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The cost of modal shift: a short sea shipping service compared to its road alternative in Greece

Ernestos Tzannatos[1*], Stratos Papadimitriou[1,2], Aphrodite Katsouli[1]

[1] *University of Piraeus, Greece*
[2] *King Abdulaziz University, Saudi Arabia*

Abstract

The promotion of short sea shipping (SSS) aims at providing a more sustainable mode of freight transport in comparison to other land based alternatives, mainly to the dominant mode of road-borne freight. In meeting this objective, SSS must demonstrate its superiority against competing freight transport modes in terms of several service criteria, amongst which those of internal and external costs have a significant influence on selecting the most appropriate transport option.
In this work, an SSS service comprised of a long sea leg and a short road leg connects two main freight centres in Greece and is compared with its road alternative. The results show that the SSS has a lower internal cost, but produces higher negative externalities with the vessel's air pollution being the predominant source of damage. Overall, the cost of the SSS service is lower than that of the road connection, whilst the cost contribution of the SSS road leg reveals the importance of proximity of freight centres and ports in SSS operations. Furthermore, it was found that increasing the capacity utilisation of the vessel improves the cost comparison of the SSS service. Finally, in view of the continuous effort to control ship emissions, it was shown that the trade-off of using cleaner (but more expensive) marine fuels is positive with regard to the overall cost of the SSS service, because for near-the-coast vessel operations the averted cost of air pollution is higher than the additional fuel expenditure.

Keywords: short sea shipping, modal shift, transport, externalities, air pollution, Greece.

1. Introduction

Globalisation of demand and decentralised production have led to high growth of freight transport in Europe and elsewhere, increasing the need for effective and efficient transport networks in order to support economic growth in an environment of fierce competition. At the same time, the boom in cargo unitisation in the form of containerised consignments (trucktainers) has led to the establishment of intermodal door-to-door transport services. However, it has become evident that a modal shift of freight from road to sea is necessary in order to alleviate the social and environmental problems associated with the increased use of road services. In such modal shift, Ro-Ro

[*] Corresponding author: Ernestos Tzannatos (et@unipi.gr)

vessels are usually called upon to cover the long-haul leg, whereas road vehicles are used for the short-haul, i.e. for the freight collection and distribution leg. Amongst various SSS definitions (Trujillo et al., 2011), a simple version reads '*shipping of cargo or goods for relatively "short" distances or to nearby coastal ports*' (Henesey and Yonge, 2006).

The environmental friendliness of short sea shipping (SSS) and its other advantages over road transport (mainly with regard to accidents and congestion) have been recognised by numerous researchers over the last twenty years, dating back to The First European Research Roundtable Conference on Short Sea Shipping (Windjnolst, 1993). These SSS attributes have constituted the basis upon which the SSS promotional campaign was built within the framework of the European Commission's 2001 White Paper on European transport policy (EC, 2001), emphasising that short sea shipping (inc. Ro-Ro services) should be fully integrated into TEN-T as the "Motorways of the Sea". At the same time, it has been documented that "*Road transport is regarded as the mode that fulfils to a higher degree customers' requirements .....*" (Paixao and Marlow, 2002) and despite a decade-long policy campaign in favour of SSS in Europe current data shows that road transport still accounts for the largest share of intra-european transport (EUROSTAT, 2011). In response to this development, recent research has been focussed on the factors which have limited the growth of SSS (Baindur and Viegas, 2011; Medda and Trujillo, 2010).

The option of using the sea instead of the road for intra-European freight transport has been analysed in numerous European research projects (PROPS, 2011; COMPASS, 2010; SUTRANET, 2007; REALISE, 2005). Other studies have focused on regional SSS corridors (Morales-Fusco et al., 2012; Feo et al., 2011; Lee et al., 2010; Martinez de Oses and Castells, 2009; Medda and Trujillo, 2009; US DoT, 2006; Baird, 1997) and services at a national and local scale (Sambrakos and Maniati, 2012; Hallock and Wilson, 2009).

Most of the aforementioned research includes reference to the general advantage of SSS with regard to its negative externalities in comparison to other transport modes. However, under certain operating conditions, the road alternative may be environmentally more favourable (Kim and Van Wee, 2011; Styhre, 2009), whereas in certain regions of the world the stricter fuel quality limits of auto-diesel are currently threatening the competitive environmental advantage of SSS (Hjelle, 2010). With reference to Europe, the latter appears to be particularly the case for any SSS operation outside an Emission Control Area (ECA), i.e. within the entire Mediterranean (incl. the Black Sea) and the Atlantic region of Western France (Bay of Biscay), Spain, Portugal and the Irish Sea.

Meanwhile, other recent research attempts to capture the negative influence of rising bunker costs on specific SSS corridors due to stricter air pollution regulations (Notteboom et al., 2010), whilst the cost of vessel acquisition acts as a barrier of entry to the SSS market and presents a competitive disadvantage in the absence of a "road equivalent" public funding policy for the SSS infrastructure, namely for the vessel itself, (Baird, 2007). Therefore, it is important that a techno-economic comparison between competing services should include the capital cost associated with the supply of equal freight carrying capacity. Furthermore, the need for developing integrated transport networks and improving hinterland accessibility towards the promotion of SSS has been addressed in various studies (Ng, 2009; Paixao and Marlow, 2009). The connectivity of freight centres to ports is instrumental in establishing successful SSS operations and its influence on incurred costs should be analysed for any specific case (Feo-Valero et al., 2011; Ferrari et al., 2011). Finally, sea distance is also important for SSS competiveness to road transport and it has been found that even short SSS operations can be more favourable than alternative modes (MINISTERIODE FOMENTO, 2004). Therefore, the detailed cost comparison of negative externalities, particularly that of air pollution is imperative for reaching conclusive results.

The trend towards the internalisation of negative externalities in any industrial activity, including the provision transport services, dictates the need to approach modal shift appraisals through a full, i.e. internal and external, cost comparison between competing modes. This need was demonstrated through the earlier work of DeCorla-Souza et al. (1997) and its impetus has been maintained till recently (Janic, 2007). Adhering to this objective, the full cost analysis and comparison between two different transport services connecting the freight centres of Athens and Thessaloniki is performed, taking into account that a significant domestic and international freight flow exists along this north-south corridor in Greece. More specifically, the currently available road connection is compared with an SSS service comprised of a Ro-Ro operation over a long sea leg between the ports of Lavrio (near Athens) and Thessaloniki and a truck operation over a short road leg between the Athens freight centre (AFC) and the nearby port of Lavrio[1]. Although the analysis is based on an assumed Ro-Ro utilisation (load) factor, the influence of its variation on the cost comparison of services will be also examined. Through this work, the application of an activity-based methodology for estimating the external costs of the two competing services and the inclusion of the road leg as part of the SSS service extends on existing research in terms of methodology and scope.

