EEA Technical report | No 10/2008

Maximising the environmental benefits of Europe's bioenergy potential

ISSN 1725-2237

European Environment Agency

EEA Report | No 10/2008

Maximising the environmental benefits of Europe's bioenergy potential

European Environment Agency

Cover design: EEA
Layout: EEA

Luxembourg: Office for Official Publications of the European Communities, 2008

ISBN 978-92-9167-375-9
EEA Technical report series: ISSN 1725-2237

DOI 10.2800/49213

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark
Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99
Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

Contents

Acknowledgements

This report was prepared by Ayla Uslu (European Environment Agency — hereinafter EEA), Jan-Erik Pedersen (EEA), Gustav Resch (Vienna University of Technology) and Uwe Fritsche (Oeko Institut). The EEA project manager was Ayla Uslu.

The present report builds on the findings of the EEA report *How much bioenergy can Europe produce without harming the environment* and the EEA Technical report *Environmentally compatible bioenergy potential from agriculture* that were prepared for the European Environment Agency (EEA) by the European Topic Centre (ETC) on Air and Climate Change (Oke Institute, partner of the EEA's ETC on Air and Climate Change), and AEA Technology. Additional input to the report was provided by André Jol, Jeff Huntington, Anca-Diana Barbu, Peder Jensen, Martin Adams, Ricardo Fernandez, Ybele Hoogeveen, Hans Vos, Josef Herkendell (all EEA), Mario Ragwitz, Felipe Toro, Lynn Dicks, Stephanie Schlegel and Bettina Kampman. The EEA offers grateful acknowledgments to Tobias Wiesenthal who initiated this project and made significant contributions to the present report.

The EEA would like to acknowledge the comments on the draft report received from the national focal points of EEA member countries and from the European Commission (DG Env, DG Tren and DG Agri). These comments are included in the final version of the report as fully as proved practically feasible.

Executive summary

Biomass as a source of energy for Europe

Bioenergy — energy from biomass — can play an important role in combating climate change as well as e.g. improving the security of energy supply in Europe. However, plant biomass is used for a large number of purposes, as apart from energy it also provides food, feed, clothing, paper, bioplastics and building materials. There can therefore be direct competition between different uses of the same type of biomass, or competition for land on which to grow biomass, also with other uses of land, e.g. for nature protection.

Biomass production (for whatever purpose) interacts strongly with the environment. Cultivation, harvesting and collection of biomass from the field or forest consumes energy and water, and gives rise to emissions of air and green house gas (GHG) pollutants. There are risks of soil erosion, and potential threats to biodiversity and water resources. The subsequent conversion of biomass into usable energy and its use for heat, electricity and transport results in emissions of air and GHG pollutants. Further expansion of bioenergy production may cause direct adverse effects on the environment and indirect effects due to displacement effects (changes and shifts in land-use, e.g. from grassland to arable land). These direct and indirect effects may undermine an important goal society is trying to achieve with the use of bioenergy — reducing greenhouse gas emissions — and jeopardise the achievement of other environmental goals, such as the protection of biodiversity and water resources.

On the other hand, an appropriate choice and management of energy crops can also decrease soil erosion or water pollution risks from agricultural and pastoral practices and provide certain biodiversity benefits. Such benefits will only come about, however, if policy and economic incentives are in place to steer bioenergy production in this direction. Strong efforts are therefore required in a range of policy areas to minimise the potential negative environmental impacts of bioenergy production, including the use of harmonised internationally recognised environmental sustainability standards. Protecting soil and water resources as well as avoiding loss of biodiversity need particular attention at local and regional level whereas issues such as climate change have a strong global dimension.

Until such global sustainability standards and related control mechanisms are in place, it could be argued that basing EU bioenergy on domestic resources is preferable from an environmental point of view. In line with this, the present study focuses solely on quantifying the benefits that could be gained through the optimal use of the EU bioenergy potential.

Bioenergy potential in Europe

The technical potential for bioenergy production in EU-25 was estimated in an earlier EEA report *How much bioenergy can Europe produce without harming the environment?*. This study assessed the technical [1] maximum potential for utilising biomass from the waste, forestry and agriculture sectors under a given set of environmental constraints. These constraints were developed to ensure that the resulting potential would in principle be environmentally compatible, but did not include potential effects outside the EU.

Exploiting Europe's bioenergy potential

This study assesses the environmental impacts of various ways of converting the technical bioenergy potential from the 2006 EEA study into usable electricity, fuel or heat. It models various European bioenergy developments up to 2030, using the most environmentally beneficial technologies. It aims

(1) Technical potential is understood as the theoretical upper potential limited by the demand for land used for other purposes and based on an assumed level of agricultural productivity. However, in the study conducted in 2006, when estimating the overall potential, the economic and logistical barriers could not be included.

to demonstrate what bioenergy can offer Europe, in terms of climate mitigation and energy security, and to provide a clear picture of the possible role of bioenergy in the future energy mix, which is assumed to be in transition from a fossil fuel economy to a low carbon energy system. Thus this study aims to illustrate the implications of different ways of using Europe's biomass resources rather than to assess the potential impact of current policy proposals or practices.

Scenarios used

A specially adapted software tool, Green-$X_{ENVIRONMENT}$, was used to develop a number of bioenergy scenarios, building on reference energy pathways created using the EU-wide PRIMES model.

The Low Carbon Emission Pathway (LCEP) scenario developed earlier by the EEA (EEA, 2005a and b) was used as the reference scenario. The LCEP scenario assumes that ambitious GHG emission reduction policies result in a carbon permit price of EUR 20/ton (by 2020) rising to EUR 65/ton by 2030 (and it assumes low fossil fuel prices). The share of renewable energy is 13 %, the share of nuclear energy 12 % and the share of solid fuels only 4.9 % of the gross in land energy consumption by 2030 in this scenario.

The Green-X scenarios, all assuming full use is made of the technical potential for bioenergy production, include a 'least-cost' bioenergy deployment model run without policy intervention, which serves as the main 'reference' case ('LCEP reference scenario'). To test sensitivity to carbon and fossil fuel prices, this 'least-cost' reference option was also run with a relatively low carbon price and higher fossil fuel price ('Alternative scenario').

Other scenario cases studied reflect different energy and environment policy priorities including prioritisation of Combined Heat and Power (CHP); minimising CO_2 emissions; reducing air pollutant emissions; prioritising renewable energy and prioritising transport biofuels.

The LCEP reference and alternative reference scenarios, as well as the different priority scenarios were evaluated in terms of bioenergy contribution to total energy demand in the three sectors (electricity, heat and transport), additional generating costs and fossil fuel savings, avoided GHG emissions and changed air pollutant emissions. Emissions were calculated as both life cycle and direct assessments, based on the Global Emission Model for Integrated Systems (GEMIS).

Key findings

In the following, key findings from some of the scenarios are presented. In all cases, these build on the crop mixes assumed in the 2006 EEA study and the optimal bioenergy pathways calculated by the Green-$X_{ENVIRONMENT}$ model.

The LCEP reference scenario demonstrates that using the entire environmentally-compatible bioenergy potential in a 'least cost' manner would avoid 394 million tonnes of annual CO_2-equivalent emissions by 2020 and 617 million tonnes by 2030, corresponding to 7 % of the total volume of GHG emissions in EU-25 in 1990, and to 11 % in 2030. This underpins the importance of bioenergy for meeting EU's future GHG reduction targets.

1 700 TWh of fossil fuel energy would be saved and 2 700 TWh in 2030, at a value of EUR 25 billion and EUR 47 billion respectively at predicted 2020/2030 prices (or EUR 42 billion and EUR 70 billion respectively assuming today's energy prices ([2]). This would have a positive affect on Europe's trade balance as most fossil fuels are imported, and would help to compensate for the additional generating costs arising from an enhanced bioenergy deployment. These are relatively low, at about EUR 19 billion in 2020 and 2030.

By comparison, the alternative reference scenario with relatively higher fossil fuel prices but on the other hand lower carbon permit prices result in a reduction of 426 million tonnes (8 %) of GHG emissions in 2020 and 695 million tonnes (13 %) in 2030. Higher emissions reductions and cost savings occur due to the fact that absolute GHG emissions are higher in this alternative reference scenario, so that the use of bioenergy has a greater positive impact.

Comparing the two reference scenarios demonstrates that while the specific numbers change, the overall picture remains the same. Substantial reductions in GHG emissions accrue from the use of bioenergy, and the additional generating costs associated with the use of bioenergy are smaller than the value of the fossil fuels replaced.

([2]) December 2007 import prices are applied.

Bioenergy would also make a substantial contribution to achieving the EU renewable energy target for 2020. If all the theoretical potential estimated in the EEA 2006 study would be viable in economic and logistics terms, around 10.5 % of Europe's gross energy consumption (9.5 % of final energy demand) in 2020 could be met with biomass alone (compared to 4.5 % of gross energy demand in 2005), nearly half of the target of 20 % as defined in terms of final energy. In 2030, 16 % of the EU-25 gross energy demand would be met by bioenergy. Bioenergy would meet 18.1 % of European demand for heat, 12.5 % of electricity demand and 5.4 % of transport fuel demand(corresponding to 7 % of the diesel and gasoline demand in road transport).

Finally, to the extent that bioenergy is replacing imported fuels, e.g. gas from Russia, it would also contribute to ensuring the security of EU's energy supply (see also below).

If additional priorities and investments were implemented to increase the use of heat from combined heat and power systems, the CHP scenario indicates that overall GHG emissions reductions would increase (454 million tonnes in 2020, 695 million tonnes in 2030), and the bioenergy share of heat would increase to 23 % in 2030. Additional generating costs would be substantially lower and fuel savings slightly higher than in the LCEP reference scenario, but it was not possible to include the costs of additional investments in district heating networks in the analysis.

Giving priority to the achievement of the proposed 10 % target for renewable energies in the transport sector by 2020 with an imposed constraint of using EU biomass resources leads to GHG emissions reductions in 2020 and 2030 of the same order as in the LCEP reference scenario, but with substantially higher additional generating costs (about EUR 27 billion on 2020 and EUR 28 billion in 2030) and similar fossil fuel savings (EUR 26 billion in 2020 and EUR 44 billion in 2030). Intra-European trade in refined biofuels and a fast development and introduction of second generation technologies are imperative for achieving the 2020 target, given the modelling constraints of using solely domestic biofuels and prioritising the environment. Only second generation technologies could successfully employ the large share of woody biomass in total European potential that was assumed in the 2006 EEA study for transport biofuels.

Changing levels of bioenergy use will have different effects (positive or negative) with respect to Europe's air quality depending on the scenario. The LCEP reference scenario implies a significant switch from coal to natural gas, generally leading to improved air quality. The various scenarios analysed indicate that additional bioenergy deployment would result in increased NO_X and SO_2 emissions compared to the reference scenario, but these emissions are lower than current emission levels. To improve the understanding of the potential impacts of bioenergy on air quality further studies are needed.

Review of certain key modelling assumptions

a) Modelling the potential role of transport biofuels

In assessing the key findings it is worthwhile highlighting that in the scenarios it is assumed that using biomass for transport fuels will become more attractive in the future from an environmental viewpoint:

- Second generation biofuels from low impact, high-yield perennials will give higher avoided GHG emissions than first generation biofuels. Second generation biofuels are assumed to be readily available by 2020 and penetration rates for second generation biofuels of 80 % of total biofuels are assumed.

- The assumed fuel switching from coal to gas in the electricity and heat sectors could reduce the avoided GHG emissions resulting from using biomass in those sectors. Currently Europe's energy mix is based on 24 % natural gas and a little over half of its total energy consumption is based on imported energy. The share of natural gas in the fuel mix used in this study is projected to increase significantly in the future with for example, around 80 % of the natural gas being imported, mainly from Russia. By 2030 the main fossil fuel substitutes will be gas (60 % of the total volume replaced) followed by oil (30 % of the total volume avoided).

However, it is likely that these assumptions overstate the potential role of biomass-based transport fuels compared to using biomass in electricity and heat generation. Firstly, there is considerable doubt at the present time as to whether second generation biofuels meeting stringent sustainability criteria will be readily available by 2020. Secondly, the trend of switching from coal to gas might be reversed or limited by the need to ensure security of energy supply, EU coal being more attractive than imported gas in this regard.

b) Implications of high fossil fuel prices

The 2006 study assumed far lower fossil fuel costs than currently observed on world markets. Rising fossil fuel prices could bring down the relative cost of bioenergy production compared to fossil fuels. Increasing oil prices, in particular, may be perceived as transport biofuels becoming more competitive against electricity and heat generation from biomass. However, this might be outweighed as the high fossil fuel prices are likely to increase both the feedstock production costs (especially the arable crops due to increased fertiliser prices) and the capital costs. Thus, a more thorough assessment is required in order to understand the full impact of rising fossil fuel prices, in particular the prices for oil on bioenergy systems.

c) Modelling agricultural markets and indirect effects

The modelling approach employed by the EEA in 2006 had to set its system boundaries at Europe's borders. The area needed to grow food and feed in Europe was assumed to fall due to productivity improvements and reduced production as a consequence of an opening up of European agricultural markets to increased competition. This approach did not include feedback loops with global agricultural or bioenergy markets and did therefore not take account of the recent price increases for food/feed on the world markets.

Furthermore, in the real world Europe's agricultural production makes a significant contribution to supplying world agricultural markets, which is likely to increase in importance given strong growth in future world food demand. Given this fact and the interactions between world food and biomass markets a change in Europe's imports of biomass for energy or in its agricultural export potential is likely to have implications for global land-use trends. Such effects and the associated GHG emissions or biodiversity impacts were not part of the original analysis. Consequently, an update of the 2006 modelling exercise would ideally be required for estimating the likely environmental effects and CO_2 efficiency of European bioenergy policies.

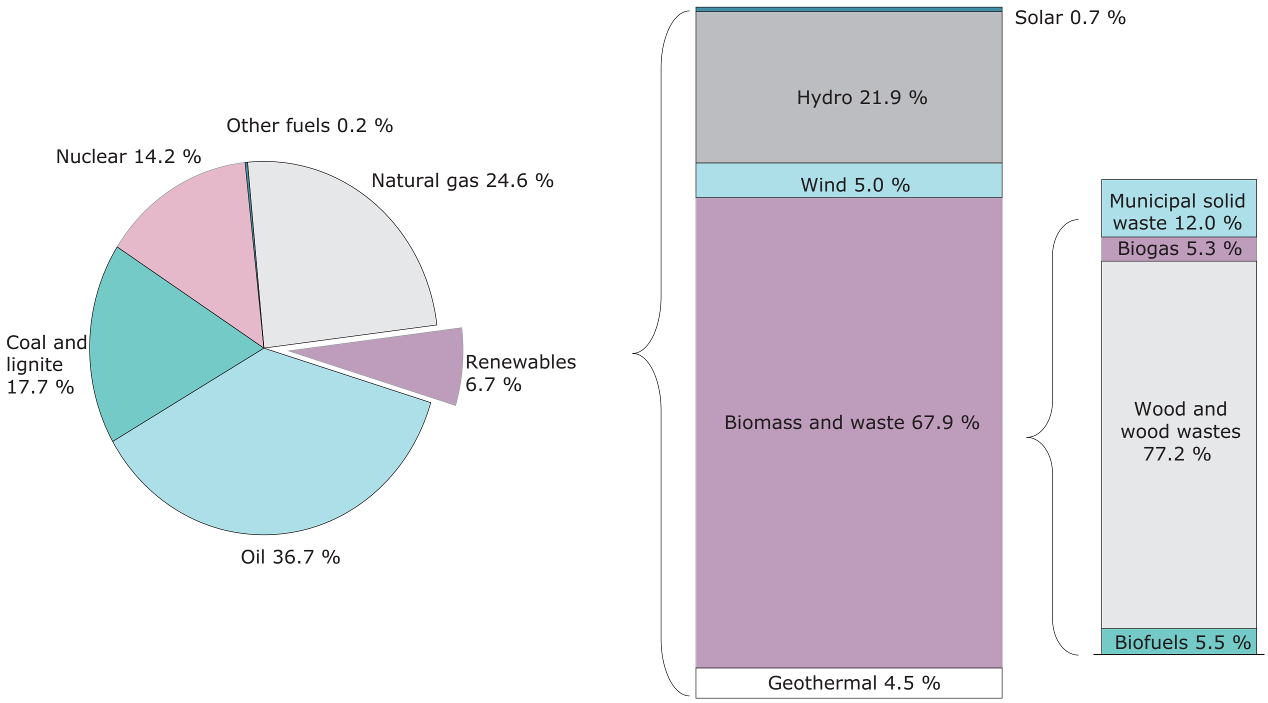
1 Introduction

The EU is seeking to increase the use of renewable energy in order to limit climate change and enhance the security of energy supply. In 2005, renewables accounted for 6.7 % of EU's gross energy consumption; of which two thirds were biomass and waste (see Figure 1.1). Significant amounts of additional bioenergy are likely to be needed to reach the legally binding renewables target of 20 % of the overall EU final energy consumption by 2020 proposed by the Commission (EC, 2008a) to implement the agreement reached by the European Council last year. There is also a proposal that each Member State should introduce a national minimum target of 10 % for renewables in the transport sector — under the condition of production being sustainable and second generation technologies being commercially available.

As a contribution to assessing the potential for increased use of renewable energy in Europe, the European Environment Agency (EEA) published a report that provides assessment of Europe's technical potential to produce bioenergy without negative environmental impacts (EEA, 2006). The report identified the environmental pressures arising from the increased bioenergy demand and sought to eliminate them as far as possible by applying various environmental criteria to biomass production strategies. Thus, it identified the quantities of bioenergy Europe could potentially produce in 2010, 2020 and 2030, whilst protecting its environment.

Having assessed a significant bioenergy potential in Europe, the next step has been to identify the most environmentally efficient and cost-effective ways of using the biomass. There are many different sources of biomass and many different ways to use it for energy. It can be converted into electricity, heat or transport fuels (hereinafter called 'biofuels').

Figure 1.1 Share of energy consumption by fuel type in 2005, EU-27



Source: EEA, 2007a.

This means that there will be competition for the significant, but finite, primary bioenergy feedstocks that can be produced in Europe. As the different processes and types of end use have different economic and environmental consequences, it is important to use the available biomass as effectively as possible in a climate change and the energy supply perspective.

Several studies have examined different biomass-to-energy pathways. But most are either limited to a few feedstock types and conversion technologies, or their focus was solely on either electricity or biofuel production. This study looks at the efficient pathways of using the environmentally compatible bioenergy potential for all energy purposes in Europe.

Realising the environmental benefits of bioenergy and reducing the negative impacts requires an integrated approach. The figure below (Figure 1.2) summarises approaches applied both in previous and the present studies of the bioenergy potential.

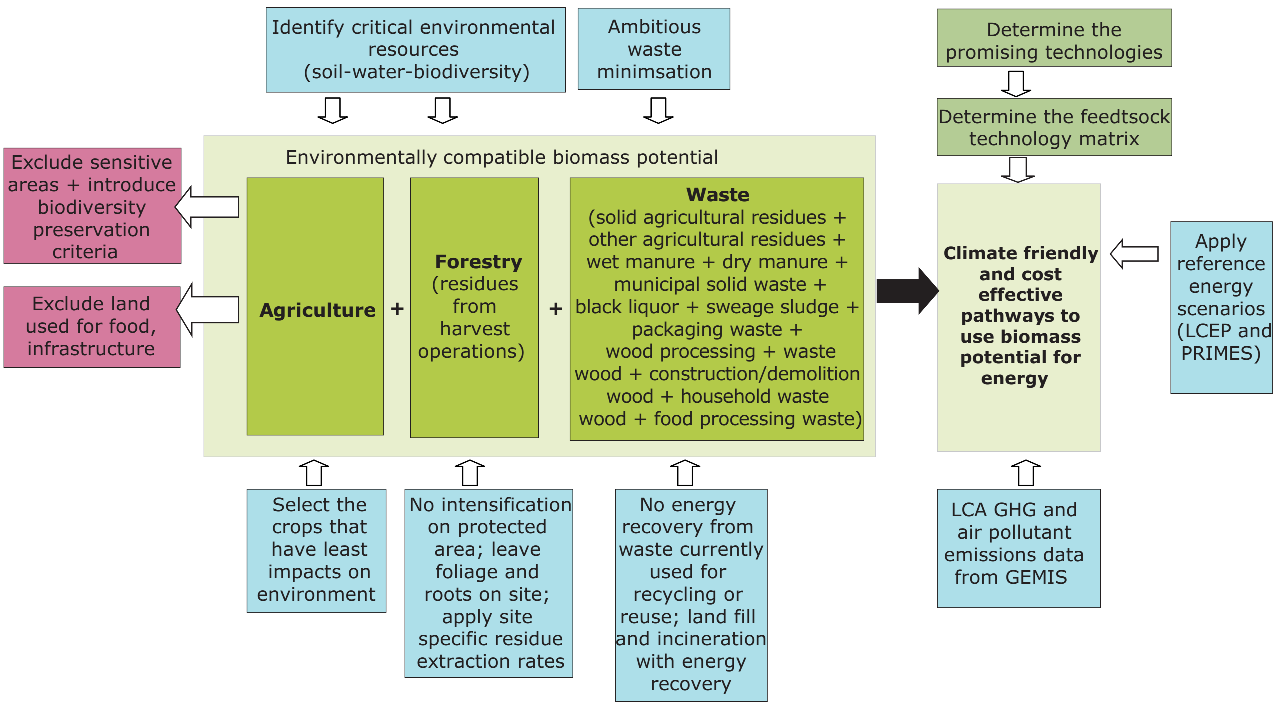
1.1 Limitations of this study

The main limitations relate to some of the modelling boundaries and input parameters developed for the previous study identifying the environmentally-compatible biomass potential in Europe. Three factors in particular need to be discussed in the light of current knowledge and recent economic trends: the environmental effect of indirect land-use change linked to bioenergy production, assumed trends in yield increase for food and energy crops as well as the recent strong increase in fossil fuel prices compared to scenarios utilised in the study.

a) *Modeling boundaries and potential indirect effects*

The modelling boundaries of the 2006 EEA study were set at Europe's borders for modelling reasons and lack of data and knowledge for estimating effects beyond the EEA member countries. It focused therefore on the biomass potential that could be produced in Europe in an environmentally-compatible manner if certain rules to minimise impacts on soil, biodiversity, landscapes and water resources in Europe were followed. Within these environmental conditions biomass could be produced on land not required to fulfil European demand as the area needed to grow food and feed in Europe was assumed to fall due to productivity improvements and reduced

Figure 1.2 Analytical framework applied in this study



Note: The previous study (done in 2006) is on the left and the current study is on the right. The white arrows show the flow of data and/or constraints.

production as a consequence of an opening up of global agricultural markets to increased competition. For the purposes of the 2006 study, therefore, impacts on societies and the environment outside Europe were assumed to be negligible.

In a more detailed technical perspective it should be noted that the land-use figures underlying the 2006 study are derived from the CAPSIM (The Common Agricultural Policy SIMulation) model runs which assumed full competition of EU agriculture with the world market. The land which in those model runs was 'freed' from agriculture is a function of assumed food and feed price developments, and the CAPSIM runs did not include the recent price increases for food/feed on the world markets. The CAPSIM results would therefore benefit from a revision that includes today's perspective. Such a revision would either reduce the amount of 'freed' land, or make the competition between food/feed production and bioenergy production on that land depending on the price ratio (i.e. higher oil prices vs. higher food/feed prices).

Thus, the development of markets and prices for agricultural commodities (OECD-FAO, 2007), world population growth, climatic conditions and changes in diet ([3]) that influence supply and demand for food, feed and bioenergy crops could change overall demand and the agricultural trade balances between Europe and other world regions. Therefore, recognising that large-scale production of bioenergy requires considerable land areas, an evaluation of bioenergy policies should take into account direct and indirect impacts on global land-use change, even if the focus is on home-grown biomass.

This matters as indirect land-use change, in particular deforestation, affects the overall greenhouse balance of bioenergy production (Fargione *et al.*, 2008; MNP, 2008). Deforestation and associated land-use change were responsible for about 17 % of global greenhouse gas emissions in 2004 (IPCC, 2007). In fact, deforestation is a more important factor at the global level than emissions from transport (Stern, 2006). Deforestation and the combustion of vegetation happens mainly in the tropical countries of the world linked to legal and illegal logging (FAO, 2005), the expansion of cropping and pasture areas (FAO, 2003; Morton *et al.*, 2006) and the use of woody biomass for fuel (UN-Energy, 2007). The issue of land-use change, preservation of indigenous forests, and expansion of forest resources as a mechanism for establishing carbon sinks, has therefore gained considerable attention (Righelato and Spracklen, 2007; Kindermann *et al.*, 2006), also in the context of global climate change negotiations.

In conclusion, there are strong agricultural and land-use trends that impact on the world's ecosystems (e.g. OECD, 2008), including their capacity to act as carbon sinks. These trends would continue independent of bioenergy production. On the other hand, care needs to be taken that biomass production for energy does not aggravate the environmental issues associated with global land-use trends (Searchinger *et al.*, 2008; MNP, 2008). Future revisions of the EEA 2006 modelling work should therefore address potential indirect effects of EU bioenergy production and consumption, in particular on land use.

b) Assumed yield increases

The yield increases included in the 2006 modeling exercise for agricultural as well as energy crops matter as they influence the overall biomass potential that was estimated. In any given modeling system yield increase can be treated as an exogenous variable (i.e. imposed on the modelling run on the basis of external factors) or as endogenous, meaning that yield trends would be influenced by other variables in the modeling system itself, e.g. increased food demand or prices in the case of in agricultural yields.

The 2006 study based its agricultural feedstock calculations on the yield figures estimated in the CAPSIM model which used trend predictions on a range of modelling exercises carried out for DG Agriculture, the US Department for Agriculture and FAO. Yields for energy crops were estimated from published field research quoted in previous bioenergy studies. The yield increase trends used in the study were developed as a combination of historic yield trends for food and 1st generation energy crops as well as yield trend estimates as a function of increased demand and active breeding and research, in particular for novel energy crops. The following yield trends were applied:

- For '1st generation' oil crops in the EU, a constant 1 %/year increase of the energy yield over the whole period which is a function of the moderate demand increase, and historic developments.

([3]) An increase in worldwide demand for animal products will significantly increase the area of land needed to feed the population.

- For '1st generation' starch crops in the EU, a constant 1.5 %/year increase of the energy yield over the whole period which is due to the assumed higher demand increase for ethanol.

- For '2nd generation' starch crops (i.e. whole plant material use), two-culture schemes and all lignocellulose (short rotation coppice and perennial grasses) produced in the EU, a 1 % per year increase of the energy yield from 2000 to 2010, and 1.5 %/year from 2010 to 2020, and 2 % per year from 2020 to 2030. This dynamic is based on the demand increase which develops over time.

These figures, however, can only be considered as estimates as there are a number of uncertainties that may affect them, e.g. the impact of higher energy and other input prices, the success of new breeding technologies as well as climatic and environmental limitations in the future. Variations in the total estimated available biomass due to differential yield increases should, however, not significantly affect the results of the main modelling objective in this study, that of determining an optimum use of available biomass in Europe.

c) Possible impacts of increased fossil fuel prices

This modeling work is based on the 2004/2005 fossil fuel price assumptions which do not reflect the current perceptions of future energy and agriculture market. The impact of rising fossil fuel prices, in particular the oil prices, however, require a more thorough assessment as they will affect the extra costs to produce biofuels, bio-electricity and bio-heat (in comparison to the conventional energy systems). Particularly the soaring oil prices may change the potential role of biomass based transport fuels compared to using biomass in electricity and heat generation. On the other hand bioenergy production costs will rise as capital costs, fuel costs and the feedstock production costs are likely to increase due to increasing fossil fuel prices. Depending on the feedstock type the production cost increase may counterbalance the positive impact of high fossil fuel prices on the competitiveness of bioenergy over fossil fuels.

1.2 Outline of this report

This report presents various ways to optimise the benefits of bioenergy use in Europe by the years 2020 and 2030 — by identifying GHG and air emissions, and also cost-efficient methods of using biomass for each energy sector: electricity, heat and fuel.

Chapter 2 reviews the available data on the various bioenergy resources that Europe can provide and discusses life cycle analysis (LCA) approaches to estimating emissions of greenhouse gases and air pollutants related to different bioenergy pathways. Chapter 3 outlines the structure and assumptions of the Green-$X_{ENVIRONMENT}$ model. The model is set up to find out how well bioenergy can deliver against the targets of reduced greenhouse gas emissions and increased energy security — two major objectives of European policy. Chapter 4 presents the model results, showing how the European biomass can be used in a cost-effective and environmentally efficient way. It also analyses the emitted air pollutants within the life cycle of bioenergy production. The analysis is done for individual European Member States for the years 2010, 2020 and 2030. Then the model is used to analyse the impacts of different policy strategies and priorities on the future bioenergy market, and their consequences in respect of the energy security and emissions. This chapter also analyses the possible consequences of prioritising the use of biofuels in the transport sector. Finally, the last chapter discusses the future challenges to achieving the environmentally efficient bioenergy pathways as presented in the previous chapters.

2 The biomass potential of Europe and the life cycle GHG emissions of different bioenergy pathways

2.1 EEA estimates of biomass potential

Biomass is the world's fourth largest energy source, providing around 10 % of the demand for energy worldwide. Most of it is used in developing countries for cooking and heating. Only around 4.4 % of the EU's primary demand for energy is met through the use of biomass, equivalent to around 6.5 % of the global biomass primary energy supply (IEA, 2006a). In 2005, primary energy production from biomass in Europe was around 80 MtOE (Eurostat, 2007), most of which was from wood or wood waste.

A number of studies have assessed the biomass potential in Europe and the world as regards energy and material purposes (see Annex 1). This study is making use of the bioenergy potential estimated by the EEA in 2006, because it is the only study that explicitly includes environmental considerations in its assessment of how much bioenergy could be produced. The study assumed that the following environmental measures have been taken (see Box 2.1):

With these restrictions in place, in the short term biomass comes largely from the waste sector, with bioenergy crops reaching their full potential in the longer term (due to expected yield increases and a reduction in agricultural exports).

These figures represent Europe's technical potential for biomass production, restricted by environmental considerations. They do not allow for economic or logistical constraints on production. It should be noted that even a much lower total bioenergy production can lead to significant environmental pressures — if the EEA assumptions of the choice of energy crops, energy pathways and the EU policy framework are not met.

2.2 The life cycle approach

The life cycle assessment (LCA) approach takes into account both direct and upstream emissions like mining, processing and transport as well as the materials and energy needed for manufacture at all stages. This study focuses on the life cycle of the greenhouse gas and air pollutant emissions from different energy chains. It is an unambiguous way to analyse the environmental performance of different energy systems, so they can be compared with conventional fuels, in the light of the global and EU objectives to reduce greenhouse gas emissions.

Comprehensive data on life cycle emissions from fossil fuels and bioenergy systems in the EU Member States are provided by the Global Emissions Model for Integrated Systems (GEMIS), used in this study. It was first developed in the late

Box 2.1 Environmental assumptions implicit in the assessment of biomass potential

- At least 30 % of agricultural land is retained under environmentally oriented farming.
- Important types of extensive farming, including grassland areas, are maintained.
- By 2030, 3 % of intensively farmed land is set aside as areas for ecological compensation.
- Bioenergy crops with low environmental pressure are favoured.
- Currently protected forest areas are maintained and the area of protected forest is increased by 5 % in each country.
- Forest residue removal is adapted to local site conditions. Foliage and roots are not removed.
- At least 5 % of the deadwood is left in all forests.

Source: EEA, 2006; EEA, 2007b.

1980s, and is continuously updated. The data used from the GEMIS database can be found in Annex 2.

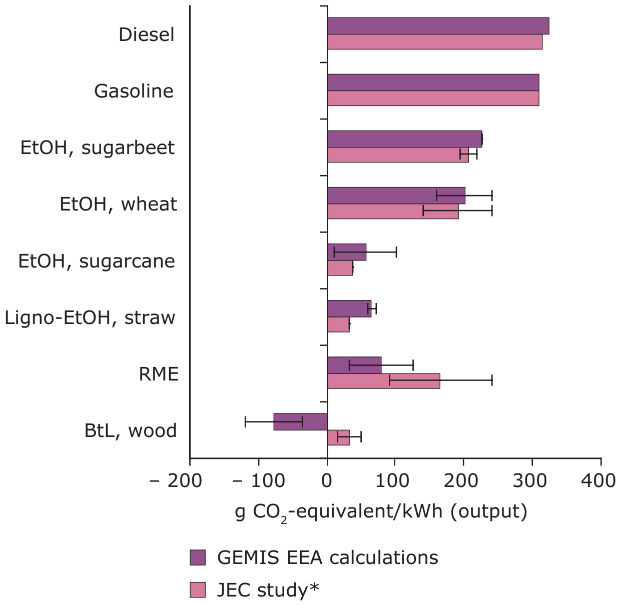
Although LCA methodology is generally quite well-defined, results from different LCA studies may vary significantly, depending on the assumptions used and the methodological choices made. The main differences are mostly due to:

- assumptions regarding important input data describing the biofuel and bioenergy chains;
- treatment of by-products;
- treatment of emissions due to land-use and vegetation change.

Some important factors which can vary between studies, and subsequently create different results, include: the amount of fertilizer use and crop yield, N_2O emission factors during crop cultivation, energy efficiency of the processes and the type of fuel used for the bioenergy/biofuel production process.

In view of these variations in methodology and LCA results, it is useful to see how the GEMIS modelling results used in this report compare with results from other LCA studies.

Figure 2.1 The net life cycle greenhouse gas emissions of fossil fuels and various biofuels



Note: * CONCAWE/JRC/EUCAR, 2007 is referred to as JEC study.

Source: CONCAWE/JRC/EUCAR, 2007.

As regards biofuel, GEMIS data used in this analysis have been compared with the CONCAWE/JRC/EUCAR, (2007) results for similar biofuel chains (see Figure 2.1).

In certain cases GEMIS results match JEC results quite well, except for rapeseed biodiesel (RME) and biomass-to-liquid (BtL) processes. Emission reductions calculated by GEMIS are higher than from JEC — due to by-product substitution applied (i.e. glycerine by-product is substituted as synthetic glycerine) ([4]). It should be noted that none of these models include emissions due to land-use change ([5]).

In general, fewer international LCA studies have been conducted concerning bioenergy — compared to those for biofuels, because biomass utilization as a fuel for heat and/or power is much more of a country-specific issue than that of biofuels. Furthermore, LCAs for bioenergy routes are difficult to compare, since there are many more feedstocks and process configurations possible for bioenergy than for biofuels, each leading to different emission results.

An accurate comparison of the GEMIS results with that of other models would, thus, require a very specific analysis of the configurations used, which has not been possible within the scope of this project. However, in general it is clear from GEMIS and other models that the net GHG emission reduction increases significantly where CHP is applied and credits for the heat are included in the calculations.

More information on the LCA approach (and results) can be found in Annex 3.

([4]) In LCAs of biofuels, relatively modest differences in assumptions may lead to significant differences in outcome.
([5]) If land-use change occurs due to biofuels production, this may cause significant GHG emissions, both from above and below ground, see, e.g. JRC (2008) or Fargione (2008).

3 Applying the Green-X$_{ENVIRONMENT}$ model to bioenergy

3.1 Background and aims

The Green-X model is a simulation tool developed by the Energy Economics Group at Vienna University of Technology, from 2002 to 2004, as part of a joint European project, Green-X. It allows quantitative analysis of interactions between renewable energy sources, conventional energy systems and policies to reduce GHG emissions, both for the EU as a whole as well as for individual Member States.

In this study, the Green-X model is adapted to provide an analysis of the entire European bioenergy market from both an economic and environmental viewpoint, including the energy uses of biomass: biofuels for transport and solid biomass for heat and electricity generation. The new model is called Green-X$_{ENVIRONMENT}$. The detailed coverage of Europe's biomass resources, the corresponding conversion technologies and the derivation of scenarios to identify environmentally beneficial ways of using biomass for energy purposes are the strengths of this new model.

This model is used in this study to obtain a thorough understanding of the potential for bioenergy deployment in the European energy sector and the environmental and economic consequences associated with different strategies. The study had the following objectives:

a) Identify an environmentally optimised bioenergy deployment with a least cost approach ([6]). This means modelling deployment of biomass across the electricity, heat and transport sectors, using only environmentally compatible European biomass resources, the most environmentally favourable technology options and assuming a relatively high carbon price.

b) Assess the greenhouse gas emissions and air pollutant emissions reduced (from a life cycle perspective) by the optimised deployment; evaluate how these changes with different priorities.

c) Analyse the impact of the environmentally optimised bioenergy system on the security of supply (import dependency).

d) Derive the additional generation costs of the environmentally optimised bioenergy system and the costs of imposing different environmental priorities.

The aim of the analysis is to give policy makers an idea of different future options, in terms of the contribution of biomass to each bioenergy sector (electricity, heat and transport), to get the most environmental benefit. Thus, this study neither aims to analyse the current renewable energy policy proposals nor the transport fuel policy proposal. However, it includes an assessment of 10 % biofuel target in the transport sector by 2020 with an imposed constraint of using solely EU's domestic biomass resources. Nevertheless this model run should not be interpreted as a thorough assessment of the Commission's alternative transport policy, nor does it aim to identify the best (environmental, economic, social) ways to reach the proposed target. Such an analysis was beyond the scope of this study.

In each case, the analysis is done for individual EU Member States for the years 2010, 2020, and 2030.

3.2 Methodology

3.2.1 How the model works

The Green-X$_{ENVIRONMENT}$ model uses the modelling concept of dynamic cost-resource curves. These allow static cost-resource curves, technological

([6]) This is an artificial instrument that looks for the cheapest way of achieving a set target, across all energy sectors. It could not be applied in the real world, but it allows showing an economically optimal outcome. The model assumes full competition among market actors, and minimises additional generation costs, relative to conventional options.

change and technology diffusion to be linked (see Figure 3.1).

Biomass is characterised in the model as a limited resource. Cost dynamics should be considered since costs can rise with increasing utilization because the cheaply available fractions of the overall potential will be exploited first. As a consequence, rising generation costs occur. The static cost-resource curve is a proper tool to describe these costs and potentials.

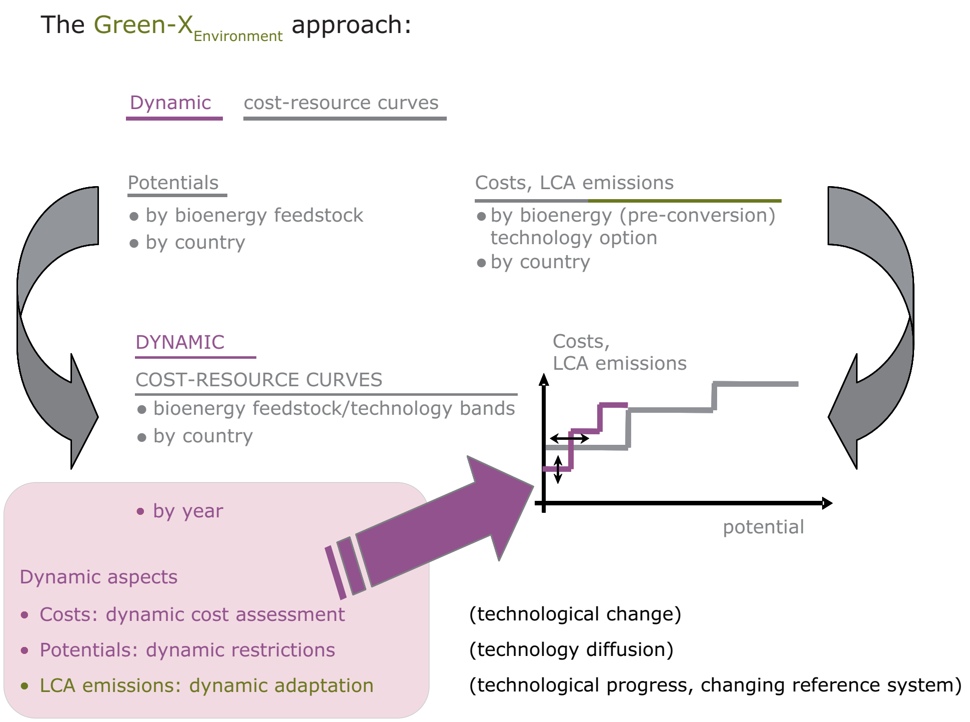
Changes in resource conditions and conversion technologies are represented in the model as aspects of technological change and technology diffusion. Costs and efficiency data are adapted to this model dynamically on technology level. Thus, standard cost forecasts are applied to reflect the expected technological progress with reference to the GEMIS database in case of bioenergy and the PRIMES (7) energy scenarios for the conventional energy systems applied.

