

# NOTA DI LAVORO

13.2009

---

## The External Cost of European Crude Oil Imports

---

By **Andrea Bigano**, **Mariaester Cassinelli**, **Fabio Sferra**, FEEM, Milan

**Lisa Guarrera**, **Sohbet Karbuz**,  
Observatoire Méditerranéen de  
l'Energie, Sophia-Antipolis, France

**Manfred Hafner**, FEEM, Italy and  
Observatoire Méditerranéen de  
l'Energie, Sophia-Antipolis, France

**Anil Markandya**, FEEM, Italy,  
University of Bath, UK and Basque  
Centre for Climate Change Research,  
Bilbao, Spain

**Ståle Navrud**, Department of  
Economics and Resource Management  
Norwegian University of Life Sciences,  
Oslo, Norway

## SUSTAINABLE DEVELOPMENT Series

Editor: Carlo Carraro

### The External Cost of European Crude Oil Imports

By Andrea Bigano, Mariaester Cassinelli, Fabio Sferra, FEEM, Milan  
Lisa Guarrera, Sohbet Karbuz, Observatoire Méditerranéen de l'Energie,  
Sophia-Antipolis, France

Manfred Hafner, FEEM, Italy and Observatoire Méditerranéen de  
l'Energie, Sophia-Antipolis, France

Anil Markandya, FEEM, Italy, University of Bath, UK and Basque Centre  
for Climate Change Research, Bilbao, Spain

Ståle Navrud, Department of Economics and Resource Management  
Norwegian University of Life Sciences, Oslo, Norway

#### Summary

This paper is the first to assess operational and probabilistic externalities of oil extraction and transportation to Europe on the basis of a comprehensive evaluation of realistic future oil demand-supply scenarios, of the relative relevance of import routes, of the local specificities in terms of critical passages and different burdens and impacts along import routes. The resulting externalities appear reasonable both under the assumption of high future demand and under low demand. Estimates range from 2.32 Euro in 2030 in the low demand scenario to 2.60 Euro in 2010 in the high demand scenario per ton of imported oil.

**Keywords:** Oil Transport, Externalities Oil Spills, Risk Analysis

**JEL Classification:** Q32, Q25, Q41, R40

*Address for correspondence:*

Andrea Bigano  
Fondazione Eni Enrico Mattei  
Corso Magenta 63  
20123 Milano  
Italy  
E-mail: andrea.bigano@feem.it

# The External Cost Of European Crude Oil Imports

31<sup>st</sup> January 2008

## **Abstract**

This paper is the first to assess operational and probabilistic externalities of oil extraction and transportation to Europe on the basis of a comprehensive evaluation of realistic future oil demand-supply scenarios, of the relative relevance of import routes, of the local specificities in terms of critical passages and different burdens and impacts along import routes.

The resulting externalities appear reasonable both under the assumption of high future demand and under low demand. Estimates range from 2.32 Euro in 2030 in the low demand scenario to 2.60 Euro in 2010 in the high demand scenario per ton of imported oil.

**Keywords:** oil transport, externalities oil spills, risk analysis

**JEL Classifications:** Q32, Q25, Q41, R40

## 1. Introduction

The most recent large scale accidents in oil sea transport (such as the Erika and Prestige accidents) have highlighted the threats posed by oil spills to the environment, health, economy, and socio-economic activity, particularly for a world region so dependent from oil imports as Europe. The associated externalities have been very poorly analysed in previous work and as their impact can locally be very high, there is a need to deepen the knowledge in this field. Moreover, in order to assess properly the overall damage cost associated to carrying oil into Europe, these kinds of damages must be assessed together with the damages routinely caused by this transport activity, within a consistent framework.

The externalities generated by oil transport are of two kinds. On one hand there are *accidental externalities*, caused by accidental oil spills, whose nature is intrinsically stochastic. On the other hand, there are *operational externalities*, caused by day to day operations of the ship, which do not depend upon the occurrence of any uncertain event, and by and large are generated by the discharge of polluting emissions from the ship engines<sup>1</sup>.

This study summarises four years of research within the EU FP6 integrated project NEEDS (New Energy Externalities Developments for Sustainability), and it is the first to provide a comprehensive evaluation of the external costs associated with importing oil into Europe, on the basis of realistic future oil demand-supply scenarios, the knowledge of the relative relevance of import routes, the local specificities in terms of critical passages, the differences in terms of burdens and environmental and socio-economic impacts along the different routes, and the development of oil spills prevention and remediation technologies and regulations.

For the first kind of externality, the perception of European citizens of the risks involved in carrying oil to Europe and the associated *risk aversion* are particularly important. In order to incorporate all these features into a consistent evaluation framework, one needs to develop a methodology suitable to deal with *probabilistic externalities*. In this perspective, we use an original approach for analyzing the risks related to oil tanker accidents. This methodology is described in Bigano et al. (2006) and briefly summarised in the next section.

---

<sup>1</sup> Due to the lack of reliable data we are unable to assess externalities related to the operational discharges of small amounts of oil during cleaning operations. Ship-related oil pollution is attributed mostly to operational discharges, which have consistently overshadowed accidental discharges. However, the majority of these discharges happen either close to the mainland or within port areas and terminal stations, usually resulting in small spills that are dealt with by the local authorities and seldom reported.

For the second kind of externality, we follow the Impact Pathway Approach developed in ExterneE (1995) as adopted and further refined within the NEEDS project. This yields geographically differentiated unit externality values for each pollutant, which take into account the local specificities of oil producing regions and the likely dispersion paths of air pollutants along the import routes to Europe.

Finally, the external cost associated with carrying one ton of oil in Europe in 2010, 2020 and 2030 is evaluated by attaching to each ton oil projected to be transported along the different import routes, the relevant unit external costs for both probabilistic and operational externalities. The import volumes projections are derived using an original import–export flows model developed within the project.

The resulting overall externality values from this exercise appear reasonable both under the assumption of high demand for oil in the next decades and under assumption of low demand. Estimates range from 2.32 Euro in 2030 in the low demand scenarios to 2.60 Euro in 2010 in the high demand scenario per ton of oil transported to Europe.

The rest of this paper is organised as follows. The next section illustrates the methodology and the main results of the probabilistic externalities assessment. Section 3 describes the methodology and the results of our unit operational externality evaluations. Section 4 describes how these two kinds of externalities have been brought together to arrive to an overall assessment of the future externalities connected to importing one ton of oil into Europe in the coming decades.

## 2. Probabilistic externalities of oil transportation by tanker route

The main methodology for probabilistic externalities assessment including risk aversion has been described in detail in Bigano et al (2006). The reader is referred to that paper for the details of our approach. In a nutshell the methodology adopted involves the following steps:

- identify the possible causes of an oil spill;
- evaluate the probabilities related to these types of accidents;
- monetize probabilistic externalities;
- introduce risk aversion and lay risk assessment in a theoretically sound and empirically founded framework.

The main motivation for applying this methodology is the inadequacy of the traditional approach (Expert Expected Damage EED). This approach estimates damages by simply monetising expected consequences, relying on expert judgements about both the probability of consequences and their magnitude. This approach disregards three fundamental traits of human behaviour when confronted with situations involving the risk of catastrophic accidents. On one hand, people need more money to compensate them for taking risks than the actuarial value of these risks (risk aversion). On the other hand, when confronted with the perspective of being potentially affected by the consequences of a negative event, people naturally adopt an ex-ante perspective, rather than the ex-post perspective implicit in standard externality evaluation. Finally, the public and the experts usually do not share the same information set. This influences the perception of the relevant probabilities. Hence subjective probabilities held by the public are in general different from probabilities assessed by the experts (lay vs. expert probabilities). Unless these issues are addressed, the sum of money estimated as the damage will not match the amount needed to make whole those potentially harmed.

Accidental oil spills from a tanker can be caused by a limited number of accidental event.. The most likely causes of accidental oil spills are grounding and ship to ship collision. Fire and explosion used to be significant causes of accident. Their importance is now negligible, due to recent changes in unloading regulations that prevent the formation of explosive gas mixtures in the hull. Structural failures, foundering and loading-unloading errors can also cause sizeable spills; in these cases the human element, which can play a role also in case of grounding and collision, is particularly important.

Our study focuses on groundings, collisions and structural failure & foundering as these are the most relevant causes of accidents

For each cause of accident the probability that an accident of such kind happens and oil is actually spilt, are determined applying the Fault Tree Analysis methodology. The Fault Trees were constructed to show the possible accident trajectory of opportunity which could lead to an oil spill, and standard probabilities were attributed to the initiator events. These were then combined using Boolean algebra techniques. The fault trees contains elements which are site specific and elements which are independent on the location, i.e. they could happen anywhere along the route. The probabilities associated with the elements dependent on the location are then multiplied by site-specific weightings to give the relative site probability of this accident trajectory of opportunity.

Weighting factors are based on the physical characteristics, preventive measures taken and level of spill preparedness of the location<sup>2</sup>. This allows us to determine the probability that oil is spilt, given that grounding or a collision or a structural failure has occurred, and the probability that different amounts of oil are spilt given that oil is lost.

The probabilities of two scenarios are computed:

- the spill occurs and its size is the average one for that kind of accident and
- the spill occurs, is exceptional and 90% of cargo is lost (“Worst Case Scenario”).

For probabilistic externality evaluation, we group the oil tanker traffic into three main routes: (a) the Novorossisk–Augusta route which we take as representative of the oil transport from the Black sea to Mediterranean Route, (b) the Ras Tanura–Rotterdam route which captures the traffic from the Persian Gulf to Northern Europe, and (c) the Promorsk/Mongstad -Rotterdam route which captures the Baltic/North Sea traffic to Europe. Along these routes particularly sensitive passages (hotspots) have been identified on the basis of the exposure to accident risk and the environmental/cultural value of the area. The routes and the critical passages are highlighted in Figure 1 and .Figure 2.