2. Description of transport services

2.1 SSS service

The SSS service involves a sea leg connecting the ports of Lavrio and Thessaloniki with a Ro-Ro vessel and a road leg between the Athens freight centre (AFC) and the port of Lavrio (Figure 1).

[1] Unlike Piraeus, the port of Lavrio provides a significantly shorter sea link between Athens and Thessaloniki.

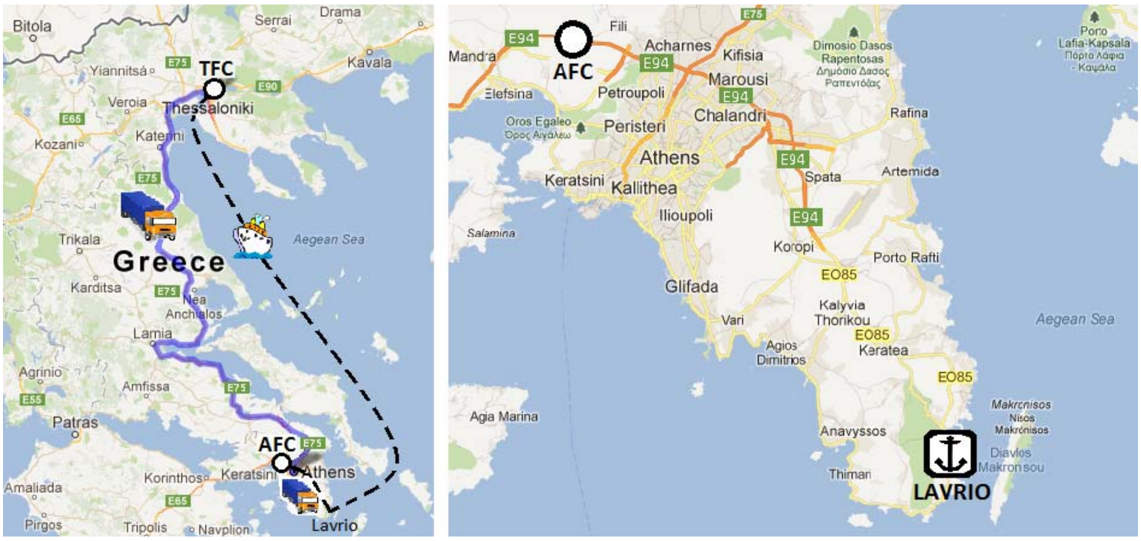

Figure 1. Schematic of the SSS (including detail of SSS road leg) and road-only service.

The sailing distance between the two ports is equal to 224 nm and with a vessel service speed of 25 knots, the sailing time is 8.95 hours. With a port turnaround time of 3.05 hours in each port, the vessel does one round trip per day for 335 days in a year (allowing for 30 days off-hire, for annual inspection and maintenance). The size of the Ro-Ro vessel is 32,290 gt and its overall length is equal to 199.8 m. It has a propulsion power requirement of 20,070 kW (MCR) covered by a single propulsion engine, whereas the auxiliary power of 6880 kW (MCR) is provided by four equally rated electricity generators. Finally, four Ro-Ro decks offer a carrying capacity equal to a lane length of 3830 m which is assumed to be utilised at 62.5% on average, i.e. around 200 trucktainers[2] are transported by sea in each direction. This Ro-Ro utilisation corresponds on average to around 57% of the daily observed flow of road freight along the Athens – Thessaloniki corridor[3] and is considered to be a feasible modal shift. The vessel's basic technical and operational parameters are as shown in Table 1.

Table 1. Technical and operational parameters of Ro-Ro vessel.

Gross Tonnage (gt)	32289
Net Tonnage (nt)	9686
DWT	10070
Length Overall (m)	199.80
Breadth (m)	26.50
Draft (m)	7.35
Lane Length (m)	3830
Service Speed (knots)	25.0
Propulsion Power (kW)	20070
Auxiliary Power (kW)	6880

[2] Average lane length occupancy is equal to 12 m per trucktainer.
[3] Based on traffic flow survey and National Road Fund (NRF) records. http://www.teo.org.gr/.

Although the Thessaloniki freight centre (TFC) is adjacent to the port's cargo terminal, the road distance between the Athens freight centre (AFC) and the port of Lavrio is 68.7 km (Figure 1). With an average truck speed of 55 km/h, the distance is covered in 1.25 hours. For the assumed Ro-Ro capacity utilisation is necessary to deploy 50 trucks for performing four loaded round trips daily i.e. carrying 200 trucktainers to and from the AFC daily for 335 days in a year. Each truck is mounted on a 5-axle chassis and is powered with a 365 kW (MCR) tractor engine[4]. The trucks move through a motorway (E94) for almost 55% of the distance, the remaining being a national road (EO85). The motorway section includes two toll posts through which the trucks pass using the e-tolling facility.

2.2 Road service

The road service involves the deployment of 200 trucks mounted on a 5-axle chassis and powered with a 365 kW (MCR) engine. Each truck is performing a loaded round trip daily along the Athens-Thessaloniki motorway (E75), as shown in Figure 1. The road distance between the freight centres of Athens (AFC) and Thessaloniki (TFC) is equal to 504 km and with an average truck speed of 80 km/h is covered in 6.3 hours. Along this motorway, the truck intersects eleven toll posts where five of them involve e-tolling, the remaining being "stop-and-pay".

3. Internal cost methodology

3.1 Internal costs of road service

The annual internal costs of the road service are comprised of the fixed and variable costs for the fleet of 200 trucks and were based on the unit costs of Sambrakos and Maniati (2012) and other sources[5]:

Fixed costs of road service

The purchase of a new truck (tractor and trailer) involves a capital investment of around 120,000 euro. Assuming: (a) a fixed annual interest rate of 5%, (b) a useful (repayment) life of 25 years and (c) a residual value of 10,000 euro, the annualised capital investment cost equals 7805 euro.

In addition, the road service includes the following fixed cost items:

- driver's annual cost of 25,284 euro (including basic salary, pension contribution and health insurance);
- vehicle's insurance at 3000 euro per year;
- vehicle's administration cost at 2400 euro per vehicle and year;
- vehicle's MOT cost (including emission inspection) at 70 euro per year;
- vehicle's road tax at 1320 per year (for a HGV).

Variable costs of road service

The variable costs of the road service comprise:

- vehicle's maintenance and repairs estimated at 2000 euro per year;

[4] http://www.scania.com/products-services/trucks/

[5] Based on quotations by a major truck operator, statutory tariff/salary provisions and market prices.

- road tolling costs estimated at 86.31 euro per vehicle and one-way trip, utilising the frequent pass discounted tariff rates as applicable at the 11 toll posts;
- cost of fuel estimated at 262.08 euro per vehicle and one-way trip, based upon an average fuel consumption of 0.4 litres/km and auto diesel fuel cost of 1.4 euro per litre;
- cost of lubricants assumed to be around 0.1 euro per vehicle-km.
- cost of tyre replacement estimated at 600 euro per tyre for every 60,000 km of travel.

