Alternative Maritime Power in the port of Rotterdam

A feasibility study into the use of shore-side electricity for containerships moored at the Euromax terminal in Rotterdam

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Executive summary

Although air quality in the Rotterdam-Rijnmond region has improved considerably over the past years, legal limits for contaminants like NOx and PM10 are exceeded regularly today. Combined with increasingly stringent legislation and the intention to expand our port this requires all parties involved to investigate pro-actively how emissions can be reduced.

Ships that visit the port of Rotterdam emit pollutants via their exhaust gasses. While most vessels turn off their main engines once they're safely alongside, generators are kept running to provide electrical power on board.

The construction of the new Euromax container terminal on the existing Maasvlakte I area created an opportunity for the Port of Rotterdam Authority to investigate the feasibility of incorporating a shore-side electricity infrastructure into the terminal design. Visiting vessels would be able to connect to it and switch their generators off, resulting in less air pollution. To present more accurate results and to allow for extrapolation of the report data and findings for strategic policy decisions on new Maasvlakte II terminal designs, the effects on the air quality have also been calculated for 2010, when new legislation on ships' fuel quality enters into force.

The use of shore-side electricity for seagoing vessels is a relatively new development, and many technical, organizational and legal aspects had to be taken into account. The lack of standardization forced us to research best practices and define standards for the electrical system infrastructure. One of the technical challenges found during our research is the frequency difference between the European power grid and the electrical system on seagoing vessels. Where adopting voltages to a certain level is relatively easy to accomplish, changing frequencies is a technically more complicated task and due to space restrictions on board it has to be done on the terminal.

To determine exactly how much reduction is achieved at several investment levels four scenarios were investigated, where respectively 0%, 20% and 100% of all ships calling at the Euromax terminal would to be connected to a shore-side electricity supply, both under current and future fuel quality legislation.

Although the levels of air pollution reduction found close to the terminal are significant, the effects on the air quality on nearby urban areas will be minimal, at high design and annual costs. Furthermore, it is uncertain how shore-side electricity standards may develop, and investing now could mean investing in a system that might be outdated by the time the terminal will be operational.

Therefore, we recommend not to incorporate shore-side electricity into the design of the Euromax terminal. However, other vessels like inland barges and dedicated roro/passenger vessels seem likely candidates for shore-side electricity, although more research has to be done for these specific ship types. Alternative locations will have to be investigated. It is imaginable that providing shore power at terminals closer to urban areas will have a significantly larger positive impact on the air quality in the Rotterdam communities than terminals like the Euromax, located far to the west, away from the city of Rotterdam.

By the time the Maasvlakte II terminals will be constructed shore side electricity standards will have been set. Monitoring developments closely in the next couple of years is deemed necessary to reconsider deploying shore side electricity for Maasvlakte II container terminals.

Acknowledgements

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Index

1 Introduction

Despite considerable improvements in recent years, the air quality in the Rotterdam-Rijnmond region is still giving cause for concern. Limit values are being exceeded (particularly those for NO_x and PM_{10}). Besides adversely effecting public health this produces an economic risk when spatial and economic developments might be put on hold.

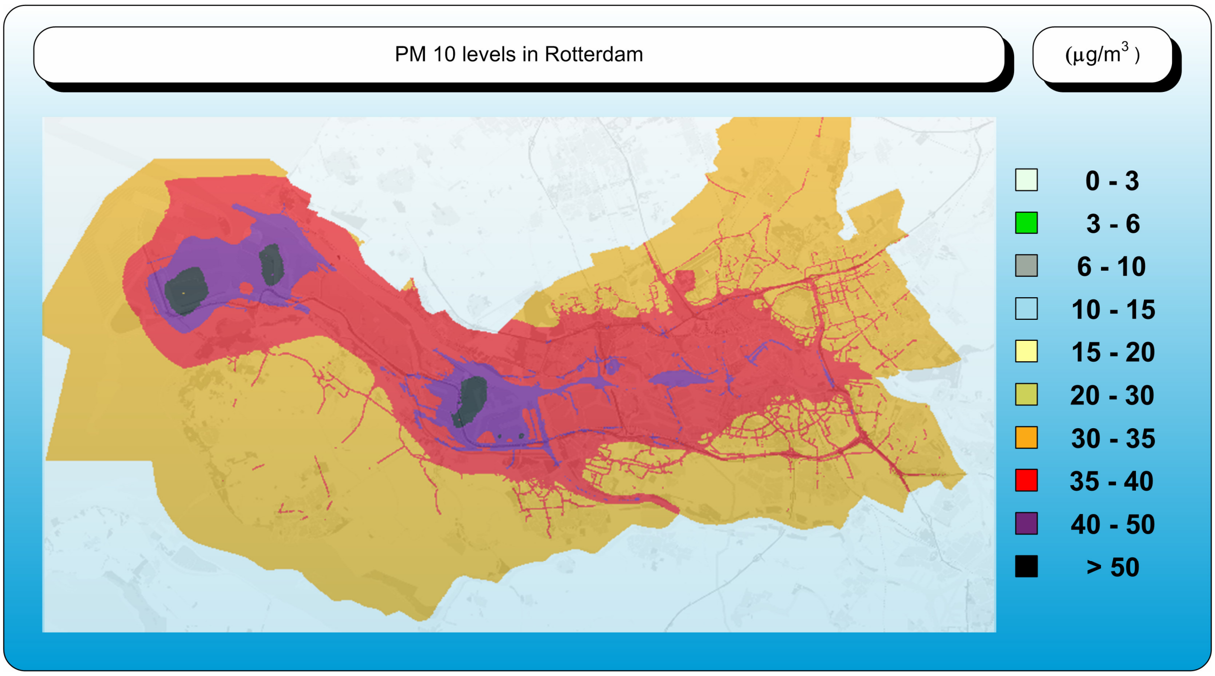


Figure 1 - PM10 levels in Rotterdam. Source: DCMR Environmental Protection Agency, *Feitenstudie luchtkwaliteit in Rijnmond (1990-2004)*

In 2005 the ROM-Rijnmond platform drew up a package of regional measures to improve air quality in the greater Rotterdam region[1]. One of the measures that are mentioned under ‘measures which could be further elaborated in 2006’ is the use of shore-side electricity for ships. This, combined with the planned expansion of the port (the Maasvlakte II area, scheduled to be operational in 2013) called for an investigation into the use of shore-side electricity for seagoing vessels.

For some specific applications shore-side electricity is already available in the port of Rotterdam. Many of the lay berths for inland barges are equipped with electrical power outlets. These are relatively simple to install and maintain as industry standards have developed on voltages, frequency, power requirements and outlet design. Shore-side electricity is also available at our cruise terminal, but the power requirements of modern cruise ships are much bigger than anticipated at the construction phase, and the system has never been used.

[1] Rijnmond Regional Air Quality Action Programme, ROM-Rijnmond, 2005

The development of the Euromax terminal close to where the port expansion Maasvlakte II will take place offered an unparalleled opportunity to conduct a feasibility study for a full-size container terminal, with vessels requiring large amounts of power, where calculated effects will be very similar to these of new Maasvlakte II container terminals. The first results of the study were available in time to actually incorporate the ducts and outlets into the quay wall design when investing in shore-side electricity was deemed sensible.

As can be seen from the graph below, the contribution from shipping to PM10 and NOx levels is considerable, on average 8% of the ambient PM_{10} and 19% of the NO_2 concentrations[2] originate from shipping. However, vessels emit most when they're sailing, and those emissions will not diminish when ships at berth are connected to shore power.

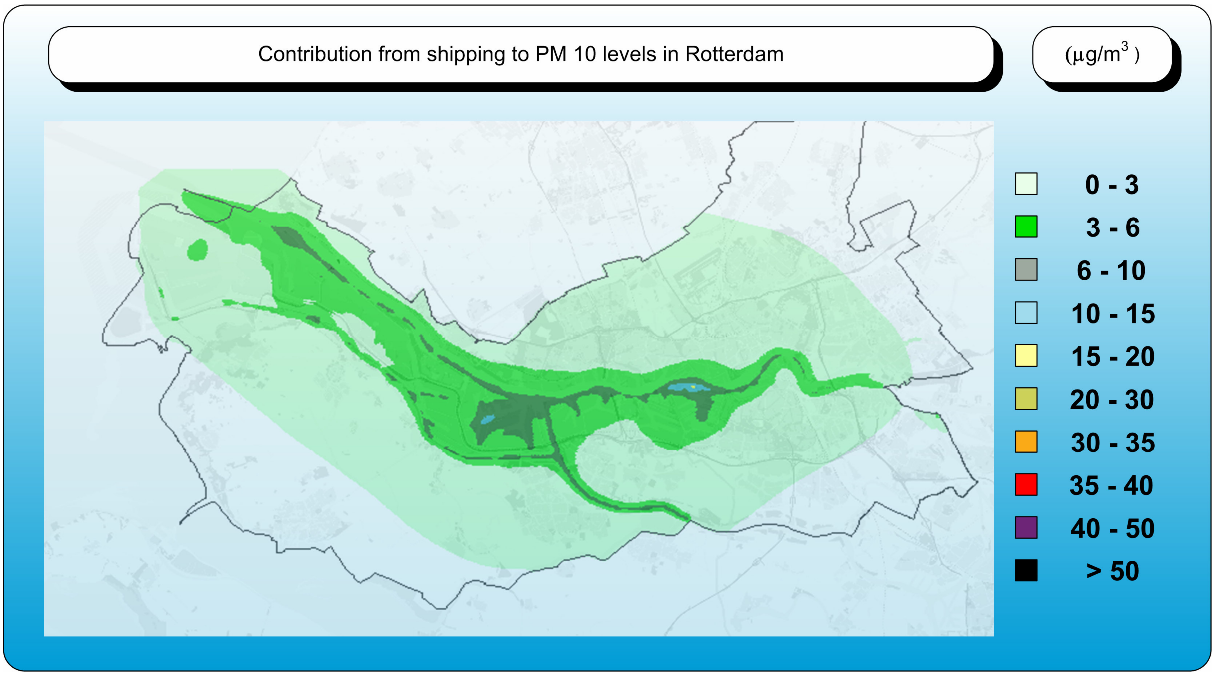


Figure 2 - PM10 contribution from shipping. Source: DCMR Environmental Protection Agency, *Feitenstudie luchtkwaliteit in Rijnmond (1990-2004)*

[2] See also Appendix I for more graphs on the relative contribution from shipping to the ambient levels of PM_{10} and NO_2

1.1 Study outline

The main research question "Is *it feasible to provide ships calling at the Euromax terminal with shore-side electricity?*" was broken down into three sub-questions:

- ***What is the best way to connect deep sea container ships and feeders to a shore-side power supply?***

Container vessels that called the port of Rotterdam voluntarily submitted information on their electrical systems, voltages, frequencies and fuel and power consumption. Discussions were held with Port of Los Angeles representatives on the design of their Alternative Maritime Power system, and with various private companies. Our findings led to the definition of parameters for a shore-side electrical system suitable for deployment in the port of Rotterdam.

- ***How much does it cost to design, build and maintain the ship- and quayside infrastructure?***

Based on information provided by Euromax on the terminal layout and the electrical system parameters defined, GTI Electrical Engineering was asked to design a shore-side system capable of providing power to several moored ships at once, both for deep sea container vessels and feeders.

- ***What are the effects on the air quality in the Rotterdam-Rijnmond area?***

A volume prognosis for the Euromax terminal combined with data from the Dutch Ministry of Transport model on air emissions from moored ships generated data on what emissions are to be expected from visiting vessels at Euromax. Insertion of this data by the Rotterdam DCMR Environmental Protection Agency into dispersion modelling software KEMA STACKS resulted in geographical presentation of the air pollutant levels found at various locations around the terminal. Four different scenario's were calculated, where respectively 100%, 20% and 0% of all visiting ships would use shore-side electricity, under current and anticipated future fuel quality legislation.

2 Introduction to shore-side electricity

2.1 Power production on board

Electricity is used on board of vessels to provide power for a wide range of applications, including lighting, air-conditioning, ventilation, safety equipment and cargo-related activities. On container vessels in particular, a large amount of energy is consumed by reefer containers, used to transport perishable goods at a set temperature. When ships are sailing at sea, electricity is usually produced by shaft generators that take their power from the main engine.