---

<sup>2</sup> For structural failure, time is also taken into account.

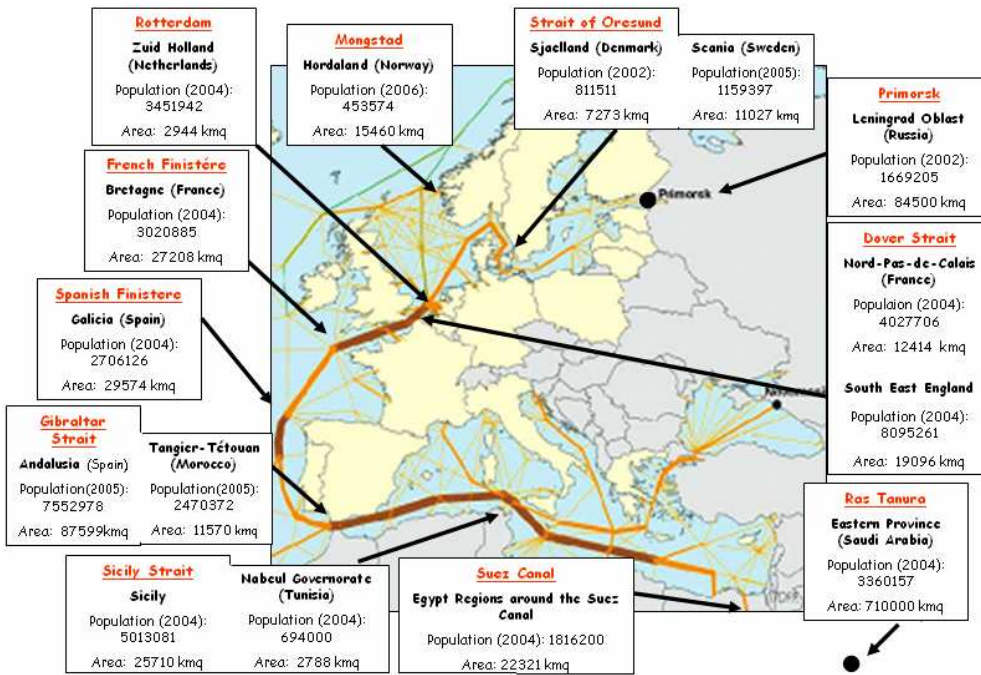


Figure 1. Hotspots along the Ras Tanura–Rotterdam–Promorsk/Mongstad routes.

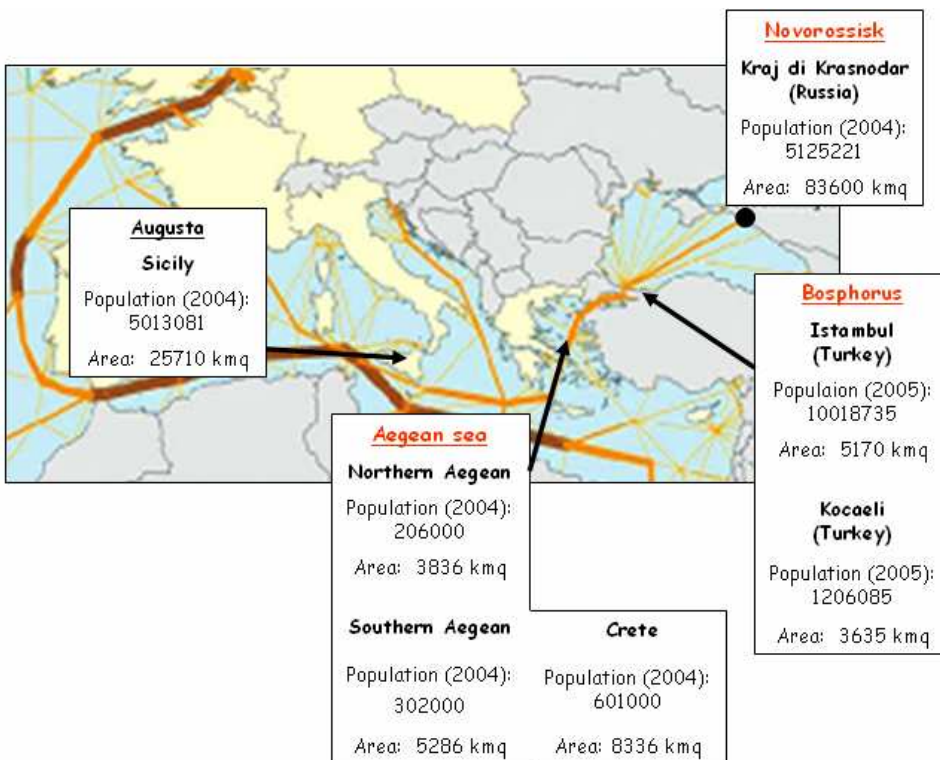


Figure 2. Hotspots along the Novorossisk–Augusta route.



In the following tables the weightings (Table 1 and Table 2) and the probabilities (Table 3 and Table 4) computed for the critical passages along the selected routes are listed.

<b>Factor</b>	<b>Novorossiysk</b>	<b>Bosphorus Strait</b>	<b>Aegean Sea</b>	<b>Augusta</b>
<b>Assistance unable to help</b>	2	4	1	1
<b>Non Arrival of Assistance</b>	2	1	4	1
<b>Desired Track Unsafe</b>	4	5	2	4
<b>Grounding Obstacle</b>	4	5	1	4
<b>Other Vessel</b>	3	5	2	3
<b>Vision impairment</b>	3	4	1	1
<b>Erroneous/Untimely Action</b>	1	3	1	1
<b>Bad Weather/Currents</b>	2	4	1	1
<b>Manoeuvre Not Possible</b>	3	4	1	3
<b>Passage Time (hours)</b>	8	20	100	8

**Table 1 Estimation of the probabilities of occurrence along the sample routes: the weightings for the Novorossisk–Augusta route.**

Factor	Ras Tanura	Suez	Sicily Strait	Strait of Gibraltar	French finistère	Dover Strait	Baltic Sea	Red Sea	Spanish Finistere	Primorsk
Assistance unable to help	5	4	1	1	1	1	1	4	1	1
Non Arrival of Assistance	3	3	2	1	3	2	1	2	2	2
Desired Track Unsafe	5	4	2	4	3	4	5	3	2	1
Grounding Obstacle	4	5	2	3	1	4	5	3	2	2
Other Vessel	2	4	3	3	2	5	3	3	4	2
Vision impairment	2	2	2	3	2	4	2	2	3	3
Erroneous/Untimely Action	3	4	1	3	1	3	3	3	3	3
Bad Weather/Currents	4	2	2	4	5	4	4	5	4	1
Manoeuvre Not Possible	3	4	2	3	2	4	3	2	2	2
Passage Time (hours)	8	42	20	25	15	20	23	63	14	8

Table 2. Estimation of the probabilities of occurrence along the sample routes: the weightings for the Ras Tanura–Rotterdam-Promorsk route.

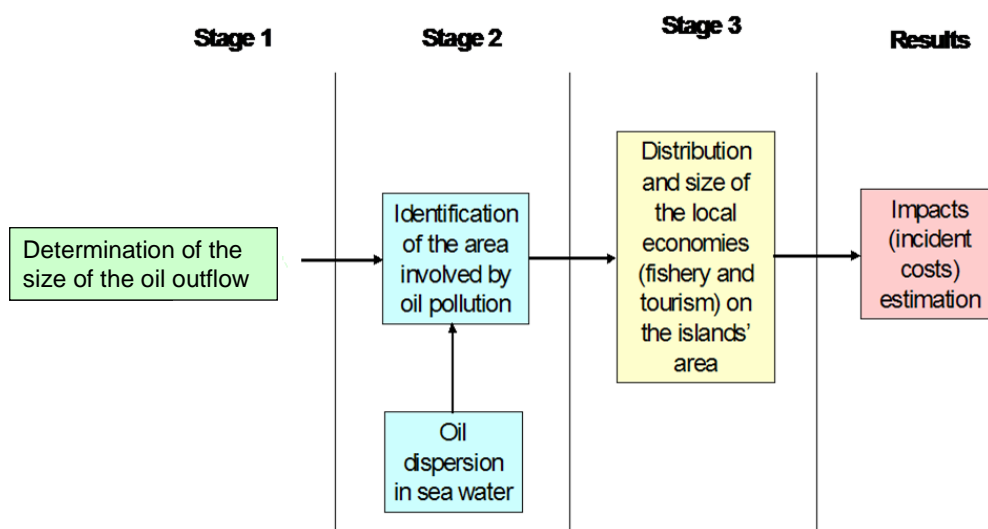
	Collision	Collision + Spill	Grounding	Grounding + Spill	structural failure	structural failure + Spill	(Total) + spill
<b>Novorossiysk</b>							
expected	2,57E-04	7,05E-05	2,81E-04	1,05E-04	7,40E-05	7,40E-05	2,50E-04
worst case	2,57E-06	7,05E-07	5,63E-06	2,11E-06	2,52E-05	2,52E-05	2,80E-05
<b>Turkish Straits</b>							
expected	2,84E-04	7,76E-05	7,74E-04	2,90E-04	7,80E-05	7,80E-05	4,46E-04
worst case	2,84E-06	7,76E-07	1,55E-05	5,80E-06	2,65E-05	2,65E-05	3,31E-05
<b>Aegean Sea</b>							
expected	2,41E-04	6,59E-05	3,64E-04	1,37E-04	7,20E-05	7,20E-05	2,75E-04
worst case	2,41E-06	6,59E-07	7,29E-06	2,73E-06	2,45E-05	2,45E-05	2,79E-05
<b>Augusta</b>							
expected	2,57E-04	7,05E-05	2,70E-04	1,01E-04	7,20E-05	7,20E-05	2,44E-04
worst case	2,57E-06	7,05E-07	5,39E-06	2,02E-06	2,45E-05	2,45E-05	2,72E-05

Table 3. Estimation of the probabilities of occurrence along the sample routes: the probabilities for the Novorossisk–Augusta route.

