fleet characterization data input sheet.

Urban		Highway		
Route type (Gradient):	Medium	Route type (Gradient):	Medium	
Load factor:	100%	Load factor:	100%	
Engine type:	Fleet average	Engine type:	Fleet average	
Average Speed (km/h):	40	Average Speed:	80	
Length (km):	100	Length:	1200	
Average inhabitants	1000000	Country1:	Spain	10%
Country1:	Spain 60%	Country2:	France	30%
Country2:	Italy 40%	Country3:	Italy	60%

Source: Own

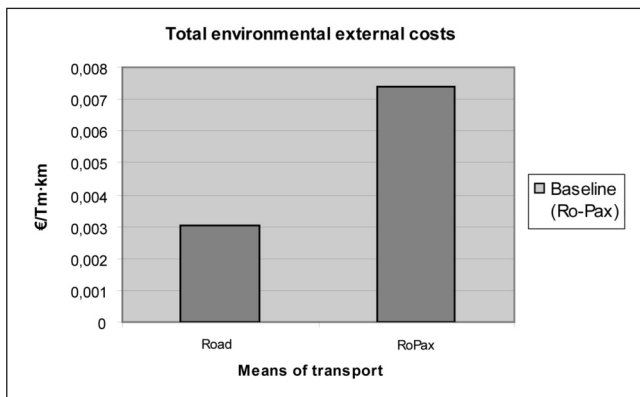
Four ship types (Containership, RoRo, RoPax and ConRo) and three scenarios (Baseline (2012), Baseline (Ro-Pax) and Baseline (2020)) have been considered for maritime transport. This enables to conduct comparative analysis between current and future scenarios. Thus permitting to anticipate to prospective problems and try to overcome them before they arise. Moreover, having considered four different ship types, enables the model to rank them with regards to their environmentally friendly performance and to compare them in an individual basis against road transport.

**Figure 2.** Total environmental external costs in €/Tm-km of ship types and road transport considering current scenario Baseline (2012).



Source: Own

**Figure 3.** Total environmental external costs in €/Tm-km of RoPax ship and Road transport considering current scenario Baseline (RoPax).

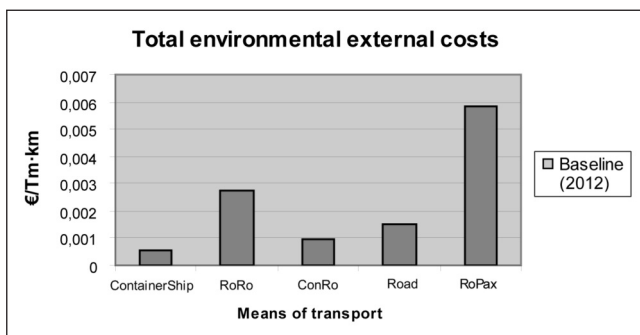


Source: Own

Results in figures 2 and 3 show the current scenario considering two different scenarios for maritime transport (Baseline (2012) and Baseline (RoPax)). This comparative analysis identifies that the best alternative considering total environmental external costs is the container ship and the ConRo ship. RoRo and RoPax ships present higher values than road transport (0.0029 €/Tm-km), 0.0046 €/Tm-km and 0.0073 €/Tm-km respectively.

Figure 4 shows the environmental performance of each of the considered alternatives in 2020. Obtained results confirm that container and ConRo ships continue presenting a more environmentally friendly performance than road

**Figure 4.** Total environmental external costs in €/Tm-km of mode of transport considering future scenario Baseline (2020).



Source: Own

transport (0.0015 €/Tm-km) regarding air pollution and global warming. However, RoRo and Ro-Pax ships continue with worse results, 0.0027€/Tm-km and 0.0058 €/Tm-km respectively.

*11.1. Conclusions and areas for further research*

Once the model has been developed the Barcelona-Civitavecchia route is taken as case study for a practical application. Thus emissions and derived impacts for each of the transport alternatives and applicable scenarios at this route are estimated. Finally a comparative analysis is carried out trying to identify the best actual and future alternatives.

Although maritime transport is known as the most environmentally friendly mode of transport; it is proved that this is not true in all cases. Results, which emerge from the developed model, prove airborne emissions to be a weak point of maritime transport: especially for RoRo and RoPax ships. The necessity to further improve the maritime environmental performance with regards to air pollution and GHG emissions is demonstrated. Therefore ship owners, port authorities and policymakers bearing in mind these results should consider new greening formulas for the sector.

Today already are concerns about the capability of the sector to comply with already approved, scheduled and increasingly tighter regulations. Hence it is not feasible to try to further improve the environmental performance with an even more stringent regulatory framework. However the success potential of introducing into the market newly developed and greener technologies seems higher.

RoRo and RoPax ships weak performance is related to inherent characteristics such as smaller cargo capacity, higher engine power to ship size ratio and higher service speed; resulting these characteristics in higher consumption and hence higher emission factors per tonne of cargo.

**Table 6.** Environmental performance summary table.

	Road Transport (€/tm.km)	Maritime transport			
		Container (€/tm.km)	ConRo (€/tm.km)	RoRo (€/tm.km)	RoPax (€/tm.km)
Baseline 2012	0.0029	0.0008	0.0015	0.0016	—
RoPax 2012	0.0029	—	—	—	0.0073
Baseline 2020	0.0015	0.00052	0.0009	0.0027	0.0058

Source: Own

Looking into 2020 results and comparing them with those obtained for 2012, it is easy to detect that the greening process of road transport takes place faster than that of maritime transport. This is due to a shorter fleet recycling period of road transport, 11 years on average (AEA 2011) against 25 years for maritime transport, which enables the faster introduction of new and greener technologies into the fleet.

The model presented in this paper is the first version and the base for further developments. Together with the first implementations of the model a few improvement areas have been identified, which have resulted in further



research areas. The purpose of improving the model is to reproduce transport chains more comprehensively and hence more realistically. The introduction of logistical parameters such as different intermodal transport units (ITU), load factor and utilisation factor will with no doubt improve the model. Moreover a bigger ship database incorporating complete data of years 2010 and 2011 even will permit to further characterise the fleet engaged in SSS services, enabling to split each ship type group by size and engine type. The third and final detected possible improvement is to consider pre and post haulage, which will enable to incorporate multimodal transport chains into the model.

Finally and with regards to the strengths of the model, say that this model's strengths lie on the broad array of air pollutants considered together with the good geographical characterization for emission site sensitiveness and hence produced impact assessment. Moreover the ability of assessing both local and rural impacts cannot be contemned.

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