SHORE-SIDE ELECTRICITY FOR SHIPS IN PORTS

Case studies with estimates of internal and external costs,

prepared for the North Sea Commission

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CONTENT

INTRODUCTION

Sea transport has some obvious environmental benefits compared to land-based transport modes, including the small needs for infrastructure, low barrier and congestion effects, and low noise pollution. However, as emissions of air pollutants from land-based sources have diminished dramatically over the last ten to twenty years, those from sea transports show a continuous increase. It is therefore of interest to investigate various ways of reducing air pollutant emissions from sea transport.

During loading and unloading operations in ports, emissions from ships often take place close to urban areas. Consequently these emissions are of special interest from a health perspective. One measure aimed at reducing ship emissions in ports is to provide ships in ports with shore-side electricity. The purpose of this study was to investigate the practicalities, costs and benefits of switching from onboard ship generated electricity to shore-side electricity connections, and also to investigate for which type of sea transport systems such measure may be relevant.

This study has been prepared on behalf of the *North Sea Commission*, the organisation of Regional Authorities around the North Sea (www.northsea.org). *Per Hörberg* Coordinator of the *North Sea Commission Environment Group* has been acting as contact person. Many persons have contributed to this study though *Per Lindeberg* and *Christer Ågren* deserve special thanks.

The calculations made in this study should be seen as test examples for evaluating some sea transport systems' potential to reduce their environmental impacts by using shore side electricity connections, and to compare the cost of shore-side electricity with those of normal onboard power generation. It should be noted that the use of assumptions and general figures is inevitable for this type of cost-benefit analyses, and that the results therefore should be seen as "best estimates". Depending on local conditions or other circumstances, shore-side power connections can in specific cases be either more expensive or cheaper. Also, the benefits will vary from case to case depending on e.g. the type of fuel used in the ships, the possible use of onboard emission abatement measures, the size of the exposed population, and the environmental performance of the land-based power generation.

Six different ship services with frequent regularity have been investigated as case studies. The estimated emissions from onboard power generation at berth have been compared to the corresponding emissions from shore-side electricity. Also, the direct cost for onboard generating of electricity has been compared to the costs of supplying power from the shore-side electricity system.

Onboard power has been calculated for two types of diesel electric generation: the burning of *Heavy Fuel Oil* (HFO) and the burning of *Marine Gas Oil* (MGO).

Today, three commercial shipping lines operating the North Sea are using shore power connections in ports. Some more vessels, such as the Stena Line's high speed catamarans, use shore-side connections during idling and night stay at berth. The oldest installation is run by *Stena Line* in Gothenburg, Sweden, and is used by the two Ro/Ro-passenger-ferries *Stena Scandinavica* and *Stena Germanica* in their Gothenburg – Kiel, Germany, service. This installation uses the older *low voltage connection systems* (400 V connection cables). The two others also operate from Gothenburg, but they use modern high voltage connections (6-10kV) between shore-side to the ship, see Figure 3. These two are *Cobelfret*, which runs a Ro/Ro service on behalf of *Stora Enso* between Gothenburg and Zeebrugge, Belgium, and *DFDS Tor Line*, which runs a Ro/Ro service between Gothenburg and Immingham, United Kingdom.

The environmental aspects from the different ways of generating power have been compared and valuated in monetary terms by estimating the emissions of air pollutants and applying the *ExternE* valuation model in respect to the geographic site where the emissions take place. The valuation figures used have been taken from *Holland and Watkiss* (2002). This valuation model was chosen because it corresponds to other benefits valuations of the impacts of air pollution made recently on the behalf of the *European Commission*.

In order to investigate the marginal benefits achieved for vessels connecting to shore-side power in a specific port, calls to the Port of Gothenburg have been analysed. It was found that of all vessels calling the Port of Gothenburg in one year, approximately 20 individual ships (of totally approximately 750 individual ships) were responsible for about 30% of the total emissions of sulphur and nitrogen oxides at berth (see Figure 1 and Figure 2). Focusing on the ships that most frequently visit the port therefore appears to be an effective way to cut quay emissions. Moreover, these frequent visitors are also likely to be more suitable for shore-side electricity connections as compared to other vessels, e.g. those trading on the spot market.

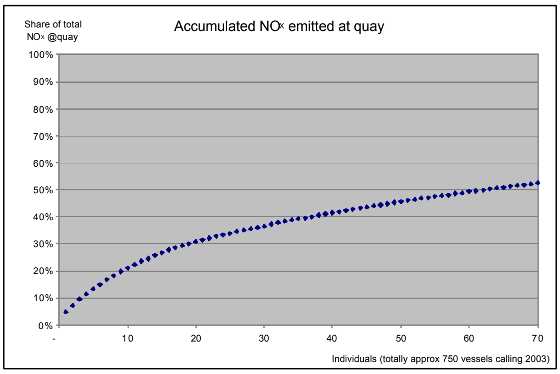

Figure 1 Accumulated emissions of nitrogen oxides emitted at berth for the highest emitting individuals ships. Calculated for vessels calling to the Port of Gothenburg during 2003.

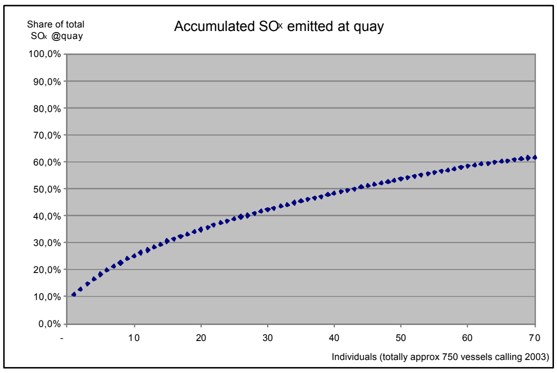

Figure 2 Accumulated emissions of sulphur dioxides emitted at berth for the highest emitting individuals ships. Calculated for vessels calling to the Port of Gothenburg during 2003.

SHORE-SIDE ELECTRICITY – PRACTICALITIES AND COSTS

There is currently no existing standard for shore-to-ship electricity supply systems, but the general principles for modern high voltage systems would anyway be the same and can be seen in Figure 3.

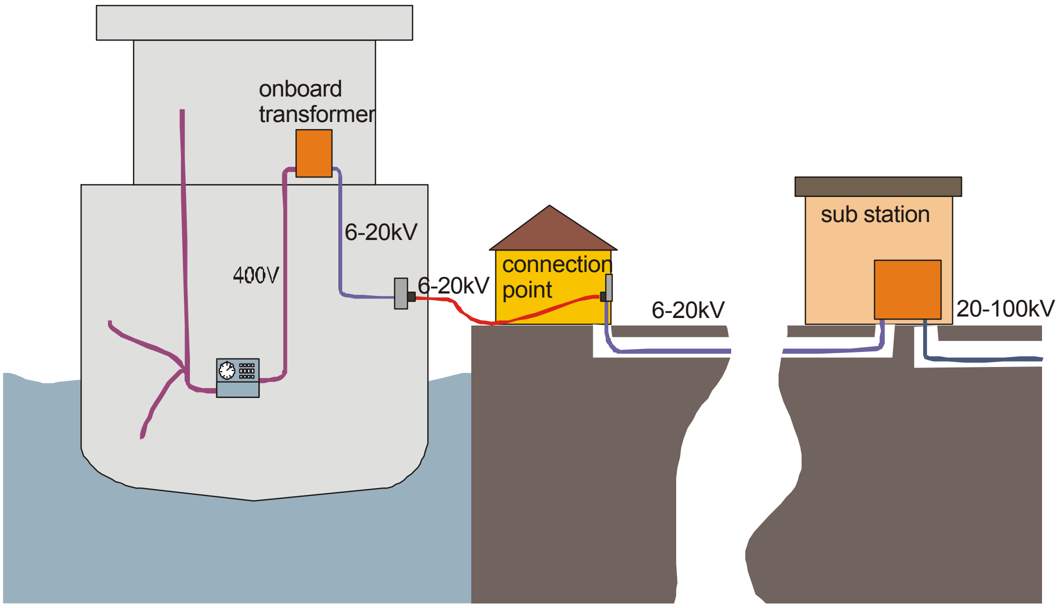

Figure 3 Typical shore-side power connection principles.