The model uses 'S-curve' patterns to describe the impact of market and administrative restrictions, which are the most important non-economic barriers to deployment of a new energy technology.

The Green-X$_{ENVIRONMENT}$ model covers 37 fractions of biomass that can be converted to electricity, heat or transport fuel. They comprise dedicated energy crops on agricultural land (crops used for conventional first generation (8) biofuels, short-rotation coppice, perennial grasses and biogas feedstock), various fractions of biogenic waste (such as municipal solid waste, wood processing residues or straw) and forestry resources. The primary potentials for each feedstock, and the corresponding fuel costs, are based on an in-depth assessment of the biomass resources in all EU Member States (EEA, 2006; EEA, 2007b).

The model dedicates a broad but limited set of conversion technologies and upstream processes to each biomass feedstock. The promising bioenergy

Figure 3.1 Methodology regarding dynamic cost-resource curves by means of dynamic bioenergy feedstock/technology bands (for the model Green-X$_{ENVIRONMENT}$)



Source: Energy Economic Group (EEG), Vienna University of Technology, www.green-x.at.

(7) PRIMES is a market equilibrium model of the European energy market, designed to predict changes in energy demand, supply and technology. It was developed at the National Technical University of Athens, funded by the European Commission.

(8) First generation feedstocks are the conventional crops(such as sugar can, sugar beets, corn, wheat, rapeseed, soybean, palm oil) harvested for their sugar, starch and oil content and they are converted into biofuels using conventional technologies. Second generation feedstocks, on the other hand, comprise cellulosic biomass (such as wood, tall grasses, forestry and crop residues) that require advanced technologies to be converted into biofuels.

pathways in terms of their efficiency and GHG emissions are pre-selected (see Annex 4).

The Green-X$_{ENVIRONMENT}$ model forecasts bioenergy deployment under various scenarios, their corresponding greenhouse gas and air pollutant emissions, and additional generation costs, up to 2030. The emissions comprise the LCA (direct and upstream) emissions of different technologies and pathways, provided from the adapted GEMIS database.

3.2.2 *The feedstock potential and costs*

The total biomass potential, as estimated in EEA (2006), has the components as described below.

(i) *Agricultural biomass from dedicated bioenergy crops*. These can be 'conventional' bioenergy crops such as starch crops (cereals, sugar beets) or oil crops (rapeseed, sunflower) as well as perennial grasses or short rotation forests (SRF) on agricultural land. Agricultural residues (straw, green tops and manure) are assigned to 'biowaste'.

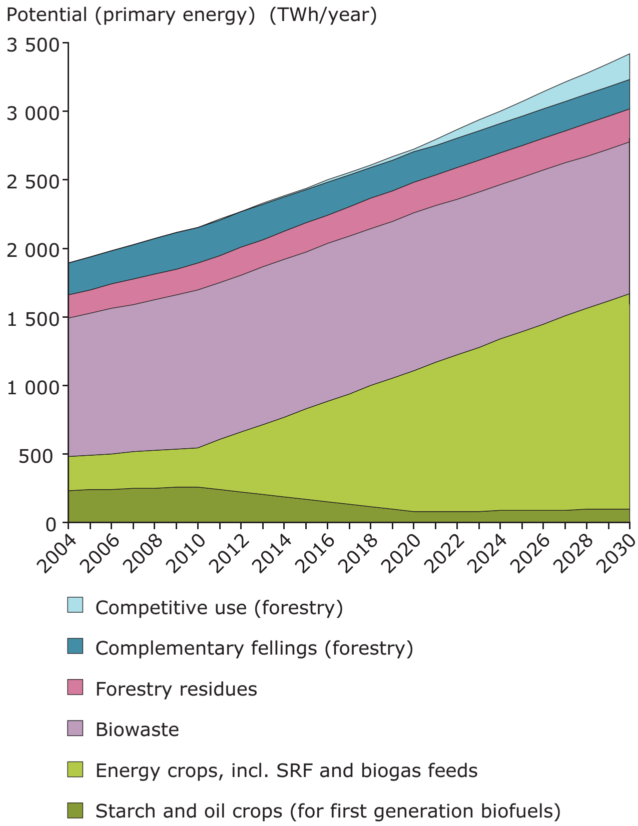
(ii) *Forestry biomass* comprises residues from harvest operations that are normally left in the forest after stem wood removal, such as stem top and stump, branches, foliage, and roots. Additional sources of forestry bioenergy potential are described as complementary fellings. These represent the difference between the maximum sustainable harvest level and the actual harvest needed to satisfy round wood demand.

(iii) *Biowaste/residues* comprise residues, by-products and types of wastes of biological origin arising from agriculture, industry and households. The following specific waste streams were considered:

- (a) solid agricultural residues — cereal and rapeseed straw, stalks from sunflowers and prunings from vineyards and olive trees;
- (b) other agricultural residues — green tops from potatoes and beets;
- (c) wet manure — manure from cows, pigs and laying hens;
- (d) dry manure — manure from fattening hens;
- (e) municipal solid waste (MSW) — the biological component of municipal solid waste (mainly kitchen and garden waste, paper and cardboard);
- (f) black liquor — liquid by-products from pulp and paper production;
- (g) wood-processing waste wood –sawdust and off-cuts from primary wood processing (sawmills) and secondary wood processing (furniture manufacture, for example);
- (h) construction and demolition wood — wood off-cuts from construction and wood recovered during demolition;
- (i) packaging waste wood — from the packaging and palettes industry (palettes, crates, etc.);
- (j) household waste wood — items such as old furniture, fencing;
- (k) sewage sludge;
- (l) food processing wastes — wastes from the dairy and sugar industry and wine and beer production.

Figure 3.2 shows the contribution of the different biomass sources to the total biomass potential, up to 2030. Notice the increasing share of second-generation energy crops (short-rotation coppice, perennial grasses and biogas feedstock).

Figure 3.2 Development of the European (EU-25) environmentally-enhanced bioenergy potentials (in terms of primary energy), by source category



Source: EEA, 2006.

The corresponding feedstock costs were calculated for the same study (EEA, 2006). However, before conversion to bioenergy, a feedstock has to be processed to meet the specifications of the conversion technology, for example, in terms of size or moisture content. To get from biomass to final conversion, a pre-conversion stage is required that includes pre-processing. The pre-conversion costs for various pathways in the EU are shown in Figure 3.3, derived from the GEMIS database.

3.2.3 *Technologies*

Available technologies were screened with respect to their efficiency, life cycle emissions and costs. Bioenergy technologies with high emissions or costs were excluded, so only the most promising technologies were included in the model. This screening was done using data from a comprehensive study on sustainable bioenergy in Germany, which used peer-review and expert workshops to assure data quality (Fritsche *et al.*, 2004). Below is a brief summary of the technologies after the screening. A detailed overview of the selected technologies is given in Annex 4.

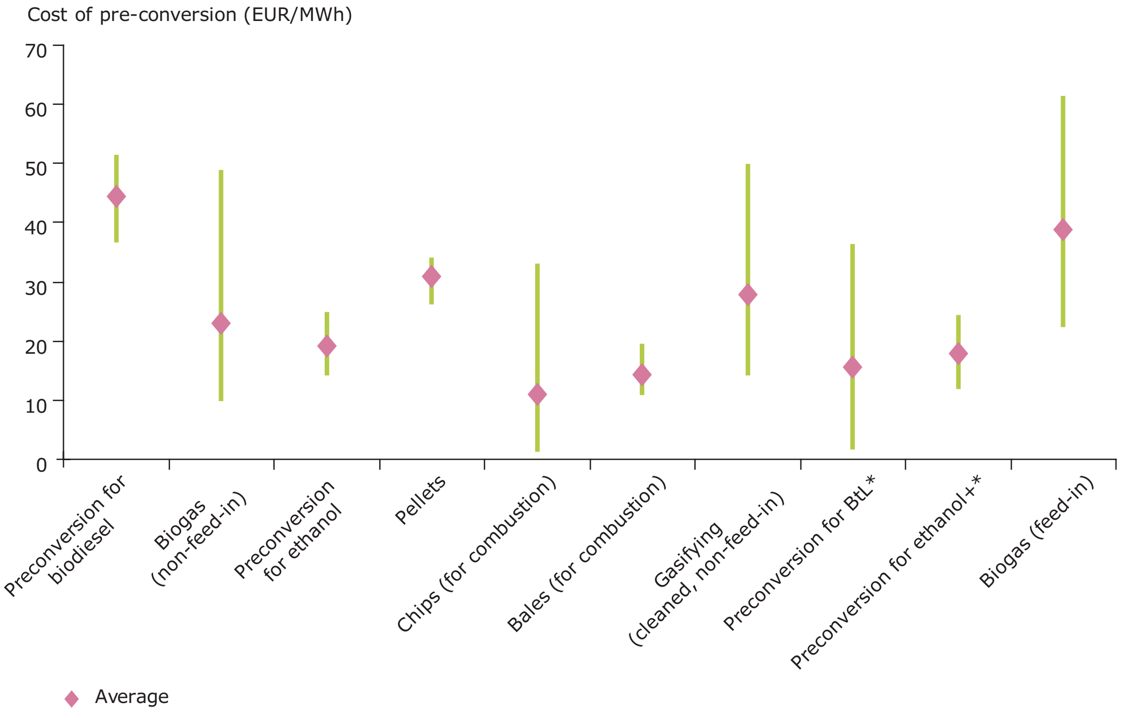
- Electricity
  - Co-firing in non-combined power plants — biomass is added to the conventional fuel (coal) as a percentage of < 5 % straw or 10 % wood. Attention is given to the availability of appropriate filters in these plants.
  - Combined heat and power (CHP) generation — plant sizes from 1 to 20 MWel are characterised, as are those fed with biogas, wood and various waste streams. CHP co-firing also includes gas-CHP fed with a mix of natural gas and biogas after a series of pre-treatment processes.

Both types of electricity generation are based on almost all biomass resources — forestry, energy crops and waste streams.

- Heat, non-grid
  - Pellets
  - Wood chips

Both mainly based on forestry, selected energy crops and wood-based waste streams.

Figure 3.3 Cost ranges of pre-conversion options for bioenergy feedstocks in the EU-25



Note: * BtL and ethanol data are for 2020, the remaining costs are estimated for 2010.

Source: Öko, 2006.

- Heat, grid-connected
  - Heat plants
  - CHP

Both based on various biomass resources — forestry, energy crops and waste streams.

- Transport fuels
  - First generation feedstocks (such as sugarcane, sugar beet, sweet sorghum, oilseeds, and starch crops) are already being converted into liquid fuels using the following conventional technologies:
    - Fermentation. Sugar extracted from sugar crops is easily fermented into ethanol. Starch crops such as wheat and corn are also hydrolysed into sugar, which is then fermented into ethanol. These processes are called ethanol in our model.
    - Transesterification to FAME (fatty acid methyl ester). This process converts oil from oil seed crops into biodiesel.
  - Second generation feedstocks, including the whole body of the crop (crop residues), wood, tall grasses and forestry residues are jointly referred to as cellulosic biomass. Cellulosic biomass is composed of cellulose, hemicellulose and lignin, with smaller amounts of proteins, lipids (fats, waxes and oils) and ash. They are naturally resistant to being broken down, so they require advanced technologies to be converted into fuels. Cellulosic biomass can be converted to fuel either by thermochemical or biochemical conversion:
    - Thermochemical conversion. Biomass can be gasified into syngas (at 600 to 1 100 °C), which can then be converted to biodiesel using the Fischer-Tropsch (F-T) process. This process is called Biomass to Liquids (BtL) and can be applied to woody or grass-derived biomass. Currently there are no commercial plants producing fuels in this way. The first commercial BtL plant is under construction in Freiberg, and is expected to produce 18 million litres biodiesel a year from mid-2008. Cellulosic biomass can also be converted to a liquid fuel called bio-oil or pyrolysis oil, by heating to around 475 °C. However, pyrolysis oils are not currently used for transportation.
    - Bio-chemical conversion. This involves breaking biomass into its component sugar molecules, followed by fermentation to covert sugar into ethanol fuel. There are three demonstration cellulosic ethanol plants in the EU: in Sweden, Spain and Denmark. In our model, this process is called Ethanol+.

3.2.4 *Allocating the feedstocks among the technologies*

In theory, there are manifold ways to combine different biomass feedstocks with bioenergy conversion technologies. Since not all of these combinations are likely to be applied at full scale commercially by 2030, and since the model could not handle every possible combination, we selected a set of process chains to use in the model. As shown in Figure 3.4 each chain starts with a feedstock, which is transformed by a pre-conversion path, then enters the final conversion technology.

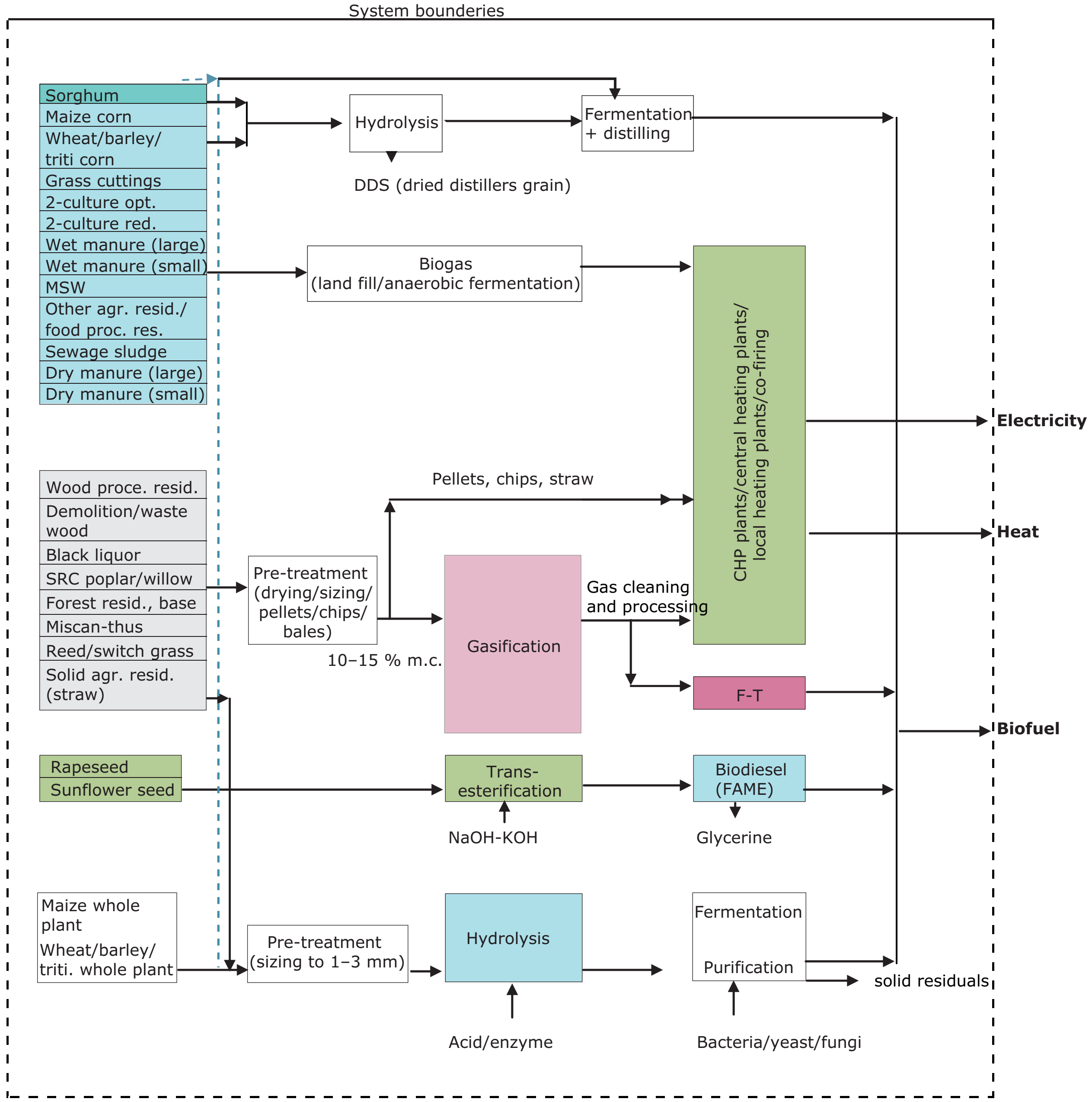
These pathways are listed in Annex 5. Some potential pathways were excluded because the literature and expert knowledge suggests they will not be commercially viable in our timeframe to 2030.

For example, using pellets made from forest residues and complementary fellings in residential heating systems are excluded because pellets can be made easily from numerous materials with small particles, such as sawdust. It would be financially very costly and energetically not efficient to make pellets from wood chips or stems. By contrast, chipped wood is considered a viable option for use in medium- to large-scale decentralized heating systems.

Among the bioenergy pathways for transport biofuels, conversion of lignocellulosic biomass to ethanol, referred to here as ethanol+, does not use wood or perennial grasses in the model. According to Fritsche *et al.* (2004), the pre-treatment of wood and the amount of enzymes needed to convert woody biomass to ethanol will incur prohibitive costs, even in 2020. As for perennial grasses, costs and potential yields for converting them to ethanol are unknown, and the process would leave residues that must themselves be burned or gasified. While there is potential for hybrid schemes, combining ethanol production with BtL routes or possibly electricity generation and raw material production, this 'bio-refinery' concept is at a very early research stage and it is unlikely that it reaches fruition in the time frame applied (10 to 20 years).

Amongst BtL processes for producing biofuels, the use of black liquor as a feedstock is excluded, although this would in principle represent one of the cheapest options. According to industry experts, this is unlikely to be available for transport

Figure 3.4 The bioenergy process chains



biofuels production, as it is already used for electricity generation within the pulp and paper industry.

The suitability of the different technologies for each country depends on the amount of primary biomass that is potentially available. For example, a small country like Cyprus has limited potential for large-scale biomass power plants or large-scale BtL plants, so these would not appear as a suitable option.

3.2.5 Assumptions of the model

This study uses the Green-X$_{ENVIRONMENT}$ model to illustrate how the future bioenergy deployment might look like, if it delivers the best possible outcome for meeting the general objectives in a least cost manner including:

(i) reducing greenhouse gas emissions;
(ii) reducing air pollutant emissions;
(iii) increasing fossil fuel substitution.

Strong policies and environmental standards will be required at a European, national, regional and sectoral level, to ensure the market is focussed on achieving these outcomes. However, the model does not assume a specific policy framework. The purpose of this report was to look at the potential of bioenergy to deliver these objectives in Europe, if the domestic biomass resources are fully exploited in an environmentally beneficial manner.

The only specific policy applied in the modelling is the use of quotas for biofuels (10 % by 2020), in the case of biofuel prioritisation (Chapter 6). In addition to that, in one case biomass exploitation is derived from the model run carried out for DG Environment to assess the effects of the 20 % renewable energy target set for the year 2020 (Ragwitz *et al.*, 2006).

Some conditions of the model are listed below:

(i) time horizon: 2004 to 2030. Results are derived on a yearly basis;

(ii) geographical coverage: European Union as of 2006 including 25 Member States (referred to as the EU-25 ([9]));

(iii) reference energy system: the model uses scenarios for how the overall EU energy system will develop, in terms of fuel and carbon prices, taken from the PRIMES model of the European energy market. In particular the Low Carbon Energy Pathway (EEA, 2005a, 2005b) and the 'alternative' scenarios are used (EC, 2006). Some details of these scenarios are given in Section 3.2.6;

(iv) use of domestic resources: the model assumes that converting domestic biomass to other energy carriers is the best use of the resource.

3.2.6 Scenario parameters and priority cases

The bioenergy scenarios are based on the projected development of the overall EU energy system. The key reference scenario is the low carbon energy pathway (LCEP) scenario, which is characterised by moderate fossil fuel prices but a high carbon permit price up to EUR 65/tonne by 2030 (EEA , 2005b). This scenario was chosen due to the fact that it describes an energy system with significant GHG emission reduction.

For a sensitivity analysis, the alternative scenario is used (EC, 2006), which is characterised by relatively high fossil fuel prices and a moderate carbon permit price (EUR 20/tonne).

Details of these two scenarios, including energy prices, energy demand, efficiency figures and generation structure can be found in Annex 6.

The cross-sectoral least-cost approach is applied to all the model runs within the environmental system boundaries of each model run. The model assumes full competition among market actors, and minimises additional generation costs, relative to conventional options.

Competition for biomass occurs on three levels:

- among biomass feedstocks (depending on their cost);
- among technological pathways for the use of each feedstock;
- among energy sectors — heat, transport and electricity.

Table 4.1 gives a short description of the cases investigated in this report. Cases 1 to 4 impose environmental priorities. For example, in Case 1, the deployment of CHP is encouraged by assuming the market for heat produced by CHP plants functions perfectly, and all heat produced can actually be sold. This assumes the removal of major barriers that currently limit the economic attractiveness of CHP. Case 5, on the other hand, gives priority to a key EU policy objective. In this case priority is given to the achievement of a 10 % target proposed for renewable energies in the transport sector by 2020 — using solely EU's domestic biomass resources ([10]).

More details on how the model works and how the priorities were applied can be found in Annex 7.

3.2.7 Assessing the environmental and economic impacts of the model runs

Environmental impacts

To assess the specific environmental benefits of the bioenergy scenarios simulated by this model, they had to be compared with the 'conventional' energy scenario (for the reference scenario, for instances, it should be compared with the PRIMES LCEP).

([9]) The model covers EU-25 Member States, but does not include Bulgaria and Romania.
([10]) Following the Commission's proposal for a 10 % RE target in transport by 2020, imported biofuels are expected to make a significant contribution. Consequently, as preconditions differ substantially, this investigation shall not be misinterpreted as a thorough impact assessment of the 10 % target.

Table 3.1 Overview of the investigated cases

General assumption for all cases		• Biomass potential fully exploited • Least-cost approach • Energy economy as described by PRIMES LCEP (EEA, 2005a, 2005b), except Case 6 (alternative reference scenario) which uses the PRIMES baseline scenario, for comparison • Full competition among technology pathways, feedstocks and energy sectors		
Case	**Name**	**Optimisation based on**	**Prioritisation**	**Assumptions**
Reference scenario		Primary energy	None	No weighting amongst sectors
Case1	Optimised CHP case	Primary energy	Optimised CHP	Heat produced in CHP plants is assumed to be sold completely
Case 2	Avoided GHG	Avoided GHG emissions	Decreased greenhouse gas emissions (CO_2-equivalent)	Emissions of greenhouse gases are decreased
Case 3	Air pollutant emissions decrease	Avoided air pollutant emissions	Decreased PM-equivalent	Emissions of SO_2, NO_x and particulates were converted to particulate matter equivalent (PM-equivalent), using factors of 0.7 for SO_2 and 0.88 for NO_x (based on de Leeuw, 2002)
Case 4	Renewables	20 % RE by 2020	Accelerating the bioenergy deployment to allow a meeting of the overall renewable target (in line with Ragwitz, 2006)	The target of 20 % renewable energy by 2020 takes priority
Case 5	Biofuels	Primary energy	Transport sector, no trade of bio energy from outside the EU	• The target of 10 % for RE in the transport sector by 2020 takes priority • EU domestic biomass feedstock use
Alternative reference scenario		Primary energy	None	This scenario uses the PRIMES baseline scenario, so assumes a high price for fossil fuel and a much lower carbon permit price

'Environmental benefits' in this study relate to the impact of different feedstock types and bioenergy pathways on total emissions of greenhouse gases and air emissions.

For greenhouse gas emissions, avoided emissions were calculated, based on the fossil fuel substituted in the bioenergy model. The net avoidance is the total life cycle emissions of fossil fuel produced and used, minus the life cycle emissions from producing the bioenergy. Emissions from electricity generation are calculated including the generation of electricity, but do not include transfer of the electricity, or its domestic and commercial use. Calculation of the emissions from transport fuel includes the production of the fuel, but it does not include the steps that take place after conversion of feedstock to biofuels (e.g. use of the fuel in road transport).

For air pollutants, emissions were compared with emissions from a conventional energy system model (described in detail in EEA, 2005b), in which coal power generation switches significantly to gas in the years leading up to 2030. Calculations of air pollutant emissions are also taken from the GEMIS database, derived in exactly the same way and with the same scope as the life cycle assessments for greenhouse gas emissions.

Economic impacts

Economic impacts are assessed by means of deriving the (additional) generation costs imposed by the enhanced bioenergy deployment. As no explicit policy analysis is conducted, policy cost — i.e. the consumer expenditures arising from financial support offered to stimulate bioenergy deployment — are not assessed within this study.

The generation costs are calculated based on the cost data provided in Annex 4 (feedstock cost, investment cost, operation and maintenance costs, technology specific life time (15–25 years), etc.). Thereby, all cost and performance data for the selected conversion technology options are taken from the GEMIS database. The calculation of generation cost is based on a (real) interest rate of 6.5 %, and all cost data are expressed in real terms using EUR_{2005}.

The conventional energy system price figures are presented in Annex 6. The additional generation cost is calculated as the difference between the total generation cost of bioenergy systems and conventional energy systems provided from the reference and alternative reference scenarios.

4 Model results

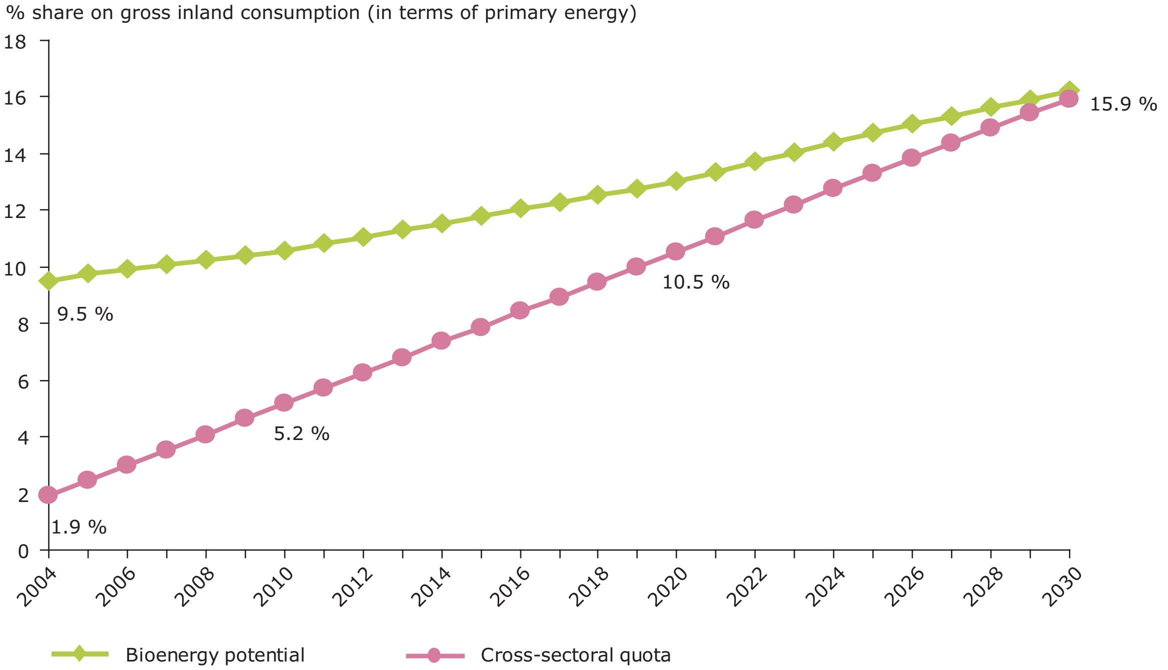
This chapter presents the main results obtained from modelling the reference scenario. This is followed by the alternative reference scenario (as sensitivity case) and the scenario cases where prioritisation of different options are applied: priority for CHP, reducing greenhouse gas emissions, reducing air pollution or meeting Europe's proposed renewable energy target. In the last model run the case of prioritising biofuels (in order to meet the 10 % target by 2020) is considered. This case is analysed separately, because the environmental implications of the 10 % biofuel target are the subject of considerable debates at present, and require extra attention. However, as mentioned earlier, not all relevant aspects of biofuel enhancement have been analysed in this study.

4.1 The reference scenario

4.1.1 Bioenergy deployment

In this scenario, primary bioenergy deployment increases linearly with time and reaches a value of 10.5 % of total primary energy consumption (7.7 % of final energy consumption) in 2020; and finally — 15.9 % (13 % of final energy consumption) by 2030 (see Figure 4.1). This corresponds to 2 202 TWh in the year 2020 and 3 355 TWh in the year 2030. As stated in Section 1, the share of bioenergy in the total energy consumption within EU-25 in the year 2005 was around 4.5 % (EEA, 2007a), whereas this modelling work calculates the environmentally compatible bioenergy deployment as approximately 2.5 % by the year 2005 (see Figure 4.1) ([11]).

Figure 4.1 Evolution of bioenergy deployment and bioenergy potential in EU-25 — energy expressed as share of gross primary energy consumption



Source: EEA, based on Green-X$_{environment}$ modeling.

([11]) The comparatively large difference to current bioenergy use is caused by the widespread use of bioenergy for heating purposes, where old small-scale stoves mostly do not meet stringent criteria with regard to air pollutant emissions as used for the technology pre-selection in this study.

Figure 4.2 shows what proportion of the total energy demand in each sector is supplied, according to the reference case, by biomass. By 2030, bioenergy compromises 18.1 % of the overall demand for heat, and a 12.5 % share of the gross electricity demand.

By 2030, only a moderate share — 5.4 % — of the total transport energy demand is met with biofuels. This corresponds to about 7 % of the demand for road transport fuels (diesel and gasoline). Second generation biofuels become an option with a large share from 2010 onward. In this scenario, the share of second generation biofuels is about 30 % by 2015 and reaches more than 65 % by 2030.

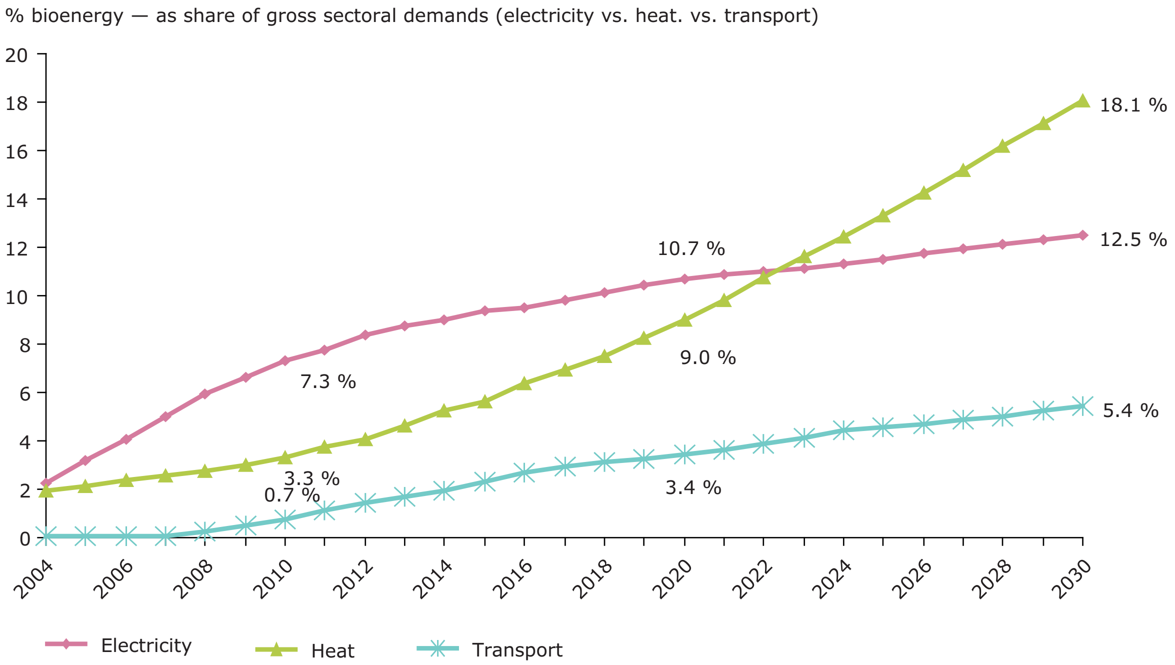
The results show that bioenergy can make a major contribution towards achieving current European renewable energy targets. The projection is that 7.3 % of electricity can be generated from biomass by 2010 ([12]) — just over one third of the 21 % renewable electricity target set for the EU-27. By 2020, around 8 % of the EU's overall final energy demand can be met with biomass — nearly half the 2020 target of 20 %.

All these results represent averages across the European Union. The details vary significantly between Member States. For example, the largest heat deployment rates (> 40 %) are reached in Lithuania, Estonia, Latvia, Sweden and Slovenia, while Poland and Lithuania generate the largest electricity deployments from bioenergy in 2030. The model shows that in Lithuania, Latvia and Estonia by 2030 more than 20 % of transport energy will be coming from biofuels. However, those high shares correspond to substantial amounts of second generation biofuels. Model results for individual Member States are presented in Annex 8.

Figure 4.3 illustrates, by sub-sector, the yearly development of electricity, heat and biofuel generation from bioenergy. Further details on the technology-specific deployment are given in Figure 4.4, which offers a breakdown of the produced electricity, heat and biofuels into technology clusters for certain years (2010, 2020 and 2030).

In this scenario, bioenergy is clearly used primarily for heat and electricity. By 2030, the bioenergy allocated to district and decentralised heating systems and CHP is 1 660 TWh (fuel input), which is approximately 49 % of the total bioenergy used. This demonstrates the economic attractiveness of biomass

Figure 4.2 Bioenergy deployment as a share of gross sectoral demands (electricity, heat and transport)



Source: EEA, based on Green-X$_{environment}$ modeling.

([12]) This value is presented for the EU-25.

for heating purposes. CHP plants offer significant benefits, through increased efficiency of power generation, fuel flexibility (many plants are designed to burn more than one fuel), reduced greenhouse gas emissions per unit of energy output and reduced transmission costs. However there are limitations on the development of this sector. In addition, district heating systems are expensive to install and have a long lifetime, once they are in place. In some countries there are barriers to the deployment of district heating systems with CHP plants. These include a lack of infrastructure to provide fuel, lack of access to national grids to sell surplus electricity, absence of a secure heat demand, and difficulties related to legislation and taxation.

The other prevailing cheap option for bioenergy is electricity generation, where 1239 TWh primary bioenergy is used by the year 2030. Electricity generation is the dominant option in the period up to 2020, but with a decreasing availability of economically attractive technology options, such as co-firing or large-scale CHP plants, the deployment has been saturating in the final years. According to the reference scenario, by 2030, around 60 % of the electricity produced from bioenergy will be generated in CHP plants, whilst pure electricity plants will generate 37 %. The remaining gap of 3 % refers to the by-product electricity arising from second generation biofuel production. By 2010, the biomass electricity produced from CHP will contribute only 4 % of the total electricity demand.

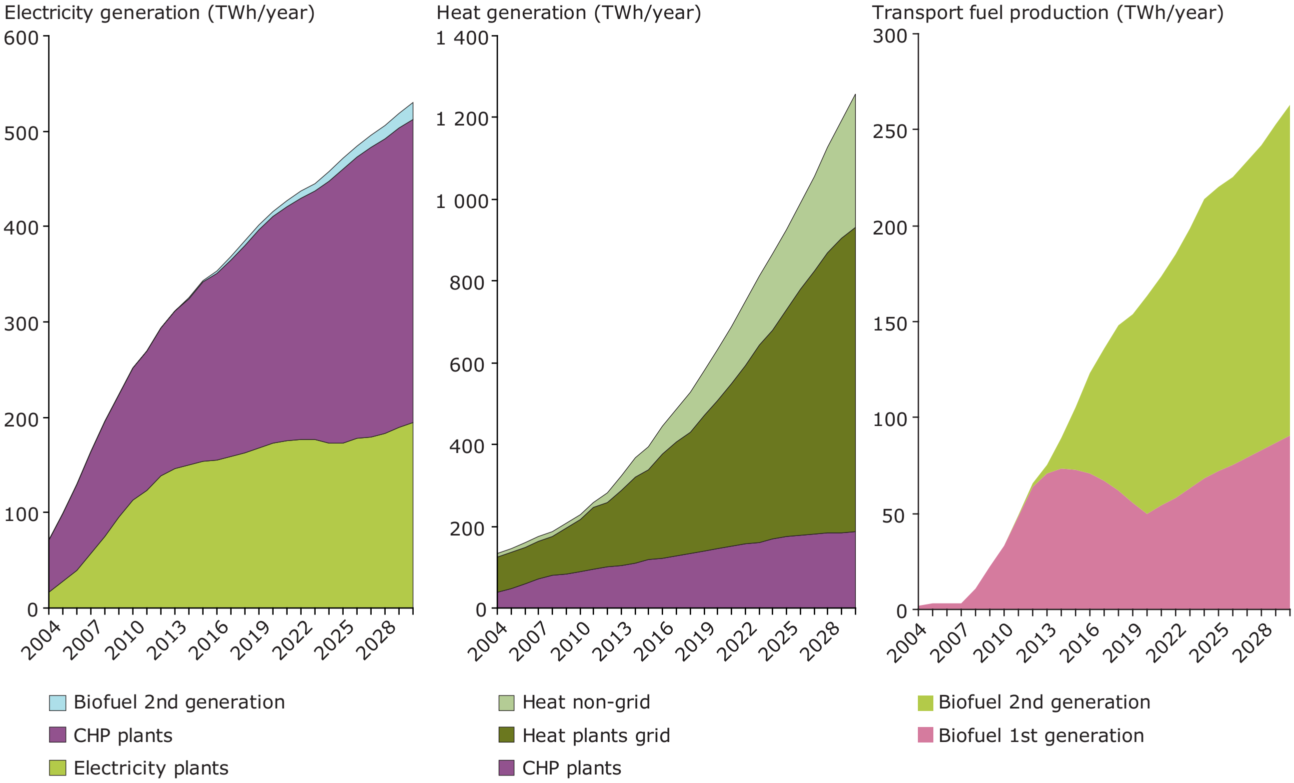
Around 14 % of the bioenergy is used in transport sector which contributes, by 2030, around 456 TWh in terms of primary bioenergy.

4.1.2 *Climate change mitigation potential*

The reference scenario indicates that up to 394 million tonnes of CO_2-equivalent emissions could be saved per year by 2020, and 617 million tonnes per year — by 2030 (the EU-25), as a result of the full exploitation of the assessed bioenergy potential (see Figure 4.5). These figures refer to net balances where arising bioenergy life cycle emissions are taken into account similarly to the substituted conventional ones.