3.2 Internal costs of SSS service

The annual fixed costs of the road leg were based on the corresponding unit costs of the road service for a fleet of 50 trucks. With the exception of road tolling which was estimated at 8.08 euro per vehicle and one-way trip, all variable costs follow the corresponding unit costs of the road service as presented previously.

The newbuilding price for the Ro-Ro vessel varies depending on shipbuilder's location (North Europe or Far East), financing scheme, special design specification (e.g. heavy duty deck) etc. Based on these factors, an initial cost of 50,000,000 euro was considered to be an appropriate estimate being in agreement with the quotation offered by a shipping operator specialising in this market[6]. Assuming: (a) a fixed annual interest rate of 5%, (b) a useful (and repayment) life of 25 years and (c) an average scrap value of 1,600,000 euro[7], the annualised capital investment cost equals 3,434,099 euro. The other annual fixed cost items for the Ro-Ro service were based on figures by Sambrakos and Maniati (2012) and other sources[8]:

- crew cost estimated at 453,833 euro;
- vessel's insurance assumed to be equal to 2% of its initial cost, i.e. 1,000,000 euro;
- general expenses associated with administration and office costs estimated at 20,000 and 30,000 euro, respectively;

The annual variable costs of the Ro-Ro service include:

- fuel costs estimated at 11,987,663 euro, with the main engine fuel (heavy oil) average cost assumed to be 525 euro/ton and the diesel generator fuel (MDO) 650 euro/ton[9];
- lubrication oil cost assumed to be proportional and equal to 12% of the fuel costs, i.e. 1,438,520 euro.
- maintenance and repair costs averaging 775,000 euro, based upon the percentage of the vessel's initial cost depending upon vessel's age as follows:
    - 0.75% = 375,000 euro for years 1-5;
    - 1.0% = 500,000 euro for years 6-10;
    - 1.5% = 750,000 euro for years 11-15;

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[6] Personal communication with Captain Richard Berg-Larsen, DFDS Seaways Fleet management (29/11/2012).

[7] Based on 8000 tons of scrap metal (Ro-Ro light ship displacement = 0.8 x DWT), at an average scrap metal price of 200 euro/ton.

[8] Based on quotations given by a Ro-Ro operator, statutory tariff/salary provisions and market prices.

[9] http://www.bunkerworld.com/prices/region/medblsea/

- 2% = 1,000,000 euro for years 16-20;
- 2.5% = 1,250,000 euro for years 21-25;

- port dues:
  - at the port of Lavrio[10], the cost is based on a cargo loading/unloading tariff equal to 75 and 85 euro/cargo unit, respectively, which for 335 round trips and 200 units of cargo amounts to an annual total cost of 10,720,000 euro;
  - at the port of Thessaloniki[11], the cost is based on a port call fee of 0.0351 euro per gross ton (including a 35% frequent calling discount); a mooring fee of 0.4305 euro per metre of vessel's length; a cargo loading/unloading charge of 59.93 euro/cargo unit, producing an annual total cost of 8,439,105 euro, for 335 round trips and 200 cargo units.

4. External Cost Methodology

Negative externalities account for the damage costs incurred by society in the provision of the two transport services under consideration and according to the classification performed by Maibach et al. (2008) for the IMPACT study include: traffic congestion; accidents; atmospheric pollution; noise; climate change; nature and Landscape; soil and water and up- and downstream processes (i.e. costs of the whole energy cycle).

With the exemption of atmospheric pollution and climate change, the external costs of the other items were based on the external cost factors reported by Maibach et al. (2008), with 2000 as a base year. The factors were updated according to the country's CPI change during the last decade as reported by OECD[12]. With reference to road transport, these factors were adjusted through an activity-based methodology accounting for the portion of distance driven in urban, semi-urban and rural regions, as well as along motorway and national road sections. Table 2 presents the external cost factors applicable to all cost items (exempt atmospheric) for the two transport services under consideration.

Table 2. External cost factors of transport services (excl. atmospheric).

Cost Item	*euro/vehicle-km*		
	Road Service	*SSS Service*	
		Road leg	*Sea leg (Ro-Ro)*
Congestion	0.161	0.322	0.000
Accidents	0.043	0.086	0.000
Noise	0.000	0.046	0.000
Nature and Landscape	0.014	0.007	0.001
Soil and Water	0.012	0.012	0.004
Upstream and downstream processes	0.020	0.023	0.000

Amongst all external costs, the impact of services on air pollution and global warming was considered to be of high significance, due to the current general awareness on this

[10] According to the port of Lavrio port dues policy (http://www.oll.gr), no other charges apply to cargo vessels which stay at port for loading/unloading only.
[11] According to port of Thessaloniki port tariff system (http://www.thpa.gr).
[12] For Greece, CPI(2012) = CPI(2000) x 1.34 http://stats.oecd.org/Index.aspx?DataSetCode%BCMEI_PRICES

issue at a European and international policy level as well as with regard to the promotion of modal shift. Therefore, an activity-based methodology was applied to estimate the annual emission inventories of the exhaust pollutants (namely, SO_2, NO_X and PM) and GHGs (CO_2) and the corresponding negative externalities of the road and SSS service.

The first step in this activity-based methodology is the detailed description of engine loading conditions according to the operating profile of the vehicles (trucks and Ro-Ro) in each transport service and activity phase, as shown in Table 3. The combination of engine load factors (LF) and portion of their operating time in each activity phase defined the effective load factor (ELF).

In the road service case, the trucks operate along the extensive motorway stretch with an engine load factor of 60% for 90% of the overall travel time to allow for toll post passing and other stoppages, whereas the limited national road sections are driven with 30% engine load for 10% of the time to allow for the approach to the freight centres. With regard to the SSS service, the road leg involves truck driving along the motorway section (around 55% of the overall distance) for 40% of the time with an engine load of 60%, whereas the national road section is covered in 60% of the overall travel time at 30% engine load.

For the Ro-Ro operation, the engines' load factors (LF) of main engine and electricity generators at sea and in port were based upon figures initially reported by Cooper (2002) and adopted by Whall et al. (2007) for the ship emission inventory in the Mediterranean and adapted according to the following case specific characteristics. While at sea, main engines and electricity generators operate continually at 80% and 30% load respectively, covering propulsion and auxiliary power requirements (including cooling of some trucktainers). In port, the propulsion engine is assumed to operate at 20% of its MCR for 20% of the time, whereas it is turned off for the remaining 80% of port time. Similarly, while in port, the auxiliary power requirements of the Ro-Ro vessel are 20% of generators MCR for 80% of the time and 60% MCR for the remaining 20% of port time. The load factors and operating times applied to electricity generators refer to the auxiliary power requirements for hotelling (at sea and in port), as well as for the bow thruster operation during vessel's manoeuvring. Figures for electricity generator operation represent annual averages, which also take into account the seasonal peaks in hotelling power demand (e.g. summer air conditioning).

