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EXIOPOL

A NEW ENVIRONMENTAL ACCOUNTING FRAMEWORK USING EXTERNALITY DATA AND INPUT-OUTPUT TOOLS FOR POLICY ANALYSIS

EXIOPOL DELIVERABLE DIV.3.d-1

EXIOPOL DELIVERABLE DIV.3.d-2

ENERGY POLICY IMPLICATIONS ON EXTERNALITIES

Report on the policy measure selected and the impacts and damage costs of the analysed policy measure

Report of the EXIOPOL project

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Preamble

The present Deliverable combines the Deliverables DIV.3.d-1 “Report on the policy measure selected and the future scenarios” and DIV.3.d-2 “Report on impacts and damage costs of the analysed policy measures”. Starting from the selected policy measures, emission scenarios were developed. Reference scenarios were defined and emission changes due to the implemented policy measures were analysed. Finally, impacts were identified and, by monetary valuation, damage costs were determined.

Focus of the policy measures to be considered was on the EU’s climate change policies and climate change mitigation measures. Two parts of the EU directive on renewable energy sources in energy generation and transport:

- A scenario was developed based on the EU’s 2020-policy that regards the impacts of the increased use of renewable energies in electricity and heat generation.
- A scenario on the impacts of increasing use of biofuels in transport was developed including effects on agriculture through the additional demand for energy crops

The scenarios were studied regarding their impacts on human health, the quality of the ecosystem and climate change. The emissions included in the impact analysis were air pollutants (ammonia (NH_3), nitrogen oxides (NO_X), non-methane volatile organic compounds (NMVOC), particulate matter (PM_{10}, $PM_{2.5}$) and sulphur dioxide (SO_2)) as well as greenhouse gases (methane (CH_4), dinitrogen oxide (N_2O) and carbon dioxide (CO_2)).

Wolf Müller

Coordinator of WS IV.3

EXIOPOL project

February 2011

Executive Summary

Overview

This report is the report of the EXIOPOL project on a selected policy measure and the quantification of emissions and impacts for the energy sector. The selected policy measure refers to EU Directive 2009/28/EC promoting the use of renewable energy technologies targeting a share of 20% of renewables in gross energy consumption as well as a 10%-share of biofuels used in transport energy consumption in the EU-27 Member States. The changes resulting from this increasing use of renewable technologies with respect to the activities within the sectors of electricity generation, heat generation and transport were assessed in this study. Based on the changes in activities, the emissions of greenhouse gases (methane (CH_4), dinitrogen oxide (N_2O) and carbon dioxide (CO_2)) and airborne pollutants (ammonia (NH_3), nitrogen oxides (NO_X), non-methane volatile organic compounds (NMVOC), particulate matter (PM_{10}, $PM_{2.5}$) and sulphur dioxide (SO_2)) were estimated in order to assess the directive's success with respect to reducing climate change as well as in order to calculate the impacts on human health and the ecosystem.

The project has started in March 2007 and will run until March 2011.

Approach

Two scenarios were analysed in context of this study. The target year was 2020, respectively. The first scenario covers a business as usual scenario where no additional climate change policies then the ones already agreed upon or already implemented by 2012 are included. Thus, for this scenario the EU directive and its goals for 2020 have not been implemented. The second scenario includes the EU directive to be assessed in this study along with a number of other policy measures aiming at a reduction of greenhouse gas emissions by 70% compared to the level of emissions in 1990. To assess the changes in emissions and related impacts caused by the implementation of the EU directive, the differences in activities between the business as usual case and the climate policy scenario were analysed. This analysis was done by assuming a non-implementation of the directive and regarding a hypothetical situation where the demanded amounts of electricity, heat and transport activities in the climate scenario would have been generated by fossil energy carriers such as coal, lignite, oil and gas or by vehicle engines using conventional diesel or gasoline. These assumed changes in energy production and transport lead to a new scenario, where demand is equal to the climate scenario but technologies to meet the demand reflect the business as usual case. The resulting changes in emissions from the additional application of fossil technologies instead of renewable ones were estimated and impacts caused by these emissions where calculated. The estimation of emissions was split into an analysis of the emissions from the operational phases of electricity and heat generation, e.g. combustion activities in power plants, and transport activities and an analysis of the other phases of the life cycle, e.g. construction, maintenance, fuel supply and dismantling of power plants or the production of diesel and gasoline and the cultivation of energy crops for biofuel production. These emissions were then related to impacts which can then be regarded as benefits from the implementation of the EU directive.

Results

For all sectors covered in the analysis of the study, i.e. electricity and heat generation as well as transport, the effect of the EU directive promoting the use of renewable technologies led to a substantial reduction in greenhouse gas emissions. Thus, for the main target of the implementation of the directive by 2020 a successful completion is clearly possible. In addition to these positive effects on climate change, the impacts on human health caused by airborne pollutants in sum also can be reduced. However, while there is potential for reducing impacts on human health and climate change, the impacts on the quality of ecosystems, assessed here via biodiversity losses due to acidification and eutrophication, increase. This is in most cases and most countries related to the increasing demand for agriculturally cultivated area for energy crops such as sunflower, starch crops or woody biomass. The overall benefits across all sectors and the EU-27 Member States sum up to about 11 billion $Euro_{2000}$, showing that the implementation of the EU directive on renewable energy technologies can have a substantial positive impact with respect air pollution and climate policy issues. The results for the changes in emissions will be presented per country and per pollutant, while the monetary damages are divided by human health impacts, ecosystem impacts and climate change.

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1 Introduction

In order to ensure harmonisation with WP IV.2.c, the work package will focus on the analysis of environmental and human health impacts due to policy measures with respect to the energy sector in the European Union. The decision to focus on the energy sector instead of the industrial sector as planned earlier is based on the fact that the industrial sectors cover a large range of different activities that would require different policy regulations. Furthermore, the effects of regulation for single industrial sectors can be assumed to be relatively low. At this stage, the policy option will focus on the implications of the EU targets with respect to biomass use as renewable energy by 2020. The analysis of this policy option will also be part of the estimations in WP IV.3.a focusing on the agricultural sector. Therefore, the impacts of the selected scenario will be analysed with respect to the energy and the agricultural sector. The results will be prepared as to allow for a comparison of the top-down and the bottom-up approach in WP IV.4.

In a first step of the analysis the selected energy policy measure will be described and the assumptions for the resulting scenarios will be presented. This includes a brief documentation of the TIMES model which was applied for the estimations of the scenarios.

The third chapter will then provide an in-depth analysis of the three sectors affected by the EU policy on renewable energy sources and biofuels, i.e. electricity generation, heat generation and road transport. For each of these sectors changes in the activities between a business-as-usual and a climate scenario estimated using the TIMES model will be calculated on the basis of the hypothetical assumption of non-implementation of the EU directive in 2020. Based on the estimated changes in emissions for this scenario, divided into an analysis of emissions from operation of power plants, heat generating facilities and vehicles and an analysis of the life cycle of electricity and heat generation as well as biofuel and conventional fuel production, the resulting impacts will be estimated. These impacts will be presented applying monetary damage values for human health, ecosystem and climate change impacts which have been estimated in course of the EXIOPOL project.

In a final chapter, the results for the electricity, heat and transport sector will be summarised and the overall results of the EU directive on the promotion of renewable energy sources and biofuels will be presented and discussed.

2 Energy policy scenario

2.1 Methodology

The scenario selected to be analysed in detail in this study refers to the EU energy and climate policy targets defined in EU Directive 2009/28/EC (European Commission, 2009). This directive sets out the EU targets for promotion of the use of energy from renewable sources. The directive aims at the establishment of national targets for renewable resource use with an overall target value of a 20% share of energy from renewable sources in the EU-27 gross final consumption of energy and a 10% share of energy from renewable resources in each Member State's transport energy consumption by 2020. Therefore, three different sectors for energy related activities have to be regarded: the electricity production sector, the heat generation sector and the transport sector using biofuels.

The assessed emission scenarios targeting these sectors in the EU were developed in the EU project HEIMTSA.[1] This project aimed at estimating the human health impacts of a large number of climate policy measures applying an integrated assessment approach. Following the HEIMTSA approach, a business-as-usual (BAU) scenario, including only those measures which have been agreed to be implemented by 2012, are compared to an energy scenario with additional measures to reach the targets of the EU energy strategy (so-called 450ppm scenario because of the target of not exceeding 2°C temperature increase after 2100 a stabilization at 450ppm CO2eq would be necessary). As the EU energy targets up to 2020 are implemented in the 450ppm scenario of the HEIMTSA estimations, this scenario will then be compared to the situation in the BAU scenario in order to find out the changes in emissions that can be related to the additional policy measures. The changes in emissions can then be used to identify the costs and benefits with respect to impacts on human health and the ecosystem.

2.1.1 Analysis of the electricity production sector

The analysis here will be based on three steps. First, the estimates of the HEIMTSA project for the BAU and the 450ppm scenario for 2020 will be analysed with respect to the share of renewable energy sources in gross energy consumption. As the EU targets have been implemented only in the 450ppm scenario, the targeted share of 20% for electricity and heat production in gross energy consumption should be reached in this scenario.

Second, the estimated difference between the BAU and the 450ppm scenario for 2020 will be applied to estimate a hypothetical scenario where the difference in the amount of electricity production is produced by other available energy technologies. Thus, this second scenario will provide insights on the case where the electricity production would have been based on conventional energy carriers such as coal, gas or oil.

In a final step the difference in the emissions for both scenarios will be estimated and evaluated in terms of their impacts on human health and the ecosystem. This comparison will not only include the emissions of the operation of different energy producing technologies but will also include the emissions from processes which are upstream and downstream the overall production process, i.e. construction, maintenance and dismantling of a power plant. This overall life cycle analysis (LCA) is especially important for the assessment of

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[1] More information on the project can be found at http://www.heimtsa.eu/TheProject/tabid/170/Default.aspx

renewable energy sources as the emissions only result in the non-operational processes. As a result of the estimations, the benefit of increasing the share of renewable emission sources will be presented in terms of avoided external costs resulting from damages to human health and the environment.

2.1.2 Analysis of the heat generation sector

The analysis will be analogous to the estimations carried out for the electricity production sector. Again, the estimates of the HEIMTSA project for the climate scenario for 2020 will be analysed with respect to the share of renewable energy sources in gross energy consumption. As the EU targets have been implemented in this scenario, the targeted share of 20% for both heat and electricity should be reached in this scenario.

The analysis of the hypothetical production of heat with other energy carriers will be analogue to the assessment of the electricity market. This includes the extension of the analysis for emissions occurring during the overall life cycle of the heat generating technology.

2.1.3 Analysis of the use of biofuels in the transport sector

For the transport sector the analysis differs from the above presented approach in a way as the EU regulations target a share of 10% of total fuel consumption to be based on biofuels.

In a first step, data on energy consumption differentiated by fuel types will be analysed for the year 2000 and compared with the situation in the year 2020 when the target of the EU directive on renewable energies is planned to be reached in the EU-27 Member States. These data will again be analysed for the 450ppm HEIMTSA scenario. Analogously to the above presented approach for the electricity and heat generating sectors, the analysis of a hypothetical scenario where no (or less) biofuels are available for the transport sector will help to estimate the avoided emissions and the related impacts on human health and the environment. For this hypothetical scenario assumptions on the share of conventional diesel and petrol fuel vehicles as well as gas fuels will have to be made in order to estimate the case without additional biofuels in the transport sector.

2.2 The HEIMTSA scenarios

The estimation of energy and transport related policy measures within the HEIMTSA project have been carried out with the application of the TIMES model. The model estimates changes in net electricity production as well as energy consumption for each of the 27 EU Member States. Based on changes in the production of energy, the changes in emissions and resulting impacts of these emissions have been estimated.

2.2.1 The TIMES model

This chapter is designed to provide some details on the general functionality of the TIMES model. The presented description of the main features of the model is based on publications by the team of developers, i.e. Blesl (2008a) and Blesl et al. (2008b).

The Pan-European TIMES energy system model (short TIMES PanEU) based on the model generator TIMES. It is a model of 30 regions which contains all countries of EU-27 as well as Switzerland, Norway and Iceland. The model covers on a country level all sectors connected to the energy supply and demand, for example the supply of resources, the public and industrial generation of electricity and heat and the industrial, commercial, household and transport sectors. Both greenhouse gas emissions (CO_2, CH_4 and N_2O) and air pollutant emissions (NO_X, SO_2, NMVOC, PM_{10}, $PM_{2.5}$) are covered. The generation of electricity and heat in electric power plants, combined heat and power (CHP) plants and heating plants is differentiated into public and industrial production. The TIMES model contains three different voltage levels of electricity (high, medium, and low voltage) and two independent heat grids (district heat and local heat). The transport sector integrates the areas of road transport, rail transportation, navigation and aviation in the model. The road transportation encloses five demand categories for passenger transportation and one for freight service. The rail transportation includes the three categories rail passenger transportation (short and long distance) and also rail freight transportation. The household sector contains eleven demand categories (space heating, air conditioning, hot water, cooking, lighting, refrigeration, washing machines, laundry dryer, dishwasher, other electrics, other energy use) whereof the first three are specified according to building types (single family houses in urban and rural areas and multi-family houses, each with stock and new buildings). The commercial sector is represented by a similar reference energy system (RES).The industrial sector is divided into energy intensive and non-intensive branches. While the intensive ones are modelled by a process orientated approach, the other industries have a similar structure of energy services. The industrial sector is subdivided into several branches. Further assumptions relevant for the estimation of future scenarios, i.e. population growth, growth of GDP as well as the development of oil, gas and coal prices, which are implemented in the TIMES model are presented in Table 1 below.

Table 1: Assumptions implemented in the TIMES model for future scenario development

		2005	2020	2030	2040	2050
Development of economy and population in the EU-27						
Population	Mill.	488	496	495	487	472
Av. annual growth	%		0.01	0.00	-0.2	-0.3
GDP	$10^{12}€_{2007}$	11.7	15.0	17.8	20.8	24.4
Av. annual growth	%		1.7	1.7	1.6	1.6
Energy prices (free boarder)						
Crude oil	$\$_{2007}$/bbl		88	100	106	109
Natural gas	$€_{2007}$/GJ	4.3	7.1	7.9	8.3	8.5
Coal	$€_{2007}$/GJ	1.9	2.6	2.8	2.9	2.9
Households and living space						
Number of dwellings	Mill.	197.9	260.2	273.6	267.9	259.8
Number of buildings	Mill.	114.9	147.2	154.4	156.1	152.0
Living space of dwellings	Mill. m^2	15856	20502	22041	22619	22320
Renewable Electricity						
Min. electricity quantities according to national policies in the EU-27	REF [TWh]	455	770	835	855	895
	450ppm [TWh]	455	995	1330	1510	1785
Potentials of renewable electricity generation in the EU-27	TWh	455	1700	2460	2880	3310

Source: Blesl et al. (2010)

The scenario estimations in course of the HEIMTSA project have also been summarised and published in Blesl et al. (2010). Here, the EU target of a share of 20% of renewable energy sources is highlighted as a major policy measure for the reduction of greenhouse gas emissions in Europe. The TIMES model has been applied for the estimation of two scenarios: a business-as-usual scenario (BAU) and a climate scenario (henceforth 450ppm scenario). The BAU scenario only covers those policy measures referring to climate change that have already been agreed on and that have been implemented in the European legislations by 2012. For the 450ppm scenario additional climate change measures have been assumed to be implemented in future years aiming at a reduction of EU-wide greenhouse gas emissions by about 70% in 2050 compared to 1990. These additional scenarios include the following regulations and targets:

- Reduction of EU greenhouse gas emissions by 20 % until 2020 and 71 % until 2050 compared to 1990
- Reduction of emissions in the ETS sector by 21 % until 2020 compared to 2005
- **Minimum share of renewable energy in total final energy consumption (20 % in 2020, 40 % in 2050)**
- Increased minimum production of electricity from renewables
- Lower demand for space heating due to improved building isolation
- Faster and stronger improvement of conventional vehicle efficiencies compared to the BAU case
- Minimum market shares for hybrid electric, battery electric and plug-in hybrid electric vehicles based on national targets
- **Implementation of EU directive 2009/28/EC requesting a minimum quota of renewable transport fuels in transport final energy consumption (10 % in 2020)**
- Stronger modal shift from motorized individual transport to public transport

As can be seen from the listed policies and targets with respect to climate policies there a number of different regulations that will have an impact on the amount of electricity generated by renewable energy sources. However, it was not feasible to extract the effects of one single regulation on the energy sector, therefore, in context of the present study, it will be assumed that only the EU regulation on the minimum share of renewable energy in total final energy consumption (20% in 2020) will have a major impact on the renewable energy production sector.