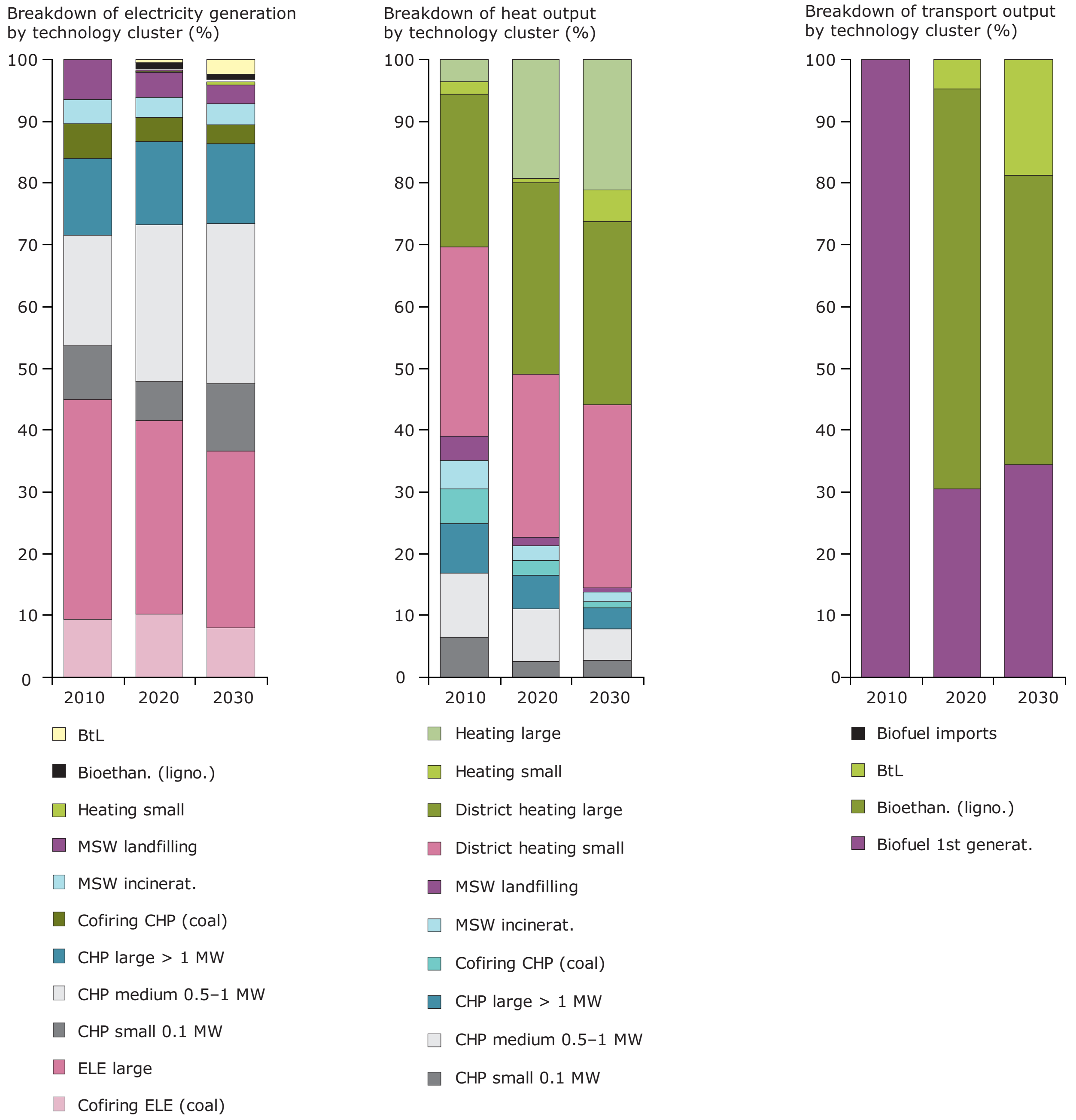
To put this in perspective, according to the recent EC greenhouse gas inventory (EEA, 2008); the EU-27 total greenhouse gas emission in 1990 was around 5 572 million tonnes CO_2-equivalent. Total GHG emissions, without LULUCF, in the EU-27 decreased by 7.7 % between 1990 and 2006

Figure 4.3 Yearly development of electricity, heat and biofuel generation by sub-sector



Source: EEA, based on Green-$X_{environment}$ modeling.

Figure 4.4 Breakdown of electricity, heat and biofuel generation by technology cluster for 2010, 2020 and 2030

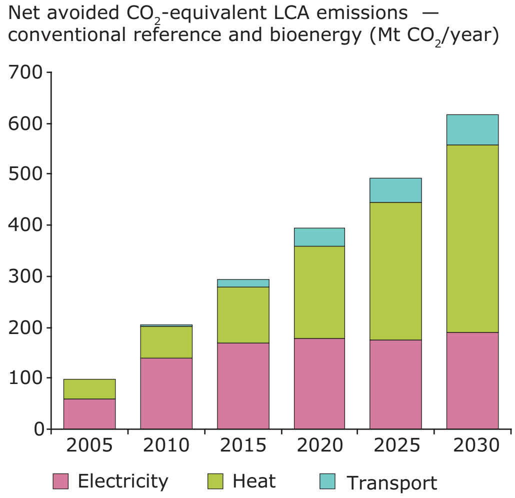


Source: EEA, based on Green-X$_{environment}$ modeling.

(429 million tonnes CO_2-equivalent). In 2007, however, EU made a firm commitment to achieve at least a 20 % reduction of greenhouse gas emissions by 2020 compared to 1990. Thus, reaching the 20 % greenhouse gas reduction target by 2020, compared to 1990, means reducing around 1 114 million tonnes CO_2-equivalent. per year. Even though the Kyoto Protocol and the unilateral 2020 target applies to direct emissions (thus, the life cycle GHG emissions cannot be compared to this target), one can conceive that bioenergy deployment can play an important role in decreasing GHG emissions and reaching the target.

Electricity and heat together contribute 91 % of total net avoided greenhouse gas emissions while the rest (9 %) is from transport (mostly due to second generation biofuels). The highest net avoided emissions are projected in the heat sector, reaching almost 368 million tonnes CO_2-equivalent.

Figure 4.5 Net avoided emissions of CO_2-equivalent due to the enhanced bioenergy deployment



Source: EEA, based on Green-$X_{environment}$ modeling.

per year, approximately 60 % of the total by 2030. In comparison to the high CO_2 intensity of the conventional energy systems, the types of biomass allocated for heat and electricity production (such as biomass residues and waste chains) cause comparatively low life cycle emissions. In contrast to this, first generation transport biofuels demand dedicated biomass crops with higher life cycle emissions from the conversion chain.

Table 4.1 shows the net avoided greenhouse gas emissions per unit of primary fuel for each sub-sector. Clearly, biomass heating systems are the most attractive option for reducing greenhouse gas emissions, followed by electricity generation. However, in the early years up to 2010, power generation achieves the highest greenhouse gas reduction. This shows the effectiveness of co-firing in power generation as an option to reduce greenhouse gas emissions.

This assessment is based on an energy system (LCEP) where the introduction of carbon permit prices changes the energy mix in favour of low carbon fuels. Thus, the use of conventional solid fuel in the LCEP scenario is 80 % lower, and the use of oil is 10 % lower than the 1990 levels. In a 'business as usual' scenario, on the other hand, the bioenergy deployment may become more important. The oil market may remain tight — due to the gap between the oil supply and demand in the coming years, as stated in the World Energy Outlook (IEA, 2006a). This might give incentives to coal-to-liquid (CtL) technologies or use of unconventional oils (i.e. tar sand).

4.1.3 Air pollutant emissions

The modelling assessment shows that after 2010–2015, there may be an increase in air pollutant emissions relative to conventional energy systems, as a result of the increased bioenergy use.

Emissions of SO_2, NO_X and particulate matter from bioenergy production are presented in Figure 4.6, Figure 4.7 and Figure 4.8, respectively.

By 2030, enhanced bioenergy deployment causes annual emissions of almost 363 kilotonnes of SO_2. The heat sector is the most important source of SO_2 (76 %), followed by electricity (20 %). Biofuels in the transport sector account for only 3 %, or approximately 12 kilotonnes of SO_2 per year in 2030. However, it is important to note that the emissions from car use are not included in these calculations.

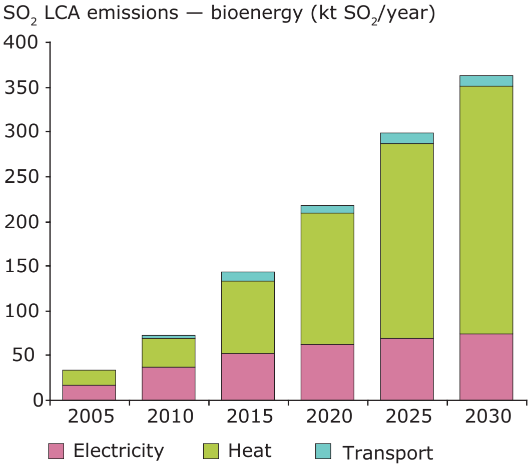
NO_X emissions from bioenergy show that across the three sectors, the highest share comes from

Table 4.1 Net avoided life cycle CO_2-equivalent emissions from different energy subsectors, per unit of energy

Net avoided greenhouse gas emissions							
	Unit	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Pure power generation	kg CO_2-equivalent/$MWh_{primary}$	264	274	246	214	195	187
CHP — electricity and heat	kg CO_2-equivalent/$MWh_{primary}$	166	150	138	130	119	119
District heat	kg CO_2-equivalent/$MWh_{primary}$	258	265	261	263	265	266
Decentralised heat	kg CO_2-equivalent/$MWh_{primary}$	265	263	265	265	263	261
Transport	kg CO_2-equivalent/$MWh_{primary}$	68	57	84	122	128	138
TOTAL (average overall)	kg CO_2-equivalent/$MWh_{primary}$	201	194	180	179	177	184

Source: EEA, based on Green-$X_{environment}$ modeling.

Figure 4.6 SO_2 emissions from different bioenergy sectors



Source: EEA, based on Green-$X_{environment}$ modeling.

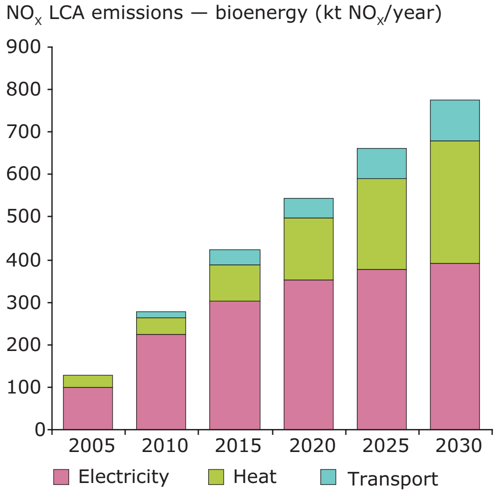
the electricity sector, which is responsible for approximately 50 % of the total 774 kilotonnes per year of NO_X emissions by 2030. Bioenergy in the heat sector accounts for 290 kilotonnes of NO_X per year by 2030 — about 37 % of the total.

Biofuels in the transport sector contribute 12 %, or 94 kilotonnes, of NO_X emissions per year by 2030. This is higher than their contribution to emissions of other air pollutants. One main cause of high NO_X emissions from the biofuels sector is the deployment of dedicated biomass crops, which are grown using fertilisers and create NO_X emissions during growing and harvesting. However, a switch from conventional transport fuels to biofuels in the EU is roughly neutral in terms of direct air pollutant emissions from car use. Moreover, these emissions are comparatively small — due to the stringent controls imposed by EU on vehicle standards, whereby in countries with currently lower standards, the switch will tend to have beneficial effects.

The electricity sector makes the highest contribution to emissions of particulate matter (PM) from bioenergy, with about 18 kilotonnes per year in 2030. A smaller amount, approximately eight kilotonnes comes from the heat sector. Even lower particulate emissions — of about two kilotonnes in 2030 — come from the production of biofuels in the transport sector.

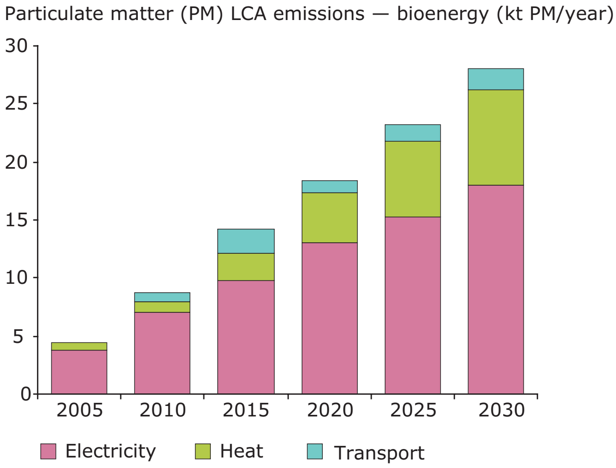
To ensure that the technologies applied in this modelling work are not violating the relevant air pollutant emission legislations, the direct emissions from the different technologies are compared

Figure 4.7 NO_x emissions from different bioenergy sectors



Source: EEA, based on Green-$X_{environment}$ modeling.

Figure 4.8 Particulate matter (PM) emissions from different bioenergy sectors



Source: EEA, based on Green-$X_{environment}$ modeling.

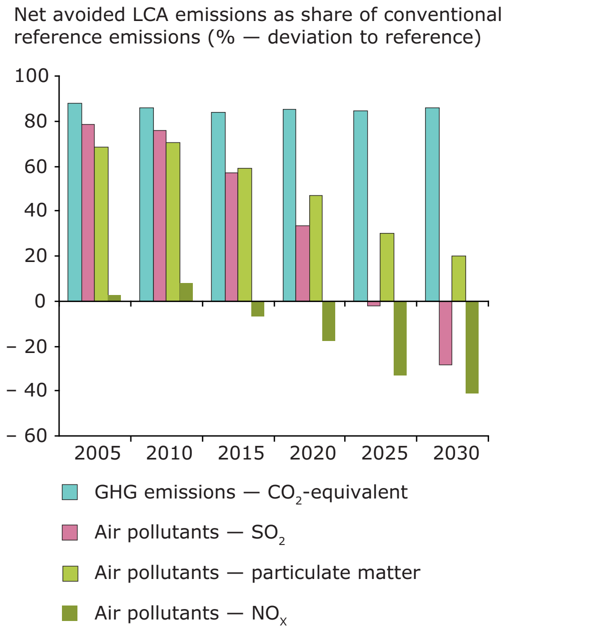
against limits set in the legislations. In the case of smaller plants, where national rather than Europe-wide legislation often applies, the strictest limit in national legislation or voluntary codes are used as a benchmark. The legislation used to check the emissions for each fuel type and pollutant is shown in Annex 9. Several emissions standards were used in each category to reflect the range of sizes of plant modelled. In all cases, modelled emissions are below the limits set by legislation.

In addition, a reality check was performed to see how the predicted emissions from this study compare to national emissions reported by Member

States and their respective future national emission ceilings. National ceilings for 2010 (for SO_2 and NO_X only) from the National Emission Ceilings Directive (EC, 2001) and indicative 2020 ceilings (for SO_2 and NO_X only) designed to match the environmental interim targets of the European Commission's Thematic Strategy on Air Pollution (IIASA, 2007) were used in this reality check ([13]).

In all instances, emissions estimated in this study are below present levels of reported emissions and future emission ceilings. There are only a few instances where the reference scenario emissions make a relatively high contribution to reported emissions. For example, reference scenario emissions of SO_X for Latvia are 33 % of the reported (2005) emissions for Latvia for the relevant sectors. A number of Member States have modelling emissions in 2010 in the order of 10 to 20 % of the indicative 2020 emission ceilings. In particular, for Lithuania, Green-X estimated emissions are larger than 50 % of the indicative ceilings for SO_X and NO_X in 2020. This reality check, however, is based on a comparison of life cycle air pollutant emissions from this modelling work with annual emission ceilings. Thus, the annual contribution of air pollutant emissions from relevant sectors (in this model run) is anticipated to be lower in percentage terms (compared to the national ceilings) than these illustrative values.

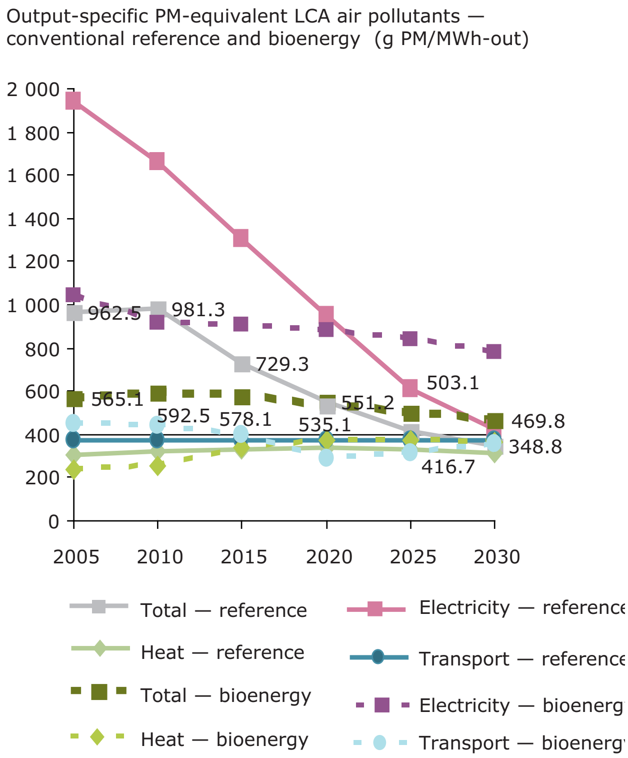
Figure 4.9 Net avoided emissions as share of emissions from a conventional energy system



Note: Positive values show a net improvement, or emissions reduction. Negative values show an increase in emissions relative to conventional energy.

Source: EEA, based on Green-$X_{environment}$ modeling.

Figure 4.10 Air pollutant emissions from different sectors of bioenergy and the conventional energy system, per unit of energy



Source: EEA, based on Green-$X_{environment}$ modeling.

The net effects of bioenergy deployment on pollutant emissions relative to the LCEP energy mix are presented in Figure 4.9. In this figure, a positive value means a net improvement, or reduction in emissions, whilst a negative value means an increase of emissions. The figure includes net life cycle greenhouse gas emissions, for comparison.

After 2015, air pollution from bioenergy appears to be worse than the conventional energy. This is mainly because the LCEP scenario already shows very large reductions of air pollutants, particularly

([13]) Reported emissions from Member States and the national emission ceilings of the NEC Directive represent total annual emissions of air pollutants from anthropogenic activities. In contrast, the emission values available from this work comprise life cycle air pollutant emissions. A comparison of the two can, therefore, be performed as an illustrative exercise only.

Table 4.2 Avoided fossil fuels at European level (EU-25) — breakdown by sector in energetic (above) and monetary terms (below)

Supply security — avoided fossil fuels	Avoided fossil fuels in energetic terms — by sector						
	Unit	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Electricity	TWh/a	264	628	799	890	960	1 073
Heat (grid-connected)	TWh/a	137	213	346	538	782	1 016
Decentralised heat	TWh/a	10	13	58	125	195	325
Transport	TWh/a	3	35	111	172	232	277
Total	TWh/a	415	889	1 315	1 725	2 168	2 691
Supply security — avoided fossil fuels	**Avoided fossil fuels in monetary terms — by sector**						
	Unit	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Electricity	MEUR/a	2 313	6 044	8 718	11 055	13 605	15 959
Heat (grid-connected)	MEUR/a	1 632	2 761	5 067	8 727	13 782	19 086
Decentralised heat	MEUR/a	128	176	876	2 008	3 383	5 908
Transport	MEUR/a	43	520	1 815	3 073	4 486	5 771
Total	MEUR/a	4 116	9 501	16 476	24 863	35 256	46 724

Note: In the reference scenario the fossil fuel prices applied for 2020 are: EUR 5.2/MWh for hard coal and lignite, EUR 17.9/MWh for oil and EUR 15.3/MWh for gas. According to the recent data (import prices at the German wholesale energy market as observed in December 2007), hard coal and lignite prices are EUR 10/MWh, oil EUR 40/MWh and gas EUR 21/MWh.

Source: EEA, based on Green-$X_{environment}$ modeling.

NO_x and SO_2 in the conventional energy system. In the final years leading up to 2030, the conventional energy system applied (taken from EEA, 2005b) assumes a switch from coal to gas in the power sector.

In case of particulate matter, a net saving in air pollutant emissions occurs over the whole period with enhanced bioenergy deployment. But by 2030, particulate emissions are only about 20 % less than those from the conventional energy economy. This is because the particulate emissions from electricity production using biomass are comparatively high.

Figure 4.10 compares the projected air pollutant emissions from bioenergy and the conventional reference system in specific terms, per unit of energy generated. It includes all three specific pollutants considered (SO_2, NO_x and particulates) converted to PM-equivalent. Bioenergy air pollutant emissions remain stable over time, with a slight decrease over the full time period. In contrast, emissions from the conventional energy system are projected to decrease significantly over time, a drop that is entirely due to changes in the electricity sector. Overall, there is no net avoidance of air pollutant emissions due to the enhanced bioenergy deployment, in the final years up to 2030.

Such figures would differ in a 'business as usual' scenario where the energy mix does not follow a low carbon energy pathway. The results, thus, would show a sharp decline in bioenergy air pollutant emissions for an enhanced bioenergy deployment, as the bioenergy deployment would substitute hard coal instead of the natural gas, as is the case in the LCEP scenario.

4.1.4 *Security of energy supply*

In the reference scenario, enhanced bioenergy deployment significantly reduces the demand for fossil fuel and substantially improves the security of energy supply in Europe ([14]).

The modelling analysis shows that by 2030, around 2 691 TWh of fossil fuels can be saved, an amount of fuel worth almost EUR 47 billion a year at the predicted 2030 prices. Table 4.2 shows the fossil fuel

([14]) In general, a reduction of EU's domestic demand for fossil fuels may lead to either a decline of primary fuel imports or a rise of exports of refined products (diesel, gasoline). In both cases, a positive impact on supply security and Europe's trade balance is apparent.

Table 4.3 Substituted fossil fuels at European level (EU-25) — fuel-specific breakdown in energetic (above) and monetary terms (below)

	Avoided fossil fuels in energetic terms — by fuel						
Unit TWh/a	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	
Hard coal	91	200	236	191	141	156	
Lignite	37	85	73	69	54	53	
Oil	74	147	278	446	646	844	
Gas	213	457	728	1 019	1 327	1 639	
Total	415	889	1 315	1 725	2 168	2 691	
	Avoided fossil fuels in monetary terms — by fuel						
Unit MEUR/a	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2030***
Hard coal	495	1 069	1 246	997	737	815	1 508
Lignite	199	454	385	357	279	274	507
Oil	1 045	2 190	4 549	7 960	12 509	17 579	33 459
Gas	2 376	5 787	10 295	15 549	21 732	28 057	34 808
Total	4 116	9 501	16 476	24 863	35 256	46 724	70 282

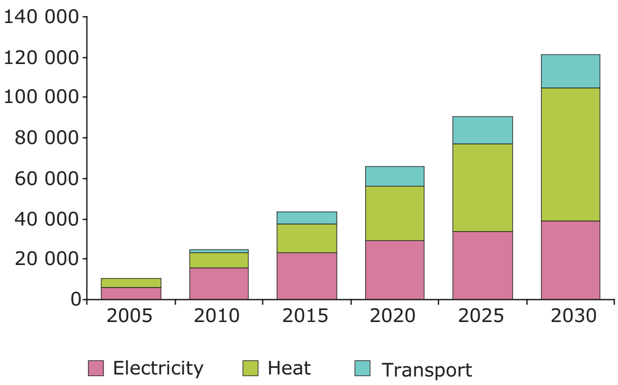
Note: * with prices as of December 2007.

Source: EEA, based on Green-X$_{environment}$ modeling.

savings in each energy sector, in terms of energy and money diverted. In this scenario, heat and electricity generation account for 88 % of the expenditure saved on fossil fuels.

Table 4.3 shows the types of fossil fuel saved. Gas accounts for more than half (about 60 %) of the fossil fuel substituted. Oil accounts for 31 % of the fossil fuel energy substituted, but in monetary terms it contributes to a significant amount; 37 % of the money not spent on oil. When the cost figures are calculated based on the today's price levels (December 2007), oil substitution is much more favourable from an economic view point.

Figure 4.11 Total generation costs for bioenergy



Source: EEA, based on Green-X$_{environment}$ modeling.

4.1.5 Cost of enhanced bioenergy deployment

Bioenergy costs are an important aspect to consider when assessing possible enhanced bioenergy deployment. This section presents bioenergy generation costs and compares them with conventional energy systems.

Figure 4.11 shows the total generation cost for European bioenergy, split across the sectors of electricity, heat and transport. The heat sector comprises the highest cost, amounting to almost EUR 66 billion a year in 2030, followed by the electricity sector, which costs about EUR 39 billion a year at the same time. Generation of biofuels costs around EUR 17 billion by 2030. These costs are about 20 % higher than the equivalent costs of a conventional energy mix.

Table 4.4 compares these generation costs with the corresponding costs in the reference conventional energy system. The figures are presented as additional generation costs per unit of fuel input ('input-specific' — i.e. per unit of primary bioenergy) as well as per unit of energy output ('output-specific' –i.e. referring to the produced electricity, heat or transport fuel). Thereby, the terminology 'additional (generation) cost' shall mean the cost of bioenergy production minus the cost of using conventional (fossil) energy. Negative numbers indicate a cost saving from bioenergy.

Table 4.4 Additional generation costs for bioenergy

	Output-specific additional generation cost						
	Unit	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Total	EUR/MWh-o	11.7	11.4	13.6	15.6	12.3	9.1
Pure power generation	EUR/MWh-o	– 1.1	11.9	15.0	17.6	10.8	7.6
CHP — electricity and heat	EUR/MWh-o	11.7	10.2	14.0	17.6	13.5	12.7
District heat	EUR/MWh-o	13.8	10.8	8.2	8.1	5.6	3.4
Decentralised heat	EUR/MWh-o	25.1	23.1	17.3	18.3	18.9	11.8
Transport	EUR/MWh-o	20.0	15.2	19.3	23.5	21.6	15.9
	Input-specific generation cost						
	Unit	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Total	EUR/MWh-p	5.9	5.5	7.1	8.6	7.2	5.6
Pure power generation	EUR/MWh-p	– 0.4	5.0	6.4	7.4	4.6	3.2
CHP — electricity and heat	EUR/MWh-p	4.8	4.1	5.7	7.3	5.7	5.4
District heat	EUR/MWh-p	11.7	9.2	7.0	6.9	4.9	3.0
Decentralised heat	EUR/MWh-p	21.4	19.8	14.9	16.0	16.6	10.4
Transport	EUR/MWh-p	11.5	8.7	10.9	13.0	12.1	9.2

Source: EEA, based on Green-X$_{environment}$ modeling.

Relative to conventional energy, (pure) power and district heating and electricity generation (CHP) are the most cost-attractive options for bioenergy. However, cost figures do not include the distribution network costs following to the power plants. Decentralised heat and biofuel production are the more cost-intensive options, which explain their dependence on support incentives to achieve market penetration. However, this depends largely on the price assumptions in the conventional energy system used for reference. Also, the costs of bioenergy given here are averages. There are cost ranges within each sub-sector.

4.1.6 Differences at national level — a case study of Spain and Poland

The modelled bioenergy deployment differs across Member States, because it depends on the available domestic biomass resources as well as the climate conditions within each country. The additional costs of bioenergy vary too, depending also on the projected conventional energy economy (in the LCEP scenario) in each country. Here, the examples of Spain and Poland, two countries that differ widely in their relevant circumstances, are presented to give an indication of the effects of these differences. The key results for all 25 Member States are given in Annex 8.

In the Green-X model, bioenergy is deployed very differently across the energy sectors in Spain and Poland. Table 4.5 shows a summary of the national bioenergy developments in these two countries, and what the impacts are on emissions of greenhouse gases (CO_2-equivalent), air pollutants and energy costs, relative to the reference scenario (LCEP). The figures on emissions and costs represent what proportion of the net pollution caused by a conventional energy system is reduced by taking the enhanced bioenergy route. Negative figures mean that bioenergy causes greater emissions — emissions have not been avoided but increased.

In terms of additional cost, a negative figure means there is no additional cost, and consequently bioenergy costs less than the conventional energy.

The two countries make similar use of biomass for heat supply. But in Spain biofuels dominate over electricity, while in Poland the electricity sector takes a leading role. This is mainly due to the feedstock characteristics in each country.

Because Spain has a much lower deployment of electricity from bioenergy than Poland, it reduces less greenhouse gas emissions overall, but adds less to the air pollutant burden. Conversely, Poland achieves better climate mitigation, but pollution by NO_X and SO_2 is substantially worse than with conventional energy.

Both countries benefit from comparatively favourable low-cost bioenergy feedstocks. The result

Table 4.5 Reference scenario results for Spain and Poland in the year 2030

	Deployment	Net LCA emission avoidance expressed as share of reference emisions				Additional generation cost
	%	% — deviation to reference				% of reference cost
		CO_2-equivalent	SO_2	NO_x	PM	
Spain						
Electricity	6 %	72 %	27 %	– 69 %	– 8 %	– 7 %
Heat	22 %	95 %	– 38 %	5 %	64 %	– 14 %
Transport	10 %	43 %	48 %	– 25 %	38 %	19 %
TOTAL	15 %	77 %	– 17 %	– 18 %	46 %	– 5 %
Poland						
Electricity	42 %	79 %	35 %	– 89 %	– 7 %	– 5 %
Heat	23 %	94 %	– 327 %	– 8 %	58 %	– 11 %
Transport	12 %	89 %	82 %	– 14 %	86 %	3 %
Total	38 %	85 %	– 50 %	– 56 %	13 %	– 6 %

Note: This table shows bioenergy deployment, life cycle emissions of greenhouse gases and air pollutants, and the additional costs of bioenergy, relative to a conventional energy system applied in the modelling work (PRIMES LCEP).

Source: EEA, based on Green-$X_{environment}$ modeling.

is negative additional cost in 2030, which means that by that time bioenergy would be more cost-effective than the conventional market options.

4.2 Alternative reference-scenario case and the environmental priority cases

In order to illustrate the impacts of carbon permit prices and the energy prices on the results, an alternative reference scenario is presented here. This case uses the data from the scenario developed for the European Commission (EC, 2006). In the alternative reference scenario case, the carbon permit price was assumed constant over time and lower than in the LCEP reference scenario (EUR 20/tonne for the alternative reference scenario, whereas it increases from EUR 20/tonne to EUR 65/tonne in 2030 for the LCEP reference scenario). Moreover, the fossil fuel prices in the alternative reference scenario were projected to be higher than the reference scenario (LCEP). The projected prices for both scenarios can be found in Annex 6. Nevertheless, the projected fossil fuel prices for both scenarios were lower compared to the current real world prices.

In addition to the comparison of LCEP reference scenario with the alternative reference scenario case, various other model runs were conducted to find out whether imposing certain priorities would improve the reduction of greenhouse gas and air pollutant emissions. In this section, four scenarios with environmental priorities are presented. They prioritise CHP, decreasing CO_2 emissions, decreasing air pollution and meeting the 2020 20 % renewables target.

When analysing the LCEP reference scenario case in comparison with the alternative reference scenario case (Figure 4.12, left side of the figure), one can observe a slight shift of biomass contribution from the heat sector to the transport sector in the alternative reference scenario. This shift can be understood by the fact that the alternative reference scenario is characterised by higher primary energy prices and lower CO_2 allowance prices, whereas the latter do not affect the heat and biofuels sector. Therefore, the relative competitiveness of renewable biofuels is higher for the alternative reference scenario. Additionally, the relative share of bioheat is much lower — due to the higher energy demand under the alternative reference scenario — than in the corresponding LCEP case, which affects especially the heat sector.

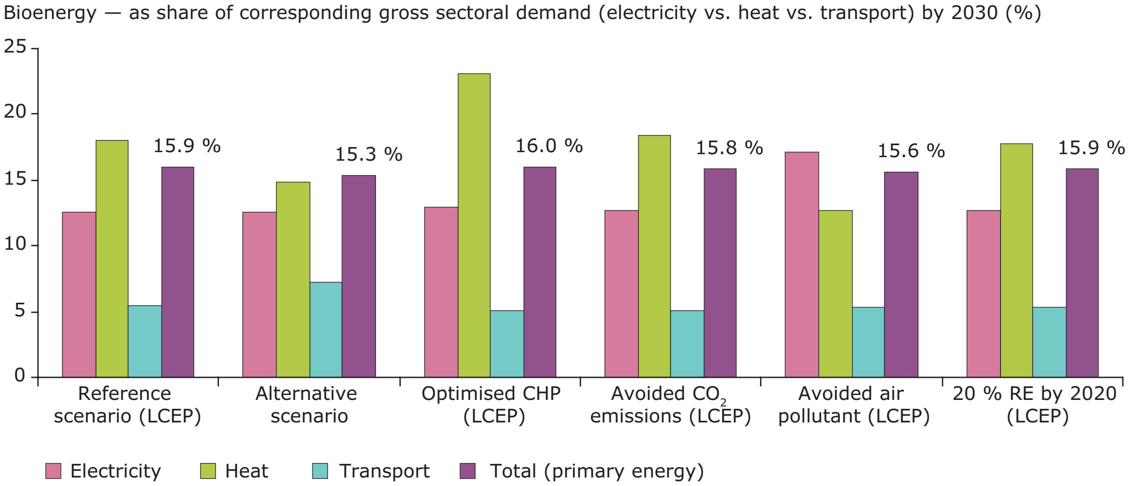
In Figure 4.12 the case, which prioritises CHP, gives the highest overall bioenergy deployment, mostly in the heat sector. This case assumes that all heat produced in CHP plants is completely sold on the market. It leads to an increased deployment of CHP plants — around 52 % of biomass electricity and heat come from CHPs by 2030. For comparison, it was around 28 % in the reference case. Also, the share of gross electricity demand derived from biomass CHP reaches 8.6 % (6.1 % for reference) by 2020, and 10.8 % (7.5 % for reference) by 2030. However, relative to the reference scenario, the shares of co-firing, large-scale electricity generation and biofuels are reduced, as the overall bionergy potential is kept equal in all cases. When the least-cost optimisation is conducted to increase GHG savings (CO_2 optimised), there are hardly any differences applicable in comparison to the reference case (where the economic optimisation purely aims to increase bioenergy deployment). This can be explained by the fact that LCEP reference scenario already includes an important carbon price.

When the model is optimised to keep air pollutant emissions as low as possible, the use of biomass in the electricity sector increases, while the use of bioenergy for heating purposes decreases. There is a shift towards large-scale power plants, including CHP. The biofuel share is unaffected by this optimisation, but the selected technology options differ. There is more second generation lingo-cellulosic bioethanol, less first generation biofuel and BtL.

4.2.1 Avoided greenhouse gas emissions

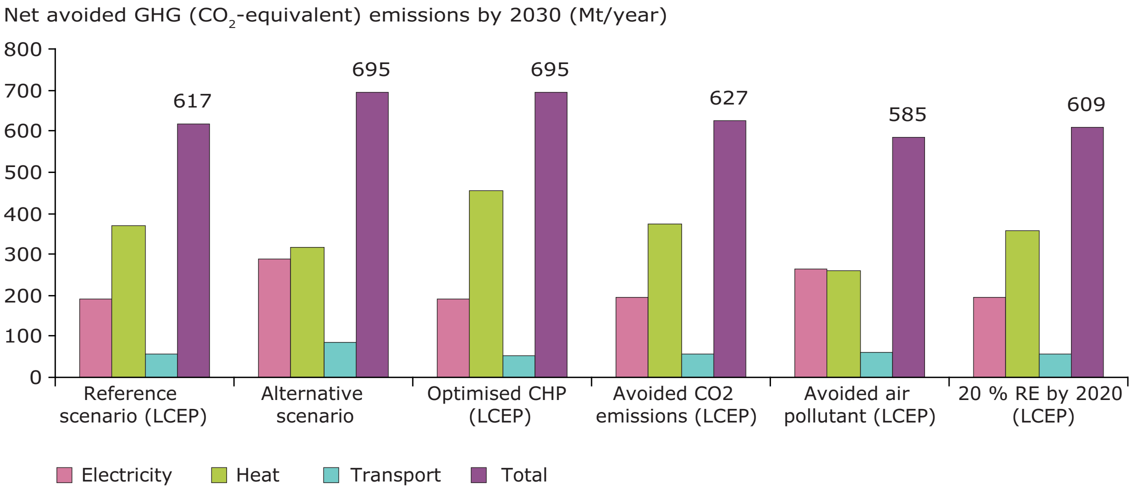
Figure 4.13 shows the avoided life cycle greenhouse gas emissions for each of the environmental priority

Figure 4.12 Bioenergy deployment as share of conventional gross energy consumption



Source: EEA, based on Green-$X_{environment}$ modeling.

Figure 4.13 Net avoided greenhouse gas emissions in 2030, in four cases with environmental priorities, compared to the reference (least-cost only) PRIMES LCEP and alternative scenario



Source: EEA, based on Green-$X_{environment}$ modeling.

cases. It also compares the alternative reference scenario to the LCEP reference case. Optimising CHP leads to the highest greenhouse gas benefits. This is largely because more energy is produced from biomass in this case, especially in the heat sector, so demand for fossil fuels is lower. The result demonstrates that more efficient ways of using bioenergy also leads to the most significant reductions of greenhouse gas emissions.

When the avoided GHG emissions are analysed, the alternative reference scenario and the optimised CHP case give the highest figures. The higher GHG emission reduction in the alternative reference scenario is caused by higher reference emissions in conventional energy supply. Another factor is the shift of bioenergy use from pure electricity and heat generation towards CHP (as feasible in this scenario — due to an increased demand for (grid-connected) heat. Thus, this increase is the same as it happens in an optimised CHP case.

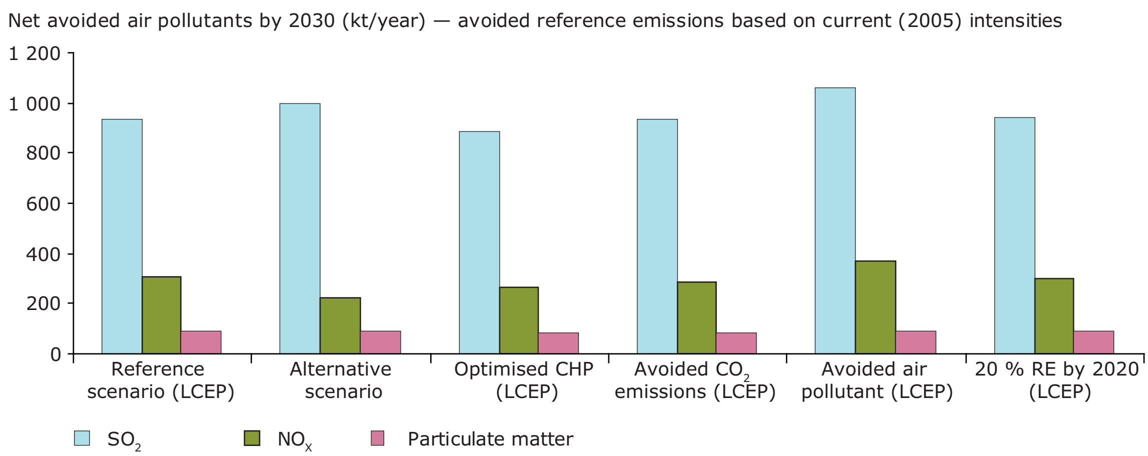
When the priority is to reduce air pollutant emission, the resulting GHG emission reduction is lower. This is mainly due to the decrease of the amount of energy produced from bioenergy, especially in the heating sector. Giving priority to the 2020 targets for renewables may lead to slightly higher greenhouse gas emissions in 2030 ([15]).

4.2.2 *Avoided air pollutant emissions*

The total life cycle of SO_2, NO_X and particulate emissions from bioenergy, and the emissions avoided by enhanced deployment of bioenergy are depicted for the alternative reference scenario and different environmental priority cases in Figure 4.14. The rationale behind presenting those figures based on 2005 reference emission intensities is to show the air emission resulting from bioenergy deployment — compared to the current energy mix. Since the scenarios applied assume that a significant shift from coal to natural gas occurs by 2030, and also, that the best available pollution abatement options are in place, the results for those years would appear to be negative, even though the air pollutant emissions from bioenergy deployment do not increase compared to 2005 emission figures.