Apart from engine power ratings, exhaust emissions are further dependent on exhaust emission factors which vary according to engine type and fuel used. For the trucks, Euro 5 specifications apply, with the sulphur content of auto diesel limited to 10 ppm (0.001%) by mass. All figures for truck exhaust emission factors were based on the results of the EU-PEMS project (Carriero, 2010) and the work of Erlandsson et al. (2008), with reference to new truck engines.

With regard to the air pollution regulations for the specific Ro-Ro[13] operation, the following apply:

- according to the requirements of the European Directive (DIRECTIVE 2005/33/EC), from 01/01/2010:

[13] A Ro-Ro vessel is classified as a cargo vessel, so freight shipping emission regulations apply.

- all ships at EU berths (for more than two hours) must use oil with a maximum sulphur content of 0.1% (1000 ppm) by mass or use shore-side electricity;
- the maximum permissible level for the sulphur content of marine distillates (MDO/MGO) placed on the market must be 0.1% (1000 ppm) by mass;
- according to MARPOL Annex VI and its amendments:
  - the Mediterranean Sea is not designated as an Emission Control Area (ECA);
  - with the global level of sulphur for heavy fuel oil limited to 3.5% by mass, the average sulphur content of fuel oil stands at 2.7 % (27,000 ppm).

Taking into account the influence of the aforementioned ship emission regulations in Greece, the exhaust emission factors of the Ro-Ro vessel were based on the research by Cooper (2002) and Whall et al. (2007). For PM emissions from combustion of ultra low sulphur fuels (0.1% sulphur), the results according to the relevant study by the California Air Resources Board (CARB, 2007) were also considered. The exhaust emission factors for the trucks and the Ro-Ro vessel are shown in Table 3.

Table 3. Engine load, emission and external cost factors for road and SSS service.

Engine effective load factors (ELF) for road and SSS vehicles

Engine Type	*Road Service (Truck)*		*SSS Service*							
			Road leg (Truck)		*Sea leg (Ro-Ro)*					
	ELF = %LF x %Time		*ELF = %LF x %Time*		*At Sea*			*In Ports*		
	Motorway	*National Road*	Motorway	National Road	LF (%)	Time (%)	ELF	LF (%)	Time (%)	ELF
Main Engine	60 x 90 = 0.54	30 x 10 = 0.3	60 x 40 = 0.24	30 x 60 = 0.18	80	100	0.8	0	80	0.04
								20	20	
Electricity Generator	--------------------				30	100	0.3	20	80	0.28
								60	20	

Exhaust emission factors for trucks and Ro-Ro vessel

Ro-Ro Emission Factors (g/kWh)					*Truck Emission Factors (g/kWh)*				
Fuel Sulphur Content (% by mass)	SO_2	*PM*	NO_X	CO_2	*Fuel Sulphur Content (% by mass)*	SO_2	*PM*	NO_X	CO_2
2.7*	11.3	0.8	13.5	690	0.001	0.0042	0.02	2	950
0.1**	0.4	0.3	9.7	677					

External cost factors of exhaust emissions for road and SSS service (euro/ton emitted)

Emission Type	*Rural Motorway/Sea*	*Urban Motorway/Port City*
SO_2	5494	53734***
NO_X	8040	8040
PM	10452	275800***
CO_2	7	7

*Average sulphur content of fuel oil used by main (propulsion) engine.
**Maximum sulphur content of distillate oil used by electricity generators.
***Based on the average population of Athens, Lavrio and Thessaloniki.

The external cost factors of exhaust pollutants were based on the findings of the European Commission's DG Research ExternE project as adapted by Holland and Watkiss (2002), with reference to Greece and the country's CPI updating as already mentioned. The external costs include acute and chronic effects of SO_2 and PM on mortality and morbidity, the effects of SO_2 (acidity) on materials used in buildings and structures (excluding those of cultural value) and the effects of NO_X on arable crop yield. The external cost factors were estimated for the in-port and at sea operation of Ro-Ro vessel as well as for the urban and rural operation of the trucks, in order to account for the dependence of SO_2 and PM emission impact on location and specifically on the human population.

The CO_2 external cost factor was based on CO_2 pricing in Europe[14]. Carbon prices have followed a sharp (80%) downward trend during 2008-2012, mainly attributed to the global and particularly European economic crisis. In 2012, the price for CO_2 emissions according to the EU Emission Trading System (ETS) averaged 7 euro/ton. On the basis of the above, the external cost factors of exhaust emissions applicable to the transport services under consideration are also presented in Table 3.

The application of the aforementioned activity-based methodology for damages to the atmospheric environment (Table 3) and the utilisation of the external cost factors for all other damage items (Table 1) led to the estimation of the annual external costs for the road and the SSS service.

5. Results and Discussion

5.1 Presentation of results

The variable costs of the road service constituted 92% of its overall annual internal costs of 72.62 million euro (Figure 2). Fuel expenditure at 35.12 million euro was the dominant cost item, contributing 48.4% to the annual internal cost of the service. The costs of road tolling and tyres were nearly equal, presenting a combined contribution of almost 31%. With regard to fixed costs, drivers' expenditure at 5.6 million euro was the highest cost item (7%), followed by the capital recovery cost for the 200 trucks at 1.56 million euro (2.2%).

The variable costs for the SSS service were equal to 48.97 million euro, constituting 87.6% of the overall annual internal costs of 55.88 million euro (Figure 3). The highest cost item was associated with the fuel consumption of the trucks and the Ro-Ro vessel with a total of 21.83 million euro and distributed at 45% and 55% between the two legs, respectively). This cost was closely followed by road tolling (for the trucks) and port dues (for the Ro-Ro vessel) which totalled 21.03 million euro, with port dues having a share of 91% (19.13 million euro). This particular cost item of the sea leg is the main contributor (68.5%) to the SSS internal costs. The annual cost towards the capital investment in the 50 trucks and the Ro-Ro vessel was the third highest cost overall and the top fixed cost item, whereas the annual cost for the capital recovery of the Ro-Ro vessel was nearly tenfold to that of the trucks.