2.2.2 Results for the electricity generating sector

The application of the TIMES model provides results with respect to the activities in the electricity production sector. Of major interest for the present study are the activities related to renewable energy sources. These activities are summarised in Table 2 below where the share of different energy carriers in the overall net energy production for the EU-27 is shown for the BAU and the 450ppm scenarios for the years 200 and 2020. It has already been mentioned before, that the focus of the present study is to analyse the changes in impacts on human health and the ecosystem resulting from the European target of a share of 20% of renewable energy in the EU-27 gross electricity consumption by 2020. It also has to be mentioned that the given shares do only reflect the share of electricity produced with renewable sources in gross electricity consumption and thus, while a share of more than 20% is reached in the BAU scenario for 2020 already, this does not mean that the EU target of reaching 20% of energy produced by renewable sources. The analysis of the energy production for heat will be discussed in the next chapter.

Table 2: Net electricity generation in EU-27 and share of renewable energy sources in gross energy consumption

EU-27	Unit	2000	2020	
		BAU	BAU	450ppm
Coal	TWh	537	871	485
Lignite	TWh	313	386	324
Oil	TWh	176	52	51
Natural gas	TWh	484	397	545
Nuclear	TWh	883	790	850
Hydro	TWh	372	394	398
Wind	TWh	20	235	398
Solar	TWh	0	17	54
Biomass / Waste ren.	TWh	30	146	167
Other Renewables	TWh	5	7	7
Others / Waste non-ren.	TWh	3	22	24
Sum	**TWh**	**2,822**	**3,318**	**3,303**
of which CHP	TWh	325	568	576
Renewable Share at Gross Consumption	**%**	**13.4%**	**21.8%**	**28.5%**

The table shows that the amount of electricity produced by renewable energy sources in Europe in the BAU scenario grows from 427 TWh in 2000 to 799 TWh in 2020. Comparing the BAU and the 450ppm scenario in 2020, the share of electricity produced by using renewable energies in gross electricity consumption is clearly higher in the 450ppm scenario. This absolute difference of 225 TWh is assumed to be the result of the EU target of reaching the 20% share of energy produced by renewable sources. This information will serve as the base for the hypothetical scenario. It is obvious that the analysis will have to be carried out on a country specific basis as the structure of the energy sector varies substantially between countries. This will be taken into account in the assessment of the hypothetical scenario in chapter 3.

2.2.3 Results for the heat producing sector

The TIMES model can also be applied for the assessment of the heat producing sector to analyse the share of the renewable energy sources in heat production by combined heat and power plants (CHP) and public heating plants. The data on activities in the heat producing sector provided by the TIMES model for the EU-27 are presented in Table 3 below. The table shows that the amount of heat produced in CHP by biomass and renewable waste increases from about 274 PJ in the BAU scenario for 2020 to 559 PJ in the climate scenario for 2020. Furthermore, the amount of heat produced by renewable sources (heat pumps, biomass, renewable waste and solarthermal) in heating plants increases from about 111 PJ to 206 PJ. Thus, in total an increase of 380 PJ produced by renewables in the 450ppm scenario compared to the BAU scenario is assumed to result from the implementation of the EU directive on renewable energy production. Therefore, for the hypothetical scenario to be assessed in the next chapters it will be assumed that this amount of heat would be produced by conventional energy technologies.

The presented information will serve as the base for the hypothetical scenario. It is obvious that the analysis will have to be carried out on a country specific basis as the structure of the energy sector varies substantially between countries. This will be taken into account in the assessment of the hypothetical scenario in chapter 3.

Table 3: Heat production in EU-27

District heat generation		**2000**	**2020**	
		BAU	**BAU**	**450 ppm**
CHP (public)	**unit**	**1308,47988**	**1345,9729**	**1386,47857**
Coal	PJ	479,836665	542,909384	271,111941
Lignite	PJ	156,279426	103,081456	93,3135824
Oil	PJ	160,525086	120,133424	119,861827
Natural Gas	PJ	450,224082	290,839982	328,832862
Nuclear	PJ	0	0	0
Biomass / Waste ren.	PJ	55,6917429	274,432913	559,323976
Other renewables	PJ	0	0	0
Others / Waste non-ren.	PJ	5,92288186	14,5757392	14,0343864
Heating plants (public)	PJ	**693,788748**	**348,901329**	**376,067859**
Coal	PJ	164,595643	62,530333	57,8196433
Lignite	PJ	24,1393996	8,51387712	8,25277856
Oil	PJ	66,5247278	4,08634169	4,08634172
Natural Gas	PJ	322,954052	158,690988	95,2264431
Electricity (incl. Heat Pumps)	PJ	45,0712575	35,9802	35,9802
Biomass / Waste ren.	PJ	59,1738761	74,7691901	170,395118
Solarthermal	PJ	0	0,00255451	0,00279406
Others / Waste non-ren.	PJ	11,3297921	4,32784495	4,30453984
Waste heat	PJ	**0**	**0**	**0**
Sum	**PJ**	**2002,26863**	**1694,87423**	**1762,54643**

2.2.4 Results for the transport sector

The TIMES model not only focuses on the electricity and heat producing sectors but also on the transport sector. Here, the energy consumption is provided by different types of fuels and vehicles. These data are available for the two years of interest in this study, 2000 and 2020. Based on these data the share of biofuels in total energy consumption of the transport sector can be estimated. As can be seen from Table 4 the share of biofuels (here: biodiesel, ethanol, FT-fuel bio) is substantially higher in the 450ppm scenario for 2020 than for the BAU case in the same year. This can directly be linked to the implementation of the EU directive that is in the centre of the analysis in the present study.

Table 4: Final energy consumption in transport sector by fuel type

EU-27	Unit	2000	2020	
			BAU	450ppm
Diesel	PJ	6,313	7,412	6,448
Gasoline	PJ	5,497	4,402	3,911
LPG	PJ	164	204	157
Kerosene	PJ	1,878	3,268	2,903
Heavy fuel oil	PJ	34	96	70
Biodiesel	PJ	0	108	532
of which as blend	PJ	0	86	286
Ethanol	PJ	0	27	394
of which as blend	PJ	0	23	71
FT-Fuel bio	PJ	0	88	292
of which as blend	PJ	0	80	276
FT-Fuel fossil	PJ	0	950	16
of which as blend	PJ	0	636	16
Dimethyleter bio	PJ	0	0	0
Dimethyleter fossil	PJ	0	0	1
Methanol bio	PJ	0	0	0
Methanol fossil	PJ	0	0	0
Hydrogen liquified	PJ	0	0	0
Hydrogen compressed	PJ	0	0	1
Biogas	PJ	0	0	0
Natural Gas	PJ	0	275	132
Electricity	PJ	258	381	390
Sum	**PJ**	**14,144**	**17,211**	**15,247**
Share of biofuels in total diesel and gasoline consumption	**%**	**0.0%**	**1.9%**	**10.5%**

3 Estimating the environmental impacts of the EU directive on renewable energy sources in energy consumption and transport

It has already been mentioned that the analysis of the impacts of the EU directive targeting a 20% share of energy consumption generated by renewable sources and a 10% share of biofuels in total fuel consumption will be analysed on the basis of alternative scenarios for 2020. These scenarios will be based on the developed BAU and 450ppm scenarios from the HEIMTSA project which – in the 450ppm case – include the successful implementation of the directive. Thus, for the analysis of the impacts this successful implementation will have with respect to human health and ecosystem effects, it will be assumed here that the implementation has not been successful and thus that the amount of electricity, heat or fuels for transport would have been substituted by conventional energy generation technologies.

The different substitution effects as well as the changes in emissions and related changes in impacts will be discussed in the following sections.

3.1 Environmental impacts caused by electricity generation

3.1.1 Scenario description

In chapter 2.2.2, the amount of electricity produced by additional renewable sources in the 450ppm scenario compared to the BAU scenario has been identified to be 225 TWh for the EU-27. For the assessment of the benefits of this change in electricity production, it will now be assumed that this amount of 225 TWh will be produced by fossil energy carriers.

The estimated 225 TWh are generated differently across the Member States of the EU-27. Thus, a country-specific analysis of the changes is necessary. In order to enable this county-specific analysis the difference between the amounts of electricity produced by renewable energies in the 450ppm scenario compared to the BAU case will be estimated for each country. In a second step this difference (in TWh) will be set into relation with the overall amount of electricity produced in the 450ppm scenario in each country. The resulting ratio will then be applied and subtracted from the existing share of the corresponding renewable energy source in the total electricity production in each country in the 450ppm scenario in 2020. At the same time, this ratio for each of the renewables will be translated into a ratio that will be added to the fossil energy carriers coal, lignite, oil and gas. With this approach it will be assumed that the additional electricity generated by renewable sources in the 450ppm case compared to the BAU case will be substituted by existing fossil energy carriers. This approach can be interpreted as the analysis of how total emissions would change assuming that the additional electricity generation in the 450ppm scenario (compared to the BAU scenario) would not have been produced by renewable energy sources but by fossil energy sources.

In order to replace the electricity produced with renewable sources by fossil energy carriers, substitution factors for the different electricity generating technologies need to be applied. These based on the German Federal Environmental Agency (UBA, 2009). In this study, the substitution of fossil energy carriers by renewable energy sources has been analysed and substitution factors have been estimated. These factors are presented in Table 5 and will now be applied to estimate the vice versa substitution. Although these factors have originally been derived for Germany they will be applied for the assessment of the changes in emissions for all of the EU-27 Member States in this study.

Table 5: Substitution factors for renewable energy sources

Renewable heat	Substitution factors			
	Oil	Gas	Coal	Lignite
Hydro power and geothermal	0%	25%	45%	30%
Wind	2%	24%	63%	11%
Photovoltaics	0%	50%	50%	0%
Thermal	0%	0%	50%	50%
Solid biomass and renewable waste	0%	25%	59%	16%
Liquid biomass and biogas	1%	32%	62%	5%

There are some additional minor assumptions:

- Countries where no electricity is generated by either coal or lignite technologies in 2000 are excluded from the analysis because a substitution of the additional electricity generated by renewable sources in the 450ppm scenario is not feasible for these countries for the year 2020 as no coal or lignite fired power plants are available. The problem does not arise for gas and oil as there is a certain share of the national amount of electricity produced by either of these fossil energy carriers.
- There are countries where already in the 2000 scenario a major share of electricity (more than 90%) is produced by nuclear technologies and hydro power (such as CH) or by hydro power alone (e.g. in LV). For these countries no major changes in the shares of renewable energy sources between the BAU and the 450ppm scenario can be expected as there is no need for additional adjustments based on climate policy measures. The only changes result from cost-efficiency estimations but can be considered as negligible.
- Furthermore, the potential changes in total national emissions in case of not generating the additional electricity with renewable sources but with conventional fossil energy carriers for those countries where the changes are marginal, i.e. below 1% of the overall electricity generation, will not be assessed in this approach.

The presented assumptions lead to the exclusion of 5 countries among the EU-27 Member States in the analysis, namely CY, LT, LU, LV and MT. The following Table 6 shows the amount of electricity in TWh reflecting 1% of the total electricity production within each of countries in 2020.

Table 6: Amount of electricity equivalent to 1% of total national electricity generation per country

countries	2020
	TWh
AT	0.79
BE	0.68
BG	0.42
CZ	0.81
DE	5.54
DK	0.44

EE	0.05
ES	2.78
FI	0.85
FR	5.68
GR	0.58
HU	0.55
IE	0.31
IT	2.90

NL	1.05
PL	1.85
PT	0.44
RO	0.76
SE	1.61
SI	0.24
SK	0.33
UK	4.18

Finally, Table 7 shows the resulting differences in electricity produced by renewable energy technologies in the 450ppm case and the BAU case given as a share in total national electricity generation. These shares will now be combined with the above presented substitution factors and from the resulting changes in activities the changes in total emissions will be estimated applying emission factors derived in course of the NEEDS project.

A negative sign in the following table signals that the amount of electricity produced by the respective renewable energy source was estimated to be higher in the BAU case than it is now in the 450ppm scenario although this scenario promotes the generation of electricity by renewable sources. Thus, the negative sign means that in the hypothetical scenario analysed here, additional facilities will be constructed. This sign results in an addition of electricity produced by renewables and thus directly substitutes fossil energy carriers, limiting the overall changes in emissions.

Table 7: Percentage shares per country and renewable technology which are assumed to be substituted by fossil energy carriers

countries	Biomass / renewable waste	Biogas	Hydro power	Wind onshore	Wind offshore	Solar PV	Solar thermal
AT	0.96%	0.00%	0.00%	0.26%	0.00%	0.33%	0.00%
BE	0.84%	-2.68%	0.00%	0.66%	3.63%	0.00%	0.00%
BG	1.47%	1.20%	0.00%	0.13%	0.00%	0.00%	0.00%
CZ	1.79%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DE	-1.91%	-0.91%	0.00%	-0.54%	6.01%	2.11%	0.00%
DK	3.10%	0.19%	0.00%	1.20%	32.38%	0.00%	0.00%
EE	3.75%	0.00%	0.00%	1.30%	0.00%	0.00%	0.00%
ES	0.01%	-0.47%	0.00%	1.72%	4.91%	3.69%	0.85%
FI	0.35%	-0.67%	0.00%	-0.61%	2.39%	0.00%	0.00%
FR	1.82%	0.00%	0.00%	0.00%	1.81%	0.44%	0.00%
GR	0.15%	0.00%	0.00%	4.77%	0.00%	2.65%	0.00%
HU	2.50%	0.00%	0.00%	0.00%	0.00%	1.02%	0.00%
IE	0.83%	0.00%	0.00%	3.07%	16.41%	0.00%	0.00%
IT	0.00%	0.00%	1.10%	0.52%	2.01%	2.23%	0.00%
NL	0.00%	0.00%	0.00%	0.60%	20.79%	0.00%	0.00%
PL	6.83%	0.00%	0.00%	0.11%	0.13%	0.00%	0.00%
PT	0.97%	1.21%	0.00%	1.11%	1.37%	1.63%	0.00%
RO	2.45%	0.00%	0.00%	1.79%	0.00%	0.00%	0.00%
SE	0.86%	0.00%	0.00%	-2.28%	5.21%	0.00%	0.00%
SI	1.32%	0.00%	0.00%	1.33%	0.00%	0.00%	0.00%
SK	3.56%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
UK	-0.18%	0.00%	0.00%	0.00%	8.54%	0.00%	0.00%

3.1.2 Resulting changes in emissions

It has already been stated that the changes resulting from the hypothetical replacement of renewable energy sources by fossil energy carriers leads to changes in the activity data of these technologies. These changes will be linked to changes in emissions through the application of emission factors per functional unit, i.e. per kWh. These emission factors have been derived on a country-specific level for a large number of technologies in course of the NEEDS project.