Some form of connection point at the quay site is needed where a “flexible cable” can be attached between the ship and the shore-side electrical system. The power must be distributed to the connecting point near the ship, from a local high-voltage sub station. A high-voltage cable makes it possible to transfer 25 times more power than with a normal 400V cable of the same dimension. It is therefore a very handy and simple operation to connect a ship to shore-side supply using a high-voltage system. Consequently, modern shore-to-ship electricity systems use high voltage flexible cables between the quay and the ship.

When a quay is close to a residential or industrial area, high voltage power (6-20 kV) will most probably be available. It is therefore likely that almost all ports in Europe with regular services have high-voltage electricity available nearby.

Figure 4 Connection practicalities (Photos: Port of Gothenburg)

Onboard the vessel an entrance for the connecting cable is needed as well as socket for the cable. The high-voltage electricity transferred to the ship must also be transformed onboard to the 400V that is being used in the ship. This is made in an onboard transformer, preferably located near the main switch board in the engine room.

The following parameters are usually of importance when the cost and system requirements are investigated:

- Shore-side frequency (50 Hz in Europe)
- Onboard frequency (60 Hz or 50 Hz)
- Shore side supply of high voltage electricity (voltage, distance to nearest supply point and installation practicalities)
- Required power level
- Available spaces for onboard transformer, and weight restrictions of the vessel. The extra weight of equipment (transformer) or loss of cargo space may for some vessels result in reduced profitability or increased fuel consumption. In most cases these costs can be neglected, but for high-speed crafts or other special vessels the factors could be of importance
- If the space where the onboard transformer is being located can be weather sheltered or not
- Onboard cable installation practicalities and distances

- Cost for shore supplied electricity versus that for onboard generated electricity cost (fuel, maintenance etc)

The two parameters that have the greatest impact on the installation cost for shore-side electricity connections are the onboard frequency and the cost of supplying the quay with high-voltage electricity.

If the vessel is using a frequency of 60Hz, the shore-side electricity must be transformed from the standard 50Hz to the onboard 60Hz frequency. This is made via a shore-located frequency transformer and does not pose any technical problem. The costs for frequency transformers (that converts from 50 Hz to 60 Hz) in the power range suitable for shore-to-ship electricity systems are between 300 000 and 500 000 euro. One frequency transformer can serve several berths as long as high-voltage connections between the transformer and the berth connections exist. In order to estimate the need for frequency transformer 300 random vessels were checked according to their onboard frequency (see Figure 5). Just over 50 % of the vessels seem to use 60Hz as onboard frequency.

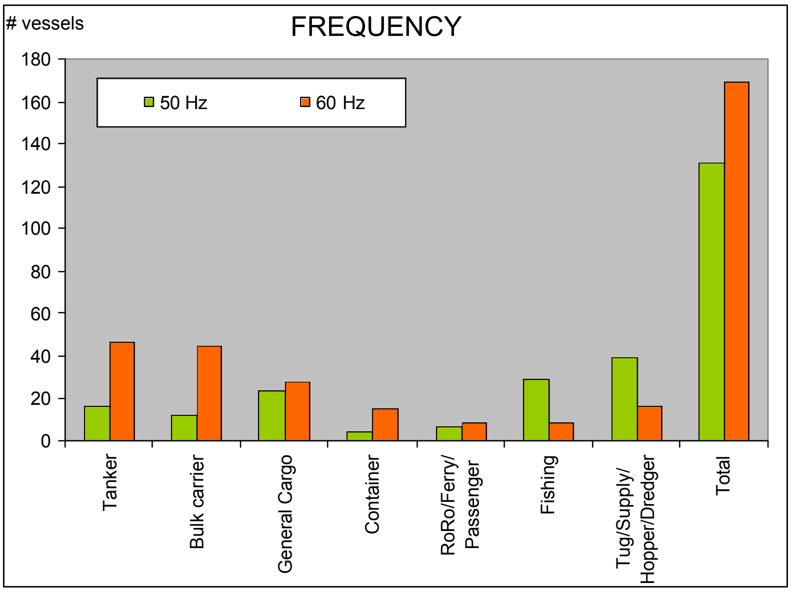

Figure 5 Frequency used onboard different vessel types (300 random vessels from Lloyd's Register – Fairplay, 2002)

The costs for the power supply of high-voltage at the quay side can vary largely, depending on the distance to the nearest high voltage supply and other local conditions. If new canalisation has to be made and the distance is long, the supply costs can be significant. Typical harbour canalisation (to bury cables etc. in the ground) costs are 100-150 euro per meter and high voltage cable (10kV) could cost 10-15 euro per meter. The distance between the needed berth supply point and the nearest high-voltage access point can typically be anything between 30 meters to 500 meters in ports. The connection cable used between the shore connection and the ship is the same kind of flexible cable used to the cranes in the port, and crane cable (10kV) cost is typical 20-25 euro per meter.

So the cost for supplying a terminal with 1-10 MW high-voltage power can be anything between 10 000 and 500 000 euros. This varies with distances, how many transformation stations/connections that have to be upgraded backwards and with the local conditions. In the end, of course, decisions as to who will carry the cost for a specific connection is also a matter of negotiation on how the varying costs are to be allocated.

The required maximum power level may also influence the costs for the power supply, but this will depend on each specific port's type of electricity delivery contract. Higher power levels will also need bigger and more expensive equipment as regards transformers, cables etc.

As an onboard transformer is being used to transform for example 10 or 6kV to 400V, it would be of advantage if all ports would have had access to the same high-voltage level. A vessel having an onboard transformer for 10kV incoming electricity supply can not automatically be connected to 6kV without special arrangements. Vessels calling many different ports could possibly be equipped with transformers that can connect to different voltage levels, but the cost for such equipment has not been investigated in this study.

Typical cost for onboard transformers (0.5-2 MW) is 40 000 to 70 000 euro. Retrofit and unsheltered transformer installations are more expensive. Typical total onboard installation cost is 60 000 to 140 000 euro, including the transformer.

It is important to note that it is always possible to use the vessels' own auxiliary electricity generation system in case of shore-side power connection problems or in case the vessel calls a quay without shore electricity connection. This also makes it unnecessary to dimension the shore-side electricity systems for non-normal peaks or loads. It is often possible to get reduced fees for electricity connections if the electricity providers have the possibilities to disconnect a connection in case of extreme peaks in demand.

The old types of low-voltage shore-side connection systems have higher costs for maintenance and investments. As these systems are much heavier to handle (to connect) they are also normally only possible to use at the specific berth where the shore connection station is located resulting in limited flexibility of the system.

Energy prices and onboard generating costs

The cost for electricity will vary depending on for example the total amount of electricity that the client buys every year and negotiations, but it also varies between the European countries. Electricity prices used for the calculations are taken from a yearly study made by Inra (2003) on behalf of seven European electricity companies. Example of how electricity prices vary over Europe can be seen in Figure 6. The costs for the shore installations are added as a running cost of 0,006 euro/kWh in all ports (see Table 1).

Note that the electricity consumed in ports by vessels includes taxes but the corresponding bunker fuel bought by the vessels is *totally free of taxes* (and environmental fees etc.).