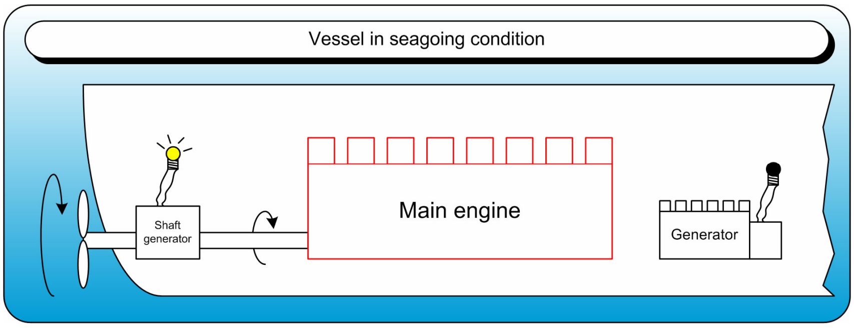


Figure 3 - Vessel in seagoing condition, main engine is running

Before entering a port, generators are started on board to provide electricity when the main engine runs at different speeds to manoeuvre the ship to its berth. These generators are kept running during the entire visit to the port, and are only switched off when the vessel is back at sea.

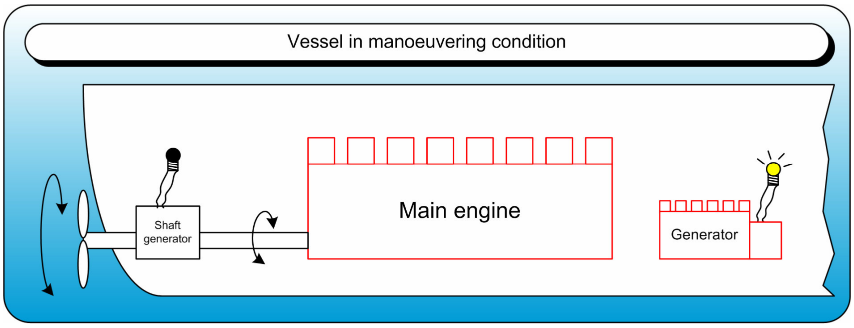


Figure 4 - Vessel in maneuvering condition, main engine and generators are running

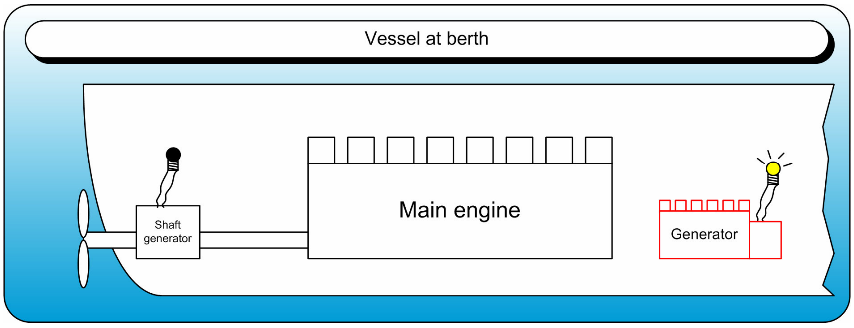


Figure 5 - Vessel at berth with no shore-side electricity, generators are running

The power generated and consumed on board of large container vessels is in the range up to 7 Megawatts, enough to provide power to several thousands of households[3]. Transferring this amount of power from a shore-side infrastructure to a vessel requires large cables, high voltages and extensive protection systems.

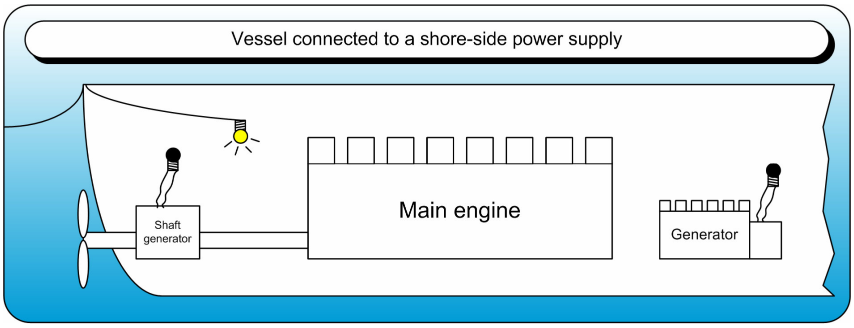


Figure 6 - Vessel connected to shore-side electricity

[3] A deep sea container vessel consumes as much as power 5000 as households at the average Dutch power consumption of 3500 kWh per household per annum.

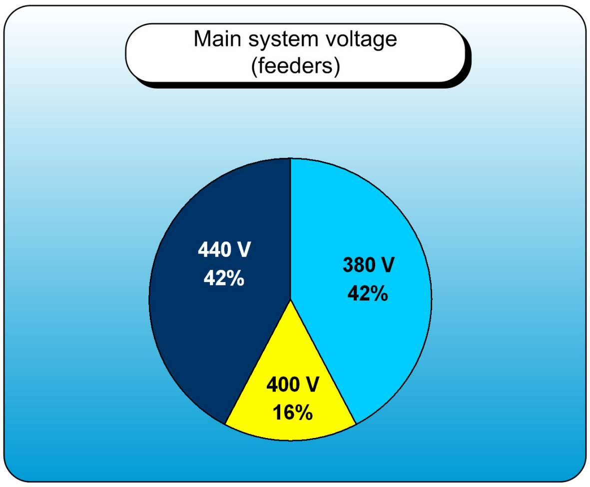
2.2 Power requirements in port

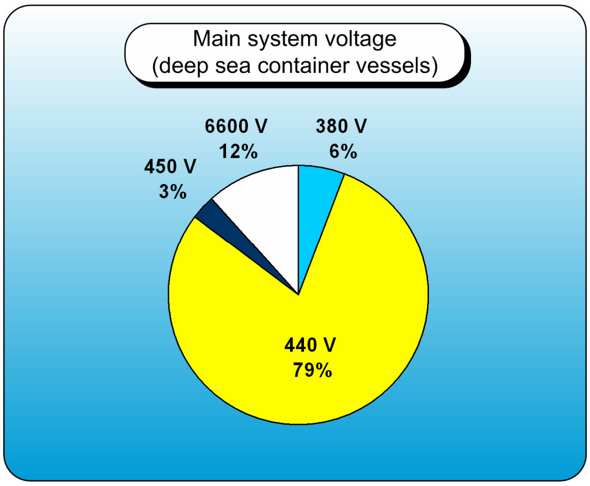
To investigate the power requirements from different container vessels the Port of Rotterdam asked 53 visiting container vessels about their electrical system characteristics, power requirements and fuel consumption in port, and whether any connections to provide shore-side electricity had already been installed[4]. A distinction was made between feeder vessels (typically smaller than 140 m in length) and deep sea container vessels.

Although all investigated ships are capable of receiving some power for maintenance purposes when the vessel is in dry-dock, only one vessel was found equipped with a connector capable of carrying the full load of a ship in normal operating conditions.

2.2.1 Voltage

The voltages used on board ranged from 380 to 6600 volts, where the majority of the larger vessels use 440 volts. 6600 volts was only found on vessels built after 2001. Various sources told us that many of the vessels currently under construction will be equipped with 6600 volts electrical systems.



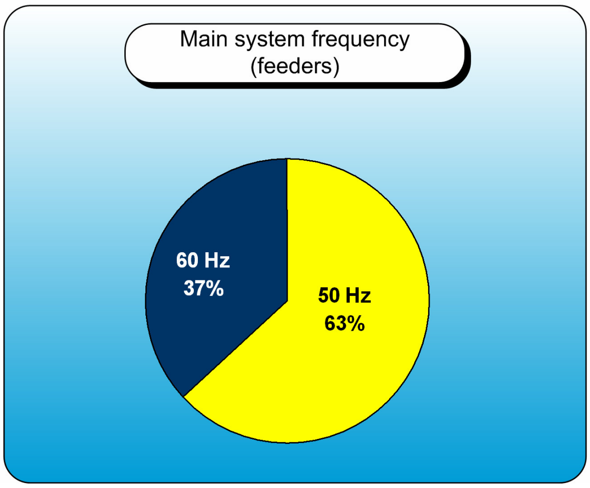


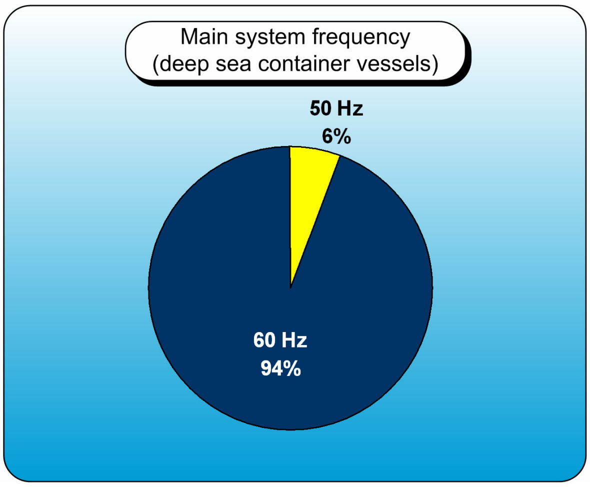
4 See Appendix II for the research data

2.2.2 Frequency

The frequencies found are either 50 or 60 Hertz, where the majority uses 60 Hz. Remarkably, all but two of the deep sea container vessels are equipped with 60Hz electrical systems.

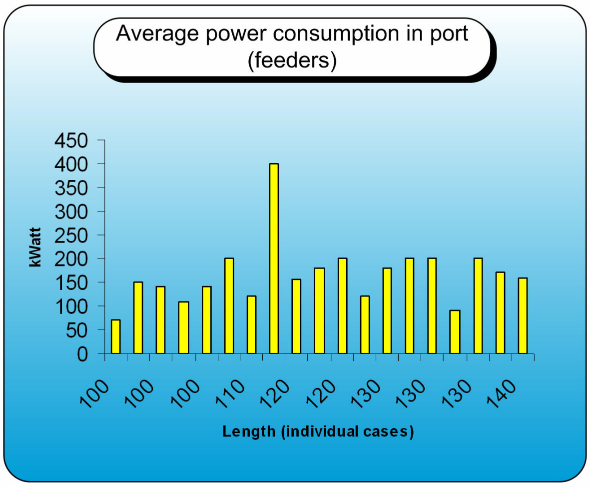
Changing a certain given voltage to the one used on board is a straightforward electrical operation involving a transformer, and is relatively easily accomplished on board although space is limited. Changing a certain given frequency (50 Hz in mainland Europe) to the 60 Hz used on board of the majority of the investigated container vessels is more difficult, requires more space and is costly.