[14] http://www.eex.com/en/Market%20Data/Trading%20Data/Emission%20Rights#

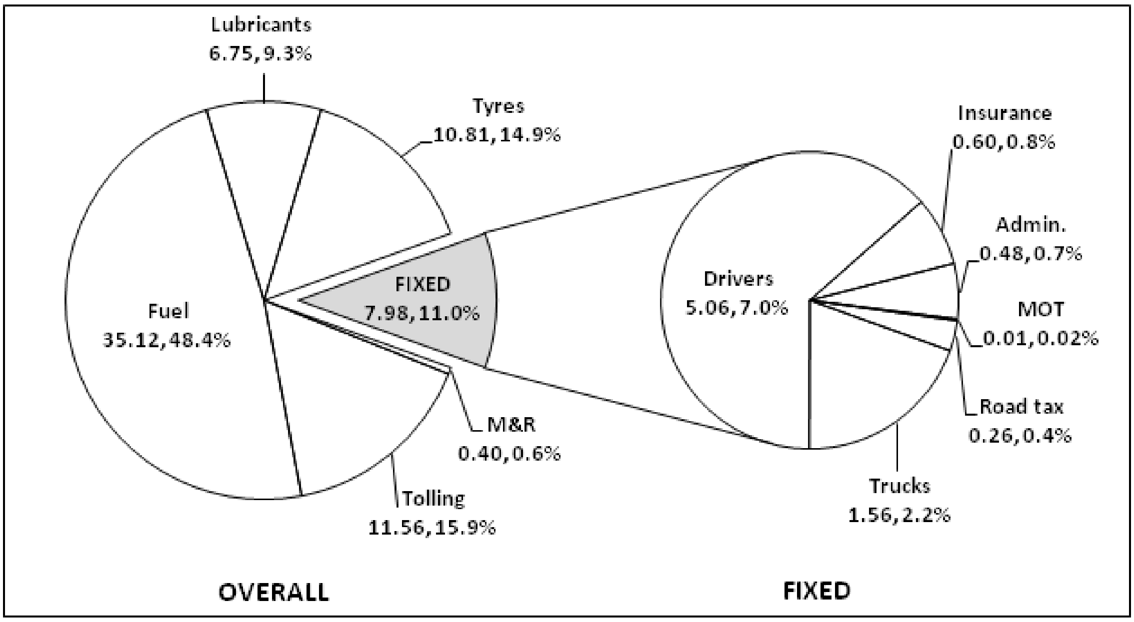

Figure 2. Analysis of annual internal costs of road service.

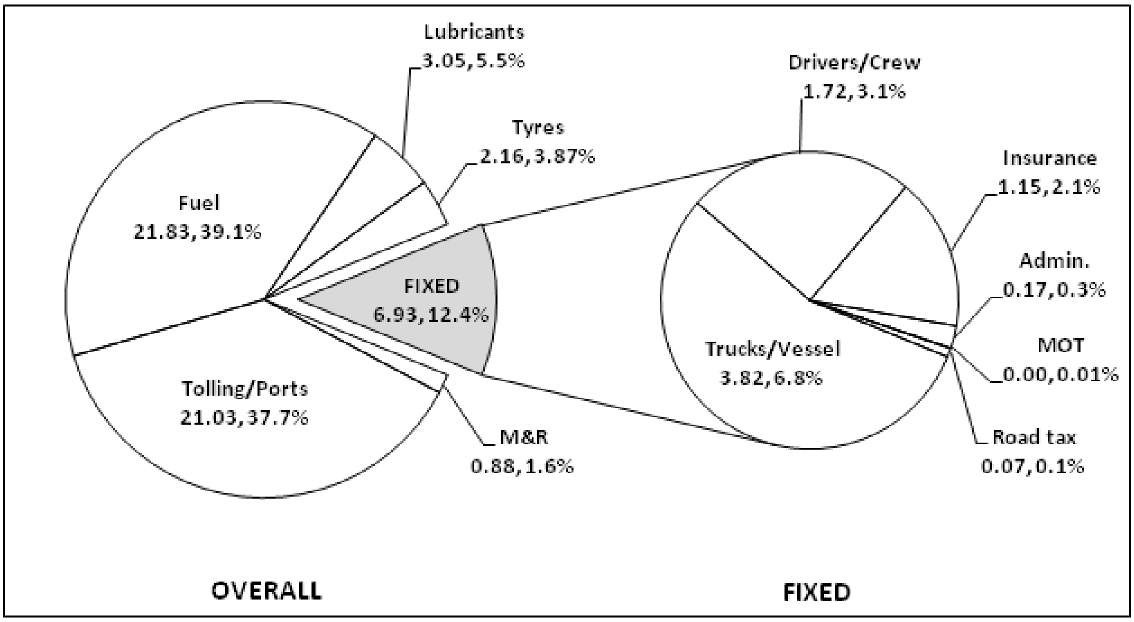

Figure 3. Analysis of annual internal costs of SSS service.

The annual external costs of the road service were dominated by the influence of traffic congestion, which with 10.86 million euro represented 48.4% of the overall negative externalities of the service estimated at 22.45 million euro (Figure 4). The second highest external cost item was associated with the road accidents estimated at 2.93 million euro and 13.1% contribution to the overall negative externalities. Damage to air quality was found to be the third highest cost item with 2.92 million euro and 13% contribution. Each of the remaining external costs of the road service had a lesser influence (less than 8.5%), with the annual costs of climate change equal to 1.5 million euro and a share of 6.7%.

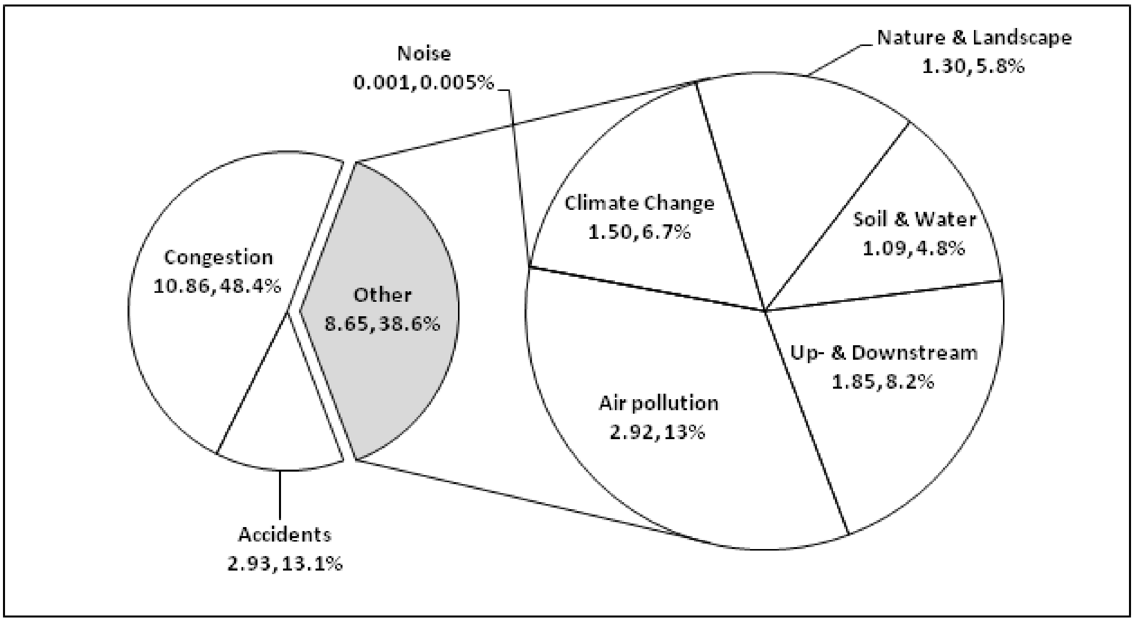

Figure 4. Analysis of annual external costs for road service.