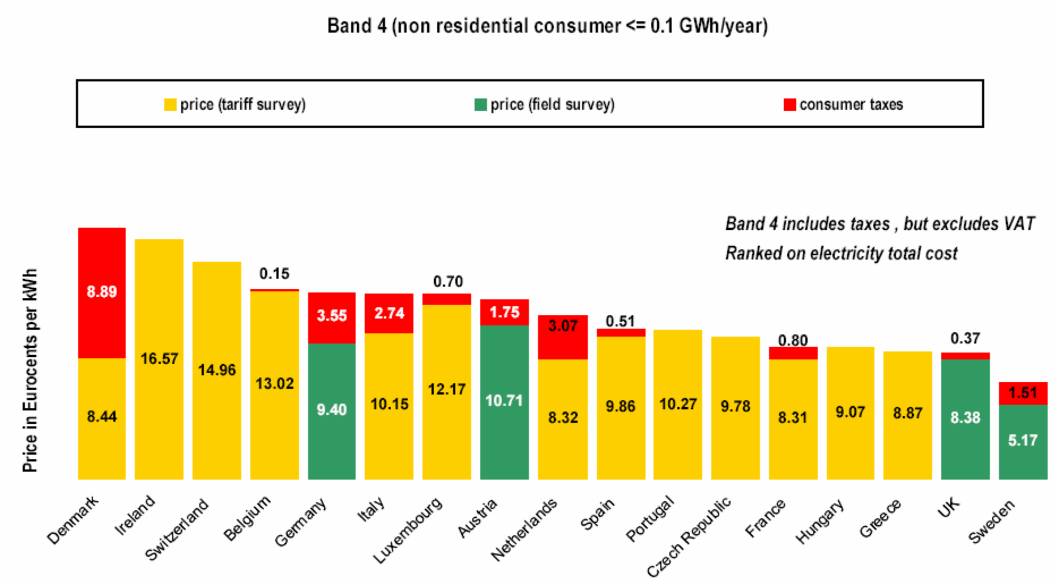

Figure 6 Electricity prices in 17 European countries including taxes (VAT excluded). Source: Inra (2003).

Table 1 Electricity prices depending on country and type of consumer. Source: Inra (2003).

Non residential consumer	Electricity price Inra, 2003	Port facility costs	Electricity cost		Total port customer	
Electricity prices in Port A: Gothenburg	0,0668	0,0060	**0,07**	Euro/kWh	*<0,1GWh/year*	*Band 4*
Electricity prices in Port B: Immingham	0,0875	0,0060	**0,09**	Euro/kWh	*<0,1GWh/year*	*Band 4*
Electricity prices in Port C: Kiel	0,1295	0,0060	**0,14**	Euro/kWh	*<0,1GWh/year*	*Band 4*
Electricity prices in Port D: Zeebrugge	0,1317	0,0060	**0,14**	Euro/kWh	*<0,1GWh/year*	*Band 4*
Electricity prices in Port E: Portsmouth	0,0875	0,0060	**0,09**	Euro/kWh	*<0,1GWh/year*	*Band 4*
Electricity prices in Port F: Liverpool	0,0875	0,0060	**0,09**	Euro/kWh	*<0,1GWh/year*	*Band 4*
Electricity prices in Port G: Antwerp	0,1317	0,0060	**0,14**	Euro/kWh	*<0,1GWh/year*	*Band 4*
Electricity prices in Port H: Bremerhaven	0,1295	0,0060	**0,14**	Euro/kWh	*<0,1GWh/year*	*Band 4*
Electricity prices in Port I: Rotterdam	0,0866	0,0060	**0,09**	Euro/kWh	*0,1-1 GWh/year*	*Band 5*
Electricity prices in Port J: Hull	0,0875	0,0060	**0,09**	Euro/kWh	*<0,1GWh/year*	*Band 4*
Electricity prices in Port K: Middlesbrough	0,0875	0,0060	**0,09**	Euro/kWh	*<0,1GWh/year*	*Band 4*
Electricity prices in Port L: Rosyth (Edinburgh)	0,0875	0,0060	**0,09**	Euro/kWh	*<0,1GWh/year*	*Band 4*

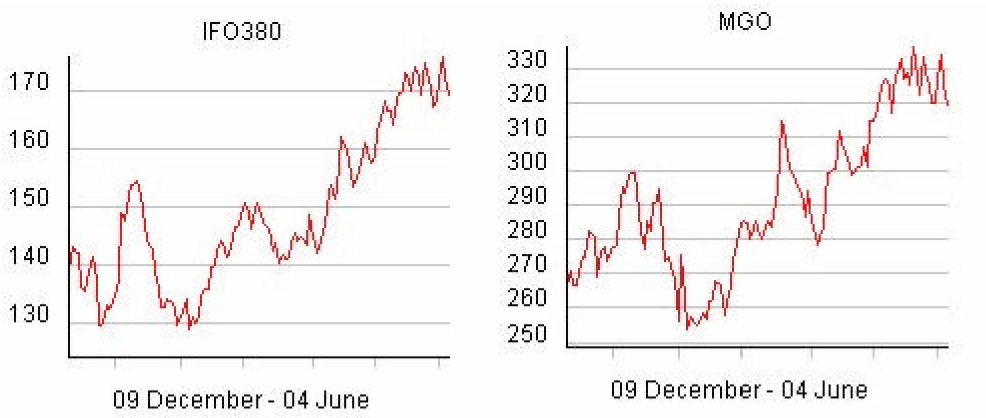

Figure 7 Bunker fuel prices (USD/ton) in Rotterdam for a running 6 month period. Source: www.bunkerworld.com 2004-06-07

Table 2 Bunker fuel prises used in the study are Heavy fuel oil: 113 euro/ton and Marine Gas Oil: 227 euro/ton

BUNKER FUEL PRICES	USD/ton	*SEK/m3*	Density	*SEK/ton*		€/ton	
IFO380 (Rotterdam Around Jan 2004)	140			1 046	**HFO**	**113**	*Bunkerworld.com, 2004-06-07*
MGO (Rotterdam Around Jan 2004)	280			2 091	**MGO**	**227**	*Bunkerworld.com, 2004-06-07*
MDO (Rotterdam Around Jan 2004)	240			1 792		**194**	*Bunkerworld.com, 2004-05-19*
IFO180 ((Rotterdam Around Jan 2004)	150			1 120		**122**	*Bunkerworld.com, 2004-05-19*
Diesel (2004-05-24)		2 250	0,93	2 093		**227**	*Sannes Oil AB, 2004-05-24*
Diesel (Average 2003-01-01 - 2004-05-24)		1 975	0,93	1 837		**199**	*Sannes Oil AB, 2004-05-24*
City diesel (2004-05-24)		2 700	0,93	2 511		**272**	*Sannes Oil AB, 2004-05-24*
City diesel (Average 2003-01-01 - 2004-05-24)		2 275	0,93	2 116		**229**	*Sannes Oil AB, 2004-05-24*

The total costs for onboard generation of electricity will depend on the design of the ship's power supply system and the fuel used. As shown in Figure 7, the fuel prices vary largely over time and by fuel quality. The total cost will also depend on costs for investments and maintenance. The investment costs for onboard auxiliaries have been ignored in this study, as the power supply system in most cases has to be installed even if the vessel is using shore-side electricity in all harbours. The maintenance cost will vary with the type of engine (two/four stroke, engine brand, size etc), age and running hours per year. A general cost of 1.6 euro/running hours for a 900 kW auxiliary engine is used in this study. In the calculations, the maintenance cost was raised a bit for larger auxiliaries.

External costs

The values for external costs used in this study are taken from *Holland and Watkiss* (2002), and shown in Table 3. The figures are based in the work made in the *European Commission's DG Research ExternE project*. Land-based emissions from electricity generation were valued with rural valuation factors for the country of the port. *Carbon dioxide* (CO_2), *Carbon oxide* (CO) and *Polycyclic aromatic hydrocarbons* (PAH) were not valuated by *Holland and Watkiss*, and therefore also not in this study. The electricity production was in this study assumed to take place in modern coal-fired power plants (see Table 6), and the emitted amount of *carbon dioxide* will therefore be in the same range for onboard and land-based production. *PAH-emissions* are of great importance for public health, and it would therefore have been useful to include them in the valuation, but lack of valuation data unfortunately made that impossible.

The valuation figures in *Holland and Watkiss* are different for each pollutant, and vary between different countries and sea areas. They also differ due to the density of people living close to the emission source.

Table 3 The external costs used for emissions of air pollutants are sensitive to country and population density near the emission source. Based on Holland and Watkiss (2002).