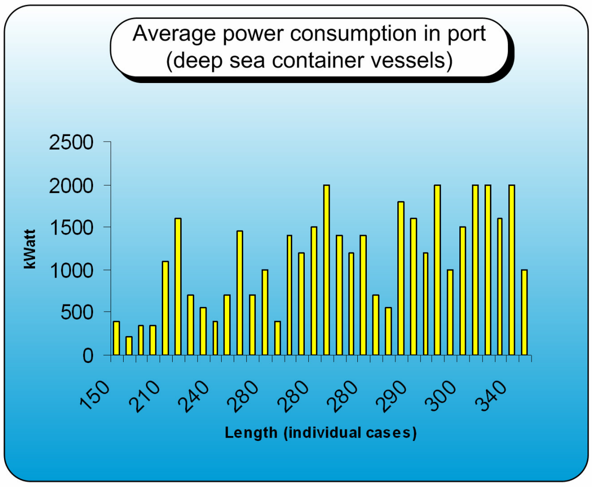


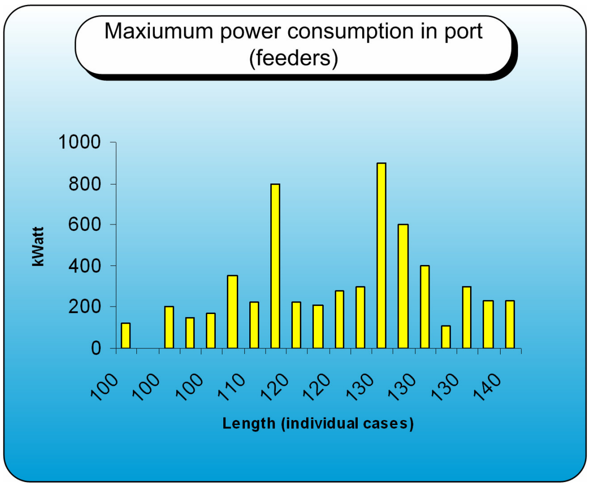


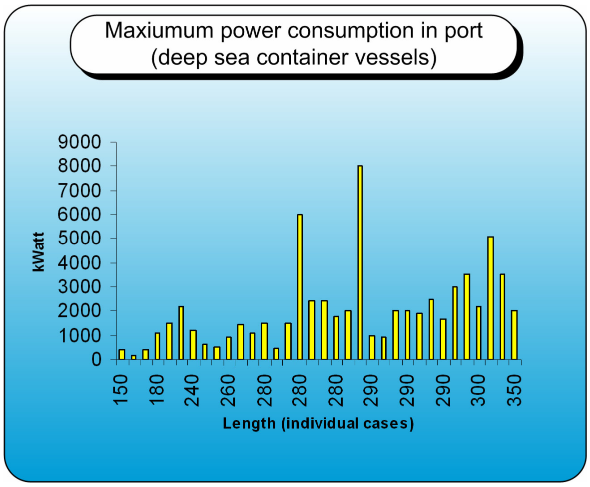
2.2.3 Power consumption

The amount of power generated and consumed in port varies greatly. Some vessels report an average power consumption several times greater than vessels with comparable characteristics.



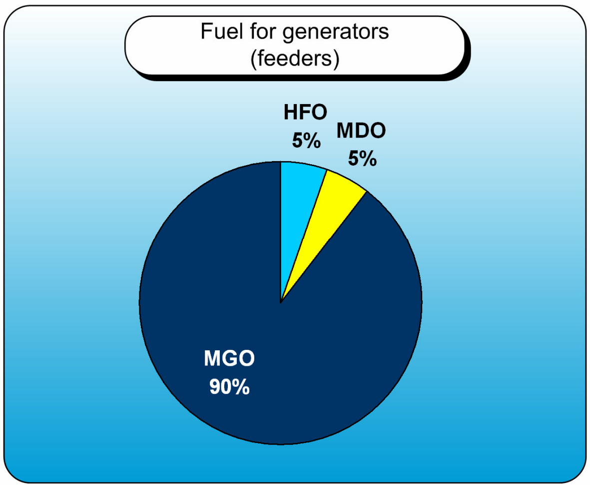


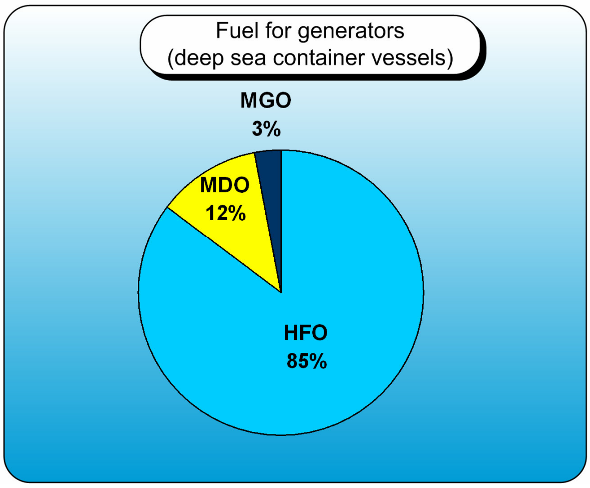




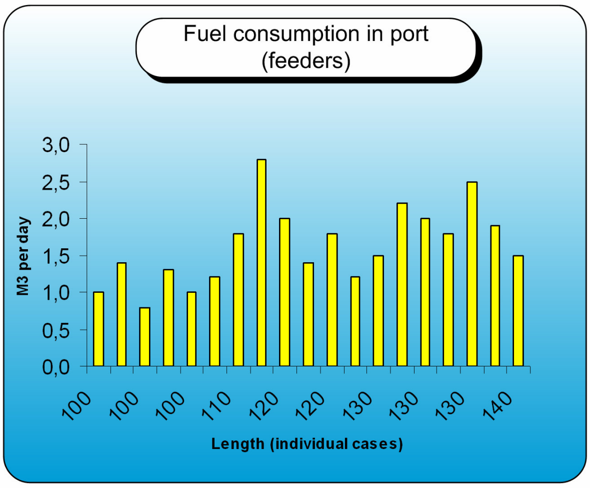
2.2.4 Fuel types and fuel consumption

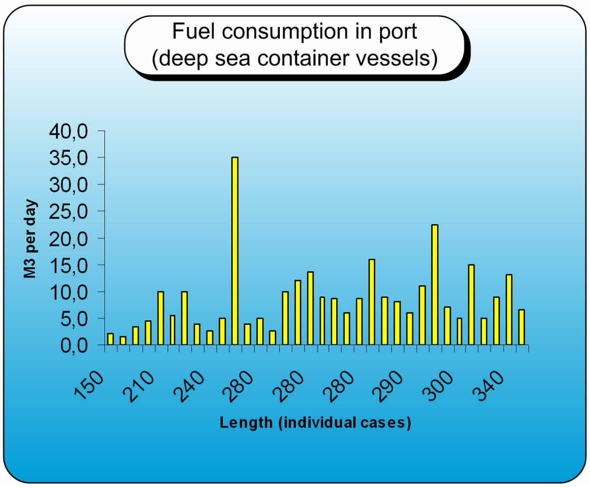
It clearly shows from the graphs below that the majority of the feeder vessels use Marine Gas Oil for their generators, whereas the deep sea container vessels tend to use Heavy Fuel Oil. The maximum sulphur content for MGO is currently 0.2%, that of HFO 1.5%. At the time of research a maximum sulphur level of 4.5% was still allowed for HFO.





The reported fuel consumption in port for the two vessel types varies quite considerably:





2.2.5 Conclusions

The most significant conclusions from the power requirements study are:

- There majority of the investigated vessels use 440 volts electrical systems.
- 60 Hertz is standard for the deep sea vessels, 50 Hz is still common on feeder vessels.
- The reported power consumption in port varied greatly and seemed only partly related to vessel characteristics like gross tonnage, main engine power or the amount of reefer connections.
- The amount of power required is in the range up to several Megawatts.
- Practically no vessels (only 1 in our research) are ready to receive shore-side electricity.

2.3 Connecting vessels to shore-side electricity

Some ports (in particular Los Angeles) require ships to use shore-side electricity. The engineering solutions chosen vary, but as the mainland power grid frequency is 60 Hertz in de United States they are generally less complicated than would be required in Europe.

2.3.1 Solution 1: Los Angeles barge with transformer

The 6600 volts taken from the shore-side are transformed to 440 volts on a barge moored at the stern of the container vessel. Transferring the same amount of power using a lower voltage means the cable size and/or the number of cables will increase. In this particular setup in Los Angeles, nine heavy cables have to be hoist into position (using a crane) and connected every time the container vessel docks.

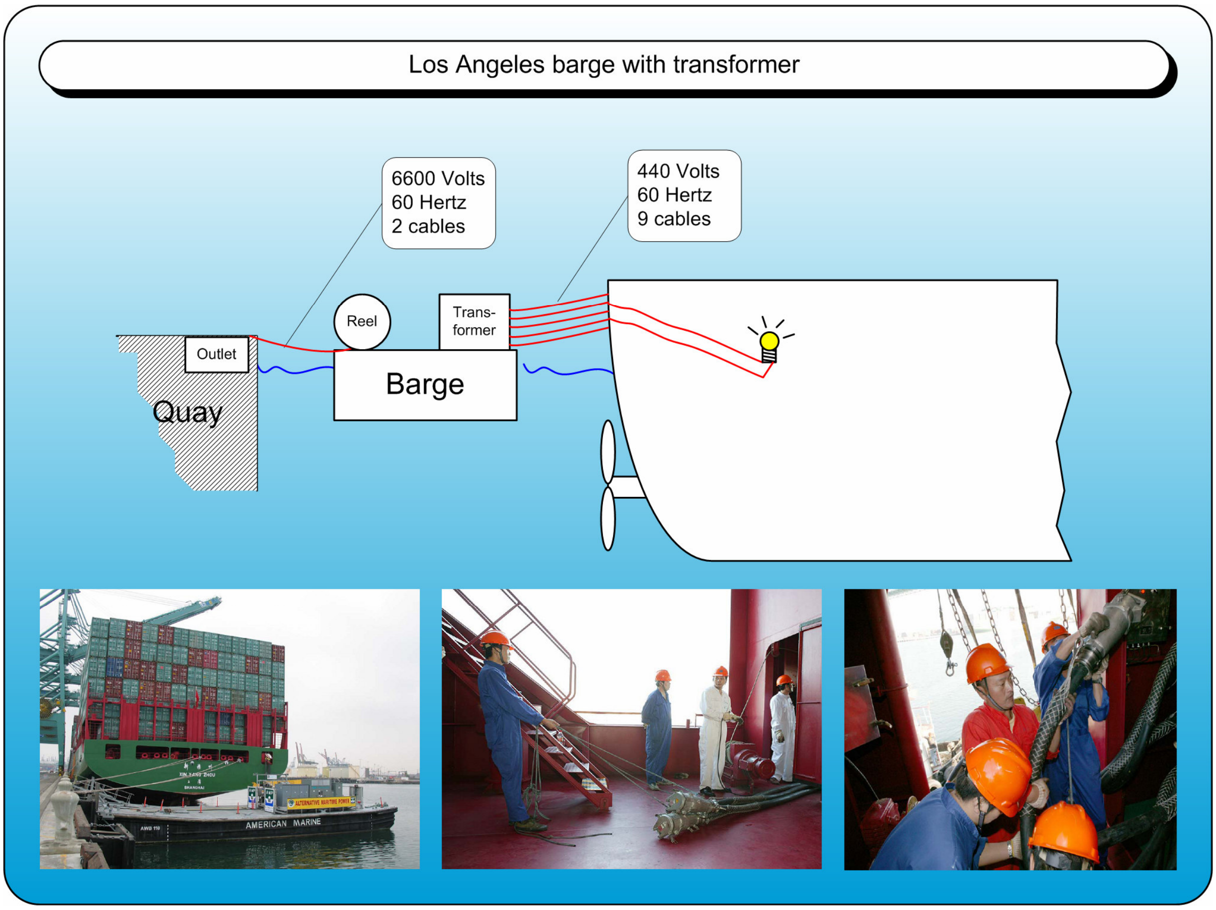


Figure 7 - Los Angeles barge with transformer. Pictures courtesy Port of Los Angeles

Advantages of this solution:

+ Few modifications on board are required (approximately $ 500.000 per vessel)

Disadvantages

- Costly design due to barge
- One barge is needed per vessel
- High operating costs, a crew is needed for the barge
- Cables have to be hoist into position using a crane
- Positioning the barge and (dis)connecting the cables takes a considerable amount of time
- Possible safety problems when high electrical voltages and currents are handled close to the water surface

2.3.2 Solution 2: Los Angeles 6600 Volts with cable reel

In this setup, the vessel uses a cable reel to lower one or two high-voltage cables onto the dock. The cables are connected to shore outlets. On board of the high voltage is transformed to the correct voltage required by the vessel's electrical system.