	Collision	Collision + Spill	Grounding	Grounding + Spill	struct failure	struct failure + Spill	(Total) + spill
<b>Ras Tanura</b>							
expected	2,50E-04	6,85E-05	7,15E-04	2,68E-04	7,80E-05	7,80E-05	4,15E-04
worst case	2,50E-06	6,85E-07	1,43E-05	5,36E-06	2,65E-05	2,65E-05	3,26E-05
<b>Suez</b>							
expected	2,74E-04	7,50E-05	1,01E-03	3,78E-04	7,40E-05	7,40E-05	5,27E-04
worst case	2,74E-06	7,50E-07	2,02E-05	7,56E-06	2,52E-05	2,52E-05	3,35E-05
<b>Sicily</b>							
expected	2,50E-04	6,85E-05	2,79E-04	1,05E-04	7,40E-05	7,40E-05	2,47E-04
worst case	2,50E-06	6,85E-07	5,58E-06	2,09E-06	2,52E-05	2,52E-05	2,79E-05
<b>Gibraltar</b>							
expected	2,57E-04	7,05E-05	7,10E-04	2,66E-04	7,80E-05	7,80E-05	4,15E-04
worst case	2,57E-06	7,05E-07	1,42E-05	5,33E-06	2,65E-05	2,65E-05	3,26E-05
<b>French Finisterre</b>							
expected	2,46E-04	6,72E-05	2,79E-04	1,05E-04	8,00E-05	8,00E-05	2,52E-04
worst case	2,46E-06	6,72E-07	5,58E-06	2,09E-06	2,72E-05	2,72E-05	3,00E-05
<b>Dover Strait</b>							
expected	2,84E-04	7,76E-05	7,31E-04	2,74E-04	7,80E-05	7,80E-05	4,30E-04
worst case	2,84E-06	7,76E-07	1,46E-05	5,48E-06	2,65E-05	2,65E-05	3,28E-05
<b>Baltic Sea</b>							
expected	2,57E-04	7,05E-05	7,20E-04	2,70E-04	7,80E-05	7,80E-05	4,18E-04
worst case	2,57E-06	7,05E-07	1,44E-05	5,40E-06	2,65E-05	2,65E-05	3,26E-05
<b>Red Sea</b>							
expected	2,50E-04	6,85E-05	1,10E-03	4,13E-04	8,00E-05	8,00E-05	5,62E-04
worst case	2,50E-06	6,85E-07	2,20E-05	8,26E-06	2,72E-05	2,72E-05	3,61E-05
<b>Spanish Finisterre</b>							
expected	2,55E-04	6,98E-05	6,84E-04	2,56E-04	7,80E-05	7,80E-05	4,04E-04
worst case	2,55E-06	6,98E-07	1,37E-05	5,13E-06	2,65E-05	2,65E-05	3,23E-05
<b>Primorsk</b>							
expected	2,46E-04	6,72E-05	6,42E-04	2,41E-04	7,20E-05	7,20E-05	3,80E-04
worst case	2,46E-06	6,72E-07	1,28E-05	4,81E-06	2,45E-05	2,45E-05	3,00E-05

**Table 4. Estimation of the probabilities of occurrence along the sample routes: the probabilities for the Ras Tanura–Rotterdam–Promorsk route.**

In order to monetize the external impacts, we consider three main categories of burdens of accidental oil spills: tourism, fisheries and natural environment. The steps followed in order to compute the monetary impacts are illustrated in Figure 3.



**Figure 3. Determination of the impacts on fisheries and tourism.**

For Stages 1 and 2, the following assumptions were made: we assumed three possible spill sizes, two for the average spill scenario according to whether it occurs in the open sea or in a harbour, and one for the worst case scenario, independent of the location of the spill. The average spill sizes are based on two actual spills. For harbour spills, we assumed that the spill would have the characteristics of the one that occurred in La Coruña (Spain) in 1992. For open sea spills we take as reference the Braer spill, that occurred in the Shetland islands in 1993. For the worst case scenario, we assume that 130,000 tons of oil (about 90 per cent of a Suezmax cargo) is spilled. However, we assume that if the oil spill occurs in a harbour area it will contaminate more land. These assumption are summarised in Table 5 below.

	Average oil spill		Worst case scenario oil spill	
	Harbour	Open sea	Harbour	Open sea
spill size (t)	72000	84700	130000	130000
Shoreline:	3%	1%	1%	3%
Oil arrived on land (t):	3% of 72000=2160	1% of 84700=847	1300	3% of 130000 = 3900
Land contaminated (kmq):	60	60	(847r:60kmq=1300r:x kmq) = <b>92.1</b>	(2160r:60kmq=3900r:x kmq) = <b>108.3</b>

**Table 5 Assumptions concerning oil spill size, dispersion and land contamination.**

For Stage 3, we assume that population and workforce at the hotspots are evenly spread across each hotspot's administrative region, that tourism and fisheries will stop activities for a year (11 months) if affected and that the impacts will be more severe in the proximity of the spill. The latter assumption captures the observations that usually the degree of severity of an oil spill decreases with the distance from the oil spill site and that risk aversion have a higher impact on those more intensely affected by an accident. The area around the oil spill has thus been divided into three sub-

areas, with increasing population and decreasing severity of the impacts, according to the assumptions specified in Table 6 and illustrated in Figure 4.

Land area	Impact groups	% involved	% of oil spill impact
Area 1	Group 1	0.2%	10%
Area 2	Group 2	9.1%	45%
Area 3	Group 3	90.7%	45%
	Total	100%	100%

Table 6. Assumptions related to the determination of differentiated impacts on local economies

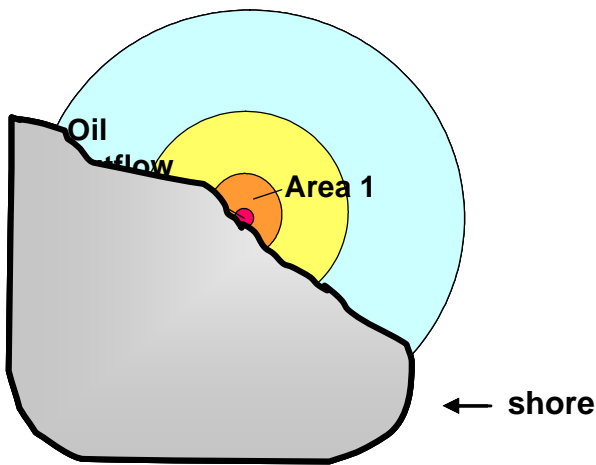


Figure 4. Vulnerability areas around a oil spill site.

The income likely to be lost has been derived from the sectoral GDP in 2004 of fisheries and tourism in the administrative regions around the hotspots. It is assumed, in order to avoid unreasonably high risk premiums that the sectors will never lose their full annual income, but will be able to count on at least one month's worth of financial resources. Moreover, sectoral GDPs are scaled down from the administrative region level to the level of the areas affected by the spill assuming that workers are distributed evenly in the region and then using the ratio of the workers of the sectors under scrutiny in the affected area to the total workers of that sector in that administrative region.

For environmental impacts, we have used the Belgian Coast CV study by Van Biervliet et al (2005), as it is the only valuation study in Europe (except the Blücher study in Norway, which is based on a small sample and a very local spill). The Belgian Coast CV study was based on the Exxon Valdez study (Carson et al 1992, 2003) which is the prototype study that satisfies the NOAA Panel guidelines for CV studies (Arrow et al 1993), and which also satisfies the requirements listed in Söderqvist and Soutukorva (2006). As both of these are national studies, the WTP from these studies will probably be a lower estimate of WTP among a more affected regional population.

However, Belgium is a small country, and therefore there might not be a large difference between the regional and national WTP. Therefore, we will base the benefit transfer exercise on the Belgian Coast study, but we also look at the Exxon Valdez study as a consistency check.

Since there are too few CV studies of oil spills to perform a meta analysis, and since we do not have data on variables needed to perform a value function transfer (as these variables are typically not available from statistical sources at the policy site, but are typically elicited during a CV survey), unit transfer is the only available transfer method. However, since income data are available at the policy sites we perform income adjustments based on GDP measures (national GDP figures, or regional GDP figures where these are available and the affected population is determined to be regional rather than national). Even though WTP is determined by many factors, a recent meta analysis (Bredahl, Jacobsen and Hanley 2007) of 35 CV studies (with a total of 107 WTP estimates) on 5 continents (80 % of which are from Europe and the US) of WTP for nature protection where existence values play a major role (which is also the case for WTP to avoid damages to marine and coastal ecosystems from oil spills), shows that GDP per capita is a significant and good predictor of WTP. They report that adjusted  $R^2$  was 0.53 in a single linear regression between WTP and GDP per capita (with no constant since at zero income WTP also has to be zero). Often an income elasticity of WTP equal to 1 is assumed (implicitly) in unit value transfers, but CV studies typically show an income elasticity of WTP lower than 1 for CV studies of environmental goods, typically in the 0.3-0.7 range (Kriström and Riera 1996, Höckby and Söderquist 2003, Bredahl Jacobsen and Hanley 2007). Therefore, we have used an income elasticity of WTP equal to 0.5.

