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## **NEEDS**

# **New Energy Externalities Developments for Sustainability**

## **INTEGRATED PROJECT**

*Priority 6.1: Sustainable Energy Systems and, more specifically,  
Sub-priority 6.1.3.2.5: Socio-economic tools and concepts for energy strategy.*

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#### **1.6b. IMPACTS FROM OIL TRANSPORTATION PHASE OF OIL BY PIPELINE AND FROM OIL EXTRACTION**

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## **Abstract**

This report collects the relevant information regarding the operational impacts related to oil extraction and those related to oil transportation by pipeline and tanker route. Only for crude oil transportation by tanker it was possible to report publicly available Life Cycle Inventory data on emissions. For other impacts (and as an alternative source, for oil tankers as well) a proprietary database was used, whose emissions data could not be disclosed. In these cases the analysis is summarised by combining emission factors of the major pollutants (NO<sub>x</sub>, SO<sub>2</sub>, volatile organic compounds, greenhouse gasses) per unit of oil produced or transported at regions relevant for oil import to Europe, by the corresponding externality per ton of pollutant used in NEEDS. Externality values for local pollutants take into account health impacts, environmental impacts, and impacts on crops and materials, while those for greenhouse gasses are marginal damage costs computed by an ad hoc model. Externality values are found to be non negligible, but very sensitive to the quality of the LCI data used. This is shown by comparing the externality values for oil tankers resulting from the proprietary database with those resulting from the application of a publicly available LCI model for maritime transportation.

## Table of Contents

Abstract .....	2
Table of Contents .....	3
Figures and Tables in the Text.....	3
1. Introduction.....	4
2. Oil extraction.....	5
3. Oil Transportation .....	11
4. Concluding Remarks.....	16
5. References.....	17
Annex 1. Emissions and Externalities from alternative tanker configurations.....	19

## Figures and Tables in the Text

Table 1 Oil Spills Reported in UK, 1991 – 2000.....	6
Figure 1 Oil discharged from British platforms, 1991-2000 data and linear projections. ....	6
Figure 2 Total Amounts of Petroleum Inputs in the Worldwide Marine Environment. Sources: National Research Council, 1975, 1985, 2002.....	7
Table 2 Unit External Costs [Euro per Ton] non –GHG emissions from crude oil, at production, offshore and onshore, in 2010.....	8
Table 3 Unit External Costs [Euro per Ton] non –GHG emissions from crude oil, at production, offshore and onshore, in 2020.....	9
Table 4 Unit External Costs [Euro per Ton] GHG emissions from crude oil, at production offshore .....	10
Table 5 Averaged Unit External Costs [Euro per Ton] GHG emissions from crude oil, at production. Weights vary with year and scenario.....	10
Table 6 Unit External Costs [Euro per Ton]. Emissions from crude oil transport, by long distance pipeline, NMVOC and GHG-emissions in 2010, 2020 and 2030, Russia.....	11
Table 7 Unit External Costs [Euro per Ton.Km], non- GHG emissions from Tanker operations. Source: Own elaboration on Ecoinvent and Ecosense data. ....	12
Table 8 Unit External Costs [Euro per Ton.Km], GHG emissions from Tanker operations. Source: Own elaboration on Ecoinvent and Ecosense data. ....	12
Table 9. Unit emissions from oil tankers fuelled mainly with low sulphur oil. Source: own computations from TEAMS model output.....	14
Table 10 Unit External Costs [Euro per Ton.Km] for non-GHG emissions from oil transportation by tanker in 2010. Source: Own elaboration on TEAMS and Ecosense data.....	14
Table 11 Unit External Costs [Euro per Ton.Km] for non-GHG emissions from oil transportation by tanker in 2020. Source: Own elaboration on TEAMS and Ecosense data.....	15
Table 12 Unit External Costs [Euro per Ton.Km] for GHG emissions from oil transportation by tanker, in 2010, 2020, 2030. Source: Own elaboration on TEAMS and Ecosense data.....	15

# IMPACTS FROM THE TRANSPORTATION PHASE OF OIL BY PIPELINE AND FROM OIL EXTRACTION

## **1. Introduction**

The aim of this report is to complete the analysis impacts of the oil production chain.

This report will try and collect the relevant information regarding to the operational impacts related to oil extraction and those related to oil transportation by pipeline and tanker route. Probabilistic impacts are covered in Deliverable 1.7b.

Only for crude oil transportation by tanker it was possible to report publicly available Life Cycle Inventory data on emissions. For other impacts (and as an alternative source, for oil tankers as well) a proprietary database was used, whose emissions data could not be disclosed. In these cases the analysis is summarised by combining emission factors of the major pollutants (NO<sub>x</sub>, SO<sub>2</sub>, volatile organic compounds, greenhouse gasses) per unit of oil produced or transported at regions relevant for oil import to Europe, by the corresponding externality per ton of pollutant used in NEEDS. These externality values take into account health impacts, environmental impacts, and impacts on crops and materials. Moreover, they are differentiated according to the dispersion and deposition patterns of emissions originated in various regions in Europe and surrounding regions. Unit emission factors are taken from Ecoinvent<sup>1</sup> or for oil tankers are derived using the model TEAMS; externalities per ton of pollutant are taken from Ecosense. Externality values are found to be non negligible, but very sensitive to the quality of the LCI data used. This is shown by comparing the externality values for oil tankers resulting from the proprietary database with those resulting from the application of a publicly available LCI model for maritime transportation. Externality values for local pollutants take into account health impacts, environmental impacts, and impacts on crops and materials, while those for greenhouse gasses are marginal damage costs computed by an ad hoc model.

The rest of this report is organised as follows. Section 2 looks at oil extraction. Section 3 looks at oil transportation, and Section 4 concludes.

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<sup>1</sup> Ecoinvent data have been provided by POLITO

## 2. Oil extraction

Ordinary oil extraction activities at offshore and onshore facilities generate different impacts on human health and the environment. Air emissions generated by the two kinds of installation are similar in their consequences on the environment and human health, but offshore platforms generate emissions which are more easily dispersed before they can cause damages. Also, operational spillages from offshore platforms get easily dispersed by currents, while those onshore pollute a limited area around the rig.

Offshore crewed platforms generate **domestic waste** associated with day-to-day living; throwing this waste directly into the sea is usually the most convenient and cost-effective form of disposal for the crew. Garbage bags thrown overboard can pose a threat to local wildlife as well as divers that work in the area. Waste can accumulate on the sea floor surrounding long-lived platforms. Human waste is generally not a major issue for onshore installation, as it can be disposed of much in the same way as analogous waste generated in the region.

Further effects of oil offshore operations are the leaching of **heavy metals** that accumulate in buoyancy tanks into water; and risks associated with their disposal. There has been concern expressed at the practice of partially demolishing offshore rigs to the point that ships can traverse across their site; there have been instances of fishery vessels snagging nets on the remaining structures. The termination of onshore oil operations can leave behind heavily contaminate land, if the area is not restored properly. The focus of this report however is on the production and transportation phase; the damages associated to the disposal of abandoned installations is outside the scope of this report. Unfortunately the externality database used in this study do not cover wastes and heavy metals.