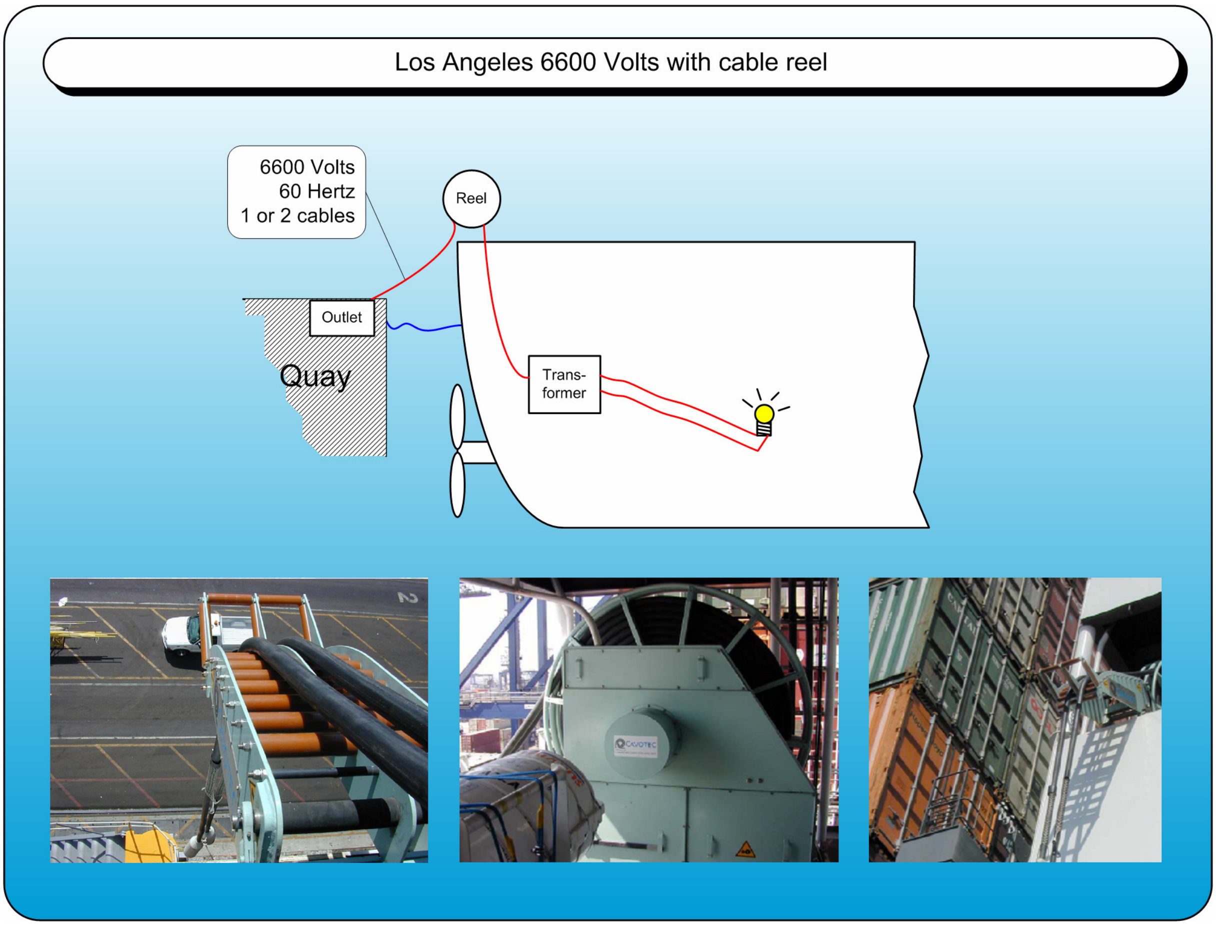


Figure 8 - Los Angeles cable reel. Pictures courtesy Port of Los Angeles. The cable reel is located on Port and Starboard side of vessel, drawn here on rear deck for comparison with previous barge design.

The advantages are:

+ Few cables to attach
+ Cables are lowered onto the dock; no crane is required
+ Lower installation and operating costs than with barge
+ Possibility to set a standard for the voltage level

The disadvantages are:

- More modifications on board are required (with space-consuming transformers), estimated cost per vessel $ 800.000.

2.3.3 Solution 3: Gothenburg Ferry

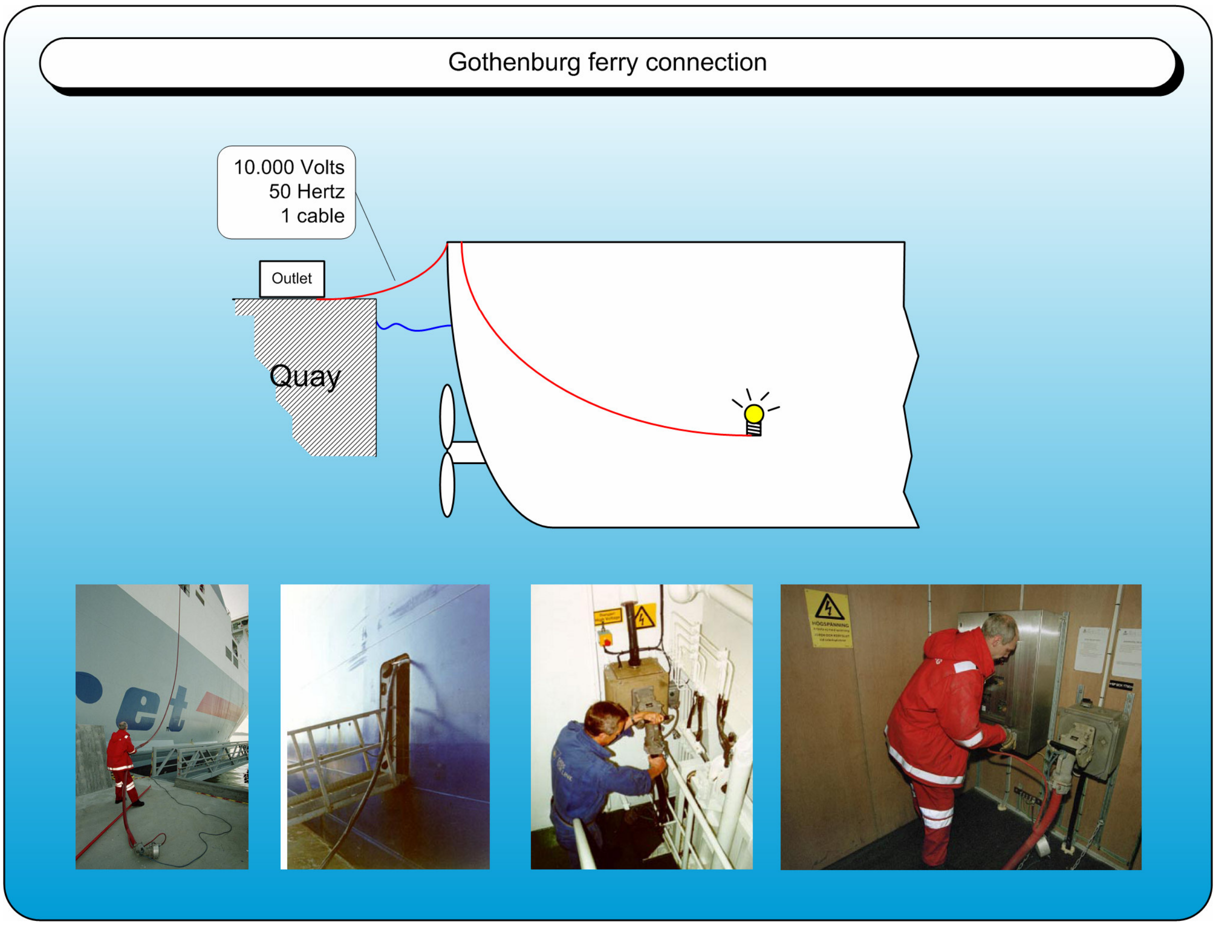


Figure 9 - Port of Gothenburg ferry connections, pictures courtesy Port of Gothenburg

The Port of Gothenburg requires some of its ferries to hook up. Because of the relatively low power requirements of ferries (typically 4-8 times smaller than a deep sea containership) and the use of high-voltage cables, the system is easy to handle. Due to the design’s limited power transfer capabilities it’s not suitable for large container vessels.

Advantages

+ Only one (lightweight) cable

Disadvantages

- Not suitable for large container vessels
- Only suitable for 50 Hz vessels

2.3.4 Solution 4: Rotterdam shore power connection

As standards on voltage, frequency, and connector type have not yet been agreed upon on an international level[5], it makes sense to stay close to systems that have recently been developed. Looking at the different solutions currently in use, the Los Angeles 6.6 kV system with a reel to lower cables onto the quay has many operating advantages over the other systems. Although the voltage will have to be transformed to the vessel's main system voltage, handling two 6.6 kV cables is much easier than for example nine 440 volts cables that have to be hoist into position.

The results from our electrical systems' study of visiting container vessels led to the following design characteristics for a 'Rotterdam' shore connection:

- Average power consumption of a deep sea container vessel: 2 MW
- Peek power consumption for a deep sea container vessel: 7 MW
- Average power consumption for a feeder: 200 KW
- Peek power consumption for a feeder: 1 MW
- Voltage and frequency for deep sea container vessels: 6.6 kV / 60 Hz
- Voltage and frequency for feeders: 6.3 kV 50 Hz and 6.6 kV 60 Hz

- Coupling: the plug in use in Los Angeles was chosen as it has become an (unofficial) standard. It was developed by a private company called Cavotec but work is underway to make its specifications publicly available, and the plug has not been patented.

- Cable: some parties argue that the terminal should provide the cable to the ship. This has operating disadvantages, as the cable will have to be hoist into position. We opted for the other solution, where the cable is lowered onto the dock, which requires less manpower, no crane, and is faster.

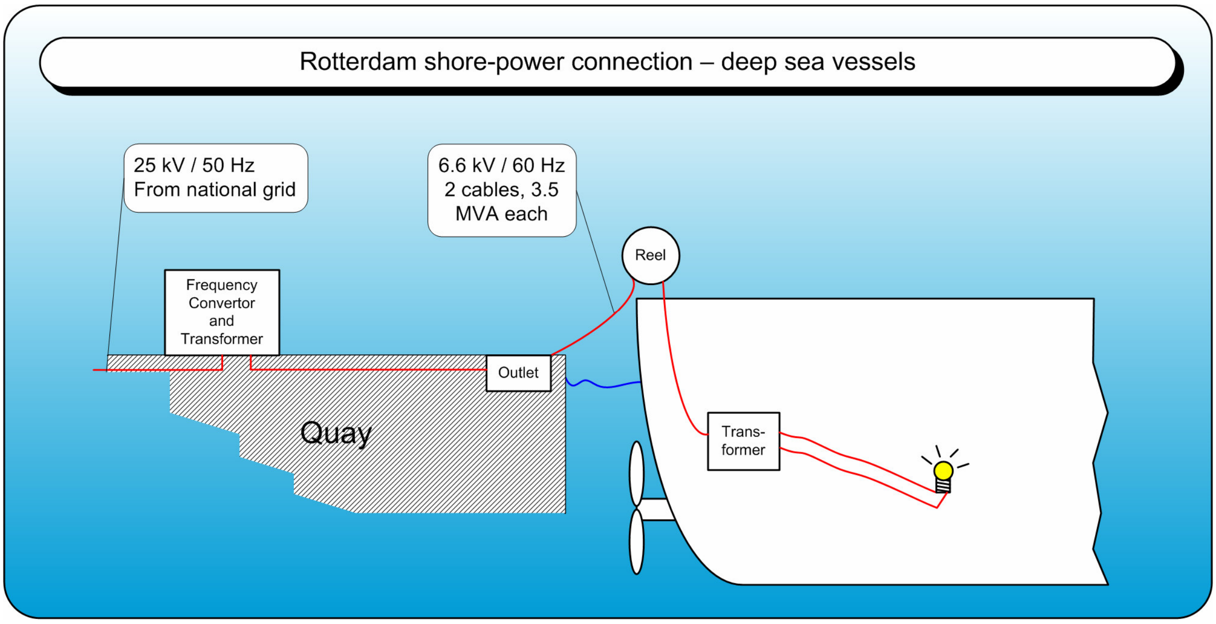
- Outlets: outlet boxes will be required to protect the outlets from the harsh terminal environment. These outlet boxes are positioned at a certain interval. Spacing them too wide apart would hamper the terminal's possibilities to position vessels freely along the quay wall, spacing them too close together would result in additional costs. It was decided that an interval of 45 meters between outlet boxes would be sufficient. This means that any vessel would need to carry sufficient cable to reach the quayside, plus an additional 25 meters to reach the nearest outlet.