Since the estimated values in the original CV studies are carried out in different years and stated in different currencies, we convert the different currencies to the same unit in the same year, which we refer to as 2007-Euros. This is achieved by adjusting the original estimate with the Consumer Price Index in the study country to 2007, and then converting to euros using Purchasing Power Parities (PPP) - adjusted exchange rates. The resulting mean WTP per household (as a one-time amount, i.e. present value) to avoid the described natural resource injuries in these two original CV studies are presented in Table 7 and Table 8.

	<b>Mean WTP/household</b>
US, 1991 current prices	97
US, 2007 current prices <sup>3</sup>	140
Euro, 2007 current prices <sup>4</sup>	102
<b>Euro, 2007ppp<sup>5</sup></b>	<b>120</b>

**Table 7. Exxon Valdez CV study. WTP/household (one-time amount).Sources: Carson et al (1992, 2003)**

<sup>3</sup> Estimated value on the basis of Consumer Price Index for USA (source: IMF); see e.g. <http://investintaiwan.nat.gov.tw/en/env/stats/cpi.html>

<sup>4</sup> This value is calculated according to the average exchange rate of Euro and US\$ in August

<sup>5</sup> Estimated value on the basis of 2007-PPPs from OECD: <http://www.oecd.org/dataoecd/48/18/18598721.pdf>

	Mean WTP/household <b>Medium Spill</b>	Mean WTP/household <b>Large Spill</b>
Euro, 2001current prices	118	143
<b>Euro, 2007ppp<sup>6*</sup></b>	<b>130</b>	<b>158</b>

**Table 8. Belgian Coast CV study. WTP/household (one-time amount).Source: Van Biervliet et al (2005)**

The WTP (in 2007-Euros) from these two CV studies are very close. This can be viewed as a consistency check (although the damages valued are not directly comparable). We will base our benefit transfer exercise on the result from the Belgian Coast CV study, i.e. **130 euro per household** for **medium size** oil spills (both in open sea and in the harbour), and **158 euro per household** for worst case grounding scenario (both in the open sea and harbour). We do not distinguish between WTP to avoid oil spills in the open sea versus the harbour area, as the CV studies on oil spills (see Table 1) are so few that it is not defensible to distinguish between these two scenarios in terms of environmental damage assessment. However, we do distinguish between WTP to avoid medium and large (worst case) oil spills, but recognize that the CV literature does not support an increase in WTP proportionally to the oil spill size. The Belgian Coast CV study shows a 22 % increase in WTP with an approximately 100 % increase in spill size from medium to large oil spills (from 26.000 to 53.000 tons of oil spilled, and about 100% increase in the described impacts). Unit value transfer with corrections for differences in GDP/capita between Belgium (national figure; as the sample was representative for the Belgian population) and the hot spots (using national GDP figures, and regional GDP where these are available), and an income elasticity of 0.5 are estimated using equation (1) below

$$WTP_p' = WTP_s (Y_p / Y_s)^\beta \quad (1)$$

where  $WTP_s$  is the original WTP estimate from the study site,  $Y_s$  and  $Y_p$  are the income levels at the study and policy site, respectively, and  $\beta$  is the income elasticity of WTP for the environmental good in question.  $\beta$  for different environmental goods are typically smaller than 1, and seems to be in the 0.3 - 0.7 range for environmental goods in European countries (Kriström and Riera 1996; Hokby and Söderquist 2003, Bredahl Jacobsen and Hanley 2007).

These corrected unit values are then multiplied by the size of the affected regional population, using equation (1). The resulting environmental damage costs (present values) for each hot spot are

---

<sup>6</sup> Estimated value on the basis of Consumer Price Index for Belgium (source: IMF); see e.g. <http://investintaiwan.nat.gov.tw/en/env/stats/cpi.html>. To get 2004-euro, which the impacts on fisheries and tourism are measured in, just add 3.3 % to the 2001-figures (i.e. CPI 2002 = 1.64 and CPI 2003 = 1.59, to get values as of January 1 2004)

presented in table 4. To calculate the expected value of the damage costs, these estimates must be multiplied with the probability of an oil spill occurring.

Hotspot (and affected area)	Ratio of GDP/capita between the hotspot and Belgium <sup>7</sup>	Transferred WTP/hh (one- time) for medium / large oil spill <sup>8</sup>	Number of hh in the affected area	Environmental damage costs; if a medium / large (worst case) oil spill occur; Million euro
<b>Novorossisk</b> (Kraj Krasnodar, Russia)	0.10 (N)	41 / 51	1,830,436	75.0 / 93.4
<b>Aegan Sea</b> (Northern Aegan, Southern Aegan and Crete, Greece)	N. Aegan: 0.47 S. Aegan: 0.53 Crete: 0.48	89 / 109 95 / 115 90 / 109	N. Aegan: 79,231 S. Aegan: 116,154 Crete: 231,154	7.1 / 8.6 11.0 / 13.4 20.8 / 25.2
<b>Bosphorus</b> (Istanbul and Kocaeli, Turkey)	0.12 (N)	46 / 55	2,494,405	114.7 / 137.2
<b>Augusta</b> (Sicily, Italy)	0.51	92 / 112	2,005,232	184.5 / 224.6
<b>Ras Tanura</b> (Eastern Province, Saudi Arabia)	0.05	29 / 33	550,845	16.0 / 18.2
<b>Suez Canal</b> (Regions around canal, Egypt)	0.18	55 / 66	386,426	21.3 / 25.5
<b>Sicily Strait</b> (Nabeul Governorate, Tunisia and Sicily, Italy)	Nabuel:0.07 Sicily: 0.51	34 / 41 92 / 112	Nabeul : 147,660 Sicily: 2,005,232	5.0 / 6.0 184.5 / 224.6
<b>Strait of Gibraltar</b> (Andalusia, Spain and Tangier – Tétouan, Morocco)	Andalucia: 0.50 Tangier-Tétouan: 0.03	92 / 112 23 / 27	Andalucia: 2,604,475 Tangier-Tétouan: 466,108	239.6 / 291.7 10.6 / 12.7
<b>Spanish Finistere</b> (Galicia, Spain)	0.52	94 / 114	933,147	87.7 / 106.4
<b>French Finistere</b> (Bretagne, France)	0.77	114 / 139	1,313,428	149.7 / 182.6
<b>Dover Strait</b> (Nord-Pas-de-Calais, France and South East England, UK)	Nord-Pas-de-Calais : 0.69 South East England : 1.03	108 / 131 132 / 160	Nord-Pas-de-Calais: 1,751,177 South East England: 3,373,025	189.1 / 229.4 445.2 / 539.7
<b>Rotterdam</b> (Zuid-Holland, The Netherlands)	1.01	130 / 158	1,500,844	195.1 / 237.1
<b>Oresund Strait</b> (Sjaelland, Denmark and Scania, Sweden)	Sjaelland: 0.88 Scania: 1.02	122 / 148 131 / 160	Sjaelland: 896,338 Scania: 552,094	109.4 / 132.7 72.3 / 88.3
<b>Primorsk</b> (Leningrad Oblast, Russia)	0.10 (N)	41 / 51	596,145	24.4 / 30.4
<b>Mongstad</b> (Hordaland County, Norway)	1.08	135/164	197,206	26.6 / 32.3

**Table 9. Recommended environmental damage cost estimates (in 2007-euro) for the hotspots**

Based on the results from validity tests of international benefit transfer these estimates could have errors of  $\pm 40\%$ .

<sup>7</sup> Based on regional GDP/capita figures for the hot spots; except in a few cases where only national GDP/capita figures are available (These are marked “N”). GDP per capita in Belgium was 30.600 euro and 31,100 euro in 2004 and 2005, respectively. We divide GDP per capita from the hotspots by one of these figures (dependent on whether the GDP/capita at the hotspot was from 2004 or 2005)

<sup>8</sup> Calculated as WTP/hh to avoid medium/large oil spill from the Belgian Coast CV study in table 3 multiplied by (GDP-ratio) <sup>$\beta$</sup> ;  $\beta$  is the income elasticity of WTP equal to 0.5 (see equation (1))



The environmental damage costs for each of the 15 hotspots are presented in Table 9. These estimates have been added to the economic assessment of impacts on commercial fisheries and tourism to provide an estimate of total external costs from accidental oil spills at these hotspots.

Risk premiums have been computed using a specific expected utility model, under the assumption of logarithmic utility function<sup>9</sup>. These computations have yielded a large amount of information, which is omitted here for economy of space<sup>10</sup>. In particular the risk premiums for each of the three impact groups and for each potentially affected sector (tourism, fisheries, environment) at each relevant location around a hotspot have been evaluated. The risk premiums are computed according to the probabilities of each accident cause (structural failure, collision and grounding) and according three alternative assumptions regarding accident probabilities perceptions by the public: expert evaluation, lay public's perception 20 times the experts' probabilities, and lay public's perception 100 times the experts' probabilities. Generally speaking, the highest premiums are related to the impacts in the tourist and fishery sectors, and would be required by the more exposed groups (Group 1 and 2), usually resident in Northern Europe, and they get proportionally higher the higher the probabilities assumed by the public. However, the maximum value (0.88 M€) is attained by the tourist sector in Andalucia, for grounding accidents, under the assumption of lay public's perception 100 times the experts' probabilities. This is due to the relevance of the tourist sector in the local economy. Similar values are attained in south-east England, where fisheries play a more important role. Hotspots in developing countries usually display the lowest risk premiums, due to the lower incomes at stake. For the Reader's convenience, Table 10 summarises the total expected utility losses, including risk premiums, at each hotspot, under the assumption of lay public's perception 20 times the experts' probabilities.