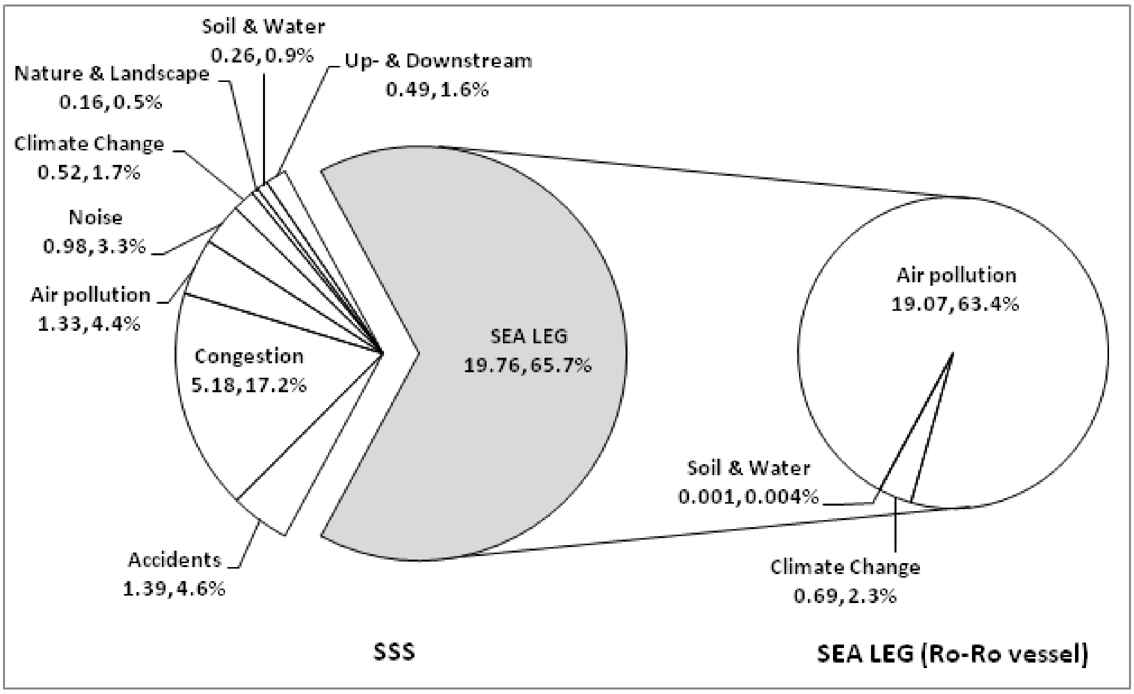

Figure 5. Analysis of annual external costs for SSS service.

The external costs of the SSS service were estimated at 30.07 million euro per year, with the contribution of the sea leg (Ro-Ro operation) found to be equal to 65.7% (Figure 5). Overall air pollution damage with 20.4 million euro and 67.8% contribution was the highest external cost item for the SSS service. The Ro-Ro vessel produced 93.5% of the overall air pollution costs, the remaining (6.5%) being attributed to the road leg of the SSS service. The second and third highest cost items were those of congestion (17.2%) and accidents (4.6%) respectively, both associated with the road leg of the SSS service.

All other negative externalities of the SSS had a minor influence to the overall external costs of the service each service with individual contributions not exceeding 3.5%. With regard to climate change, the annual costs of the SSS service were 1.2 million euro, the sea leg presenting the higher contribution with 57%.

5.2 Comparative presentation and discussion of results

By virtue of the acknowledged importance of fuel expenditure and atmospheric damage in modal comparisons, it is considered appropriate to concentrate on the comparative analysis and discussion of these cost items in particular. With regard to fuel costs, the road service averaged 0.52 euro/truck-km, whereas the SSS was equal 0.413 euro/truck-km. The latter was made up by 0.611 euro/truck-km for the road leg and 0.216 euro/truck-km for the sea leg. These findings provide a clear confirmation of the energy efficiency advantage of the SSS service and particularly of the Ro-Ro operation in comparison to the road alternative.

On the contrary, the highest air pollution cost per truck-km was presented by the Ro-Ro vessel with 0.343 euro/truck-km, which led to an average of 0.213 euro/truck-km for the SSS service as opposed to the significantly lower 0.043 euro/truck-km for the road alternative. This result reveals the superiority of the current road emission control measures (with regard to new truck engines and their fuel specifications) in comparison to their marine counterparts, as well as the detrimental influence of some SSS specific operational characteristics. With particular reference to fuel quality, the auto-diesel used by trucking is currently cleaner (in terms of sulphur content) than the MDO and HFO of the Ro-Ro vessel by a factor of 100 and 2700, respectively. This is clearly reflected in the comparatively high emission factors of the sulphur dependent SO_2 and PM emissions, as applied to the Ro-Ro vessel. Furthermore, SSS operations as opposed to deep-sea shipping, involve frequent port calling and in the case of "urbanised ports", such as Lavrio and Thessaloniki, SO_2 and PM emissions are particularly harmful and high emission cost factors apply. It is also important to note that this air pollution disadvantage of the Ro-Ro operation holds while the deployment of overall engine power is in favour of the Ro-Ro vessel, since the power of its main engine is about a third of the overall engine power associated with the deployed truck fleet.

Finally, in line with the aforementioned energy (fuel) performance, the Ro-Ro vessel produced the most carbon efficient operation with the lowest climate change cost of 0.012 euro/truck-km. However, the contribution of its road leg at 0.032 euro/truck-km led to to an almost equal performance between the SSS and the road service with 0.022 euro/truck-km.

With respect to the full cost comparison between the two transport modes, the total cost of the SSS service with 86 million euro per year was 9.6% lower than that of the road alternative (Figure 6). This favourable comparison for the SSS is attributed to its internal costs which at 55.9 million euro were found to be 23% lower than the road service, as opposed to the SSS negative externalities which at 30.1 million euro were 25.6% higher. The road leg of the SSS service shared 31.5, 34.2 and 32.4% of the internal, external and total costs of the SSS service, respectively. Without the road leg, the SSS would have been cost competitive in terms of external costs too, since the external costs of the sea leg (Ro-Ro) were 11.6% lower than the road alternative. This finding in conjunction with the overwhelming influence of distance dependent costs (i.e. variable internal costs and all other external costs) reveals the importance of freight centre location relative to ports for the establishment of cost effective SSS services.