Not surprisingly, the best avoidance of air pollutants happens when the model is prioritised to minimise them. A closer look at the assessed air pollutants shows that only comparatively small differences occur between the different cases with regard to particulate matter emissions, whilst with regard to NO_X deviations are getting apparent. The highest net avoidance of SO_2 emissions (compared to 2005 emission levels) or lowest increase (compared to the projected future reference emissions), respectively, occurs (besides the above

Figure 4.14 Air pollutant emissions (net) avoided by enhanced bioenergy deployment in 2030 (based on 2005 reference emission intensities), in four cases with environmental priorities, and the reference (least cost only) PRIMES LCEP scenario



Note: The calculation is based on current (2005) intensities.

Source: EEA, based on Green-$X_{environment}$ modeling.

([15]) This minor difference is caused by the accelerated bioenergy deployment in the period up to 2020, and, consequently, less deployment in the final period of novel technology options, such as second generation biofuels offering higher GHG reduction potentials.

mentioned case of prioritising the avoidance of air pollutants) for alternative scenario case. The primary reason is that this scenario contains relatively higher solid fuels in the conventional energy mix compared to LCEP scenario.

4.2.3 *Generation costs*

Figure 4.15 presents the cost dynamics for each scenario and cases for the years 2010, 2020 and 2030. This figure offers a depiction of the average additional generation (for electricity, heat and transport fuels) in relative terms, expressing them as share of the conventional reference generation cost at sectoral level. Optimising bioenergy deployment to avoid air pollutant emissions entails a tremendous cost increase. Compared to the reference case, total generation costs are 19 % higher, whereas when additional generation costs are compared, these costs are 59 % higher on average, and up to 75 % higher by 2030.This is mainly due to the exclusion of relatively cheaper but dirtier bioenergy pathways from the system. For instance, there is a significant reduction in the bioheat sector. It is especially true when the small scale bioheat plants are eliminated and the number of large scale (i.e. pure power plants as well as CHPs) plants is increased. Subsequently, the generation costs are increased.

In contrast, prioritising CHP reduces the additional generation costs substantially. Nevertheless, one needs to bear in mind hat those cost figures do not include the required distribution systems, as the cost comparison refers to conventional CHP or district heating system. Thus, the cost figures presented, especially for the CHP, are possibly underestimated.

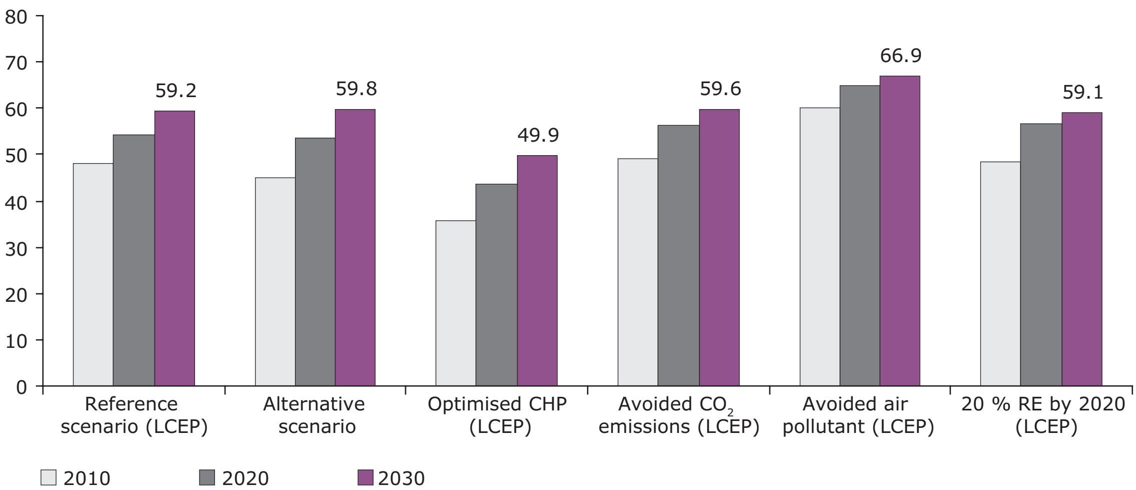
Despite the fact that technological learning takes place, in the scenarios and cases considered the output-specific additional generation costs do not decrease between 2010 and 2030. It is particularly obvious during the period between 2010 and 2020, as the more expensive biomass resources and technology options lead to sharp increase of the generation costs. However, between 2020 and 2030, there is a decline in this increase due to the fact that, on the one hand, the prices for energy and carbon are rising (in the reference energy system) and on the other hand, technological advances are taking place.

Accelerating bioenergy deployment in the years up to 2020 to meet the 20 % target for renewables initially brings about a 10 % rise in the additional costs — compared to the reference scenario, which describes a steady linear penetration of bioenergy into the energy markets. However, by 2030, there is only a minor difference in average costs (approximately 4 %).

The development of additional generation costs over the time period shows a similar pattern in all cases, except for the alternative reference scenario case (see Figure 4.16 ([16])). This scenario shows the situation

Figure 4.15 Output-specific generating costs over time for each scenario

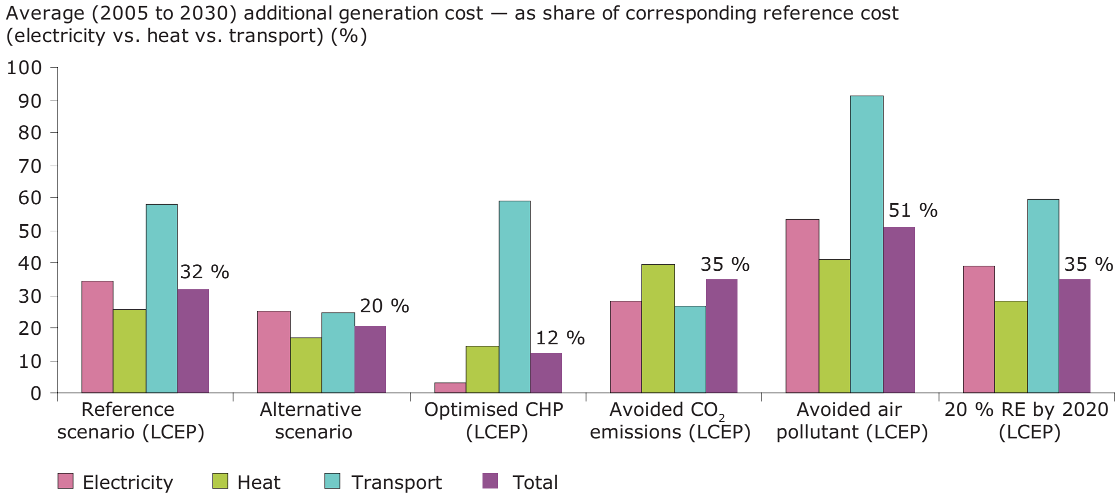
Development (2010 to 2030) of average output-specific generation cost (EUR/MWh-out)



Source: EEA, based on Green-$X_{environment}$ modeling.

([16]) This figure offers a depiction of the average additional generation (for electricity, heat and transport fuels) in relative terms, expressing them as a share of the conventional reference generation cost at the sectoral level.

Figure 4.16 The average additional generation cost of bioenergy, as a percentage of the conventional cost



Note: Costs are averaged over the full time period: 2005–2030. The conventional costs are the generation costs derived from the PRIMES LCEP scenario.

Source: EEA, based on Green-X$_{environment}$ modeling.

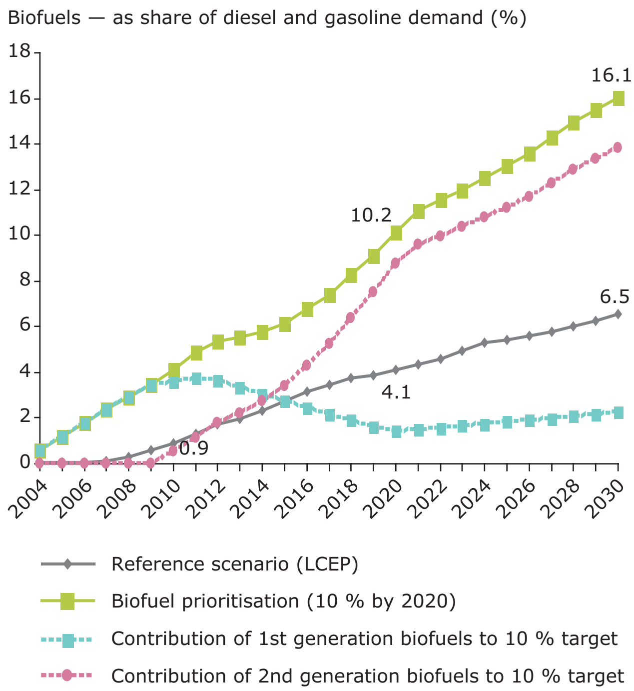
based on the assumption of lower additional costs due to higher fossil fuel prices, which affects especially biofuels in the transport sector. The case where priority is given to CHP also shows lower additional generation costs — as compared to the reference scenario. These figures are used due to technological progress in CHP (meaning that all the heat would be sold in the market), and the fact that prices for conventional energy are rising, which is particularly important for CHP deployment.

4.3 Prioritising biofuels

In yet another case presented here, the prioritisation is applied to the transport sector. The bioenergy deployment is analysed from the point of view of a prerequisite of achieving the 10 % biofuel target by the year 2020 (the LCEP scenario is used as the reference). The imposed constraint is using solely domestic biofuels. In contrast to the Commission proposal, this analysis excluded the option of importing bioenergy from other regions of the world. The main reason for this decision is the current debate on sustainability criteria and the uncertainties around this discussion. Until robust and globally agreed sustainability criteria are in place, we prefer to exclude this option from our analysis and, thus, focus this analysis on the use of domestic EU biomass resources.

Figure 4.17 shows the penetration over time of biofuels into the transport fuel market — compared to the biofuel development in the reference scenario. This figure also presents the breakdown

Figure 4.17 Biofuel deployment over time in case of biofuel prioritisation



Note: Biofuel deployment is expressed as the share of demand for diesel and gasoline. The graph shows biofuel priority case in comparison to the reference scenario case of biofuel deployment.

Source: EEA, based on Green-X$_{environment}$ modeling.

of the overall biofuel deployment (as first and second generation biofuels (dotted lines)).

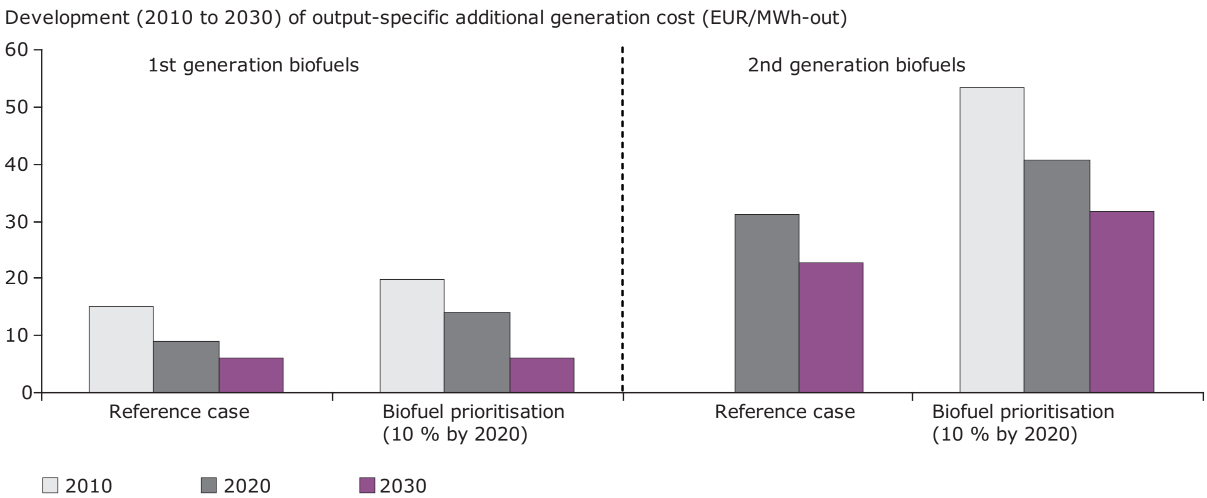
It is becoming apparent that if the ambitious policy target of 10 % were to be met — and this in observing the imposed constraint of using solely European (EU-25) environmentally compatible biomass resources, the market penetration would require a substantial share of second generation biofuels (more than 80 %). This is due to increase in better performing woody crops that were applied in the previous EEA report (EEA, 2006). Currently, however, there are no commercially available second generation technologies in the market. Additionally the current (2007) share of biofuels in Europe is 2.6 % (EurObserver, 2008). Consequently, it can be concluded that in order to meet the proposed policy objective, it appears necessary to import biofuel from abroad.

Moreover, if the target were achieved and the share of biofuel in the European feedstock reached 10 %, it could lead to a decreased biomass deployment in the other energy sectors, whereby the heat sector may be affected most. According to our modelling exam, the use of bioenergy for heating purposes at the European level would decline by approximately 46 % in comparison to the reference case. Thus, the share of bioheat in the corresponding gross heat demand would be decreased to 6.6 % by 2020, and to 9.7 % — by 2030.

Figure 4.18 shows the additional generation costs, per unit of energy output, associated with attempting to meet the 10 % RE target with solely domestic biofuels — in comparison to the biofuel costs calculated in reference scenario case. Obviously, this attempt will lead to an increase of the additional generation costs. This is mainly because of using more expensive feedstock to achieve the target. This explains the relatively higher additional generation costs for the same type of technology applied (both for the first generation and second generation biofuels). However, this figure clearly illustrates how the generation costs are expected to go down over the years due to increasing reference cost figures for the conventional energy systems. In addition, there are also the learning effects and economies of scale, especially for the second generation technologies (see the right side of the figure). In the reference scenario case, the second generation biofuels do not appear by 2010, and since there is no push for biofuels. Thus, the available feedstock in this scenario is then used for other means of energy generation, which appears more cost effective under the applied assumptions.

In the 10 % biofuel priority case, the production costs of second generation biofuels are calculated to be around EUR 77/MWh output by 2020. For comparison: the conventional transport system cost figure is assumed to be EUR 36/MWh in the same year. It is important to highlight the fact that the LCEP scenario projections assumed much lower fossil fuel prices than the current (2007) fossil fuel prices (i.e. the 2020 oil price projections are 50 % lower than the prices in 2007). In the case of prioritising biofuels, total generation costs for biofuel production is calculated as EUR 29.5 billion

Figure 4.18 Output-specific additional generation costs in 2020 — prioritisation of biofuel vs. reference case



Source: EEA, based on Green-$X_{environment}$ modeling.

Box 4.1 Cost assumptions — comparison to other studies

Cost parameters are a crucial input for the economic assessment of bioenergy technologies and pathways. A broad range of studies have been conducted in the past for bioenergy in general or focussed on certain pathways like bioheat, bioelectricity or biofuels. The GEMIS database builds on consolidated outcomes and aims to present a comprehensive overview on conversion technologies among all energy sectors.

However, for assessing the robustness of the GEMIS data used in this analysis, a comparison of these data with the recently conducted comprehensive 'Well-to-Wheels Analysis of future automotive fuels and powertrains in the European context' (JEC, 2007) ([17]) was undertaken. As the focus of this study was on the transport sector, similar biofuel chains were compared in details in Table 4.6 and the resulting biofuel generation costs are illustrated in Figure 4.19.

As demonstrated in the graph, the data from GEMIS and JEC are comparable with regard to Bioethanol and BtL, but significant differences are observed for biodiesel and lignocellulosic bioethanol. In the case of biodiel, GEMIS demonstrates higher cost figures as the investment costs are about 20 % higher compared to JEC and a broader range with regard to fuel cost. Thus, these deviations may arise from varying plant sizes (i.e. data from GEMIS refers to small-scale plants) and the country-specific assessment of yields and, consequently, fuel costs as conducted within the GEMIS/EEA work. With respect to lignocellulosic bioethanol GEMIS indicates a broader cost range whereby the upper limit matches well to JEC data. Significant differences are seen for investment cost, possibly caused by a differing timely reference ([18]).

Figure 4.19 Bandwith of generation cost for various biofuel chains — comparison of data used in this study with results from JEC study

Source: CONCAWE/JRC/EUCAR, 2007; EEA, 2008.

([17]) The JEC study applies a certain (but low) correlation between cost data for assessed biofuel chains and the assumed oil price development. Thus, the indicated data is taken from the low oil price case (at 4.6 EUR/GJ) which matches well to the oil price assumptions applied in this study.

([18]) GEMIS data on second generation biofuels (i.e. lignocellulosic bioethanol and BtL) represents cost expectation for 2020, whilst for JEC data the timely reference appears unknown.

Box 4.1 Cost assumptions — comparison to other studies (cont.)

Table 4.6 Key economic parameter for biofuel chains — comparison of data used in this study with results from JEC, 2007

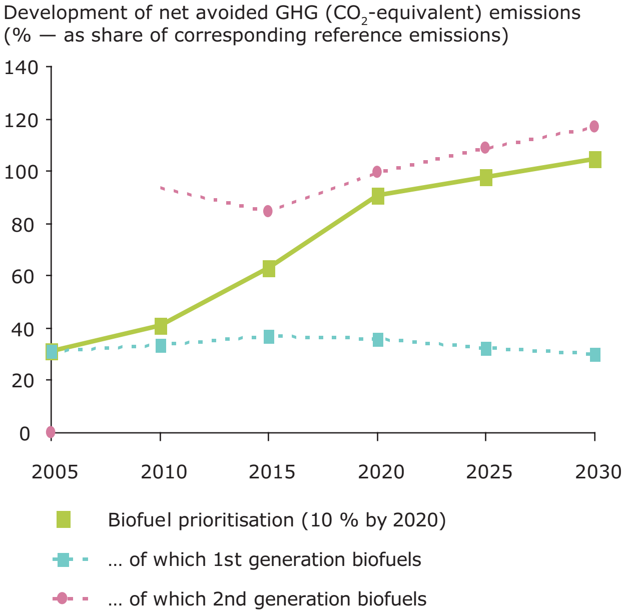
	Process name			Bioethanol plant		Biodiesel plant		Lignocellulosic bioethanol plant		BtL plant	
General data	Fuel input			Wheat grain		Rapeseed		Energy crops (whole plant)	Wood (waste), Wheat straw	Wood (waste), energy crops	
	Data source			**GEMIS/ EEA**	**JEC study**	**GEMIS/ EEA**	**JEC study**	**GEMIS/ EEA**	**JEC study**	**GEMIS/ EEA**	**JEC study**
	Main output			Biofuel (ethanol)	Biofuel (ethanol)	Biofuel (diesel)	Biofuel (diesel)	Biofuel (ethanol)	Biofuel (ethanol)	Biofuel (diesel)	Biofuel (diesel)
	2nd output				DDGS		Cake and glycerine	Electricity		Electricity	
	Plant size (main output)		(MW)	96	93	13	150	100	66	500	102–194
Performance data	Efficiency (main output)		(%)	58 %	54 %	67 %	63 %	55 %	35–42 %	45 %	48–54 %
	Couple ratio (2nd output)				DDGS: 42.4 kg/GJ	Glycerol: 3.15 kg/GJ glycerol	Cake: 25.1 kg/GJ, Glycerine: 1.64 kg/GJ	4 %		25 %	
	Full load hours		(h/year)	8 300	8 000	8 000	7 000	7 500	8 000	7 500	7 500
	Lifetime		(year)	15	n.a.	20	n.a.	15	n.a.	20	n.a.
Cost data	Investment cost		(EUR/ kW)	765	842–1 129	250	208	406	1 805–2 058	1 800	1353–2524
	O&M cost		(EUR/ kW/year)	41.4	19.4–78.5	52.4	55.3	160.0	124.2–174.2	105.0	76.3–142.7
	Fuel cost (input)		(EUR/ MWh_{in})	17.0–25.0	23.3	37.0–51.0	36.8	17.0	8.4–10.1	12.0–36.0	10.1–15.5
	Generation cost (main output)	Minimum	(EUR/ MWh_{out})	**44.1**	**46.9**	**64.6**	**57.1**	**56.2**	**71.8**	**51.2**	**50.4**
		Maximum		**57.9**	**66.3**	**85.5**	**57.3**	**70.7**	**72.6**	**104.5**	**91.5**
	Capital recovery factor (C.R.F.)			11 %	12 %	9 %	12 %	11 %	12 %	9 %	12 %
			Reference year	2010	n.a.	2010	n.a.	2020	n.a.	Table 4.6	n.a.

Source: CONCAWE/JRC/EUCAR, 2007; EEA, 2008.

by 2020 (for comparison: conventional transport system generation costs are calculated as EUR 14.5 billion).

Figure 4.20 shows the level of reduced GHG emission in the transport sector as compared to the conventional transport system described by the reference scenario. Significant amounts of GHG emissions can be avoided if second generation biofuels come to comprise a large share in the total biofuel system. The presented figures show the potential for reducing the life cycle GHG emission. It is possible to save significant amounts of GHG if using second generation biofuels, since the by-products are credited (see Annex 3). Solid agricultural products (i.e. short rotation coppice (SRC) of poplar or willow) and forest residues are used as feedstock for the second generation biofuels. The effects of any potential change in the land use and the impacts on GHG emissions are not included in this study. In the EEA 2006 study, utilisable agricultural land that will be made available for bioenergy purposes was matched with potential biomass crops. The crops under consideration are those which neither create environmental pressures nor lead to soil carbon emissions.

Figure 4.20 Net avoided greenhouse gas emissions by 2030, in case of biofuels prioritisation



Note: All the GHG emission figures exclude both possible direct and indirect land-use change emissions.

Source: EEA, based on Green-$X_{environment}$ modeling.

5 Outstanding issues and research challenges

5.1 Introduction

Enhancing bioenergy deployment in Europe can help with both combating climate change and improving the security of energy supply. On the other hand, its production, processing and consumption may create possible environmental impacts that can outweigh its environmental benefits if a less effective bioenergy strategy is chosen. This study presents the most promising bioenergy pathways, along with their potential to reduce GHG and air pollutant emissions. Even though the current analysis does not cover other environmental consequences (i.e. impact on soil and water, or biodiversity), the modelling assumptions are based on the European potential in terms of environmentally compatible bioenergy. This potential previously estimated. Consequently, such potential impacts are implicitly considered and are assumed to have been avoided. Nevertheless, environmental impacts resulting from EU bioenergy targets are not limited to Europe only, even in the case of using only domestic biomass resources.

Even though Europe holds significant amounts of biomass to support strong renewable energy targets, it is not yet clear if these large amounts can be completely mobilised. Moreover, the strict environmental constraints applied in this study and the environmentally favourable pathways modelled are yet to be realised. To quote the 2006 EEA report 'An appropriate policy framework, combined with advice and guidance to bioenergy planners, farmers and forest owners on environmental considerations, needs to be in place to steer bioenergy production in the right direction'. The following two sections briefly discuss outstanding issues and research challenges that have to be tackled for realising the full potential of the European bioenergy policies as regards GHG savings.

5.2 Realising the most efficient pathways

The modelling results in this study show that the use of biomass in heat and power pathways leads to greater GHG efficiency — in comparison to transport fuels. The model also includes assumptions of a strong reliance on second generation crops and the use of woody biomass in combined heat and power (CHP) plants. Overall, attention is increasingly being paid to bioenergy pathways but in most cases a range of important barriers still needs to be overcome. These barriers can be grouped under the following three sections.

5.2.1 Achieving the required shift to novel perennial energy crops;

Achieving the required shift to perennial energy crops faces several challenges. For instance, farmers and policy-makers are unsure of the crop's nutrient or water requirements, how to create optimum conditions for maximising yields, or how to develop dedicated crop breeding initiatives. Moreover, farmers are reticent to lose their flexibility when switching from annual to multi-annual crops. The following factors need to be overcome:

(a) lack of established practices for harvesting and marketing;
(b) lack of public awareness of the advantage of perennial energy crops in an environmental perspective;
(c) lack of mid- to long-term demand for woody biomass by processing industries;
(d) risk aversion amongst farm and forest owners;
(e) lack of capital and logistics to establish harvesting and processing businesses related to novel energy crops.

In order to overcome the above barriers and secure a sufficient, reliable and long term bioenergy supply, further research and development are required. In addition to public awareness campaigns, it is important to promote the need to improve cooperation among farmers and bioenergy industries (Eppler *et al.*, 2007).

5.2.2 *political support and financial incentives;*

One important factor for political support is suitable legislation. At the EU level, the Directive on the Promotion of High Efficiency Cogeneration (CHP) (EC, 2004) encourages Member States to promote CHP take-up and help overcome barriers. The EU's strategy aims to increase the CHP market share to 18 % of gross electricity generation by 2010.

Financial incentives include relative price levels and taxation policies. CHP plants are sensitive to energy prices, especially fuel prices. With liberalisation, electricity prices in many countries decreased, creating a barrier to investments in new CHP plants. During the early part of this century, growth of CHP was relatively slow: mainly because natural gas prices were increasing and electricity prices — decreasing.

A number of EU Member States have introduced laws or other support mechanisms to promote new CHP. Such measures include (EEA, 2007a- EN20):

- legal provisions prescribing a mandatory CHP-oriented energy audit in the case of new installations or major reconstructions above a given capacity (e.g. 5 MW in the Czech Republic);
- statutory duty to connect particular types of CHP to the grid and purchase their electricity (Germany, 2002); provisions obliging the utilities to provide CHP access to the networks, adopted in many new Member States;
- fiscal measures to provide support to CHP.

However, in 2004, renewable energies and wastes provided only 18 % of the fuel input in CHP plants in the EU-15 and 2 % — in the EU-10 (EEA, 2007a). Natural gas accounted for half of the fuel input in the EU-15 (10 % in the EU-10), while solid fossil fuels such as coal and lignite provided 77 % of the fuel input in the new Member States (18 % in the EU-15).The use of bioenergy in CHP can be encouraged by the support measures for renewable fuels as a whole (such as feed-in tariffs), as these can help to develop the necessary supply chains. In some countries, such as Germany, there is a premium for the use of bioenergy in CHP compared to heat or power-only production, which further encourages growth in this sector. The price for carbon determined by the EU ETS also provides incentives for replacing conventional fuels in CHP. Measures demonstrating the governmental support for the bioenergy supply chain as a whole will also improve the situation for CHP.

5.2.3 *development of suitable energy infrastructure.*

The development of energy infrastructure capable of the optimal use of the type of biomass assumed to be grown in this modelling study is particularly geared towards the combined production of heat and power. However, Member States are facing a number of barriers that must be overcome in order to increase the share of CHP as estimated. Some of the barriers to CHP listed by Gochenour (2003) are listed below.

- *Fuel infrastructure*. Introducing CHP to the existing infrastructure for electricity and heating can be difficult, especially in the countries where infrastructure is based on energy systems with an inexpensive fuel source (such as nuclear and hydropower). Introducing new district heating systems with CHP may require expensive reconstruction.
- *A secure and stable demand for heat*. Improved building standards and insulation, especially in Western Europe, have brought about a decrease in the demand for heat. Existing district heating (DH) networks are not expected to grow. CHP plants using solid biomass need to be sited near both the supply of fuel and the heat users. Nordic countries have been successful in using biomass for CHP district heating schemes — since the infrastructure is available both to supply fuels and to use heat on a large scale. Such infrastructure is more limited or lacking in other countries.
- *Delays and costs caused by authorization and issue of permits*. The process of issuing licences, permits and consents by various authorities can be slow and expensive. This barrier is particularly difficult for small-scale CHP plants.

5.3 Options for the future development of the Green-X$_{ENVIRONMENT}$ modelling framework

The analytical possibilities that are offered by the Green-X$_{ENVIRONMENT}$ model are substantial. The quality of results obtained, however, depends to a large degree on the reliability of input data as well as on relevant framework assumptions. Three possible areas for future work emerge in this context.

(i) Further development of better input data regarding available biomass. Further knowledge has been and will be gained concerning the relative environmental advantages and constraints of different energy crops as well as the likely patterns of adoption of these crops by farmers and other growers. In addition, the potential consequences of indirect changes in land use for the GHG balance of different bioenergy pathways constitute an important factor that must be taken into account when calculating the land area likely to be available in the EU under the strict environmental criteria. Thirdly, the likely impact of climate change on the conditions for growing biomass feedstock also needs to be included in future projections. Lastly, economic and logistic constraints need to be applied to an (improved) estimate of the technical biomass potential.

(ii) Improvement of assumptions regarding the likely technical and economic penetration of different bioenergy pathways, including the required investments into the public infrastructure. This should also include improved analysis of the likely competition with other societal uses of biomass, e.g. for biomaterials. Other relevant framework conditions include the development of future oil prices, societal energy demand, etc.

(iii) A range of scenarios could be developed that analyse the effect of different political or global framework conditions on modelling results. These scenarios could help to evaluate policy options. Such options could include: a scenario where Europe becomes a net exporter due to increased food prices and another — where the opposite assumptions are applied; priority to the use of biomass for transport fuels, etc. Any of these scenarios would influence the assumptions made about available land area, crop choices as well as preferred bioenergy pathways.

In conclusion, there is clearly a wide range of opportunities for the further development and employment of the Green-$X_{ENVIRONMENT}$ modelling framework. Such exercises could be very useful in evaluating the costs and benefits of different policy choices and bioenergy options. On the other hand, before these opportunities can be realised, a considerable investment would be required in data collection and suitable modelling capacity. They would seem useful, though, for the further development of a bioenergy policy that could minimise societal costs and maximise the potential gains from producing energy from biomass inside and outside of Europe.

List of abbreviations

BAU	Business as usual
BER	Bioethanpol Rotterdam
BtL	Biomass-to-liquid
CAPSIM	The Common Agricultural Policy SIMulation
CHP	Combined Heat and Power
CO_2	Carbon dioxide: The principal greenhouse gas
CO_2-eq.	Carbon dioxide equivalent (emissions)
Cogen	Cogeneration
CtL	Coal to liquid
DDGS	Distiller's Dried Grain with Soltubles: a residue arising from ethanol production from wheat grain
EFISCEN	The European Forest Information Scenario Model
EJ	Exa Joule (energy unit)
ETS	Emission Trading System
EU	European Union
FAME	Fatty acid methyl ester: scientific name for biodiesel produced from vegetable oil and methanol
FAO	Food and Agriculture Organization, United Nations
FC	Fuel cell
F-T	Fischer-Tropsch: A process to convert syngas to hydrocarbon chains, named after its inventor
GDP	Gross Domestic Product
GEMIS	Global Emission Model for Integrated Systems
GHG	Greenhouse gas
GLUE	Global-land-use-and-energy model
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre of the European Commission
ktonnes	Kilotonnes (mass unit)
kW	Kilowatt (power unit)
kWhe	Kilowatthour of electrical energy (energy unit)
LCA	Life cycle analysis
LCEP	Low Carbon Emission Pathway
LFO	Light fuel oil
MSW	Municipal solid waste
Mtoe	Million tonnes oil equivalent (energy unit)
NEC	National Emission Ceilings
NG	Natural gas
NO_x	A mixture of various nitrogen oxides as emitted by combustion sources
O&M	Operation and Maintenance
ORC	Organic Rankine Cycle
PM	Particulate matter
PT	Payback time
R&D	Research and Development
RE	Renewable energy
SME	Sunflower Methyl Ester: biodiesel derived from rapeseed oil
SRC	Short rotation coppice
TGC	Tradable Green Certificate
yr	Year

References

BTG, 2004. *Bio-Energy's Role in the EU Energy Market: A view of developments until 2020*. Report for the European Commission, the Biomass Technology Group, BTG, 2004. http://ec.europa.eu/environment/etap/pdfs/bio_energy.pdf.

CE, 2006. *Milieuanalyse 4 alternatieve (bio-)brandstoffen voor de Gelderland 13.* Vroonhof, J.; Croezen, H.; Sevenster, M., and Singels, K., CE Delft.

CE, 2007. *Nieuwe electriciteitscentrale in Nederland, De 'vergeten' kosten in beeld.* Sevenster, M.; Croezen, H.; Blom, M.; Rooijers, F., CE Delft.

CONCAWE/JRC/EUCAR, 2007. *Well-to-Wheels analysis of future automotive fuels and power trains in the European contex*t, Well-to-Tank Report, Version 2c, JRC/IES (the Institute for Environment and Sustainability of the EU Commissions Joint Research Centre), EUCAR (the European Council for Automotive R&D), CONCAWE (the oil companies European association for environment, health and safety in refining and distribution), 2007.

De Leeuw, 2002. A set of emission indicators for long-range transboundary air pollution. *Environmental Science & Policy,* No 5, 2002, pp. 135–145.

EC, 2001. National Emission Ceilings Directive (2001/81/EC).

EC, 2004. Directive of the European Commission on the Promotion of High Efficiency Cogeneration (CHP), 2004/8/EC.

EC, 2006. European Energy and Transport: Trends to 2030', DG TREN, EC, 2006.

EC, 2008a. Proposal for a Directive 2008/0016 (COD) of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. EC, 2008.

EC, 2008b. Commission staff working document SEC(2008)xxx, COM(2008)xxx, *Annex to the Impact Assessment (provisional)*, EC, Brussels, 2008b.

EEA, 2005a. *The European environment — State and outlook 2005*. European Environment Agency, Copenhagen, 2005. http://reports.eea.europa.eu/state_of_environment_report_2005_1/en.

EEA, 2005b. *Climate change and a European low-carbon energy system*, EEA Report No 1/2005. European Environment Agency, Copenhagen, 2006. http://reports.eea.europa.eu/eea_report_2005_1/en.

EEA, 2006. *How much bioenergy can Europe produce without harming the environment?* EEA Report No 7/2006. European Environment Agency, Copenhagen, 2006.

EEA, 2007a. *Energy and environment indicators*. European Environment Agency, Copenhagen. http://www.eea.europa.eu/themes/energy/indicators.

EEA, 2007b. *Estimating the Environmentally Compatible Bio-Energy Potential from Agriculture*, EEA Technical report No 12/2007. European Environment Agency, Copenhagen, 2007.

EEA, 2008. *Annual European Community greenhouse gas inventory 1990–2006 and Inventory Report*. Submission to the UNFCCC Secretariat, EEA Technical report No 6/2008, European Environment Agency, Copenhagen, 2008. http://reports.eea.europa.eu/technical_report_2007_7/en.

Eppler, U.; Petersen, J.-E. and Couturier, C., 2007. Background paper for expert consultation, on *Short Rotation Coppice and Perennial Energy Grasses in the European Union: Agro-environmental aspects, present use and perspectives.* http://re.jrc.ec.europa.eu/biof/html/srf_src_en_grasses_rothamstead.htm.

Ericsson, K. and Nilsson, L.-J., 2006. Assessment of the potential biomass supply in Europe using a resource-focused approach. *Biomass and Bioenergy*, Vol. 30, 2006, pp. 1–15.

EU, 2005. Biomass Action Plan Impact Assessment, SEC(2005) 1573, European Commission, 2005.

Eurostat, 2007. Eurostat web page data.

EurObserver, 2008. Biofuels barometer 2007, *Le journal d'énergies renouvelables*, No 185/2008, EurObserver, June 2008.

FAO, 2003. *World Agriculture: Toward 2015/30 — An FAO Perspective,* J. Bruinsma, J. Ed., FAO (UN Food and Agriculture Organization), Rome.

FAO, 2005. Global Forest Resources Assessment 2005. 15 Key Findings, FAO (UN Food and Agriculture Organisation), Rome. www.fao.org/forestry/foris/data/fra2005/kf/common/GlobalForestA4-ENsmall.pdf.

Fargione, F.; Hill, J.; Tilman, D.; Polasky, S., and Hawthorne, P., 2008. Land clearing and the biofuel carbon debt. *Science* 319, 2008, pp. 1235–1238.

Farrel, A. and O'Hare, M., 2008. Greenhouse gas emissions from indirect land use change (LUC). *Memorandum to Courtis, J., of California Air Resources Board*. Energy & Resources Group, University of California, Berkeley, January 2008.

Fischer, G. and Schratteholzer, L., 2001. Global bioenergy potential through 2050. *Biomass and Bioenergy*, Vol. 20, 2001, pp. 151–159.

Frischer, G.; Prieler, S.; van Velthuizen, H. T., 2007. *Europe's Land Resource Potential for Biofuel Production.* IIASA, Austria, 2007.

Fritsche, Uwe R.; Rausch, L.; Schmidt, K., 2006. *Life-Cycle Analysis of Renewable and Conventional Electricity, Heating, and Transport Fuel Options in the EU until 2030*. Final report for the European Environmental Agency (EEA), Öko-Institut e.V., Darmstadt, Germany, July 2006.

FZKA, 2007. *Kraftstoff, Strom und Wärme aus Stroh und Waldrestholz, Eine systemanalytische Untersuchung Forschungszentrum*. Leible, L.; Kälber, S.; Kappler, G.; Lange, S.; Nieke, E.; Proplesch, P.; Wintzer, D. and Fürniß, B. FZKA, Karlsruhe.

GM, 2002. *Well-to-Wheel Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems — A European Study*. L-B-Systemtechnik, 2002.

Gochenour, C., 2003. *Regulation of Heat and Electricity Produced in Combined-Heat-and-Power Plan*t. Infrastructure and Energy Department, Europe and Central Asia, World Bank, Washington DC, 2003.

ETSU, 1996. *Alternative Road Transport Fuels: A Preliminary study for the UK.* Gover, M. P.; Collings, S. A.; Hitchcock, G. S.; Moon D. P., and Wilkins, G. T., 2006. ETSU Report R92 for DTI and DfT, March 1996.

IEA, 2004. *Biofuels for Transport: An International Perspective*. International Energy Agency (IEA), 2004.

IEA, 2006a. *World energy outlook*.

IEA, 2006b. IEA Task 38, GHG Impacts of Pellet Production from Woody Biomass Sources in BC, Canada, 2006.

IFEU, 2004. *CO_2 Mitigation through Biofuels in the Transport Sector: Status and Perspective*s. Quirin, M.; Gärtner, S. O.; Pehnt, M.; Reinhardt, G. A. Institute for Energy and Environmental Research (IFEU), Heidelberg.

IFEU, 2006. *Eigene Abschätzungen bzw. bereghnungen.*

IIASA, 2007. *Cost-Effective Emission Reductions to Meet the Environmental Targets of the Thematic Strategy on Air Pollution under Differ Greenhouse Gas Constraints: NEC Scenario Analysis.* Amann, M.; Asman, W.; Bertok, I.; Cofala, J.; Heyes, C.; Klimont, Z.; Schöpp, W.; Wagner, F. Report No. 5, International Institute for Applied Systems Analysis (IIASA), June 2007. www.iiasa.ac.at/rains/CAFE_files/NEC5-v1.pdf.

IPCC, 2006. *Guidelines for National Greenhouse Gas Inventories*, Revised, Vol. 4. www.ipcc-nggip.iges.or.jp/public/2006gl,.

IPCC, 2007. *Fourth Assessment Report — Climate Change 2007; Synthesis Report — Summary for policy makers*. www.mnp.nl/ipcc/pages_media/Summary-for-policy-makers.html.

Kindermann, G. E; Obersteiner, M; Rametsteiner, E.; McCallum, I., 2006. Predicting the deforestation-trend under different carbon prices. *Carbon Balance and Management,* 1, Article 15. Open access: doi: 10.1186/1750-0680-1-15. www.cbmjournal.com/content/1/1/15.

Levelton, 2000a. *Assessment of Net Emissions of Greenhouse Gases from Ethanol-Gasoline Blends in Soutern Ontario*, Cross-Sectoral Policy Development Division, Industry Performance and Analysis Directorate, Agriculture and Agri-Food Canada, R-2000-1, Levelton Engineering Ltd, (S&T)^2 Consulting Inc., J.E. and Associates. www.oregon.gov/energy/renew/biomass/docs/forum/ghg_eth.pdf.

Levelton, 2000b. *Assessment of Net Emissions of Greenhouse Gases from Ethanol Blended Gasolines* *in Canada: Lignocellulosic Feedstock*, Levelton Engineering Ltd. in consultation with (S&T)[2] Consulting, Agriculture and Agri-Food Canada , 2000. www.oregon.gov/energy/renew/biomass/docs/forum/ghg_lig.pdf.