Hotspot	Expected losses	Hotspot	Expected losses
Ras Tanura	46,329	Spanish Finistere	255,976
Novorossisk	131,079	French Finistère	257,023
Primorsk	67,974	Dover Strait	1,980,070
Mongstad	109,030	Strait of Oresund	615,377
Rotterdam	326,132	Bosphorus	782,841
Augusta	310,734	Northern Agean Sea	13,726
Suez Canal	82,663	Southern Agean Sea	21,263
Sicily Strait	323,029	Crete	40,119
Gibraltar Strait	751,767		

**Table 10. Expected losses at each hotspot for probabilistic externalities caused by European oil imports by tanker(Euros).**

<sup>9</sup> The logarithmic functional form proved the most stable and robust in the sensitivity analysis.

<sup>10</sup> The interested reader is referred to Bigano et. al (2007b).

### 3. Unit operational externalities

#### 3.1 Extraction

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>co</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>co</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>co</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>co</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 11. 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 12. 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 13 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 11 and in Table 13. 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 14 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 14 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>90</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 14. Averaged Unit External Costs [Euro per Ton] GHG emissions from crude oil, at production. Weights vary with year and scenario.**

### .3.2 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. 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 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>11</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
NMVOC	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 15. 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.**

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 16 and in Table 17 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

<sup>11</sup> More details on the TEAMS model can be found further in this section.

of Table 16 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>12</sup> and of the route Novorossirsk –Augusta).

	N.E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea	North Sea
<b>Human Health</b>					
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
<b>Loss of Biodiversity</b>					
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
<b>Crops &amp; Material</b>					
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
<b>Total</b>					
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 16. 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 17. 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 16 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

<sup>12</sup> Including the alternative northern branch Mongstad – Rotterdam.

due to the fact that LCI data from Ecoinvent are based on data for old and existing ships. Moreover 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 19, Table 20 and Table 21 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>13</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 18 below<sup>14</sup>. 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>.

---

<sup>13</sup> This is at the moment only a theoretical scenario; however, the Suez canal is currently being expanded and will allow the transit of VLCCs from 2010.

<sup>14</sup> 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) can be obtained from the authors upon request.

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 18. 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
<i>Human Health</i>					
NMVOC	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>
<i>Loss of Biodiversity</i>					
NMVOC	-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>
<i>Crops &amp; Material</i>					
NMVOC	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>					
NMVOC	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 19. 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.**



	N:E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea	Average
<b>Human Health</b>					
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>
<b>Loss of Biodiversity</b>					
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>
<b>Crops &amp; Material</b>					
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 20. 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 21. 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.**

To sum up, it must be noted that 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.

#### 4. Overall assessment of external costs for oil Imports to Europe.

The final step of our externality assessment for the oil chain entails combining the unit externality values with the scenario projections of oil production and import to Europe for the present and for selected future years, under reasonable assumptions about energy markets trends. This step was performed on the basis of oil demand and import flows scenarios developed by the Observatoire Méditerranéen de l'Energie, and generated overall externality values which ranging from 2.32 Euro in 2030 in the scenario assuming low demand to 2.60 Euro in 2010 in the High demand scenario per ton of oil transported to Europe.

The unit externality values described and listed in Section 3 give an overall indication of how much external damage is caused by producing a ton of oil and by transporting it for one kilometre in the seas around Europe. However they do not yet give a precise evaluation of how much external cost is generated by *bringing* that ton of gas *into* Europe. More importantly, these values do not allow us to assess what *will be* the evolution of these externality costs in the future.

In order to do that, one needs to combine the unit values above with an assessment of the flows of oil produced for European consumption, and transported to Europe along the main import channels (pipelines and tanker routes) now and in the future. In principle, this can be done with varying degrees of refinement and precision. Our procedure is quite accurate but still entails some simplifying assumptions.

For one thing, “the future” enters into our analyses as three selected years: 2010, 2020 and 2030. Moreover, we have strived to include as much dynamic elements as possible. In particular, time-dependent parameters and variables in our computations are the following:

- the volumes of oil extracted and transported to Europe,
- the routes and the transportation modes used to deliver the oil to European consumers,
- the unit externality values for operational externalities<sup>15</sup>,
- the weights used to compute average operational externalities for the extraction phase<sup>16</sup>

---

<sup>15</sup> 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.

<sup>16</sup> 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

- the maintenance standards of oil pipelines<sup>17</sup>.

However, probabilistic externalities are not allowed to vary between these years. This assumption has two main motivations. On one hand, the alternative would have involved the addition of further uncertainty to the computation. In fact, the factors which may influence future probabilistic externality values are many, spatially differentiated, and very hard to project in the future with any confidence, at the hot spot level of spatial resolution. Relevant factors, for each hot spot, include: population size, per capita income, evolution of ecosystems, evolution of the local economy, etc.

On the other hand, the assessment of the likely influence of the upcoming trends in marine regulation and technology performed within the NEEDS project showed the presence of contrasting and counterbalancing trends, with a roughly neutral influence on the overall safety standards of the industry.

Finally, even oil flows may vary according to the assumptions one can make about the main drivers influencing international energy markets. In order to at least partially capture some of this particular source of variation, we use two alternative scenarios: one assuming a lower demand level and one assuming a higher demand level. A reference scenario has not been used in this evaluation exercise, as it is conceived as instrumental for the derivation of the other two. However it is briefly described in Section 2 to help illustrating the other scenarios.

For each of these scenarios and for each pollutant, two kind of external costs are computed. On one hand, as in the case of natural gas, operational externalities along the main import routes and at the most relevant production sites for European oil imports are computed. Their values are then averaged to yield externality values, for each pollutant, per ton of oil produced and per ton of oil imported into Europe. On the other hand, probabilistic externalities are also included using a specific methodology to be illustrated in more detail below. Finally, external costs pertaining to the two categories considered are summed up to yield an overall external cost value per ton of oil imported into Europe in the base year and in each demand scenario.

---

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 23 and Table 24 are based on six different sets of weights, capturing the relative relevance of the various production areas in each year and scenario.

<sup>17</sup> Pipelines are assumed to reach European standards by 2020.

#### .4.1 Oil demand scenarios

The following is a summary of the main assumptions behind the three demand scenarios used in this analysis, as depicted in Guarrera and Karbuz (2007), to which the interested reader is referred for further details.

- **Reference Scenario.** Crude oil imports are set to increase by 0.3% per year over the next 25 years, reaching 619 Mt in 2030, up from 567 Mt in 2004. While the FSU region and the Middle East will remain the main exporters to the EU, North Africa and Western Africa will gain in share. By 2030, the African continent will account for nearly a third of all EU crude imports up from 17% in 2004. A quarter of all exports to the EU will come from North African countries alone and especially from Libya and Algeria. Except for pipeline imports all crude imports to Atlantic and Mediterranean ports increase over time. For Atlantic ports, crude imports increase from 283 Mt in 2004 to 339 Mt in 2030, while for Mediterranean ports, crude imports are expected to increase from 197 Mt in 2004 to 208 Mt in 2030. For pipeline imports, the decrease in share and in total is the consequence of falling Norwegian crude oil production. Indeed, Norwegian crude oil exports by pipeline exports are expected to fall from 31 Mt in 2004 to 3 Mt in 2030. All imports through pipeline to the UK will therefore reduce drastically. However, pipeline oil imports from the FSU region are increasing rapidly from 56 Mt in 2004 they are forecasted to reach 71 Mt in 2030.
- **Low Case Scenario.** Compared to the *Reference Scenario*, in the *Low Case Scenario*, import requirements for the EU are expected to be 15% lower in 2030 reaching 526 Mt, 548 Mt in 2020 and 526 Mt in 2030. In 2030, 53% of these imports will come to EU Atlantic ports, 34% through its Mediterranean ports and 13% directly by pipeline. In 2010 the difference with the *Reference Scenario* is not likely to be that great since most of the policies to be put in place to reduce demand would not yet be effective; in 2020 however, in the *Low Case Scenario*, imports are expected to drop by 8% from the *Reference Scenario*. Compared with the Reference Scenario, in the Low Case imports would be reduced by more than 90 Mt in 2030. In the *Low Case Scenario*, the lesser needs for imports compared with the *Reference Scenario* are expected to affect routes unevenly. Indeed, imports from Africa and the Caspian region will be less pronounced. While the drop in Norwegian oil production in the *Low Case Scenario* will still lead to a shift towards other regions, these regions will not need to contribute as much to oil imports of the EU as in the *Reference Scenario*. Over 20% less crude will be needed from regions such as Africa (-21%) and Caspian (-28%),

while other regions such as Middle East or even Russia, who are already currently substantial EU trade partners, will see their imports less affected. Compared to the *Reference Scenario*, in the *Low Case*, imports from the Middle East are expected to be reduced by 13% and imports from Russia by less than 7%.

- **High Case Scenario.** In this scenario, the increase in demand, and thus in imports, will lead to a supply constraint forcing EU countries to get the oil wherever they can - using the full extent of routes and pipelines available. In this scenario, the effects of growing demand would be visible as soon as 2010 due to increasing demand and unchanged production in the EU; and would therefore lead to an immediate increase of imports by 5% compared to the Reference Scenario. By 2020 the increase in imports in this scenario would be as high as 8%, to reach 681 Mt in 2030 –more than 10% increase compared to the Reference Scenario. Compared with the Reference Scenario, in the High Scenario, over 60 Mt of additional crude oil will need to be imported by 2030. Overall, in the High Case Scenario, EU imports are expected to reach 596 Mt in 2010, 646 Mt in 2020 and 681 Mt in 2030. In 2030, 53% of these imports will come to EU Atlantic ports, 34% through its Mediterranean ports and 13% directly by pipeline.

