TREMOVE 2
Maritime model and runs

CONTRACT B4-3040/2002/342069/MAR/C.1

European Commission
DG ENV
BU 9
1043 Brussels
Belgium

28 July 2006

TRANSPORT & MOBILITY LEUVEN

Bruno Van Zeebroeck
Griet De Ceuster
Bart Van Herbruggen

TRANSPORT & MOBILITY LEUVEN
VITAL DECOSTERSTRAAT 67A BUS 0001
3000 LEUVEN
BELGIË
+32 (16) 31.77.30
http:\\www.tmleuven.be

Index

Tables

Figures

Preface

This document gives an overview of the **maritime module of the TREMOVE model and baseline**.

TREMOVE is a transport and emissions simulation model developed for the European Commission. It is designed to study the effects of different transport and environment policies on the emissions of the transport sector. The model estimates the transport demand, the modal split, the vehicle fleets, the emissions of air pollutants and the welfare level under different policy scenarios. All relevant transport modes are modelled, including air and maritime transport. The model covers the 1995-2020 period, with yearly intervals.

TREMOVE predicts the overall emissions from the transport sector in different policy scenarios. The strength of the model is that it also enables also to assess the effects of environmental policies on future vehicle fleets and on overall transport demand and its modal split. The calculated welfare effect of a policy then is not only determined by technology costs and emission reductions, but also by effects on household mobility, industry logistic processes and government tax income from the transport sector.

The TREMOVE model has been developed by Transport & Mobility Leuven in a service contract for the European Commission, DG Environment. The first version of the model dates 1997-1998. At that time, the model covered 9 countries and focussed on road transport. The K.U.Leuven and DRI developed the first model as an analytical underpinning for the European Auto-Oil II programme.

In 2002-2005, TREMOVE has been enhanced and extended. The new model also covers explicitly rail, air and shipping and deals with a larger set of pollutants. Moreover, it covers all EU15 countries, plus Switzerland, Norway, the Czech Republic, Hungary, Poland and Slovenia. The new model has been made consistent with other European transport and energy scenarios and takes on board the most recent emission computation methodology available at EU level.

Since March 2005, the TREMOVE transport and emissions model is available for policy runs. Both the baseline scenario and the results of policy simulations will be crucial inputs for the Clean Air for Europe (CAFE) programme for air quality and the European Climate Change Programme (ECCP), as well as for other programmes

Maritime transport is treated separately and allocated to maritime regions, thus is not coupled directly to the different country models. The European sea area is subdivided in 8 modelled maritime regions.

The maritime model estimates both the maritime movements (km) and port callings (#) for all maritime freight vessels and passenger ferries for 1995-2020. The fuel consumption, emissions and welfare are also modelled.

I The maritime model

The approach adopted for maritime transport in TREMOVE is based on the recent work performed by Entec[1] on activity and emissions from ships in the European Community.

I.1. Geographical structure

TREMOVE describes land and air as taking place within a country. Maritime transport is treated separately and allocated to maritime regions, thus is not coupled directly to the different country models. The European sea area is subdivided in 8 modelled maritime regions, chosen on the basis of the Entec report.

Table 1: Maritime areas covered by TREMOVE

AO	North East Atlantic Ocean	IS	Irish Sea
BA	Baltic Sea	MS	Mediterranean
BL	Black Sea	NS	North Sea
EC	English Channel	RE	Rest of EMEP

Within these 8 sea regions, TREMOVE covers freight vessels and ferries. Fishing vessels are not included. Indeed, a lot of uncertainty is involved in the estimation of fishing vessels emissions, while the contribution to overall emissions in European waters is small and the influence on corresponding air quality is correspondingly low.

I.2. Maritime transport demand

I.2.1. Modelling approach

Different reasons suggest that the demand modelling approach adopted for the other modes (using CES trees) is not feasible for maritime transport. One of the major reasons is that the Scenes model does not contain detailed information on maritime transport (for example, only two categories of maritime transport are distinguished within the model). Also, the substitution possibility between maritime transport and other modes is very limited, as is the availability of information on price and substitution elasticities. Moreover, for an important share of maritime movements, starting ports and/or destination ports are not located in Europe. Another problem is that the Entec report does not contain data on the split in short sea and deep sea shipping. Only short sea shipping is expected to compete with land transport modes.

For all these reasons, maritime transport demand is considered to be exogenous in TREMOVE. As substitution possibilities between maritime transport and other modes are very limited (except for some specific zones and short sea shipping), it is assumed that the maritime movements are not affected by policy measures on land based transport and vice versa. In addition, TREMOVE does not include an endogenous link between total maritime transport demand and maritime transport costs and prices.

It should be noted that the shortcomings of TREMOVE when it comes to modelling the impacts of policies on maritime transport demand can be overcome when needed for policy simulations. Demand changes cannot be modelled endogenously in the model, but can be introduced exogenously. This can be

[1] Entec. (2002) Quantification of emissions from ships associated with ship movements between ports in the European Community. Report to the European Commission.

done by using different demand input data for base case versus simulation. The simulation demand input data could come from other models or from expert judgements on the impacts of the considered policies on overall maritime transport demand.

I.2.2. Demand baseline

I.2.2.1. Base year 2000

The primary source of information in terms of *freight ship movements* in this study was the database provided by Lloyds Marine Intelligence Unit. This is the only commercial database on all ship movements world-wide and links data on movements to port callings, vessel types, engine types and vessel sizes. The data-base covers all ships greater than 500 tons; smaller freight vessels were not taken into account in the study. In the Entec study, Lloyds data on four months in 2000 was analysed and extrapolated to twelve months to estimate freight ship movements and port callings per vessel type in the year 2000.

For *ferry vessel movements* in 2000, Entec adopted a different approach. Ferry movements were estimated by identifying the maximum number of crossings possible in one day and applying seasonal ratios to derive the real number of crossings per day. The ratios were derived from published timetable information for selected ferries.

Also, the number of *port callings* is modelled. For Norway, no data on port callings are available from Entec.

A previous model version contained higher figures for 2000. These figures have been adapted after a new version of the Entec figures came available. Vehicle kilometres decreased as a whole around 15% compared to the previously used input figures. Number of port callings grew by 8% compared to the previously used input figures. This is due to a different method used to derive vehicle kilometres. Entec is nevertheless aware that not all movements are actually covered due to several reasons of missing information in the underlying data. Final vehicle kilometres could be in the order of the previous figures or even slightly higher.

These changes have a significant impact on the base case emissions and on the costs of technical measures. Global welfare effects could therefore be underestimated.

I.2.2.2. Forecast for 2000-2020

Although Entec used these 2000 movement figures to develop a forecast until 2020, the Entec forecasts were not adopted in TREMOVE. Instead, in order to develop a maritime transport baseline up to 2020, growth rates derived from the Scenes maritime transport were applied to the 2000 Entec figures.

This resulted in an annual growth of 2.5%.for freight and 3.9% for passengers.

This approach guarantees the consistency of the TREMOVE baseline across modes.

I.2.3. Maritime fleet modelling and baseline data

In addition to the transport demand, the TREMOVE maritime module is able to take into account *flag and size of ships*. In that way, TREMOVE can cope with all policy simulation foreseen by the European Commission.