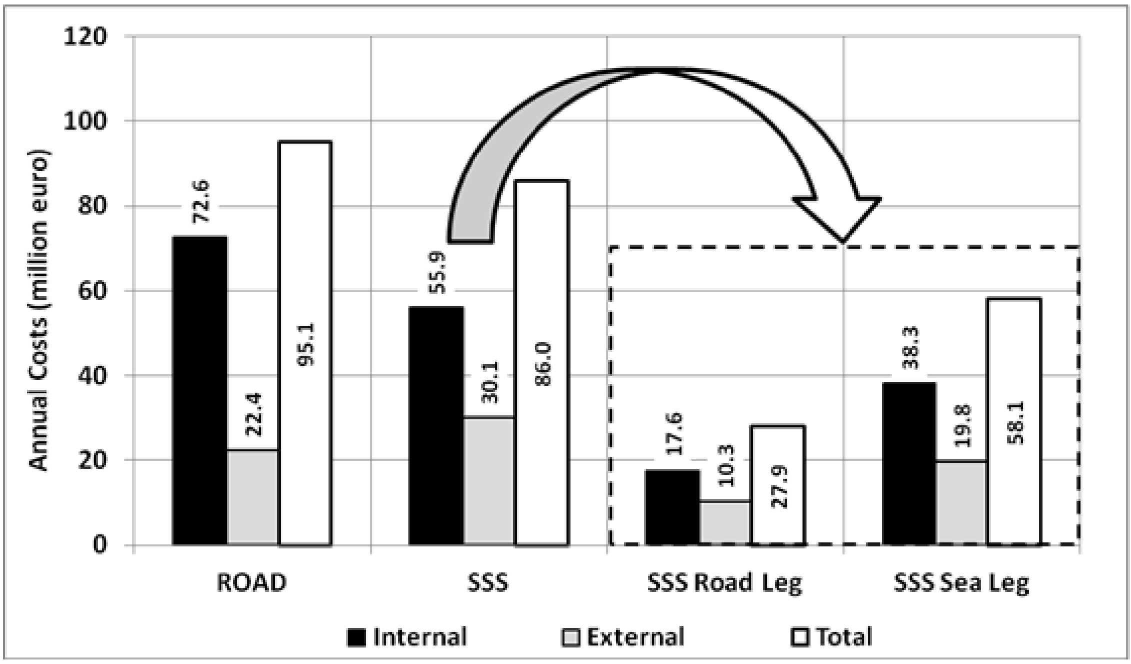

Figure 6. Overall cost comparison of road and SSS service.

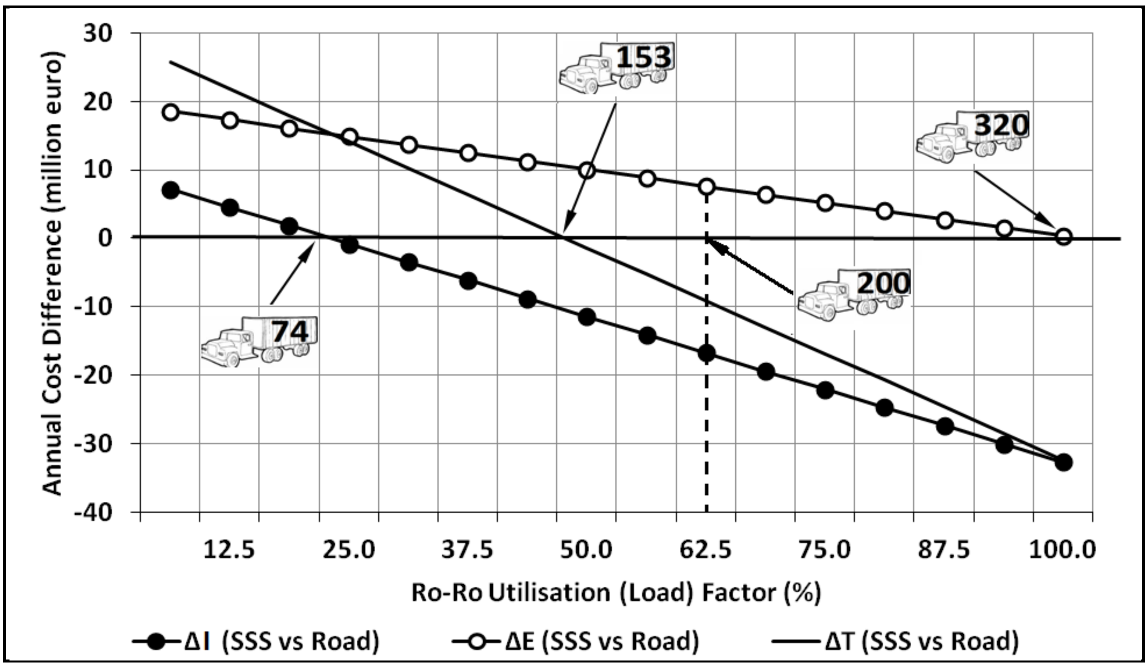

Figure 7. Influence of Ro-Ro utilisation factor on the cost comparison of road and SSS service.

In the cost comparison between the SSS and the road service, it was also considered important to examine the influence of the Ro-Ro utilisation (load) factor, assuming that variations of Ro-Ro utilisation apply equally to the number of trucks deployed for the provision of the road alternative service and the road leg of SSS (Figure 7). To this extent, it was found that the internal costs of the SSS service were lower (i.e. negative ΔI) for Ro-Ro utilisation higher than 23.1%, corresponding to the carriage of more than 73 cargo units. Also, the SSS external and total costs were more favourable than the road (i.e. negative ΔE and ΔT) for at least 100% (320 units) and 47.8% (153 units) utilisation, respectively. This implies that the SSS is favourable with regard to negative externalities only in the case of full Ro-Ro capacity utilsation.

The influence of Ro-Ro utilisation changes significantly when the road service is compared with the that of the Ro-Ro only, as the latter is found to be cost competitive at considerably lower utlisation factors (Figure 8).