The estimations result in large changes in the emissions on the overall EU-27 level. While for some pollutants the substitution of a renewable technology by a fossil energy carrier results in a decrease of emissions (shown by a negative sign in the table below), in the majority of countries this substitution goes along with a significant increase in emissions. Table 8 clearly shows that emissions of greenhouse gases such as CH_4, N_2O and especially CO_2 would largely increase. The emissions of CO_2 would rise by almost 150,000 kt. Thus, these results in the emissions that would have occurred if the electricity generation would not be based on renewable energy sources as targeted by the EU directive can already be regarded as a large potential benefit, especially in the context of climate change.

In addition, the table shows the share these changes have in the total amount of emissions estimated for the sector of electricity production. Again, it can be seen that the changes for greenhouse gas emissions reflect the highest share in total emissions. However, it can also be seen from the table, that the changes in SO_2, NO_X and PM are relatively high. Thus, it is now necessary to assess the impacts these changes in emissions would have on human health, the ecosystem and climate change.

Table 8: Resulting changes in emissions from substitution of renewable electricity production sources by fossil energy carriers in the EU-27 [in kt]

countries	CH_4	N_2O	CO_2	NH_3	NMVOC	NO_X	PM_{10}	PM_{25}	PM_{coarse}	SO_2
AT	2.05	-0.05	894.41	-0.05	-0.02	-0.53	0.00	-0.02	0.03	0.37
BE	3.95	0.01	665.48	-0.01	0.23	1.63	0.35	0.18	0.17	3.80
BG	0.34	-0.04	818.84	-0.06	-0.06	-0.83	-0.09	-0.08	-0.01	-0.49
CZ	2.28	-0.11	528.65	-0.11	-0.10	-1.53	-0.02	-0.05	0.03	0.27
DE	45.07	1.82	18,207.98	1.13	4.49	36.91	2.05	1.10	0.95	25.69
DK	32.16	0.34	8,066.59	0.63	1.48	8.55	0.60	0.18	0.42	8.09
EE	0.44	-0.01	155.90	-0.01	-0.01	-0.17	0.00	-0.01	0.01	0.08
ES	49.48	0.69	25,739.59	0.30	2.51	18.63	1.18	0.41	0.78	17.30
FI	2.04	0.00	934.39	-0.01	0.10	0.74	0.13	0.05	0.07	1.55
FR	46.82	-0.37	17,213.00	-0.62	1.05	-2.44	0.32	-0.26	0.58	9.41
GR	7.97	0.12	2,318.86	0.03	0.50	2.44	0.13	0.03	0.10	2.26
HU	1.24	-0.10	1,091.91	-0.11	-0.05	-1.39	-0.03	-0.06	0.03	0.35
IE	11.27	0.16	3,923.10	0.04	0.63	3.61	0.21	0.03	0.17	3.59
IT	23.48	0.37	10,294.80	0.18	1.27	9.52	0.42	0.11	0.31	8.38
NL	38.79	0.57	14,609.45	0.38	1.86	14.10	0.80	0.21	0.60	12.40
PL	18.75	-1.01	8,874.78	-0.93	-0.99	-13.07	-0.14	-0.44	0.30	2.52
PT	4.40	0.02	1,990.84	-0.01	0.13	0.53	-0.02	-0.05	0.03	0.44
RO	5.16	-0.11	2,542.36	-0.12	0.00	-1.08	0.02	-0.05	0.08	1.13
SE	9.49	0.01	5,305.79	-0.06	0.29	1.73	0.15	-0.02	0.17	3.05
SI	0.91	-0.02	372.58	-0.02	0.00	-0.13	0.01	-0.01	0.02	0.23
SK	1.82	-0.09	221.46	-0.09	-0.08	-1.22	-0.01	-0.04	0.03	0.22
UK	58.87	0.94	22,766.62	0.45	2.85	23.40	1.27	0.32	0.95	20.09
TOTAL	**366.79**	**3.13**	**147,537.39**	**0.91**	**16.08**	**99.41**	**7.32**	**1.52**	**5.79**	**120.70**
% of total emissions from electricity production	**21.6%**	**6.5%**	**16.1%**	**4.0%**	**8.4%**	**9.4%**	**8.6%**	**4.7%**	**10.9%**	**14.4%**

3.1.3 Assessment of the impacts

The assessment of the impacts caused by the changes in the emission of the above presented pollutants requires a differentiation of source of the emissions. That is, it has to be differentiated between emissions resulting during the operational phase of the electricity generating process and the other life cycle phases such as the construction, the provision of fuels, the maintenance and the dismantling of the power plant. This differentiation becomes important as the emissions in the two not necessarily occur in the same spatial area. While the operational phase can obviously be linked to a certain spatial area, the parts for construction of the power plant as well as the provision of fuels in many cases leads to emissions in very different geographical regions. The applied emission factors from NEEDS allow for this differentiation in the emissions. The tables A1 and A2 in the appendix to this study show the amounts of emissions per country divided by operation and LCA phase.

The assessment of the impacts will be carried out by applying monetary damage factors that have been derived in course of the EXIOPOL project. In work package III.1.b external cost factors have been estimated that will serve as a link between the physical data on environmental extensions and the monetary input-output (IO) tables. Only when the environmental extensions can be expressed in monetary terms the link to the IO tables can be made and cost-benefit analysis become feasible.

The monetary values derived by Müller et al. (2010) refer to emissions in the year 2000. Furthermore, as the valuation of impacts on human health and the ecosystem is based on stated preferences of (affected) individuals, an adjustment of these values becomes necessary. This so-called uplift takes into account the economic growth which leads to higher stated values of willingness to pay and thus higher monetary damage factors for the assessment of the impacts. The following Table 10 presents the monetary values that have been applied to estimate the impacts on human health, the ecosystem and climate change. These damage factors are presented for stacks with height of more than 100m as this is assumed to be the case for electricity generating power plants using fossil energy carriers. These values will thus be applied for the estimation of impacts resulting from emissions from the operational phases. In addition, monetary values are provided for low and medium high stacks as it is assumed that the emissions of the LCA phases occur in these lower heights. It is assumed that 50% of the emissions occur in 5-20m height and another 50% in 20-100m height. Additionally, it is also assumed that half of the emissions in each of these height categories is emitted in urban and the other half in rural areas. Furthermore, for the quantification of impacts from LCA phases average monetary damage factors for the overall EU-27 will be applied. The reason behind that is the lack of information where the production of parts for construction takes place, where fuels are extracted and where the disposal of wastes occurs. These factors are summarised in Table 9 below.

Table 9: Monetary damage factors for low and medium stacks and emissions in 2020 in EU-27 [in $Euro_{2000}$]

	SO_2	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM_{coarse}	CH_4	CO_2	N_2O
EU-27, low height, rural	9,151	9,336	1,221	18,063	36,501	2,067	677	29	8,708
EU-27, low height, urban	9,151	9,336	1,221	18,063	79,312	8,010	677	29	8,708
EU-27, medium height, rural	9,151	9,336	1,221	18,063	36,501	2,067	677	29	8,708
EU-27, medium height, urban	9,151	9,336	1,221	18,063	37,589	2,562	677	29	8,708

Table 10: Monetary damage factors per country for high stacks and emissions in 2020 [in Euro$_{2000}$]

countries	SO_2	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM_{coarse}	CH_4	CO_2	N_2O
AT	10,031	11,748	1,303	26,029	20,672	658	677	29	8,708
BE	11,988	9,629	2,108	35,601	27,706	2,038	677	29	8,708
BG	6,357	6,698	-42	9,777	12,841	530	677	29	8,708
CZ	10,113	10,267	696	30,941	22,839	785	677	29	8,708
DE	11,696	11,695	867	27,084	30,679	1,247	677	29	8,708
DK	5,713	5,475	730	11,907	9,856	493	677	29	8,708
EE	4,797	2,375	186	11,811	6,145	200	677	29	8,708
ES	6,335	3,243	419	7,288	9,413	408	677	29	8,708
FI	3,659	2,648	199	7,006	4,109	62	677	29	8,708
FR	9,599	10,436	905	16,402	22,861	869	677	29	8,708
GR	6,074	2,404	202	6,901	9,638	417	677	29	8,708
HU	9,482	11,538	608	23,609	22,991	934	677	29	8,708
IE	6,597	4,022	689	3,058	7,837	321	677	29	8,708
IT	8,951	8,600	607	22,206	18,464	895	677	29	8,708
NL	11,814	8,715	1,614	28,492	30,263	1,994	677	29	8,708
PL	9,124	6,923	558	18,935	20,704	845	677	29	8,708
PT	4,105	990	420	5,590	5,911	275	677	29	8,708
RO	7,688	7,667	378	12,526	15,843	765	677	29	8,708
SE	4,843	4,451	346	10,542	5,361	143	677	29	8,708
SI	10,922	10,770	1,042	29,637	19,526	703	677	29	8,708
SK	9,267	9,861	462	28,791	19,715	775	677	29	8,708
UK	7,711	4,865	870	18,901	16,909	948	677	29	8,708

3.1.4 Results for the electricity generation scenario

3.1.4.1 Results for the operational phase

The combination of the changes in emissions resulting from the substitution of renewable electricity generation by fossil technologies with the monetary damage factors for the operational phase results in damages to human health, the ecosystem and climate change of about 5.1 billion Euro$_{2000}$. These external costs would arise if the targeted change in electricity generation leading to a 20%-share of renewable energy sources in overall electricity consumption would not be implemented and electricity would be produced by fossil energy carriers.

Table 11 presents the estimated monetary values for the three different impact categories. As can be seen from the table, the impacts on climate change account for clearly the highest part of the total external cost estimated. More than 80% of the monetised damages can be accounted to climate change impacts. This fact can easily be explained by the high emissions of greenhouse gases, especially CO_2 from fossil energy carriers such as coal, compared to the very low, almost zero emissions of renewable energy technologies. Following these, with about 17%, human health impacts are the second most important issue. Impacts on ecosystems are clearly not as important in this context.

Table 11: External costs for operation per country and impact category [in million Euro$_{2000}$]

countries	Human health	Ecosystem quality	Climate change	total
AT	-7	-2	25	**17**
BE	11	0	2	**13**
BG	-3	0	28	**25**
CZ	-16	-4	14	**-6**
DE	440	68	478	**987**
DK	49	9	227	**284**
EE	0	0	4	**4**
ES	90	9	725	**824**
FI	2	0	22	**24**
FR	-40	-8	488	**441**
GR	12	0	65	**78**
HU	-14	-2	31	**16**
IE	22	2	111	**136**
IT	94	11	292	**398**
NL	151	21	414	**587**
PL	-92	-24	249	**134**
PT	2	0	61	**64**
RO	-9	-1	72	**62**
SE	-5	-2	5	**-1**
SI	21	2	151	**174**
SK	-1	0	10	**9**
UK	157	16	645	**819**
TOTAL	**865**	**96**	**4,124**	**5,086**

3.1.4.2 Results for the LCA phases

A different picture is drawn by the resulting external costs for the LCA phases of the different electricity generating technologies. As is shown in Table 12 for this part of the total life cycle the impacts are highest for human health. More than 60% of the total external costs estimate can be accounted to health effects. The major reason for this is the lower level of emissions in combination with emission taking place in urban, highly populated areas. Thus, the number of affected individuals is higher than in the case of emissions from the operational phase occurring from high stacks. In total, impacts of about 1.6 billion Euro$_{2000}$

have been estimated to potentially occur when electricity is produced by fossil energy technologies and not by renewables as targeted by the EU directive analysed here.

Table 12: External costs for LCA phase per country and impact category [in million Euro$_{2000}$]

countries	Human health	Ecosystem quality	Climate change	total
AT	4	0	2	**6**
BE	47	3	20	**71**
BG	-11	-1	-4	**-16**
CZ	3	0	2	**5**
DE	227	20	104	**351**
DK	73	7	36	**115**
EE	1	0	0	**1**
ES	153	14	72	**238**
FI	17	1	7	**25**
FR	87	6	47	**140**
GR	18	2	9	**29**
HU	0	0	1	**0**
IE	26	2	13	**42**
IT	59	6	29	**94**
NL	100	10	47	**157**
PL	26	0	16	**42**
PT	-1	0	0	**-1**
RO	9	1	5	**15**
SE	22	2	11	**36**
SI	2	0	1	**3**
SK	2	0	1	**4**
UK	157	15	72	**245**
TOTAL	**1,022**	**88**	**492**	**1,602**

3.1.4.3 Summarised results

In summary about 6.7 billion Euro$_{2000}$ have been estimated resulting from the rise in emissions when electricity is produced by fossil energy carriers instead of the targeted 20% share of renewables. Table 13 presents the summarised results for each country and impact category.

Table 13: Total external costs per country and impact category [in million $Euro_{2000}$]

countries	Human health	Ecosystem quality	Climate change	total
AT	-3	-1	27	**22**
BE	58	4	22	**84**
BG	-14	-1	24	**9**
CZ	-13	-4	16	**-1**
DE	667	88	582	**1,337**
DK	122	15	262	**400**
EE	0	0	5	**5**
ES	243	23	797	**1,063**
FI	19	2	29	**49**
FR	47	-1	535	**581**
GR	30	2	75	**106**
HU	-14	-3	32	**16**
IE	49	4	124	**177**
IT	153	17	322	**492**
NL	252	31	461	**743**
PL	-66	-24	265	**175**
PT	1	0	62	**63**
RO	0	-1	77	**77**
SE	18	0	17	**35**
SI	23	2	152	**177**
SK	1	0	12	**13**
UK	314	32	718	**1,064**
TOTAL	**1,887**	**185**	**4,616**	**6,687**

To further show the differences in the impacts across country the following Figure 1 presents the total monetised damages per country. Form this figure it can be seen that those countries producing most electricity in Europe by fossil energy technologies and at the same time having high levels of population density have the highest impacts. This is especially the case for Germany where impacts on human health exceed the impacts due to climate change. Germany is the only country among the EU-27 Member States showing this effect. A major reason for this is the high level of population density in Germany. Another reason could be that even though Germany produces its electricity using fossil energy carriers, the technologies applied in Germany are cleaner with respect to the emission of greenhouse gases than in many other European countries.