I.2.3.1. Ship types

The maritime ship vessel-km and port callings in the Entec study and in TREMOVE are detailed into the following 27 ship types:

Table 2: Maritime ship types in TREMOVE

Liquified Gas	Other Bulk Dry	Passenger	Towing / Pushing
Chemical	General Cargo	Other Dry Cargo	Dredging
Oil	Passenger/General Cargo	Fish Catching	Other Activities
Other Liquids	Container	Other Fishing	Other Activities
Bulk Dry	Refrigerated Cargo	Offshore Supply	Other Activities
Bulk Dry / Oil	Ro-Ro Cargo	Other Offshore	Other Activities
Self-Discharging Bulk Dry	Passenger/Ro-Ro Cargo	Research	

In their study, Entec reported *maritime movements by ship type, by engine type and fuel* used. Moreover they noted that irrespective of ship category (container, passenger ferry…) the installed engine type on board of a ship and the fuel used largely dictates the ship's emissions. Therefore, Entec derived emission factors for five different engine types and three different fuel types from published sources. This was repeated for three activities or operating modes of the ships: at sea, in port and manoeuvring. Combining movement data and emission factors, total on-sea and in-port emissions were derived for the sea regions and ports considered.

I.2.3.2. Flagging

Data for the *distribution over EU and non EU flagged ships* in the fleet is available for both ship movements and port callings.

I.2.3.3. Vehicle turnover

The renewal of the fleet takes place at a rate of 4% per year. This corresponds to a life expectancy for a ship of 25 year. This assumption has been made in accordance with Entec.

I.2.3.4. Ship type distribution

In the Entec 2020 baseline, forecast one *freight transport growth rate* is applied to all freight ship types, and one passenger transport growth rate is applied to all passenger ship types. Also, the shares of different engine types and fuel types in the fleet has been assumed constant in the Entec baseline forecast. Thus no changes in overall freight and passenger ship fleet composition are included in the Entec forecast.

TREMOVE uses the same baseline assumptions as Entec, thus it reports no changes in fleet composition or in shares of different engine types and fuels in the *baseline forecast*. Though TREMOVE uses growth rates from Scenes for maritime passenger transport and maritime freight transport which are not equal to the growth rates used in Entec.

Thus, the share of the different ship types for passenger or freight transport is constant in the maritime 1995-2020 baseline. TREMOVE also does not include endogenous modelling of changes in these shares under the influence of policy measures. One of the reasons for this is that not all ship types in the Entec classification can be used for all types of goods. Liquified gas or oil ships are used for transporting gas and oil only. This leads to the fact that changes in the vessel fleet composition should be linked to changes in the demands for the transport of the different goods. For land transport TREMOVE disaggregates total freight transport to 3 categories of freight goods, which are derived from more detailed Scenes categories. For maritime transport information in Scenes is much more limited. Another reason is that the international character of maritime transport raises similar issues as for the aircraft fleet modelling.

The vehicle stock provided makes no difference between *small, medium and large ships* in spite of the fact that the model has been adapted to threat this feature. This is due to lack of data on small, medium and large fleets.

As for the maritime demand module, it should be noted that the shortcomings of TREMOVE when it comes to modelling the impacts of policies on maritime fleets can be overcome when needed for policy simulations. *Fleet changes* cannot be modelled endogenously in the model, but can be introduced exogenously. TREMOVE will be used to simulate the impacts of changes in fuel specifications and in engine and after-treatment technology within the CAFE programme.

I.2.4. Maritime fuel consumption and emissions

Maritime fuel consumption and emissions are calculated

1. For in-port emissions : per county for 1995-2020
2. For at-sea emissions : per sea region (8 seas) for 1995-2020

The number of port visits in 2000 is derived form the Entec data. A growth factor from the Scenes model has been applied to calculate the figures for 1996-2020. The amount of visits for each year is multiplied with an emission or fuel consumption factor per port visit in order to achieve the total emissions. The emission or fuel consumption factor consists of a weighted average of the emission of the mean engine (ME) plus the emission of the auxiliary engine (AE) taking into account engine types and fuel types used by the mean engine and the auxiliary engines. Average engine using time and engine load is taken into account here. Engine using time means the time the engine is operating, engine load means the share of maximal engine capacity that is used. The full emission calculation methodology developed by Entec has been included in the TREMOVE model. The reader therefore is referred to the Entec report for further details.

The number of vessel-kilometre per sea in 2000 is derived form the Entec data. A growth factor from the Scenes model has been applied to calculate the figures for 1996-2020. The amount of vessel-km for each year has been multiplied with an emission factor per vessel-km in order to achieve the total emissions. As for port emissions the emission factor consists of a weighted average of the emission of the mean engine (ME) plus the emission of the auxiliary engine (AE) taking into account engine types and fuel types used by the mean engine and the auxiliary engines. Average engine using time and engine load is taken into account.

I.2.4.1. Marpol agreement AnnexVI and low sulphur EC directive

The Marpol agreement Annex VI and the EC directive on sulphur content for marine fuel have been taken into account in the base case.

I.2.4.2. *NO_x emission factors*

The NO_x emission factors we use from De Jonge, Hugi, Cooper, 2005 decrease over the period in accordance with the Marpol agreement.

I.2.4.3. *Low sulphur areas*

For the English Channel (from 2008 on), the North Sea (from 2008 on), the Baltic Sea (from 2006 on) and passenger vessels (from 2006 on) the use of low sulphur fuel (1.5 %S) is taken into account for sea emissions[2]. Therefore emission reduction factors are applied for SO2 (44%) and PM (18%) in those particular sea areas. The reduction factors are applied in a general way to all ship emissions without distinction for fuel used, thus also to ships using marine diesel. In 2000 only 2% of ships used marine diesel.

I.2.4.4. *Low sulphur fuel in ports*

The 0.1% S fuel in ports is taken into account in the emission factors for auxiliary engines at berth provided by Entec from 2010 on. Entec assumes that in practice the 0.1% fuel in port will only apply for auxiliary engines at berth and not to main engines[3].

The reason is that they assume that main engines are only running during a short time just after arriving at berth and just before leaving the berth. Ships will probably not switch to low sulphur fuel for these transitional periods. By using the Entec emission factors, we implicitly made the same assumption. This means that SO_2 and PM emissions are overestimated for tankers who use their main engines for longer periods at berth and will switch at these moments[4]. This will nevertheless not influence the conclusions of the policy evaluations, as the simulations focus on differences between base case and simulations.[5]

I.2.4.5. *Resulting base case emission*

The total base case emissions for all sea regions can be found in the table below.

Table 3: Base case emissions, 2010-2020 total, all sea regions, tonnes

NOx	SO2	PM	CO2	VOC
37 325 871	23 011 698	3 121 722	1 819 072 462	1,472,967

I.2.5. External costs

Pollution costs are calculated based on emissions and on external costs. The TREMOVE input database contains the most recent available external cost data, i.e. the BeTa table that came available in March

[2] In the base case, emission reductions in the low sulphur areas for manoeuvring emissions and port emissions have not been taken into account. For policy simulations 1 to 17, at berth emissions, low sulphur fuels (0.1%) have been taken into account from 2010 on for auxiliary engines. As a consequence only emission reductions in low sulphur areas for manoeuvring activities and port emissions of main engines are omitted. For policy simulations 18 to 21, low sulphur fuels have been taken into account for all port emissions, at berth and manoeuvring. More explanations are given in the next paragraph.

[3] For the low sulphur policy simulations 18 to 21 we took into account the use of low sulphur fuel 0.1% at berth not only for the auxiliary engines but also for the main engine in the base case.