- Switch-over: ships have to be equipped with seamless power transfer capabilities to avoid blackouts.

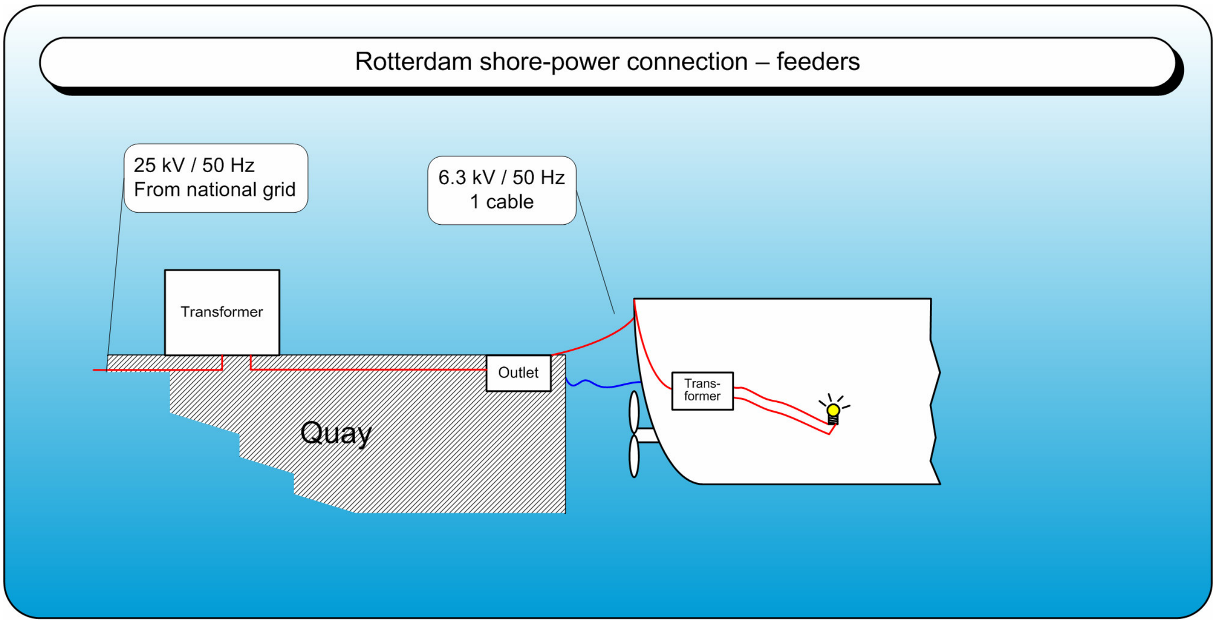
- Backup: ships' generators will have to be on standby during the port call to start up immediately if the shore connection should fail.

As explained, the large and midsize container vessels calling at the Euromax terminal use 60 Hz electrical systems on board and cannot directly be coupled with the 50 Hz European power grid. Therefore a frequency converter is needed. The preferred solution for deep sea vessels is shown below:

[5] Within the International Organization for Standardization (ISO), a working group was formed in September 2006 to develop an international standard for shore power connections.



To supply power to feeders, a 50 Hz outlet needs to be available as well. The two frequencies can be combined in one single outlet box. Where 6.6 kV is a voltage frequently used in high-voltage 60 Hz systems, 6.3 kV is often used in high-voltage 50 Hz systems. Therefore, 6.3 kV at 50 Hz was chosen as the preferred power source for feeder vessels. Feeders that need a 60 Hz power supply can use one of the 6.6 kV / 60 Hz deep sea outlets.

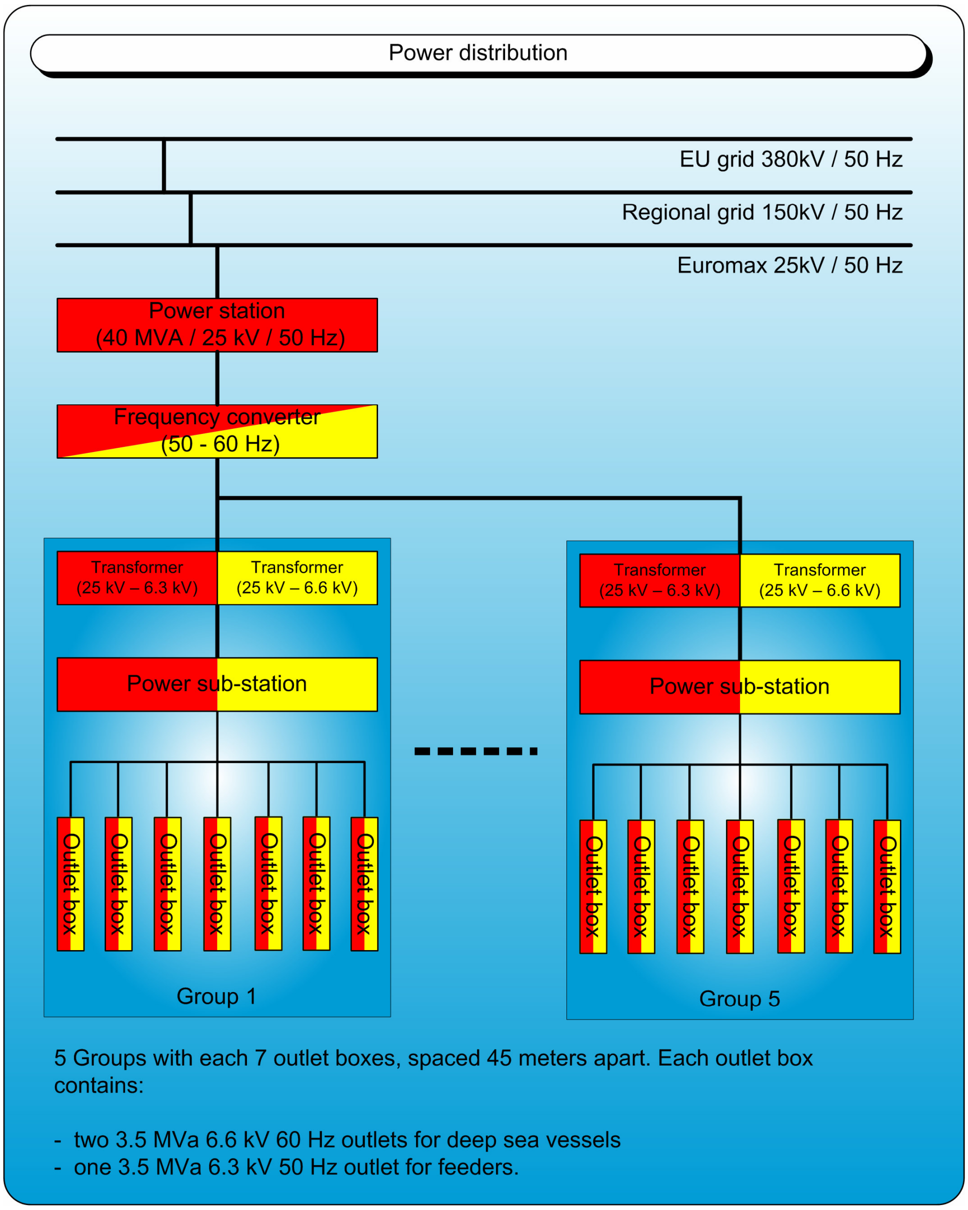


3 Euromax case study

3.1 Euromax electrical system design

Euromax cv (owned jointly by Europe Container Terminals and Maersk) is developing a 132 hectare terminal in the western part of the port of Rotterdam. Phase 1 of the project will be operational by the end of 2007 and consists of 1500 meters of quay wall for 3 deep sea berths and 4 feeder/barge berths and stacking capacity for 40.000 TEU. The terminal's flexible and highly automated design allows for ships to be positioned anywhere along the quay wall.

To provide shore power meeting the criteria mentioned above, GTI Electrical Engineering was asked to design an electrical system that would be capable of providing power to all moored ships, whereby the flexible terminal design had to be safeguarded. They came up with the following solution:



3.1.1 Annual operating costs

The estimated installation costs for the Euromax shore-power system are € 28.500.000[6]. Linear depreciation of the system in 20 years, maintenance and the 24/7 presence of a high-voltage technician to connect and disconnect the various vessels amount to a total of € 3.250.000 in annual costs.

When 20% of all vessels expected to call at the Euromax terminal use shore-side electricity, these operating costs will have to be born by only a limited number of vessels. Calculated back to kW/h this means the costs in this scenario will be € 0.82 per kW/h.

When 100% of all vessels expected to call at the Euromax terminal use shore-side electricity, the kW/h costs drop considerably to € 0.17 per kW/h. The figures mentioned above were based on a kW/h price (for 50 Hz) of € 0.05. Buying large quantities of power on a global market could lower this figure significantly.

[6] See Appendix III for cost calculations

3.2 Scenario's

Four different scenarios were investigated, to exemplify what emissions occur when all feeder and deep sea vessels expected at the Euromax terminal would berth under the following conditions[7]:

- The current fuel quality legislation, without the use of shore power (scenario 0)
- The 2010 fuel quality legislation, without use of shore power (scenario 1)
- The 2010 fuel quality legislation, 20% of the visiting vessels connected to shore power (scenario 2)
- The 2010 fuel quality legislation, 100% of the visiting vessels connected to shore power (scenario 3)

3.2.1 Scenario 0: Current fuel quality legislation.

The current legislation stipulates a maximum sulphur content in deep sea ships' fuel of 4.5%, where on average HFO contains 2.7% sulphur. Feeder vessels running their generators on MGO currently have to obey a 0.2% sulphur limit. When all 2968 and 561 deep sea vessels expected to call at the Euromax terminal would do so under current legislation, this would result in de following emissions:

Emissions:

Scenario 0	Annual emissions (tons)	Index (scenario 0 = 100)
NOx	392.0	100
PM10	16.7	100
SO2	252.0	100
CO2	18205.9	100
VOS	15.0	100
CO	69.9	100

Costs:

Scenario 0	Costs per call	Index
Feeder	€ 283 (fuel only)	100
Deep sea vessel	€ 2040 (fuel only)	100

7 See Appendix IV for elaborate datasets

3.2.2 Scenario 1: 2010 Fuel quality legislation

In 2010 new European fuel quality legislation will enter into force, requiring moored vessels to use fuel with a maximum sulphur content of 0.1%. HFO with a 0.1% Sulphur content will most likely not be available; therefore all ships will resort to using MGO for their generators, which results in fewer emissions:

Emissions:

Scenario 1	Annual emissions (tons)	Index (scenario 0 = 100)
NOx	335.5	86
PM10	10.3	62
SO2	24.6	10
CO2	15453.2	85
VOS	12.9	86
CO	59.8	86

Costs:

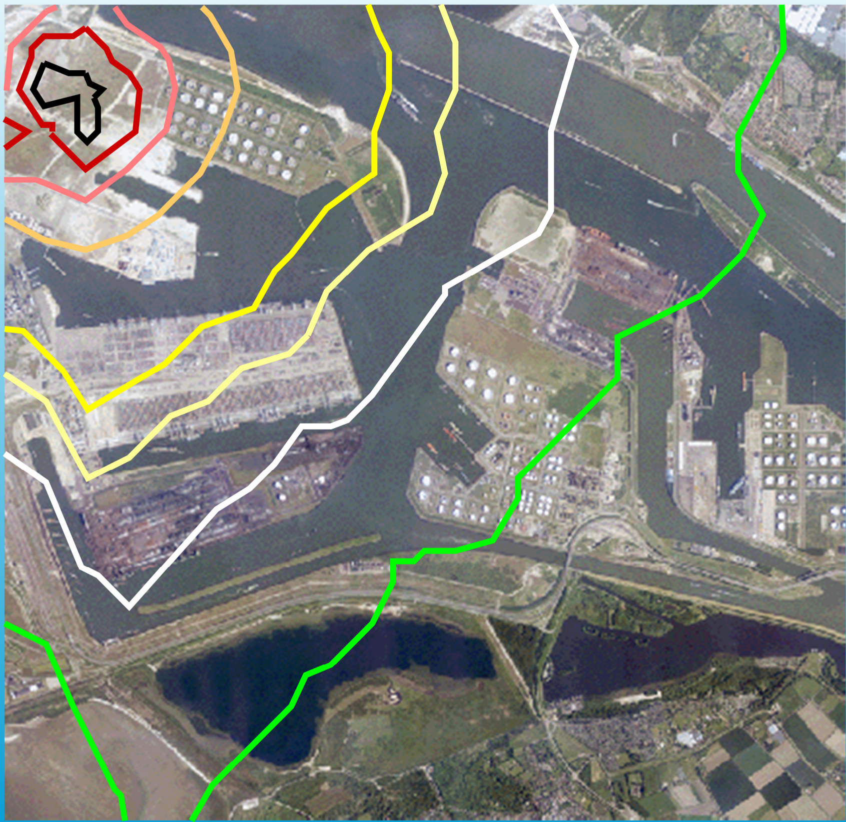
Scenario 1	Costs per call	Index (scenario 0 = 100)
Feeder	€ 283 (fuel only)	100
Deep sea vessel	€ 4040 (fuel only)*	198

* MGO is more expensive than HFO, resulting in higher costs per call

The information above was entered into dispersion modelling software KEMA STACKS by the Rotterdam DCMR Environmental Protection Agency, to graphically show the contribution of ships at berth to both NO_2 and PM_{10} levels. The results are shown in the following drawings. Note that the nearest residential area (Hoek van Holland) is located at the top right corner of the picture, where only minor increases in NO_2 level (0.6%) and PM_{10} level (0.1%) remain.