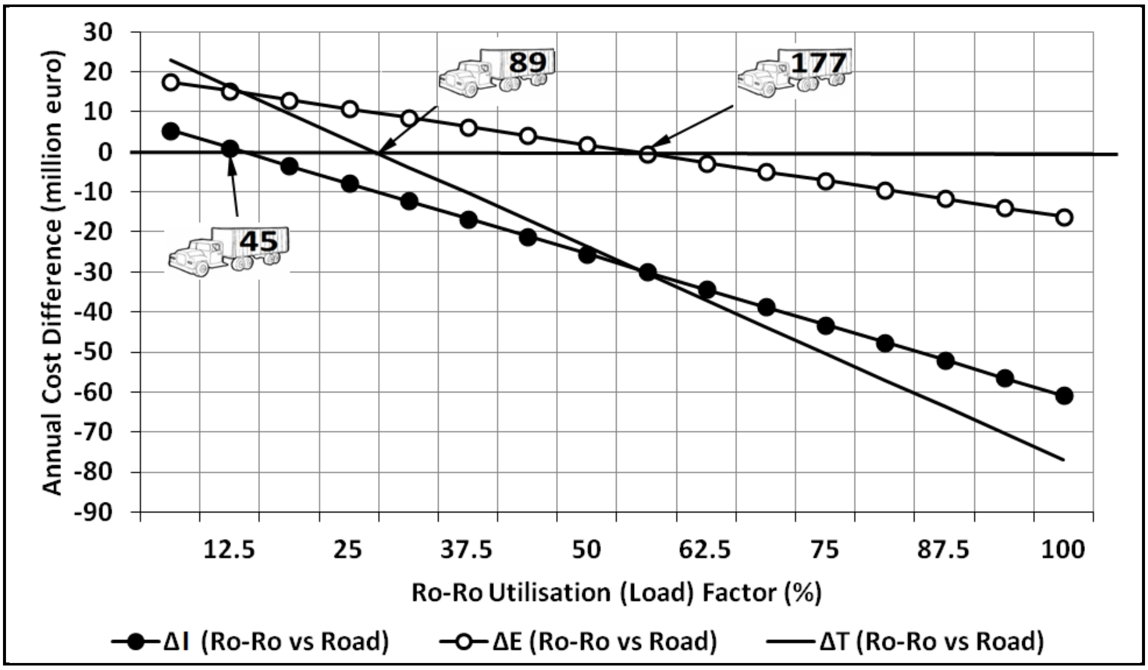

Figure 8. Influence of Ro-Ro utilisation factor on cost comparison of road and Ro-Ro service.

More specifically, the total costs of the Ro-Ro vessel are lower than the road service for at least 27.8% utilisation (89 units), whereas external and internal costs need a minimum 55.3% (177 units) and 14.1% (45 units) utilisation, respectively. In general, it has been demostrated that by increasing Ro-Ro utilisation the influence of economies of scale associated with the Ro-Ro operation makes the SSS service more cost competitive than the road alternative.

Table 4 presents a summary of the main results associated with the cost comparison between the two freight transport modes, as well as the minimum Ro-Ro utilisation factor which makes the SSS service the favourable option in terms of incurred costs.

Table 4. Summary of results.

Transport Mode	*Transport Service Costs (mil. euro/year) at 62.5% Ro-Ro Load Factor*						
	Internal			*External*			*Total*
	1st item	*2nd item*	*Total*	*1st item*	*2nd item*	*Total*	
Road Service	Fuel: 35.1	Tolls: 11.6	72.6	Congestion: 10.9	Accidents: 2.9	22.4	95.1
SSS Sea leg (Ro-Ro)	Ports: 19.1	Fuel: 12.0	38.3	Air Pollution: 19.1	Climate Change: 0.7	19.8	58.1
SSS Road leg	Fuel: 9.8	Tolls: 1.9	17.6	Congestion: 5.2	Accidents: 1.4	10.3	27.9
SSS Total	Fuel: 21.8	Tolls & Ports: 21.0	55.9	Air pollution: 20.4	Congestion: 5.2	30.1	86.0

Minimum Ro-Ro Load Factor (%) for SSS cost advantage			
SSS Service Details	*Internal Costs*	*External Costs*	*Total Costs*
SSS with road leg	23.1	100.0	47.8
SSS without road leg (Ro-Ro only)	14.1	55.3	27.8

The above mentioned costs (as shown in Table 4) and particularly those of externalities involve uncertainties which have to be addressed in order to assess the comparison between the two freight transport options. The uncertainty margin associated with the internal costs of the road and SSS service is very limited, because the dominant cost items of fuel and toll/port expenditure are based on real life data with regard to fuel prices and toll/port dues, as well as technical and operational parameters which affect vehicle (vessel or truck) fuel consumption. On the contrary, the evaluation of negative externalities is generally considered to have a high margin of uncertainty, but in this case the most significant cost items are of the type and level which cannot alter the qualitative comparison between the two freight transport options. More specifically, the air pollution costs of the Ro-Ro operation have by far the highest share (63.5%) of total SSS external costs and are overwhelmingly higher than the corresponding costs of the road service. This is mainly due to the sizable difference of SO_2 and PM emissions between the two transport services, as the quality of the Ro-Ro's heavy fuel is around 2,700 times worse than that of auto-diesel in terms of the sulphur content (i.e. 27,000 ppm Vs 10 ppm, respectively). On the other hand, congestion damage is the leading externality of the road service (48.7% of the total) followed by accidents (12.9% of the total) and both of these items are almost non-existent for the Ro-Ro operation.

Finally, it should be mentioned that stricter environmental control of shipping operations in the Mediterranean is bound to alter the cost structure of the considered SSS service and the comparison between the two transport services. Opting for the use of low-sulphur marine fuels towards meeting the requirements of stricter air pollution regulations, the dependence of the Ro-Ro internal costs on fuel expenditure indicates that the associated increase in the price of bunkers will reduce the internal cost advantage of the SSS service. The trade-off between more expensive and cleaner fuels is the lower air pollution cost of the Ro-Ro operation through the reduction of the SO_2 and PM exhaust emissions. Therefore, assuming an ECA designation of the Mediterranean and taking into account that the price premium for low-sulphur (1% content) fuel currently stands on average at around 25 euro/ton whilst its use will produce an almost threefold reduction of the SO_2 and PM emissions, it is evident that this change will improve the position of the SSS due to the weighing difference of the associated cost items on the overall cost of the competing modes.

6. Conclusions

In this comparison of freight transport modes, the SSS service was found to be cost competitive in terms of total and internal costs, whereas its external costs were higher to the road service. The latter finding is in agreement with the scepticism raised through the work of Hjelle (2010) and Kim and Van Wee (2011) with regard to the environmental superiority of SSS amidst the stricter quality specification of auto-diesel currently applicable to road trucks.

The road leg of the SSS service was a significant contributor of its internal and external costs, revealing the importance of proximity between freight centres and ports in establishing sustainable SSS operations, a finding which is consistent with the work of Feo-Valero et al. (2011) and Ferrari et al. (2011).

Furthermore, it was found that increasing the Ro-Ro utilisation factor improves the cost comparison of the SSS service, as the Ro-Ro internal and external costs are not so significantly affected through the loading of the vessel, whereas the variation in the number of deployed trucks impacts on the costs of the road service accordingly. This influence of capacity utilisation on SSS operations is in agreement with the work by Styhre (2009).

In general, it is concluded that the overall SSS competitiveness is improved through:

- the use of ultra-low sulphur marine fuels;
- its application as a "point-to-point" substitute rather than a complement to road transport;
- the increase of vessel's capacity utilisation (i.e. higher freight shift).

The above mentioned conclusions strengthen the existing knowledge base on the determinants of SSS growth and offer support to the international and European policy making with regard to modal shift promotion. The adoption of such measures leads to the establishment of SSS-inclusive intermodal transport networks designed to ensure the provision of sustainable freight services. It is the importance attached to the design details of such networks that dictates the need to treat all modal shift ventures as case-specific exercises for which the full cost analysis between competing freight transport services constitutes an essential component.

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