[4] The overestimation for total SO_2 port emissions will be important, especially for tankers. A rough estimation showed an SO_2 port emission estimate three times higher with 2.7%Sfuel compared to 0.1% S fuel.

[5] For sea water scrubbing conclusions will be biased and emission reductions are overestimated as the 0.1% S fuel at berth for main engines has not been taken into account.

2005[6]. In accordance with the Commission the external costs set providing the highest values have been integrated. The difference between the set with the highest values for external costs and the set with the lowest value is nearly a factor 3. A sensitivity analysis with lower values of external costs has is discussed in section II.5.2.

External costs used for port emissions are the country specific rural values. For sea emissions also specific costs have been used, though these are not available for each sea. To evaluate the sea emissions, we made the assumptions below in accordance with in the cost benefit analysis team within the Clean Air For Europe Programme. Especially for the emission evaluation of RoEMEP the estimate is rather rough. We assumed external costs of 'rest of EMEP' (RoEMEP) to be 50% of the North East Atlantic external costs.

Table 4 : Approximation of external costs for sea regions

Sea area	External costs used	Estimation quality
North East Atlantic	North East Atlantic	
Baltic Sea	Baltic Sea	
North Sea	North Sea	
English Channel	North Sea	acceptable
Irish Sea	North Sea	acceptable
Mediteranean Sea	Mediteranean Sea	
Black Sea	Mediteranean Sea	acceptable
RoEMEP	North East Atlantic/2	very rough

I.2.6. *Calculation of welfare*

The goal of a model simulation is to calculate a welfare measure, this is a difference in welfare between the base case and the simulation.

Pollution costs and other costs are calculated and compared to each other for each year. The difference between both is the difference in welfare. This difference can be a criterion for policy choice.

[6] Benefits Table, CAFE, AEA Technology Environment, March 2004

II TREMOVE *maritime runs*

II.1. Overview of maritime scenarios

This chapter gives an overview of the policies. Some brief technical specifications are also given for the different emission reduction technologies. Three groups of policies can be distinguished: shore side electricity (3), NO_x reducing policies (12) and sulphur reducing policies (5).

All policies take effect in 2010.

The goal of each simulation is to calculate the welfare effect of the measure, this is a difference in welfare between the base case and the simulation. The welfare here is composed of a difference in external costs of pollution (pollution costs) and costs of installing new technologies (user costs)[7]. Pollution costs are generally reduced and therefore increase welfare while user costs reduce welfare.

Table: 5 Overview of maritime policies

TECHNOLOGY	APPLICATION	EMISSIONS & REDUCTIONS
Shore side electricity		
SSE1	New-build; tankers, ro-ro, passenger and cruise ships; auxiliary engines; all flags; all ports	NOx, SO_2, VOC, PM, noise (100% of AE),
SSE2	New-build; regular service ships with large auxiliary engines; EU flags; 500 berths in ports	NOx, SO_2, VOC, PM, noise (100% of AE)
SSE3	New-build & retrofit; tankers, ro-ro, passenger and cruise ships; auxiliary engines; EU flags	NOx, SO_2, VOC, PM, noise (100% of AE)
NO_x reducing policies		
Slide valves		
SV4	Retrofit; slow-speed engines; all flags	NOx (20%)
SV5	Retrofit; slow-speed engines; EU flags	NOx (20%)
Internal engine modifications		
IEM6	New-build; all flags	NOx (30%)
IEM7	New-build; EU flags	NOx (30%)
Water vapour humidification		
WV8	New-build; all flags	NOx (70%)
WV9	New-build; EU flags	NOx (70%)
WW10	New-build & retrofit; EU flags	NOx (70%)
Direct water injection		
DWI11	New-build; all flags	NOx (50%)
DWI12	New-build; EU flags	NOx (50%)
Selective catalytic reduction		
SCR13	New-build; all flags	NOx (90%)
SCR14	New-build; EU flags	NOx (90%)
SCR15	New-build & retrofit; EU flags	NOx (90%)
SO_2 reducing policies		
Sea water scrubbing		
SWS16	New-build; 50% EU-fleet	SO_x (75%), PM (25%)
SWS17	New-build & retrofit; 50% EU-fleet	SO_x (75%), PM (25%)
Low sulphur fuel		
LSF18	Common Position base case 1.5% S fuel; all flags, Baltic, North Sea, English Channel	

[7] The user costs are given in the Entec reports (Entec, 2005) without specific information on benefit margins included in them. We assume all margins cover overhead and research costs and do not provide an extra profit for the producers.

	and regular passenger vessels; 0.1% in port	
LSF19	EP 1st reading 0.5% S fuel; all flags, all sea areas; 0.1% in port	SO_x 40% to 80% PM 20%
LSF20	SECA for all EU seas 1.5% S fuel; all flags, all sea areas; 0.1% in port	SO_x 40% PM 18%
LSF21	Possible compromise All flags; Baltic, North Sea, English Channel & regular passenger vessels: 75% of ships using 1.5% S fuel at sea; 0.1% in port (as LSF1), remaining 25% of ships using 0.5% at all times	SO_x PM

II.1.1. Costs of implementing the measures

The table below shows the costs used for the different policy scenarios (source: Entec, 2005). Costs are annualized costs expressed in euro per year. Further specific policy related assumptions explained in the remainder of this section.

Table 6: Costs of implementing different policies, euro per vessel

policy		small ship	medium ship	large ship
SSE	low cost berths	42 615	45 834	49 053
SSE	new build ships	11 243	20 287	42 529
SSE	retrofit ships	15 595	26 563	53 530
SV	retrofit ships		1 756	3 555
IEM	new build ships	6 867	7 666	11 047
WV	new build ships	43 985	123 900	265 918
WV	retrofit ships	50 129	151 380	353 957
DWI	new build ships	43 134	138 351	331 438
SCR	new build EU ships	142 329	357 894	837 585
SCR	retrofit EU ships	156 990	391 985	915 927
SCR	new build non EU ships	144 532	363 017	849 359
SCR	retrofit non EU ships	159 193	397 109	927 701
SWS	new build ships	50 260	148 461	338 499
SWS	retrofit ships	74 310	226 091	533 309

This has an impact on the vehicle stock and vehicle turnover. We calculated the ratio of "new" vessels in the fleet for the years between 2010 and 2020 compared to 2010 and the ratio of "old" vessels in the fleet for those years compared to 2010. It is important to know the share of new ships and old ships as costs for installing new technologies differ between retrofitting and installation on new ships.

II.1.2. Emission reductions and costs in simulations

In a policy simulation, a general emission reduction factor is applied to the base case emission factors to calculate the emissions in the simulation. Emission reduction factors are unfortunately not differentiated between engine and fuel types nor between vessel types. Only one general reduction factor applicable to the whole fleet is provided by Entec. The high level of detail of the model could therefore not be totally exploited in the scenario emission modelling.

The technical installation and research and maintenance costs are provided by Entec as well. They are still subject to change. Dependent on policies, it concerns installation costs (nearly all policies), fuel costs (fuel switching policies) and electricity costs (Shore side electricity). Different costs are given for small, medium and large vessels. To evaluate a policy the installation costs taken into account are those for the whole featured fleet. This means that for policies concerning all flag ships, also the costs for non European ships are taken into account.

All emission and cost data are based on the Entec interim confidential reports for the EC DG ENV of February 2005 Task 2a shore side electricity in ports, Task 2b No_x abatement technologies, Task 2C Sea Water Scrubbing and Task 2 general report.