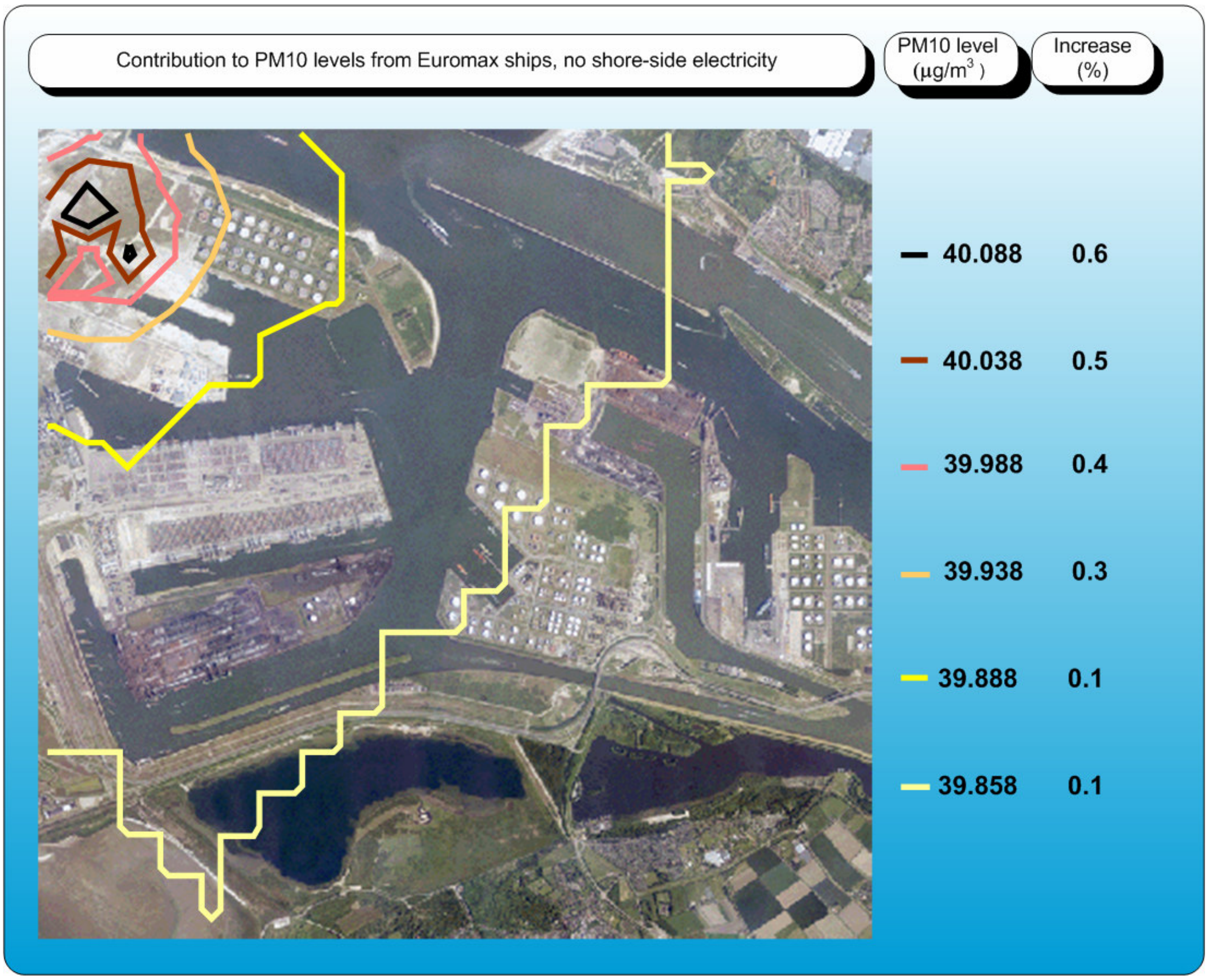
However, the need to take action on PM_{10} levels is clear, as the maximum level of PM_{10} will be 40 µg/m3 in 2010, this limit is exceeded close to the terminal.

Contribution to NO2 levels from Euromax ships, no shore-side electricity



NO2 level (µg/m³)	Increase (%)
25.4	9.8
24.9	8.0
24.4	6.1
23.9	4.2
23.4	2.1
23.3	1.7
23.2	1.3
23.1	0.9

* The background NO_2 level was calculated at 22,9 µg/m^3



* The background PM_{10} level was calculated at 39.838 µg/m³

3.2.3 Scenario 2: 2010 legislation, 20% use of shore-side power

When 20% of all vessels calling at the Euromax terminal would use shore-side electricity, air pollutant emissions would decrease, but not by 20%, as it requires some time to connect to shore-power and to disconnected before leaving the terminal. The additional emissions generated by power plants that need to supply extra energy to the national grid have not been taken into account. These emissions won't influence the local Rotterdam-Rijnmond statistics. There's only one (coal-fired) power plant located near the port, and its stacks are so high we won't measure any additional emissions at ambient level. The emissions do exist, naturally, and will be transported with the prevailing winds.

Emissions:

Scenario 2	Annual emissions (tons)	Index (scenario 0 = 100)
NOx	288.7	74
PM10	8.9	53
SO2	21.2	8
CO2	13298.2	73
VOS	11.1	74
CO	51.5	74

Costs:

Scenario 2	Shore power only required in Rotterdam*		Shore power required in all EU ports*	
	Costs per call	Index (scenario 0 = 100)	Costs per call	Index (scenario 0 = 100)
Feeder on shore power (20%)	€ 1440	507	€ 1360	497
Feeder no shore power (80%)	€ 284	100	€ 284	100
Deep Sea on shore power (20%)	€ 42504	2084	€ 39042	1914
Deep sea vessel no shore power (80%)	€ 4040	198	€ 4040	198

*When all EU ports require the use of shore-side electricity, the depreciation of the shipboard installation is spread over an additional 3 ports for the deep sea vessel, and an additional 5 port for the feeder, therefore lowering the depreciation costs per call in Rotterdam.

Operating the shore-side electricity system in this scenario is highly unadvisable: the whole infrastructure has been installed and needs to be maintained while all costs are born by only a limited number of vessels. Using different ways of funding, subsidies, incentives or even make all vessels pay although they're not using shore-side electricity could resolve this.

3.2.4 Scenario 3: 2010 legislation, 100% use of shore-side power

When 100% of all vessels would connect, the following emissions would occur:

Emissions:

Scenario 3	Annual emissions (tons)	Index (scenario 0 = 100)
NOx	20.3	5
PM10	0.6	4
SO2	1.5	1
CO2	935.7	5
VOS	0.8	5
CO	3.6	5

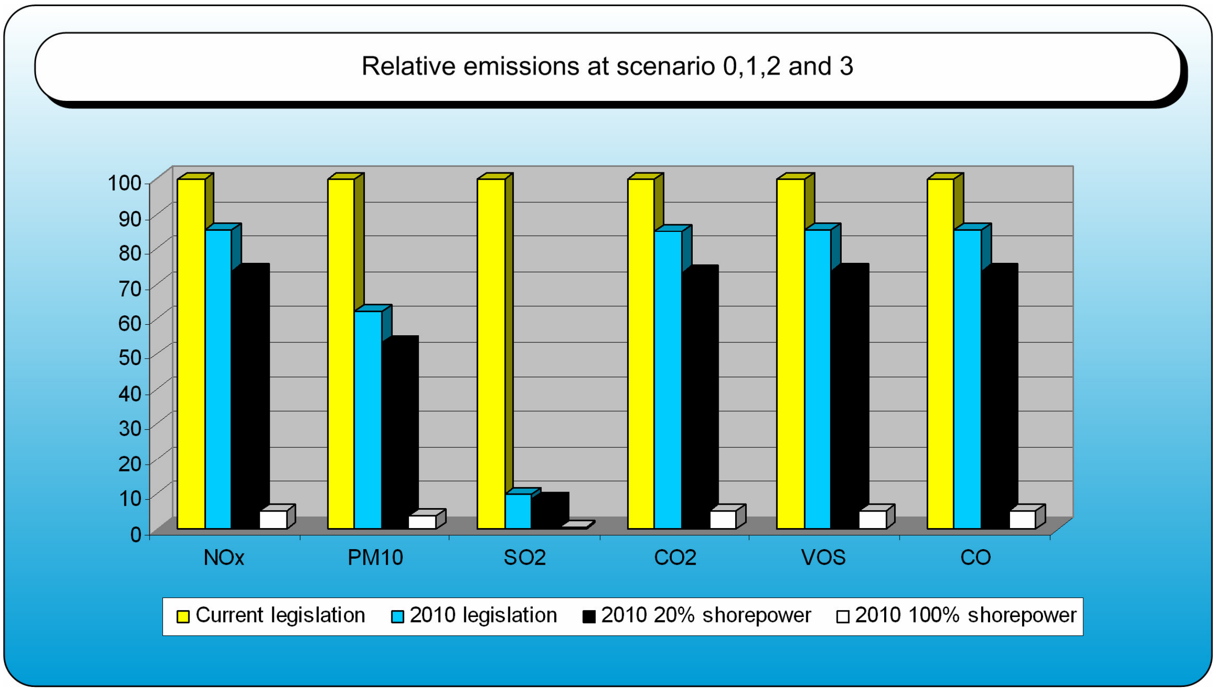
Costs:

Scenario 3	Shore power only required in Rotterdam		Shore power required in all EU ports	
	Costs per call	Index (scenario 0 = 100)	Costs per call	Index (scenario 0 = 100)
Feeder	€ 400	141	€ 320	112
Deep sea vessel	€ 12604	618	€ 9142	448

In these tables all costs (shore-side infrastructure, maintenance, personnel, ship-side infrastructure and electricity costs) have been calculated back to a single ship's call. This clearly shows that the costs of using shore-side electricity far outweigh the fuel savings on board. Connecting a deep sea container vessel will cost 6.6 times more than a ship owner pays now for the onboard electricity, and 3.3 times more than a ship owner will pay in 2010, in the most favourable scenario, where all EU ports require the use of shore-power.