MNP, 2008. *Local and global consequences of the EU renewable directive for biofuels.* Eickhout, B.; van den Born, G.J.; Notenboom, J.; van Oorschot, M.; Ros, J.P.M.; Van Vuuren, D.P.; Westhoek, H.J. MNP Report 500143001/2008. Iwww.mnp.nl/bibliotheek/rapporten/500143001.pdf.

Morton, D. C.; DeFries, R. S.; Shimabukuro, Y. E.; Anderson, L. O.; Arai, E.; del Bon Espirito Santo, F.; Freitas, R., and Morisette, J., 2006. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. *Proceedings of the National Academy of Sciences of the U.S.A* , Vol. 103: 14637–14641, 2006.

Little, Novem/ADL, 1999. *Analyse en evaluation van GAVE ketens: Management summary*. Arthur D. Little International Inc., GAVE-rapport 9908, Rotterdam.

OECD-FAO, 2007. *Agricultural Outlook 2007–2016*. www.agri-outlook.org.

OECD, 2008. *OECD Environmental Outlook to 2030*. Organisation for Economic Development and Cooperation (OECD), Paris.

OEKO, 2006. *GEMIS version 4.4-pre-release*, Oeko Institute-Institute for Applied Ecology, August 2006. www.gemis.de.

Ragwitz, M. T. F.; Resch, G.; Faber, T.; Haas, R.; Hoogwijk, M.; Voogt, M.; Rathmann, M., 2006. *Economic analysis of reaching a 20 % share of renewable energy sources in 2020*. Final report for the European Commission, DG Environment (Contract no. ENV.C.2/SER/2005/0080r),. Fraunhofer ISI, Energy Economics Group/TU Wien, Ecofys, August 2006.

Righelato, R. and Spracklen, V. Carbon, 2007. Mitigation by biofuels or by saving and restoring forests? *Science*, 317, p. 902.

Searchinger, T.; Heimlich, R.; Houghton, R.A.; Dong, F.; Elobeid, A.; Fabiosa, J.; Tokgoz, S.; Hayes, D., and Yu T., 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land use change. *Science* 319, 2008, pp. 1238–1240.

Smeets, E. M. W.; Faaij, A. P. C.; Lewandowski, I. M.; Turkenburg, W. C., 2007. A bottom-up assessment and review of global bio-energy potentials to 2050. *Progress in Energy and Combustion Science*, Vol. 33, 2007, pp. 56-106.

Stern, 2006. Stern Review, *The Economics of Climate Change*, Cambridge University Press, United Kingdom, 2006.

UN-Energy, 2007. *Sustainable Bioenergy: A Framework for Decision Makers*. Paper by UN-Energy, an Inter-body working group of the United Nations, FAO (UN Food and Agriculture Organisation), Rome, 2007.

Van Dam, J.; Faaij, A. P. C.; Lewandowski, I.; Fischer, G., 2007. Biomass production potential in Central and Eastern Europe under different scenarios. *Biomass and Bioenergy*, Vol. 31, 2007, pp. 345-366.

Viewls, 2005. *Biofuel and bioenergy implementation scenarios.* Wakker, A.; Egging, R.; van Thuijl, E.; van Tilburg, X.; Deurwaarder, E.; De Lange, T.; Berndes, G.; Hansson, J. Final Report, VIELS WP5, modelling studies, ECN, the Netherlands; Chalmer University of Technology, Energy and Environment, Sweden, 2005.

Wang, 2001. *Greet Model version 1.5a Centre of Transportation Research*, Argonne National Laboratory, 2001.

WWF, 2007. *Rain Forest for Biodiesel? Ecological effects of using palm oil as a source of Energy*. Reinhardt G.; Rettenmaier, N.; Gärtner, S.; Pastowski, A., 2007. Rainforest for Biodiesel? . www.wwf.fi/wwf/www/uploads/pdf/rainforestforbiodiesel_final_042007.pdf.

Yamamoto, H.; Fujino, J.; Yamaji, K., 2001. Evaluation of bioenergy potential with a multi-regional global-land-use-and-energy model, , *Biomass and Bioenergy*, Vol. 21, 2001, pp. 185–203.

Annex 1 Assessments of bioenergy potential (literature review)

The variation in results between the various studies is due to differences in assumptions (e.g. regarding agricultural yield improvements, costs, etc.), models used and variations in scope. Some of the key differences are summarized in the table below, and include:

- Ericsson and Nilsson (2006) exclude waste in their assessment;
- Fischer *et al.* (2007) only assess biomass for biofuels potential, and exclude municipal waste and forestry residues;
- Van Dam *et al.* (2007) only made an assessment of Central and Eastern Europe;
- the high outcome of Smeets *et al.* (2007) might be caused by high expectations concerning the efficiency of food production.

Table 8.1 Summary of the literature

Study	Period	Region	Source
EEA, 2006	2010–2030	EU-25	A, F, W
Ericsson & Nilsson, 2006	2010–2050	EU-25	A, F
Viewls, 2005	2030	EU-25	A, F, W
BTG, 2006	2010–2020	EU-27	A, F, W
Fischer *et al.*, 2007	2030	EU-27 +	A, F, (W([19]))
Smeets *et al.*, 2007	2050	World	A, F, W
Fischer and Schrattenholzer, 2001	2050	World	A, F, W
Dam *et al.*, 2007	2030	HU, SK, CZ, PO, LT, LV, EE	A, F
Hoogwijk *et al.*, 2005	2050–2100	World	A, F, W
Yamamoto *et al.*, 2001	2050–2100	World	A, F

Note: A = Agriculture; F = Forestry; W = Waste.

([19]) Only crop residues, no municipal and forestry waste.

Table 8.2 Comparison of the bioenergy potential studies

Source	Potential	Methodology	Strengths/weaknesses
EU-25			
EEA, 2006	2010 • 8.0 EJ/year 2030 • 12.4 EJ/year	Sources √ Agriculture √ Forestry √ Waste	Strengths • All possible biomass sources included • Environmental considerations explicitly included
		Assessment based on a model with environmental assumptions. Different approaches are used for each source: • Agriculture: amount is primarily dependent on the available land area and the yields of the cultivated bioenergy crops. The CAPSIM model is used to determine the land area. • Forestry: the potential is determined by the market demand for round wood. For future development of forest resources the EFISCEN model is used. • Waste: three different approaches are used: • For municipal solid waste and construction and demolition waste, forecasts of waste generation were available under a BUA scenario. • For agriculture and food wastes the data from the agriculture was used, combined with information on the amount of biowaste generated per tonne product and per animal. • For other biowaste streams, estimates of current quantities were obtained and then projections of the main socio-economic driver for that waste production were used to generate forecasts.	Weaknesses
Ericsson and Nilsson, 2006	Short term (10–20 years) • 3.1 EJ/year (EU-15) • 4.8-6.0 EJ/year (EU-15) • 2.1-2.6 EJ/year (ACC10)	Sources √ Agriculture √ Forestry x Waste	Strengths • Transparent and simple method
		A resource-focused approach and the assessments are made on the national level. Biomass categories included in this study are: forest residues, forestry by-products, straw, maize residues and energy crops. Municipal solid waste, used wood (i.e. demolition wood and railway sleepers) and manure are excluded. Constant population in Europe using the data from 2000 is applied for all time frames. International statistics rather than national data are applied in the overall assessment. Forestry data are taken from the Temperate and Boreal Forest Resource Assessment and agricultural data from the Food and Agricultural Organization (FAO).	

Table 8.2 Comparison of the bioenergy potential studies (cont.)

		Detailed assumptions: Forestry residues and forest industry by-products • based on biomass growth rather than current national fellings • only fellings from exploitable forest are included • all roundwood removals assumed to be used in the forest industry (excluding delicate stemwood from thinning operation) • the national fellings for each scenario are assumed to remain constant in absolute terms at a level of 100 % of the increment in 2000. • the residue-to-stem ratio is assumed to be 50 %higher for coniferous trees than for deciduous trees • a low(0.15-0.1) and a high harvest ratio(0.3-0.2) are applied • 25 % of felled roundwood is assumed to be available for energy purposes. Crop residues • include straw from wheat, barley, rye and oats, plus maize residues • only part of a residue is assumed to be harvested to ensure lonf term productivity (residue generation ratio for straw to cereal grain: 1.3 and for maize residue to maize :1) • one quarter of the residues is harvested and one third of the harvested residue is assumed to be used in animal husbandry • assessments are based on 1998-2002 average cereal and maize yields • assumption of yield increases are included Energy crop yields • short rotation forestry and herbaceous crops(e.g. Miscanthus) are assumed • the energy crop yields are assumed to be 50 % higher than the wheat yield • in the medium term perspective higher yield are applied(around 40 % higher) • a 30 % higher yields are applied to include the learning effect • area used for energy crops increases from 10 % of arable land to 25 % within scenarios.	Weaknesses • Cyprus and Malta are not included (should not pose a real problem) • Waste is not included in the assessment
Viewls, 2005	2030 • 12,2 EJ/year	Sources √ Agriculture √ Forestry √ Waste	Strengths • All potential biomass sources included • Assessment of impact of various biofuel policy and development scenarios.
		Calculations based on the BIOTRANS model, a cost optimisation model for biofuels production. Calculated as the supply potential of lignocellulosic biomass in the form of residues and energy crops, assuming that the available land in 2030 is used for production of lignocellulosic crops.	Weaknesses • Methodology unclear • Focus on effect of biofuel policies, rather than on max. biomass potential

Table 8.2 Comparison of the bioenergy potential studies (cont.)

EU-27			
BTG, 2004	2010 • 7.7 EJ/year 2020 • 8.8 EJ/year	Sources √ Agriculture √ Forestry √ Waste	Strengths • Thorough analysis on several streams of biomass availability, based on a demand and supply model • All potential biomass sources included
		Calculation is based on the assumption that 10 % of the arable land is used to produce biomass fuels, and that half of that area is available for raw materials for bio-diesel and bio-ethanol.	Weaknesses • Based on rough assumptions regarding available land for biomass production
Fischer *et al.*, 2007	2030 (EU-27+) • 3.4–8.6 EJ/year (bio-fuel feedstock) • 2.6 EJ/year (agricultural residues) 2030 (Ukraine) • 2.3–4.6 EJ/year (bio-fuel feedstock) • 0.3 EJ/year (agricultural residues)	Sources √ Agriculture √ Forestry ~ Waste	Strengths • Detailed analysis • Various land use scenarios are assessed
		Europe's biofuel production potential has been determined for various scenarios up to 2030 using a detailed Pan-European resource database and a spatially explicit feedstock suitability and productivity modeling framework. Future available land for bio-fuel production was estimated while satisfying projected food and feed demand at current aggregate European self-reliance levels for agricultural products. Using IIASA, CORINE, FAO models and databases.	Weaknesses • No forest residues • No municipal waste • Assessment limited to biomass potential for biofuels
Other			
Dam *et al.*, 2007	2030 Only Hungary, Slovakia, Czech Republic, Poland, Lithuania, Latvia, Estonia • 1.3–7.6 EJ/year	Sources √ Agriculture √ Forestry x Waste	Strengths • Detailed, national approach
		Bottom-up approach on a country-to-country basis, using a model based demand for food and wood production, productivity for livestock, agricultural crops and forestry and costs for energy crop production. Five scenario's are created and several energy crops are simulated on the available land space, rated for suitability.	Weaknesses • No municipal waste • Limited number of countries

Table 8.2 Comparison of the bioenergy potential studies (cont.)

World			
Smeets *et al.*, 2007	2050 • 215–1 272 EJ/year (surplus agricultural land) • 76–96 EJ/year (agricultural and forestry residues) • 74 EJ/year (surplus forest growth)	Sources √ Agriculture √ Forestry √ Waste	Strengths • Global technical potential, all potential biomass sources included • Including several limitations like demand for food and biodiversity • Including export possibilities
		Bottom-up assessment using the Quickscan model, based on an evaluation of data and studies on relevant factors such as population growth, per capita food consumption and the efficiency of food production. Bioenergy from surplus natural forest growth is based on: • protected forest areas excluded • deforestation for bioenergy production was not allowed • competition between bioenergy and woodfuel, or industrial roundwood production is avoided	Weaknesses • Large range • Possible high outcome, due to high expectations concerning improvements of efficiency of food production
Fischer and Schrattenholzer 2001	2050 • 370–450 EJ/year	Sources √ Agriculture √ Forestry √ Waste	Strengths All potential biomass sources included
		Estimates are based on a classification of total land into four major land-use categories: arable land, grassland, forests and "other" land. Using FAO and IIASA data.	Weaknesses • Rough estimates due to division in large regions
Hoogwijk *et al.*, 2003	2050 • 35–1 135 EJ/year	Sources √ Agriculture √ Forestry √ Waste	Strengths • All potential biomass sources included • Attention is paid to competing biomass use for material • Assesses the conditions under which high potential can be achieved
		Explorative study of the geographical potential, based on a literature analysis. Six biomass resource categories for energy are identified: energy crops on surplus cropland, energy crops on degraded land, agricultural residues, forest residues, animal manure and organic wastes. The analysis makes use of a wide variety of existing studies on all separate categories. The study researches the upper limit of the amount of biomass that can come available as (primary) energy supply without affecting the supply for food crops.	Weaknesses

Table 8.2 Comparison of the bioenergy potential studies (cont.)

Yamamoto *et al.*, 2001	2050 • 182–270 EJ/year 2100 • 136–287 EJ/year	Sources √ Agriculture √ Forestry O Waste	Strengths
		Simulation using a global-land-use-and-energy model (GLUE-11)	Weaknesses • Not all regions are included in all analyses • Waste streams are not included
Hoogwijk *et al.*, 2005	2050 • 311–657 EJ/year 2100 • 395–1115 EJ/year	Sources √ Agriculture √ Forestry √ Waste	Strengths • Detailed and comprehensive study, all potential biomass sources included • Use of different scenarios
		Determine the geographical and technical potential of biomass at the grid cell level for the four IPCC SRES scenarios using the IMAGE 2.2 model. Based on four scenarios that differ according to: • Population growth • GDP development • Technological development; i.e. the MF for food production • The degree of social/environmental prioritizing; i.e. the diet • The degree of globalization; i.e. the trade level The geographical potential is the product of the available area for energy crops and the productivity level. Three categories of potential available areas are distinguished: (1) abandoned agricultural land; (2) low-productive land; and (3) rest land not required for food, forest or bioreserves. The potential of low-productive land is negligible.	Weaknesses • Large range of outcomes

Figure 8.1 EU bioenergy potential (literature review)

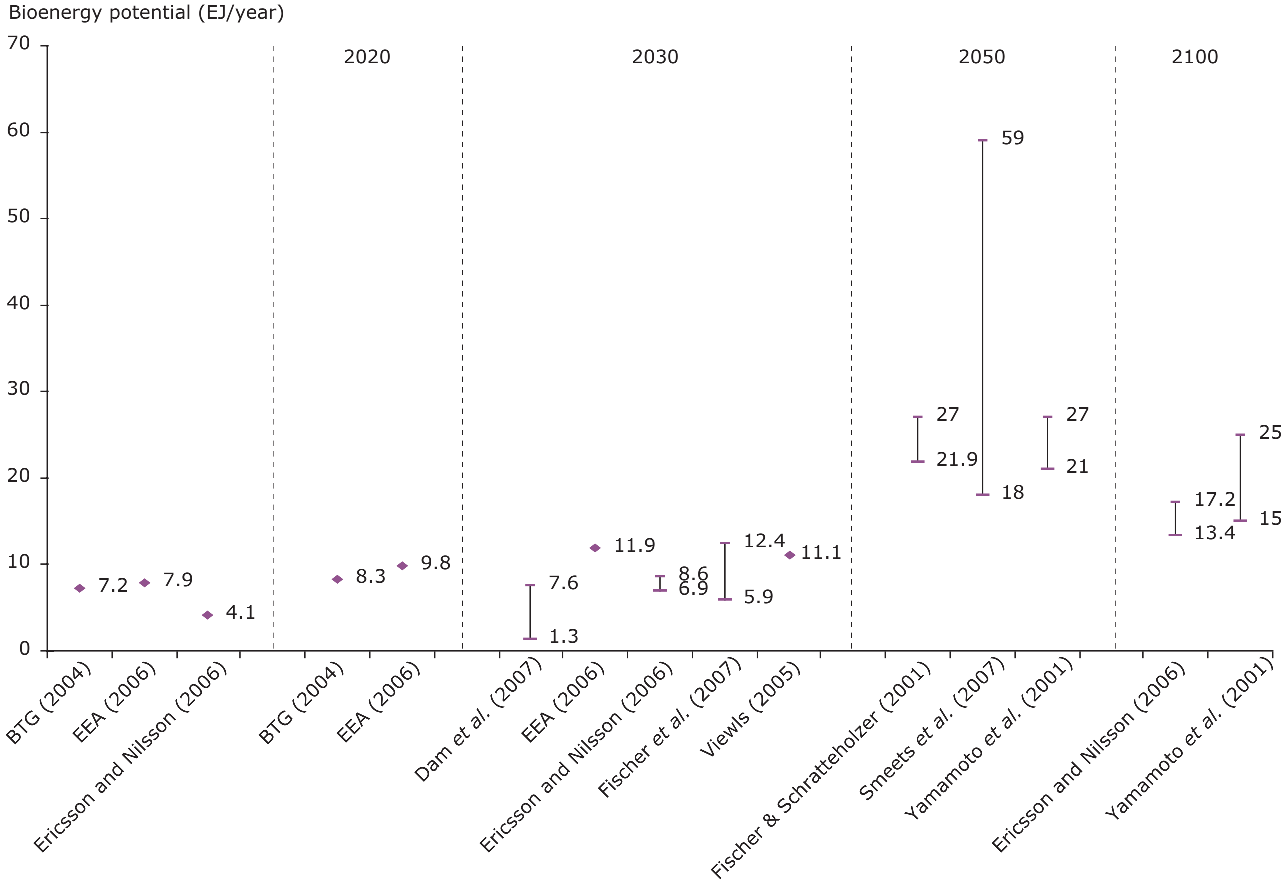
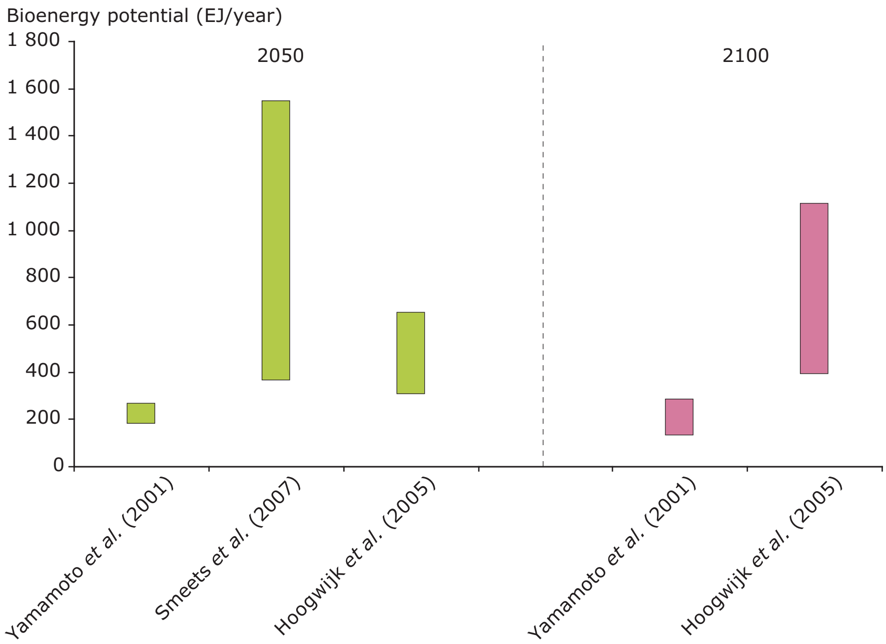
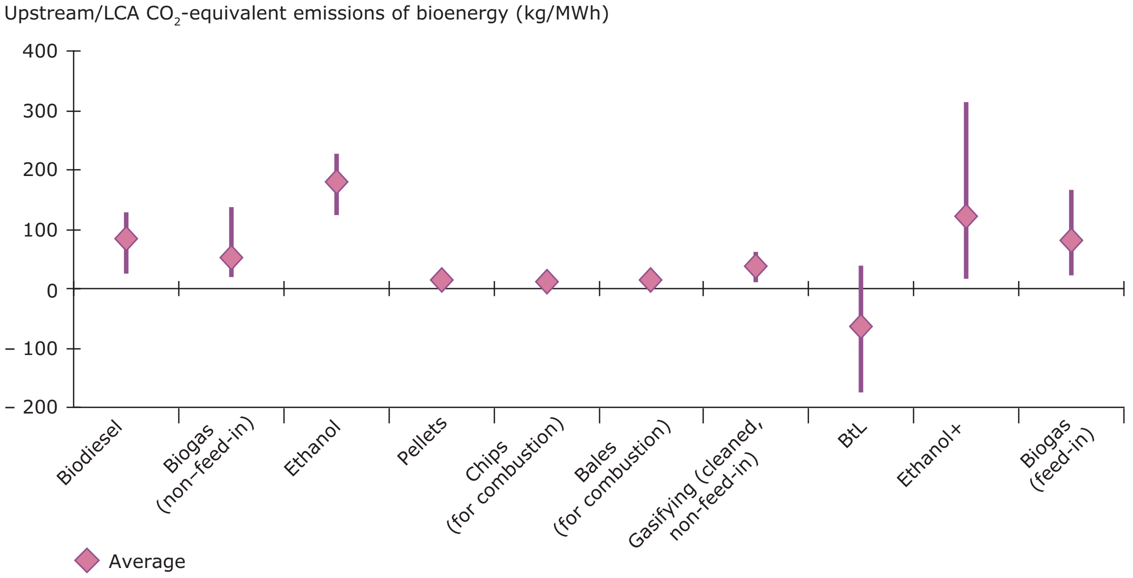


Figure 8.2 Global bioenergy potentials (literature survey)



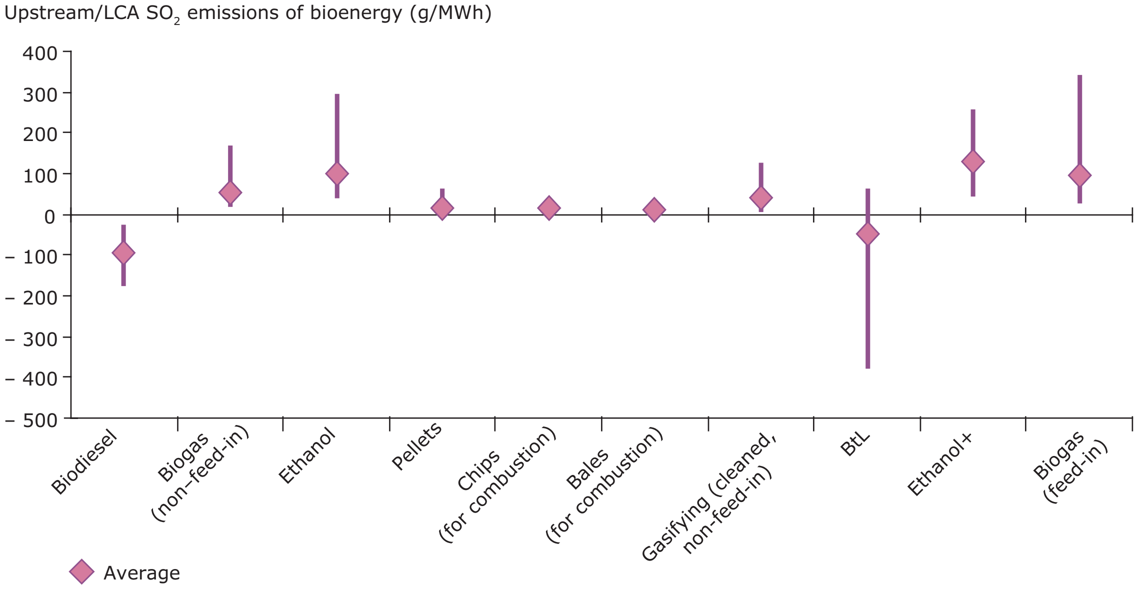
Annex 2 GEMIS database figures on LCA emissions from bioenergy pathways

Figure 8.3 Upstream/LCA GHG (CO_2-equivalent) emissions for bioenergy life-cycles in EU Member States



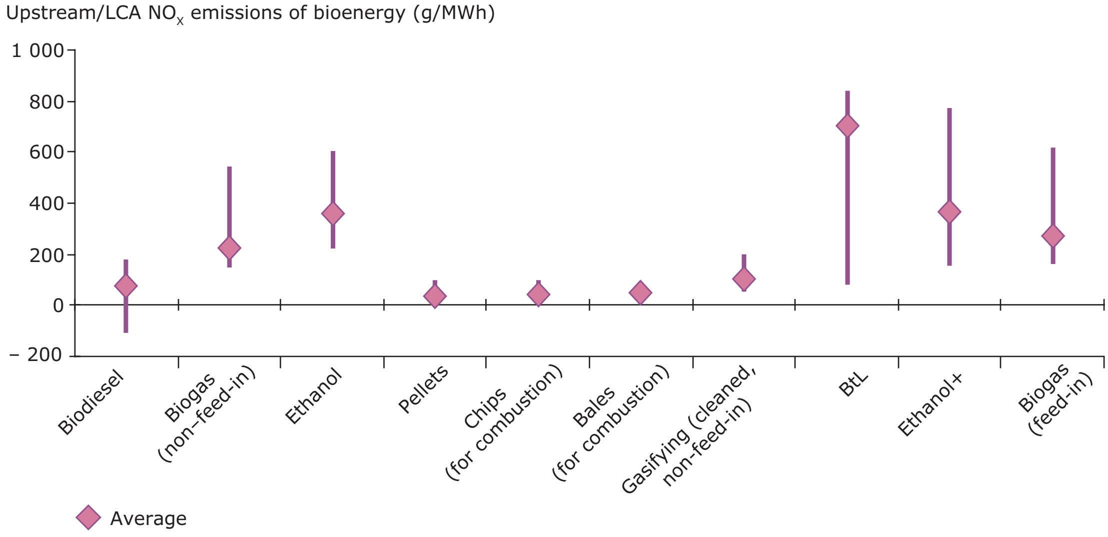
Source: Based on Fritsche *et al.*, 2006.

Figure 8.4 Upstream/LCA SO_2 emissions for bioenergy life-cycles in EU Member States



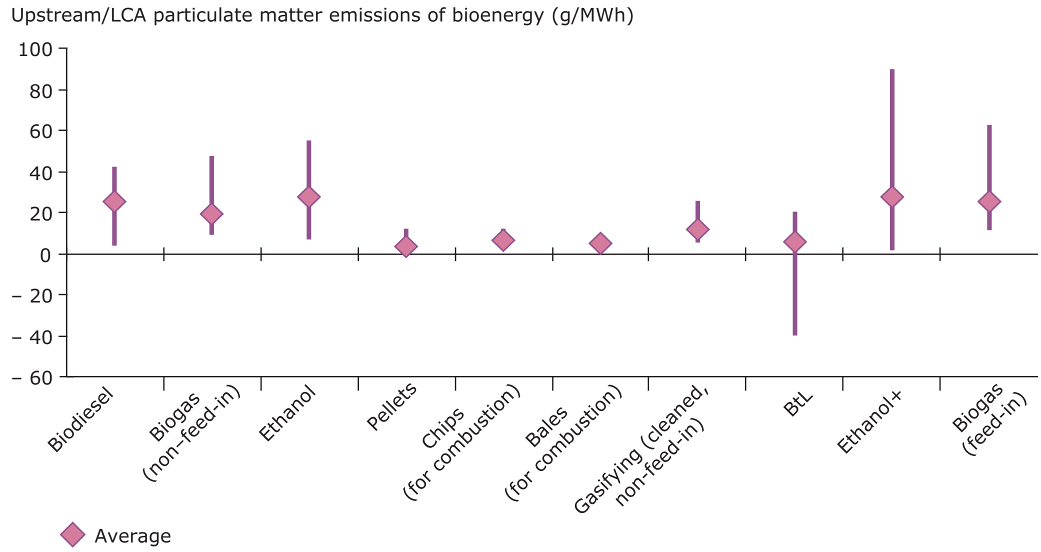
Source: Based on Fritsche *et al.*, 2006.

Figure 8.5 Upstream/LCA NO_x emissions for bioenergy life-cycles in EU Member States



Source: Based on Fritsche *et al.*, 2006.

Figure 8.6 Upstream/LCA particulate matter emissions for bioenergy life-cycles in EU Member States

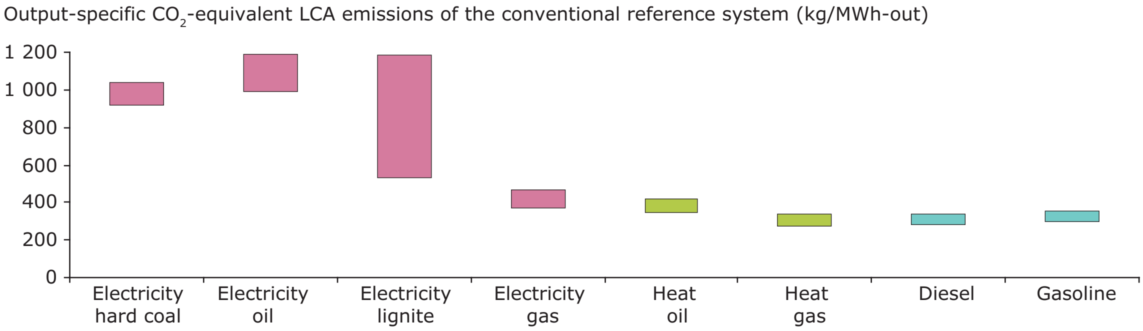


Source: Based on Fritsche *et al.*, 2006.

Conventional energy systems life cycle assessments from GEMIS

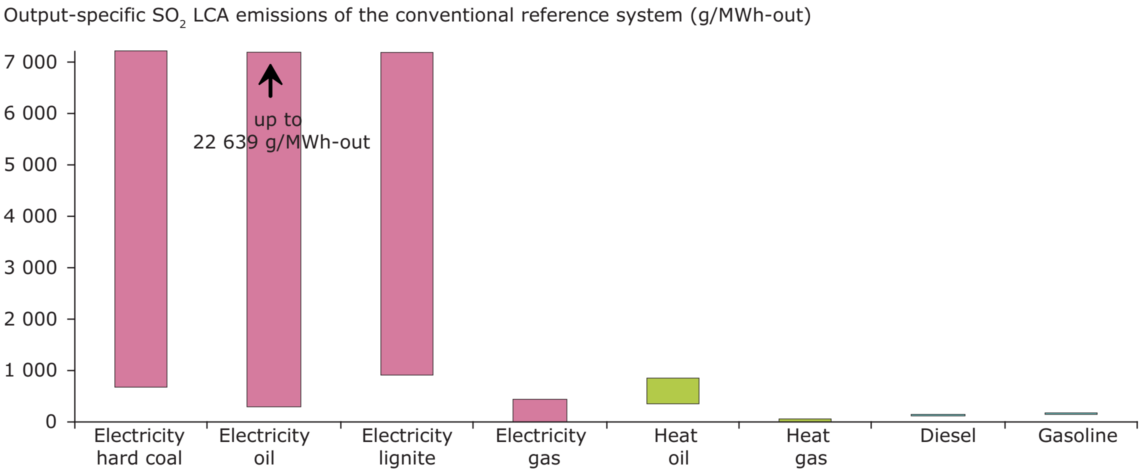
The following figures illustrate the data on greenhouse gas and air pollutant emissions from conventional energy in EU Member States for 2010. Fritsche *et al.* (2006) supplies an in-depth discussion of the figures as well as their evolution up to 2030. The coal-to-electricity fuel cycles vary to a large extent between EU Member States according to their coal extraction, transport distances, power plant efficiencies, and emission control technologies. In contrast, lesser differences can be observed in the case of gas or oil based systems, either for electricity generation or heating. The results for air pollutant emissions will be quite different between countries by 2010. It is expected that these differences will get smaller up to 2030 due to improvements in efficiency as well as improved control technologies.

Figure 8.7 LCA greenhouse gas (CO_2-equivalent) emissions for conventional energy life-cycles in the year 2010 in EU Member States



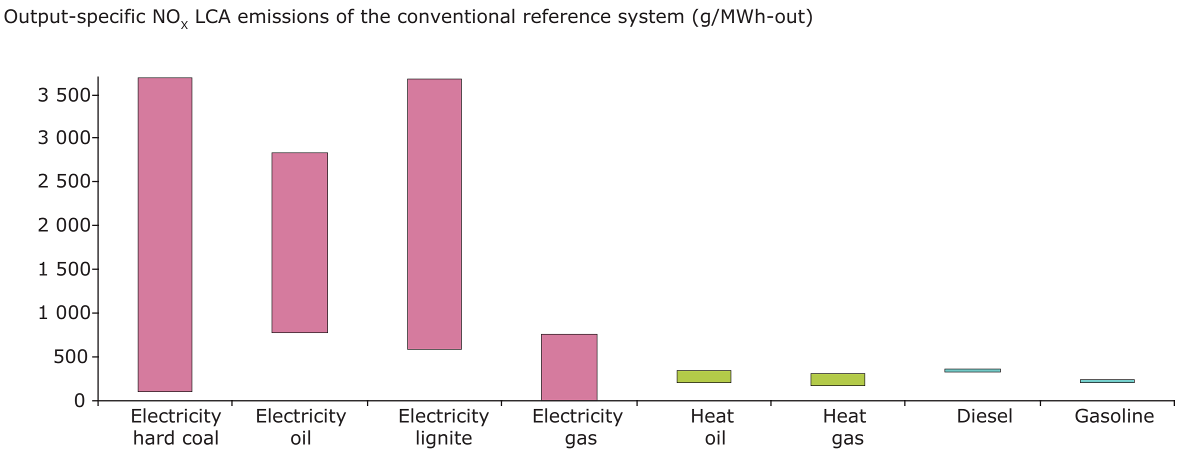
Source: Based on Fritsche *et al.*, 2006.

Figure 8.8 LCA SO_2 emissions for conventional energy life-cycles in the year 2010 in EU Member States



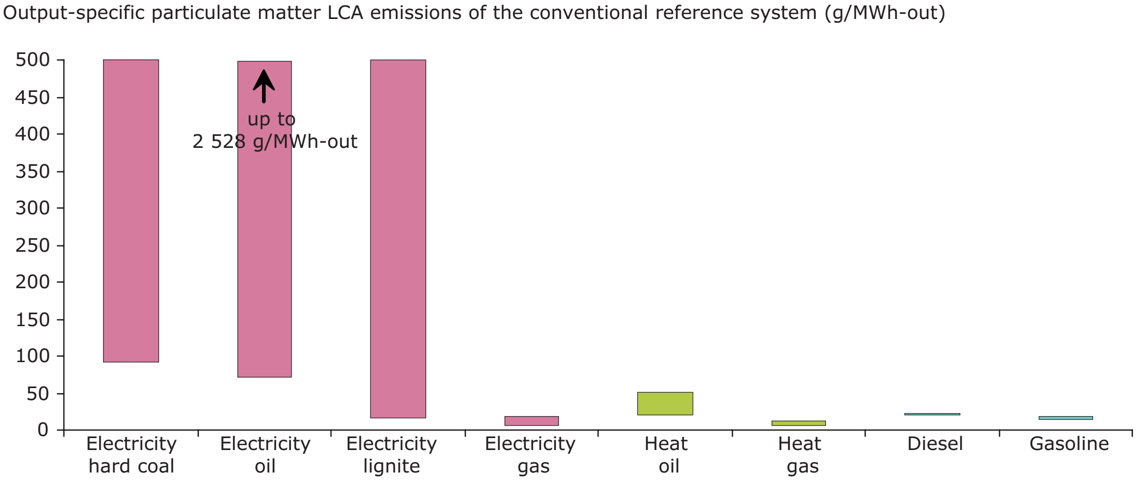
Source: Based on Fritsche *et al.*, 2006.

Figure 8.9 LCA NO_x emissions for conventional energy life-cycles in the year 2010 in EU Member States



Source: Based on Fritsche *et al.*, 2006.

Figure 8.10 LCA particulate matter emissions for conventional energy life-cycles in the year 2010 in EU Member States



Source: Based on Fritsche *et al.*, 2006.

Annex 3 LCA GHG emissions of biofuels and bioenergy — methodological discussion

Although the LCA methodology is generally quite well defined, results from different LCA studies may vary significantly, depending on the assumptions used and the choice of method. The main differences are mostly due to:

a) assumptions regarding important input data to the biofuel and bio energy chains;
b) treatment of by-products;
c) treatment of emissions due to land-use and vegetation change.

Some important factors that can vary between studies and subsequently create different results are the amount of fertilizer use and crop yield, N_2O emissions during crop cultivation, the energy efficiency of processes and the fuel used for the bioenergy/biofuel production process.

There may be several reasons for differences in input data:

- actual physical and economic differences between regions; e.g. soil fertility, precipitation, sunlight availability, temperature, regional market conditions, and regional energy infrastructure;
- use of information referring to different situations (e.g. a different year of reference);
- differences in technology and management, (e.g. field management and production plant configuration and specifications);
- the fact that some input parameters are not known exactly and can only be given with a relatively large degree of uncertainty.

Ethanol, for example, may be produced from wheat in the classical way, fermenting only the C6 sugars and supplying heat for fermentation and distillation by a gas fired boiler with a back pressure turbine. The still wastes are sold as feed. Alternatively, production plants like BER in Rotterdam apply industrial residual heat or CHP, digest the still wastes for methane production and may also capture CO_2 from fermentation and digestion for geological storage. This already optimized configuration could be improved further by pretreatment of the feedstock, for example by steam explosion to make the organic material more readily available for conversion.

The same potential diversity also applies to biomass utilization for power and/or heat production, where biomass may be co-fired or applied in stand alone plants that may differ with respect to scale and thermal and electric efficiencies.

Uncertainties in the data can be quite large, especially regarding the GHG emissions from crop cultivation. These are very difficult to determine accurately and the ranges of N_2O emission factors provided in the scientific literature are therefore very large.

Treatment of by products

Crops are a complex combination of various components (sugars, proteins, fats). This means that by-products arise when physical or biological processes are applied for biofuel production. Examples are pulp from sugar beet or press cake from rape seed.

The treatment of these by products in the various LCA's differs in two aspects:

- The application of these by-products;
- The appraisal of these by-products, as expressed in the methodology used by which part of the environmental impact related to crop cultivation and biofuels production is allocated to the by-products.

Since LCAs aim to include the GHG emissions saved due to the reduced need for alternative products, the result will depend on these two aspects, which are further elaborated as follows:

Effects of by-product use on GHG emissions

The by-products of biofuel chains can often be used for different applications, for example for animal feed or for energy generation. These products then replace other products, such as grain or natural gas, which would have also caused GHG emissions. The emissions thus prevented by the by-products should be accounted for in the biofuel LCA. LCA results therefore depend on the assumed use of the by-products.

An illustration of the effect of different uses of the by-product on the LCA results is shown in Table 8.3 (from EC, 2008b), where GHG savings of a number of biofuels are shown for two different by-product applications: animal feed and energy.

Clearly, in all cases considered here, the calculated GHG savings are higher if the by-products are used for energy than as animal feed. However, in practice, the majority of by-products are currently used for animal feed since that generates the highest market value. As pointed out in EC (2008b), using the by-products as animal feed is also optimal from a land-use perspective. Cultivating wheat, soy, corn or other comparable animal feed crops requires land for agriculture, and causes GHG emissions due to land-use conversion that is not currently included in LCAs for these crops.