II.2. Shore side electricity

While at berth, ships switch off their auxiliary engines and use electricity from the national grid. The national grid suppliers have in general lower emission factors per MWh of electricity due to the type of electricity production or stringent emission controls.

II.2.1. Assumptions

These policies simulate the introduction of shore side electricity on passenger ships, RO-RO ships and tankers. These vessel types correspond to the categories A11, A12, A13, A14 and A35, A36, A37 in the classification used by Entec.

Exhaust emissions of NO_x, SO_2, VOC, PM and CO_2 from auxiliary engines at berth become zero for the featured vessel types and flags. Emissions for the electricity production replacing the power generation of the auxiliary engines at berth are calculated based on EU25 average emission factors provided in the preliminary Entec (2005) report except for CO_2. For CO_2 an EU25 average emission factor based on Primes has been used[8].

We assume that all ships having shore side facilities can use those at berth. We do not take into account the fact that ships occupying a berth can prevent arriving ships of using a shore side electricity berth place. The received Entec data provides no precise indication on the number of berths necessary to convert to make this assumption reasonable and acceptable.

We assume the conversion of 500 low cost berths as reasonable for the three policies. The sensitivity of the results of the policy simulations with respect to the number of berths is investigated, once for 250 berths converted, once for 1000 berths converted. We only take into account low cost berths. This is coherent with the vessel types equipped by the policy. For the ship types proposed, only low cost berths are necessary.

The number of small, medium and large berths to be installed is assumed to be proportional to the presence of small, large and medium vessels in the fleet.

The number of ships that need to be served by the berths based on growth rate of the fleet of 2.5% and a renewal rate of 4% is:

- For SSE1: between 698 in 2010 and 3743 in 2020;
- For SSE2: between 175 in 2010 and 939 in 2020;
- For SSE3: between 2717 in 2010 and 3482 in 2020.

[8] We took an average of the values for 2010, 2015 and 2020, i.e. 350 g/kwh.

The ship costs given in Table 6 also include the cost of electricity purchased in the port. An average EU15 electricity price is taken into account here.

For SSE2 we ideally need data on port callings of large ships. These are not available. We assume emission reductions of ships at berth with large auxiliary engines proportional to the part of their engine capacity in the total engine capacity. This means that this policy realizes 36% of the emission reduction in comparison to a similar policy applied to the whole EU fleet of tankers, RORO ships and passenger ships. This emission reduction is probably an overestimation as large ships spend probably less time at berth compared to small ships.

This is a policy simulation with a **high degree of uncertainty** due to the high uncertainty in the estimation of the installed auxiliary engine capacity. Another element of uncertainty is the absence of indications on port callings in function of the size of the ship. We can reasonably assume that small ships are more often used for smaller distances and therefore spend more time at berth than large ships. The emission gains will therefore probably be overestimated.

II.2.2. Results

The results can be found in the table below.

Table 7: Emission reductions and costs of shore side electricity policies

Policy	N/R	Flag	NO_x	SO_2	PM	CO_2	VOC	Ratio 1	Benefit
SSE1	N	All	233 519 0.63 %	388 0.00 %	5 821 0.19 %	7 339 976 0.40 %	8 193 0.56 %	2.0	1 442
SSE2	N	EU	50 016 0.13 %	83 0.00 %	1 247 0.04 %	1 572 102 0.09 %	1 755 0.12 %	1.3	152
SSE3	N+R	EU	502 690 1.35 %	826 0.00 %	12 386 0.40 %	15 616 622 0.86 %	17 432 1.18 %	6.4	3 963

The different columns in Table 7 represent the following:

- Policy specifications (columns 1-3):
  - policy name;
  - policy applying to new build ships (N), retrofitting of ships (R) or policy for both (N+R);
  - policy for all ships (All) or only for EU ships (EU).
- Absolute and relative emission reductions, totals over the 2010-2020 period and over all sea regions. Absolute emission reductions are in tonnes. Relative emission reductions are relative to the base case[9].
- The ratio (ratio 1) between the reductions in external costs and the financial costs of the policy in 2010 and 2020. This is an indication for the cost per unit reduction of external costs. The financial costs are not actualised as the physical reductions are not actualised neither.
- The cost per ton of pollutant abated in Euro per ton (ratio 2)[10].

[9] Base case emissions indicated in the table are those used for the LSF policies. SO_2 and PM emission are slightly lower than in the base case used for the other policy simulations. This is of no importance in the calculation of the welfare gains for the NO_x reducing policies.

[10] The costs per ton abated here are higher than the figures given in the Entec (2005) draft report for the policies implementing technological measures (policy 1 to 17). Several factors contribute to the explanation of this difference:

- The figures in the table do not take into account the emission reductions in non-EU waters .

- The net benefit over the period thanks to the policy. This net benefit (welfare increase) is the sum of the actualised benefits of the different years of the simulation. The welfare is calculated as the difference between emission reductions and financial costs.

The SSE policies have only minor impacts and they are rather expensive for the emission reductions they offer compared to other policy options.

II.3. NO_x abatement policies

Twelve policies are simulated with different technologies and applied to different groups of ships depending on flag and new or existing ships.

- Slide valves (SV): Exchanging the conventional fuel valves with low NO_x valves. This measure is only applicable for slow speed two stroke engines. This technique is also called basic internal engine modification.

- Internal engine modification (IEM): Different types of "advanced" IEM, beyond fuel injection modifications are under development.

- Water vapour humidification (WV): The Humid air motor concept uses heated charge air enriched with evaporated seawater to reduce NO_x formation during the combustion process.

- Direct water injection (DWI): The combustion chamber is cooled before combustion commences by injecting fresh water. The NO_x formation is thereby reduced.

- Selective catalytic reduction (SCR): The SCR process relies on injecting an urea solution into an exhaust gas stream in combination with a catalyst housing in the exhaust channel.

II.3.1. Assumptions

II.3.1.1. Slide valves

Slide valves are **already installed** on new vessels since the year 2000. The base case takes into account the uptake of slide valves by all new vessels. Retrofitting means therefore only an acceleration of the installation of slide valves. Accelerating the installation implies also that the emission reduction and the user costs decrease over time. Once ships are replaced, costs are the same as those of the base case.

A conservative **NO_x reduction** of 20% for SSD2 stroke medium and large main engines (ME) have been taken into account for this policy simulation. Entec assumed there was not enough evidence for also taking into account emission reductions of other pollutants.

The Entec base case emission factors we use do not take into account explicitly the installation of slide valves on new vessels since 2000. They take into account slide valves implicitly by using a decreasing emis-

- The vehicle kilometres are probably underestimated as mentioned earlier in the report. Emissions and emission reductions are proportional to the vehicle kilometres in the TREMOVE model.
- The share of new ships takes the renewal of the fleet into account (4%) and the yearly expansion of the fleet (2.5%). The increase of the fleet is not taken into account as by Entec. Costs, not vehicle kilometres are dependant on the number of ships in the TREMOVE modelling.

sion factor for the Marpol agreement. As a consequence the base case takes already into account the uptake of slide valves by all new vessels. For this reason, the emission reduction potential is rather small and decreases from 2010 to 2020.

Concerning costs, the only relevant costs are those for retrofitting in the simulation case. The costs of installing slide valves for the renewal of the fleet and the increase of the fleet are already present in the base case. They are therefore not taken into account in any scenario calculation.