#### .4.2 Inclusion of probabilistic externalities

Probabilistic externalities, refer, by definition, to damages that may or may not take place in any given moment and at any given location, in this case along the oil import routes to Europe. Therefore, any given ton of oil that reaches Europe does not need to cause any damage of this kind (actually, if it *has reached* Europe, it has not caused any damage!). However, in its route to Europe, it stands chances to cause damages by being spilt and not reaching its final destination. Thus the first step is to define the “probabilistic externality content” of each ton of oil imported. In our study this is done by looking at this issue in terms of expected utility loss. That is, each ton of oil reaching Europe brings about a reduction in welfare, which is the utility losses that may be caused by accidents along the routes to Europe weighted by their probability of occurrence, and including the discomfort suffered by the affected population for being exposed to such risks.

In principle, each single kilometre along these import routes has such a risk attached, and therefore, in principle, multiple accidents could happen anywhere along these routes. The complete evaluation of the exposure of each kilometre of each import route is a daunting task, and thus we had to resort to some simplifying assumptions.

In particular we assume that a) accidents occur only at well identified “hot-spots” where oil coming from different exporting countries transits in its way to Europe, and where historical records for oil

tanker accidents indicate a significant exposure to accident risk; b) that each ton of oil “collects” its bits of probabilistic externalities by passing through the hot spots relevant for the route actually followed. Thus, for instance, oil imported from Algeria to Southern France will carry attached only its own shares of probabilistic externalities potentially occurring at the relevant hot spots in western Mediterranean, but not those occurring, say, in the North Sea.

In practice, probabilistic externalities are allotted to the various routes by dividing their values at the relevant hotspots along that route by the volume of oil transported along that route in a given year. This is exemplified in Table 22 below, which shows the computations performed for the case of Norwegian oil exports to Northern Europe in 2010. In Table 22, the values in the green row are just the expected losses at the hotspots in the column headings of Table 22, as reported in Table 10, divided by the total volume of oil imports to Europe projected to pass through each hotspot in 2010 in the Low demand scenario. To compute the relevant probabilistic externality values, Table 22 multiplies in its blue cells, the externality values per ton (green row) by the volume of oil projected to leave Norway (orange column) for each European destination (yellow column), but *only if* the correspondent hotspot in the column heading pertains to the route from Norway to the destination country. In this case, only two hotspots are relevant: the departure port of Mongstad and the destination port of Rotterdam. The blue cells for the remaining hot spots are therefore 0: Norwegian oil does not need to pass through Augusta to reach any Northern European destination. Finally, the last row computes the probabilistic externality per ton of Norwegian oil imported to through Atlantic ports by dividing the total probabilistic externalities (blue cells, bold numbers) by the total import volume in 2010 (orange row, bold number x 1 Million).

			Ras Tanura	Novorossisk	Primorsk	Mongstad	Rotterdam	Augusta
<b>Probabilistic Accidents value at Hot Spots (euros/t)</b>			186	6.776	566	1.315	1.044	1.964
<b>FROM</b>	<b>TO</b>	<b>oil flows (Mt)</b>						
<b>NORWAY</b>	Belgium	3,8	0	0	0	4,974	3,947	0
	France	15,0	0	0	0	19,767	15,684	0
	Germany	18,0	0	0	0	23,714	18,815	0
	Netherlands	13,0	0	0	0	17,105	13,572	0
	Sweden	5,7	0	0	0	7,514	5,962	0
	United Kingdom	10,7	0	0	0	14,127	11,209	0
	<b>All EU Atlantic importers</b>	<b>66,3</b>				<b>87,202</b>	<b>69,189</b>	
	<b>Probabilistic externalities in €/per ton</b>					<b>0.0013</b>	<b>0.0010</b>	

Table 22. Example of the procedure used to allocate probabilistic externalities among import routes. The case of imports from Norway to European Atlantic ports in 2010 in the Low demand scenario.

#### .4.3 Overall externality assessment

Operational externalities are evaluated in a simpler way. As far as oil transport is concerned, for each import flow in each scenario and for each pollutant, unit externality values, in terms of Euros per ton of oil transported for a kilometre, are multiplied by the relevant volume transported and distance covered. These values are then summed up and divided by the total volume of oil imported to yield the externality content of one ton oil imported to Europe. An analogous procedure is followed for oil extraction, although the computation is even simpler as in this case there are no bilateral flows to trace down, but only extracted volumes for each producing country.

The results are summarised in the tables below. Detailed externality values per pollutant have been computed, but for economy of space are summarised in terms of “non-GHG” and GHG externalities<sup>18</sup>. Also for economy of space, Table 23 and Table 24 illustrate only the values in the High and Low Case demand scenarios.

Total externalities appear to be quite low: both in the low and in the high demand scenario they are around 2.5 Euro per ton, in each period considered, ranging from 2.32 Euro in 2030 in the low demand scenarios to 2.60 Euro in 2010 in the high demand scenario. The bulk of external costs is caused by operational externalities of oil extraction, followed by oil tankers’ operational externalities: probabilistic externalities and those deriving from pipeline transport have very limited

<sup>18</sup> It is worth mentioning that a complete and exhaustive evaluation of the damages linked to GHG emissions is still an open issue, as the research on the consequences of climate change has still a lot left to cover and uncertainty is high and probably will persist for long in the future. However, damage cost ranges have been produced in the climate change literature. The externality value used here are the most updated values selected within the NEEDS project



impacts on the overall assessment. For probabilistic externalities, this not unexpected. The probabilistic externalities values listed in Table 10 range from the tens of thousand Euros to over one million Euro, and refer to accidents that typically occur along any given route with probabilities in the order of  $10^{-4}$  to  $10^{-5}$  per year. Thus the actual damage caused should such accident actually occur would range between  $10^8$  to  $10^{11}$  Euros, that is between 100 million and 100 billion Euro. These sizeable damages are diluted twice: first by the low probability of occurrence and then by the huge volume of oil passing through each hotspot. Thus results in terms expected damage per ton of oil import of about one Eurocent are not unexpected.

<b>2010 High</b>	Extraction Externalities	Tanker Transport Externalities	Total Accident Externalities	<i>Non-GHG costs</i>	<i>GHG costs</i>	<i>Total emissions costs</i>	<b>Total Externalities</b>
To Atlantic Ports	1,39	0,48	0,013	<i>1,16</i>	<i>0,71</i>	<i>1,87</i>	1,89
To Mediterranean Ports	1,39	0,41	0,011	<i>1,10</i>	<i>0,70</i>	<i>1,81</i>	1,82
<b>Total EU</b>	1,39	0,45	0,012	<i>1,14</i>	<i>0,71</i>	<i>1,85</i>	<b>1,86</b>
<i>Pipeline</i>				<i>0,00</i>	<i>0,74</i>	<i>0,74</i>	0,74
<b>Total Externalities</b>	<b>1,39</b>	<b>1,19</b>	<b>0,01</b>	<b><i>1,14</i></b>	<b><i>1,44</i></b>	<b><i>2,58</i></b>	<b>2,60</b>
<b>2020 High</b>	Extraction Externalities	Tanker Transport Externalities	Total Accident Externalities	<i>Non-GHG costs</i>	<i>GHG costs</i>	<i>Total emissions costs</i>	<b>Total Externalities</b>
To Atlantic Ports	1,72	0,67	0,014	<i>1,50</i>	<i>0,89</i>	<i>2,39</i>	2,41
To Mediterranean Ports	1,73	0,48	0,007	<i>1,34</i>	<i>0,87</i>	<i>2,20</i>	2,21
<b>Total EU</b>	1,72	0,59	0,011	<i>1,44</i>	<i>0,88</i>	<i>2,32</i>	<b>2,33</b>
<i>Pipeline</i>				<i>0,000</i>	<i>0,035</i>	<i>0,035</i>	0,035
<b>Total Externalities</b>	<b>1,72</b>	<b>0,63</b>	<b>0,01</b>	<b><i>1,44</i></b>	<b><i>0,91</i></b>	<b><i>2,35</i></b>	<b>2,37</b>
<b>2030 High</b>	Extraction Externalities	Tanker Transport Externalities	Total Accident Externalities	<i>Non-GHG costs</i>	<i>GHG costs</i>	<i>Total emissions costs</i>	<b>Total Externalities</b>
To Atlantic Ports	1,83	0,72	0,013	<i>1,69</i>	<i>0,86</i>	<i>2,55</i>	2,57
To Mediterranean Ports	1,84	0,47	0,006	<i>1,47</i>	<i>0,84</i>	<i>2,31</i>	2,31
<b>Total EU</b>	1,83	0,63	0,010	<i>1,61</i>	<i>0,85</i>	<i>2,46</i>	<b>2,47</b>
<i>Pipeline</i>				<i>0,00</i>	<i>0,04</i>	<i>0,04</i>	0,04
<b>Total Externalities</b>	<b>1,83</b>	<b>0,66</b>	<b>0,01</b>	<b><i>1,61</i></b>	<b><i>0,89</i></b>	<b><i>2,49</i></b>	<b>2,51</b>

**Table 23. External costs of oil extraction and transport. Projections to 2010, 2020 and 2030 in the high demand scenario. Euros per ton.**

On the other hand, the very low values for pipeline transport are an indication that, most probably, transferring emission values from natural gas transportation cannot capture in satisfactory way the impacts, and therefore the external damages, caused by crude oil pipeline transportation. Note that even disregarding technical improvements in pipeline maintenance would not result in significant increases of the relevance of pipeline externalities. However, neither LCI data for oil pipelines nor

unit externality values for oil leakages from pipelines were available; thus the alternative given the information available at the moment is simply to leave oil pipeline externalities unaccounted for.