The impact in terms of **oil spillage**<sup>2</sup> of offshore operations is in general quite limited, and has been constantly declining overtime. Moreover, these infrastructures, at least in the North Sea, are usually installed at a considerable distance from the nearest coast, thus the impact of oil spillages (operational and accidental) from these installations can be regarded as negligible. Table 1 below illustrates the case of British platforms, and Figure 1 illustrates their trend.

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<sup>2</sup> Given the limited relevance of oil spillages, and the impossibility to tell them apart in the available data accidental and operational spillages are considered jointly.

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
<b>Total Oil Discharged with produced water (tonnes) (x)</b>	5490	4850	4232	4418	5855	5706	5767	5692	5641	5395
<b>Oil from oil-based mud spills</b>	116	49	145	74	29	28	38	35	3	0.05
<b>Other oil spills</b>	76	176	79	100	55	99	828	102	117	70.05.00
<b>Third Party Reports</b>										7 <sup>(9)</sup>
<b>Number of Installations Reporting Spills (y)</b>	39	43	43	50	52	77	96	101	112	117
<b>Total Number of Reports</b>	234	194	183	147	145	300 <sup>(3)</sup>	349 <sup>(3)</sup>	392 <sup>(3)</sup>	372 <sup>(3)</sup>	423 <sup>(3)</sup>
<b>Oil discharged per platform (x/y)</b>	140,77	112,79	98,42	88,36	112,60	74,10	60,07	56,36	50,37	46,11
<b>Oil discharged per platform (without discontinuity)</b>	140,77	112,79	98,42	88,36	80,00	74,10	60,07	56,36	50,37	46,11

Table 1 Oil Spills Reported in UK, 1991 – 2000

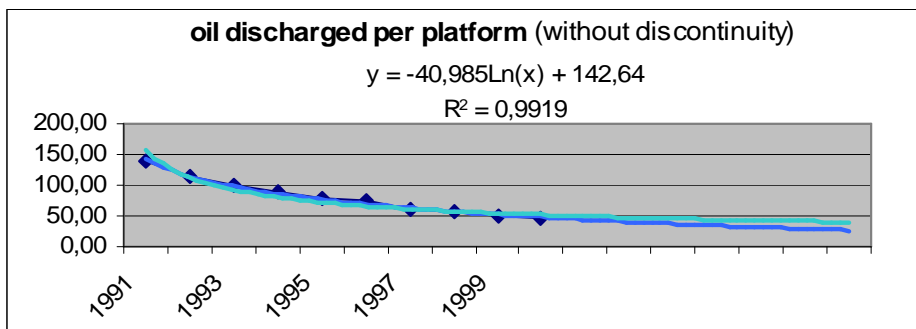
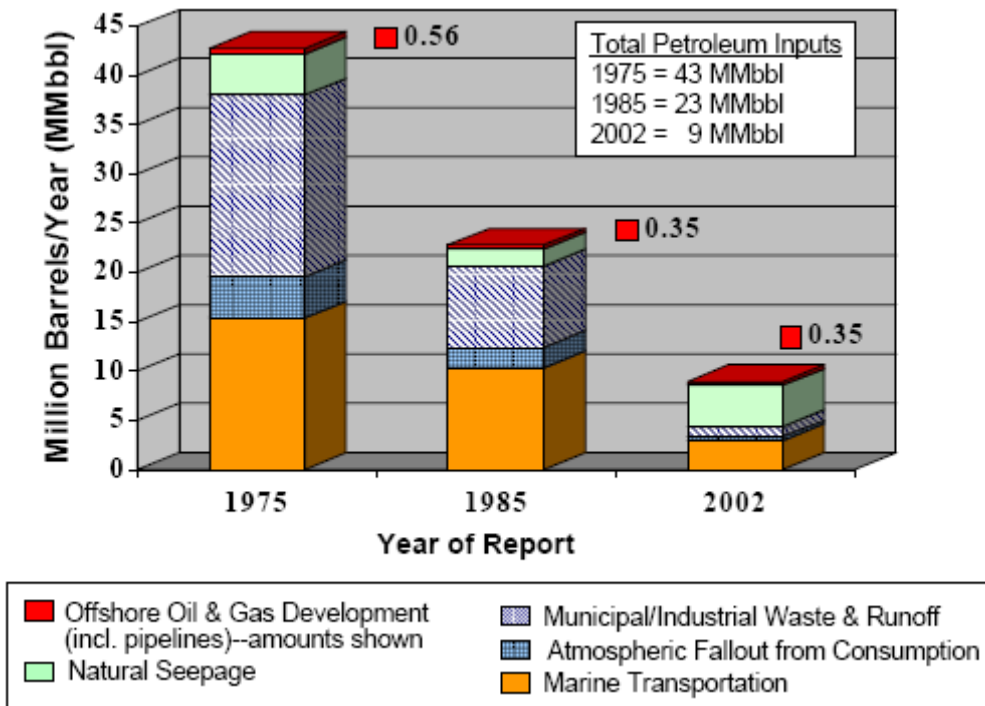


Figure 1 Oil discharged from British platforms, 1991-2000 data and linear projections.

This trend is fortunately not exclusive of the British platforms, as the following figure illustrates.



**Figure 2 Total Amounts of Petroleum Inputs in the Worldwide Marine Environment. Sources: National Research Council, 1975, 1985, 2002.**

Figure 2 clarifies that, worldwide, the relevance of oils spills from offshore platform has been declining since 1975, although it has stabilised since 1985. Moreover, its relative contribution to oil spillage in world’s seas is very little much lower than oil spills from marine transportation and even considerably lower than natural seepage of oil.

Oil extraction generates air and water emissions of pollutants. An extensive catalogue of unit emissions from this phase of the oil chain is available in the Ecoinvent database. Ecoinvent data are extracted from a proprietary database. Therefore they are confidential and cannot be reproduced as they appear in the database. In order to ensure their confidentiality and provide a result foreseen in any case by the project, these data have been combined with Ecosense data on externalities per ton of pollutant (which are also confidential). Their combined output will allow the protection of both databases while providing the relevant information about operational externalities. Externalities vary with the different regions in which operations take place, due to the different deposition patterns of the pollutants and hence the different socioeconomic and environmental characteristics of the regions exposed. Ecosense covers only continental Europe and surrounding regions, for Asian regions, unit externality values are proxied by the EU-27 average, as Krewitt (2002) shows similar exposition per unit of release in EU and Asia. This approximation is accurate only for human health impacts. For other impacts, we used values for the Mediterranean. This approximation is less accurate, but its impact on final estimates is very limited. Unfortunately

neither externality data nor reasonable proxies are available for unit externalities of Nigerian air emissions.