The Entec report provides a different **cost** for young engines (built after 1990) and older engines (built in 1990 or before). The cost estimation for the older engines is rather uncertain. The cost we use as input in our model for the simulation is a weighed average of these costs. We assume therefore the engines being replaced in the simulation case in 2010 will be 1/5 old engines and 4/5 young engines (retrofit). The cost we apply in accordance with this assumption are 1755.8 euro for medium vessels and 3554.8 euro for large vessels. The retrofit costs for the total fleet decreases over time as part of the ships are replaced every year. Once they are replaced, we have costs similar to the base case and do not take them into account any longer.

The Entec report gives no indication on uncertainties, but we assume that the uncertainty margins here are small as the use of slide valves is widely spread.

II.3.1.2. Internal engine modifications

Cost and emission reduction estimations have a low degree of certainty as advanced internal engine modifications are not operational yet. Emission reductions are estimated at 30% which is a conservative estimate. The estimations used for the annual costs are given in Table 6.

II.3.1.3. Water vapour humidification

Costs and emission reductions are **highly uncertain**. At present, only four installations are in commercial use onboard a passenger ferry which makes it difficult to get a representative view.

The annualised costs for water vapour humidification technology used in the simulation are given in Table 6. The emission reduction estimate proposed by Entec is a conservative estimate of **70%**.

II.3.1.4. Direct water injection

Cost and emission estimations are relatively certain for new build vessels. Costs are given in Table 6. Emission reduction is set at 50%.

II.3.1.5. Selective catalytic reduction

The **cost estimations** for the installation of this technology have a relatively high degree of certainty. They are dependant on the sulphur content of the fuel used by the ships. As a consequence, costs are also dependant on the sea regions where the ships move as some sea regions are low sulphur areas .

More than 98% of the EU fleet and world fleet uses residual oil (RO) according to Entec[11]. Therefore, in the simulation we assume all ships use RO and apply the costs for ships using RO.

To take into account the different costs in different sea regions, we calculate an average of costs in low sulphur sea regions and other sea regions weighed in accordance with the vessel kilometres in the respective areas. Low sulphur zones considered here are the North Sea, the Baltic Sea and the English Channel. The applied annualized costs are given in Table 6 once for EU ships and once for a world fleet ship. They are based on the figures of the Entec report. The table shows that the costs are lower for EU ships than for the whole fleet. This means that EU ships move proportionally more in low sulphur areas.

The **emission reduction** percentage for NO_x taken into account is 90%. Reductions for other pollutants have not been taken into account.

II.3.2. Results

Table 8 : NO_x abatement policies : Emission reductions and costs

Policy	N/R	Flag	NO_x		Ratio 1	Ratio2	Benefit
			Tonnes	%			
SV4	R	All	949 521	2.54%	15.4	217	2965
SV5	R	EU	449 374	1.20%	26.8	174	1436
IEM6	N	All	3 085 144	8.27%	15.4	331	9373
IEM7	N	EU	1 498 041	4.01%	31.6	159	4656
WV8	N	All	7 198 669	19.29%	3.0	1676	15717
WV9	N	EU	3 495 430	9.36%	5.9	854	9321
WV10	N+R	EU	12 685 932	33.99%	5.2	967	34886
DWI11	N	All	5 141 907	13.78%	2.0	2602	8201
DWI12	N	EU	2 496 736	6.69%	3.8	1337	5891
SCR13	N	All	9 255 432	24.80%	1.3	4044	6289
SCR14	N	EU	4 494 124	12.04%	2.5	2025	8640
SCR15	N+R	EU	16 310 484	43.70%	2.4	2102	32306

The different columns in Table 8 represent the following:

- Policy specifications (columns 1-3):
    - policy name;
    - policy applying to new build ships (N), retrofitting of ships (R) or policy for both (N+R);
    - policy for all ships (All) or only for EU ships (EU).
- Absolute and relative emission reductions, totals over the 2010-2020 period and over all sea regions. Absolute emission reductions are in tonnes. Relative emission reductions are relative to the base case.[12]
- The ratio (ratio 1) between the reductions in external costs and the financial costs of the policy in 2010 and 2020. This is an indication for the cost per unit reduction of external costs. The financial costs are not actualised as the physical reductions are not actualised neither.

---

[11] Whall C., Cooper D., Archer K., Twigger L. Thurston N., Ockwell D., McIntyre A., Ritchie A. (2002) *Quantification of emissions from ships associated with ship movements between ports in the European Community, Entec,* Final report to EC – DG Environment.

[12] Base case emissions indicated in the table are those used for the LSF policies. SO_2 and PM emission are slightly lower than in the base case used for the other policy simulations. This is of no importance in the calculation of the welfare gains for the NO_x reducing policies.

- The cost per ton of pollutant abated in Euro per ton (ratio 2).[13] For the sulphur abatement policies the ratio takes only sulphur reductions into account.
- The net benefit over the period thanks to the policy. This net benefit (welfare increase) is the sum of the actualised benefits of the different years of the simulation. The welfare is calculated as the difference between emission reductions and financial costs.

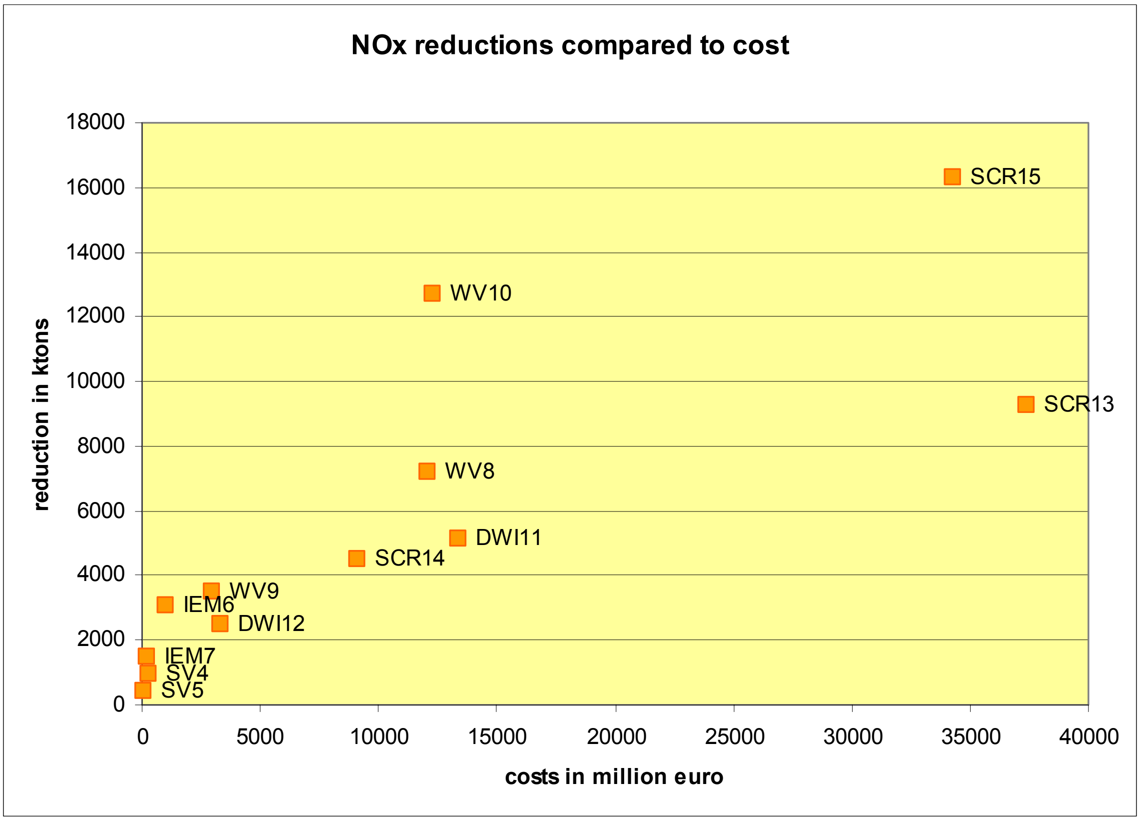
The **cheapest policies** to reduce NO_x are the policies SV4 to IEM7 (slide valves and internal engine modification). The gains for the SV5 policy in 2010 are 34 times higher than the costs for example.