Port emission costs - Emission costs BeTa Version E1.02a	NOX	SO2	CO2	CO	VOC	PM	PAH		Inhabitants (approx.)	Area
Port A: Gothenburg	2,60	30,00	-	-	0,68	165,00	-	Euro/kg	500 000	Sweden
Port B: Immingham	2,60	4,50	-	-	1,90	9,70	-	Euro/kg	RURAL	UK
Port C: Kiel	4,10	15,00	-	-	2,80	82,50	-	Euro/kg	250 000	Germany
Port D: Zeebrugge	7,70	7,90	-	-	3,00	22,00	-	Euro/kg	RURAL	Belgium
Port E: Liverpool	2,60	45,00	-	-	1,90	247,50	-	Euro/kg	1 500 000	UK
Port F: Antwerp	7,70	30,00	-	-	3,00	165,00	-	Euro/kg	500 000	Belgium
Port G: Bremerhaven	4,10	6,00	-	-	2,80	33,00	-	Euro/kg	100 000	Germany
Port H: Rotterdam	4,00	30,00	-	-	2,40	165,00	-	Euro/kg	500 000	Netherlands
Port I: Hull	2,60	18,00	-	-	1,90	99,00	-	Euro/kg	300 000	UK
Port J: Middlesbrough	2,60	9,00	-	-	1,90	49,50	-	Euro/kg	150 000	UK
Port K: Rosyth (Edinburgh)	2,60	30,00	-	-	1,90	165,00	-	Euro/kg	500 000	UK

Table 4 External costs for emissions of air pollutants from land-based electricity generation. From Holland and Watkiss (2002).

Rural area - Emission costs BeTa Version E1.02a	NOX	SO2	CO2	CO	VOC	PM	PAH	
Belgium	7,70	7,90	-	-	3,00	22,00	-	Euro/kg
Germany	4,10	6,10			2,80	16,00		Euro/kg
Netherlands	4,00	7,00			2,40	18,00		Euro/kg
Sweden	2,60	1,70			0,68	1,70		Euro/kg
UK	2,60	4,50			1,90	9,70		Euro/kg
EU-15 average	4,20	5,20			2,10	14,00		Euro/kg

Emission factors

Emission factors used for onboard auxiliary engines are taken from *Cooper (2003)* and shown in Table 5. The sulphur content assumed in this study for *Heavy Fuel Oil* are set at 2.2%, which can be seen as a high value for some of the shipping lines studied, but can on the other hand be considered as a low level as compared to fuel used by international shipping in general. The alternative fuel used in the calculations was a *"low sulphur" Marine Gas Oil*[1] with a sulphur content of 0.2%. Emission factors for ships vary largely between different engines and fuels. The figures from *Cooper (2003)* are in the same range as those of other recently published reports.

Table 5 Emission factors used for onboard power generation in auxiliary engines. The Compilation is based on Cooper (2003).

Heavy Fuel Oil	NOX [kg/ton fuel]	SO2 [kg/ton fuel]	CO2 [kg/ton fuel]	CO [kg/ton fuel]	VOC [kg/ton fuel]	PM [kg/ton fuel]	PAH [kg/ton fuel]	
Auxiliary Engine E	70	44	3 199	4,17	0,79	3,10	50,93	Residual Oil
Auxiliary Engine F	59	44	3 212	3,55	0,88	2,49	43,78	Residual Oil
Average HFO	**65**	**44**	**3 206**	**3,86**	**0,83**	**2,80**	**47,35**	
		2,2% % S"						

Marine Gas Oil	NOX [kg/ton fuel]	SO2 [kg/ton fuel]	CO2 [kg/ton fuel]	CO [kg/ton fuel]	VOC [kg/ton fuel]	PM [kg/ton fuel]	PAH [kg/ton fuel]	
Auxiliary Engine G	83		3 159	3,32	1,38	0,70	6,54	MGO
Auxiliary Engine A	80		3 189	3,63	0,78	1,56	-	MGO
Auxiliary Engine C	75		3 175	2,05	1,00	1,69	0,77	MGO
MGO	**79**	**4**	**3 174**	**3,00**	**1,05**	**1,31**	**2,44**	

If ships start to use shore-side electricity, this will lead to additional electricity consumption and could therefore be regarded as a marginal consumption. The marginal generation of electricity in most European countries is likely to take place in coal-fired power plants. Emission factors for coal-fired power plants fulfilling the *EU Directive 2001/80/EC* have therefore been used in this study. On the other hand, ports could opt to buy so-called green electricity (i.e. electricity generated exclusively by renewable energy sources), or to build and run their own wind turbines, for example. By choosing to base the calculations in this study on emission factors from coal-fired power stations, the resulting figures on external costs for shore-side electricity will represent the upper bound of such costs.

Table 6 Emissions from electricity produced in modern coal fired power plants >500MW.

Coal plants >500MW according to Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001

Emissions factors - electricity production	NOX	SO2	CO2	CO	VOC	PM	PAH	
(According to *Article 4(3)*)	175	140				17,50		g/GJ
Complement from Vattenfall - Life Cycle Inventories								
Coal fired power plants			980					g/kWh
European Commission, 1999, Meet - Estimated for 2020				0,15	0,60			g/kWh
Compilation	0,63	0,50	980	0,15	0,60	0,06	-	g/kWh

[1] Expressed differently, a so-called low-sulphur gas oil with 0.2% sulphur has a sulphur content of 2000 ppm (parts per million), i.e. 200 times higher than that of the ordinary truck diesel fuel commonly used in for example Sweden, which has a sulphur content of maximum 10 ppm.

SIX SHIPPING LINES AROUND THE NORTH SEA

Analyses of energy use at berth have been made for the six shipping lines below.

1. **Gothenburg – Immingham (500 NM), DFDS Tor Line**
2. **Gothenburg – Kiel (236 NM), Stena Line**
3. **Zeebrugge – Gothenburg (544 NM), Cobelfret**
4. **Liverpool – (692 NM) – Antwerp – (351 NM) – Bremerhaven – (372 NM) – Gothenburg, ACL**
5. **Rotterdam – Hull (197 NM), P&O Ferries**
6. **Zeebrugge – Rosyth (405 NM), Superfast Ferries**

The purpose of this study was to investigate the practicalities, costs, and benefits of shore-to-ship electricity connection systems in ports. Each of the six shipping lines has therefore been investigated from local, shipping line and vessel specific conditions. In order to systematically find the type of systems that are most suitable for shore power connections and to fill in missing parameters some more general figures have been used.

The analyses have been made based on general figures for fuels and emission factors. Some of the vessels in the listed services are for example using low sulphur fuels while others don't. This has not been taken into account. The power level (annual energy consumption) in each port for the vessels has been known for the lines 1-4, but estimated for service 5 and 6.

Three different electricity production cases have been calculated for each of the vessels in the service.

- Onboard electricity generating with auxiliaries running on Heavy Fuel Oil (2.2 % S)
- Onboard electricity generating with auxiliaries running on Marine Gas Oil (0.2% S)
- The vessels connected to shore-side electricity in port

Three shipping lines trading on the North Sea are using shore-side electricity in ports today (services 1-3 above). They all call the port of Gothenburg and have been running for several years. These three lines have been picked just because they use shore-side power today, to see if this can be justified in a cost-benefit analysis. The other lines have been chosen as they are operated in regular service with specific vessels designated for the services.

The oldest shore to ship electricity system operating on the North Sea is *Stena Line's* Gothenburg-Kiel services that use the old 400V power connections. This service is run by the two combined passenger and Ro/Ro ferries *Stena Scandinavica* and *Stena Germanica*.

In the year 2000, *DFDS Tor Line* and *Cobelfret* installed shore-side power connections on three vessels each on their Gothenburg service. *Cobelfret's* vessels *Spaarneborg*, *Schieborg* and *Slingeborg* are connected to shore-side power in both ends (Gothenburg and Zeebrugge). The *DFDS Tor Line* vessel's *Tor Selandia*, *Tor Brittania* and *Tor Suecia* are shore-side connected in Gothenburg but not in Immingham.

The *ACL* services between European ports, Canada and USA was evaluated for shore-side power connections in ports some years ago, but such system was not installed. The low port regularity, the onboard 60Hz, and high costs are the most probable reasons for not yet installing the system.