Effects of LCA methodology on GHG emissions

The environmental impact of utilizing the by-products, and substituting primary products in the process, may be taken into account by using system extension, analysing in detail the GHG emissions prevented by the by-product. Alternatively, an allocation methodology can be applied. Part of the GHG emissions in the product chain are then allocated to the by-products, reducing the emissions allocated to the biofuel. Allocation can be based on product characteristics, such as energy content, mass or market value. Considering the latter as an example for how allocation works; if the financial value of the by-products is 30 % of the value of the biofuel, 30 % of the GHG emissions of the product chain up to the by-product production should be allocated to the by-product.

System extension is generally considered to be the most accurate methodology and is applied in the JEC WTW study for biofuels (CONCAWE/JRC/EUCAR, 2007) for example. However, allocation is usually easier to implement as the data required are generally much easier to gather. Because of this, the EU (EC, 2008b) and some of the EU Member States that currently develop default values and/or tools to calculate the GHG emissions of specific biofuels sold (Germany, Netherlands), have opted for allocation. Discussions have been ongoing between the various countries to arrive at a common allocation methodology ([20]). A discussion on the pros and cons of substitution and the various allocation options can be found in (EC, 2008b).

The different methods to account for by-products in a biofuel LCA lead to different GHG emission results. Substitution and allocation by energy content, mass or market value all lead to a different share of GHG emissions in the biofuel chain being allocated to the by-products. Clearly, the results differ significantly depending on the methodology used, as Table 8.4 illustrates (from (EC, 2008b)).

Treatment of emissions due to land-use and vegetation change

Land-use change and the vegetation change resulting form crop cultivation for biofuels or

Table 8.3 GHG savings of various biofuels, according to the substitution approach, for two different by-product applications

Biofuel production pathway	By-product	GHG savings according to substitution approach	
		By product used for animal feed	By product used for energy
Rape seed biodiesel	Press cake	38 %	69 %
Sunflower biodiesel	Press cake	64 %	86 %
Sugar beet ethanol	Beet pulp	31 %	65 %
Wheat ethanol (processing: conventional natural gas burner)	Distillers dry (DDGS)	29 %	40 %

Source: EC, 2008b.

([20]) These discussions so far have not led to a common methodology for by-product treatment in the various CO_2-tools calculations tools. However, we would expect that the Member States involved will follow the proposal of the European Commission to use allocation by energy content (EC, 2008b), or any other methodology to be defined in the final renewable energy EU directive.

Table 8.4 LCA results for different allocation methods and the substitution approach: GHG emission reductions of various biofuel chains

	Substitution		Allocation, by		
	By product to animal feed	By product to energy	Mass	Energy	Economic value
Rape seed biodiesel	38 %	69 %	60 %	44 %	36 %
Sunflower biodiesel	64 %	86 %	69 %	59 %	49 %
Sugar beet ethanol	31 %	65 %	60 %	49 %	29 %
Wheat ethanol (conventional natural gas boiler)	29 %	40 %	57 %	45 %	19 %
Sugar cane ethanol	n.a.	88 %	77 %	77 %	75 %

Source: EC, 2008b.

bioenergy that has not been met through yield increases, can result in massive GHG emissions. As with by-products the issue has several different aspects that have to be taken into account in LCA's:

- the sheer size of the resulting GHG emissions;
- how should 'a once only' event be accounted for in an LCA covering a period of time of at least several decades?
- should indirect land-use changes resulting from the first order land-use change induced by crop cultivation, be taken into account and how this should be done?

The issues are discussed in the three paragraphs below.

GHG emissions from land-use change

Cultivation of crops for biofuels or bioenergy may require extra land when increased demand for agricultural commodities, such as that caused by bioenergy, can no longer be met by increasing yields. All land on earth already has a function, whether for economic activities, for nature conservation or as area under common exploitation (which can lead to degradation). In such cases cultivation of crops for biofuel or bioenergy production automatically means land-use change and also changes in vegetation, since the original vegetation will have to be cleared.

Change in vegetation can have both adverse and beneficial effects depending on the relative size of the carbon stock present in the original vegetation and soil, and in the vegetation and soil in the case of crop cultivation for biofuels.

Natural forests and grasslands contain significant amounts of carbon in the vegetation and soil. Hence, when natural grassland or forest is converted to agricultural land for biomass production, the carbon in the soil and in the original plants (roots, tree trunks, stems, branches, humus, etc.) is released. These emissions may amount to hundreds of tonnes of CO_2-equivalent per hectare.

On the other hand, a new forest established to produce wood for bioenergy on an area of previously barren soil, may lead to increased carbon sequestration.

The type of soil and its management also have a significant impact on GHG emissions arising from land-use change. Peat soils store enormous amounts of carbon and drainage for crop cultivation starts the oxidation of these stocks, making this kind of soil as poor an option for biofuel or bioenergy crop cultivation as for food crops if GHG emissions are to be avoided.

Intensive tillage of other soils without the addition of organic materials (e.g. crop residues, green manure, manure) will ultimately result in the oxidation of a large percentage (up to 50 %) of soil carbon. On the other hand, adding large quantities of organic material in combination with no tilling or a limited number of cultivation furrows will probably result in the accumulation of extra carbon in the soil.

Studies differ as to whether they include any or all of these emissions or carbon sequestrations in the emission factors, the depreciation methodology used and in their assumptions regarding whether or not biomass cultivation led to land conversion. The following sections, provides some examples to illustrate how large these effects can be.

The potential importance of land-use change emissions in the LCA

The second issue examines how to take into account 'once only' emissions related to land-use change in studies that consider initiatives that span at least several decades.

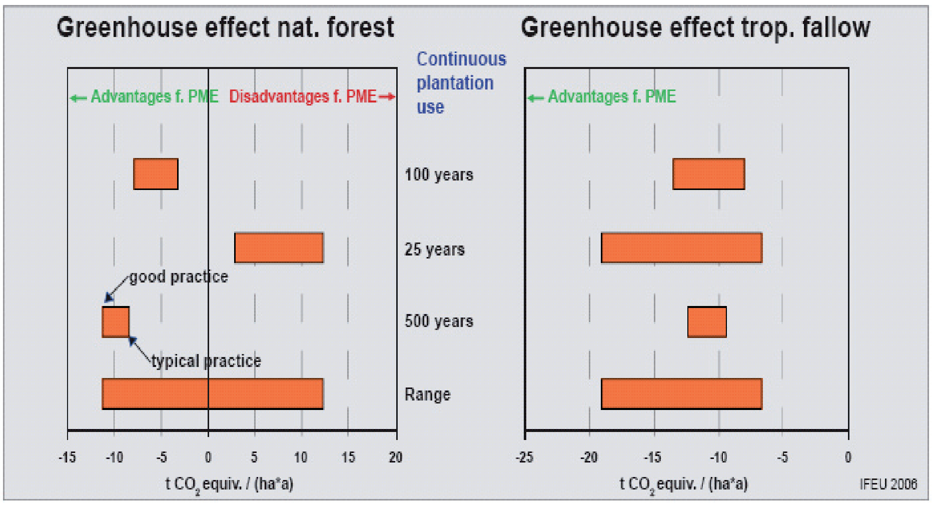
A significant part of land-use change GHG emissions may occur during or shortly after the conversion of the land, although some of the carbon stock will take much longer to release. Since the carbon stock is emitted during or shortly after conversion of the land, it is generally not considered to be realistic to allocate the specific land-use change emissions that take place in one year to the biomass produced in that specific year. After all, the land has not been converted for this one year of biomass production only, but for the biomass produced during the lifetime of the plantation. If the initial emissions were allocated to the biomass produced in the first year only, the year's biomass would probably score extremely negatively on the GHG balance, whereas the biomass in later years would score much better. Therefore, if an LCA takes these emissions into account, a decision has to be made regarding how they will be allocated to the biomass produced. Some LCA studies spread these emissions over 100 years of biomass production (i.e. 1/100th of these emissions will be allocated to the annual biomass produced on that land). Other LCAs opt for other time frames such as 10, 20 or 50 years. The IPCC has provided a methodology to calculate the annual effect of land-use change on the soil carbon balance (kg/ha/year) (IPCC, 2006), using a standard time period of 20 years ([21]).

The effect of land-use change emissions on the GHG savings by palm oil and the sensitivity of the results to soil type and depreciation period are illustrated in Figure 8.11 (WWF, 2007). In this graph, the GHG savings are shown for palm oil biodiesel for two different soil types and three different depreciation periods. In these calculations it is assumed that the land is degraded after the time period considered. The results show that these biofuels are expected to lead to GHG emissions reductions if the plantation is replacing tropical fallow land, even if a depreciation period of 25 years is chosen. If the soil used to be natural forest but not peat soil, GHG emissions are still saved if the conversion emissions are depreciated over 100 or 500 years. However, the emissions are found to increase if a 25 years depreciation period is used.

The potential importance of indirect land-use change

More recently, the effects of indirect land-use change are receiving more attention. The basic premise behind this effect is that, since the increasing demand for biofuel is not compensated for by a reduced demand from the food industry, increased

Figure 8.11 Effects of different depreciation periods and original soil type on the GHG savings of palmoil biodiesel



Source: IFEU, 2006.

([21]) The purpose of the IPCC work was to decide after how many years one can reasonably assume that land has reached its new carbon stock equilibrium. This differs from the question asked here, which is how many years to allow for the greenhouse gas savings from the use of bioenergy to pay back the greenhouse gas damage caused by the land-use change.

biofuel crop cultivation increases global demand for agricultural production. On a global scale, this increased demand can be met by:

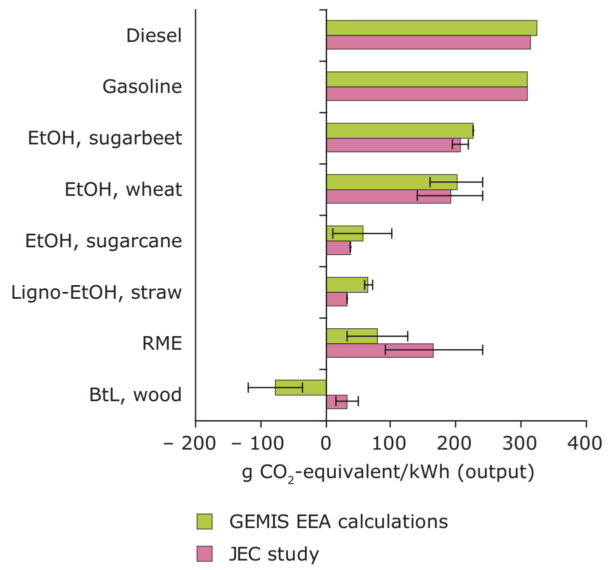
- increased productivity of existing agricultural land;
- biofuel feedstock cultivation on previously uncultivated land;
- biofuel producers buying feedstock from existing agriculture, forcing other users to shift to other products or regions.

The first option will not cause any significant effects arising from land-use change. The second will cause direct land-use changes that have to be taken into account in the LCA according to standard LCA methodology. The last option leads to indirect land-use changes: even though the feedstock used for the biofuel production is harvested from land that is not changed the increased biofuel demand leads to new agricultural cultivation somewhere else in the world. For example, where rapeseed is bought by biofuel producers from land that used to produce rapeseed for food the short fall in food will have to be replaced from elsewhere,. This effect is much harder to quantify, since cause and effect relationships can really only be evaluated through agro-economic modelling. However, if indirect land-use change occurs due to increased biofuel demand, the biofuel LCAs should take this into account methodologically.

It is not yet clear how large these indirect effects are, since the effects of biofuels and bioenergy on the (global) agricultural market are not yet well understood, and researchers have only recently started to investigate this topic. In addition, results will depend on what the starting point is for the calculation of potential indirect effects from bio-energy cultivation, as the pressure from global food demand on world land resources is currently much lower than can be expected by 2030, for example (e.g. OECD, 2008).

In a recent memorandum on the issue Farrel and O'Hare (2008) roughly estimate the upper boundary of indirect emissions. They conclude that indirect land-use change can be expected to be a very large contributor to the global warming impact of biofuels.

Figure 8.12 The net life cycle greenhouse gas emissions of fossil fuels and various biofuels — comparison of data used in this study with results from JEC study



Note: Data shown are net GHG emissions, i.e. credits for by-products are included. In both calculations, the by-product of ethanol (DDGS) is used as animal feed, in the RME routes the glycerine is used as a chemical and the rapeseed cake is used as animal feed.

Source: CONCAWE/JRC/EUCAR, 2007.

Comparison of different LCA studies

In view of the variations in methodology and the LCA results, it is useful to see how the GEMIS modelling results used in this report compare with results from other LCA studies.

Biofuels

In the past 5 to 10 years, various research institutes have assessed the life cycle GHG emissions of biofuels for transport in the EU and in other world regions. In the EU, the JRC, Eucar and Concawe (JEC) published a comprehensive Well-to-Wheel analysis of various biofuels currently available and under development, in which various specific process configurations are considered. The JEC study is updated regularly and therefore incorporates recent data on feedstock production, production processes, etc. Its results are used for most analyses of biofuels by the European Commission. In addition, many other studies have been published that assess specific biofuel routes (e.g. ethanol from sugar beet or wheat, biodiesel from rapeseed, etc.) and/or countries or regions.

A comprehensive literature analysis on the environmental impact of biofuels for transport was carried out in 2004 (IFEU, 2004). In this report, results of 63 detailed studies were compared and.showed that results varied significantly, mainly depending on the assumptions and data used, regarding fertilizer use, yields, process technology and co-product assessment (as discussed in Section 1.1.1).

In order to assess the robustness of the GEMIS data used in this analysis, we have compared these data with the JEC results for similar biofuel chains, the results of which are shown in Figure 8.11. A more extensive comparison with results in the literature is provided in Table 8.5, where the GHG emission reduction used in this report (referred to as EEA or GEMIS), is compared to the results of (CONCAWE/JRC/EUCAR, 2007), (IFEU, 2004) and other recent studies (taken from Biofuels for Transport, IEA, 2004).

As these data show, GEMIS results match JEC and other results from the literature quite well in some cases, but differ significantly in others. The GHG emission reduction of the ethanol (EtOH) routes for GEMIS are in general slightly lower than the estimates from JEC and other sources, whereas the emission reductions from rapeseed biodiesel (RME) and BtL as calculated by GEMIS seem to be higher than other results in the literature due to the by-product substitution applied (i.e. the by-product glycerine is substituted as synthetic glycerine) ([22]). It should be noted that none of these models include emissions due to land-use change ([23]).

Table 8.5 An overview of greenhouse gas emission reduction data in the literature, compared to the data used in this study (referred as EEA, 2007)

Type of biofuel and feedstock	Literature source	Percentage GHG emission reduction
Ethanol from sugar beet	EEA	26 %
	CONCAWE/JRC/EUCAR, 2007	29–37 %
	IFEU, 2004	32–88 %
	GM, 2002	41 %
Ethanol from wheat	EEA	22–48 %
	JEC, 2007	22–54 %
	IFEU, 2004	9–70 %
	Levelton, 2000	29 %
	ETSU, 1996	47 %
Ethanol from cellulosic feedstock	EEA (straw and short rotation coppice)	74–81 %
	CONCAWE/JRC/EUCAR, 2007 (wheat straw)	90 %
	IFEU, 2004 (various feedstocks)	70–117 %
	GM, 2002 (wood, poplar plantation)	51 %
	Wang, 2001 (wood)	107 %
	GM, 2002 (straw)	82 %
	Levelton, 2000	57 %
Rape methyl ester (rme)	EEA	59–90 %
	CONCAWE/JRC/EUCAR, 2007	24–71 %
	IFEU, 2004	17–86 %
	GM, 2002	49 %
	Levelton, 2000	58 %
'Biomass–to–liquid' (btl)	EEA	100–138 %
	CONCAWE/JRC/EUCAR, 2007	84–95 %
	IFEU, 2004	77–94 %
	Little, Novem/ADL (eucalyptus), 1999	108 %

Note: Ranges in the results from EEA are due to regional differences within Europe.

([22]) In LCAs of biofuels, relatively modest differences in assumptions may lead to significant differences in outcome.
([23]) If land-use change occurs due to biofuels production, this may cause significant GHG emissions, both from above and below ground.

Bioenergy

In recent years there have been fewer international LCA studies on bioenergy than those for biofuels. The main reason is probably that the use of biomass as a fuel for heat and/or power is more of a country specific issue than its use for biofuels. Furthermore, because the use of biomass for heat and power has traditionally been a matter of waste processing or has evolved naturally from biomass based industries such as the wood industry and the paper industry its use for heat and power production has been less of an issue than its use for biofuels.

LCAs for different bioenergy routes are often difficult to compare. Many more feedstocks and process configurations are possible for bioenergy than for biofuels, and each leads to different emission results. Biomass can, for example, be co-fired in a coal power station, replacing coal. Power production in a stand alone power plant based on the same biomass fuel, however, will substitute average electricity production in the region considered. Plant configuration (e.g. CHP or power only, net efficiencies) and regional reference power production will determine net reductions in GHG. In addition, results may vary significantly depending on the reference use of the feedstock (e.g. would the biomass decay, or would it be burned). Finally, LCAs tend to differ with respect to the methodologies adopted.

An accurate comparison of the GEMIS results with those of other models would, therefore, require a very specific analysis of the configurations used, which has not been possible within the scope of this project.

The LCAs of bioenergy routes that have been carried out consistently show that this use of biomass may indeed lead to very high reductions in GHG percentages. A brief overview of results from several

Table 8.6 An overview of GHG emissions of various bioenergy routes, as found in literature

	Biomass/Bioenergy route	CO_2 emissions (g CO_2–equivalent/kWh_{el})	
GEMIS (EEA)		Incl. credit for by-products (net)	Excl. credit (gross)
	Wood chips SRF poplar Cogen ORC SNCR ATC 2010	– 1 340	125
	Straw bales cogen ORC SNCE ATC 2010	– 1 406	59
	Biogas (double crop) ICE cogen PAN 2010	– 24	148
EU, 2005	Bioenergy based energy supply (EU mix)	60	
FZKA, 2007	Emissions biomass CHP plant	– 740	
	Emissions biomass Cogen (500 MWel), or 20–47 MWel biomass plant	30	
CE, 2006 and CE, 2007	Eucalyptus wood pellets (waste), cofiring in existing coal fired power station, substituting coal 1 GJ ÷ 1 GJ Reference is pile burning	970	
	Forest industry waste streams (Canada), cofiring in modern coal fired power station substituting coal 1 GJ ÷ 1 GJ. Reference is landfilling	– 1 295	18.4
IEA, 2006b (Task 38)	Co–combustion of saw mill residues based pellets and Mountain Pine Beetle invested pines based pellets in a Dutch coal power plant, which also provides heat for district heating	– 1.3	Not relevant
WWF, 2007	Utilization of palm oil in different types of power plants:		
	CHP — substituting NG	– 390 to – 180	
	CHP — substituting LFO	– 270 to – 60	
	Undefined power plant, substituting av. electricity mix	– 230 to – 30	
	Undefined power plant, substituting power produced by NG power plant	– 230 to – 20	

studies is provided in Table 8.6 to illustrate how the data used in this report compare with results from the literature.

As stated previously, comparison between the different studies is difficult without an in-depth analysis of the calculations, and the basic and methodological assumptions applied in each study.

However some general observations can be made:

- the largest variations in these results are due to the impact of CHP in the GHG balance: the net reduction of GHG emission increases significantly where CHP is applied and credits for the heat are included in the calculations (these cases are indicated in grey);
- the CE Delft studies illustrate that utilizing organic waste is beneficial if the alternative is landfill or uncontrolled burning;
- the WWF study for palm oil applications in power production illustrates two effects;
- direct substitution of a fuel in a power plant yields larger reductions in GHG emissions than producing electricity in a dedicated power plant. In the latter case there is also competition with low carbon electricity production technologies, such as wind, hydropower and nuclear energy;
- good management practice in plantations can significantly reduce the GHG emissions related to the production of a particular biomass fuel.

The IFEU study considers a time horizon of 100 years. Emissions resulting from land-use change — e.g. from forest clearing to make space for palm oil plantation — are spread over this period of time. As shown earlier, the chosen time horizon has a very large impact on the resulting net GHG emission because it is the denominator for such 'once-only' emissions. Completely different but equally logical choices other than 100 years could also be made. For example, the IPCC methodology, applies a horizon of 20 years, because most emissions related to land-use change occur within this timescale. On the other hand, in some regions land has been used for agriculture for hundreds or even more than 1 000 years, so it could be argued that the former is still a legitimate time horizon.

The effects of allocation on the net GHG emissions allocated to electricity in CHP power plants have already been mentioned but the effects depend on the allocation methodology. In the EcoInvent LCA database, for example, GHG emissions have been calculated for a wood fired small CHP plant with a net electric efficiency of 15 % and a net thermal efficiency of 65 %, applying three different allocation methodologies: distribution according to energy content, exergy content or heat content. The resulting GHG emissions per kWhe amount to 4, 9 and 1 grams respectively for biomass production (avoided fossil fuel related emissions not being taken into account). Other allocation rules that might be applied are economic value or system expansion.

Annex 4 Selected technologies: description of selected conversion technologies

Table 8.7a Main characteristic of applied conversion technologies (electricity and CHP)

General data					Performance data			
Process name	Fuel input	Main output	2nd output	Plant size (main output) (MW)	Efficiency (main output) (%)	Couple ratio (2nd output) **	Full load hours (h/year)	Life-time (year)
Biogas/landfill gas/woodgas CHP plant (gas engine) small to large scale units	Biogas from energy crops (e.g. Src, maize, wheat, grass cuttings) and waste streams (e.g. Msw, wet and dry manure, sewage sludge, food proc. Residues) and forestry	Electricity	Heat	0.20–1.00	32–37 %	1.22–1.65	6 000–7 000	15
					37–42 %	1.00–1.27		
Woodgas CHP plant (fuel cells, MC or SO)	Gas from gasifier–based on forestry and energy crops (e.g. Src)	Electricity	Heat	0.30	50–54 %	0.60	6 000	15
					52–56 %	0.4–0.5		
Gas-fired CHP plant, small scale units	Gas from gasifier–based on waste streams (black liquor, straw) and forestry	Electricity	Heat	50.00	43 %	1.13	6 000	20
					45 %	1.00		
Gas-fired power plant, small scale units	Gas from gasifier–based on waste streams (black liquor, straw) and forestry	Electricity		50.00	48 %		6 000	20
					48 %			
Woodgas CHP plant (gas enginefixed bed), smalls cale units	Gas from gasifier–based on forestry and energy crops (e.g. Src)	Electricity	Heat	0.10	32 %	1.41	6 000	20
					37 %	1.14		
Woodgas CHP plant (micro gas turbine–fixed bed), small scale units	Gas from gasifier–based on forestry and energy crops (e.g. Src)	Electricity	Heat	0.10	33 %	1.53	6 000	10
					40 %	1.15		
CHP plant based on gasified miscanthus (gas engine with circulating fluitized bed combustion)	Gas from gasifier–based on energy crops (i.e. Miscanthus)	Electricity	Heat	1.00	37 %	1.22	6 000	20
					42 %	1.00		
Cofiring in a (natural) gas-fired combined cycle power plant	Gas from gasifier–based on waste streams (black liquor, straw) and forestry	Electricity		450.00	47 %		6 000	20
					50 %			
Local CHP plant for wood chips	Wood chips–from forestry and energy crops (i.e. Src poplar, src willow)	Electricity	Heat	0.80	14 %	4.71	6 000	20
					17 %	3.88		
Local CHP plant for wood chips based on ORC	Wood chips–from forestry and energy crops (i.e. Src poplar, src willow)	Electricity	Heat	0.80	13 %	5.23	6 000	20
					15 %	4.60		
Cofiring (forestry: 10 %, straw: 5 %) in a coal-fired CHP plant (steam turbine (back pressure) with fluidized bed combustion)	Wood chips from forestry and energy crops (i.e. Src poplar, src willow) or straw bales	Electricity	Heat	5.00	28 %	2.10	6 000	25
					30–32 %	1.80		
Cofiring (forestry: 10 %, straw: 5 %) in a new coal-fired power plant (steam turbine with FGD)	Wood chips from forestry and energy crops (i.e. Src poplar, src willow) or straw bales	Electricity		35.00–70.00	44 %		6 000	30
					50 %			
Local CHP plant for straw	Straw bales	Electricity	Heat	0.80	13 %	5.15	6 000	20
					16 %	4.19		
Local CHP plant for straw based on ORC	Straw bales	Electricity	Heat	0.80	10 %	7.10	6 000	20
					15 %	4.60		
CHP plant based on rapeseed oil (diesel engine) small to large scale units	Processed rapeseed and sunflower oil	Electricity	Heat	0.01–0.10	29–38 %	1.21–2.86	6 000	15
					29–38 %	1.21–2.86		
CHP plant based on RME (diesel engine) small to large scale units	Processed rme	Electricity	Heat	0.10–0.50	37–38 %	2.18–2.24	6 000	15
					37–38 %	2.18–2.24		
MSW incineration plant	Msw	Electricity	Heat	10.00	15.5 %	2.50	7 000	15
					18.1 %	2.50		
Wood pellet heating system with stirling engine	Wood pellets–mainly from wood processing residues	Electricity	Heat	0.05	17 %	3.76	6 000	10
					21 %	2.95		

Note: * Based on default settings with regard to W.A.C.C. (6.5 %) and technology-specific lifetime (15–25 years). In case of combined heat and power etc. a heat bonus is taken into account.
** ($MWh_{main}/MWh_{sec.output}$).

Source: Based on Öko, 2006.

Table 8.7a Main characteristic of applied conversion technologies (electricity and CHP) (cont.)

General data	**Cost data**						**Direct emissions**						**Reference year**
Process name	Investment cost (EUR/kW)	Operation and maintenance cost (EUR/kW/year)	Fuel cost (input)		Generation cost * (main output)		SO_2	NO_x	Particulate matter	CO_2	CH_4	N_2O	
			Minimum	Maximum	Minimum	Maximum							
			(EUR/MWh_{in})		(EUR/MWh_{out})		(g/MWh_{out})	(g/MWh_{out})	(g/MWh_{out})	(g/MWh_{out})	(g/MWh_{out})	(g/MWh_{out})	
Biogas/landfill gas/woodgas CHP plant (gas engine) small to large scale units	575–896	86–203	10.4	53.6	21.7	160.4	1–279	616–811	3–22	0	3–30	10–19	2010
	556–787	85–137	8.6	55.1	19.8	153.9	1–121	299–570	3–20	0	3–16	3–14	2030
Woodgas CHP plant (fuel cells–MC or SO)	1 100	171	30.2	53.6	91.6	140.3	0	3–9	0	0	1–76	0	2020
	900–1 000	160	14.4	51.1	58.3	130.2	0	3–5	0	0	1–13	0	2030
Gas-fired CHP plant, smale scale units	850	53	14.8	49.7	28.3	110.5	1	756	5	0	38	30	2010
	675	56	11.5	51.1	20.2	108.2	1	238	5	0	12	14	2030
Gas-fired power plant, smale scale units	810	49	14.8	49.7	51.1	123.8	0	670	5	0	34	27	2010
	657	55	11.5	51.1	42.2	121.4	0	214	4	0	11	13	2030
Woodgas CHP plant (gas engine–fixed bed), small scale units	1 207	208	30.2	53.6	112.3	185.4	1	926	26	0	26	26	2010
	1 167	207	14.4	51.1	62.6	161.9	1	445	22	0	11	4	2030
Woodgas CHP plant (micro gas turbine–fixed bed), small scale units	737	185	30.2	50.0	101.1	161.1	1	332	27	0	66	27	2010
	597	179	14.4	51.1	50.9	142.7	1	165	11	0	55	11	2030
CHP plant based on gasified miscanthus (gas engine–with circulating fluitized bed combustion)	575	98	18.0	40.0	43.3	102.7	1	800	22	0	22	22	2010
	556	97	30.6	41.4	72.4	98.1	1	392	20	0	10	4	2030
Cofiring in a (natural) gas-fired combined cycle power plant	435	25	14.8	49.7	42.1	116.4	0	684	5	0	34	27	2010
	383	22	11.5	51.1	32.5	111.7	0	214	4	0	11	13	2030
Local CHP plant for wood chips	3 885	453	18.4	32.8	147.6	250.4	840	1 397	4	0	70	14	2010
	3 170	430	15.8	39.6	115.8	255.6	691	1 150	1	0	29	6	2030
Local CHP plant for wood chips based on ORC	4 670	413	18.4	32.8	149.9	260.7	980	1 630	5	0	81	16	2010
	3 932	391	15.8	39.6	115.2	273.6	784	1 304	1	0	33	7	2030
Cofiring (forestry: 10 %, straw: 5 %) in a coal-fired CHP plant (steam turbine (back pressure) with fluidized bed combustion)	200	123	11.2	32.8	9.4	87.2	33–83	922–939	0	0	5	487–661	2010
	200	123	13.7	39.6	19.0	110.7	31–73	806–876	0	0	4–5	426–617	2030
Cofiring (forestry: 10 %, straw: 5 %) in a new coal-fired power plant (steam turbine with FGD)	150	95	11.2	32.8	47.2	91.6	14–35	390–397	0	0	14–15	40–41	2010
	150	95	13.7	39.6	45.2	97.3	12–31	230–235	0	0	13	13	2030
Local CHP plant for straw	4 494	471	11.2	14.0	103.5	125.7	953	2 953	7	0	74	15	2010
	3 803	451	13.7	18.4	113.4	142.7	774	2 399	4	0	30	6	2030
Local CHP plant for straw based on ORC	5 397	436	11.2	14.0	103.5	127.5	1 032	3 199	8	0	80	16	2010
	4 522	410	13.7	18.4	112.9	144.1	826	2 559	4	0	32	6	2030
CHP plant based on rapeseed oil (diesel engine) small to large scale units	2 200–3 500	151–236	45.4	59.8	153.3	271.6	0	1 843	16–78	0	4	34	2010
	2 200–3 500	151–236	43.6	65.2	148.6	290.2	0	1 843	16–78	0	4	34	2030
CHP plant based on RME (diesel engine) small to large scale units	880–1 500	65–106	45.4	59.8	153.1	149.6	26	1 875	79–126	0	4	35	2010
	880–1 500	65–106	43.6	65.2	86.5	164.2	26	1 875	79–126	0	4	35	2030
MSW incineration plant	8 948	539.97	0.0	4.0	150.6	181.0	121	2 422	21	564 743	81	40	2010
	8 948	539.97	0.0	0.0	150.6	150.6	58	877	15	674 896	35	12	2030
Wood pellet heating system with stirling engine	4895	165	26.6	33.5	128.2	168.5	667	1 677	0	0	70	28	2010
	3652	128	31.0	38.5	120.5	156.5	540	1 357	0	0	57	23	2030

Note: * Based on default settings with regard to W.A.C.C. (6.5 %) and technology-specific lifetime (15–25 years). In case of combined heat and power etc. a heat bonus is taken into account.

Source: Based on Öko, 2006.

Table 8.7b Main characteristics of applied conversion technologies (heat and transport)

General data					Performance data				Cost data					
Process name	Fuel input	Main output	2nd output	Plant size (main output)	Efficiency (main output)	Couple ratio (2nd output) **	Full load hours	Life-time	Invest-ment cost	Operation and main-tenance cost	Fuel cost (input)		Generation cost * (main output)	
											Minimum	Maximum	Minimum	Maximum
				(MW)	(%)		(h/year)	(year)	(EUR/kW)	(EUR/kW/year)	(EUR/MWh$_{in}$)		(EUR/MWh$_{out}$)	
Residential central heating systems for wood chips, small to large scale units	Wood chips–from forestry and waste streams (e.g.Demolition wood, wood proc. Residues) and energy crops (i.e. Src poplar, src willow)	Heat		0.01–0.05	85–87 %		1600	15	454–611	15–20	2.5	32.8	42.3	91.5
					88–90 %				421–567	15–20	2.5	39.6	40.0	95.1
Local heating plant for wood chips, small to large scale units	Wood chips–from forestry and waste streams (e.g.Demolition wood, wood proc. Residues) and energy crops (i.e. Src poplar, src willow, miscanthus)	Heat		1.00–5.00	85–87 %		4 000	20	428–475	37–39	2.5	32.8	22.5	58.5
					88–90 %				383–425	17–35	2.5	39.6	15.7	63.5
Residential central heating systems for wood pellets, small to large scale units	Wood pellets–mainly from wood processing residues	Heat		0.01–0.05	86–88 %		1 600	15	720–765	23	26.6	33.5	92.5	104.2
					88–90 %				680–723	23	31.0	38.5	94.0	106.2
Local heating plant for wood pellets, small scale units	Wood pellets–mainly from wood processing residues	Heat		0.50	89 %		4 000	15	630.00	19.00	26.6	33.5	51.4	59.1
					91 %				595.00	19.00	31.0	38.5	54.6	62.9
Local heating plant (gasifier) for straw, smallscale units	Straw bales	Heat		0.15	89 %		3 200	15	703.00	66.00	11.2	14.0	56.4	59.7
					93 %				660.15	63.85	13.7	18.4	56.6	61.6
Local heating plant for straw, largescale units	Straw bales	Heat		5.00	87 %		4 000	20	575.00	118.40	11.2	14.0	55.5	58.8
					90 %				517.50	116.90	13.7	18.4	56.3	61.6
Biodiesel plant (FAME)	Rape and sunflower seed	Biofuel	Glycerol	12.50	67 %	3.15 kg/GJ	8 000	20	250.00	52.43	37.0	51.0	64.6	85.5
					67 %	3.15 kg/GJ			250.00	52.43	43.6	65.2	74.4	106.6
Bioethanol plant (EtOH)	Energy crops (i.e. Sorghum and corn from maize, triticale, wheat)	Biofuel		96.30	58 %		7 500	15	765.00	39.25	17.0	25.0	44.1	57.9
					58 %				650.00	33.94	17.0	25.0	41.7	55.5
Advanced bioethanol plant (EtOH+)	Energy crops (i.e. Sorghum and whole plants of maize, triticale, wheat)	Biofuel	Electricity	100.00	55 %	0.04	7 500	15	406.00	160.00	17.0	25.0	56.2	70.7
					60 %	0.04			350.00	145.00	17.0	27.0	50.8	67.5
BtL from gasifier	Energy crops (i.e. Src, miscanthus, red canary grass, switchgrass, giant red), selected waste streams (e.g. Straw) and forestry	Biofuel	Electricity	500.00	45 %	0.25	7 500	20	1 800.00	105.00	12.0	36.0	51.1	104.3
					50 %	0.25			1 600.00	97.50	14.0	39.0	49.1	99.1

Note: * Based on default settings with regard to W.A.C.C. (6.5 %) and technology-specific lifetime (15–25 years). In case of combined heat and power etc. a heat bonus is taken into account.
** ($MWh_{main}/MWh_{sec.output}$).

Source: Based on Öko, 2006.

Table 8.7b Main characteristics of applied conversion technologies (heat and transport) (cont.)

General data					Direct emissions						Reference year
Process name	Fuel input	Main output	2nd output	Plant size (main output)	SO_2	NO_x	Particulate matter	CO_2	CH_4	N_2O	
				(MW)	(g/MWh_{out})	(g/MWh_{out})	(g/MWh_{out})	(g/MWh_{out})	(g/MWh_{out})	(g/MWh_{out})	
Residential central heating systems for wood chips, small to large scale units	Wood chips–from forestry and waste streams (e.g.Demolition wood, wood proc. Residues) and energy crops (i.e. Src poplar, src willow)	Heat		0.01–0.05	107–109	379–388	14	0	126–129	5	2010
					103–105	265–271	5–6	0	68–69	3	2030
Local heating plant for wood chips, small to large scale units	Wood chips–from forestry and waste streams (e.g.Demolition wood, wood proc. Residues) and energy crops (i.e. Src poplar, src willow, miscanthus)	Heat		1.00–5.00	135–161	225–230	0–1	0	10–21	2–4	2010
					131–156	163–167	0	0	5–11	1–2	2030
Residential central heating systems for wood pellets, small to large scale units	Wood pellets–mainly from wood processing residues	Heat		0.01–0.05	133–136	292–299	0	0	12–13	5	2010
					130–133	206–243	0	0	7	3	2030
Local heating plant for wood pellets, small scale units	Wood pellets–mainly from wood processing residues	Heat		0.50	132	241	0	0	12	2	2010
					129	170	0	0	7	1	2030
Local heating plant (gasifier) for straw, small scale units	Straw bales	Heat		0.15	123	525	3	0	4	3	2010
					121	188	1	0	4	3	2030
Local heating plant for straw, large scale units	Straw bales	Heat		5.00	139	431	1		11	2	2010
					138	427	1		5	1	2030
Biodiesel plant (FAME)	Rape and sunflower seed	Biofuel	Glycerol	12.50	Not available separately — included in fuel-specific combined data for LCA and direct emissions						2010
											2030
Bioethanol plant (EtOH)	Energy crops (i.e. Sorghum and corn from maize, triticale, wheat)	Biofuel		96.30							2010
											2030
Advanced bioethanol plant (EtOH+)	Energy crops (i.e. Sorghum and whole plants of maize, triticale, wheat)	Biofuel	Electricity	100.00							2020
											2030
BtL from gasifier	Energy crops (i.e. Src, miscanthus, red canary grass, switchgrass, giant red), selected waste streams (e.g. Straw) and forestry	Biofuel	Electricity	500.00							2020
											2030

Note: * Based on default settings with regard to W.A.C.C. (6.5 %) and technology-specific lifetime (15–25 years). In case of combined heat and power etc. a heat bonus is taken into account.

Source: Based on Öko, 2006.

Annex 5 Feedstock-technology matrix

Table 8.8 Applied combination of feedstocks and technologies

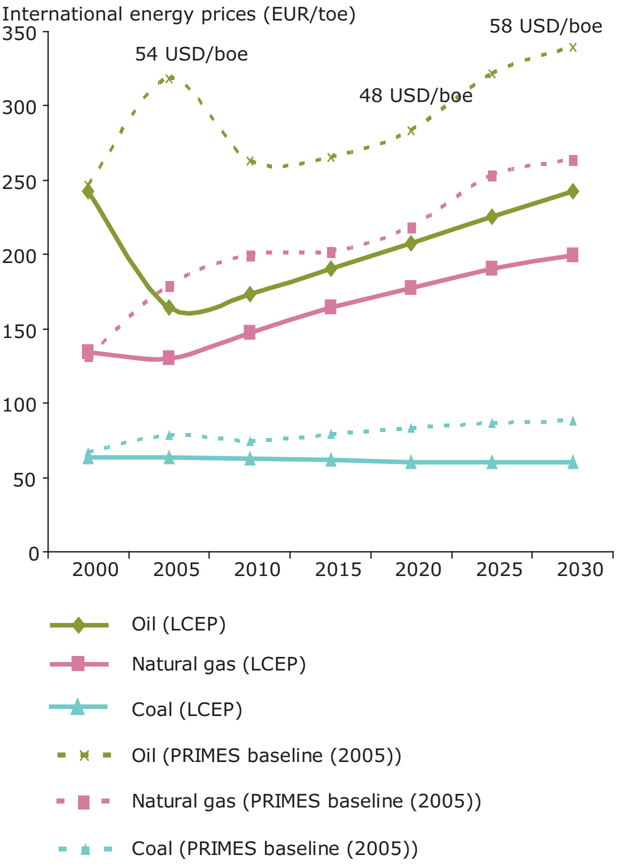
	Feedstock — technology — matrix	Biogas/Landfill gas/Woodgas CHP plant (gas engine) — small to large-scale units	1Woodgas CHP plant (fuel cells — MC or SO)	Gas-fired CHP plant — smale-scale units	Gas-fired power plant — smale-scale units	Woodgas CHP plant (gas engine — fixed bed) — small-scale units	Woodgas CHP plant (micro gas turbine — fixed bed) — small-scale units	CHP plant based on gasified miscanthus (gas engine — with circulating fluitized bed combustion)	Cofiring in a (natural) gas-fired combined cycle power plant	Local CHP plant for wood chips	Local CHP plant for wood chips based on ORC	Cofiring (forestry: 10 %, straw: 5 %) in a coal-fired CHP plant (steam turbine (back pressure) with FBC)	Cofiring (forestry: 10 %, straw: 5 %) in a new coal-fired power plant (steam turbine with FGD)	Local CHP plant for straw	Local CHP plant for straw based on ORC	CHP plant based on rapeseed oil (diesel engine) — small to large-scale units	CHP plant based on RME (diesel engine) — small to large-scale units	MSW incineration plant	Wood pellet heating system with stirling engine	Residential central heating systems for wood chips — small to large-scale units	Local heating plant for wood chips — small to large-scale units	Residential central heating systems for wood pellets — small to large-scale units	Local heating plant for wood pellets — small-scale units	Local heating plant (gasifier) for straw — small-scale units	Local heating plant for straw — large-scale units	Biodiesel plant (FAME)	Bioethanol plant (EtOH)	1Advanced bioethanol plant (EtOH+)	1BtL from gasifier
Agricultural biomass	Sweet sorghum	X																									X	X	
	Switch-grass	X						X	X												X								X
	Giant reed	X						X	X												X								X
	Reed canary grass	X						X	X												X								X
	Miscanthus	X						X	X												X								X
	Src willow	X	X			X	X	X	X	X	X	X	X							X	X								X
	Src poplar	X	X			X	X	X	X	X	X	X	X							X	X								X
	2-Culture red.	X							X																				
	2-Culture opt.	X							X																				
	Wheat whole plant																											X	
	Triticale whole plant																											X	
	Maize whole plant																											X	
	Grass cuttings	X							X																				
	Barley/triticale corn	X							X																		X		
	Wheat corn	X							X																		X		
	Maize corn	X							X																		X		
	Sunflower seeds															X	X									X			
	Rape seeds															X	X									X			
		Electricity and CHP																		Heat (incl. district heat)						Transport (fuels)			

Table 8.8 Applied combination of feedstocks and technologies (cont.)