For SCR13 and SCR15 we observe similar costs with for the latter an important share of retrofit costs. The reductions of SCR15 (only EU flagged ships) are much more important. If the use of low sulphur fuel is generalised, the costs of implementing SCR will also fall and the SCR technology will become more attractive.

The **reduction potential** for these policies is nevertheless limited. The SV5 policy procures the lowest emission reduction of all specific NO_x reducing policies (SV4 to SCR15). The highest absolute NO_x reductions are obtained through policies 10 and 15 (water vapour humidification and selective catalytic reduction with retrofit).

This can also be seen on the graph below.

Figure 1: Comparison of physical NOx reductions and financial costs



[13] As for the other simulations, The costs per ton abated here are higher than the figures given in the Entec (2005) draft report for the policies implementing technological measures (policy 1 to 17). For the slide valves policy, the reduction potential is limited as the base case takes into account already the uptake of slide valves for new vehicles. For example 4% of the retrofitted fleet in 2010 would have been replaced in 2011, so costs have been incurred, but reductions have only been there for one year.

Also the **welfare gains** of the two latter policies are the most important of all the simulated NO_x policies. The welfare gain of WV10 is bigger than that of SCR15 unless a considerable lower reduction in NO_x emissions. The high costs for ship owners to install the selective catalytic reduction technology is the reason. The WV10 welfare gain is still significantly lower than that of the LSF19 policy.

Retrofit policies have in general a higher cost per unit of external cost reduction. They generate nevertheless a larger welfare increase thanks to higher emission reductions.

Policies applied to **EU ships** are cheaper per unit reduction of external costs (except SSE2, see below). The reason is that EU ships sail on average more km in EU waters and call more European ports than non-EU flagged ships. On the other hand, one could argue that costs for non-EU ships should not be taken into account in a welfare assessment for the EU. From that point of view, forcing non-EU flagged ships to comply with a policy should only generate benefits.

II.4. SO_2 abatement policies

Five policies are modelled, two based on sea water scrubbing, three with low sulphur fuel.

- Sea water scrubbing (SWS): Sea water "scrubs" the exhaust gas and removes the sulphur dioxide from it.
- Low sulphur fuels (LSF): Emission of sulphur dioxide is reduced thanks to the use of fuels containing less sulphur.

II.4.1. Assumptions

II.4.1.1. Sea water scrubbing

The annualised costs proposed in the Entec report and used in the simulation are given in Table 6. These costs will be applied to 50% of the EU fleet. SO_x and PM emission reductions are respectively 75% and 25%. Only 50% of these reductions will be reached as the policy applies only to 50% of the fleet.

II.4.1.2. Low sulphur fuels

For passenger vessels we used the categories A36 Passenger RO-RO cargo and A37 Passenger. The LSF18 is our base case situation. As a consequence, no particular simulation is done for LSF18.

For these simulations we modified the base case. We adapted the emission factors from Entec to take into account 0.1% S fuel in ports at berth and during manoeuvring not only for the auxiliary engines but also for the main engine in the base case. We assumed that 0.1% S fuel can only be reached by using marine diesel in stead of residual oil. Therefore also PM and CO_2 and fuel consumption are adapted (reduced)[14].

The extra cost for low sulphur fuels is calculated by multiplying the specific fuel consumption by the fuel premium. The fuel premiums used are given in the table below:

[14] Simulations 1 till 17 have been done with the initial Entec (Entec, 2005) emission factors which take 0.1% S fuel only into account for auxiliary engines at berth in port. (see also **Error! Reference source not found.** Low sulphur fuel in ports in the general comments)

Table 9: Fuel premiums per ton for switching to low sulphur fuels

Applied fuel premiums per ton	
fuel switching 2.7 to 1.5 % RO	30 euro
fuel switching 2.7 to 0.5 % RO	75 euro
fuel switching 1.5 to 0.5 % RO	45 euro

By applying these premiums, we assumed that all fuel used is 1.5% S fuel in the low sulphur areas and 2.7% S fuel in the other areas. This means a small overestimation as a limited number of ships use already low sulphur fuels now.

We used the relative emission reductions for PM and SO_2 sea emissions presented in the table below. The Entec report provided the reduction percentages. The fuel switching from 1.5% to 0.5% was calculated by TML.

Table 10: Relative emission reductions for switching to low sulphur fuels

Relative emission reductions	SO_2	PM
fuel switching 2.7 to 1.5 % RO	44%	18%
fuel switching 2.7 to 0.5 % RO	81%	20%
fuel switching 1.5 to 0.5 % RO	66%	2%

For LSF19 and LSF20 no changes in port emissions are accounted for as the 0.1% fuel is already present in the base case.

II.4.2. Results

The results can be found t-in the table below.

Table 11 : SO_2 abatement policies: emission reductions and costs

Policy	N/R	Flag	SO_2		PM		Ratio 1	Ratio 2	Benefit
			Tonnes	%	Tonnes	%			
SWS16	N	EU*	2 335 948	10.15%	106 832	3.42%	6.2	1 540	5 934
SWS17	N+R	EU*	8 382 688	36.43%	383 416	12.28%	4.6	2 083	20 983
LSF19	N+R	All	17 595 642	76.46%	452 808	14.51%	4.2	1 881	69 335
LSF20	N+R	All	7 622 299	33.12%	389 787	12.49%	5.0	1 286	26 186
LSF21	N+R	All	792 480	3.44%	-35 188	-1.13%	4.0	2 712	3 565

* For the SWS policies, emission reductions have been doubled compared to the simulated policy to facilitate comparison between policies.

The different columns in Table 11 represent the following:

- Policy specifications (columns 1-3):
    - policy name;
    - policy applying to new build ships (N), retrofitting of ships (R) or policy for both (N+R);
    - policy for all ships (All) or only for EU ships (EU).
- Absolute and relative emission reductions, totals over the 2010-2020 period and over all sea regions. Absolute emission reductions are in tonnes. Relative emission reductions are relative to the base case.[15]

[15] Base case emissions indicated in the table are those used for the LSF policies. SO_2 and PM emission are slightly lower than in the base case used for the other policy simulations. This is of no importance in the calculation of the welfare gains for the NO_x reducing policies.

- The ratio (ratio 1) between the reductions in external costs and the financial costs of the policy in 2010 and 2020. This is an indication for the cost per unit reduction of external costs. The financial costs are not actualised as the physical reductions are not actualised neither.
- The cost per ton of sulphur abated in Euro per ton (ratio 2).[16] Other emissions are not included here.
- The net benefit over the period thanks to the policy. This net benefit (welfare increase) is the sum of the actualised benefits of the different years of the simulation. The welfare is calculated as the difference between the sulphur emission reductions and financial costs.