The *P&O* service between Rotterdam and Hull is operated with the combined Ro/Ro and passenger ferries *Pride of Hull*, *Pride of Rotterdam*, *Norsun* and *Norsea*.

The high speed ferries *Superfast X* and *Superfast IX* are operated by Superfast Ferries between Zeebrugge and Rosyth.

In the calculations, the same assumptions have been used for all of the six services as regards cost levels and environmental performance. General data on the vessels have been used in order to estimate the annual energy consumption in ports for services 5 and 6.

RESULTS AND CONCLUSIONS

Shore-side electricity connection can effectively reduce air pollutant emissions and noise from vessels in ports, thus providing environmental and health benefits. As a result staff onboard is exposed to less noise and emissions on deck, the engine room environment is quiet at port calls, and stevedores are exposed to less emission from the ship. The total noise emitted from the vessel is normally significantly lower with the vessel's auxiliaries shut down, although this depends on the characteristics of each specific vessel. All operators involved that have been interviewed experience that high-voltage shore-side supply of electricity at berth is a very positive measure.

The valuation of the external costs associated with emissions of air pollutants from ships in port, show that these costs are significantly lower for ships connected to shore-side electricity (Figure 10 and Table 7). Depending on the fuel (HFO or MGO) and the type of shipping service investigated, the external costs for onboard generation of electricity were found to be between 15 to 75 times higher than those for shore-side electricity connection.

The direct cost for shore-side electricity is however 2-4 times higher than the direct costs of generating electricity onboard by auxiliary engines running on heavy fuel oil (Figure 8 - Figure 9, and Table 7). A part of this higher cost consists of energy taxes paid for the land-based electricity (see the example in Figure 12). Energy taxes for electricity vary between the European countries, as illustrated in Figure 6.

A comparison between the direct costs of electricity generation with the estimated external costs shows that the external emission costs for onboard power generation are much higher than the total direct costs for electricity from a shore-side power connection (Figure 11). This illustrates that the benefits associated with shore-side electricity connection clearly outweigh the costs for those systems (Figure 13).

It should be noted that these conclusions are based on the use of some general figures and assumptions, and applicable to the six shipping services investigated. It should also be noted that the figures used for estimating the costs for shore-side connection tend to be at the upper end of expected costs. The estimated external benefits, on the other hand, are likely to be underestimates. This results from the fact that they include valuation only for a limited number of the relevant air pollutants, and because a number of types of damage, including e.g. effects on ecosystems and cultural heritage, are not accounted for in the economic valuation by *Holland* and *Watkiss (2002)*.

The practicalities of handling the shore-side power systems are simple for the modern high-voltage systems. The total procedure to switch from onboard generated power to shore-side electricity is done in less than 10 minutes, including the phase in of new electricity and closing down of the onboard auxiliaries.

If a wide scale implementation of shore-side power connections were to be envisaged and planned, it would be useful to develop a common international practice - or international standards - for shore-to-ship electricity supply systems.

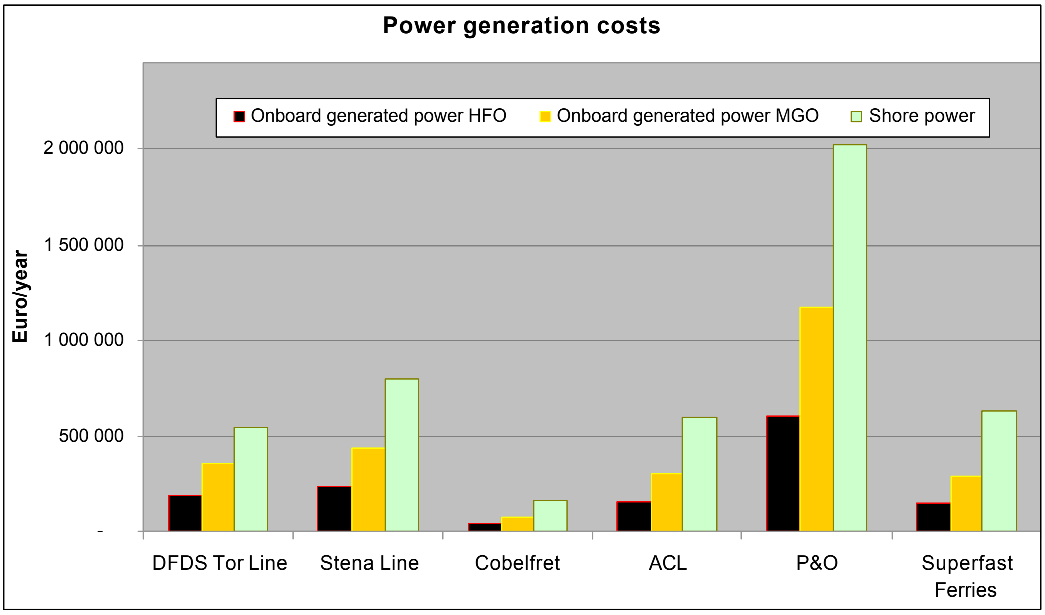

Figure 8 Power generation costs if onboard electricity is generated with onboard auxiliary engines run by Heavy Fuel Oil or Marine Gas Oil or if the vessel is connected to shore-side electricity facilities.