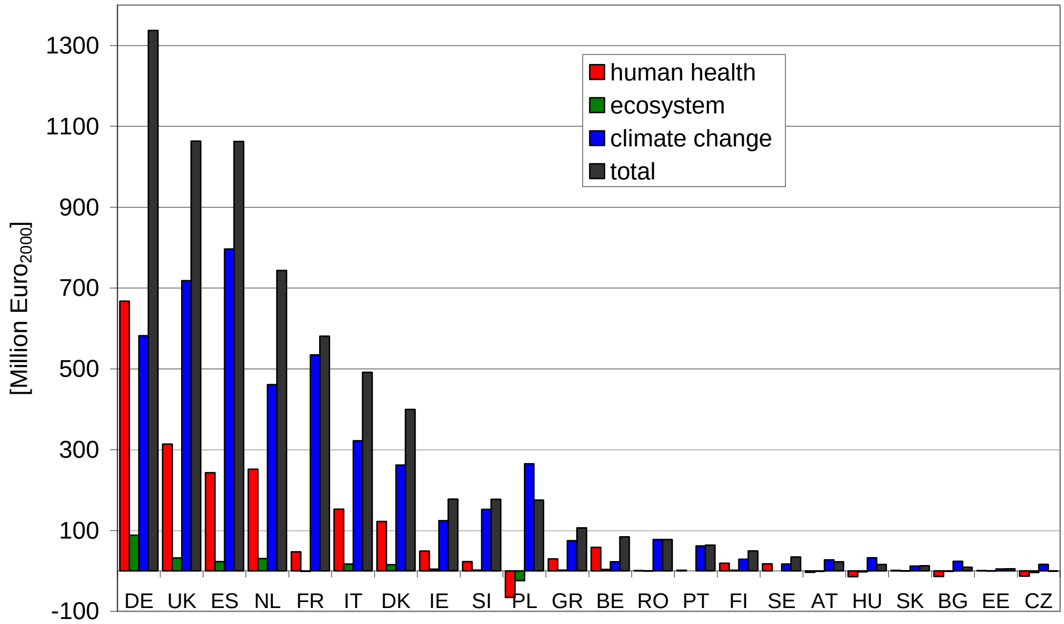


Figure 1: Presentation of results per country for electricity generation ranked by total monetised impacts

3.2 Environmental impacts caused by heat generation

3.2.1 Scenario description

In chapter 2.2.3, the amount of heat produced by additional renewable sources in the 450ppm scenario compared to the BAU scenario has been identified to be 285 PJ for heat production in CHP plants and 95 PJ in public heating plants in the EU-27. For the assessment of the benefits of this change in electricity production, it will now be assumed that this amount of 380 PJ will be produced by fossil energy carriers.

The estimated difference in heat production by renewables is generated differently across the Member States of the EU-27. Thus, again a country-specific analysis of the changes is necessary. In order to enable this county-specific analysis the difference between the amounts of heat produced by renewable energies in the 450ppm scenario compared to the BAU case will be estimated for each country. Therefore, the resulting data from TIMES referring to PJ(output) by heat production technologies have to be transformed into PJ(input) for these technologies. This has been done by estimating the share of fuel input used for heat production in combined heat and power plants (CHP) as well as for public heating plants applying efficiency factors which were derived in TIMES. In a second step this difference (in PJ) will be assumed to be produced by conventional fossil energy technologies instead of renewable technologies. In order to estimate the substituted amounts of PJ by the different fossil technologies substitution factors for the different heat generating technologies need to be applied. These are provided by the German Federal Environmental Agency (UBA, 2009). In this study, the substitution of fossil energy carriers by renewable energy sources has been analysed and substitution factors have been estimated. These factors are presented in Table 14 and will now be applied to estimate the vice versa substitution. The category other will be applied for the category “other/waste non-renewable” as shown in Table 3. Although these factors have originally been derived for Germany they will be applied for the assessment of the changes in emissions for all of the EU-27 Member States in this study.

Table 14: Substitution factors for renewable energy sources

Renewable heat	Substitution factors				
	Oil	Gas	Coal	Lignite	Other
Solarthermal	45%	51%	0%	0%	5%
Heat pumps	45%	44%	1%	2%	8%
Solid Biomass (Industry)	17%	55%	10%	12%	7%

With the presented substitution factors the changes in activities that result from the hypothetical replacement of renewable sources in heat production by fossil energy carriers can be estimated. For the estimation of the new activities it has been assumed that whenever a technology was available in 2000 it would be available in 2020 as well. If only one technology was used to generate public heat then the substitution was assumed to only refer to this technology. Wherever two technologies were available each of the technologies was assumed to produce half of the additional amount of PJ resulting from the replacement of renewables, etc. Furthermore, in case no heat was produced by coal (or lignite) in the 2020 BAU scenario, then the additional activities that were estimated applying the above presented substitution factors were assumed to be produced by lignite (or coal). The analogous approach has been applied for gas and oil. As non-renewable waste was not used for heat generation in all countries potentially resulting amounts of PJ were allocated equally among the existing fossil technologies. The resulting changes in activities for CHP plants by technology and country for 2020 are presented in Table 15. The results for public heating plants are presented in Table 16.

Table 15: Changes in activities for heat production from CHP plants in 2020

CHP (public)	Coal	Lignite	Oil	Natural gas	Others / Waste non-ren.
AT	0.000	0.000	-0.104	-0.242	-0.025
BE	-0.042	0.000	0.000	-0.128	0.000
BG	1.021	0.000	0.000	3.123	0
CY	0.000	0.000	0.000	0.000	0.000
CZ	1.836	2.139	0.000	11.444	0.000
DE	-0.102	-0.122	-0.183	-0.575	-0.071
DK	4.075	0.000	0.000	13.791	1.297
EE	0.000	0.000	0.000	0.361	0.000
ES	0.000	0.000	0.000	0.000	7.722
FI	0.000	-2.658	-2.215	-6.428	0.000
FR	27.787	0.000	0.000	84.951	0.000
GR	0.000	0.000	0.000	0.000	0.000

HU	0.000	2.804	0.000	9.491	0.892
IE	0.000	0.206	0.000	0.629	0.000
IT	-0.013	0.000	-0.011	-0.033	-0.004
LT	5.006	0.000	0.000	16.944	1.593
LU	0.000	0.000	0.000	0.000	0.000
LV	0.000	0.000	0.000	0.574	0.000
MT	0.000	0.000	0.000	0.000	0.000
NL	0.000	0.000	0.000	-0.903	-0.066
PL	16.570	19.945	0.000	123.588	11.621
PT	0.000	0.000	-0.594	-1.301	0.000
RO	0.000	0.000	0.000	0.000	0.000
SE	0.000	1.319	1.076	3.389	0.420
SI	-0.209	-0.218	0.000	0.000	0.000
SK	2.106	0.000	0.000	6.437	0.578
UK	0.000	0.000	0.000	0.000	0.000

Table 16: Changes in activities for heat production from public heating plants in 2020

Heating plants (public)	Coal	Lignite	Oil	Natural gas	Others / Waste non-ren.
AT	0.000	0.000	0.000	-0.192	-0.015
BE	0.000	0.000	0.000	0.000	0.000
BG	0.000	0.000	0.000	0.790	0.000
CY	0.000	0.000	0.000	0.000	0.000
CZ	1.565	1.883	0.000	11.013	1.097
DE	0.211	0.000	0.000	0.611	0.058
DK	0.000	0.000	0.000	10.663	0.809
EE	0.000	1.216	0.000	0.000	0.000
ES	0.000	0.000	0.000	0.000	8.515
FI	0.000	3.247	2.706	7.293	0.000
FR	0.000	0.000	0.000	12.224	0.000
GR	0.000	0.000	0.000	0.000	0.000
HU	0.000	0.000	0.000	12.940	0.000
IE	0.000	0.000	0.000	0.287	0.000
IT	0.336	0.000	0.000	1.074	0.107
LT	0.000	0.000	0.000	0.000	0.000
LU	0.000	0.000	0.000	0.000	0.000
LV	0.000	0.000	0.000	0.282	0.000

MT	0.000	0.000	0.000	0.000	0.000
NL	0.000	0.000	0.000	0.000	0.000
PL	6.232	0.000	0.000	18.031	0.000
PT	0.000	0.000	0.000	0.213	0.000
RO	0.000	0.000	0.000	0.000	0.000
SE	0.000	1.826	1.340	4.161	0.564
SI	0.000	0.000	0.000	1.048	0.000
SK	0.000	0.000	0.000	5.545	0.000
UK	1.720	0.000	1.434	3.864	0.000

3.2.2 Resulting changes in emissions

It has already been stated that the changes resulting from the hypothetical replacement of renewables by fossil energy carriers leads to changes in the activity data of these technologies. These changes will be linked to changes in emissions for the operational phase of heat plants as well as the LCA phases through the application of emission factors per functional unit, i.e. per PJ. The emission factors for the operational phase of heat production have been derived on a country-specific level for a large number of technologies in the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model.[2]

For the calculation of changes in emissions from within the LCA phases of heat generation emission factors from the life cycle inventory ecoinvent 2.0 have been applied.[3] However, due to a lack of availability of data only the fuel supply as part of the LCA could be analysed. For the other stages of the life cycle, i.e. construction and dismantling of power plants, the emissions have been assumed to be negligible. The approach of the identification of the emission factors for the different technologies are summarised in different reports. Thus, the approach for hard coal is presented in detail by Dones et al. (2007), natural gas emissions are analysed in Faist-Emmenegger et al. (2007) and emission factors for oil are available from Jungbluth et al. (2007). There are no emission factors for the supply of lignite as fuel for energy generation available as it is assumed that the power and heating plants are closely located to the location of the mines. The emission factors for the fuel supply activities have been applied to the estimated changes in activities presented in Table 16.

The estimations result in changes in the emissions on the overall EU-27 level for both the operation and the other LCA phases of heat production. While for some pollutants the substitution of a renewable technology by a fossil energy carrier results in a decrease of emissions (shown by a negative sign in the table below), in the majority of countries this substitution goes along with a significant increase in emissions. Table 25 clearly shows that emissions of greenhouse gases, especially CO_2 would largely increase in the operational phase. The emissions of CO_2 would rise by almost 30,000kt. Thus, these results in the emissions for the operation of heat plants, that would have occurred if the electricity generation would not be based on renewable energy sources as targeted by the EU directive, can already be regarded as a large potential benefit, especially in the context of climate change. This becomes even more obvious when regarding the share these changes in emissions have in total emissions for the operation of heat generating facilities. For CH_4 the

[2] More information on the GAINS model is available at: http://gains.iiasa.ac.at/gains/EU/index.login

[3] For more information please refer to http://www.ecoinvent.ch/.

estimated changes in emissions would make up for almost two thirds of the total emissions of CH_4 in the operational phase of heat production. Similarly, the changes for CO_2 make up for almost 40% of the total emissions.

Table 17: Resulting changes in emissions from operation of heat plants in EU-27 in 2020 [in kt]

countries	CH_4	CO_2	N_2O	NH_3	NO_X	$PM_{2.5}$	PM_{coarse}	SO_2	NMVOC
AT	-0.01	-32.20	0.00	0.00	-0.02	0.00	0.00	-0.01	0.00
BE	0.00	-11.10	0.00	0.00	-0.01	0.00	0.00	0.00	0.00
BG	0.26	314.62	0.04	0.00	0.19	0.01	0.00	0.09	0.01
CY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CZ	0.37	1,973.90	0.30	0.02	1.16	0.07	0.02	0.51	0.06
DE	0.00	-13.86	0.00	0.00	-0.01	0.00	0.00	-0.01	0.00
DK	0.29	1,748.76	0.17	0.02	1.19	0.02	0.01	0.10	0.07
EE	0.02	149.99	0.05	0.00	0.10	0.02	0.01	0.11	0.02
ES	0.49	0.00	0.06	0.02	1.06	0.01	0.00	2.03	0.16
FI	0.01	147.93	0.02	0.00	0.13	0.01	0.00	0.11	0.00
FR	0.22	8,133.38	0.03	0.03	4.50	0.28	0.39	1.72	0.24
GR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HU	1.46	1,533.22	0.11	0.00	1.35	0.09	0.05	0.43	0.06
IE	0.01	72.30	0.01	0.00	0.05	0.00	0.00	0.02	0.00
IT	0.01	97.41	0.01	0.00	0.05	0.00	0.00	0.01	0.00
LT	1.11	1,417.58	0.20	0.01	1.07	0.07	0.05	3.75	0.05
LU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LV	0.06	47.77	0.00	0.00	0.05	0.00	0.00	0.00	0.00
MT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NL	-0.01	-50.40	0.00	0.00	-0.03	0.00	0.00	0.00	0.00
PL	9.25	12,055.07	1.73	0.10	6.60	0.31	0.10	3.01	0.50
PT	-0.01	-105.80	0.00	0.00	-0.07	0.00	0.00	-0.04	0.00
RO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SE	0.11	916.43	0.13	0.01	0.62	0.03	0.01	0.25	0.07
SI	0.02	16.71	-0.02	0.00	0.01	-0.01	-0.01	-0.03	-0.01
SK	0.21	867.14	0.09	0.01	0.55	0.02	0.01	0.20	0.04
UK	0.04	486.20	0.07	0.00	0.30	0.01	0.01	0.16	0.02
TOTAL	**13.89**	**29,765.09**	**3.01**	**0.22**	**18.83**	**0.94**	**0.64**	**12.41**	**1.29**
% share of emissions in total emissions from operational phase for heat production	**62.3%**	**37.4%**	**13.7%**	**7.9%**	**18.0%**	**20.5%**	**17.2%**	**19.7%**	**5.9%**

Analogously, the resulting changes in emissions from the fuel supply in heat generation activities are presented in Table 18. As for the results of the operation of heating plants and CHP plants, the largest change in the emissions can be seen for CO_2. The estimation of the share of these changes in the emissions in total emissions from fuel supply for heat generation was not feasible as no data for this part of the life cycle was available for biomass in the ecoinvent database.