The LSF19 policy generates clearly the highest benefits, thanks to a high reduction in SO_2 emissions. The monetized benefit amounts to more than 80 000 million euro with reasonable costs. The welfare gain for this policy is the highest of all the 20 simulated policies.

The LSF21 policy has the particularity that it increases PM emissions, due to a very small assumed PM emission difference between 1.5 and 0.5 % S fuel.

II.5. Overview of results

II.5.1. Summary

A summarising graph and tables are presented below.

The graph represents for all the policies the actualized monetized costs and benefits of the policies in million euros over the 2010-2020 period. Monetized values have some advantages compared to physical units although the valuation of external costs is not always easy.

- Effects of emission reductions depend on the place where they take place. Emissions in coastal seas, in port or in deep sea have completely different effects. The monetization valuation of the physical emissions takes this into account.
- The emission reduction figures do not account for a preference for reductions in the near future compared to the further future. The monetized values account also for this time preference.

[16] As for the other simulations, the costs per ton abated here are higher than the figures given in the Entec (2005) draft report for the policies implementing technological measures (policy 1 to 17). For the low sulphur policies (19-21), the Entec costs per ton abated are higher. This is due to the fact that the number of vessels does not intervene in this calculation and that the premium used in the TREMOVE simulation is lower than that used by Entec.

Figure 2: Actualized monetized costs and benefits for different policy scenarios 2010-2020, in million euro, highest set of external values -

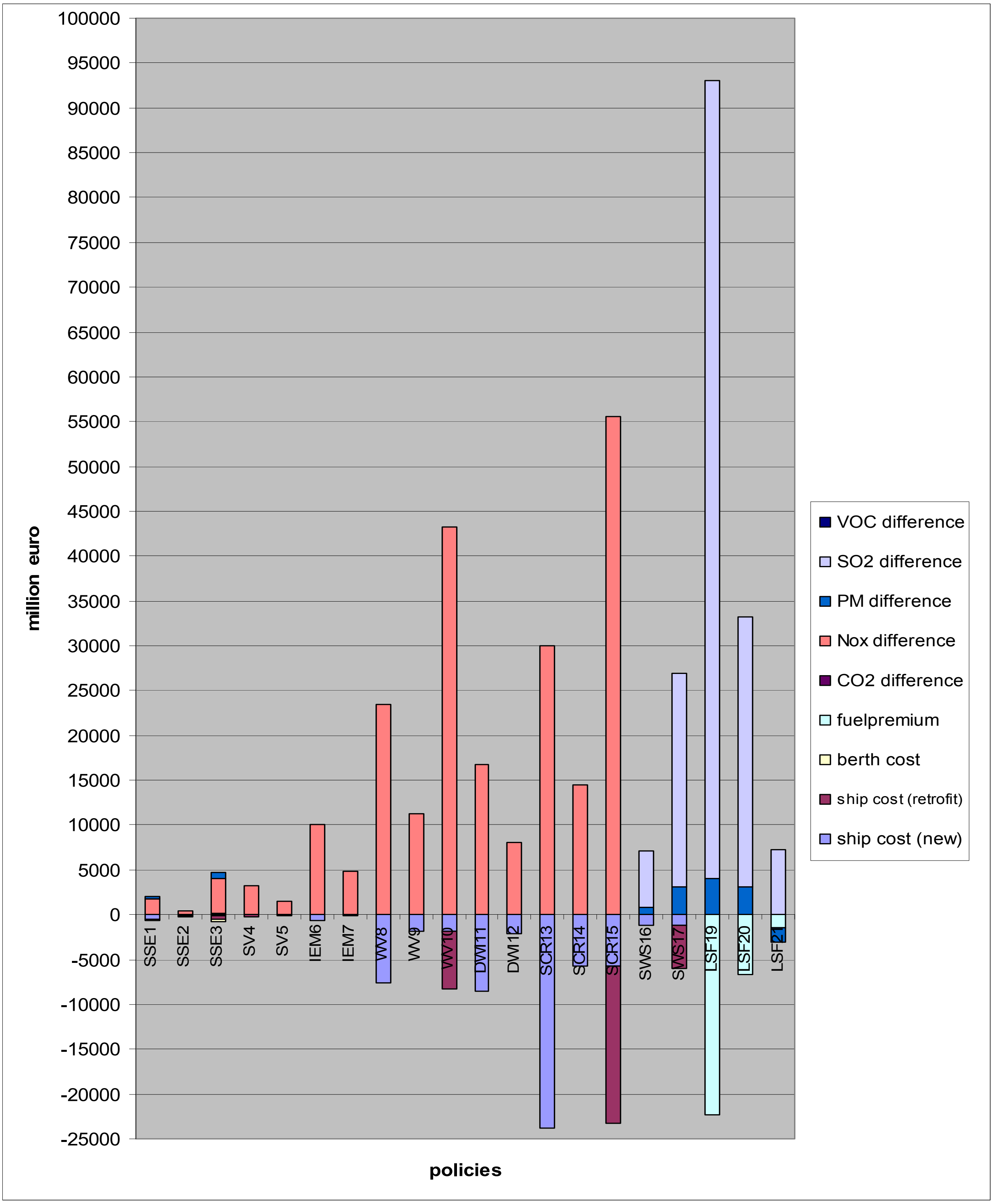


Table 12: Base case emissions, 2010-2020 total, all sea regions, tonnes

NOx	SO2	PM	CO2	VOC
37 325 871	23 011 698	3 121 722	1 819 072 462	1,472,967

SSE policies

The SSE policies have only minor impacts and they are rather expensive for the emission reductions they offer.

NO_x reducing policies

The cheapest policies to reduce NO_x are the policies SV4 to IEM7 (slide valves and internal engine modification). The gains for the SV5 policy in 2010 are 34 times higher than the costs for example. For SCR13 and SCR15 we observe similar costs with for the latter an important share of retrofit costs. The reduction potential for these policies is nevertheless limited.

The welfare gains of the policies WV10 and SCR15 are the most important of all the simulated NO_x policies. The welfare gain of WV 10 is bigger than that of SCR 15 unless a considerable lower reduction in NO_x emissions. The high costs for ship owners to install the selective catalytic reduction technology is the reason. The WV10 welfare gain is still significantly lower than that of the LSF 19 policy.

Retrofit policies have in general a higher cost per unit of external cost reduction. They generate nevertheless a larger welfare increase thanks to higher emission reductions.

Sulphur reduction policies

The LSF19 policy generates clearly the highest benefits, thanks to a high reduction in SO_2 emissions. The monetized benefit amounts to more than 80 000 million euro with reasonable costs. The welfare gain for this policy is the highest of all the 20 simulated policies.