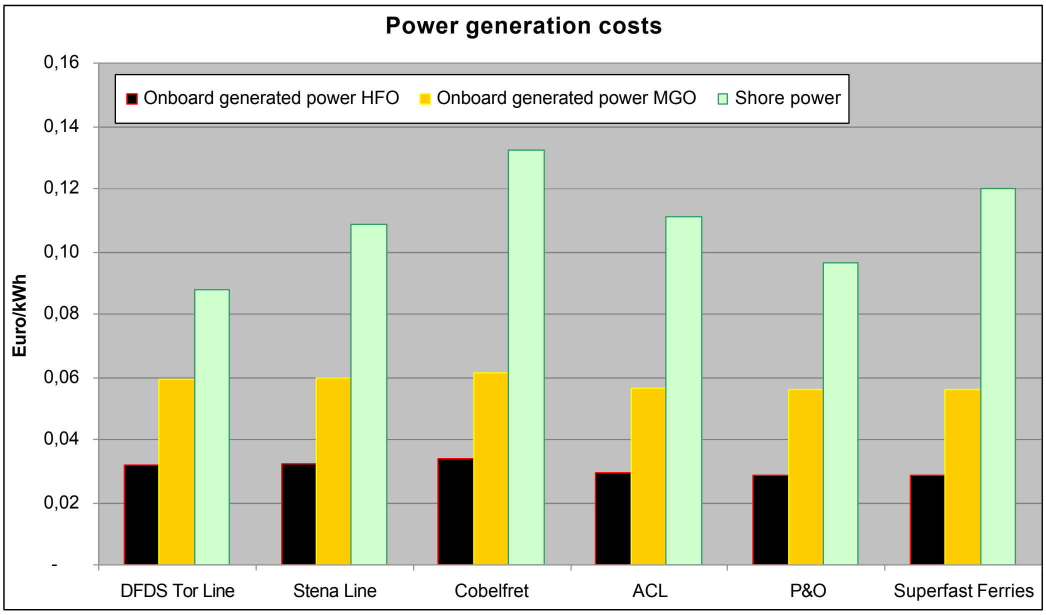

Figure 9 Calculated power generation costs per kWh

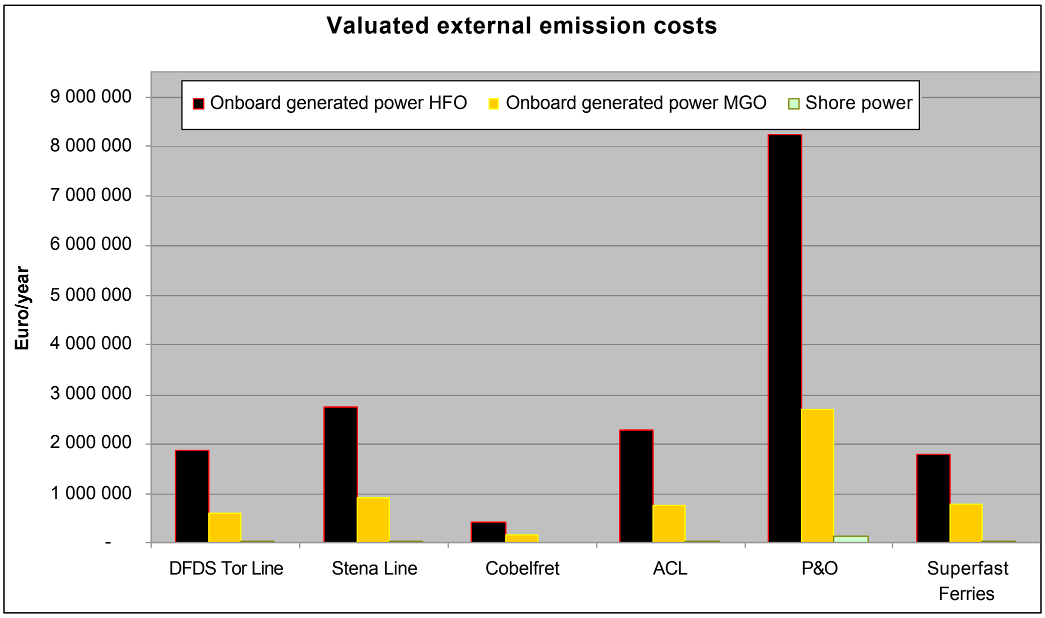

Figure 10 External costs for emissions depending on generation source. The emission valuation is taken from Holland and Watkiss.

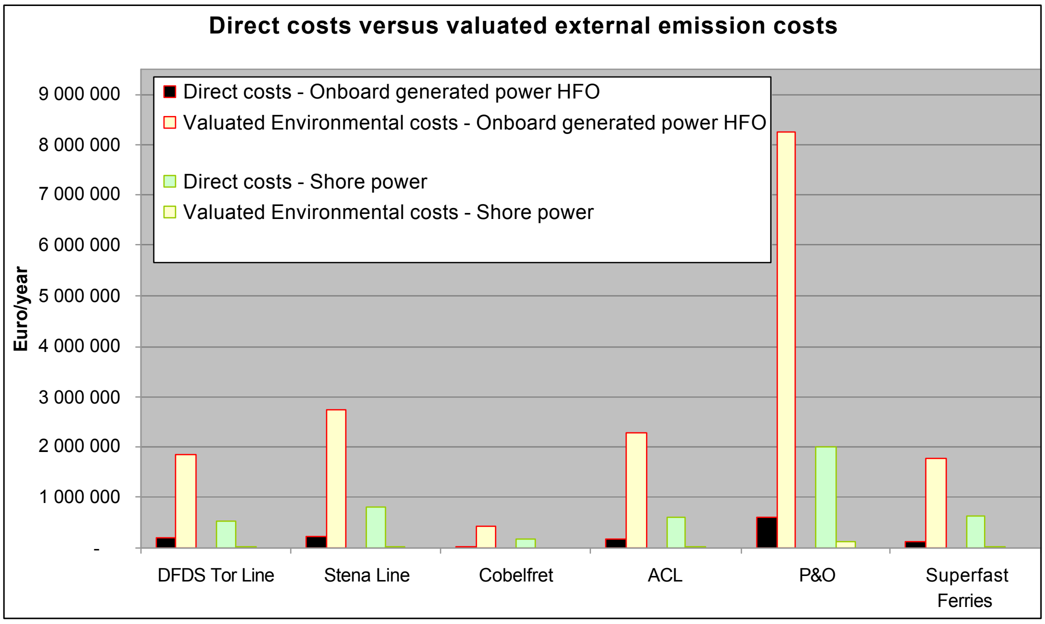

Figure 11 Power generation costs vs. corresponding external cost for the emissions calculated on the basis of Holland and Watkiss.

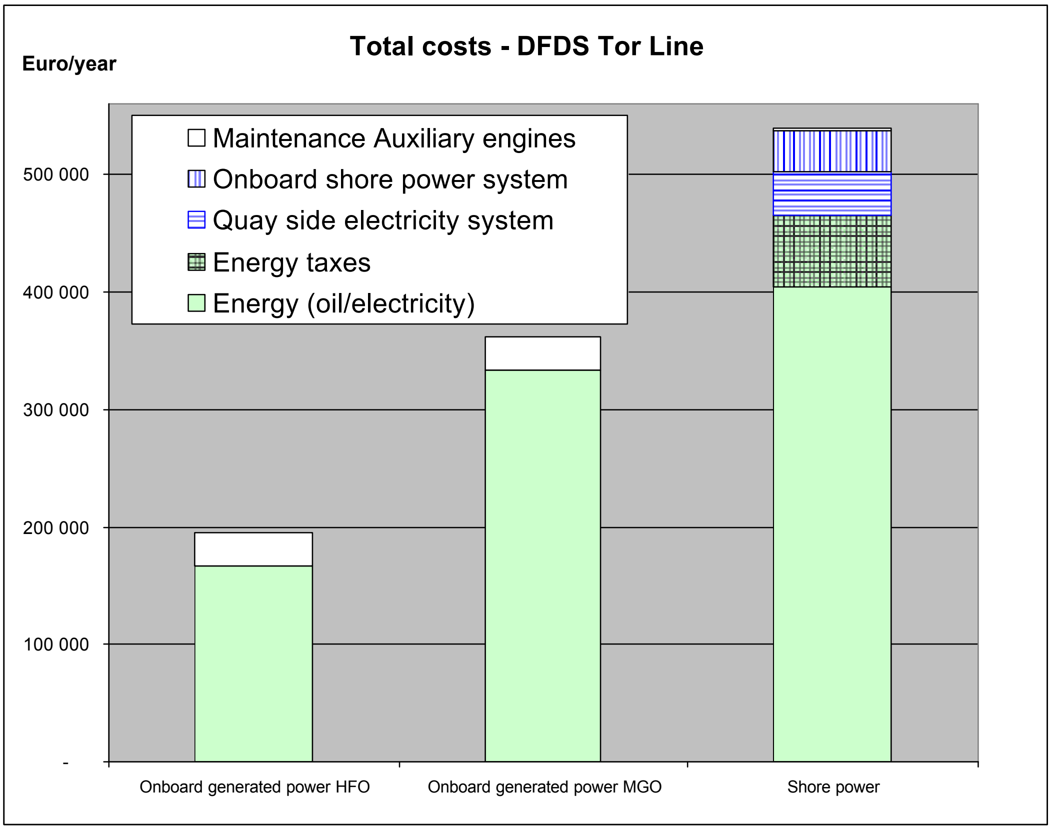

Figure 12 Total energy generating cost with energy taxes shown for the DFDS Tor Line, Gothenburg – Immingham service.

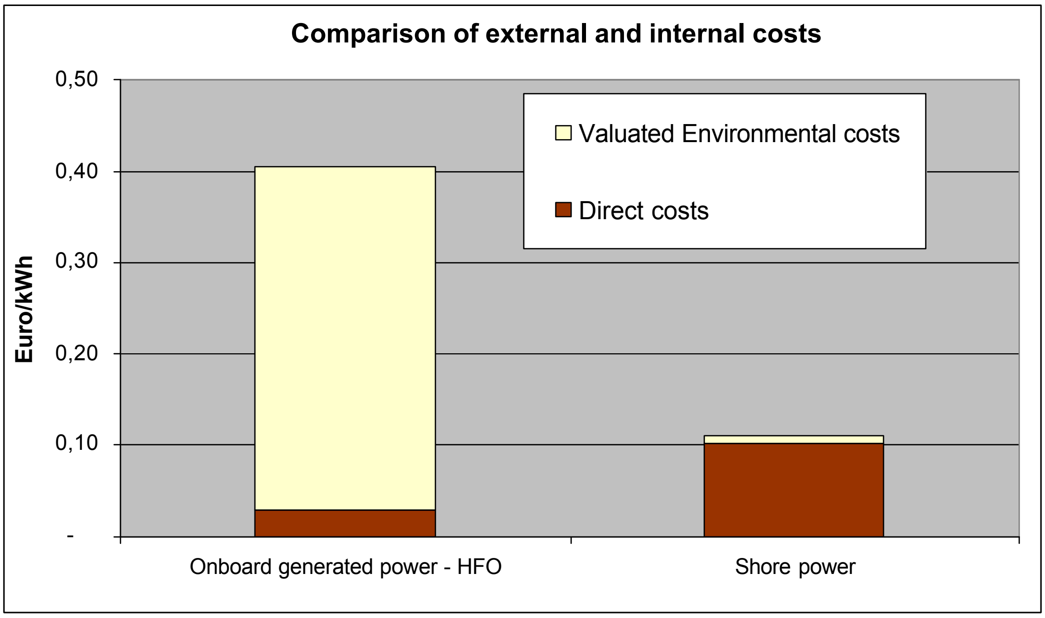

Figure 13 Comparison of external and internal costs for onboard and shore-side generation of electricity in average for the six different services investigated.