Feedstock — technology — matrix		Biogas/Landfill gas/Woodgas CHP plant (gas engine) — small to large-scale units	1Woodgas CHP plant (fuel cells — MC or SO)	Gas-fired CHP plant — smale-scale units	Gas-fired power plant — smale-scale units	Woodgas CHP plant (gas engine — fixed bed) — small-scale units	Woodgas CHP plant (micro gas turbine — fixed bed) — small-scale units	CHP plant based on gasified miscanthus (gas engine — with circulating fluitized bed combustion)	Cofiring in a (natural) gas-fired combined cycle power plant	Local CHP plant for wood chips	Local CHP plant for wood chips based on ORC	Cofiring (forestry: 10 %, straw: 5 %) in a coal-fired CHP plant (steam turbine (back pressure) with FBC)	Cofiring (forestry: 10 %, straw: 5 %) in a new coal-fired power plant (steam turbine with FGD)	Local CHP plant for straw	Local CHP plant for straw based on ORC	CHP plant based on rapeseed oil (diesel engine) — small to large-scale units	CHP plant based on RME (diesel engine) — small to large-scale units	MSW incineration plant	Wood pellet heating system with stirling engine	Residential central heating systems for wood chips — small to large-scale units	Local heating plant for wood chips — small to large-scale units	Residential central heating systems for wood pellets — small to large-scale units	Local heating plant for wood pellets — small-scale units	Local heating plant (gasifier) for straw — small-scale units	Local heating plant for straw — large-scale units	Biodiesel plant (FAME)	Bioethanol plant (EtOH)	1Advanced bioethanol plant (EtOH+)	1BtL from gasifier
		Electricity and CHP																		Heat (incl. district heat)						Transport (fuels)			
Forestry	Competitive use	X	X	X	X	X	X		X	X	X	X	X							X	X								X
	Complementary fellings	X	X	X	X	X	X		X	X	X	X	X							X	X								X
	Forest resiudes	X	X	X	X	X	X		X	X	X	X	X							X	X								X
Biowaste	Household waste wood	X								X	X	X	X							X	X								
	Packaging waste wood	X								X	X	X	X							X	X								
	Demolition wood	X								X	X	X	X							X	X								
	Black liquor	X		X	X	X	X	X	X																				
	Sewage sludge	X							X																				
	Msw (composted)	X																											
	Msw (to landfill)	X																											
	Msw (not to landfill, recyling or compost)																	X											
	Wood processing residues																		X			X	X						
	Food proc. Resid.	X							X																				
	Dry manure (small farms)	X																											
	Dry manure (large farms)	X							X																				
	Other agricultural residues	X							X																				
	Wet manure (small farms)	X																											
	Wet manure (large farms)	X							X																				
	Solid agricultural residues	X		X	X	X	X	X				X	X	X	X									X	X			X	X

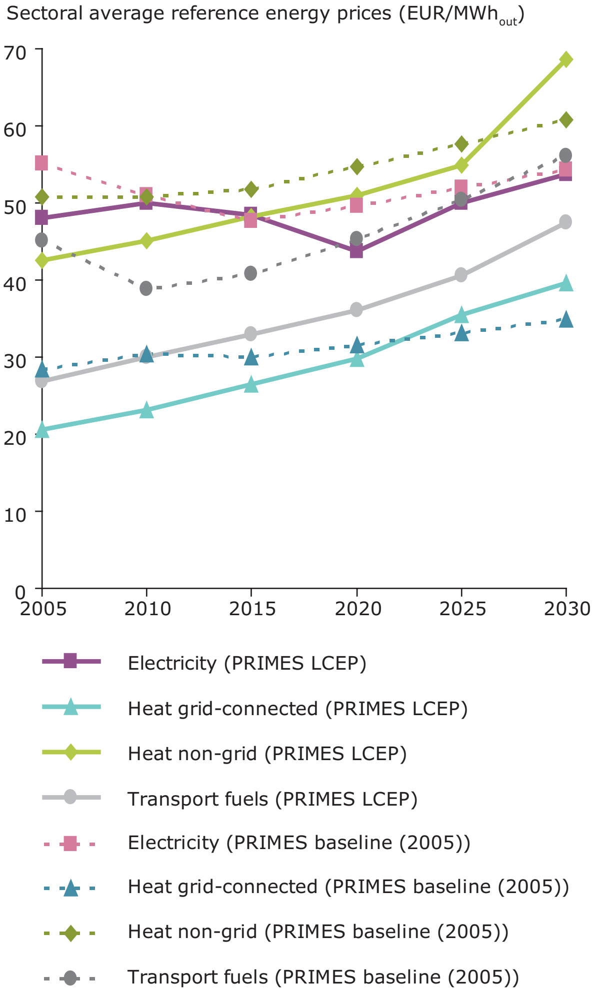
Annex 6 Scenario parameters: details of the PRIMES LCEP and baseline scenarios

Figure 8.13 Development of primary energy prices



Source: Based on PRIMES, 2004 and 2005.

Figure 8.14 Development of European average sectoral reference energy prices



Source: Based on PRIMES, 2004 and 2005.

Based on the primary energy prices, the applied carbon pricing and the typical country-specific conventional supply portfolio sectoral reference energy prices were derived. These prices reflect the competitive price floor with regard to bioenergy and determine the additional generation of bioenergy representing the difference between total generation cost and the reference prices. Figure 8.14 depicts the average dynamic development of derived reference prices at the European level. Note that, in the case of grid-connected heat supplies from district heating and CHP-plant, heat prices do not include the cost of distribution — i.e. they represent the price directly at a defined handover point.

Table 8.9 shows the development of the total and the sectoral energy demands of the two underlying scenarios — the conventional reference (PRIMES LCEP) and the alternative scenario (PRIMES baseline as of 2005). The alternative scenario is characterized by higher energy demand as compared to the PRIMES LCEP of 5 % in overall demand and as high as 10 % in terms of heat consumption.

Table 8.9 Energy consumption parameters

PRIMES LCEP	Unit	2005	2010	2015	2020	2025	2030
Gross inland consumption	Mtoe/year	1 708	1 750	1 778	1 800	1 792	1 811
	TWh/year	19 868	20 350	20 681	20 930	20 844	21 060
Gross electricity demand	TWh/year	3 155	3 426	3 670	3 900	4 089	4 236
Gross heat demand	TWh/year	6 768	6 923	7 008	7 022	6 954	6 964
Gross transport fuel demand	TWh/year	4 213	4 450	4 585	4 783	4 810	4 836
PRIMES baseline (2005)	**Unit**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Gross inland consumption	Mtoe/year	1 741	1 811	1 856	1 885	1 888	1 899
	TWh/year	20 250	21 067	21 588	21 920	21 963	22 081
Gross electricity demand	TWh/year	3 207	3 509	3 789	4 030	4 237	4 392
Gross heat demand	TWh/year	6 860	7 161	7 420	7 560	7 606	7 630
Gross transport fuel demand	TWh/year	4 119	4 354	4 462	4 642	4 650	4 608

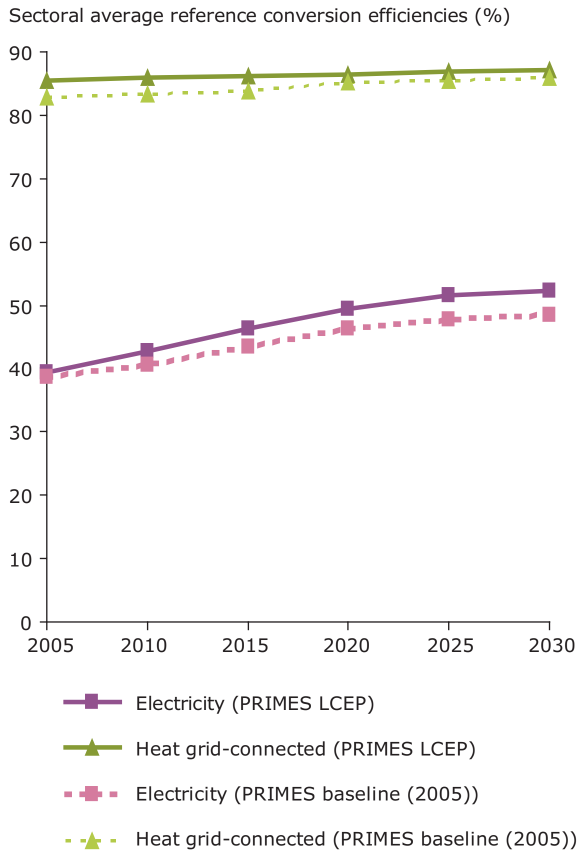
Source: Based on PRIMES, 2004 and 2005.

The conventional supply portfolio, i.e. the share of the different conversion technologies in each energy sector, was based on the PRIMES forecasts on a country specific basis. These projections on the portfolio of conventional technologies have a particular impact on this study's calculations of the avoidance of fossil fuels and the resulting CO2 emissions avoided. It is outside the scope of this study to analyse in detail which conventional power plants would actually be replaced by an alternative technology such as, a biogas plant installed in the year 2014 in a particular country (For example a less efficient existing coal-fired plant being replaced by a new high-efficient combined cycle gas turbine), so the following assumptions are made:

- Keeping in mind that besides renewable energies, fossil energy represents the marginal generation option that determines prices on energy markets, it was decided at the country level to stick to the sector-specific conventional fossil supply portfolio projections provided by PRIMES. Sector- as well as country-specific conversion efficiencies, as derived on a yearly base, are used to get a sound proxy to calculate from derived bioenergy generation figures back to the amount of avoided primary energy at the sectoral level. Assuming that the fuel mix is unaffected, avoidance can be expressed in units of coal or gas replaced.

- The determination of the GHG emissions and air pollutants avoided builds on the fossil fuels replaced. However, as LCA emissions are taken into account GEMIS serves as a database

Figure 8.15 Development of European average conversion efficiencies of conventional (fossil-based) electricity and grid-connected heat production



Source: Based on PRIMES, 2004 and 2005.

in this respect. An overview of the data for LCA emissions from fossil fuels, that form the conventional reference energy system, is provided in the following section.

The derived data on aggregate conventional conversion efficiencies characterizing the conventional reference energy system is as follows.

Figure 8.15 shows the dynamic development of average conversion efficiencies as projected by PRIMES for conventional fossil-based electricity generation, as well as for grid-connected heat production at the European level. Conversion efficiencies are shown for both the PRIMES baseline (as of 2005) and the PRIMES LCEP case. For the transport sector, where efficiencies are not explicitly expressed in PRIMES results, the average efficiency of the refinery process to derive fossil diesel and gasoline was assumed to be 95 %.

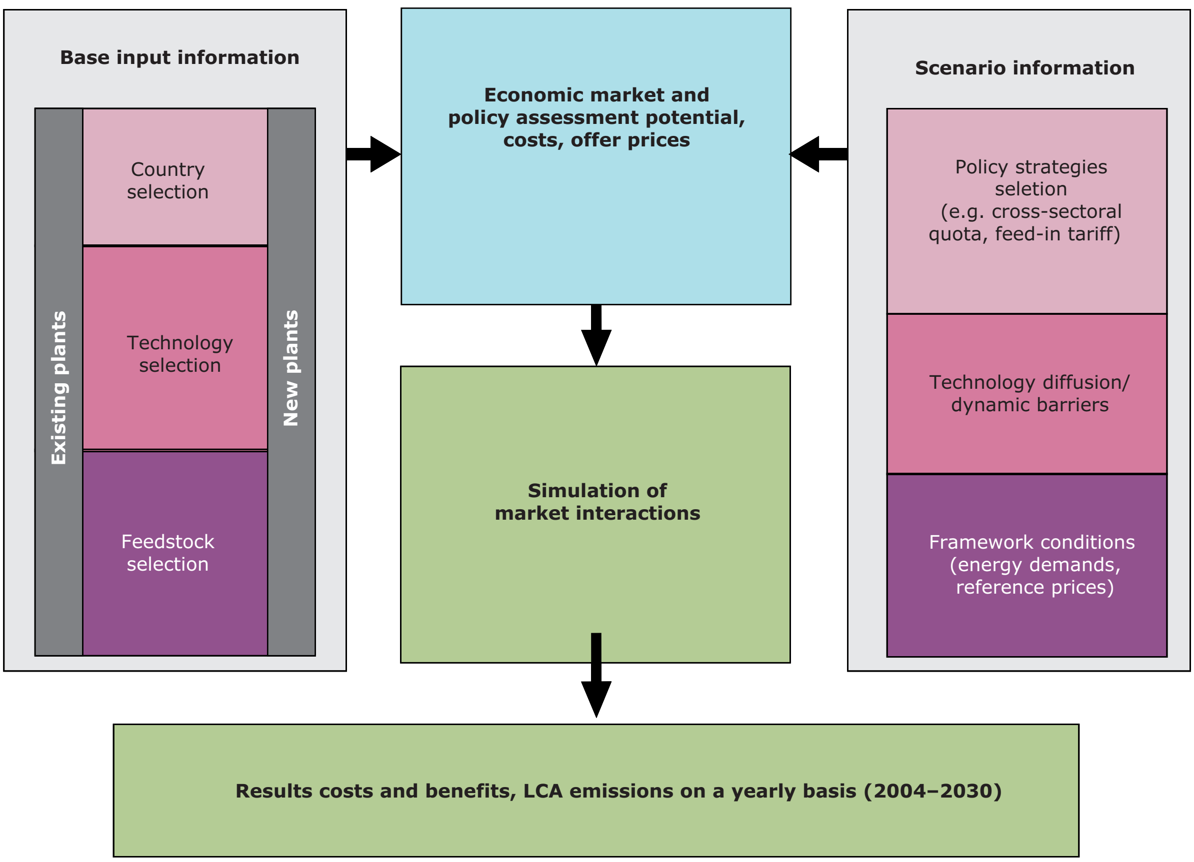
Annex 7 Method of approach — 'how the model works'

In the following we provide a detailed description of the methodology and how the model works with respect to resource allocation relative to the decision criteria selected.

The core elements of the model are depicted in Figure 8.16. The general modelling approach for the supply-side of bioenergy technologies is to derive dynamic cost-resource curves that include information on the available biomass feedstocks, the potential conversion technologies drawn from the feasible process chains defined by country and by sector and the corresponding LCA emissions.

Dynamic cost-resource curves are characterized by the fact that costs, LCA emissions and the generation potential can change from year to year. The magnitude of these changes is derived endogenously within the model, so that the difference in the values in one year compared to the previous year depend on the outcome of the current year and the policy framework conditions set for the simulation year. A clear distinction between capacities that are already installed and potential new plants is made in the underlying database of the model. This information is continuously adapted by data from resource exploitation during a simulation run (24).

Figure 8.16 Core elements of the Green-X$_{ENVIRONMENT}$ model



(24) The model calculates biomass exploitation and accompanying results on costs and emissions on a yearly basis, starting from 2004 and ending by 2030.

An economic assessment is based on the dynamic cost-resource curve considering scenario specific conditions like selected policy strategies, investor behaviour, technology diffusion and dynamic non-economic barriers, as well as energy price and demand forecasts. Within this step, there is a transition from generation costs to bids, offers and switch prices. The results, on a yearly basis, are derived by determining the equilibrium level of supply and demand within each market segment considered, for example the tradable green certificate market (TGC both national and international), and the electricity power or (grid and non-grid) heat market. This means that the different technologies are collected within each market and the point of equilibrium varies with the underlying demand.

Let us focus now on the detailed procedure in line with the cases investigated: Assuming a cross-sectoral quota is applied as a (virtual) policy instrument, a demand for bioenergy will be stipulated that is defined on a yearly basis by country in terms of primary energy as a share of gross domestic consumption. Additionally, a severe ([25]) penalty is introduced, setting the upper limit for bioenergy deployment in order to exclude highly inefficient supply options.

The first step within each year investigated is to build the cost-resource curve, listing all supply options in order of merit. Thereby, a clear distinction is made between that which has already been achieved (i.e. existing plants) and the additional realizable potential (i.e. potential new plant).

- In the case of new plants, besides costs, deployment is limited by non-economic parameters such as the availability of sufficient biomass feedstock needed for a certain technology or plant type and overall technology diffusion constraints as defined at cluster ([26]) level by country.
- For existing plants, only the short-term marginal costs — comprising fuel and O&M cost as well as revenues arising from the selling of a possible by-product — are relevant to the economic decision ([27]) as to whether the plant should be used for generation or not. For new capacities, the long-term marginal costs are important, comprising the discounted investment cost as well as the short-term marginal costs.

In this context, the cost calculation is done in line with Formula 1 (see next page) The starting point is the calculation of the total generation cost (see Formula 1), where revenues arising from the sale of selected by-products such as heat, in case of CHP, and glycerine, in case of biofuels, are also taken into account. Next, additional generation cost are derived (Formula 2) which represent the difference between total generation costs and the reference market price within each end-use sector (electricity, heat (subdivided into grid and non-grid) and transport). Finally, the generation added has to be transformed independently of the decision criteria applied; whether a least cost case in terms of primary energy (see Formula 3a), in terms of GHG emissions avoided (see Formula 3b) or air pollutant emissions avoided (see Formula 3c).

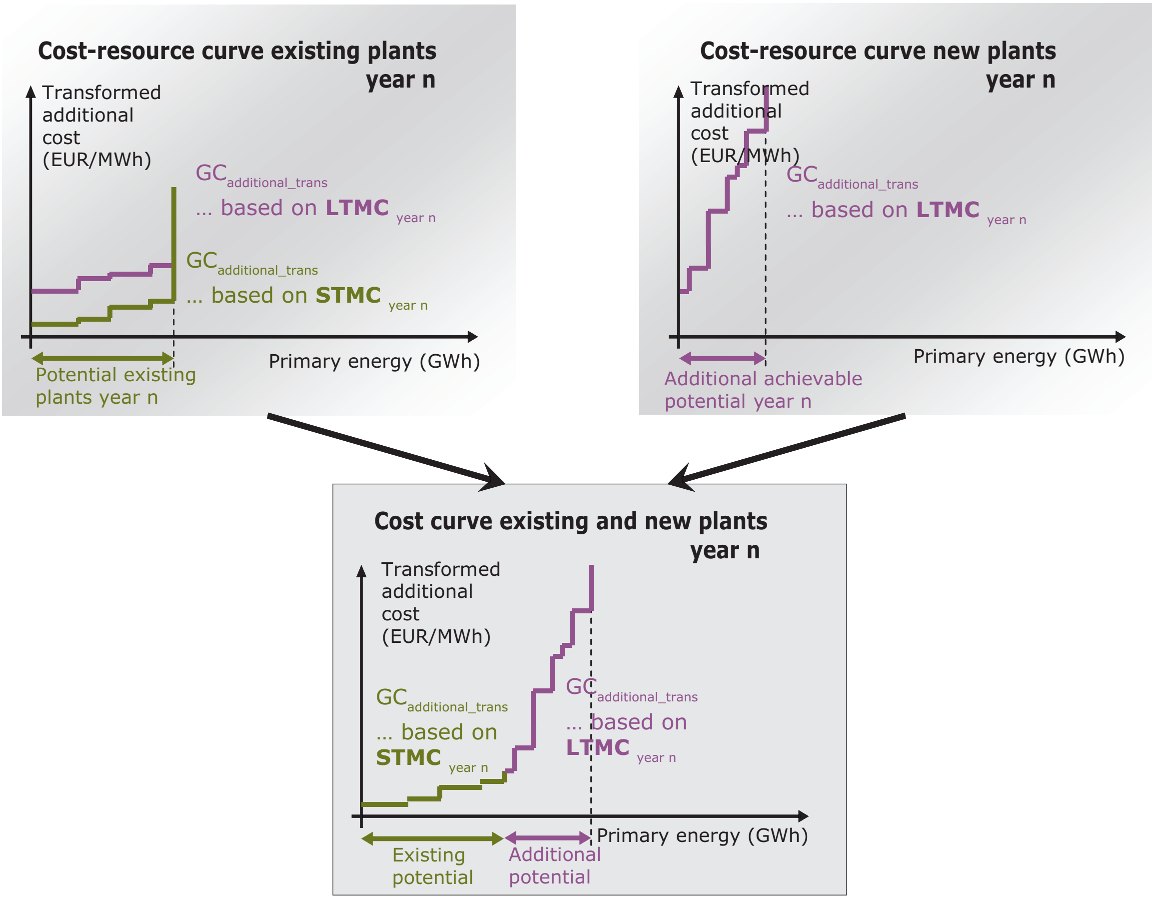
The overall cost-resource curve for each year can be derived by horizontal addition of the potential already achieved from existing plants) and the available additional potential from new plants. This procedure is shown schematically in Figure 8.17. All least cost scenarios based on cross-sectoral quotas are investigated at country level, listing the potential of all supply options in terms of primary energy. Finally, any potential deployment of new plant on the market is examined in terms of when they become operational — as long as the yearly quota is filled (or the penalty exceeded). At the end of the simulation process for a particular year, results including cost, generation and emission balances are calculated, and the supply-side database adapted to add new installations to the basket of existing plants and subtract decommissioned plants that exceeded their lifespan.

([25]) The exact severity of the penalty depends on the decision criteria applied. E.g. in case of a least cost approach in terms of primary this means a maximum value of transformed additional cost in size of 100 EUR/MWhprimary.

([26]) A set of 16 technology clusters are defined for which deployment is limited in line with e.g. sectoral energy demands (taken from PRIMES) or the projected conventional reference system, i.e. in particular the installed generation capacity of coal-fired power plants as relevant for co-firing.

([27]) Please note that, in contrast to the economic operational decision, long-term marginal generation cost are considered for the representation of the overall result regarding (additional) generation cost in case of existing plant ——, aiming to provide a fair depiction of the resulting cost burden.

Figure 8.17 Combination of cost-resource curves for existing and potentially new plants in year n



Source: Energy Economic Groups (EEG), Vienna University of Technology, www.gree-x.at.

The main formulas:

$$G = \frac{G_{pre\text{-}conversion}}{\eta_{main}} + 1000 * \left(\frac{I * CRF + O\&M}{FLH_{main}} \right) - R_{by\ product} \qquad \text{(Formula 1)}$$

with: GC ... Total specific (long term) generation costs [€/MWh_{output}]

$GC_{Pre\text{-}conversion}$ ... The specific generation cost of pre-conversion is commonly called fuel cost. If capital investment is involved — the calculation is done, in a similar way to the calculation of the specific generation cost of the final product as illustrated here. [€/MWh_{input}]

O&M ... Operation and maintenance costs (yearly, per installed kW) [€/(kW*yr)]

I ... Investment costs per unit of installed capacity (referring to the main output) [€/kW]

FLH_{main} ... Full-load hours are a virtual parameter, calculated by dividing the yearly generation output of a plant by its nominal power — both referring to the main output in case of combined production. [h/yr]

η_{main} ... Conversion efficiency of the corresponding conversion process [1]

$R_{by\text{-}product}$ ... Revenues arising from the sale of the by-product. In case of combined heat and power production where heat represents the by-product of electricity generation the calculation of the revenues, — the so-called 'heat bonus', is as follows:

$$R_{heat(CHP)} = P_{reference\_heat(grid)} \frac{\eta_{heat} * FLH_{heat}}{\eta_{electricity} * FLH_{electricity}}$$

The revenues per unit of heat sold, characterized by the reference market price for grid-connected heat, have to be transferred to electricity output.

CRF ... Capital recovery factor: $CRF = \frac{z * (1 + Z)^{PT}}{[(1 + z)^{PT} - 1]}$

The CRF allows investment costs incurred in the construction phase of a plant to be discounted. The amount depends on the interest rate and the payback time of the plant. For the default calculation of generation costs these factors are set for all technologies as follows:

- payback time (PT): equal to the technology-specific lifetime of the plant [yr.]
- interest rate (z): as a default, a moderate interest rate of 6.5% was applied [1]

$$GC_{additional} = GC - f_{weighting} * P_{reference}$$ Formula 2)

with: $GC_{additional}$ ... Additional specific generation costs [€/MWh_{output}]

GC ... Total specific generation costs [€/MWh_{output}]

$f_{weighting}$ ... Weighting factor to reflect the importance of a certain energy sector (i.e. electricity, heat or transport) [1]

$p_{reference}$ ... Reference market price (for conventional options by end-use sector) [€/MWh_{output}]

Decision criteria: Least cost in terms of primary energy

$$GC_{additional\_trans} = GC_{additional} * \eta_{chain}$$ (Formula 3a)

Decision criteria: Least cost in terms of net avoided CO_2-eq. emissions

$$GC_{additional\_trans} = GC_{additional} * \frac{1}{(EMI_{CO2\text{-}eq.\_reference} - EMI_{CO2\text{-}eq.\_bioenergy})}$$ (Formula 3b)

Decision criteria: Least cost in terms of net avoided air pollutants (PM-eq. emissions)

$$GC_{additional\_trans} = GC_{additional} * \frac{1}{(EMI_{PM\text{-}eq.\_reference} - EMI_{PM\text{-}eq.\_bioenergy})}$$ (Formula 3c)

with: $GC_{additional\_trans}$ ... Transformed additional specific generation cost (according to the applied decision criteria)

$GC_{additional}$ ... Additional specific generation costs [€/MWh_{output}]

η_{main} ... Conversion efficiency of the corresponding conversion process chain [1]

$EMI_{CO2\text{-}eq.\_reference}$ ... Output-specific CO_2-eq. emissions of the conventional reference system [kg CO_2-eq./MWh_{output}]

$EMI_{CO2\text{-}eq.\_bioenergy}$ .. Output-specific CO_2-eq. emissions of the bioenergy process chain [kg CO_2-eq./MWh]

$EMI_{PM\text{-}eq.\_reference}$ ... Output-specific PM_{10}-eq. emissions of the conventional reference system [kg PM_{10}-eq./MWh_{output}]

$EMI_{PM1\text{-}eq.\_bioenergy}$ .. Output-specific PM_{10}-eq. emissions of the bioenergy process chain [kg PM_{10}-eq./MWh]

Annex 8 Results of the scenarios by country

Reference scenario

Key results by country — Case: 100% exploitation of the biomass potential, cross-sectoral least cost in terms of primary energy, PRIMES LCEP — Page 1 of 2

Country:	[Unit]	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Energy output																											
Electricity - 2030	TWh/year	11	5	6	17	75	102	6	3	27	0	5	8	25	31	56	0	8	3	9	3	9	0	110	9	2	**530**
Heat - 2030	TWh/year	51	11	9	47	263	159	15	6	111	0	9	16	116	96	93	0	38	10	27	11	22	0	114	22	11	**1258**
Transport - 2030	TWh/year	8	0	0	6	38	16	13	0	49	0	0	2	54	11	11	0	2	3	4	3	13	0	26	4	1	**263**
TOTAL - 2010	TWh/year	17	4	7	30	83	70	6	2	45	0	8	10	39	56	40	0	12	4	7	5	10	0	49	7	3	**513**
TOTAL - 2020	TWh/year	42	10	10	49	218	159	17	5	118	0	11	16	116	80	88	0	28	12	23	11	32	0	142	17	9	**1212**
TOTAL - 2030	TWh/year	71	16	15	70	376	277	34	9	188	0	15	27	195	137	160	0	49	15	40	17	43	0	250	34	14	**2051**
Conversion efficiency																											
Electricity - 2030	%	46%	41%	45%	53%	43%	41%	43%	41%	39%	38%	40%	49%	45%	52%	41%	40%	45%	43%	45%	44%	45%	38%	41%	45%	47%	**43%**
Heat - 2030	%	82%	70%	62%	80%	78%	72%	72%	68%	82%	83%	65%	73%	78%	81%	67%	41%	78%	76%	74%	76%	71%	71%	73%	78%	81%	**76%**
Transport - 2030	%	57%	n.a.	n.a.	59%	59%	55%	58%	n.a.	57%	n.a.	n.a.	58%	58%	59%	56%	n.a.	57%	57%	59%	57%	57%	n.a.	58%	58%	57%	**58%**
TOTAL - 2010	%	54%	36%	41%	57%	49%	43%	42%	38%	48%	81%	41%	46%	48%	59%	45%	37%	53%	51%	51%	63%	53%	47%	49%	54%	54%	**49%**
TOTAL - 2020	%	62%	46%	44%	61%	59%	47%	53%	43%	61%	81%	45%	50%	62%	60%	46%	37%	59%	60%	60%	61%	57%	54%	51%	61%	68%	**55%**
TOTAL - 2030	%	70%	58%	54%	69%	65%	56%	59%	55%	65%	77%	54%	63%	66%	70%	54%	40%	68%	63%	64%	64%	60%	59%	53%	64%	72%	**61%**
Share of corresponding gross consumption																											
Electricity - 2010	%	10%	2%	8%	15%	7%	8%	4%	3%	6%	0%	3%	11%	4%	15%	4%	2%	5%	21%	5%	13%	33%	1%	17%	8%	7%	**7.3%**
Electricity - 2020	%	13%	5%	12%	20%	10%	13%	5%	7%	5%	0%	3%	12%	5%	18%	7%	3%	9%	24%	12%	24%	43%	1%	31%	13%	9%	**10.7%**
Electricity - 2030	%	13%	4%	12%	17%	10%	16%	7%	8%	7%	0%	3%	10%	6%	17%	9%	2%	9%	26%	15%	26%	44%	1%	42%	17%	11%	**12.5%**
Heat - 2010	%	6%	1%	4%	8%	5%	2%	3%	1%	2%	1%	1%	3%	3%	13%	2%	1%	4%	13%	3%	19%	19%	5%	4%	5%	6%	**3.3%**
Heat - 2020	%	17%	2%	4%	15%	15%	4%	7%	3%	8%	1%	2%	6%	13%	19%	4%	1%	10%	38%	14%	28%	51%	10%	13%	15%	24%	**9.0%**
Heat - 2030	%	36%	5%	9%	25%	30%	12%	11%	8%	14%	2%	3%	11%	22%	42%	10%	1%	23%	55%	23%	46%	60%	10%	23%	34%	41%	**18.1%**
Transport - 2010	%	1%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	3%	0%	1%	0%	2%	0%	1%	0%	2%	0%	0%	2%	0%	**0.7%**
Transport - 2020	%	7%	0%	0%	1%	3%	2%	3%	0%	6%	0%	0%	0%	6%	3%	3%	0%	4%	23%	0%	16%	32%	0%	4%	3%	2%	**3.4%**
Transport - 2030	%	9%	0%	0%	12%	5%	2%	11%	0%	9%	0%	0%	2%	10%	11%	1%	0%	4%	28%	6%	24%	49%	0%	12%	10%	4%	**5.4%**
Additional generation cost (as share of corresponding reference generation cost)																											
Electricity - 2030	% of ref.	86%	-12%	12%	41%	109%	23%	-1%	12%	-22%	-39%	7%	-6%	-7%	29%	56%	-75%	20%	53%	17%	80%	98%	-70%	-5%	123%	62%	**25%**
Electricity - average	*% of ref.*	*73%*	*29%*	*17%*	*49%*	*80%*	*29%*	*25%*	*25%*	*2%*	*-2%*	*30%*	*14%*	*9%*	*52%*	*55%*	*-55%*	*34%*	*58%*	*26%*	*61%*	*68%*	*-41%*	*7%*	*90%*	*46%*	***35%***
Heat - 2030	% of ref.	32%	17%	7%	11%	21%	22%	-9%	10%	0%	-39%	-10%	5%	-14%	28%	17%	3%	9%	15%	-9%	4%	4%	-4%	-11%	14%	21%	**11%**
Heat - average	*% of ref.*	*44%*	*8%*	*8%*	*18%*	*43%*	*21%*	*22%*	*8%*	*10%*	*-12%*	*2%*	*19%*	*0%*	*40%*	*14%*	*2%*	*20%*	*41%*	*5%*	*38%*	*27%*	*25%*	*9%*	*42%*	*25%*	***25%***
Transport - 2030	% of ref.	101%	n.a.	n.a.	87%	64%	35%	19%	n.a.	18%	n.a.	n.a.	22%	19%	128%	49%	n.a.	42%	13%	5%	16%	28%	n.a.	3%	92%	172%	**36%**
Transport - average	*% of ref.*	*109%*	*n.a.*	*n.a.*	*85%*	*97%*	*61%*	*39%*	*n.a.*	*40%*	*n.a.*	*n.a.*	*33%*	*27%*	*115%*	*69%*	*n.a.*	*47%*	*45%*	*36%*	*47%*	*60%*	*n.a.*	*31%*	*79%*	*180%*	***54%***
TOTAL - 2010	% of ref.	52%	25%	1%	29%	50%	25%	50%	16%	16%	5%	24%	24%	19%	34%	47%	-48%	29%	40%	20%	52%	30%	3%	18%	27%	21%	**31%**
TOTAL - 2020	% of ref.	75%	18%	22%	32%	71%	42%	26%	22%	27%	-17%	26%	13%	11%	64%	48%	-49%	33%	61%	22%	53%	62%	-9%	12%	103%	52%	**41%**
TOTAL - 2030	% of ref.	47%	6%	9%	24%	39%	23%	3%	11%	0%	-39%	-3%	3%	-5%	37%	35%	-63%	13%	24%	0%	20%	31%	-34%	-6%	43%	34%	**18%**
TOTAL - average	*% of ref.*	*57%*	*25%*	*13%*	*33%*	*55%*	*29%*	*27%*	*19%*	*13%*	*-12%*	*20%*	*17%*	*10%*	*47%*	*45%*	*-47%*	*27%*	*43%*	*15%*	*46%*	*40%*	*-5%*	*8%*	*53%*	*34%*	***32%***
GHG emissions - CO_2-eq.																											
Net avoided direct & LCA emissions																											
Electricity - 2030	Mt/year	3.8	1.3	1.7	6.7	24.9	36.2	3.1	0.9	9.3	0.0	1.0	2.2	7.7	10.9	12.5	0.1	2.0	1.0	3.1	1.1	3.3	0.0	52.9	4.4	0.6	**190.7**
Heat - 2030	Mt/year	14.7	3.0	2.3	13.2	74.0	52.6	4.6	1.8	31.9	0.1	3.1	4.7	34.5	32.2	24.6	0.0	10.8	2.6	7.5	2.9	5.6	0.0	31.8	5.9	3.5	**368.0**
Transport - 2030	Mt/year	2.9	0.0	0.0	1.9	10.6	3.9	2.5	0.0	6.4	0.0	0.0	0.3	7.3	3.6	3.1	0.0	0.6	0.7	1.1	0.8	3.6	0.0	7.3	1.4	0.3	**58.4**
TOTAL - 2010	Mt/year	5.8	0.8	2.6	11.9	30.3	39.5	2.9	0.5	14.1	0.0	1.9	4.3	10.1	20.9	9.5	0.1	4.7	2.0	2.5	1.7	3.2	0.0	30.8	2.9	1.3	**204.2**
TOTAL - 2020	Mt/year	13.5	2.6	2.7	16.6	66.6	57.3	5.6	1.4	31.6	0.1	2.6	5.6	28.9	31.7	21.3	0.1	7.9	3.5	7.2	3.3	9.2	0.0	65.6	5.9	2.8	**393.7**
TOTAL - 2030	Mt/year	21.4	4.3	4.0	21.7	109.5	92.7	10.3	2.7	47.6	0.1	4.1	7.3	49.6	46.6	40.2	0.1	13.5	4.3	11.8	4.9	12.5	0.0	92.1	11.7	4.4	**617.2**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	78%	63%	67%	83%	75%	76%	76%	67%	82%	74%	55%	69%	72%	83%	60%	92%	59%	79%	70%	79%	80%	91%	79%	87%	77%	**76%**
Heat - 2030	%of gross	96%	97%	98%	97%	97%	96%	95%	97%	95%	97%	98%	97%	95%	97%	96%	99%	96%	94%	94%	95%	94%	97%	94%	95%	96%	**96%**
Transport - 2030	%of gross	111%	n.a.	n.a.	94%	87%	79%	63%	n.a.	41%	n.a.	n.a.	42%	43%	106%	91%	n.a.	93%	79%	96%	80%	89%	n.a.	89%	123%	131%	**70%**
TOTAL - 2010	%of gross	83%	66%	89%	90%	87%	91%	86%	75%	81%	96%	74%	87%	68%	92%	68%	92%	85%	85%	82%	90%	83%	92%	91%	89%	91%	**86%**
TOTAL - 2020	%of gross	90%	81%	79%	90%	89%	84%	79%	79%	81%	96%	76%	84%	74%	92%	75%	91%	83%	86%	85%	88%	85%	93%	88%	90%	93%	**85%**
TOTAL - 2030	%of gross	93%	84%	82%	92%	90%	86%	79%	85%	79%	95%	82%	82%	77%	94%	80%	92%	87%	87%	87%	88%	88%	94%	85%	94%	95%	**86%**
Air pollutants - SO_2																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-1.5	-0.8	-0.5	-0.2	-6.7	-5.7	1.2	-0.5	-1.8	0.0	-0.2	-0.6	1.1	0.3	-8.0	0.1	-1.1	-0.1	-0.6	-0.2	-0.8	0.0	9.9	0.1	-0.3	**-16.7**
Heat - 2030	kt/year	-3.9	-0.7	0.1	1.2	-24.8	-6.4	1.2	0.0	-16.8	0.0	0.4	1.1	-12.1	37.7	-12.1	0.0	-4.0	-0.5	-5.4	-1.2	-3.4	0.0	-33.8	-3.9	0.5	**-86.8**
Transport - 2030	kt/year	1.8	0.0	0.0	0.6	3.5	1.3	1.2	0.0	3.4	0.0	0.0	0.1	3.6	1.2	1.1	0.0	0.2	0.2	0.4	0.3	1.2	0.0	2.9	0.5	0.1	**23.6**
TOTAL - 2010	kt/year	-0.7	-0.4	0.6	3.2	13.1	14.1	6.7	0.1	21.5	0.0	1.5	7.3	9.3	10.5	2.4	0.2	0.8	1.8	2.7	0.4	0.1	0.0	119.8	4.4	6.1	**225.7**
TOTAL - 2020	kt/year	-0.7	-0.9	-0.1	0.4	-7.6	1.3	5.1	-0.1	-1.3	0.0	1.0	1.3	0.6	23.9	-5.0	0.2	-2.3	-0.1	-0.3	0.2	-2.5	0.1	92.4	1.7	0.9	**108.1**
TOTAL - 2030	kt/year	-3.6	-1.4	-0.4	1.6	-27.9	-10.8	3.6	-0.5	-15.3	0.0	0.2	0.7	-7.4	39.2	-19.0	0.1	-4.9	-0.4	-5.6	-1.2	-2.9	0.1	-21.0	-3.2	0.3	**-79.9**