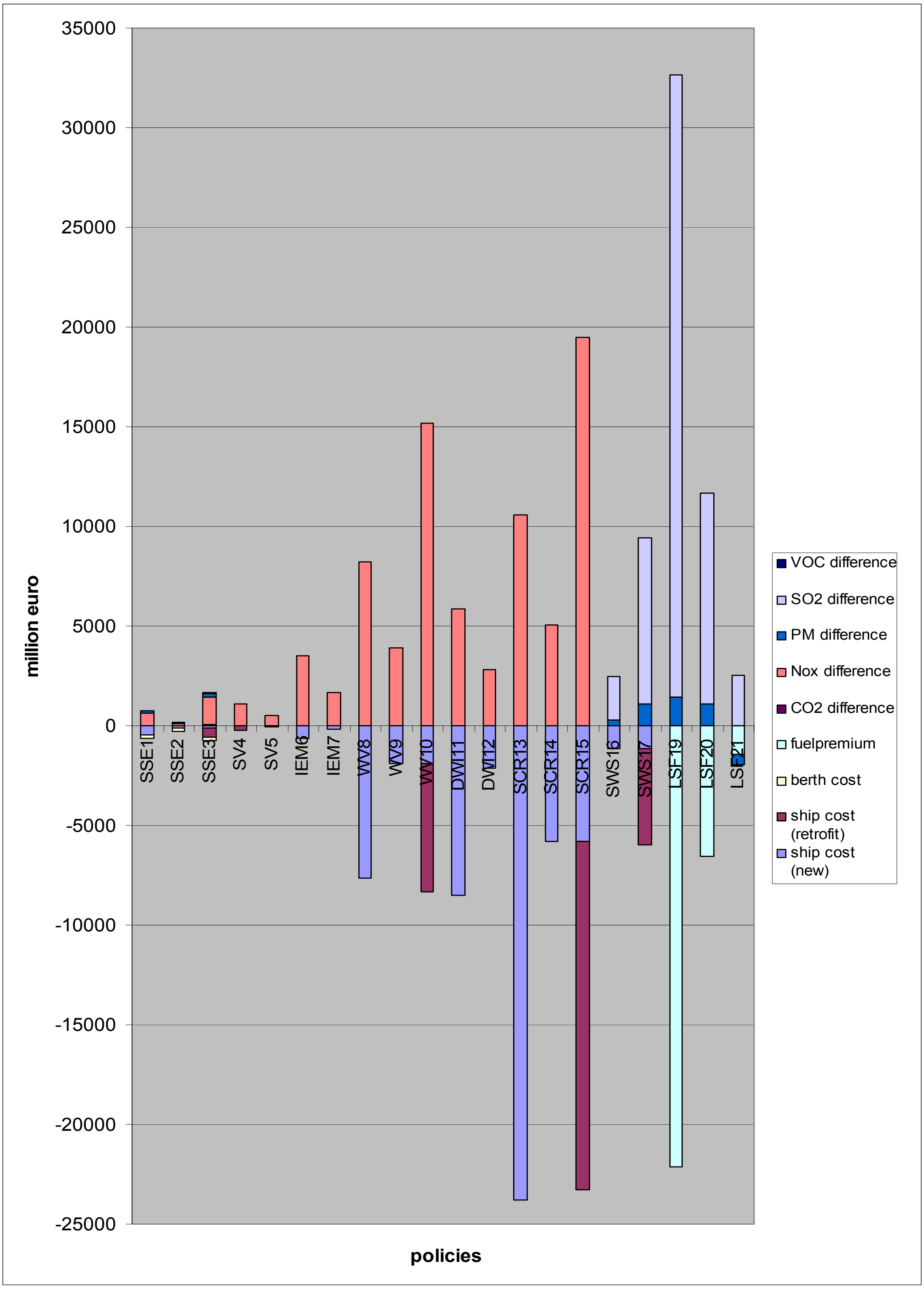
II.5.2. Sensitivity analysis

The **choice of values for the external cost valuation** of the emission reductions influences the results. The chosen values are based on the highest estimates in the BeTa (benefits table) database provided by the CBA team within the CAFE programme. Using lower BeTa values reduces the welfare gains of the policies.

Below, the same graph as represented under paragraph II.2 is presented. Now it is based on values for external costs, which are 2.85 times lower than those used in the previous graph. This is an approximation for the lower set of external values provided in the BeTa table.

The relative importance of user costs is growing. It becomes also clear that several policies do no longer increase welfare. The first two shore side electricity policies (SSE1 and SSE2), the first direct water injection policy (DWI11) and the three selective catalytic reduction policies get negative welfare values by using the lower set of external cost values.

Figure 3: Actualized monetized costs and benefits for different policy scenarios 2010-2020, in million euro, lowest set of external values



II.6. Possible improvements in maritime policy modelling

The simulation results discussed in this report are the best possible outcomes with the input available and the actual version of the TREMOVE model. Improvements in the input data and in the model are nevertheless possible. In this section some possibilities for future improvements in the input data and the model are indicated.

II.6.1. Possible improvements in input data

External costs used for port emissions are the country specific values provided by the cost benefit analysis team within the Clean Air For Europe Programme. For sea emissions, specific cost estimates have been provided, though these are not available for each sea region. Therefore assumptions had to be made. Especially the external costs for 'rest of EMEP' are only a rough estimation. In general, both for port and deep sea emissions external cost estimates could be improved.

The actual vehicle kilometres provided by Entec decreased as a whole around 15% compared to their previous set of input figures. This is due to the changed methodology used by Entec to derive vehicle kilometres. Entec is nevertheless aware that still not all movements are actually covered due to missing information in the underlying data. With extra research, this uncertainty with respect to the vehicle kilometres might be reduced.

On engine capacities, especially for auxiliary engines, Entec now dealt with missing data in a different way compared to previous estimates. These estimates remain nevertheless very uncertain. They are 7 times higher compared to previous Entec input datasets.

The TREMOVE model is able to apply different reduction factors for different engine types. Actually, only one general averaged reduction factor is provided for all engine types. Introducing different reduction factors in function of engine types could increase the accuracy of the model outputs.

II.6.2. Model specifications

The TREMOVE maritime model calculates emissions of maritime transport. The driving factors for these calculations are the vehicle kilometres and emission factors for different pollutants in function of engine types.

The vehicle kilometres are exogenous inputs. They are, for example, not influenced by a change in cost for shippers. Though in reality demand for short sea shipping is influenced by its relative price compared to long distance transport over land. Stringent emission regulations could lead to substitutions between short sea and land-based transport. Modelling substitution processes between short-sea and land-based transport could therefore be a significant improvement of the model. This would require an extension of the demand module and a desaggregation of the current maritime vehicle kilometres dataset into short sea and deep sea transport..

References

De Jonge E., Hugi C., Cooper D. (Entec, 2005) *Service Contract on ship emissions : assignment, abatement and market-based instruments, task* 2 – general report, report to EC – DG Environment.

De Jonge E., Hugi C., Cooper D. (Entec, 2005) *Service Contract on ship emissions : assignment, abatement and market-based instruments, task 2a - shore side electricity in ports*, report to EC – DG Environment.

De Jonge E., Hugi C., Cooper D. (Entec, 2005) *Service Contract on ship emissions : assignment, abatement and market-based instruments, task 2b – NOx abatement technologies*, report to EC – DG Environment.

De Jonge E., Hugi C., Cooper D. (2005) *Service Contract on ship emissions : assignment, abatement and market-based instruments, task 2c – Sea water scrubbing, report to EC* – DG Environment.

Friedrich R., Bickel P. (2001). *Environmental External Costs of Transport.*

Holland M., Hunt A., Hurley F., Navrud S., Watkiss P. (2005). *Final Methodology Paper (Volume 1) for Service Contract for carrying out cost-benefit analysis of air quality related issues, in particular in the clean air for Europe (CAFE) programme,* report to EC – DG Environment.

Proost S. (1997) *Economic evaluation of community options to limit* CO_2*,* SO_2 *and* NO_x *emissions at the horizon 2005 and 2010 – Transport Sector.* Internal report to EC.

Proost S., Van Regenmorter D. (1999) *Are there cost-efficient* CO_2 *reduction possibilities in the transport sector? – Combining two modelling approaches.* International Journal of Pollution Control, Vol 11 n°23.