Table 18: Resulting changes in emissions from operation of heat plants in EU-27 in 2020 [in kt]

countries	CH_4	CO_2	N_2O	NH_3	NO_X	$PM_{2.5}$	PM_{coarse}	SO_2	NMVOC
AT	-0.07	-4.25	0.00	0.00	-0.01	0.00	0.00	-0.02	-0.01
BE	-0.02	-0.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BG	0.62	29.27	0.00	0.00	0.09	0.00	0.00	0.09	0.06
CY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CZ	5.42	174.31	0.00	0.00	0.54	0.02	0.01	0.53	0.36
DE	-0.06	-1.68	0.00	0.00	-0.01	0.00	0.00	-0.02	0.00
DK	3.86	182.96	0.00	0.00	0.57	0.02	0.01	0.55	0.39
EE	0.62	4.60	0.00	0.00	0.02	0.00	0.00	0.02	0.01
ES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FI	0.43	12.14	0.00	0.00	0.04	0.00	0.00	0.07	0.03
FR	15.33	727.04	0.01	0.00	2.25	0.07	0.05	2.19	1.56
GR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HU	4.85	172.21	0.00	0.00	0.54	0.02	0.01	0.52	0.36
IE	0.24	7.18	0.00	0.00	0.02	0.00	0.00	0.02	0.01
IT	0.16	7.69	0.00	0.00	0.02	0.00	0.00	0.02	0.02
LT	2.67	126.77	0.00	0.00	0.39	0.01	0.01	0.38	0.27
LU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LV	0.14	6.41	0.00	0.00	0.02	0.00	0.00	0.02	0.01
MT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NL	-0.14	-6.76	0.00	0.00	-0.02	0.00	0.00	-0.02	-0.01
PL	31.66	1,090.75	0.02	0.01	3.39	0.11	0.08	3.31	2.29
PT	-0.20	-13.88	0.00	0.00	-0.05	0.00	0.00	-0.08	-0.03
RO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SE	2.77	84.75	0.00	0.00	0.29	0.02	0.01	0.42	0.19
SI	0.06	7.50	0.00	0.00	0.02	0.00	0.00	0.02	0.02
SK	1.89	89.65	0.00	0.00	0.28	0.01	0.01	0.27	0.19
UK	0.67	42.76	0.00	0.00	0.15	0.01	0.00	0.22	0.10
TOTAL	**70.91**	**2,738.46**	**0.04**	**0.02**	**8.53**	**0.27**	**0.21**	**8.52**	**5.83**

3.2.3 Assessment of the impacts

The assessment of the impacts resulting from the changes in emissions that were estimated for the hypothetical case of no additional use of renewable energies in heat production as targeted by the EU directive will be carried out analogously to the impact assessment for the electricity production scenario. Thus, the assessment of the impacts caused by the changes in the emission of the above presented pollutants requires a differentiation of source of the emissions according to the height of emission release and the location with respect to the population density. As for the assessment presented in chapter 3.1, monetary damage factors which have been derived in course of the EXIOPOL project by Müller et al. (2010) will be applied.

For the assessment of the impacts from the provision of fuels for heat generation, it will be assumed that the pollutants are emitted at medium high levels (20-100m). As the identification of the exact location of the emitting source is not feasible, average EU-27 damage factors will be applied. Furthermore, it is assumed that half of the emissions affect densely populated areas while the other half occurs in rural areas. For the operational phase, i.e. the generation of heat in CHP and public heating plants, pollutants are assumed to be released from high stacks over 100m of height only. The applied monetary damage factors have already been presented in Table 9 and Table 10 above.

3.2.4 Results for the electricity generation scenario

3.2.4.1 Results for the operational phase

The combination of the changes in emissions resulting from the substitution of renewable heat generating technologies by fossil technologies with the monetary damage factors for the operational phase results in damages to human health, the ecosystem and climate change of about 1.2 billion $Euro_{2000}$. These external costs would arise if the targeted change in energy generation leading to a 20%-share of renewable energy sources in overall energy consumption would not be implemented and heat would be produced by fossil energy carriers.

Table 19 presents the estimated monetary values for the three different impact categories. As can be seen from the table, the impacts on climate change account for clearly the highest part of the total external cost estimated. Almost 80% of the monetised damages can be accounted to climate change impacts. This fact can easily be explained by the high changes in emissions of greenhouse gases, especially CO_2 as presented in the previous chapter. Following these, with about 20%, human health impacts are the second most important issue. Impacts on ecosystems are clearly not as important in this context.

Table 19: External costs for operation of heat plants [in million $Euro_{2000}$]

countries	Human health	Ecosystem quality	Climate change	total
AT	0	0	-1	**-1**
BE	0	0	0	**0**
BG	2	0	10	**12**
CY	0	0	0	**0**
CZ	17	3	61	**80**
DE	0	0	0	**-1**
DK	6	2	53	**61**
EE	1	0	5	**6**
ES	15	1	1	**17**
FI	1	0	5	**5**
FR	64	7	240	**311**
GR	0	0	0	**0**
HU	20	2	47	**69**
IE	0	0	2	**3**
IT	0	0	3	**4**
LT	27	2	44	**73**
LU	0	0	0	**0**
LV	0	0	1	**2**
MT	0	0	0	**0**
NL	0	0	-1	**-2**
PL	72	10	376	**458**
PT	0	0	-3	**-3**
RO	0	0	0	**0**
SE	3	1	28	**32**
SI	-1	0	0	**0**
SK	7	1	26	**34**

UK	3	0	15	**18**
TOTAL	**236**	**30**	**911**	**1,177**

3.2.4.2 Results for the LCA phases

A different picture is drawn by the resulting external costs for the LCA phases of the different heat generating technologies, i.e. the fuel supply chain. As is shown in Table 20 for this part of the total life cycle the impacts are highest for human health. More than half of the total external costs estimated can be accounted to health effects. The major reason for this is the lower level of emissions in combination with emission taking place in urban, highly populated areas. Thus, the number of affected individuals is higher than in the case of emissions from the operational phase occurring from high stacks. In total, impacts of about 304 million $Euro_{2000}$ have been estimated to potentially occur when heat is produced by fossil energy technologies and not by renewables as targeted by the EU directive analysed here. It has to be mentioned that the monetary impacts will be higher when not only the fuel supply, but also other steps of the life cycle such as construction, maintenance and dismantling will be included in the analysis. For the reasons presented above this was not possible in the present study.

Table 20: External costs for the LCA phase of heat production [in million $Euro_{2000}$]

countries	Human health	Ecosystem quality	Climate change	total
AT	-0.27	-0.02	-0.17	**-0.46**
BE	0.00	0.00	-0.04	**-0.04**
BG	1.60	0.14	1.28	**3.02**
CY	0.00	0.00	0.00	**0.00**
CZ	10.28	0.81	8.80	**19.89**
DE	-0.26	-0.02	-0.09	**-0.37**
DK	10.74	0.86	7.99	**19.59**
EE	0.35	0.03	0.55	**0.94**
ES	0.00	0.00	0.00	**0.00**
FI	0.98	0.07	0.65	**1.70**
FR	42.28	3.38	31.85	**77.51**
GR	0.00	0.00	0.00	**0.00**
HU	10.19	0.81	8.35	**19.35**
IE	0.35	0.03	0.37	**0.76**
IT	0.36	0.03	0.33	**0.73**
LT	7.26	0.59	5.54	**13.38**
LU	0.00	0.00	0.00	**0.00**
LV	0.35	0.03	0.28	**0.67**
MT	0.00	0.00	0.00	**0.00**

NL	-0.35	-0.03	-0.29	**-0.68**
PL	64.03	5.15	53.69	**122.86**
PT	-1.15	-0.08	-0.54	**-1.78**
RO	0.00	0.00	0.00	**0.00**
SE	7.07	0.47	4.37	**11.91**
SI	0.36	0.03	0.26	**0.66**
SK	5.29	0.42	3.92	**9.63**
UK	3.66	0.24	1.71	**5.62**
TOTAL	**163.13**	**12.94**	**128.80**	**304.87**

3.2.4.3 Summarised results

In summary almost 1.5 billion Euro$_{2000}$ have been estimated resulting from the rise in emissions when electricity is produced by fossil energy carriers instead of the targeted 20% share of renewables. Table 21Table 13 presents the summarised results for each country and impact category.

Table 21: Total external costs per country and impact category [in million Euro$_{2000}$]

countries	**Human health**	**Ecosystem quality**	**Climate change**	**total**
AT	-1	0	-1	**-2**
BE	0	0	0	**0**
BG	3	0	11	**15**
CY	0	0	0	**0**
CZ	27	4	70	**100**
DE	0	0	-1	**-1**
DK	17	2	61	**80**
EE	1	0	5	**7**
ES	15	1	1	**17**
FI	2	0	5	**7**
FR	106	11	272	**388**
GR	0	0	0	**0**
HU	30	3	55	**88**
IE	1	0	3	**3**
IT	1	0	3	**4**
LT	35	2	50	**87**
LU	0	0	0	**0**
LV	1	0	2	**2**
MT	0	0	0	**0**

NL	-1	0	-2	**-2**
PL	136	15	430	**581**
PT	-1	0	-4	**-5**
RO	0	0	0	**0**
SE	10	2	33	**44**
SI	0	0	1	**0**
SK	12	1	30	**44**
UK	6	1	17	**24**
TOTAL	**399**	**42**	**1,040**	**1,481**

To further show the differences in the impacts across country the following Figure 2 presents the total monetised damages per country. Form this figure it can be seen that most of the estimated impacts relate to only a few countries with Poland and France clearly showing the highest level of impacts. Followed by these two countries there are a number of countries where the impacts are below 100 million $Euro_{2000}$. For some countries no or only negligible impacts could be estimated. Finally, for Austria, the Netherlands and Portugal the assumption of no implementation of the EU directive would result in benefits to human health, the ecosystem and climate change.

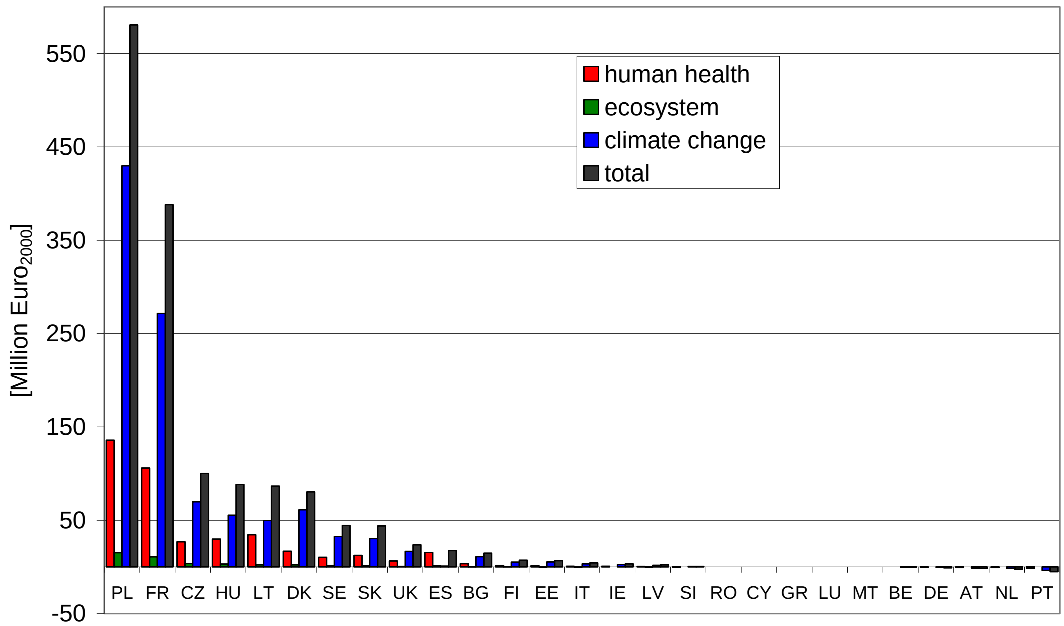


Figure 2: Presentation of results per country for heat generation ranked by total monetised impacts

3.3 Environmental impact caused by the use of biofuels

3.3.1 Scenario description

In chapter 2.2.4, the amount of energy consumption by fuel type has been presented. As can be seen there, the amount of energy consumed by biofuels (here: biodiesel, ethanol and ft-fuel bio) is assumed to increase from 223 PJ in the BAU scenario to 1218 PJ in 450ppm scenario after the implementation of the EU directive in 2020. In order to now estimate the changes in emissions and impacts related to this change in fuel use, the energy consumption had to be converted in vehicle kilometres (vkm) as emission factors are not available per fuel but per vehicle kilometre. The following Table 22 shows the resulting numbers of vehicle kilometres for the EU-27 and both scenarios in 2020.

Table 22: Amount of vehicle kilometres per fuel type in EU-27 in 2020

Fuel type	BAU (2020)	450ppm (2020)
Diesel	1,497,643,540,443	1,359,508,846,620
Gasoline	1,915,317,797,854	1,582,817,510,874
LPG	71,039,750,441	61,816,713,015
Biodiesel	15,437,298,947	91,728,200,482
Ethanol	13,808,537,508	143,788,986,557
FT-Fuel bio	9,258,144,076	56,817,305,092
FT-Fuel fossil	12,985,030,684	1,203,150,181
Dimethyleter bio	0	0
Dimethyleter fossil	90,954,682	92,128,136
Methanol bio	0	0
Methanol fossil	0	0
Hydrogen liquified	0	0
Hydrogen compressed	0	0
Biogas	0	0
Natural Gas	60,346,624,981	52,428,918,188
Electricity	1,278,455,603	65,374,031,249
Sum	**3,597,206,135,219**	**3,415,575,790,393**

Based on these data, the next step is to identify the changes in emissions that can be related to the implementation of the EU targets on biofuel use. Therefore a country-specific analysis of the changes in kilometres driven by vehicles using renewable fuels between the BAU and the 450ppm scenario has been made. In a following step the difference in vehicle kilometres by renewable fuels will be assumed to be substituted by either gasoline or diesel. This assumption is based on the argument that the total amount of vehicle kilometres in the 450ppm scenario would have been driven in any case. In order to estimate the result of this substitution it is necessary to define the substituted fuels. Within the TIMES model there is an assumption of which biofuels substitute diesel and which gasoline. This assumption is presented in Table 23 below and will also be applied in this study.

Table 23: Substitution of conventional fuels by biofuels

Biofuels	Substituted conventional fuels
Biodiesel	Diesel
FT-Fuel bio	Diesel
Ethanol	Gasoline
Dimethylether bio	Gasoline
Methanol bio	Gasoline
Biogas	Natural Gas

As a result the amount of vkm driven by vehicles using biodiesel and ft-fuel bio will be added to the existing amount of vkm for diesel engines in the 450ppm case. Analogously, the vkm of ethanol engines will be added to gasoline fuel. The other biofuel types are not relevant for the analysis here as shown in Table 22.

3.3.2 Resulting changes in emissions

In this chapter the changes in emissions resulting from the implementation of the EU directive promoting the use of biofuels will be estimated. As already stated above this estimation will be based on the assumption that the activities (in vkm) which are related to biofuels in the 450ppm scenario would have been carried out with activities using diesel or gasoline. Thus, the substitution of diesel and gasoline which is presented in the 450ppm scenario is now analysed in the opposite direction. As there is need for a distinction between the operational phase of fuel combustion in the vehicle engines and the LCA analysis of cultivation of plants for the production of biofuels, there will be two different approach of estimating the emissions. This differentiation becomes additionally important as the emissions in the two phases not necessarily occur in the same spatial area. While the operational phase can obviously be linked to a certain spatial area, the cultivation of plants for the production of biofuels leads to emissions in very different geographical regions

First, the changes in activities can be related to emissions applying emission factors per functional unit (here vkm). The emission factors have been derived from data estimated in the transport model TREMOVE (De Ceuster et al., 2007).[4] The emissions have been estimated subtracting the original emission data for diesel and gasoline fuels in the 450ppm scenario from diesel and gasoline emissions including the substituted biofuels in a new 450ppm scenario. As can be seen in the following Table 25, there are some countries where the hypothetical substitution of biofuels by diesel and gasoline lead to a decrease of emissions (shown by a negative sign in the table below). For these countries the emissions

[4] For more information on TREMOVE visit http://www.tremove.org/. Data from TREMOVE has been derived from a tool named COPERT, more information is found here: http://www.emisia.com/tools.php?tool=COPERT

from gasoline and diesel engines have been higher in the original case than in the case with additional gasoline and diesel vehicles.