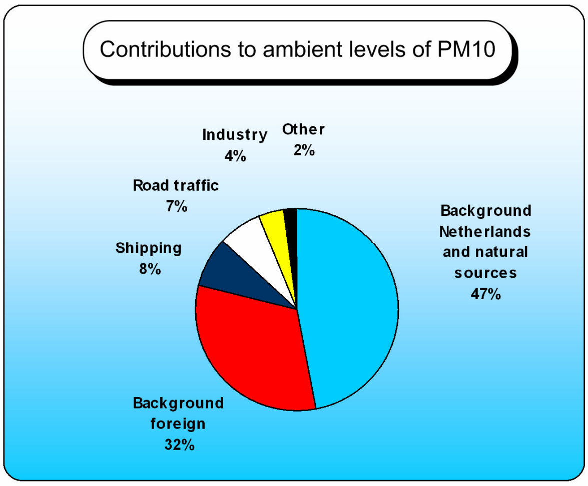
The feeder vessel calls at many EU different ports (almost daily), and therefore the depreciation of the shipboard system will be spread over many calls, resulting in relatively minor increases in cost.

Combining the different scenarios generates the following graph:



Scenario 3 is from an air quality perspective clearly the most favourable one.

4 Appendix I – Air quality graphs



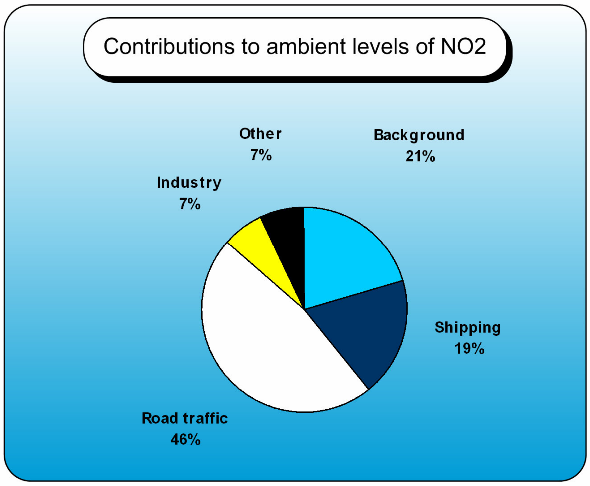


Figure 10 - Contributions from sources to **ambient concentrations** of particulate matter and NO_2 in the Rotterdam-Rijnmond region. Source: Rijnmond Regional Air Quality Action Programme, DCMR Environmental Protection Agency, 2005

5 Appendix II – Visiting container vessels research

5.1 Questionnaire

Port of Rotterdam — Voluntary electrical system questionnaire — Port of Rotterdam

1. Vessel particulars

Vessel name		IMO Number	
Inspector name		Date	

2. Main electrical system

Main voltage (V) (eg. 380V, 440V, 6.6kV, 10kV)		Frequency (Hz)	50 / 60 Hz
Are emission-reducing techniques installed on the generators (low S. fuel, water injection, etc)?			Yes / No
→ If yes, please indicate which			

3. Power consumption in port (at berth)

Average fuel consumption in port (m3/day)		Fuel type (generators)	HFO / MDO / MGO
Average electrical power consumption in port (kW)*		→ Sulphur content fuel	%
Maximum electrical power consumption in port (kW)*		→ Fuel viscosity (cSt)	

* estimated, if kW is difficult to indicate please state Volts and Amps

4. Shore connection

Is the vessel equipped with an electrical shore connection?	Yes / No	
→ Is it intended to be used only in drydock or also when the ship is fully operational?	Drydock only / Fully operational	
→ What is the type of connector used (bolt on, CEE, other)?		
→ What is the input voltage range (eg from 380 to 440V)?	from	to
→ What is the input frequency range (eg from 45 till 65 Hz)?	from	to
→ Where is the shore connection located?	Aft / Midships / Forward	Port / Center / Starbord
→ How much investment was needed to adapt the electrical system to receive shore side power?	$ / €	
→ In which ports do you use the shore connection?		

5. Remarks

If you feel your vessel could not be connected to shore power at berth (after possibly a shore connection upgrade) please indicate why

For internal Port of Rotterdam use: please return completed form to Robin Boekhorst, WPC 19.006, tel 2504, fax 252 1600. Document version: 1.0

5.2 Feeders

Number	Length over all (m)*	GT*	TEU*	Reefer Points*	Total propulsion engine power*	Main voltage	Frequency	Average fuel consumption in port (M3/day)	Fuel type for generators	Fuel sulphur content (%)	Average power consumption in port (kW)	Maximum power consumption in port (kW)
1	100	3800	390	30	3450	380	50 Hz	1,0	MGO	0,2	70	120
2	100	3000	390	50	2940	380	50 Hz	1,4	MGO		150	
3	100	3000	330	40	3840	380	50 Hz	0,8	MGO	0,2	140	200
4	100	3800	390	60	3840	380	50 Hz	1,3	MGO	0,2	110	150
5	100	4000	510	50	3825	400	50 Hz	1,0	MGO	0,2	140	170
6	100	3800	370	50	2970	440	60 Hz	1,2	MGO	0,1	200	350
7	110	4600	510	60	2099	400	50 Hz	1,8	MGO	0,2	120	220
8	120	5000	230	40	3960	440	60 Hz	2,8	HFO	1,8	400	800
9	120	5000	540	50	6000	380	50 Hz	2,0	MGO		155	220
10	120	6400	530	40	6650	380	50 Hz	1,4	MGO	0,2	180	210
11	120	6400	700	70	5299	380	50 Hz	1,8	MGO		200	280
12	130	5300	550	90	4500	440	60 Hz	1,2	MGO		120	300
13	130	6400	710	100	7200	440	60 Hz	1,5	MGO	0,2	180	900
14	130	6400	870	150	7200	380	50 Hz	2,2	MGO		200	600
15	130	10000	700	150	8100	440	60 Hz	2,0	MGO	0,2	200	400
16	130	10000	750	100	8100	440	60 Hz	1,8	MGO		90	110
17	130	10000	870	150	7950	400	50 Hz	2,5	MDO	3,0	200	300
18	130	7700	870	150	7199	440	50 Hz	1,9	MGO		170	230
19	140	8000	810	180	8400	440	60 Hz	1,5	MGO	0,2	160	230

* Data was rounded off to ensure confidentiality

5.3 Deep Sea container vessels

Number	Length over all (m)*	GT*	TEU*	Reefer Points*	Total propulsion engine power*	Main voltage	Frequency	Average fuel consumption in port (M3/day)	Fuel type for generators	Fuel sulphur content (%)	Average power consumption in port (kW)	Maximum power consumption in port (kW)
1	150	9500	1080	160	9729	440	60 Hz	2,0	MDO		400	400
2	160	14100	440	0	8238	380	50 Hz	1,5	HFO	0,2	213	200
3	160	10800	1160	100	6929	380	50 Hz	3,5	MDO		350	400
4	180	21100	1740	100	11549	440	60 Hz	4,5	MDO	0,2	350	1100
5	210	31300	2890	400	28878	440	60 Hz	10,0	HFO	3,0	1100	1500
6	210	27300	2490	570	15857	440	60 Hz	5,5	HFO	2,2	1600	2200
7	240	42400	2580	230	21068	440	60 Hz	10,0	HFO	2,5	700	1200
8	240	41000	3030	260	26480	440	60 Hz	4,0	HFO	3,5	550	650
9	240	37200	2930	150	20851	440	60 Hz	2,5	HFO	2,4	400	500
10	260	39600	3840	250	36447	440	60 Hz	5,0	HFO	3,5	700	900
11	270	50700	5060	800	45697	6600	60 Hz	35,0	HFO	1,5	1460	1460
12	280	67500	5300	500	57075	440	60 Hz	4,0	HFO	3,4	700	1100
13	280	65600	5250	500	54942	440	60 Hz	5,0	HFO	3,5	1000	1500
14	280	48200	3800	360	29199	440	60 Hz	2,5	HFO	3,5	400	450
15	280	65800	5620	1000	57099	440	60 Hz	10,0	HFO		1400	1500
16	280	66300	5550	0	60385	440	60 Hz	12,0	HFO		1200	6000
17	280	65600	5500	500	54810	440	60 Hz	13,5	HFO	3,5	1500	2400
18	280	65500	5610	500	43100	440	60 Hz	9,0	HFO		2000	2400
19	280	65100	5610	500	43097	440	60 Hz	8,5	HFO	4,0	1400	1800
20	280	68700	5780	500	62944	440	60 Hz	6,0	HFO		1200	2000
21	280	68700	5530	500	62944	440	60 Hz	8,5	HFO	3,6	1400	8000
22	290	51800	4020	350	40500	440	60 Hz	16,0	HFO	2,8	700	1000
23	290	71900	4430	350	62034	450	60 Hz	9,0	HFO		550	900
24	290	54200	4210	950	41107	440	60 Hz	8,0	HFO	2,5	1800	2000
25	290	52100	4210	950	40500	440	60 Hz	6,0	HFO	3,0	1600	2000
26	290	52100	4890	370	37080	440	60 Hz	11,0	MDO	0,2	1200	1900
27	290	52100	6350	500	37080	440	60 Hz	22,5	HFO	3,2	2000	2500
28	290	54500	5060	450	40039	440	60 Hz	7,0	HFO	2,4	1000	1700
29	300	80700	6210	500	65874	440	60 Hz	5,0	MGO		1500	3000
30	300	75600	6980	710	45306	6600	60 Hz	15,0	HFO	2,5	2000	3500
31	300	74700	6420	0	57075	440	60 Hz	5,0	HFO	2,8	2000	2220
32	330	95000	8400	700		440	60 Hz	9,0	HFO	3,0	1600	5100
33	340	75000	8150	700	68638	6600	60 Hz	13,0	HFO	4,5	2000	3500
34	350	93500	7370	840	63031	6600	60 Hz	6,5	HFO	1,5	1000	2000

6 Appendix III – Electrical system investment costs

Design	
Power connection to grid	€ 7,000,000
Main power station	€ 2,000,000
Frequency convertor	€ 2,500,000
Transformers	€ 3,000,000
Power substations	€ 1,500,000
Conduits	€ 5,000,000
Cabling	€ 2,000,000
Project management	€ 2,500,000
Outlets	€ 3,000,000
Total	€ 28,500,000
Annual costs	
Depreciation (linear, 20 years)	€ 1,425,000
Maintenance (5% of system costs)	€ 1,425,000
Personnel (1 high-voltage technician, 24/7)	€ 400,000
Total (without electricity)	€ 3,250,000
100% of vessels connected	
Electricity	€ 1,527,740
Electricity, transport	€ 35,996
Electricity, peak transport	€ 285,120
Total	€ 5,098,856
Price per KWh	€ 0.17
20% of vessels connected	
Electricity	€ 305,548
Electricity, transport	€ 7,199
Electricity, peak transport	€ 79,200
Total	€ 4,980,548
Price per KWh	€ 0.82

7 Appendix IV – Standard vessels

For emission calculation purposes, two 'standard' container vessels were created (based on the research data from Appendix 1), with the following characteristics:

	Feeder	Large container vessel
Gross Tonnage	6500	75000
Total installed propulsion engine power (kW)	7000	55000
Total installed generator power (non shaft) (kW)	900	8000
Total installed generator power (shaft) (kW)	0	2000
Fuel type (generators)	MGO	HFO
Fuel consumption in port (m3/24 hours)	1,5	8
Fuel % used for boilers*	0 (n/a)	20
Sulphur content of fuel**	0.1	0.1
Average power consumption in port (kW)	200	2000
Frequency	50 or 60 Hz	60 Hz
Hours in port per call	9	24
Connection time (hour)	0.5	0.5
Disconnection time (hour)	0.5	0.5
Calling Rotterdam every	Week	8 Weeks
Number of EU ports in string	6	4
Cost of shore power installation	€ 100.000	€ 600.000
Depreciation	Linear, 10 years	Linear, 10 years
TEU capacity	700	6500
Reefer points	150	500
Stack height (from water level) (m)	20	40
Fuel density (kg/m3)	800	985
Fuel price (€/m3)	505	250
Length (LOA) (m)	130	300

* Large container vessels running generators on HFO have to heat their fuel and the main engine fuel oil circuit, using boilers. These boilers consume approximately 20% of the fuel that's used in port. However, when running on MGO (2010 fuel quality legislation) these boilers might be shut off partly, these emissions have not been taken into account.

** A 0.1% sulphur content was assumed as it will be law in 2010. At the moment of writing, the maximum sulphur content for feeders on MGO is 0.2%, for HFO 1.5%.