Unit externalities vary with time, as the socio-economic and ecological characteristics of the areas exposed vary with time. We used the most updated projections produced by NEEDS project. For non GHG pollutants, we used values for average height of release derived using EcoSenseWebV1.2 - 21.09.2007 (based on aggregation scheme "NEEDS\_core\_SIA" for Human Health Impacts, based on average meteorology - corresponding to emissions from all SNAP-Sectors). For GHG emissions external costs used are computed as Marginal Damage Costs of GHG, taken from MDC\_Anthoff\_V1.1 under the following assumptions: -"without equity weighting",-"average 1% trimmed", -"1% discounting". The exchange from US\$ to Euro corresponds to ca. 1.35\$ per €. More details can be found in Preiss (2007). The available projections cover 2010, 2020 and 2030 for GHG emissions, and 2010 and 2020 for non-GHG emissions. For the latter, 2020 values are used for 2030 as well.

	OFFSHORE				ONSHORE		
	Norway	The Netherlands	Uk Atlantic	UK north sea	Middle East	Russia	Africa
<i>Human Health</i>							
NMVOC	1,850E-09		3,006E-05	1,496E-04	1,007E-03	1,048E-02	9,284E-04
NO <sub>x</sub>	1,252E-10	7,749E-04	3,224E-03	8,701E-03	1,337E-01	1,468E-01	5,207E-02
PPM <sup>so</sup>			3,040E-05	1,789E-04	2,082E-03	7,084E-03	1,506E-03
PPM <sup>25</sup>					1,660E-01	2,442E-01	1,195E-01
SO <sub>2</sub>		1,853E-03	1,903E-05	5,672E-05	5,023E-01	6,934E-01	5,840E-01
<i>Loss of Biodiversity</i>							
NMVOC	-8,342E-05		-1,463E-06	-6,746E-06	-5,864E-05	-3,101E-04	-5,864E-05
NO <sub>x</sub>	3,074E-05	1,348E-04	5,608E-04	2,137E-03	1,233E-02	1,064E-02	1,233E-02
PPM <sup>so</sup>			0	0	0	0	0
PPM <sup>25</sup>					0	0	0
SO <sub>2</sub>		6,241E-05	6,409E-07	2,544E-06	5,969E-03	1,006E-02	5,969E-03
<i>Crops &amp; Material</i>							
NMVOC	6,859E-10		9,151E-06	5,547E-05	2,619E-04	4,658E-04	2,619E-04
NO <sub>x</sub>	-1,721E-12	1,031E-04	4,288E-04	-1,196E-04	3,704E-03	1,041E-02	3,704E-03
PPM <sup>so</sup>			0	0	0	0	0
PPM <sup>25</sup>					0	0	0
SO <sub>2</sub>		-3,105E-05	-3,189E-07	-5,364E-07	-2,707E-03	6,486E-02	-2,707E-03
<i>Total</i>							
NMVOC	2,452E-09		3,775E-05	1,983E-04	1,210E-03	1,064E-02	1,132E-03
NO <sub>x</sub>	1,542E-10	1,013E-03	4,214E-03	1,072E-02	1,497E-01	1,678E-01	6,811E-02
PPM <sup>so</sup>			3,040E-05	1,789E-04	2,082E-03	7,084E-03	1,506E-03
PPM <sup>25</sup>					1,660E-01	2,442E-01	1,195E-01
SO <sub>2</sub>		1,884E-03	1,935E-05	5,873E-05	5,056E-01	7,684E-01	5,873E-01

**Table 2 Unit External Costs [Euro per Ton] non –GHG emissions from crude oil, at production, offshore and onshore, in 2010**

	OFFSHORE				ONSHORE		
Country:	Norway	The Netherlands	Uk Atlantic	UK North Sea	Middle East	Russia	Africa
<i>Human Health</i>							
NMVOC	9,88E-10		1,09E-05	7,99E-05	4,53E-04	5,26E-03	2,26E-04
NO <sub>x</sub>	1,49E-10	7,46E-04	3,10E-03	1,04E-02	1,60E-01	1,92E-01	7,86E-02
PPM <sup>co</sup>			3,09E-05	1,78E-04	2,17E-03	7,08E-03	1,51E-03
PPM <sup>25</sup>					1,64E-01	2,44E-01	1,19E-01
SO <sub>2</sub>		1,90E-03	1,95E-05	6,64E-05	5,34E-01	7,90E-01	6,02E-01
<i>Loss of Biodiversity</i>							
NMVOC	-7,96E-05		-1,56E-06	-6,44E-06	-4,87E-05	-2,78E-04	-4,87E-05
NO <sub>x</sub>	3,05E-05	1,32E-04	5,49E-04	2,12E-03	1,20E-02	1,08E-02	1,20E-02
PPM <sup>co</sup>			0	0	0	0	0
PPM <sup>25</sup>					0	0	0
SO <sub>2</sub>		6,75E-05	6,93E-07	2,77E-06	6,88E-03	9,09E-03	6,88E-03
<i>Crops &amp; Material</i>							
NMVOC	4,21E-10		4,24E-06	3,40E-05	1,43E-04	2,49E-04	1,43E-04
NO <sub>x</sub>	5,62E-12	8,79E-05	3,66E-04	3,91E-04	4,96E-03	1,00E-02	4,96E-03
PPM <sup>co</sup>			0	0	0	0	0
PPM <sup>25</sup>					0	0	0
SO <sub>2</sub>		-2,64E-05	-2,71E-07	-8,31E-07	-3,45E-03	6,46E-02	-3,45E-03
<b>Total</b>							
NMVOC	1,33E-09		1,36E-05	1,07E-04	5,47E-04	5,23E-03	3,20E-04
NO <sub>x</sub>	1,85E-10	9,66E-04	4,02E-03	1,29E-02	1,77E-01	2,13E-01	9,55E-02
PPM <sup>co</sup>			3,09E-05	1,78E-04	2,17E-03	7,08E-03	1,51E-03
PPM <sup>25</sup>					1,64E-01	2,44E-01	1,19E-01
SO <sub>2</sub>		1,94E-03	1,99E-05	6,83E-05	5,38E-01	8,64E-01	6,06E-01

**Table 3 Unit External Costs [Euro per Ton] non –GHG emissions from crude oil, at production, offshore and onshore, in 2020.**

	OFFSHORE				ONSHORE		
	Norway	The Netherlands	Uk Atlantic	UK North Sea	Middle East	Russia	Africa
<b>2010</b>							
CO <sub>2</sub>	0	0	0	0	1,70E-01	5,40E-01	2,67E-01
CH <sub>4</sub>	4,01E-01	0	4,86E-05	4,86E-05	6,81E-04	2,72E-03	9,74E-04
N <sub>2</sub> O	1,49E-02	8,23E-03	3,42E-02	3,42E-02	8,90E-03	6,76E-02	1,57E-02
SF <sub>6</sub>	0	0	0	0	4,99E-07	1,23E-05	4,78E-06
<b>2020</b>							
CO <sub>2</sub>	0	0	0	0	1,83E-01	5,81E-01	2,88E-01
CH <sub>4</sub>	3,45E-01	0	4,18E-05	4,18E-05	5,86E-04	2,34E-03	8,38E-04
N <sub>2</sub> O	1,51E-02	8,34E-03	3,47E-02	3,47E-02	9,01E-03	6,85E-02	1,59E-02
SF <sub>6</sub>	0	0	0	0	5,02E-07	1,23E-05	4,81E-06
<b>2030</b>							
CO <sub>2</sub>	0	0	0	0	1,68E-01	5,33E-01	2,64E-01
CH <sub>4</sub>	3,09E-01	0	3,74E-05	3,74E-05	5,24E-04	2,09E-03	7,49E-04
N <sub>2</sub> O	1,24E-02	6,85E-03	2,85E-02	2,85E-02	7,40E-03	5,62E-02	1,31E-02
SF <sub>6</sub>	0	0	0	0	4,48E-07	1,10E-05	4,30E-06

**Table 4 Unit External Costs [Euro per Ton] GHG emissions from crude oil, at production offshore**

The results for offshore and onshore oil extraction are listed in Table 2 and in Table 4. The tables show that the impact of air emissions of offshore oil extraction is in general lower than those of onshore oil extraction, both for the low volumes emitted and for the distance from inhabited areas.