Furthermore, Table 25 shows that emissions of greenhouse gases such as CH_4, N_2O and especially CO_2 would largely increase when conventional diesel and gasoline instead of biofuels would be used in road transport. The emissions of CO_2 would rise by almost 72,000 kt. Thus, these results in the emissions which would have occurred if the road transport would not include biofuels as targeted by the EU directive can already be regarded as a large potential benefit, especially in the context of climate change. On average, the changes in emissions would account for about 8% of the total emissions from the combustion of diesel and gasoline.

In another part of the analysis, the emissions of the LCA phase of biofuel production will be assessed. This assessment is split into two aspects. First, the emissions resulting from the cultivation of plants for biofuel production are analysed using results from the agricultural case study carried out in work package IV.3.a of the EXIOPOL project. The emission factors presented and applied in Wagner et al. (2011) have also been applied in the present study in order to calculate the changes in emissions from nutrient application on plants which will then be used for the production of biofuels. There will be no assessment of pesticide use for the simple reason that the analysis presented by Fankte and Wagner (2009) in work package II.2.c-1 focuses on the ingestion pathway which has been identified as being more important than the inhalation pathway with respect to impacts on human health. Thus, for the analysis of biofuel crops the ingestion pathway is not relevant and therefore pesticide application will not be regarded. The resulting emissions from the nutrition of plants in this pre-combustion phase for biofuels are presented in Table 26. As can be seen from the table, most of the values are negative. This can be explained by the scenario description as it is assumed that the additional use of biofuels estimated in the 450ppm TIMES scenario compared to the BAU TIMES scenario will not occur but is instead substituted by the use of conventional gasoline and diesel engines. Therefore, emissions from agricultural activities for the cultivation of biofuel plants would have been reduced in the hypothetical scenario. It is also shown in Table 26, that the reduction in emissions is largest for NH_3 when biofuels are substituted by conventional diesel and gasoline.

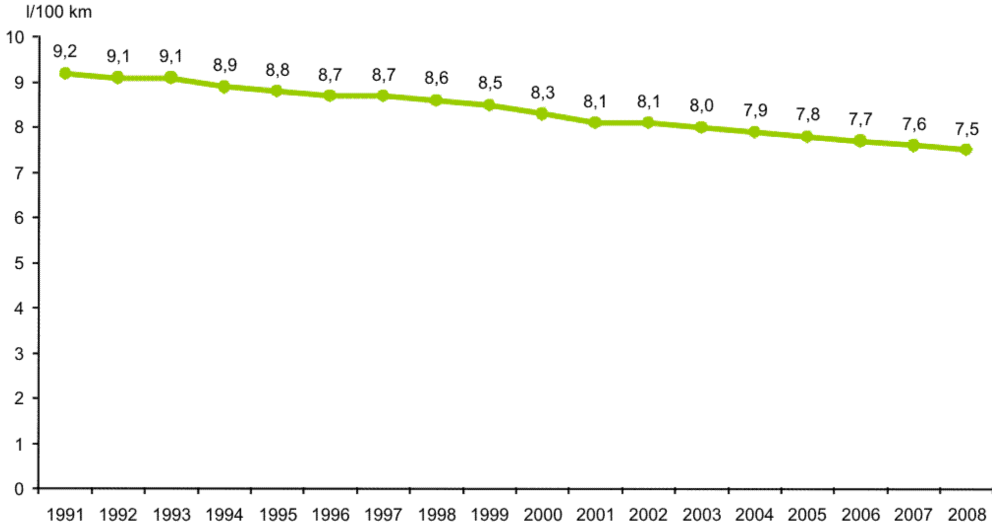
Second, the pre-combustion activities of the production of gasoline and diesel need to be taken into account. In general, the estimations have been applied for the calculated changes in activities in vehicle kilometres presented in Table 22. For the estimation of the changes in emissions resulting from the assumed additional use of diesel and gasoline engines were based emission factors provided by the life cycle inventory ecoinvent 2.0.[5] The data from the EcoInvent 2.0 database refers to "petrol, unleaded, at refinery" and "petrol, unleaded, at regional storage" for gasoline and "diesel, at refinery" as well as "diesel, at regional storage" for diesel production. For all these categories the average emission factors for Europe have been applied. In a next step data on the density of gasoline and diesel have been applied. The following Table 24 provides these densities as well as the average value which has been applied in the present estimations.

Table 24: Applied densities for gasoline and diesel

Densities	Applied Average
Gasoline 0.72 – 0.775 g/cm³	0.7475 kg/l
Diesel: 0.820 – 0.845 g/cm³	0.8325 kg/l

[5] For more information please refer to http://www.ecoinvent.ch/.

An additional assumption had to be made regarding the average fuel consumption per vehicle. These data has been taken from the following Figure 3 where the average fuel consumption per vehicle per 100km in Germany is shown. The data has been estimated based on the domestic kilometres travelled including foreign kilometres travelled by German vehicles excluding domestic routes driven by foreign cars. Based on the presented values, an average fuel consumption of 7.5 l/100km has been assumed to be valid also for 2020.



Source: Federal Ministry of Transport, Building and Urban Development[6]

Figure 3: Development of average fuel consumption per 100km in Germany

Based on the above presented assumptions, the changes in emissions due to the hypothetical additional use of diesel and gasoline vehicles in 2020 were calculated and are presented in Table 27. The table clearly shows that the largest changes in emissions would refer to greenhouse gases, i.e. CO_2 and CH_4. This obviously the case as it is the major target of the EU directive on the promotion of biofuels. Thus, in a vice versa case where additional use is made of diesel and gasoline, the emissions of greenhouse gases will increase. The estimated changes in emission for the production of diesel and gasoline account for a share of about 9% on average in the total emissions of this phase of the LCA for the transport sector.

The next section will now regard the monetary impacts resulting from these changes in emissions.

[6] The figure can be accessed at: http://www.umweltbundesamt-daten-zur-umwelt.de/umweltdaten/public/document/downloadImage.do;jsessionid=3EA30E5BDF494114720EE55EC664E226?ident=19321

Table 25: Resulting changes in emissions from fuel combustion resulting from substitution of biofuels by conventional diesel and gasoline in EU-27 [in t]

countries	PM_{coarse}	PM_{25}	CH_4	CO	CO_2	N_2O	NMVOC	NO_X	SO_2	NH_3
AT	87.29	98.85	66.14	852.98	1,827,301.08	73.36	148.56	5,747.89	11.65	8.74
BE	53.08	67.59	212.94	2,347.44	1,820,428.25	55.74	215.99	2,347.70	11.53	9.56
BG	9.68	11.03	227.11	1,624.86	406,600.85	2.81	298.83	133.49	2.56	2.63
CY	11.65	13.54	57.26	528.73	122,521.11	4.05	94.64	404.27	0.78	0.58
CZ	54.03	75.04	45.87	1,466.34	1,129,423.70	43.84	122.73	4,008.80	7.18	5.50
DE	425.40	437.14	399.72	4,414.66	7,609,950.16	367.81	738.16	24,513.09	48.48	39.21
DK	33.09	50.51	26.23	1,170.61	1,023,228.44	31.70	81.58	2,405.04	6.50	4.92
EE	10.70	11.92	4.33	155.50	188,755.27	8.34	18.29	663.91	1.20	0.98
ES	277.38	348.72	1,377.58	24,969.13	10,050,616.46	241.93	2,735.82	12,118.84	63.40	53.53
FI	35.84	38.08	10.34	556.88	679,552.81	26.18	87.37	1,879.97	4.32	3.10
FR	342.51	440.56	667.77	18,390.27	10,253,830.09	310.10	1,546.70	13,294.70	64.87	60.03
GR	189.47	201.48	71.34	2,496.23	2,676,596.57	105.78	332.45	11,607.87	17.05	10.81
HU	-212.43	-229.68	503.48	26,709.55	-328,235.59	-145.84	1,638.66	-16,988.02	-2.40	6.85
IE	-15.18	-17.81	4.32	15.35	-210,745.36	-10.42	-10.89	-1,185.16	-1.35	-0.78
IT	329.22	387.51	1,388.37	28,490.08	10,380,202.35	231.66	2,862.46	15,959.99	65.58	56.17
LT	16.85	18.47	4.86	110.78	293,870.37	14.02	18.95	1,151.29	1.87	1.49
LU	14.18	14.73	22.57	557.15	421,741.61	13.75	51.08	535.49	2.66	2.32
LV	-9.31	-10.37	5.13	443.09	-88,229.94	-9.34	25.42	-819.13	-0.57	-0.34
MT	-4.51	-4.64	21.68	119.13	-49,243.64	-4.91	24.79	-349.08	-0.32	-0.25
NL	97.03	112.22	29.69	1,167.88	2,180,244.87	81.47	172.76	5,959.50	13.88	9.86
PL	332.09	343.67	94.52	2,765.50	5,152,557.06	227.78	413.04	21,649.07	32.84	24.53
PT	125.24	142.16	26.96	1,525.76	1,753,219.83	64.07	287.20	4,763.77	11.17	9.11
RO	70.44	81.44	23.61	640.58	1,248,715.60	53.24	92.63	5,106.25	7.96	5.58
SE	66.37	84.92	20.23	645.21	1,416,273.65	62.05	113.39	5,028.48	9.03	6.16
SI	18.21	27.29	43.08	940.17	549,375.96	10.23	109.78	1,090.90	3.48	2.66
SK	29.30	32.53	31.60	1,425.65	617,961.21	20.69	114.31	1,358.16	3.91	3.88
UK	334.09	356.47	596.35	21,191.05	10,528,402.68	302.73	1,549.03	11,051.47	66.59	60.84
TOTAL	**2,721.70**	**3,133.37**	**5,983.07**	**145,720.60**	**71,654,915.45**	**2,182.83**	**13,883.72**	**133,438.53**	**453.86**	**387.68**

Table 26: Resulting changes in emissions from pre-combustion cultivation of plants for biofuel production in EU-27 [in t]

countries	$PM_{2.5}$	PM_{coarse}	NH_3	N_2O
AT	-188.74	-1,360.31	-4,677.95	-677.50
BE	-55.47	-445.43	-2,241.49	-272.71
BG	-121.55	-821.58	-1,417.36	-287.78
CY	-23.00	-148.49	-243.94	-31.94
CZ	-79.84	-579.15	-1,743.66	-355.37
DE	-514.59	-3,753.96	-17,979.12	-3,533.45
DK	-103.21	-738.36	-3,433.40	-602.80
EE	-30.95	-223.17	-297.49	-55.70
ES	-4,207.47	-28,236.19	-35,849.79	-5,926.69
FI	-200.11	-1,427.72	-4,415.39	-1,388.62
FR	-617.70	-4,497.36	-18,075.50	-3,571.25
GR	-886.62	-5,935.49	-4,296.17	-883.57
HU	-63.29	-327.28	-484.74	-115.91
IE	45.33	322.56	1,805.11	156.14
IT	-1,241.92	-8,910.88	-17,495.38	-2,681.57
LT	8.54	51.66	22.64	4.50
LU	0.00	0.00	0.00	0.00
LV	19.30	137.43	46.84	8.44
MT	-14.37	-101.80	-133.09	-8.41
NL	-270.60	-1,931.22	-10,029.41	-1,055.86
PL	-189.47	-1,450.37	-2,707.60	-505.23
PT	-435.29	-3,140.53	-4,418.06	-811.06
RO	-454.62	-3,038.61	-2,605.68	-383.41
SE	-112.38	-825.29	-3,727.99	-808.39
SI	-55.29	-394.77	-874.30	-116.68
SK	-63.34	-458.26	-876.73	-219.24
UK	-696.86	-5,021.47	-20,882.69	-4,267.72
TOTAL	**-10,553.53**	**-73,256.03**	**-157,032.32**	**-28,391.79**

Table 27: Resulting changes in emissions from pre-combustion production of diesel and gasoline in EU-27 [in t]

countries	NH_3	CO_2	N_2O	CH_4	NO_X	NMVOC	$PM_{2.5}$	PM_{coarse}	SO_2
AT	5.24	324,496.72	6.02	1,328.74	1,555.27	514.40	119.78	37.70	3,082.87
BE	7.63	544,049.51	9.18	1,941.49	2,054.53	993.17	185.88	58.32	4,957.77
BG	2.35	184,197.05	2.92	598.16	581.30	363.27	59.84	18.74	1,634.93
CH	1.11	69,856.70	1.28	282.55	328.05	112.34	25.60	8.06	661.09
CY	0.44	32,319.25	0.54	112.18	115.96	60.44	10.88	3.41	292.19
CZ	2.87	194,603.72	3.40	730.12	803.78	338.97	68.35	21.47	1,799.65
DE	25.05	1,551,035.26	28.79	6,356.78	7,444.81	2,456.15	572.80	180.29	14,739.72
DK	3.16	220,399.65	3.77	803.55	865.21	394.56	76.19	23.92	2,020.99
EE	0.50	31,687.47	0.58	126.67	145.92	51.64	11.54	3.63	298.78
ES	43.51	3,275,198.40	53.29	11,075.16	11,184.71	6,258.70	1,087.01	340.64	29,394.42
FI	2.14	136,532.18	2.48	544.02	625.32	223.30	49.61	15.61	1,286.03
FR	49.36	3,531,718.82	59.41	12,553.22	13,240.36	6,470.04	1,204.01	377.74	32,146.64
GR	4.77	300,559.84	5.51	1,210.38	1,401.24	485.74	109.88	34.57	2,840.47
HU	2.73	167,012.94	3.13	694.01	820.04	260.13	62.18	19.58	1,594.17
IE	-0.17	-4,579.77	-0.16	-42.21	-67.27	3.45	-2.91	-0.93	-60.80
IT	45.14	3,341,818.31	54.97	11,488.06	11,774.68	6,300.33	1,118.91	350.77	30,130.58
LT	0.66	39,889.76	0.75	166.70	197.67	61.70	14.90	4.69	381.44
LU	1.86	132,463.89	2.23	472.58	499.98	241.87	45.25	14.20	1,207.01
LV	0.20	22,965.37	0.29	51.28	27.47	55.93	6.25	1.94	186.67
MT	0.08	9,061.71	0.11	20.16	10.69	22.11	2.46	0.76	73.60
NL	6.08	382,360.03	7.02	1,543.60	1,789.95	616.21	139.98	44.05	3,616.33
NO	0.35	21,065.52	0.40	87.59	103.54	32.78	7.85	2.47	201.12
PL	10.39	642,956.97	11.94	2,636.48	3,088.79	1,017.53	237.52	74.76	6,111.14
PT	7.23	446,396.04	8.30	1,834.02	2,151.35	704.84	165.09	51.97	4,245.49
RO	2.65	161,240.22	3.03	672.80	797.07	249.86	60.17	18.95	1,541.11
SE	3.30	201,325.87	3.77	836.51	988.35	313.61	74.94	23.60	1,921.63
SI	2.00	148,104.07	2.43	507.74	519.15	279.86	49.52	15.52	1,334.31
SK	2.67	191,509.86	3.21	678.47	713.65	351.86	65.17	20.45	1,741.53
UK	49.31	3,643,783.31	60.01	12,548.59	12,882.04	6,859.36	1,221.19	382.85	32,869.73
TOTAL	**282.59**	**19,944,028.64**	**338.62**	**71,859.39**	**76,643.63**	**36,094.15**	**6,849.82**	**2,149.71**	**182,250.61**

3.3.3 Assessment of the impacts

The changes in emissions related to the substitution of biofuels with conventional gasoline and diesel vehicles have been estimated for each of the EU-27 Member States. Additionally, the emissions for the pre-combustion phase of cultivating plants for biofuel production have been presented. The present chapter will now estimate the impacts that can be related to the emission data and which allow for an identification of the overall external costs related to the biofuel use targeted by the EU directive.