<b>2010 Low</b>	Extraction Externalities	Tanker Transport Externalities	Total Accident Externalities	<i>Non-GHG costs</i>	<i>GHG costs</i>	<i>Total emissions costs</i>	<b>Total Externalities</b>
To Atlantic Ports	1,37	0,48	0,015	1,15	0,70	1,85	1,87
To Mediterranean Ports	1,38	0,41	0,010	1,09	0,69	1,79	1,80
<b>Total EU</b>	1,37	0,45	0,013	1,13	0,70	1,83	<b>1,84</b>
<i>Pipeline</i>				0,00	0,66	0,67	0,67
<b>Total Externalities</b>	<b>1,37</b>	<b>1,12</b>	<b>0,01</b>	<b>1,13</b>	<b>1,36</b>	<b>2,49</b>	<b>2,51</b>
<b>2020 Low</b>	Extraction Externalities	Tanker Transport Externalities	Total Accident Externalities	<i>Non-GHG costs</i>	<i>GHG costs</i>	<i>Total emissions costs</i>	<b>Total Externalities</b>
To Atlantic Ports	1,70	0,65	0,016	1,50	0,85	2,34	2,36
To Mediterranean Ports	1,70	0,48	0,009	1,35	0,83	2,18	2,19
<b>Total EU</b>	1,70	0,58	0,013	1,44	0,84	2,28	<b>2,30</b>
<i>Pipeline</i>				0,000	0,032	0,032	0,032
<b>Total Externalities</b>	<b>1,70</b>	<b>0,61</b>	<b>0,01</b>	<b>1,44</b>	<b>0,87</b>	<b>2,31</b>	<b>2,33</b>
<b>2030 Low</b>	Extraction Externalities	Tanker Transport Externalities	Total Accident Externalities	<i>Non-GHG costs</i>	<i>GHG costs</i>	<i>Total emissions costs</i>	<b>Total Externalities</b>
To Atlantic Ports	1,70	0,70	0,016	1,54	0,86	2,40	2,42
To Mediterranean Ports	1,70	0,46	0,009	1,32	0,84	2,16	2,17
<b>Total EU</b>	1,70	0,61	0,013	1,46	0,85	2,31	<b>2,32</b>
<i>Pipeline</i>				0,00	0,00	0,00	0,03
<b>Total Externalities</b>	<b>1,70</b>	<b>0,64</b>	<b>0,01</b>	<b>1,46</b>	<b>0,88</b>	<b>2,34</b>	<b>2,36</b>

**Table 24.. External costs of oil extraction and transport. Projections to 2010, 2020 and 2030 in the low demand scenario. Euros per ton.**

It must also be noticed that the results depend crucially from the unit externality values used for the extraction phase. It is worth noting that using offshore values only would have resulted in a drop of extraction externalities to a few cents a ton, and into overall externalities in the range of 0.5 - 0.6 Euro a ton.

## 5. Conclusions

Our assessment covered in detail various aspects of the externalities related to the extraction and transportation of oil to Europe, in particular the dynamic features related to the foreseeable variation of oil flows and transport modes, the evolution of the burdens and impacts of operational externalities, the relative relevance of the various production areas, the likely improvements of pipeline maintenance standards. The resulting values seem quite low, ranging from 2.32 Euro per ton in 2030 in the Low demand scenarios to 2.60 Euro in 2010 in the High demand scenario, but still about 1-2 Euro higher than those originated by the extraction and transportation phases of the natural gas chain<sup>19</sup>. Externalities due to pipeline transport are the main driver of the difference between the 2010 results and the 2030 results, as maintenance standards of Russian pipelines are assumed to close the gap with European standards after 2010. Thus, pipeline externalities in 2010 are 25 times higher than those expected in 2030, and this has stronger effect on the overall externality values than the differences in oil import volumes and exporting countries' shares between the two demand scenarios. Assuming that no improvements in the maintenance standards of Russian pipelines take place, the overall external costs in 2030 would reach 3.05 Euro in the Low demand scenario, and 3.25 Euro in the High demand scenario. It is not unlikely that more accurate LCA data for pipelines would have resulted in even higher, but not too high, external costs, as gas pipeline transport is quite energy intensive and the energy content per cubic meter of oil is higher than for natural gas and the majority of gas imports to Europe are transported via pipeline<sup>20</sup>. These values are however sensitive to the LCA and unit externality assumptions made for the various phases of the value chain; in particular, the extraction phase, appears to have a strong impact on the overall assessment.

Notwithstanding the sensitivity of these results to LCA data and to unit externality values per pollutant, it is clear that these externalities are quite low, both compared to the direct cost of oil and to the externalities generated by the use of oil as a fuel. Assuming a price of crude oil at destination of \$90 a barrel, the cost of one ton equals to \$660 or 447 euros<sup>21</sup>. The external costs of transportation then amount to about 0.6% of the cost of the product in 2010. Burning oil for electricity generation results into a much higher share of external costs over total (external + private costs). For an average European power plant burning heavy fuel oil the external costs represent on

---

<sup>19</sup> Also assessed within the NEEDS Project. See Bigano et al (2007c). External costs for oil transport are from 35% to 8 times higher (per imported ton) than those for natural gas, depending on the demand scenario considered and on whether Russian pipeline maintenance standards are updated to European standards after 2010.

<sup>20</sup> To move one ton of oil by pipeline for one kilometre it takes about 71% of the energy needed to move the same amount of natural gas along the same distance.

<sup>21</sup> Assuming an exchange rate of 1.476 Euro per US dollar

average about 45% of the total costs, while for power plant using light fuel oil in a gas turbine the share of external costs over total costs is about 24%.<sup>22</sup>

The main implication for environmental policy to be drawn from this study is that bringing oil to Europe is not the most noxious phase of the oil life cycle, as actually using oil as a fuel brings about, on average, much more serious consequences for the environment and for human health.

However, transporting oil to Europe is an activity which brings about a non negligible probability of causing very high local damages. The fact that these probabilistic externalities account for a very small fraction of the total external cost of oil transport, once weighted for their occurrence probabilities and the volume of oil transported, by no means should be used as a justification for relaxing pollution prevention and remediation standards in European waters. In fact as our analysis of probabilistic externalities has demonstrated, the impact on local populations affected can be very substantial.

---

<sup>22</sup> These shares of private and external costs on total cost of electricity generation are those assessed within the European project CASES ([www.feem-project.net/cases](http://www.feem-project.net/cases)), and reported in Bigano and Porchia (2008).

## REFERENCES:

Arrow, K.J., R. Solow, E. Leamer, P. Portney, R. Radner and H. Schuman 1993: Report of the NOAA Panel on Contingent Valuation. *Federal Register*, 58, 4601-4614 (January 15, 1993).

Bateman, I. J., R. T. Carson, B. Day M. Hanemann et al 2002: Economic Valuation with Stated Preference Techniques. A Manual. Edward Elgar Publishing, Cheltenham (UK) and Northampton, (MA, USA),

Bergland, O. 1994: Estimating oil spill damages: The case of Blücher. Report to Det Norske Veritas Research AS, Oslo. December 1994. 36 pp.

Bigano, A. , Cassinelli, M., Markandya, A., Sferra, F.,(2006). The Role of Risk Aversion and Lay Risk in the Probabilistic Externality Assessment for Oil Tanker Routes to Europe. Fondazione Eni E. Mattei Working Papers n.149.06, Milan, Italy. (Accepted for publication subject to revision by the Journal of Transport Economics and Policy).

Bigano, A. , Cassinelli, M., Markandya, A., Sferra, F.,(2007a). Impacts from oil transportation phase of oil by pipeline and from oil extraction. *NEEDS* Technical paper 1.6b - RS 1c WP 11.7b, [www.needs-project.org](http://www.needs-project.org)

Bigano, A. , Cassinelli, M., Markandya, A., Sferra, F.,(2007b). Additional potential externalities due to accidents in the oil chain. Part I: Oil extraction and transportation by tanker route. *NEEDS* Technical paper 1.7b - RS 1c WP 1, [www.needs-project.org](http://www.needs-project.org)

Bigano, A. , Cassinelli, M., Markandya, A., Sferra, F.,(2007b) Burdens, Impacts And Externalities From Natural Gas Chain. 2.3-2.6. *NEEDS* Technical paper 1.7b - RS 1c WP 1, [www.needs-project.org](http://www.needs-project.org)

Bigano A. and Navrud, S. (2007) Report on the economic evaluation of externalities due to extraction and transport of oil. *NEEDS* Technical paper 1.8 - RS 1c WP 1, [www.needs-project.org](http://www.needs-project.org)

Bigano A., Porchia, R.(2008) Development of a set of full cost estimates of the use of different energy sources and its comparative assessment in EU countries. *CASES* deliverable D.6.1, [www.feem-project.net/cases](http://www.feem-project.net/cases).

Bredahl Jacobsen, J. and N. Hanley 2007: A global study of income effects in contingent valuation studies of environmental protection. Paper presented at the 15th Annual Conference of the European Association of Environmental and Resource Economists, Thessaloniki, Greece, June 27-30th , 18 pp.

Brown, A.J., and B. Haugene (1998): 'Assessing the Impact of Management and Organizational Factors on the Risk of Tanker Grounding', *8th International Offshore and Polar Engineering Conference*, ISOPE-98-HKP-03.

Carson, R. T., R. C. Mitchell, M. Hanemann, R. J. Kopp, S. Presser and P. A. Ruud 2003: 'Contingent valuation and lost passive use: Damages from the Exxon Valdez oil spill' *Environmental and Resource Economics* 25 (3); 257-286.