Table 5 lists the weighted average values of total externalities by pollutant. To keep our analysis as general as possible, we used a weighted average of onshore and offshore extraction externalities, where the weights in each year and in each scenario analyzed, are given by the shares in total European imports, of the various production areas for which it was possible to compute unit externality values (Middle East, Africa, Russia, Norway, the Netherlands and United Kingdom). Thus the results shown in Table 5 are based on six different sets of weights, capturing the relative relevance of the various production areas in each year and scenario.

	HIGH case			Low case		
	2010	2020	2030	2010	2020	2030
NMVOC	4,17E-03	2,64E-03	2,70E-03	4,08E-03	2,37E-03	2,72E-03
NO <sub>x</sub>	1,02E-01	1,41E-01	1,59E-01	1,01E-01	1,44E-01	1,59E-01
PPM <sup>co</sup>	3,18E-03	3,96E-03	4,22E-03	3,13E-03	3,73E-03	4,24E-03
PPM <sup>25</sup>	1,42E-01	1,60E-01	1,81E-01	1,40E-01	1,61E-01	1,81E-01
SO <sub>2</sub>	4,92E-01	6,07E-01	7,02E-01	4,85E-01	6,16E-01	7,01E-01
CO <sub>2</sub>	2,79E-01	3,64E-01	3,73E-01	2,74E-01	3,54E-01	3,74E-01
CH <sub>4</sub>	5,96E-02	4,14E-02	7,05E-03	6,20E-02	3,12E-02	7,99E-03
N <sub>2</sub> O	3,40E-02	4,19E-02	3,32E-02	3,36E-02	3,79E-02	3,35E-02
SF <sub>6</sub>	5,42E-06	7,12E-06	6,89E-06	5,30E-06	6,62E-06	6,95E-06

**Table 5 Averaged Unit External Costs [Euro per Ton] GHG emissions from crude oil, at production. Weights vary with year and scenario.**

### 3. Oil Transportation

Oil pipeline operations can cause negative impacts through the air emissions of compressors at the pumping stations that propel the oil along the pipeline, and through the air emissions due to the escaping of the volatile fractions of the hydrocarbons in the oil. Impacts of accidental releases of oil from a pipeline have been dealt with in Deliverables 1.5 and 1.7b. Oil pipelines are listed in the Ecoinvent database but the fields for air emissions are empty. The only unit emissions record present in the database are heat emissions and oil spilled in the soil. Alternative LCI data for oil pipelines could not be found. However, gas pipelines work in a similar fashion, but more energy is necessary to displace gas rather than oil, since gas must be compressed first. Therefore gas pipelines' operational externalities can be considered as first approximation, an upper bound for oil pipeline externalities. In particular, according to the database used by the TEAMS model, which computes well-to-hull LCI data for marine transportation<sup>3</sup>, on average, one ton of natural gas requires 336 Btu/mile to be moved along a pipeline; crude oil requires about 240 Btu/mile. Therefore, assuming a linear relationship between energy intensity and emissions, gas pipelines' emissions should be multiplied by a factor of 0.714 to yield approximate values for analogous emissions from oil pipelines. The resulting externalities are listed in the tables below.

	2010	2020	2030
NMVOG	5,15E-07	1,19E-08	1,19E-08
CO <sub>2</sub>	6,91E-10	7,43E-10	6,82E-10
CH <sub>4</sub>	4,62E-04	1,86E-05	1,66E-05
N <sub>2</sub> O	0	0	0
SF <sub>6</sub>	0	0	0
<b>Total GHG</b>	<b>4,62E-04</b>	<b>1,86E-05</b>	<b>1,66E-05</b>

**Table 6 Unit External Costs [Euro per Ton]. Emissions from crude oil transport, by long distance pipeline, NMVOG and GHG-emissions in 2010, 2020 and 2030, Russia.**

Externalities due to the operation of oil tankers were originally computed combining Ecoinvent and Ecosense data. The resulting externalities for 2010 caused by emissions from oil tankers operations in the regions crossed by the importing routes to Europe are listed in Table 7 and in Table 8 below. Again, externalities not related to GHG emissions vary with the different regions crossed, due to the different deposition patterns of the pollutants and hence due to the different socioeconomic and environmental characteristics of the regions exposed. The average values have been computed using as weights the ratio of the lengths of the routes' legs pertaining the areas listed in the first row of

<sup>3</sup> More details on the TEAMS model can be found further in this section.

Table 7 to the total length of the main routes analysed by this Research Stream (that is, the sum of the lengths of the route Primorsk-Ras Tanura<sup>4</sup> and of the route Novorssyrsk –Augusta).

	N.E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea	North Sea
<i>Human Health</i>					
NMVOC	2,87E-07	6,28E-07	1,59E-07	3,52E-07	1,43E-06
NO <sub>x</sub>	3,73E-05	6,93E-05	8,57E-05	3,15E-05	1,01E-04
PPM <sup>CO</sup>	4,21E-07	1,16E-06	1,88E-06	1,65E-06	2,48E-06
PPM <sup>25</sup>	6,24E-06	1,58E-05	2,60E-05	2,13E-05	2,98E-05
SO <sub>2</sub>	1,30E-04	2,50E-04	4,17E-04	3,46E-04	3,89E-04
<i>Loss of Biodiversity</i>					
NMVOC	-1,00E-08	-7,00E-08	-1,00E-08	-2,00E-08	-6,00E-08
NO <sub>x</sub>	6,49E-06	3,05E-05	3,35E-06	7,46E-06	2,48E-05
PPM <sup>CO</sup>					
PPM <sup>25</sup>					
SO <sub>2</sub>	4,39E-06	2,38E-05	1,11E-06	3,54E-06	1,74E-05
<i>Crops &amp; Material</i>					
NMVOC	9,00E-08	2,30E-07	4,00E-08	1,00E-07	5,30E-07
NO <sub>x</sub>	4,97E-06	1,98E-06	2,81E-06	2,24E-06	-1,39E-06
PPM <sup>CO</sup>					
PPM <sup>25</sup>					
SO <sub>2</sub>	-2,18E-06	-2,94E-06	-4,10E-07	-1,60E-06	-3,67E-06
<i>Total</i>					
NMVOC	3,60E-07	7,86E-07	1,87E-07	4,29E-07	1,89E-06
NO <sub>x</sub>	4,88E-05	1,02E-04	9,18E-05	4,12E-05	1,24E-04
PPM <sup>CO</sup>	4,21E-07	1,16E-06	1,88E-06	1,65E-06	2,48E-06
PPM <sup>25</sup>	6,24E-06	1,58E-05	2,60E-05	2,13E-05	2,98E-05
SO <sub>2</sub>	1,33E-04	2,71E-04	4,18E-04	3,48E-04	4,02E-04