The assessment of the impacts will again be carried out by applying monetary damage factors derived in course of the EXIOPOL project. However, in contrast to the assessment of the EU directive for electricity and heat production, the assessment of the road transportation sector requires the application of monetary damage factors for ground level emissions. These values have also been derived and presented by Müller et al. (2010). In addition, a distinction between emissions in urban and rural areas has to be made as the affected population density has a substantial impact on the resulting external costs. This distinction has been made in course of the EXIOPOL project where Müller et al. (2010) assume a share of one third of the activities of road transport taking place in urban areas and two thirds in rural areas. This assumption has been applied for all countries of the EU-27.

Table 28 shows the applied monetary damage factors for the operation of road transport vehicles. Table 29 provides monetary factors for the agricultural phase of cultivating biofuel plants. The table provides monetary damage values for low emission heights (5-20m) in rural areas as it is assumed that the cultivation of plants for biofuel production occurs outside densely populated areas. Finally, Table 31 shows the monetary values to be applied for the impact assessment of the emissions from pre-combustion activities such as the production of gasoline and diesel. The category “manufacture of motor spirit (gasoline)” in the EE SUT of EXIOPOL has been defined as emitting one third of its emissions from medium stack heights (20 to 100m), with 90% in rural and 10% in urban areas, and two thirds from high stacks above 100m.

Table 28: Monetary damage factors per country for ground level emissions in 2020 [in Euro$_{2000}$]

countries	SO_2	NO_X	NMVOC	NH_3	$PM_{2.5}$ rural	$PM_{2.5}$ urban	PM_{coarse} rural	PM_{coarse} urban	CH_4	CO	CO_2	N_2O
AT	11,524	15,650	1,303	26,029	93,978	564,800	9,640	57,936	677	87	29	8,708
BE	12,482	10,522	2,108	35,601	123,878	571,733	12,707	58,647	677	87	29	8,708
BG	6,860	7,934	-94	9,962	27,874	156,421	3,280	17,985	677	87	29	8,708
CY	10,021	5,240	-558	6,024	73,995	415,249	8,708	47,744	677	87	29	8,708
CZ	10,720	12,191	696	30,941	88,045	348,337	9,031	35,732	677	87	29	8,708
DE	12,501	14,732	867	27,084	101,530	518,762	10,415	53,213	677	87	29	8,708
DK	6,412	6,010	730	11,907	60,970	527,964	6,254	54,157	677	87	29	8,708
EE	4,997	3,064	186	11,811	34,762	210,842	3,566	21,628	677	87	29	8,708
ES	5,933	3,896	419	7,288	57,100	420,743	5,857	43,159	677	87	29	8,708
FI	3,806	2,876	199	7,006	39,543	472,087	4,056	48,425	677	87	29	8,708
FR	11,594	11,626	905	16,402	107,770	540,313	11,055	55,424	677	87	29	8,708
GR	6,607	2,835	202	6,901	49,116	347,686	5,038	35,665	677	87	29	8,708
HU	10,165	14,050	608	23,609	77,861	303,702	7,987	31,153	677	87	29	8,708
IE	6,244	4,944	689	3,058	60,815	573,743	6,238	58,853	677	87	29	8,708
IT	10,148	10,815	607	22,206	93,166	510,399	9,557	52,355	677	87	29	8,708
LT	6,384	6,419	416	9,351	42,272	203,041	4,336	20,827	677	87	29	8,708
LU	11,816	14,587	2,019	34,487	120,569	694,742	12,368	71,265	677	87	29	8,708
LV	5,593	4,561	364	11,118	33,480	182,765	3,434	18,748	677	87	29	8,708
MT	5,395	1,502	354	9,850	26,550	309,808	2,723	31,779	677	87	29	8,708
NL	14,839	10,770	1,614	28,492	113,053	580,046	11,597	59,500	677	87	29	8,708
PL	9,364	8,938	558	18,935	74,157	250,236	7,607	25,669	677	87	29	8,708
PT	4,250	1,526	420	5,590	52,668	347,410	5,403	35,636	677	87	29	8,708
RO	8,287	11,179	378	12,526	32,072	179,984	3,774	20,694	677	87	29	8,708
SE	4,637	4,587	346	10,542	46,816	487,015	4,802	49,957	677	87	29	8,708
SI	10,188	13,032	1,042	29,637	76,602	363,688	7,858	37,306	677	87	29	8,708
SK	9,867	12,582	462	28,791	71,089	266,308	7,292	27,317	677	87	29	8,708
UK	8,443	6,222	870	18,901	84,234	535,916	8,640	54,973	677	87	29	8,708

Table 29: Monetary damage factors for low stacks and emissions in 2020 in EU-27 [in Euro$_{2000}$]

	SO_2	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM_{coarse}	CH_4	CO	CO_2	N_2O
EU-27, low height, rural	9,151	9,336	1,221	18,063	36,501	2,067	677	87	29	8,708

Table 30: Monetary damage factors for medium and high stacks and emissions in 2020 in EU-27 [in $Euro_{2000}$]

	SO_2	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM_{coarse}	CH_4	CO_2	N_2O
EU-27, medium height, rural	9,151	9,336	1,221	18,063	36,501	2,067	677	29	8,708
EU-27, medium height, urban	9,151	9,336	1,221	18,063	37,589	2,562	677	29	8,708
EU-27, high stack	8,393	7,162	1,221	18,063	17,391	689	677	29	8,708

3.3.4 Results for the road transport scenario

3.3.4.1 Results for the operational phase

The combination of the changes in emissions resulting from the substitution of biofuels by conventional fuels, i.e. diesel and gasoline, with the monetary damage factors for the operational phase results in damages to human health, the ecosystem and climate change of about 4 billion $Euro_{2000}$. These external costs would arise if the targeted change in road transport generation leading to a 10%-share of biofuels in total fuel consumption would not be implemented and vehicles would only have diesel or gasoline engines.

Table 31 presents the estimated monetary values for the three different impact categories. As can be seen from the table, the impacts on human health and climate change together account for almost the total external cost estimated, with climate change impact accounting for the largest share of total impacts. This fact can be explained by the high emissions of greenhouse gases, especially CO_2 from diesel and gasoline vehicles compared to the substantially lower emissions from biofuel combustion. For human health, the explanation relates to the substantially higher monetary damage factors for emissions in urban areas and the respective share of road transport emissions in urban areas. Impacts on ecosystems are clearly not as important in this context.

Table 31: External costs for operational of vehicles per country by impact category [in million Euro$_{2000}$]

countries	Human health	Ecosystem quality	Climate change	total
AT	104	13	54	**172**
BE	42	4	54	**100**
BG	2	0	12	**14**
CY	5	0	4	**9**
CZ	55	8	34	**97**
DE	425	54	227	**706**
DK	23	3	30	**57**
EE	3	1	6	**9**
ES	109	8	299	**416**
FI	11	2	20	**33**
FR	258	19	305	**582**
GR	63	2	80	**146**
HU	-249	-25	-11	**-285**
IE	-10	-1	-6	**-17**
IT	248	27	308	**583**
LT	8	1	9	**18**
LU	12	1	13	**26**
LV	-4	-1	-3	**-7**
MT	-1	0	-1	**-3**
NL	89	9	65	**163**
PL	213	32	154	**398**
PT	29	1	52	**83**
RO	61	3	37	**102**
SE	33	8	42	**83**
SI	17	3	16	**36**
SK	20	2	18	**41**
UK	154	10	313	**477**
TOTAL	**1,721**	**184**	**2,131**	**4,036**

3.3.4.2 Results for the pre-combustion cultivation of biofuel plants

As stated in chapter 3.3.2, the analysis of the pre-combustion phase of biofuel production only relates to the application of nutrients. An application of EU-27 average monetary damage factors for low level emissions to the changes in emissions resulting from the use of nutrients for cultivating the plants results in monetary damages of about 3.6 billion Euro$_{2000}$

for the EU-27. Table 32 presents the estimated monetary values. The monetary damages are presented for human health impacts, ecosystem impacts and climate change. These external costs would arise if the targeted change in road transport generation leading to a 10%-share of biofuels in total fuel consumption would not be implemented and vehicles would only have diesel or gasoline engines.

Table 32: External costs for nutrient application for cultivation of plants for biofuel production [in Euro$_{2000}$]

countries	Human health	Ecosystem quality	Climate change	total
AT	-72	-22	-6	**-100**
BE	-33	-11	-2	**-46**
BG	-25	-7	-3	**-34**
CY	-4	-1	0	**-6**
CZ	-27	-8	-3	**-39**
DE	-265	-86	-31	**-382**
DK	-51	-16	-5	**-73**
EE	-6	-1	0	**-7**
ES	-688	-171	-52	**-911**
FI	-69	-21	-12	**-102**
FR	-272	-86	-31	**-389**
GR	-102	-21	-8	**-130**
HU	-9	-2	-1	**-13**
IE	26	9	1	**36**
IT	-296	-84	-23	**-403**
LT	1	0	0	**1**
LU	0	0	0	**0**
LV	2	0	0	**2**
MT	-3	-1	0	**-3**
NL	-147	-48	-9	**-204**
PL	-46	-13	-4	**-63**
PT	-81	-21	-7	**-109**
RO	-57	-12	-3	**-73**
SE	-55	-18	-7	**-80**
SI	-14	-4	-1	**-20**
SK	-15	-4	-2	**-21**
UK	-313	-100	-37	**-450**
TOTAL	**-2,623**	**-750**	**-247**	**-3,620**

As can be seen from the Table 32, the impacts on human health are clearly highest, followed by impacts on ecosystems and climate change which are only caused by NH_3 (ecosystems) or N_2O (climate). The impacts on human health are caused by emissions of $PM_{2.5}$, PM_{coarse} and NH_3 with damages to human health caused by particulate matter having the major share. Again, the values in the table are negative meaning that the assumption of no implementation of the EU directive on biofuels would lead to benefits for human health, the ecosystem and climate change when regarding the avoided application of nutrients for biofuel plants.

3.3.4.3 Results for the pre-combustion phase for diesel and gasoline

The analysis of the pre-combustion phase for diesel and gasoline will be based on the above presented monetary damage factors in Table 30. The estimate external costs once again would arise if the targeted change in road transport generation leading to a 10%-share of biofuels in total fuel consumption would not be implemented and vehicles would only have diesel or gasoline engines. Table 33 shows that the total estimated external costs for pre-combustion activities of diesel and gasoline would sum up to about 3 billion $Euro_{2000}$.

As can be seen from Table 33, the impacts on human health are clearly highest, accounting for about 75% of the total monetised damages. Climate change impacts account for about 21% and impacts on ecosystem quality for about 4% of the total damages.

Table 33: External costs for nutrient application for cultivation of plants for biofuel production [in million $Euro_{2000}$]

countries	Human health	Ecosystem quality	Climate change	total
AT	40	3	10	**53**
BE	61	4	17	**82**
BG	20	1	6	**26**
CY	4	0	1	**5**
CZ	23	1	6	**30**
DE	191	12	50	**253**
DK	25	1	7	**34**
EE	4	0	1	**5**
ES	357	20	104	**481**
FI	17	1	4	**22**
FR	397	23	113	**533**
GR	37	2	10	**49**
HU	21	1	5	**28**
IE	-1	0	0	**-1**
IT	368	21	107	**495**
LT	5	0	1	**7**
LU	15	1	4	**20**
LV	2	0	1	**3**

MT	1	0	0	**1**
NL	47	3	12	**62**
PL	79	5	21	**105**
PT	55	4	14	**73**
RO	20	1	5	**27**
SE	25	2	7	**33**
SI	16	1	5	**22**
SK	21	1	6	**29**
UK	402	23	116	**541**
TOTAL	**2,250**	**131**	**635**	**3,017**

3.3.4.4 Summarised results

To summarise the results estimated for the hypothetical substitution of vehicles using biofuels by vehicles using conventional diesel and gasoline, the estimated monetised damages to human health, the ecosystem and climate change for the operational phase as well as the LCA phases, including the cultivation of energy crops on the one hand and the production of diesel and gasoline on the other hand, will be summed up. In Table 34 the results are shown. As can be seen there the total impact caused by the additional use of diesel and gasoline engines is about 3.4 billion Euro2000. The table also highlights that damages due to climate change have the highest impact of the three categories. This result was to be expected as the purpose of the EU directive on the promotion of biofuels is to reduce greenhouse gas emissions and thus the impact on climate change.

However, there are some countries, i.e. Spain, Finland, Hungary, Latvia and Malta, reporting negative monetary damages. This means that for these countries there would be benefits for human health and ecosystem quality if conventional fuels would be used increasingly. The reason for that becomes clear when comparing the results for the operational and the two LCA phases for these countries. From Table 35 it can be seen that these benefits result mostly from the benefits from less cultivation of biofuel crops when biofuels are substituted by diesel and gasoline.

Furthermore,

Table 34 shows that the total amount of damages to the ecosystem resulting for this hypothetical scenario is negative meaning that there would be benefits to ecosystem quality due to less acidification and eutrophication of plants. This again relates to the decrease in agricultural activities for biofuel production.

Table 34: Total external costs per country and impact category [in million Euro$_{2000}$]

countries	**Human health**	**Ecosystem quality**	**Climate change**	**total**
AT	72	-7	59	**125**
BE	70	-3	69	**136**
BG	-3	-6	15	**6**
CY	4	-1	4	**8**

CZ	51	1	37	**88**
DE	350	-20	247	**577**
DK	-2	-12	32	**18**
EE	1	-1	6	**7**
ES	-222	-143	351	**-14**
FI	-42	-18	13	**-47**
FR	383	-44	387	**726**
GR	-2	-16	82	**64**
HU	-238	-26	-6	**-271**
IE	16	8	-5	**18**
IT	320	-36	392	**675**
LT	14	1	10	**26**
LU	27	2	17	**46**
LV	0	0	-2	**-3**
MT	-3	-1	-1	**-5**
NL	-12	-36	68	**20**
PL	246	24	170	**440**
PT	3	-16	60	**47**
RO	24	-8	39	**55**
SE	3	-9	42	**36**
SI	19	-1	20	**38**
SK	27	-1	23	**48**
UK	243	-68	392	**567**
TOTAL	**1,348**	**-435**	**2,519**	**3,433**

Table 35: Comparison of countries with negative total damage costs [in million $Euro_{2000}$]

countries	**operation of diesel and gas vehicles**	**cultivation of plants for biofuels**	**production of diesel and gasoline fuels**	**total**
ES	416	-911	481	**-14**
FI	33	-102	22	**-47**
HU	-285	-13	28	**-271**
LV	-7	2	3	**-3**
MT	-3	-3	1	**-5**

As for the analysis of the electricity and heat generation sectors, the following Figure 4 is designed to show the differences of the impacts across all countries of the EU-27. Form this figure it can be seen that the larger countries, accounting for most of the European transport activities show the highest level of total impacts as the assessment of the impacts was directly connected to the difference in transport activities (vkm, see Table 22) between the BAU scenario and the 450ppm scenario in 2020.