Commission for the Mining and Other Extractive Industries & Committee on "Borehole Operations (2001): "Report on Accident Statistics 1991-2000 for the extractive industry related to the borehole operations safety and health"

Desvousges, W.H, F. R. Johnson and H.S. Banzhaf 1998: *Environmental Policy Analysis with Limited Information. Principles and Applications of the Transfer Method*. New Horizons in Environmental Economics. Edward Elgar, Cheltenham, UK and Northampton, MA, USA.

ECOINVENT Centre: "Ecoinvent Data". <http://www.ecoinvent.ch/>

EcoSense Model. <http://webeco.ier.uni-stuttgart.de/>

ENIscuola: <http://www.eniscuola.net/testo.aspx?id=5#11>

Etkin, D. S. (2001), 'Comparative Methodologies for Estimating On-Water Response Costs for Oil Spills' *International Oil Spill Conference*, p.1281.

Etkin, D. S. and Schmidt, D. (2004), *Modeling Oil Spill Response and Damage Costs*, Epa gov (14 September 2005): [www.epa.gov/oilspill/etkin2\\_04.pdf](http://www.epa.gov/oilspill/etkin2_04.pdf).

ExternE (1995): *Externalities of Energy - Vol. 2: Methodology*, European Commission DGXII, Luxembourg.

Ferguson, R. (1992): *Environmental Costs of Energy Technologies, Accidental Radiological Impacts of Nuclear Power*, CEETES, University of Newcastle.

- Friend, I., and M. Blume (1975): *The Demand for Risky Assets*, American Economic Review, 65, 900-922.
- Friis–Hansen, P., and O. Ditlevsen (2002): ‘Nature preservation acceptance model applied to tanker oil spill simulations’, *Structural Safety*, 25, 1–34.
- Gibson P. (2002): “ Oil Spills in U.S. Navigable Waters – 1991-2000”, American Petroleum Institute
- Hammond, P. (1981): ‘Ex Ante and Ex Post Welfare Optimality Under Uncertainty’, *Economica*, 48 (191), 235-250.
- Guarrera, L. and Karbuz, S.(2007) Present and future oil flows and routes from producing areas to Europe. NEEDS Technical paper n°1.2 - RS 1c, [www.needs-project.org](http://www.needs-project.org)
- Hansen, L.P., and K.J. Singleton (1982): ‘Generalized Instrumental Variables Estimation of Nonlinear Expectations Models’, *Econometrica*, 50, 1269-1286.
- Hokby S., and T. Söderquist 2003: Elasticities of Demand and Willingness to Pay for Environmental Services in Sweden, *Environmental and Resource Economics* 26; 361–383.
- Krewitt W., (2002): External cost of energy – do the answers match the questions? Looking back at 10 years of ExternE. *Energy Policy*, 30 : 839 – 848.
- Krström B. And P. Riera P.1996: Is the Income Elasticity of Environmental Improvements Less Than One? *Environmental and Resource Economics* 7, 45-55.
- Lee, R., et al. (1993): *Damages and Benefits of the Nuclear Fuel Cycle: Estimation Impacts and Values*, Oakridge National Laboratory, Oakridge USA.
- Lindhjem, H. 2006: *20 Years of Stated Preference Valuation of Non-Timber Benefits from Nordic Forests: A Meta-Analysis*, *Journal of Forest Economics* **12**: 251-277, 2007.
- Markandya, A., and T. Taylor (1999): *The External Costs of Nuclear Accidents*, IAEA.
- Mehra, R., and E.C. Prescott (1995): ‘The Equity Premium - a puzzle’, *Journal of Monetary Economics*,15, 1985, 145-161.

Navrud, S and R. Ready (eds.) 2007: *Environmental Value Transfer: Issues and Methods*. Springer, Dordrecht, The Netherlands, 290 pp.

Navrud, S. 2004: Value transfer and environmental policy. Chapter 5 (pp. 189-217) in Tietenberg, T. and H. Folmer (eds.) 2004: *The International Yearbook of Environmental and Resource Economics 2004/2005. A survey of Current Issues*. Edward Elgar Publishing, Cheltenham, UK and Northampton, MA, USA..

Navrud, S. 2007: Benefit Transfer Guidelines – The Methodological Platform. Report from NEEDS RS 3a. August 2007.

PACE (1992): *Environmental Costs of Electricity*, PACE University Centre for Environmental Legal Studies. Prepared for the New York State Energy Research and Development Authority and the US Department of Energy.

Preiss, Philipp (2007) Technical Paper n° 1.4 - RS 3a“Report on marginal external costs – Preliminary results” NEEDS deliverable, [www.needs-project.org](http://www.needs-project.org)

Preiss, Philipp (2007) Technical Paper n° 1.4 - RS 3a“Report on marginal external costs – Preliminary results” NEEDS deliverable, [www.needs-project.org](http://www.needs-project.org)

RAInews 24: [http://www.rainews24.ra.i.it/ran24/speciali/obiettivo\\_usa\\_nuovo/te\\_petrolio.htm](http://www.rainews24.ra.i.it/ran24/speciali/obiettivo_usa_nuovo/te_petrolio.htm)

Ready, R. and S. Navrud 2006: International Benefits Transfer: Methods and Validity Tests. *Ecological Economics* 60(2), 429-434.

Rowe,R.D., W.D. Schulze, W.D. Shaw, D. Schenk & L.C. Chestnut 1991: Contingent valuation of natural resource damage due to the Nestucca oil spill. RCG/Hagler, Bailly, Inc., Boulder, Colorado, USA. Final report, June 15, 1991.

Safety and Health Commission for Mining and Other Extractive Industry (SHCMOEI) *Report On Accident Statistics: “For The Extractive Industry Related To The Borehole Operations”*, (DOC. N° 1587-3-01), EU, 1991-2000. [http://ec.europa.eu/employment\\_social/health\\_safety/docs/accident\\_statistics\\_2000\\_en.pdf](http://ec.europa.eu/employment_social/health_safety/docs/accident_statistics_2000_en.pdf)

Sandrea, I, Sandrea, R. (2005) *GLOBAL OFFSHORE OIL-1: Exploration trends show continued promise in world's offshore basins*. Oil & Gas Journal, March 05, 2007, volume 105, issue 9.



Söderqvist, T. and Å. Soutukorva 2006: An Instrument for assessing the quality of environmental valuation studies. Report. Swedish Environmental Protection Agency (Naturvårdsverket)  
<http://www.naturvardsverket.se/bokhandeln/pdf/620-1252-5.pdf>

The Center for Energy Analysis and Policy: “TEAMS - The Total Energy and Emissions Analysis for Marine Systems Model”, Rochester, New York

The Health and Safety Commission: “MHIDAS (Major Hazard Incident Data Service) Database”, Great Britain

Transneft, <http://www.transneft.ru/About/History/Default.asp?LANG=EN>

UK Health and Safety Executive (HSE) *Industry Sector Profile Onshore Oil Industry 2002/03*.  
<http://www.hse.gov.uk/chemicals/onshoreoi02-03.pdf>

Van Bieryliet, K., Le Roy, D. and P.A.L.D. Nunes (2006): ‘An Accidental Oil Spill Along the Belgian Coast: Results from a CV’, *FEEM Working Paper*, 41.2006.

Xie, D. (2000): ‘Power Risk Aversion Utility Functions’, *Annals of Economics and Finance*, 1, 265-282.

**NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI**

**Fondazione Eni Enrico Mattei Working Paper Series**

**Our Note di Lavoro are available on the Internet at the following addresses:**

<http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm>

<http://www.ssrn.com/link/feem.html>

<http://www.repec.org>

<http://agecon.lib.umn.edu>

<http://www.bepress.com/feem/>

**NOTE DI LAVORO PUBLISHED IN 2009**

- SD 1.2009 Michael Hoel: [Bush Meets Hotelling: Effects of Improved Renewable Energy Technology on Greenhouse Gas Emissions](#)
- SD 2.2009 Abay Mulatu, Reyer Gerlagh, Dan Rigby and Ada Wossink: [Environmental Regulation and Industry Location](#)
- SD 3.2009 Anna Alberini, Stefania Tonin and Margherita Turvani: [Rates of Time Preferences for Saving Lives in the Hazardous Waste Site Context](#)
- SD 4.2009 Elena Ojea, Paulo A.L.D. Nunes and Maria Loureiro: [Mapping of Forest Biodiversity Values: A Plural Perspective](#)
- SD 5.2009 Xavier Pautrel : [Macroeconomic Implications of Demography for the Environment: A Life-Cycle Perspective](#)
- IM 6.2009 Andrew Ellul, Marco Pagano and Fausto Panunzi: [Inheritance Law and Investment in Family Firms](#)
- IM 7.2009 Luigi Zingales: [The Future of Securities Regulation](#)
- SD 8.2009 Carlo Carraro, Emanuele Massetti and Lea Nicita: [How Does Climate Policy Affect Technical Change? An Analysis of the Direction and Pace of Technical Progress in a Climate-Economy Model](#)
- SD 9.2009 William K. Jaeger: [The Welfare Effects of Environmental Taxation](#)
- SD 10.2009 Aude Pommeret and Fabien Prieur: [Double Irreversibility and Environmental Policy Design](#)
- SD 11.2009 Massimiliano Mazzanti and Anna Montini: [Regional and Sector Environmental Efficiency Empirical Evidence from Structural Shift-share Analysis of NAMEA data](#)
- SD 12.2009 A. Chiabai, C. M. Travisi, H. Ding, A. Markandya and P.A.L.D Nunes: [Economic Valuation of Forest Ecosystem Services: Methodology and Monetary Estimates](#)
- SD 13.2009 Andrea Bigano, Mariaester Cassinelli, Fabio Sferra, Lisa Guarrera, Sohbet Karbuz, Manfred Hafner, Anil Markandya and Ståle Navrud: [The External Cost of European Crude Oil Imports](#)