**Table 7 Unit External Costs [Euro per Ton.Km], non- GHG emissions from Tanker operations. Source: Own computations based on Ecoinvent and Ecosense data.**

CO <sub>2</sub>	2,83E-05
CH <sub>4</sub>	1,12E-08
N <sub>2</sub> O	1,25E-06

**Table 8 Unit External Costs [Euro per Ton.Km], GHG emissions from Tanker operations. Source: Own computations based on Ecoinvent and Ecosense data.**

The resulting externality values in Table 7 for particulates and SO<sub>2</sub> are, however, relatively high (1-2 orders of magnitude higher than externalities caused by other pollutants). This is most probably due to the fact that LCI data from Ecoinvent are based on data for old and existing ships. Moreover

<sup>4</sup> Including the alternative northern branch Mongstad – Rotterdam.

the Ecoinvent data at our disposal referred to a generic crude oil tanker, thus not distinguishing between alternative fuel/engine configurations and sizes of the ship. To overcome these problems we have resorted to an alternative source of LCI data for ships, the model TEAMS 1.3 developed by the Center for Economic Analysis and Policy, Rochester University, New York.

TEAMS calculates total fuel-cycle emissions and energy use for marine vessels. TEAMS captures emissions along the entire fuel pathway; however it provides emission results for each phase, including ship operation. TEAMS considers six fuel pathways: petroleum to residual oil; petroleum to conventional diesel; petroleum to low-sulphur diesel; natural gas to compressed natural gas; natural gas to Fischer-Tropsch diesel; and soybeans to bio-diesel.

TEAMS calculates total fuel-cycle emissions of three greenhouse gases (carbon dioxide, nitrous oxide, and methane) and five criteria pollutants (volatile organic compounds, carbon monoxide, nitrogen oxides, particulate matter with aerodynamic diameters of 10 micrometers or less (PM<sub>10</sub>), and sulphur oxides). TEAMS also calculates total energy consumption, fossil fuel consumption, and petroleum consumption associated with each of its six fuel cycles. TEAMS can be used to study emissions from a variety of user-defined vessels, including crude oil and LNG tankers. The results shown in Table 10, Table 11 and Table 12 are based on the case of a Very Large Crude Carrier (VLCC) of 275000 dwt, carrying 2 million barrels of oil from Ras-Tanura to Rotterdam<sup>5</sup>. Among the engine configurations available, the one combining a low sulphur oil main diesel engine with a conventional auxiliary diesel engine was selected as the most representative of current and future tanker configurations. The emissions per ton.km for the low sulphur oil configuration resulting from the TEAMS simulation are listed in Table 9 below. Annex 1 reports emissions and externality values for all other engine configurations for oil tankers (residual oil, conventional diesel, bio-diesel main engines coupled with conventional diesel auxiliary engines). Main engines using residual oil and conventional diesel are used in existing vessels, in particular in old ones, while bio-diesel is at the moment mainly a theoretical possibility.

The resulting values are much lower than those obtained from Ecoinvent data, in particular for NO<sub>x</sub>, particulates and SO<sub>2</sub>.

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<sup>5</sup> This is at the moment only a theoretical scenario; however, the Suez canal is currently being expanded and will allow the transit of VLLCs from 2010.

tons/km.ton	Main Engine Fuel:	Auxiliary Engine Fuel:	Total
	Low-Sulfur Diesel	Conventional Diesel	
CO <sub>2</sub>	1,36E-06	1,61E-07	1,51E-06
CH <sub>4</sub>	7,89E-11	9,55E-12	8,85E-11
N <sub>2</sub> O	3,45E-11	4,17E-12	7,31E-11
GHGs	1,37E-06	1,62E-07	1,54E-06
VOC	1,68E-09	2,03E-10	1,88E-09
CO	7,71E-09	9,33E-10	8,64E-09
NO <sub>x</sub>	4,23E-08	5,12E-09	4,74E-08
PM <sup>10</sup>	2,53E-10	3,06E-11	2,84E-10
SO <sub>x</sub>	1,28E-11	3,60E-11	2,77E-10

**Table 9. Unit emissions from oil tankers fuelled mainly with low sulphur oil. Source: own computations s based TEAMS model output.**

	N.E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea	Average
<b>Human Health</b>					
NMVOG	2,44E-07	5,34E-07	1,35E-07	2,99E-07	<b>2,99E-07</b>
NO <sub>x</sub>	3,86E-05	7,16E-05	8,86E-05	3,26E-05	<b>4,14E-05</b>
PPM <sup>co</sup>	6,60E-09	1,82E-08	2,94E-08	2,59E-08	<b>2,06E-08</b>
PPM <sup>25</sup>	1,12E-07	2,84E-07	4,66E-07	3,82E-07	<b>3,10E-07</b>
SO <sub>2</sub>	5,91E-08	1,14E-07	1,89E-07	1,57E-07	<b>1,30E-07</b>
<b>Loss of Biodiversity</b>					
NMVOG	-1,19E-08	-6,36E-08	-9,04E-09	-1,89E-08	<b>-2,10E-08</b>
NO <sub>x</sub>	6,72E-06	3,15E-05	3,46E-06	7,72E-06	<b>9,58E-06</b>
PPM <sup>co</sup>	0	0	0	0	<b>0</b>
PPM <sup>25</sup>	0	0	0	0	<b>0</b>
SO <sub>2</sub>	1,99E-09	1,079E-08	5,04E-10	1,605E-09	<b>2,5485E-09</b>
<b>Crops &amp; Material</b>					
NMVOG	7,42E-08	1,973E-07	3,27E-08	8,44E-08	<b>9,00E-08</b>
NO <sub>x</sub>	5,14E-06	2,046E-06	2,91E-06	2,32E-06	<b>3,03E-06</b>
PPM <sup>co</sup>	0	0	0	0	<b>0</b>
PPM <sup>25</sup>	0	0	0	0	<b>0</b>
SO <sub>2</sub>	-9,91E-10	-1,335E-09	-1,848E-10	-7,28E-10	<b>-8,21E-10</b>
<b>Sum</b>					
NMVOG	3,06E-07	6,68E-07	1,59E-07	3,65E-07	3,68E-07
NO <sub>x</sub>	5,05E-05	1,05E-04	9,50E-05	4,26E-05	5,40E-05
PPM <sup>co</sup>	6,60E-09	1,82E-08	2,94E-08	2,59E-08	2,06E-08
PPM <sup>25</sup>	1,12E-07	2,84E-07	4,66E-07	3,82E-07	3,10E-07
SO <sub>2</sub>	6,01E-08	1,23E-07	1,90E-07	1,58E-07	1,32E-07