Table 7 Compilation of calculated results from Case studies

Operator:	**DFDS Tor Line**	**Stena Line**	**Cobelfret**	**ACL**	**P&O**	**Superfast Ferries**	
Service between:	*GOTHENBURG IMMINGHAM*	*GOTHENBURG KIEL*	*GOTHENBURG ZEEBRUGGE*	*GOTHENBURG LIVERPOOL ANTWERP BREMERHAVEN*	*ROTTERDAM HULL*	*ROSYTH ZEEBRUGGE*	
Vessels:	*TOR BRITANNIA TOR SELANDIA TOR SUECIA*	*STENA GERMANICA STENA SCANDINAVICA*	*SLINGEBORG SCHIEBORG SPAARNEBORG*	*ATLANTIC CARTIER ATLANTIC COMPANION ATLANTIC COMPASS ATLANTIC CONCERT ATLANTIC CONVEYOR*	*PRIDE OF ROTTERDAM PRIDE OF HULL NORSEA NORSUN*	*Superfast X Supefast IX* - -	
Energy consumed at quay	6 122 484	7 329 024	1 230 883	5 387 200	20 926 180	5 219 500	kWh
Direct costs							
Shore power	539 138	795 999	163 032	598 036	2 022 904	625 695	Euro
	0,088	0,109	0,132	0,111	0,097	0,120	Euro/kWh
Onboard generated power HFO	195 058	236 728	42 021	159 139	605 156	149 774	Euro
	0,032	0,032	0,034	0,030	0,029	0,029	Euro/kWh
Onboard generated power MGO	361 687	436 195	75 521	305 757	1 174 683	291 827	Euro
	0,059	0,060	0,061	0,057	0,056	0,056	Euro/kWh
Valuated Environmental costs							
Shore power	25 597	41 612	9 249	31 350	149 404	46 129	Euro
	0,004	0,006	0,008	0,006	0,007	0,009	Euro/kWh
Onboard generated power HFO	1 858 485	2 739 202	423 341	2 280 176	8 254 631	1 795 791	Euro
	0,304	0,374	0,344	0,423	0,394	0,344	Euro/kWh
Onboard generated power MGO	600 833	914 817	179 889	740 643	2 678 883	763 615	Euro
	0,098	0,125	0,146	0,137	0,128	0,146	Euro/kWh

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GLOSSARY /ABBREVIATIONS

CO_2: Carbon Dioxide

Dwt: deadweight, a vessels total capacity of carrying cargo, bunker provisions etc

GJ: GigaJoule (1 GJ = 1 000 000 000 Joule)

GT: Gross Tonnage, vessel size measure based on the vessels total volume

HFO: heavy fuel oil

Hz: hertz

kV: kilovolt (1 kilovolt = 1 000 volts)

kWh: kilowatthour

MGO: marine gas oil

NO_X: Oxides of Nitrogen

NM: nautical mile (1 NM = 1.852 kilometres)

MW: megawatt

PAH: Polycyclic Organic Hydrocarbons

PM: Particulate Matter

SO_2: Sulphur dioxide

V: volt

VOC: Volatile Organic Compounds

W: watt

APPENDIX 1 EXAMPLE OF CALCULATIONS

Example of calculations of *direct power generation costs* and *external cost* for emissions for the vessels energy demand at berth. The shown example is the *DFDS Tor Line* Service between Gothenburg and Immingham.

ELECTRICITY FROM SHORE POWER CONNECTION, PORT A - GOTHENBURG		
Investmant costs per vessel	90 000	Euro
Depreciation time	10	year
Interest rate	5%	
Future value	0	Euro
Number of vessels	3	
Maintenance cost onboard	800	Euro/year
Price of electricity - GOTHENBURG	0,07	Euro/kWh
Time connected per week and vessel	32	h/vecka
Needed power in avarage	684	kW
Energy demand per vessel and week	21 888	kWh/Week
Energy per year all vessels - GOTHENBURG	**3 414 528**	kWh/year
Energy cost for electricity (all vessels) - GOTHENBURG	248 578	Euro/year
Capital cost (Shore Power electricity system onboard - 50%)	17 483	Euro/year
Maintenance cost onboard (50 % of total)	1 200	Euro/year
Total annual cost shore power, PORT A - GOTHENBURG	**267 261**	**Euro/year**

12% *(used power in average)*

Emission costs BeTa Version E1.02a

	NOX	SOX	CO2	CO	VOC	PM	PAH		
Port A: Gothenburg	*2,6*	*30*	*0*	*0*	*0,68*	*165*	*0*	*Euro/kg*	
Sweden (Electricity production)	*2,6*	*1,7*	*0*	*0*	*0,68*	*1,7*	*0*	*Euro/kg*	
Emissions - Shore power	2 151	1 721	3 346 237	512	2 049	215	-	kg	
Emission costs - Shore Power	5 593	2 926	-	-	1 393	366	-	**10 277**	**Euro**

Electricity	Onboard investment	Maintenance
248 578	17 483	1 200

ELECTRICITY GENERATED ONBOARD, PORT A - GOTHENBURG		
HFO price	0,11	Euro/kg
MGO price	0,23	Euro/kg
Specific oil consumption per produced electricity	0,240	kg oil/kWh
Energy consumption at quay - all vessels	3 414 528	kWh/year
Corresponding oil consumption	819 487	kg oil/year
HFO Costs	92 930	Euro/year
MGO Costs	185 860	Euro/year
Maintenance cost per Auxiliary Engine and hour (running on HFO)	1,6	Euro/h
Maintenance cost per Auxiliary Engine and hour (running on MGO)	1,6	Euro/h
Number of Auxiliary Engines	2	
Total running time (Auxiliary Engines at quay)	9 984	h/year
Maintenance cost (running on HFO)	16 243	Euro/year
Maintenance cost (running on MGO)	16 243	Euro/year
Total annual cost HFO, PORT A - GOTHENBURG	**109 173**	**Euro/year**
Total annual cost MGO, PORT A - GOTHENBURG	**202 103**	**Euro/year**

	NOX	SOX	CO2	CO	VOC	PM	PAH		
HFO- Emissions	53 192	36 148	2 626 887	3 161	681	2 291	38 805	kg	
MGO - Emissions	64 972	3 278	2 601 312	2 458	863	1 077	1 999	kg	
Emission costs - HFO	138 299	1 084 440	-	-	463	377 949	-	**1 601 152**	**Euro**
Emission costs - MGO	168 926	98 338	-	-	587	177 726	-	**445 578**	**Euro**

Bunker		Maintenance
92 930	-	16 243
185 860	-	16 243

Total cost per kWh shore power	***0,078***	***Euro/kWh***
Total cost per kWh HFO	***0,032***	***Euro/kWh***
Total cost per kWh MGO	***0,059***	***Euro/kWh***