8 Appendix V - Emissions and cost calculations

8.1 Scenario 0 – Current fuel quality legislation

8.1.1 Emissions

	Vessel type	Number	Hours at berth	Hours generators running	Fuel type generators	Fuel density (kg/m3)	Fuel usage (m3/hr)	Substance	Emissions (g/kg fuel)	Emissions (kg / hour / ship)†	Total emissions (tons /annum)	Emission relative (scenario 0 = 100)
Scenario 0	Feeders	2968	9	9	MGO	800	0.0625	NOx	68.11	3.4	91.0	100
					0.2% S			PM10	2.1	0.1	2.8	100
								SO2	10	0.5	13.4	100
								CO2	3140	157.0	4193.8	100
								VOS	2.61	0.1	3.5	100
								CO	12.15	0.6	16.2	100
	Deep Sea	561	24	24	HFO	985	0.3333	NOx	68.11	22.4	301.1	100
					2.7% S*			PM10	3.14	1.0	13.9	100
								SO2	54	17.7	238.7	100
								CO2	3170	1040.7	14012.2	100
								VOS	2.61	0.9	11.5	100
								CO	12.15	4.0	53.7	100
	Totaal							NOx			392.0	100
								PM10			16.7	100
								SO2			252.0	100
								CO2			18205.9	100
								VOS			15.0	100
								CO			69.9	100

* Although the legal limit for HFO Sulphur content is 4.5% at present, the world average is 2.7%, which was used for these calculations.

† Figures from The Dutch Ministry of Transport and TNO Research, '*Verbrandingsemissies stilliggende zeeschepen*' (emissions from moored vessels) publication, Adviesdienst Verkeer en Vervoer, Ministerie Verkeer en Waterstaat, Rotterdam, 2003. SOx emissions for MGO 0.1% Sulphur fuel were extrapolated from MDO 0.4% Sulphur and MGO 0.2% Sulphur data.

8.1.2 Costs

Scenario 0	Vessel Type	Fuel cost price	Fuel costs per call	KWh costs per call	Depreciation vessel installation (10 yrs, linear)	Total costs per call	Relative index (scenario 0 = 100)
	Feeder	€ 505	€ 284	€ 0	€ 0	€ 284	100
	Deep Sea	€ 255	€ 2,040	€ 0	€ 0	€ 2,040	100

8.2 Scenario 1 – 2010 fuel quality legislation

8.2.1 Emissions

	Vessel type	Number	Hours at berth	Hours generators running	Fuel type generators	Fuel density (kg/m3)	Fuel usage (m3/hr)	Substance	Emissions (g/kg fuel)	Emissions (kg / hour / ship)	Total emissions (tons /annum)	Emission relative (scenario 0 = 100)
Scenario 1	Feeders	2968	9	9	MGO	800	0.0625	NOx	68.11	3.4	91.0	100
					0.1% S			PM10	2.1	0.1	2.8	100
								SO2	5	0.3	6.7	50
								CO2	3130	156.5	4180.4	100
								VOS	2.61	0.1	3.5	100
								CO	12.15	0.6	16.2	100
	Deep Sea	561	24	24	MGO	800	0.3333	NOx	68.11	18.2	244.5	81
					0.1% S			PM10	2.1	0.6	7.5	54
								SO2	5	1.3	18.0	8
								CO2	3140	837.2	11272.7	80
								VOS	2.61	0.7	9.4	81
								CO	12.15	3.2	43.6	81
	Totaal							NOx			335.5	86
								PM10			10.3	62
								SO2			24.6	10
								CO2			15453.2	85
								VOS			12.9	86
								CO			59.8	86

8.2.2 Costs

Scenario 1	Vessel Type	Fuel cost price	Fuel costs per call	KWh costs per call	Depreciation vessel installation (10 yrs, linear)	Total costs per call	Relative index (scenario 0 = 100)
	Feeder	€ 505	€ 284	€ 0	€ 0	€ 284	100
	Deep Sea	€ 505	€ 4,040	€ 0	€ 0	€ 4,040	198

8.3 Scenario 2 – 2010 fuel quality legislation, 20% shore power

8.3.1 Emissions

	Vessel type	Number	Hours at berth	Hours generators running*	Fuel type generators	Fuel density (kg/m3)	Fuel usage (m3/hr)	Substance	Emissions (g/kg fuel)	Emissions (kg / hour / ship)	Total emissions (tons /annum)	Emission relative (scenario 0 = 100)
Scenario 2	Feeders	2968	9	1	MGO	800	0.0625	NOx	68.11	3.4	82.9	91
					0.1% S			PM10	2.1	0.1	2.6	91
								SO2	5	0.3	6.1	46
								CO2	3140	157.0	3810.3	91
								VOS	2.61	0.1	3.2	91
								CO	12.15	0.6	14.8	91
	Deep Sea	561	24	1	MGO	800	0.3333	NOx	68.11	18.2	205.8	68
					0.1% S			PM10	2.1	0.6	6.3	46
								SO2	5	1.3	15.1	6
								CO2	3140	837.2	9487.9	68
								VOS	2.61	0.7	7.9	68
								CO	12.15	3.2	36.7	68
	Totaal							NOx			288.7	74
								PM10			8.9	53
	* for the 20% that is connected to shore power. Emissions for the other 80% are equal to scenario 1, and were added to the total annual emissions							SO2			21.2	8
								CO2			13298.2	73
								VOS			11.1	74
								CO			51.5	74

8.3.2 Costs

Scenario 2	Vessel Type	Fuel cost price	Fuel costs per call	KWh costs per call	Shore power only in Rotterdam			Shore power in all EU ports)		
					Depreciation vessel installation (20 yrs, linear)	Total costs per call	Relative index (scenario 0 = 100)	Depreciation vessel installation (20 yrs, linear)	Total costs per call	Relative index (scenario 0 = 100)
	Feeder on shore power (20%)	€ 505	€ 32	€ 1312	€ 96	€ 1440	507	€ 16	€ 1360	497
	Feeder no shore power (80%)	€ 505	€ 284	€ 0	€ 0	€ 284	100	€ 0	€ 284	100
	Deep Sea on shore power (20%)	€ 505	€ 168	€ 37,720	€ 4,616	€ 42,504	2,084	€ 1,154	€ 39,042	1,914
	Deep Sea no shore power (80%)	€ 505	€ 4040	€ 0	€ 0	€ 4040	198	€ 0	€ 4040	198

8.4 Scenario 3 - 2010 fuel quality legislation, 100% shore power

8.4.1 Emissions

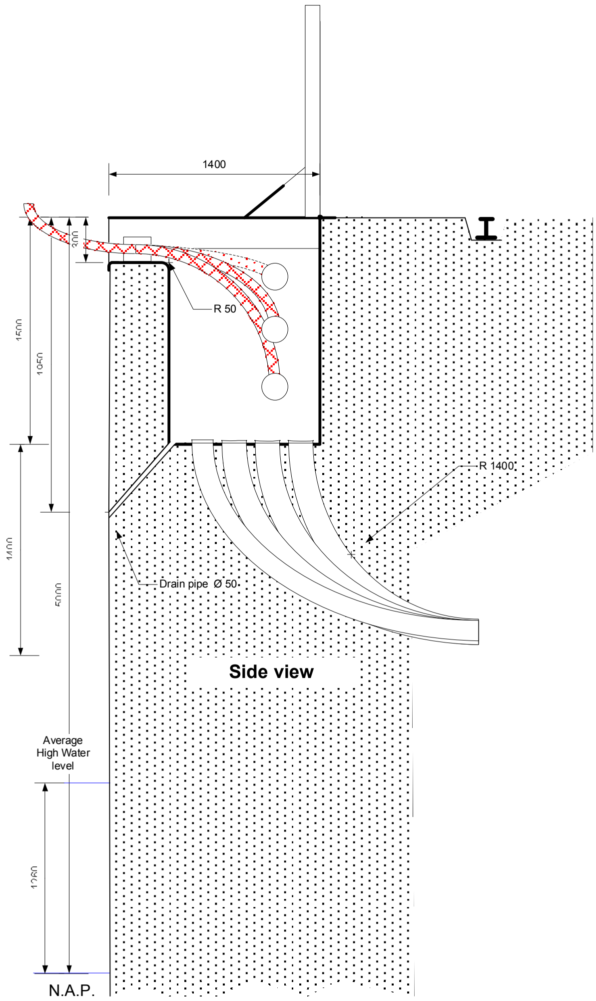
	Vessel type	Number	Hours at berth	Hours generators running	Fuel type generators	Fuel density (kg/m3)	Fuel usage (m3/hr)	Substance	Emissions (g/kg fuel)	Emissions (kg / hour / ship)	Total emissions (tons /annum)	Emission relative (scenario 0 = 100)
Scenario 3	Feeders	2968	9	1	MGO	800	0.0625	NOx	68.11	3.4	10.1	11
					0.1% S			PM10	2.1	0.1	0.3	11
								SO2	5	0.3	0.7	6
								CO2	3140	157.0	466.0	11
								VOS	2.61	0.1	0.4	11
								CO	12.15	0.6	1.8	11
	Deep Sea	561	24	1	MGO	800	0.3333	NOx	68.11	18.2	10.2	3
					0.1% S			PM10	2.1	0.6	0.3	2
								SO2	5	1.3	0.7	0
								CO2	3140	837.2	469.7	3
								VOS	2.61	0.7	0.4	3
								CO	12.15	3.2	1.8	3
	Totaal							NOx			20.3	5
								PM10			0.6	4
								SO2			1.5	1
								CO2			935.7	5
								VOS			0.8	5
								CO			3.6	5

8.4.2 Costs

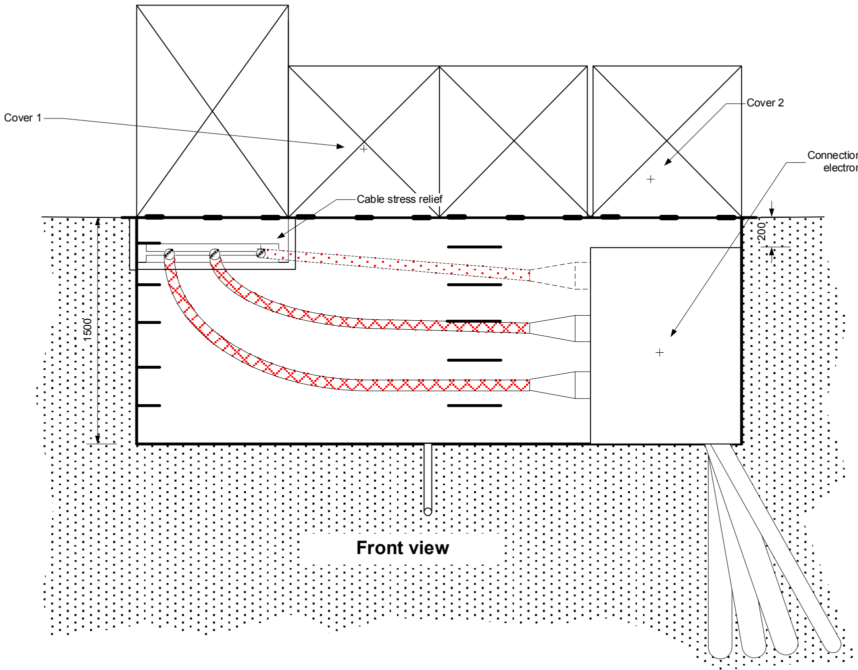
Scenario 3	Vessel Type	Fuel cost price	Fuel costs per call	KWh costs per call	Shore power only in Rotterdam			Shore power in all EU ports)		
					Depreciation vessel installation (20 yrs, linear)	Total costs per call	Relative index (scenario 0 = 100)	Depreciation vessel installation (20 yrs, linear)	Total costs per call	Relative index (scenario 0 = 100)
	Feeder on shore power (100%)	€ 505	€ 32	€ 272	€ 96	€ 400	141	€ 16	€ 320	112
	Feeder on shore power (100%)	€ 505	€ 168	€ 7,820	€ 4,616	€ 12,604	618	€ 618	€ 9,142	448

9 Appendix VI – Shore connection outlet design

Side view



Front view



Top view