**Table 10 Unit External Costs [Euro per Ton.Km] for non-GHG emissions from oil transportation by tanker in 2010. Source: Own computations based on TEAMS and Ecosense data.**

	Remaining N.E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea	Average
<i>Human Health</i>					
NMVOC	1,30E-07	3,18E-07	2,71E-09	1,07E-07	<b>2,34E-03</b>
NO <sub>x</sub>	5,17E-05	1,21E-04	1,36E-04	6,83E-05	<b>1,35E+00</b>
PPM <sup>CO</sup>	5,69E-08	1,58E-07	2,63E-07	2,2E-07	<b>3,23E-03</b>
PPM <sup>25</sup>	9,47E-07	2,4E-06	3,96E-06	3,23E-06	<b>4,81E-02</b>
SO <sub>2</sub>	7,17E-08	1,52E-07	2,28E-07	1,92E-07	<b>2,93E-03</b>
<i>Loss of Biodiversity</i>					
NMVOC	-1,87E-08	-8,3E-08	-1,4E-08	-2,3E-08	<b>-5,02E-04</b>
NO <sub>x</sub>	9,14E-06	4,3E-05	4,81E-06	1,04E-05	<b>2,39E-01</b>
PPM <sup>CO</sup>	0	0	0	0	<b>0</b>
PPM <sup>25</sup>	0	0	0	0	<b>0</b>
SO <sub>2</sub>	2,55E-09	1,34E-08	6,69E-10	2,19E-09	<b>6,05E-05</b>
<i>Crops &amp; Material</i>					
NMVOC	5,07E-08	1,42E-07	2,61E-08	6,81E-08	<b>1,26E-03</b>
NO <sub>x</sub>	6,09E-06	6,81E-06	3,37E-06	4,32E-06	<b>9,07E-02</b>
PPM <sup>CO</sup>	0	0	0	0	<b>0</b>
PPM <sup>25</sup>	0	0	0	0	<b>0</b>
SO <sub>2</sub>	-9,94E-10	-2,2E-09	-2,5E-10	-1,1E-09	<b>-2,06E-05</b>
<b>Total</b>					
NMVOC	1,62E-07	3,77E-07	1,53E-08	1,52E-07	1,69E-07
NO <sub>x</sub>	6,69E-05	1,71E-04	1,45E-04	8,31E-05	9,16E-05
PPM <sup>CO</sup>	5,69E-08	1,58E-07	2,63E-07	2,20E-07	1,76E-07
PPM <sup>25</sup>	9,47E-07	2,40E-06	3,96E-06	3,23E-06	2,62E-06
SO <sub>2</sub>	7,32E-08	1,63E-07	2,28E-07	1,93E-07	1,62E-07

Table 11 Unit External Costs [Euro per Ton.Km] for non-GHG emissions from oil transportation by tanker in 2020. Source: Own computations based on TEAMS and Ecosense data.

	2010	2020	2030
CO <sub>2</sub>	9,31E-06	9,31E-06	9,31E-06
CH <sub>4</sub>	5,61E-07	5,61E-07	5,61E-07
N <sub>2</sub> O	5,23E-07	5,23E-07	5,23E-07

Table 12 Unit External Costs [Euro per Ton.Km] for GHG emissions from oil transportation by tanker, in 2010, 2020, 2030. Source: Own computations based on TEAMS and Ecosense data.

#### **4. Concluding Remarks**

This deliverable has dealt with the evaluation of operational externalities related to the extraction and transportation of oil. Data coverage in this domain is extensive, but not complete: in particular we could not find reliable LCI information on air emissions from oil pipelines. Moreover, some available LCI data seem to be outdated. This problem is particularly relevant for tanker transportation. In order to overcome this issue, we use a source of LCI data for oil transportation alternative to Ecoinvent by tanker, the TEAMS model. This model generates specific LCI data for marine transportation, and allows to fine-tune the characteristics of the ship under scrutiny in terms of many parameters among which the size, the engine configuration, and the length of the route. This allows us to compute externality values for four alternative engine configurations, among which low sulphur diesel engines were selected as the most representative technology to be adopted now and in the near future. This results in operational externalities which are appreciable but not as high as those obtained from Ecoinvent LCI data.

These values are directly used for the economic evaluation of the externalities of the oil chain by WP 1.8 of RS 1c.

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## Annex 1. Emissions and Externalities from alternative tanker configurations

Main Engine: Conventional Diesel - Auxiliary Engine: Conventional Diesel

Source: Own computations based on TEAMS and Ecosense data.

### Emissions

ton/km.ton	Operation		Total
	Main	Auxiliary	
CO <sub>2</sub>	1,18E-06	1,61E-07	1,34E-06
CH <sub>4</sub>	7,02E-11	9,55E-12	7,97E-11
N <sub>2</sub> O	3,06E-11	4,17E-12	3,48E-11
GHGs	1,19E-06	1,62E-07	1,36E-06
VOC	1,49E-09	2,03E-10	1,69E-09
CO	6,85E-09	9,33E-10	7,78E-09
NO <sub>x</sub>	3,76E-08	5,12E-09	4,27E-08
PM <sup>10</sup>	2,25E-10	3,06E-11	2,56E-10
SO <sub>x</sub>	2,64E-10	3,6E-11	3,00E-10

### Non-GHG Externalities in 2010

Euro per Ton.Km	N.E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea	North Sea
<i>Human Health</i>					
NMVOG	3,23E-07	7,09E-07	1,79E-07	3,97E-07	1,61E-06
NO <sub>x</sub>	4,83E-05	8,97E-05	1,11E-04	4,08E-05	1,30E-04
PPM <sup>60</sup>	5,03E-08	1,39E-07	2,24E-07	1,98E-07	2,96E-07
PPM <sup>25</sup>	8,54E-07	2,16E-06	3,55E-06	2,91E-06	4,07E-06
SO <sub>2</sub>	4,30E-07	8,26E-07	1,38E-06	1,14E-06	1,28E-06
<i>Loss of Biodiversity</i>					
NMVOG	-1,57E-08	-8,44E-08	-1,20E-08	-2,51E-08	-7,26E-08
NO <sub>x</sub>	8,41E-06	3,95E-05	4,34E-06	9,66E-06	3,21E-05
PPM <sup>60</sup>	n.a	n.a	n.a	n.a	n.a
PPM <sup>25</sup>	n.a	n.a	n.a	n.a	n.a
SO <sub>2</sub>	1,45E-08	7,85E-08	3,67E-09	1,17E-08	5,75E-08
<i>Crops &amp; Material</i>					
NMVOG	9,84E-08	2,62E-07	4,34E-08	1,12E-07	5,97E-07
NO <sub>x</sub>	6,43E-06	2,56E-06	3,64E-06	2,90E-06	-1,79E-06
PPM <sup>60</sup>	n.a	n.a	n.a	n.a	n.a
PPM <sup>25</sup>	n.a	n.a	n.a	n.a	n.a
SO <sub>2</sub>	-7,21E-09	-9,71E-09	-1,34E-09	-5,30E-09	-1,21E-08
<i>Total</i>					
NMVOG	4,06E-07	8,86E-07	2,11E-07	4,84E-07	2,13E-06
NO <sub>x</sub>	6,32E-05	1,32E-04	1,19E-04	5,34E-05	1,61E-04
PPM <sup>60</sup>	5,03E-08	1,39E-07	2,24E-07	1,98E-07	2,96E-07
PPM <sup>25</sup>	8,54E-07	2,16E-06	3,55E-06	2,91E-06	4,07E-06
SO <sub>2</sub>	4,37E-07	8,94E-07	1,38E-06	1,15E-06	1,33E-06