PORT B - IMMINGHAM		
Price of electricity, PORT B - IMMINGHAM	0,09	Euro/kWh
Time connected per week and vessel, PORT B - IMMINGHAM	24	h/vecka
Energy per year all vessels, PORT B - IMMINGHAM	**2 707 956**	kWh/year
Energy cost for electricity (all vessels)	253 194	Euro/year
Capital cost (Shore Power electricity system onboard - 50%)	17 483	Euro/year
Maintenance cost (onboard shore power system, 50 % of total)	1 200	Euro/year
Corresponding oil consumption	**649 909**	kg olja/year
HFO Costs	73 700	Euro/year
MGO Costs	147 399	Euro/year
Total running time (Auxiliary Engines at quay)	7 490	h/year
Maintenance cost (running on HFO)	12 185	Euro/year
Maintenance cost (running on MGO)	12 185	Euro/year

Emission costs BeTa Version E1.02a

	NOX	SOX	CO2	CO	VOC	PM	PAH		
Port B: Immingham	3	5	-	-	2	10	-	*Euro/kg*	
UK (Electricity production)	3	5	-	-	2	10	-	*Euro/kg*	
Emissions - Shore power	1 706	1 365	2 653 797	406	1 625	171	-	kg	
Emission costs - Shore Power	4 436	6 142	-	-	3 087	1 655	-	**15 319**	**Euro**

	NOX	SOX	CO2	CO	VOC	PM	PAH		
HFO- Emissions	42 185	28 668	2 083 303	2 507	540	1 817	30 775	kg	
MGO - Emissions	51 527	2 600	2 063 020	1 950	684	854	1 585	kg	
Emission costs - HFO	109 680	129 005	-	-	1 027	17 621	-	**257 333**	**Euro**
Emission costs - MGO	133 970	11 698	-	-	1 300	8 286	-	**155 255**	**Euro**

			Electricity/oil	Onboard investment	Maintenance
Total annual cost shore power, PORT B - IMMINGHAM	**271 877**	**Euro/year**	253 194	17 483	1 200
Total annual cost HFO, PORT B - IMMINGHAM	**85 885**	**Euro/year**	73 700	-	12 185
Total annual cost MGO, PORT B - IMMINGHAM	**159 585**	**Euro/year**	147 399	-	12 185

Total Quay energy/electricity all ports and vessels	6 122 484	kWh

	Direct costs				Valuated Environmental costs			
Shore power	539 138	Euro	0,088	Euro/kWh	25 597	Euro	0,004	Euro/kWh
Onboard generated power HFO	195 058	Euro	0,032	Euro/kWh	1 858 485	Euro	0,304	Euro/kWh
Onboard generated power MGO,	361 687	Euro	0,059	Euro/kWh	600 833	Euro	0,098	Euro/kWh

	Electricity/oil		Onboard investment		Maintenance		
Shore power	501 772	93%	34 966	6%	2 400	0%	Euro
Onboard generated power HFO	166 630	85%	-	0%	28 428	15%	Euro
Onboard generated power MGO,	333 259	92%	-	0%	28 428	8%	Euro

Shore power	0,082	0,006	0,000	Euro/kWh
Onboard generated power HFO	0,027	-	0,005	Euro/kWh
Onboard generated power MGO,	0,054	-	0,005	Euro/kWh

APPENDIX 2 SHIPPING LINE AND VESSEL DATA

DFDS Tor Line, Gothenburg – Immingham

Tor Selandia, Tor Suecia and Tor Brittania

Ro-Ro vessel

Built: 1999-2000

Length overall: 197 metres

Beam: 26 metres

DW: 11.089 tons

Gross tonnage: 24.196 tons

Main engine: 2 Wärtsilä New Sulzer Diesel engines 9ZA 50 S, 10.800 kW each

Engine output: 21.600 kW

Speed: 21.5 knots

Cargo capacity: 175 trailers or 2 772 lane metres

Stena Line Gothenburg - Kiel

Figure 14 Shore to ship connections in the Gothenburg terminal

Stena Scandinavica

Ro/Ro ferry

Gross tonnage: 39 169 t

LOA: 175 m

Beam: 30 m

Draught: 6.7 m

Speed: 22 knots

Passenger capacity: 1 700

Car capacity: 590 / Freight capacity: 1 628 lane metres

Built/last rebuilt: 1988/1996/1999

Engines: 4 x Sulzer

kW: 30 617 kW

Stena Germanica

Ro/Ro ferry

Gross tonnage: 38 772 t

LOA: 175 m

Beam: 20 m

Speed: 20 knots

Passenger capacity: 1 700

Car capacity: 590 / Freight capacity: 1 628 lane metres

Built/last rebuilt: 1987/1996

Engines: 4 x Sulzer (30 617 kW)

Cobelfret

Spaarneborg, Schieborg, Slingeborg,

Ro-Ro vessel

12 457 dwt

Engine: 7-cyl, Sulzer 7 RTA 52 U diesel (10 920 kW).

Built: 1999-2000

Design speed 19 knots

Ro/Ro deck 2 475 lane meter 190 trailers

ACL Transatlantic service

Atlantic Cartier, Companion, Compass, Concert and Atlantic Conveyor

Built: 1984-855, in France, Sweden and UK

Speed 18 knots

Trans-Atlantic Crossing 6.5-8 days

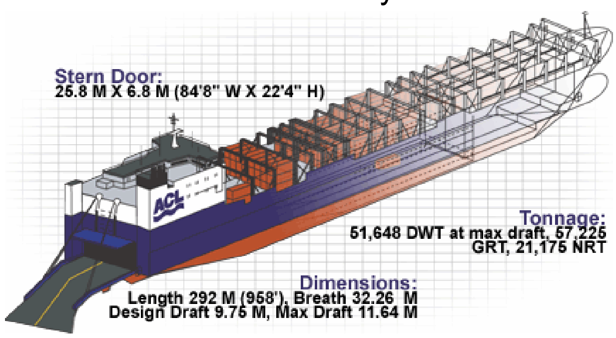
Maximum Capacity 3 100 TEUs

Stern Ramp Capacity 420 metric tons

Automobile Capacity about 1 000 units

Container Capacity about 1 850 TEUs

RORO Capacity about 1 000 TEUs



P&O Ferries, Rotterdam – Hull

Pride of Rotterdam,

Gross tonnage 59,925

Displacement tonnage 25,113

Deadweight tonnage 8,850

Length 215.45m

Breadth 31.88m

Passenger capacity 1,360

Vehicles 250 cars/285 12m units/125 double stacked containers

Built 2001

Engines 4 Wartsila Diesels

Speed 22.0 knots

Pride of Hull

Gross tonnage 60.600

Displacement tonnage

Deadweight tonnage 8,850

Length 215.00m

Breadth 31.50m

Passenger capacity 1360

Vehicles 250 cars + 400 freight units

Built 2001

Entered service with P&O Ferries 2001

Engines 4 Wartsila Diesels

Speed (knots) 22.0

Norsun

Gross tonnage 31,598

Displacement tonnage 19,332

Deadweight tonnage 6,748

Length 179.35m

Breadth 25.35m

Draught 6.18m

Passenger capacity 1,250

Vehicles 850 cars/180 trailers

Built 1987

Engines 4 Wartsila Sulzer Diesels

Speed (knots) 18.5

Norsea

Gross tonnage 31,785

Displacement tonnage 19,274

Deadweight tonnage 6,419

Length 179.20m

Breadth 25.40m

Passenger capacity 1,250

Vehicles 850 cars/180 trailers

Built 1987

Engines 4 Wartsila Sulzer Diesels

Speed (knots) 18.5

Superfast Ferries, Rosyth – Zeebrugge

Superfast IX - Superfast X

Length Overall 203.3 m

Breadth moulded 25 m

DWT: 5,525 T

Speed Service/Maximum 27.1/30.4 knots

Gross tonnage 30,285 GRT

Passengers 717 pers

661 cars (only) or 82 cars & 98 18m trailers or 82 cars & 110 16m trailers

Propulsion 4 x Wartsila NSD ZA V40S 4 x 11,520 BHP

Electric Generation 3 x MAN 8L 28/32 3 x 2,000 KW

2 x Shaft Generators 2 x 2,100 kVA