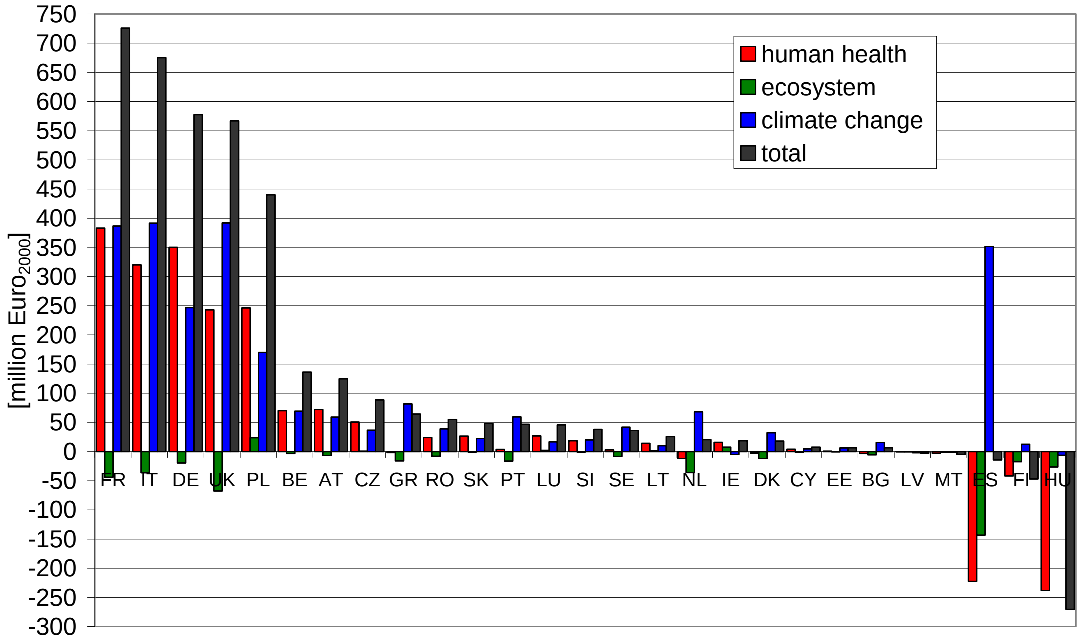


Figure 4: Presentation of results per country for transport activities ranked by total monetised impacts

4 Summary of the results

This last chapter is now designed to summarise the results for the three economic sectors analysed in detail in the previous chapters. Therefore, the estimated external costs for the three impact categories human health, ecosystem quality and climate change will be summed up to provide the overall external costs. It has been mentioned in the description of the approaches for the three sectors (electricity generation, heat generation and transport) that the scenario was to assess the impacts of the EU directive 2009/28/EC. In order to enable this analysis the approach chosen was the assumption of non-existence of the directive and an analysis of the activities that would have been necessary in order to completely substitute the electricity and heat generated by renewable sources as well as the vehicle kilometres driven by cars using biofuels instead of conventional diesel and gasoline.

The analysis in the previous chapters differentiated between the activities and resulting emissions of the operational phase, i.e. combustion processes for electricity and heat generation and the other phases of the life cycle, i.e. the construction, maintenance and dismantling of heat and power plants as well as the production of diesel and gasoline or the cultivation of biofuel crops. These results will now be summed to provide the overall amount of external costs that can be assigned to the EU directive, i.e. that are the benefits of the implementation of the directive in 2020.

Table 36 presents the total external costs estimated in this study. The total amount sums up to 11.6 billion $Euro_{2000}$. Analogously to the results for each of the sectors, the impacts caused by greenhouse gases account for the largest share of total external costs estimated. About 70% of the monetised damages can be assigned to these pollutants. This obviously means that the directive of the EU targeting the use of renewable energies reaches its overarching goal to reduce climate change impacts. In addition, the estimated external costs for human health impacts that can be saved by implementing the directive serve as a positive side effect. However, the impacts on ecosystem quality result in an overall negative value meaning that the implementation of the directive would lead to increasing impacts on ecosystems here covered as biodiversity losses due to acidification and eutrophication. This increase in impacts results from the additional need of agricultural area to cultivate the plants later used for producing the biofuels. The increase in agricultural area goes along with an increasing use of nutrients resulting in additional emissions of especially NH_3 which affects biodiversity negatively. The estimated impacts on ecosystems only make up for 1.8% of the total estimated external costs, thus, when compared to the benefits for human health and even more so for climate change, the overall benefits of the implications cause by the directive clearly outshine these costs.

In a final figure, these results are once more converted into a ranking by total external costs per country. As can be seen from Figure 5, the highest damage costs have been estimated for Germany, France and UK. This is not a surprising outcome of the study as these countries represent a large share in the activities of electricity production, heat generation and transport. The substantial negative external costs for Hungary mean that the implementation of the EU directive would not result in benefits but cost with respect to human health, the quality of the ecosystem and climate change. In case of Hungary this is mostly related to the high estimated impacts on human health (see the red column in the figure). These impacts result from the changes in the transport sector when substituting biofuels with conventional diesel and gasoline engines. In the TIMES BAU scenario for Hungary in 2020 the emissions from transport activities are substantially lower than in the 450ppm case where an increased use of biofuels is assumed.

In summary, the benefits to human health and the reduction of greenhouse gases resulting from the implementation of the EU directive targeting a 20% share of renewables in gross energy consumption and a 10% use of biofuels in transport related activities clearly outweigh the costs in form of impacts to the ecosystem caused by additional agricultural activities for cultivating energy crops.

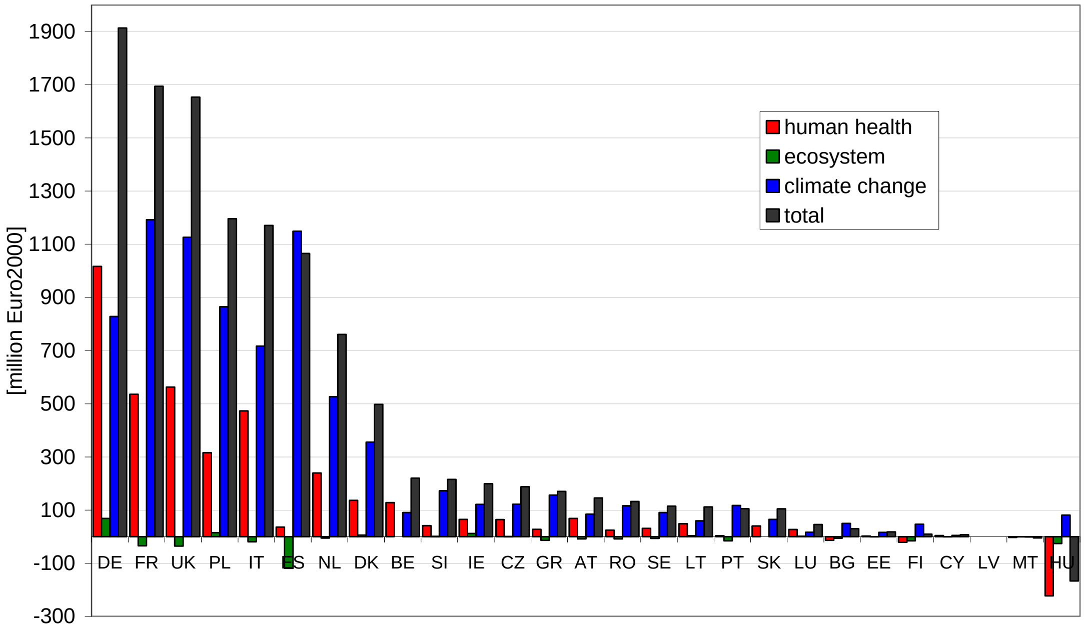


Figure 5: Total external costs per country ranked by total monetised impacts

Table 36: Sum of external costs for all sectors [in million $Euro_{2000}$]

Countries	Human health	Ecosystem quality	Climate change	total
AT	68	-8	85	**146**
BE	129	0	91	**220**
BG	-14	-7	50	**30**
CY	4	-1	4	**8**
CZ	64	1	123	**188**
DE	1,017	69	828	**1,914**
DK	137	6	355	**498**
EE	2	-1	16	**18**
ES	36	-119	1,149	**1,066**
FI	-21	-16	47	**9**
FR	536	-34	1,193	**1,695**
GR	28	-14	156	**171**
HU	-222	-26	81	**-167**

IE	65	12	122	**199**
IT	473	-19	717	**1,171**
LT	49	4	60	**112**
LU	27	2	17	**46**
LV	0	0	0	**0**
MT	-3	-1	-1	**-5**
NL	239	-5	527	**761**
PL	316	15	865	**1,196**
PT	3	-16	118	**105**
RO	24	-9	116	**132**
SE	31	-7	91	**115**
SI	42	1	173	**216**
SK	40	0	65	**105**
UK	563	-35	1,126	**1,654**
TOTAL	**3,633**	**-208**	**8,175**	**11,601**

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Annex I: Additional tables

A1: Resulting emissions for the LCA phase per country [in kt]

country	CH_4	N_2O	CO_2	NH_3	NMVOC	NO_X	PM_{10}	PM_{25}	PM_{coarse}	SO_2
AT	2.03	-0.03	27.54	-0.02	0.06	0.22	0.01	0.00	0.01	0.22
BE	3.88	0.00	600.44	0.01	0.27	1.77	0.30	0.18	0.12	2.67
BG	0.31	-0.03	-138.93	-0.03	0.01	-0.37	-0.08	-0.05	-0.03	-0.57
CZ	2.22	-0.05	26.59	-0.06	0.08	0.18	0.01	0.00	0.01	0.24
DE	43.78	0.43	2,389.95	0.73	2.51	10.45	1.12	0.65	0.47	11.00
DK	31.13	-0.03	498.81	0.12	1.31	4.20	0.28	0.11	0.17	3.38
EE	0.43	-0.01	5.70	-0.01	0.02	0.04	0.00	0.00	0.00	0.05
ES	49.03	0.04	1,295.53	0.29	2.02	8.17	0.64	0.33	0.31	7.20
FI	2.02	0.00	206.24	0.00	0.12	0.68	0.10	0.06	0.04	0.94
FR	44.94	-0.33	652.73	-0.26	2.00	4.98	0.28	0.10	0.18	4.77
GR	7.61	0.00	136.79	0.03	0.43	0.98	0.06	0.03	0.03	0.83
HU	1.12	-0.05	16.62	-0.07	0.10	-0.03	-0.01	-0.01	0.00	0.10
IE	10.81	0.00	195.21	0.05	0.55	1.45	0.10	0.04	0.06	1.25
IT	23.28	0.01	462.53	0.13	1.00	3.43	0.12	0.09	0.03	2.70
NL	38.27	0.03	696.37	0.25	1.46	5.72	0.39	0.17	0.22	4.55
PL	18.59	-0.42	228.08	-0.49	0.56	1.60	0.07	0.00	0.07	2.08
PT	4.34	-0.02	-82.45	0.00	0.14	0.22	-0.04	-0.03	-0.01	-0.16
RO	5.02	-0.06	73.67	-0.06	0.21	0.54	0.03	0.01	0.02	0.57
SE	9.34	-0.04	186.54	-0.01	0.41	1.30	0.08	0.02	0.05	1.15
SI	0.91	-0.01	14.93	-0.01	0.03	0.11	0.01	0.00	0.00	0.11
SK	1.78	-0.04	21.00	-0.05	0.06	0.14	0.01	0.00	0.01	0.19
UK	58.36	0.07	1,096.52	0.42	2.16	8.97	0.61	0.26	0.35	7.08
TOTAL	**359.20**	**-0.53**	**8,610.39**	**0.97**	**15.52**	**54.75**	**4.07**	**1.97**	**2.10**	**50.35**

A2: Resulting emissions for the operating phase per country [in kt]

country	CH_4	N_2O	CO_2	NH_3	NMVOC	NO_X	PM_{10}	PM_{25}	PM_{coarse}	SO_2
AT	0.02	-0.03	866.87	-0.03	-0.08	-0.75	-0.01	-0.03	0.02	0.15
BE	0.07	0.00	65.04	-0.02	-0.05	-0.15	0.04	0.00	0.04	1.13
BG	0.04	-0.02	957.77	-0.02	-0.08	-0.46	-0.01	-0.03	0.02	0.08
CZ	0.05	-0.07	502.06	-0.05	-0.18	-1.70	-0.03	-0.05	0.03	0.03
DE	1.30	1.39	15,818.03	0.40	1.98	26.47	0.93	0.45	0.48	14.69
DK	1.02	0.37	7,567.78	0.51	0.17	4.35	0.32	0.07	0.26	4.71
EE	0.01	-0.01	150.20	-0.01	-0.02	-0.21	0.00	-0.01	0.00	0.03
ES	0.45	0.65	24,444.06	0.00	0.50	10.45	0.55	0.08	0.47	10.10
FI	0.02	0.01	728.15	-0.01	-0.02	0.07	0.02	0.00	0.03	0.60
FR	1.89	-0.03	16,560.27	-0.36	-0.95	-7.42	0.04	-0.36	0.40	4.65
GR	0.37	0.12	2,182.08	0.00	0.07	1.47	0.07	0.00	0.07	1.43
HU	0.13	-0.05	1,075.29	-0.05	-0.16	-1.37	-0.01	-0.05	0.03	0.25
IE	0.45	0.17	3,727.89	-0.01	0.08	2.17	0.11	-0.01	0.12	2.34
IT	0.20	0.35	9,832.28	0.05	0.27	6.08	0.30	0.02	0.28	5.68
NL	0.52	0.54	13,913.08	0.14	0.40	8.38	0.41	0.04	0.37	7.85
PL	0.16	-0.59	8,646.70	-0.44	-1.55	-14.66	-0.21	-0.44	0.23	0.43
PT	0.06	0.03	2,073.29	-0.02	-0.01	0.32	0.02	-0.02	0.04	0.60
RO	0.13	-0.05	2,468.70	-0.06	-0.20	-1.62	-0.01	-0.07	0.06	0.56
SE	0.14	0.05	5,119.25	-0.05	-0.12	0.43	0.07	-0.05	0.12	1.89
SI	0.00	-0.01	357.65	-0.01	-0.04	-0.24	0.00	-0.01	0.01	0.13
SK	0.04	-0.05	200.46	-0.04	-0.14	-1.36	-0.02	-0.04	0.02	0.02
UK	0.51	0.87	21,670.10	0.03	0.69	14.43	0.65	0.06	0.60	13.01
TOTAL	**7.59**	**3.66**	**138,927.00**	**-0.05**	**0.56**	**44.66**	**3.25**	**-0.45**	**3.69**	**70.34**

Annex II: Contributors to the report

This report is the result of discussions between all partners in the EXIOPOL consortium. It has been edited by Wolf Müller. All chapters were written by Wolf Müller, University of Stuttgart.