**Non-GHG Externalities in 2020**

Euro per Ton.Km	N.E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea
<i>Human Health</i>				
NMVOG	1,17E-07	2,86E-07	2,44E-09	9,65E-08
NO <sub>x</sub>	4,65E-05	1,09E-04	1,23E-04	6,15E-05
PPM <sup>CO</sup>	5,12E-08	1,42E-07	2,37E-07	1,98E-07
PPM <sup>25</sup>	8,53E-07	2,16E-06	3,57E-06	2,91E-06
SO <sub>2</sub>	4,41E-07	9,33E-07	1,40E-06	1,18E-06
<i>Loss of Biodiversity</i>				
NMVOG	-1,68E-08	-7,45E-08	-1,22E-08	-2,08E-08
NO <sub>x</sub>	8,24E-06	3,88E-05	4,34E-06	9,40E-06
PPM <sup>CO</sup>	0	0	0	0
PPM <sup>25</sup>	0	0	0	0
SO <sub>2</sub>	1,57E-08	8,23E-08	4,12E-09	1,35E-08
<i>Crops &amp; Material</i>				
NMVOG	4,56E-08	1,28E-07	2,36E-08	6,13E-08
NO <sub>x</sub>	5,49E-06	6,14E-06	3,04E-06	3,89E-06
PPM <sup>CO</sup>	0	0	0	0
PPM <sup>25</sup>	0	0	0	0
SO <sub>2</sub>	-6,12E-09	-1,33E-08	-1,51E-09	-6,74E-09
<b>Total</b>				
NMVOG	1,46E-07	3,39E-07	1,38E-08	1,37E-07
NO <sub>x</sub>	6,03E-05	1,54E-04	1,30E-04	7,48E-05
PPM <sup>CO</sup>	5,12E-08	1,42E-07	2,37E-07	1,98E-07
PPM <sup>25</sup>	8,53E-07	2,16E-06	3,57E-06	2,91E-06
SO <sub>2</sub>	4,51E-07	1,00E-06	1,40E-06	1,19E-06

**GHG Externalities**

	2010	2020	2030
CO <sub>2</sub>	9,50001E-06	1,02254E-05	9,38005E-06
CH <sub>4</sub>	2,46589E-08	2,12091E-08	1,89721E-08
N <sub>2</sub> O	4,1812E-07	4,23653E-07	3,4792E-07

Main Engine: Residual oil -Auxiliary Engine: Conventional Diesel  
Source: Own computations based on TEAMS and Ecosense data.

**Emissions**

ton/km.ton	Operation		Total
	Main	Auxiliary	
CO <sub>2</sub>	1,29E-06	1,61E-07	1,45E-06
CH <sub>4</sub>	7,02E-11	9,55E-12	7,97E-11
N <sub>2</sub> O	3,06E-11	4,17E-12	3,48E-11
GHGs	1,3E-06	1,62E-07	1,46E-06
VOC	1,43E-09	2,03E-10	1,63E-09
CO	6,59E-09	9,33E-10	7,52E-09
NO <sub>x</sub>	3,8E-08	5,12E-09	4,31E-08
PM <sup>10</sup>	1,12E-09	3,06E-11	1,16E-09
SO <sub>x</sub>	1,88E-08	3,6E-11	1,88E-08

**Non-GHG Externalities in 2010**

Euro per Ton.Km	N.E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea	North Sea
<i>Human Health</i>					
NMVOG	1,85E-06	3,43E-06	4,24E-06	1,56E-06	4,99E-06
NO <sub>x</sub>	4,88E-05	9,05E-05	1,12E-04	4,12E-05	1,32E-04
PPM <sup>60</sup>	2,27E-07	6,29E-07	1,01E-06	8,93E-07	1,34E-06
PPM <sup>25</sup>	3,86E-06	9,78E-06	1,61E-05	1,31E-05	1,84E-05
SO <sub>2</sub>	2,69E-05	5,16E-05	8,62E-05	7,15E-05	8,02E-05
<i>Loss of Biodiversity</i>					
NMVOG	3,22E-07	1,51E-06	1,66E-07	3,70E-07	1,23E-06
NO <sub>x</sub>	8,48E-06	3,98E-05	4,38E-06	9,75E-06	3,23E-05
PPM <sup>60</sup>	n.a	n.a	n.a	n.a	n.a
PPM <sup>25</sup>	n.a	n.a	n.a	n.a	n.a
SO <sub>2</sub>	9,06E-07	4,91E-06	2,29E-07	7,31E-07	3,60E-06
<i>Crops &amp; Material</i>					
NMVOG	2,46E-07	9,80E-08	1,39E-07	1,11E-07	-6,86E-08
NO <sub>x</sub>	6,49E-06	2,58E-06	3,68E-06	2,93E-06	-1,81E-06
PPM <sup>60</sup>	n.a	n.a	n.a	n.a	n.a
PPM <sup>25</sup>	n.a	n.a	n.a	n.a	n.a
SO <sub>2</sub>	-4,51E-07	-6,08E-07	-8,41E-08	-3,31E-07	-7,59E-07
<i>Total</i>					
NMVOG	2,42E-06	5,04E-06	4,55E-06	2,04E-06	6,15E-06
NO <sub>x</sub>	6,38E-05	1,33E-04	1,20E-04	5,38E-05	1,62E-04
PPM <sup>60</sup>	2,27E-07	6,29E-07	1,01E-06	8,93E-07	1,34E-06
PPM <sup>25</sup>	3,86E-06	9,78E-06	1,61E-05	1,31E-05	1,84E-05
SO <sub>2</sub>	2,74E-05	5,60E-05	8,63E-05	7,19E-05	8,31E-05

**Non-GHG Externalities in 2020**

Euro per Ton.Km	N.E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea
<i>Human Health</i>				
NMVOC	1,13E-07	2,76E-07	2,36E-09	9,33E-08
NO <sub>x</sub>	4,70E-05	1,10E-04	1,24E-04	6,21E-05
PPM <sup>co</sup>	2,32E-07	6,42E-07	1,07E-06	8,97E-07
PPM <sup>25</sup>	3,85E-06	9,78E-06	1,61E-05	1,31E-05
SO <sub>2</sub>	2,76E-05	5,84E-05	8,76E-05	7,37E-05
<i>Loss of Biodiversity</i>				
NMVOC	-1,62E-08	-7,20E-08	-1,18E-08	-2,01E-08
NO <sub>x</sub>	8,31E-06	3,91E-05	4,38E-06	9,49E-06
PPM <sup>co</sup>	0	0	0	0
PPM <sup>25</sup>	0	0	0	0
SO <sub>2</sub>	9,81E-07	5,15E-06	2,58E-07	8,42E-07
<i>Crops &amp; Material</i>				
NMVOC	4,41E-08	1,23E-07	2,28E-08	5,93E-08
NO <sub>x</sub>	5,53E-06	6,19E-06	3,07E-06	3,92E-06
PPM <sup>co</sup>	0	0	0	0
PPM <sup>25</sup>	0	0	0	0
SO <sub>2</sub>	-3,83E-07	-8,34E-07	-9,47E-08	-4,22E-07
<b>Total</b>				
NMVOC	1,41E-07	3,28E-07	1,33E-08	1,32E-07
NO <sub>x</sub>	6,08E-05	1,56E-04	1,31E-04	7,55E-05
PPM <sup>co</sup>	2,32E-07	6,42E-07	1,07E-06	8,97E-07
PPM <sup>25</sup>	3,85E-06	9,78E-06	1,61E-05	1,31E-05
SO <sub>2</sub>	2,82E-05	6,27E-05	8,78E-05	7,42E-05

**GHG externalities**

	2010	2020	2030
CO <sub>2</sub>	1,02497E-05	1,10324E-05	1,01203E-05
CH <sub>4</sub>	2,46589E-08	2,12091E-08	1,89721E-08
N <sub>2</sub> O	4,1812E-07	4,23653E-07	3,4792E-07

Main Engine: Biodiesel - Auxiliary Engine: Conventional Diesel  
Source: Own computations based on TEAMS and Ecosense data.

### Emissions

ton/km.ton	Operation		Total
	Main	Auxiliary	
CO <sub>2</sub>	1,35E-06	1,61E-07	1,51E-06
CH <sub>4</sub>	7,89E-11	9,55E-12	8,85E-11
N <sub>2</sub> O	6,89E-11	4,17E-12	7,31E-11
GHGs	1,38E-06	1,62E-07	1,54E-06
VOC	1,68E-09	2,03E-10	1,88E-09
CO	7,71E-09	9,33E-10	8,64E-09
NO <sub>x</sub>	4,23E-08	5,12E-09	4,74E-08
PM <sup>10</sup>	2,53E-10	3,06E-11	2,84E-10
SO <sub>x</sub>	2,41E-10	3,6E-11	2,77E-10

### Non-GHG Externalities in 2010

Euro per Ton.Km	N.E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea	North Sea
<i>Human Health</i>					
NMVOG	3,59E-07	7,86E-07	1,99E-07	4,41E-07	1,79E-06
NO <sub>x</sub>	5,37E-05	9,96E-05	1,23E-04	4,53E-05	1,45E-04
PPM <sup>CO</sup>	5,58E-08	1,54E-07	2,49E-07	2,19E-07	3,29E-07
PPM <sup>25</sup>	9,47E-07	2,40E-06	3,94E-06	3,23E-06	4,52E-06
SO <sub>2</sub>	3,97E-07	7,62E-07	1,27E-06	1,05E-06	1,18E-06
<i>Loss of Biodiversity</i>					
NMVOG	-1,75E-08	-9,37E-08	-1,33E-08	-2,78E-08	-8,06E-08
NO <sub>x</sub>	9,34E-06	4,38E-05	4,81E-06	1,07E-05	3,56E-05
PPM <sup>CO</sup>	n.a	n.a	n.a	n.a	n.a
PPM <sup>25</sup>	n.a	n.a	n.a	n.a	n.a
SO <sub>2</sub>	1,34E-08	7,24E-08	3,38E-09	1,08E-08	5,31E-08
<i>Crops &amp; Material</i>					
NMVOG	1,09E-07	2,91E-07	4,82E-08	1,24E-07	6,62E-07
NO <sub>x</sub>	7,14E-06	2,84E-06	4,04E-06	3,22E-06	-1,99E-06
PPM <sup>CO</sup>	n.a	n.a	n.a	n.a	n.a
PPM <sup>25</sup>	n.a	n.a	n.a	n.a	n.a
SO <sub>2</sub>	-6,65E-09	-8,97E-09	-1,24E-09	-4,89E-09	-1,12E-08
<i>Total</i>					
NMVOG	4,51E-07	9,83E-07	2,34E-07	5,37E-07	2,37E-06
NO <sub>x</sub>	7,01E-05	1,46E-04	1,32E-04	5,92E-05	1,78E-04
PPM <sup>CO</sup>	5,58E-08	1,54E-07	2,49E-07	2,19E-07	3,29E-07
PPM <sup>25</sup>	9,47E-07	2,40E-06	3,94E-06	3,23E-06	4,52E-06
SO <sub>2</sub>	4,04E-07	8,26E-07	1,27E-06	1,06E-06	1,23E-06

### Non-GHG Externalities in 2020

Euro per Ton.Km	N.E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea
<i>Human Health</i>				
NM VOC	1,30E-07	3,18E-07	2,71E-09	1,07E-07
NO <sub>x</sub>	5,17E-05	1,21E-04	1,36E-04	6,83E-05
PPM <sup>co</sup>	5,69E-08	1,58E-07	2,63E-07	2,20E-07
PPM <sup>25</sup>	9,47E-07	2,40E-06	3,96E-06	3,23E-06
SO <sub>2</sub>	4,07E-07	8,61E-07	1,29E-06	1,09E-06
<i>Loss of Biodiversity</i>				
NM VOC	-1,87E-08	-8,27E-08	-1,35E-08	-2,31E-08
NO <sub>x</sub>	9,14E-06	4,30E-05	4,81E-06	1,04E-05
PPM <sup>co</sup>	0	0	0	0
PPM <sup>25</sup>	0	0	0	0
SO <sub>2</sub>	1,45E-08	7,60E-08	3,80E-09	1,24E-08
<i>Crops &amp; Material</i>				
NM VOC	5,07E-08	1,42E-07	2,61E-08	6,81E-08
NO <sub>x</sub>	6,09E-06	6,81E-06	3,37E-06	4,32E-06
PPM <sup>co</sup>	0	0	0	0
PPM <sup>25</sup>	0	0	0	0
SO <sub>2</sub>	-5,65E-09	-1,23E-08	-1,40E-09	-6,23E-09
<b>Total</b>				
NM VOC	1,62E-07	3,77E-07	1,53E-08	1,52E-07
NO <sub>x</sub>	6,69E-05	1,71E-04	1,45E-04	8,31E-05
PPM <sup>co</sup>	5,69E-08	1,58E-07	2,63E-07	2,20E-07
PPM <sup>25</sup>	9,47E-07	2,40E-06	3,96E-06	3,23E-06
SO <sub>2</sub>	4,16E-07	9,25E-07	1,30E-06	1,09E-06

### GHG externalities

	2010	2020	2030
CO <sub>2</sub>	1,0709E-05	1,15267E-05	1,05738E-05
CH <sub>4</sub>	2,73718E-08	2,35424E-08	2,10593E-08
N <sub>2</sub> O	8,78124E-07	8,89745E-07	7,30692E-07