Key results by country

Case: **100% exploitation of the biomass potential, cross-sectoral least cost in terms of primary energy, PRIMES LCEP**

Page 2 of 2

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Air pollutants - SO_2																											
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-314%	-490%	-107%	-17%	-179%	-71%	66%	-592%	-369%	-1430%	-26%	-294%	27%	14%	-856%	76%	-477%	-45%	-71%	-99%	-119%	72%	35%	12%	-611%	**-29%**
Heat - 2030	%of gross	-107%	-155%	10%	16%	-228%	-29%	15%	-8%	-77%	-489%	31%	27%	-38%	75%	-320%	91%	-112%	-37%	-253%	-175%	-128%	80%	-327%	-405%	20%	**-46%**
Transport - 2030	%of gross	168%	n.a.	n.a.	75%	68%	59%	68%	n.a.	50%	n.a.	n.a.	48%	48%	84%	73%	n.a.	69%	59%	72%	57%	69%	n.a.	82%	116%	135%	**66%**
TOTAL - 2010	%of gross	-26%	-213%	36%	55%	58%	66%	88%	25%	76%	-1%	54%	84%	63%	67%	35%	85%	22%	68%	56%	31%	3%	91%	91%	82%	94%	**76%**
TOTAL - 2020	%of gross	-15%	-223%	-8%	7%	-43%	5%	52%	-18%	-5%	-369%	42%	33%	2%	77%	-65%	81%	-76%	-6%	-5%	9%	-54%	86%	68%	37%	44%	**33%**
TOTAL - 2030	%of gross	-69%	-242%	-35%	18%	-141%	-33%	31%	-79%	-53%	-546%	9%	16%	-17%	73%	-308%	78%	-120%	-21%	-161%	-86%	-58%	77%	-50%	-121%	13%	**-28%**
Air pollutants - NO_X																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-4.2	-2.2	-3.6	-2.4	-22.9	-40.0	-0.9	-1.5	-4.6	0.0	-4.5	-1.7	-7.4	-8.9	-31.1	0.1	-4.9	-1.2	-6.0	-1.2	-3.1	0.0	-40.0	-2.9	-0.8	**-195.9**
Heat - 2030	kt/year	-2.3	0.1	0.8	0.3	-13.8	2.2	-0.1	-0.3	-0.4	0.0	0.4	0.4	1.5	0.3	1.0	0.0	1.2	-0.6	0.2	0.0	-1.4	0.0	-2.0	-0.5	0.2	**-12.7**
Transport - 2030	kt/year	-0.4	0.0	0.0	-0.8	2.5	1.9	-3.1	0.0	-5.8	0.0	0.0	-0.2	-3.9	-3.4	0.1	0.0	-0.2	0.3	-0.6	0.4	-2.3	0.0	-1.0	-1.0	-0.2	**-17.7**
TOTAL - 2010	kt/year	-2.3	-1.4	-1.4	-1.5	-4.4	-3.4	1.0	-0.6	-0.6	0.0	-4.4	-0.3	-5.1	-4.1	-8.9	0.2	-1.4	0.1	-0.6	-0.3	-0.9	0.0	62.2	0.7	0.8	**23.4**
TOTAL - 2020	kt/year	-4.6	-2.1	-2.9	-3.9	-24.2	-21.6	-0.5	-1.4	-5.4	0.0	-5.1	-2.4	-8.2	-7.7	-16.1	0.2	-3.6	-1.2	-2.6	-0.1	-4.6	0.0	37.7	-1.4	-0.8	**-82.5**
TOTAL - 2030	kt/year	-6.9	-2.1	-2.8	-2.9	-34.2	-35.9	-4.0	-1.8	-10.8	0.0	-4.1	-1.4	-9.7	-11.9	-30.0	0.1	-3.8	-1.4	-6.4	-0.8	-6.8	0.0	-43.0	-4.4	-0.9	**-226.3**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-96%	-113%	-210%	-33%	-73%	-114%	-29%	-148%	-44%	-173%	-14151%	-48%	-69%	-113%	-223%	39%	-163%	-113%	-189%	-82%	-89%	34%	-89%	-92%	-113%	**-101%**
Heat - 2030	%of gross	-20%	2%	45%	3%	-26%	7%	-3%	-27%	-1%	-11%	21%	11%	5%	2%	6%	50%	13%	-27%	3%	0%	-32%	-40%	-8%	-10%	6%	**-5%**
Transport - 2030	%of gross	-16%	n.a.	n.a.	-41%	23%	42%	-84%	n.a.	-42%	n.a.	n.a.	-24%	-25%	-93%	2%	n.a.	-24%	43%	-54%	41%	-63%	n.a.	-14%	-83%	-91%	**-23%**
TOTAL - 2010	%of gross	-32%	-90%	-53%	-12%	-11%	-9%	19%	-93%	-3%	-25%	-693%	-5%	-29%	-21%	-65%	64%	-31%	5%	-19%	-15%	-19%	51%	70%	18%	34%	**8%**
TOTAL - 2020	%of gross	-34%	-65%	-102%	-23%	-36%	-38%	-6%	-92%	-14%	-27%	-489%	-34%	-21%	-30%	-66%	50%	-44%	-34%	-35%	-1%	-50%	26%	33%	-24%	-29%	**-18%**
TOTAL - 2030	%of gross	-38%	-52%	-80%	-15%	-35%	-49%	-41%	-83%	-20%	-28%	-210%	-17%	-18%	-38%	-85%	40%	-29%	-36%	-57%	-18%	-59%	11%	-56%	-45%	-22%	**-41%**
Air pollutants - Particulate matter																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-0.3	-0.1	-0.1	-0.1	-1.0	-1.3	0.2	0.0	-0.1	0.0	-0.1	-0.1	0.0	-0.3	-1.6	0.0	-0.2	-0.1	-0.2	-0.1	-0.1	0.0	-0.3	0.3	0.0	**-5.7**
Heat - 2030	kt/year	0.1	0.1	0.1	0.3	0.7	2.6	0.3	0.0	0.7	0.0	0.2	0.1	1.2	1.6	0.5	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.9	0.0	0.1	**9.7**
Transport - 2030	kt/year	0.2	0.0	0.0	0.1	0.6	0.2	0.1	0.0	0.3	0.0	0.0	0.0	0.4	0.1	0.2	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.4	0.0	0.0	**3.0**
TOTAL - 2010	kt/year	-0.1	0.0	0.1	0.3	1.8	2.3	0.4	0.0	1.3	0.0	-0.1	0.4	0.6	0.2	0.0	0.0	0.2	0.2	0.2	0.1	0.1	0.0	11.0	0.8	1.2	**21.1**
TOTAL - 2020	kt/year	0.0	-0.1	0.0	0.0	0.3	1.0	0.5	0.0	1.0	0.0	-0.1	0.1	1.1	1.1	-0.2	0.0	0.1	0.1	0.2	0.2	0.1	0.0	10.2	0.6	0.1	**16.3**
TOTAL - 2030	kt/year	0.1	0.0	0.0	0.2	0.3	1.5	0.6	0.0	0.9	0.0	0.0	0.0	1.5	1.4	-0.9	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.9	0.3	0.1	**7.0**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-161%	-145%	-70%	-25%	-80%	-69%	61%	-123%	-30%	-335%	-536%	-118%	-8%	-63%	-328%	73%	-199%	-125%	-91%	-97%	-74%	62%	-7%	50%	-158%	**-46%**
Heat - 2030	%of gross	23%	52%	75%	47%	25%	76%	86%	50%	45%	21%	79%	55%	64%	76%	52%	97%	44%	27%	31%	29%	31%	39%	58%	2%	48%	**54%**
Transport - 2030	%of gross	144%	n.a.	n.a.	71%	85%	85%	45%	n.a.	35%	n.a.	n.a.	37%	38%	54%	77%	n.a.	55%	87%	58%	85%	49%	n.a.	86%	61%	61%	**61%**
TOTAL - 2010	%of gross	-19%	-104%	31%	38%	63%	69%	76%	-2%	69%	48%	-53%	70%	45%	18%	5%	91%	51%	58%	56%	65%	38%	83%	92%	89%	96%	**71%**
TOTAL - 2020	%of gross	0%	-77%	-10%	2%	9%	27%	72%	-12%	45%	10%	-44%	26%	46%	47%	-22%	85%	18%	27%	50%	58%	10%	71%	75%	72%	51%	**47%**
TOTAL - 2030	%of gross	10%	-17%	0%	24%	7%	26%	66%	-1%	33%	-8%	4%	11%	46%	50%	-55%	74%	6%	5%	-6%	9%	9%	54%	13%	39%	26%	**20%**
Avoided fossil fuels																											
Avoided fossil fuels - by fuel in energetic terms																											
Hard coal - 2030	TWh/year	0.9	0.0	1.7	1.6	12.2	40.2	1.6	0.0	0.4	0.0	0.0	0.0	1.3	9.7	0.1	0.0	0.1	0.6	0.0	0.0	3.4	0.0	82.2	0.3	0.0	**156.3**
Lignite - 2030	TWh/year	0.0	0.0	0.0	4.2	0.0	1.7	3.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	3.9	0.3	0.0	0.0	34.3	3.9	0.0	**52.6**
Oil - 2030	TWh/year	20.0	2.3	1.6	18.8	95.6	166.4	30.0	3.3	92.9	0.0	9.0	10.0	118.3	119.5	32.1	0.4	8.3	5.5	7.5	5.9	18.9	0.1	66.8	5.6	4.6	**843.5**
Gas - 2030	TWh/year	66.6	17.7	21.7	75.5	367.5	171.9	5.6	8.1	125.5	0.3	9.8	22.6	111.7	62.5	172.1	0.0	52.5	13.4	40.4	17.1	36.0	0.0	190.8	36.6	12.9	**1638.9**
Avoided fossil fuels - by sector in energetic terms																											
Electricity - 2030	TWh/year	24.6	8.6	15.7	40.1	162.3	188.3	11.8	6.0	49.3	0.0	9.3	13.9	48.6	70.0	98.0	0.3	17.7	6.1	19.5	7.8	22.4	0.1	229.2	18.9	4.9	**1073.5**
Heat - 2030	TWh/year	54.3	11.3	9.2	53.3	272.6	175.5	15.4	5.7	117.8	0.3	9.5	16.4	126.0	110.3	95.0	0.0	41.0	11.0	28.5	12.1	22.4	0.1	117.7	23.6	11.9	**1341.0**
Transport - 2030	TWh/year	8.6	0.0	0.0	6.7	40.4	16.4	13.3	0.0	51.7	0.0	0.0	2.4	56.7	11.4	11.3	0.0	2.3	2.8	3.8	3.5	13.5	0.0	27.3	3.9	0.8	**276.9**
TOTAL - 2010	TWh/year	30.6	6.0	12.6	53.0	170.5	153.9	11.9	3.1	73.5	0.2	11.7	17.2	59.5	109.7	60.1	0.3	22.1	8.6	12.5	9.2	18.6	0.1	115.4	11.6	5.5	**977.4**
TOTAL - 2020	TWh/year	57.2	13.5	17.8	80.3	293.3	249.2	22.4	7.1	141.6	0.3	14.3	24.2	140.8	133.8	115.6	0.4	37.9	15.7	31.0	16.2	43.6	0.1	234.3	23.0	10.9	**1724.7**
TOTAL - 2030	TWh/year	87.5	20.0	25.0	100.1	475.3	380.2	40.5	11.7	218.8	0.3	18.8	32.7	231.3	191.7	204.3	0.4	61.1	19.9	51.9	23.4	58.3	0.1	374.1	46.4	17.5	**2691.4**
Avoided fossil fuels - by sector in monetary terms																											
Electricity - 2030	M€/year	413	148	251	618	2638	2727	148	100	845	1	160	239	821	1086	1679	7	302	93	289	135	346	1	2555	275	84	**15959**
Heat - 2030	M€/year	969	202	162	956	4868	3560	321	110	2165	5	195	307	2382	2287	1702	1	723	197	500	210	401	1	2142	410	217	**24994**
Transport - 2030	M€/year	180	0	0	139	842	342	278	0	1078	0	0	50	1182	238	235	0	48	59	80	73	281	0	569	81	17	**5771**
TOTAL - 2010	M€/year	384	77	137	595	2024	1403	134	36	978	2	154	186	784	1306	752	5	209	84	151	114	234	1	905	109	59	**10823**
TOTAL - 2020	M€/year	894	209	248	1155	4529	3262	331	105	2321	5	227	332	2323	1835	1804	7	552	222	464	256	675	2	2629	305	172	**24863**
TOTAL - 2030	M€/year	1562	350	413	1714	8348	6629	746	209	4087	6	355	597	4385	3612	3615	8	1073	349	869	418	1028	3	5265	765	318	**46724**

CHP priority case

Key results by country

Case: 100% exploitation of the biomass potential, cross-sectoral least cost in terms of primary energy, optimised CHP, PRIMES LCEP

Page 1 of 2

Country:	[Unit]	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Energy output																											
Electricity - 2030	TWh/year	14	5	6	17	77	98	6	4	35	0	5	8	25	33	57	0	17	4	9	3	9	0	106	8	3	**549**
Heat - 2030	TWh/year	58	14	14	63	305	230	19	9	127	0	13	22	135	111	137	0	37	12	35	13	28	0	185	27	12	**1606**
Transport - 2030	TWh/year	6	0	0	4	37	16	13	0	46	0	0	2	54	9	9	0	2	3	3	3	13	0	22	4	0	**246**
TOTAL - 2010	TWh/year	22	6	9	40	105	102	8	3	60	0	11	15	51	72	57	0	15	6	10	6	13	0	71	9	4	**696**
TOTAL - 2020	TWh/year	50	13	15	63	254	213	20	7	132	0	14	22	134	99	119	0	34	14	28	13	37	0	183	21	10	**1495**
TOTAL - 2030	TWh/year	78	19	20	84	420	343	38	12	208	0	18	32	214	153	203	0	56	18	48	19	50	0	313	39	15	**2402**
Conversion efficiency																											
Electricity - 2030	%	66%	60%	68%	75%	56%	59%	58%	66%	68%	57%	60%	71%	66%	68%	63%	58%	75%	66%	67%	64%	63%	57%	58%	65%	71%	**62%**
Heat - 2030	%	84%	74%	75%	84%	81%	76%	76%	74%	80%	83%	71%	80%	81%	85%	72%	58%	80%	79%	80%	80%	78%	74%	75%	81%	83%	**79%**
Transport - 2030	%	58%	n.a.	n.a.	59%	59%	56%	58%	n.a.	57%	n.a.	n.a.	58%	58%	59%	55%	n.a.	57%	57%	57%	57%	57%	n.a.	59%	58%	58%	**58%**
TOTAL - 2010	%	69%	54%	57%	78%	62%	62%	57%	54%	64%	74%	59%	63%	62%	76%	64%	55%	69%	68%	69%	74%	70%	62%	71%	73%	70%	**66%**
TOTAL - 2020	%	73%	64%	67%	79%	69%	63%	63%	65%	68%	79%	61%	67%	71%	75%	63%	55%	73%	70%	73%	70%	67%	67%	65%	75%	77%	**68%**
TOTAL - 2030	%	77%	70%	73%	81%	73%	69%	66%	71%	72%	81%	67%	75%	72%	78%	69%	58%	77%	72%	75%	72%	68%	70%	67%	74%	80%	**72%**
Share of corresponding gross consumption																											
Electricity - 2010	%	10%	2%	9%	17%	7%	7%	4%	3%	5%	0%	3%	12%	6%	15%	4%	2%	7%	21%	6%	17%	34%	1%	15%	7%	8%	**7.2%**
Electricity - 2020	%	15%	5%	12%	20%	9%	12%	5%	7%	7%	0%	3%	12%	6%	19%	6%	3%	12%	29%	12%	28%	45%	1%	29%	11%	14%	**10.7%**
Electricity - 2030	%	16%	5%	13%	17%	11%	15%	6%	9%	8%	0%	3%	10%	6%	19%	9%	2%	19%	34%	15%	25%	44%	1%	41%	17%	15%	**13.0%**
Heat - 2010	%	9%	1%	6%	13%	7%	4%	5%	2%	5%	0%	2%	8%	6%	20%	4%	2%	5%	21%	6%	22%	29%	7%	10%	9%	9%	**6.2%**
Heat - 2020	%	22%	3%	10%	23%	19%	9%	10%	6%	9%	1%	3%	10%	17%	28%	8%	2%	13%	46%	16%	33%	64%	12%	24%	22%	26%	**13.3%**
Heat - 2030	%	41%	6%	13%	34%	35%	17%	14%	12%	16%	2%	4%	15%	26%	49%	15%	2%	22%	65%	30%	54%	79%	12%	38%	42%	45%	**23.1%**
Transport - 2010	%	1%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	1%	0%	1%	0%	1%	0%	0%	0%	1%	0%	0%	0%	0%	**0.5%**
Transport - 2020	%	6%	0%	0%	0%	3%	2%	3%	0%	6%	0%	0%	0%	4%	3%	3%	0%	3%	23%	3%	16%	32%	0%	1%	4%	1%	**3.0%**
Transport - 2030	%	7%	0%	0%	8%	5%	2%	11%	0%	9%	0%	0%	2%	10%	10%	1%	0%	2%	28%	6%	23%	49%	0%	11%	10%	2%	**5.1%**
Additional generation cost (as share of corresponding reference generation cost)																											
Electricity - 2030	% of ref.	73%	-57%	-55%	-10%	59%	-11%	-34%	-36%	-40%	-89%	-42%	-55%	-81%	-3%	11%	-96%	-7%	10%	-34%	24%	42%	-100%	-27%	68%	41%	**-10%**
Electricity - average	*% of ref.*	*54%*	*-19%*	*-35%*	*5%*	*47%*	*0%*	*-6%*	*-19%*	*-17%*	*-51%*	*-14%*	*-24%*	*-40%*	*17%*	*16%*	*-77%*	*2%*	*21%*	*-21%*	*24%*	*31%*	*-77%*	*-15%*	*54%*	*24%*	***3%***
Heat - 2030	% of ref.	24%	15%	7%	10%	18%	13%	-8%	8%	-2%	-36%	-8%	3%	-11%	24%	9%	1%	0%	14%	-9%	2%	1%	-3%	-8%	8%	19%	**7%**
Heat - average	*% of ref.*	*30%*	*6%*	*5%*	*10%*	*32%*	*9%*	*12%*	*3%*	*3%*	*-12%*	*1%*	*4%*	*1%*	*29%*	*6%*	*1%*	*3%*	*27%*	*0%*	*28%*	*17%*	*19%*	*0%*	*23%*	*15%*	***15%***
Transport - 2030	% of ref.	83%	n.a.	n.a.	65%	59%	35%	19%	n.a.	17%	n.a.	n.a.	22%	19%	128%	38%	n.a.	13%	13%	8%	16%	28%	n.a.	5%	93%	180%	**33%**
Transport - average	*% of ref.*	*90%*	*n.a.*	*n.a.*	*72%*	*85%*	*59%*	*39%*	*n.a.*	*37%*	*n.a.*	*n.a.*	*28%*	*29%*	*119%*	*63%*	*n.a.*	*38%*	*45%*	*31%*	*45%*	*61%*	*n.a.*	*31%*	*81%*	*170%*	***52%***
TOTAL - 2010	% of ref.	32%	-6%	-19%	2%	26%	4%	23%	-10%	0%	-2%	-5%	-2%	-3%	14%	18%	-55%	3%	20%	-4%	28%	11%	-15%	-3%	7%	0%	**8%**
TOTAL - 2020	% of ref.	60%	-8%	-11%	7%	52%	17%	11%	-7%	17%	-23%	-2%	-7%	0%	35%	19%	-57%	9%	40%	1%	38%	42%	-22%	-3%	66%	38%	**21%**
TOTAL - 2030	% of ref.	37%	-9%	-17%	10%	28%	4%	-6%	-9%	-6%	-41%	-20%	-10%	-13%	24%	11%	-69%	-2%	13%	-14%	8%	16%	-42%	-17%	27%	27%	**5%**
TOTAL - average	*% of ref.*	*39%*	*-3%*	*-14%*	*10%*	*38%*	*7%*	*10%*	*-7%*	*2%*	*-17%*	*-5%*	*-5%*	*-5%*	*27%*	*15%*	*-55%*	*3%*	*25%*	*-7%*	*29%*	*22%*	*-19%*	*-8%*	*29%*	*17%*	***12%***
GHG emissions - CO_2-eq.																											
Net avoided direct & LCA emissions																											
Electricity - 2030	Mt/year	4.7	1.3	1.8	6.8	24.7	32.7	2.7	0.9	10.9	0.0	1.0	2.2	7.5	11.8	11.5	0.1	4.8	1.4	3.1	1.1	3.3	0.0	50.3	4.2	0.9	**189.6**
Heat - 2030	Mt/year	15.8	3.5	3.3	16.6	82.6	74.3	5.5	2.4	35.6	0.1	4.0	5.7	38.9	36.2	34.4	0.0	10.2	2.9	9.2	3.4	7.1	0.0	51.1	7.1	3.7	**453.4**
Transport - 2030	Mt/year	2.0	0.0	0.0	1.2	10.0	3.9	2.5	0.0	5.5	0.0	0.0	0.3	7.3	3.1	2.2	0.0	0.4	0.7	1.0	0.8	3.6	0.0	5.6	1.5	0.2	**51.6**
TOTAL - 2010	Mt/year	7.2	1.0	3.3	14.5	35.0	42.6	3.2	0.7	16.6	0.0	2.6	5.9	14.2	25.1	12.9	0.1	6.1	2.3	3.3	2.0	4.1	0.0	31.7	3.4	1.6	**239.6**
TOTAL - 2020	Mt/year	14.6	3.4	3.9	19.8	72.0	69.7	6.1	2.1	34.9	0.1	3.4	6.9	34.8	37.5	27.3	0.1	9.7	4.0	8.4	3.8	10.2	0.0	71.2	6.6	3.1	**453.6**
TOTAL - 2030	Mt/year	22.5	4.9	5.1	24.6	117.3	110.9	10.8	3.3	52.0	0.1	5.0	8.2	53.7	51.1	48.1	0.1	15.3	4.9	13.3	5.2	13.9	0.0	107.0	12.7	4.8	**694.6**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	78%	63%	67%	83%	72%	71%	72%	61%	75%	75%	55%	67%	70%	83%	54%	92%	70%	79%	69%	79%	79%	91%	78%	84%	78%	**73%**
Heat - 2030	%of gross	96%	98%	99%	97%	97%	97%	96%	99%	97%	97%	99%	97%	96%	98%	97%	99%	97%	95%	95%	96%	95%	97%	97%	96%	97%	**97%**
Transport - 2030	%of gross	99%	n.a.	n.a.	85%	85%	79%	63%	n.a.	37%	n.a.	n.a.	42%	43%	105%	79%	n.a.	78%	79%	93%	79%	89%	n.a.	79%	123%	131%	**66%**
TOTAL - 2010	%of gross	86%	72%	91%	91%	87%	89%	87%	81%	81%	93%	80%	89%	78%	93%	75%	93%	88%	86%	87%	92%	86%	92%	88%	89%	92%	**87%**
TOTAL - 2020	%of gross	89%	85%	84%	92%	88%	86%	79%	82%	80%	94%	80%	86%	79%	93%	77%	92%	85%	87%	87%	89%	87%	93%	86%	90%	92%	**86%**
TOTAL - 2030	%of gross	92%	85%	85%	92%	90%	87%	79%	84%	79%	95%	85%	83%	79%	94%	81%	93%	86%	88%	87%	89%	89%	94%	86%	94%	94%	**86%**
Air pollutants - SO_2																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-1.8	-0.8	-0.5	-0.3	-6.8	-7.9	1.1	-0.5	-4.4	0.0	-0.2	-0.6	0.9	0.4	-9.1	0.1	-1.5	-0.2	-0.7	-0.2	-0.9	0.0	7.8	0.1	-0.4	**-26.5**
Heat - 2030	kt/year	-3.8	-0.5	0.5	-1.8	-23.6	4.3	2.6	0.4	-6.4	0.0	0.9	1.7	-7.6	44.5	-8.8	0.0	-1.6	-0.1	-5.0	-1.1	-2.6	0.0	-21.8	-3.7	0.6	**-32.8**
Transport - 2030	kt/year	0.9	0.0	0.0	0.4	3.3	1.3	1.2	0.0	3.0	0.0	0.0	0.2	3.6	1.0	0.7	0.0	0.1	0.2	0.3	0.3	1.2	0.0	1.9	0.6	0.1	**20.1**
TOTAL - 2010	kt/year	-0.3	-0.4	1.1	4.5	15.6	14.5	7.3	0.2	22.4	0.0	2.1	8.6	15.0	14.8	3.8	0.2	3.4	2.0	5.0	1.0	0.8	0.0	116.4	5.0	7.2	**250.4**
TOTAL - 2020	kt/year	-1.9	-0.8	0.3	-0.4	-7.5	7.1	6.0	0.4	9.3	0.0	1.8	3.1	6.6	32.5	-3.7	0.2	-1.3	0.3	1.5	0.6	-1.7	0.1	90.2	2.0	1.2	**145.8**
TOTAL - 2030	kt/year	-4.7	-1.3	0.0	-1.8	-27.1	-2.3	4.9	-0.1	-7.8	0.0	0.7	1.2	-3.1	45.9	-17.3	0.2	-3.0	0.0	-5.4	-1.1	-2.3	0.1	-12.1	-3.1	0.2	**-39.3**

Key results by country

Case: 100% exploitation of the biomass potential, cross-sectoral least cost in terms of primary energy, optimised CHP, PRIMES LCEP

Page 2 of 2

Air pollutants - SO_2

Net vs. gross avoided direct & LCA emissions

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	%of gross	-317%	-486%	-101%	-32%	-178%	-102%	62%	-650%	-694%	-1405%	-25%	-301%	22%	16%	-954%	76%	-318%	-41%	-76%	-105%	-138%	72%	28%	5%	-662%	-47%
Heat - 2030	%of gross	-109%	-101%	50%	-35%	-202%	14%	28%	49%	-23%	-499%	53%	36%	-21%	79%	-160%	95%	-47%	-6%	-190%	-136%	-83%	80%	-127%	-328%	27%	-14%
Transport - 2030	%of gross	108%	n.a.	n.a.	65%	65%	59%	68%	n.a.	47%	n.a.	n.a.	48%	48%	84%	59%	n.a.	49%	59%	71%	59%	68%	n.a.	62%	117%	129%	60%
TOTAL - 2010	%of gross	-9%	-134%	49%	73%	64%	65%	88%	36%	78%	-3%	63%	85%	75%	74%	43%	86%	74%	71%	79%	57%	25%	91%	94%	84%	95%	79%
TOTAL - 2020	%of gross	-45%	-153%	23%	-8%	-41%	23%	56%	43%	29%	-363%	57%	58%	18%	81%	-39%	82%	-37%	14%	24%	27%	-33%	86%	68%	42%	52%	41%
TOTAL - 2030	%of gross	-95%	-198%	1%	-26%	-132%	-6%	38%	-17%	-22%	-554%	27%	24%	-6%	76%	-225%	80%	-74%	-1%	-134%	-73%	-41%	77%	-26%	-111%	10%	-12%

Air pollutants - NO_X

Net avoided direct & LCA emissions

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	kt/year	-5.0	-2.1	-3.8	-2.5	-26.0	-47.7	-1.3	-2.0	-13.5	0.0	-4.5	-1.7	-8.2	-9.3	-35.8	0.1	-7.2	-1.6	-6.2	-0.9	-3.3	0.0	-50.9	-3.1	-1.2	-237.8
Heat - 2030	kt/year	-1.2	0.7	1.8	2.3	-6.6	18.4	0.4	0.5	9.8	0.0	1.1	1.4	5.8	3.5	9.9	0.0	4.8	0.0	1.6	0.3	0.0	0.0	15.1	1.0	0.8	71.4
Transport - 2030	kt/year	-0.3	0.0	0.0	0.1	3.1	1.9	-3.1	0.0	-4.6	0.0	0.0	-0.2	-3.9	-2.9	1.0	0.0	0.1	0.3	-0.4	0.4	-2.3	0.0	0.9	-1.1	-0.1	-11.0
TOTAL - 2010	kt/year	-1.1	-1.2	-1.0	1.1	-1.9	-4.6	1.2	-0.6	0.2	0.0	-4.0	0.7	-1.6	-1.7	-9.1	0.2	-0.4	0.2	0.1	0.1	-0.3	0.0	55.5	0.6	1.1	33.6
TOTAL - 2020	kt/year	-4.0	-1.5	-2.1	-1.4	-22.3	-17.8	-0.4	-1.0	-2.7	0.0	-4.6	-1.3	-3.8	-5.3	-13.9	0.2	-2.9	-0.9	-1.9	0.6	-3.6	0.0	32.1	-1.1	-0.5	-60.1
TOTAL - 2030	kt/year	-6.5	-1.5	-2.0	-0.1	-29.5	-27.4	-3.9	-1.5	-8.4	0.0	-3.4	-0.5	-6.3	-8.7	-24.9	0.1	-2.3	-1.3	-4.9	-0.2	-5.6	0.0	-34.9	-3.2	-0.6	-177.4

Net vs. gross avoided direct & LCA emissions

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	%of gross	-94%	-104%	-206%	-33%	-80%	-141%	-46%	-180%	-100%	-145%	-13660%	-48%	-76%	-111%	-252%	40%	-119%	-118%	-190%	-67%	-94%	34%	-117%	-99%	-121%	-119%
Heat - 2030	%of gross	-10%	26%	71%	17%	-11%	40%	11%	33%	32%	-8%	45%	28%	18%	16%	40%	73%	53%	-1%	20%	12%	0%	-40%	39%	15%	25%	21%
Transport - 2030	%of gross	-17%	n.a.	n.a.	10%	29%	42%	-84%	n.a.	-35%	n.a.	n.a.	-24%	-25%	-90%	42%	n.a.	14%	43%	-44%	42%	-63%	n.a.	15%	-83%	-118%	-15%
TOTAL - 2010	%of gross	-13%	-71%	-33%	7%	-4%	-12%	20%	-64%	1%	-47%	-375%	8%	-7%	-8%	-59%	65%	-6%	9%	3%	4%	-6%	51%	65%	16%	42%	10%
TOTAL - 2020	%of gross	-27%	-39%	-57%	-7%	-31%	-28%	-6%	-52%	-6%	-38%	-312%	-16%	-9%	-18%	-48%	51%	-29%	-24%	-22%	13%	-36%	26%	28%	-16%	-18%	-12%
TOTAL - 2030	%of gross	-34%	-32%	-44%	0%	-29%	-32%	-39%	-56%	-15%	-22%	-138%	-5%	-11%	-26%	-60%	42%	-15%	-30%	-39%	-5%	-44%	11%	-39%	-29%	-13%	-29%

Air pollutants - Particulate matter

Net avoided direct & LCA emissions

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	kt/year	-0.3	-0.1	-0.1	-0.1	-1.0	-1.5	0.2	-0.1	-0.4	0.0	-0.2	-0.1	-0.1	-0.4	-1.7	0.0	-0.3	-0.1	-0.2	-0.1	-0.1	0.0	-0.5	0.2	-0.1	-7.0
Heat - 2030	kt/year	0.2	0.1	0.1	0.3	1.0	4.0	0.4	0.1	1.3	0.0	0.2	0.2	1.4	1.9	1.0	0.0	0.3	0.1	0.2	0.0	0.1	0.0	1.9	0.1	0.1	14.9
Transport - 2030	kt/year	0.1	0.0	0.0	0.1	0.6	0.2	0.1	0.0	0.3	0.0	0.0	0.0	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.3	0.0	0.0	2.6
TOTAL - 2010	kt/year	0.0	0.0	0.1	0.4	1.9	2.1	0.4	0.0	1.4	0.0	0.0	0.5	1.0	0.4	0.2	0.0	0.4	0.2	0.3	0.2	0.2	0.0	10.3	0.8	1.4	22.2
TOTAL - 2020	kt/year	0.0	-0.1	0.0	0.1	0.5	1.7	0.5	0.0	1.5	0.0	0.0	0.2	1.6	1.4	0.0	0.0	0.1	0.1	0.3	0.2	0.1	0.0	9.6	0.6	0.2	18.7
TOTAL - 2030	kt/year	0.0	0.0	0.0	0.3	0.6	2.7	0.6	0.0	1.2	0.0	0.1	0.1	1.7	1.6	-0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.0	1.7	0.3	0.1	10.6

Net vs. gross avoided direct & LCA emissions

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	%of gross	-159%	-142%	-69%	-28%	-84%	-82%	59%	-147%	-107%	-318%	-536%	-128%	-11%	-67%	-350%	73%	-171%	-123%	-97%	-92%	-80%	62%	-10%	45%	-156%	-56%
Heat - 2030	%of gross	27%	63%	90%	51%	33%	85%	88%	79%	76%	29%	86%	65%	69%	81%	70%	99%	75%	45%	46%	38%	46%	39%	77%	27%	56%	68%
Transport - 2030	%of gross	104%	n.a.	n.a.	81%	86%	85%	45%	n.a.	33%	n.a.	n.a.	37%	38%	54%	85%	n.a.	51%	87%	54%	86%	48%	n.a.	70%	61%	59%	58%
TOTAL - 2010	%of gross	-2%	-66%	40%	40%	64%	65%	78%	13%	70%	14%	-5%	66%	61%	30%	22%	91%	67%	59%	73%	76%	45%	83%	91%	89%	96%	72%
TOTAL - 2020	%of gross	-3%	-41%	19%	9%	14%	40%	74%	35%	55%	-7%	0%	39%	56%	54%	2%	86%	17%	31%	50%	59%	18%	71%	72%	72%	56%	50%
TOTAL - 2030	%of gross	-3%	-6%	20%	25%	11%	40%	68%	23%	39%	1%	25%	20%	50%	53%	-30%	75%	1%	6%	4%	17%	15%	54%	21%	41%	24%	27%

Avoided fossil fuels

Avoided fossil fuels - by fuel in energetic terms

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Hard coal - 2030	TWh/year	1.0	0.0	1.8	1.6	12.5	38.7	1.5	0.0	0.5	0.0	0.0	0.0	1.3	10.5	0.1	0.0	0.0	0.8	0.0	0.0	3.4	0.0	79.3	0.3	0.0	153.4
Lignite - 2030	TWh/year	0.0	0.0	0.0	4.2	0.0	1.6	3.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.6	4.0	0.3	0.0	0.0	33.2	3.9	0.0	51.6
Oil - 2030	TWh/year	17.6	2.5	2.1	13.0	98.0	231.9	32.8	5.1	103.3	0.0	11.9	11.0	125.8	132.6	40.0	0.4	7.6	5.8	8.0	5.9	19.8	0.1	87.6	6.0	4.2	973.1
Gas - 2030	TWh/year	77.4	20.0	26.3	96.9	403.0	170.0	5.1	8.7	138.5	0.3	10.0	25.5	119.7	66.5	200.3	0.0	67.2	15.8	45.8	18.6	40.8	0.0	229.9	41.2	15.9	1843.4

Avoided fossil fuels - by sector in energetic terms

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	TWh/year	29.8	9.2	16.8	40.5	167.4	181.1	11.0	6.5	63.0	0.0	9.7	13.9	48.6	75.6	99.7	0.3	35.4	8.2	19.8	7.5	22.5	0.1	221.8	18.7	6.7	1113.6
Heat - 2030	TWh/year	59.5	13.3	13.4	70.7	307.3	244.6	18.3	7.6	130.5	0.3	12.2	20.2	141.6	124.0	131.6	0.1	38.3	12.0	34.5	13.9	28.1	0.1	185.1	28.7	13.0	1648.5
Transport - 2030	TWh/year	6.8	0.0	0.0	4.6	38.9	16.5	13.3	0.0	48.8	0.0	0.0	2.4	56.7	10.0	9.1	0.0	1.6	2.8	3.5	3.4	13.4	0.0	23.2	4.0	0.4	259.4
TOTAL - 2010	TWh/year	37.0	7.3	15.4	65.1	189.3	175.6	13.4	4.0	86.2	0.1	13.8	22.7	73.3	125.6	73.9	0.4	27.5	10.2	15.5	11.1	22.2	0.1	123.1	13.7	6.8	1133.3
TOTAL - 2020	TWh/year	64.3	16.6	22.8	94.9	320.6	294.0	24.1	9.3	159.4	0.3	17.0	28.7	159.5	154.0	139.7	0.5	46.8	17.7	35.0	18.6	48.0	0.1	261.2	26.2	12.6	1971.9
TOTAL - 2030	TWh/year	96.0	22.5	30.1	115.8	513.6	442.2	42.6	14.1	242.3	0.3	21.9	36.5	246.8	209.5	240.4	0.4	75.3	23.0	57.9	24.8	64.0	0.1	430.1	51.3	20.0	3021.5

Avoided fossil fuels - by sector in monetary terms

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	M€/year	501	158	267	625	2720	2622	137	108	1079	1	167	240	820	1172	1708	7	603	124	293	130	348	1	2473	272	115	16690
Heat - 2030	M€/year	1056	237	235	1240	5476	4987	380	148	2430	5	252	376	2676	2576	2365	2	676	216	607	243	502	1	3392	497	235	30810
Transport - 2030	M€/year	141	0	0	96	811	344	278	0	1018	0	0	50	1181	208	189	0	33	59	73	70	280	0	484	84	8	5406
TOTAL - 2010	M€/year	465	94	173	738	2277	1708	160	49	1156	2	185	257	945	1533	935	6	248	103	185	137	283	1	1043	125	72	12879
TOTAL - 2020	M€/year	994	256	327	1374	4950	4102	366	145	2616	4	276	405	2611	2188	2195	8	674	247	530	293	742	2	3119	348	197	28969
TOTAL - 2030	M€/year	1697	394	502	1961	9007	7953	796	257	4526	6	419	666	4677	3956	4262	9	1312	399	973	443	1129	3	6349	852	358	52906

Avoided CO_2

Key results by country

Case: 100% exploitation of the biomass potential, cross-sectoral least cost in terms of avoided CO_2, PRIMES LCEP — Page 1 of 2

Country:	[Unit]	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Energy output																											
Electricity - 2030	TWh/year	8	5	6	16	68	106	7	3	28	0	5	8	31	29	56	0	10	3	11	3	9	0	113	8	2	**536**
Heat - 2030	TWh/year	63	10	8	54	270	154	15	6	110	0	9	16	101	106	97	0	38	11	25	11	24	0	113	25	13	**1278**
Transport - 2030	TWh/year	6	0	1	5	35	16	12	0	51	0	0	2	57	6	9	0	2	3	4	3	12	0	22	2	0	**245**
TOTAL - 2010	TWh/year	19	4	7	31	92	71	6	2	48	0	8	10	44	62	45	0	12	4	7	6	11	0	45	7	3	**543**
TOTAL - 2020	TWh/year	48	9	11	51	236	175	17	5	123	0	11	16	116	88	103	0	29	12	22	12	35	0	137	18	9	**1284**
TOTAL - 2030	TWh/year	76	16	15	75	373	276	34	9	189	0	14	27	189	141	161	0	49	16	39	17	45	0	248	35	15	**2060**
Conversion efficiency																											
Electricity - 2030	%	46%	41%	44%	53%	42%	40%	44%	40%	42%	38%	40%	49%	44%	52%	40%	40%	43%	43%	43%	46%	46%	38%	41%	45%	46%	**42%**
Heat - 2030	%	84%	70%	62%	81%	81%	77%	72%	71%	79%	83%	65%	74%	79%	82%	69%	43%	80%	78%	78%	77%	75%	71%	73%	80%	83%	**78%**
Transport - 2030	%	58%	n.a.	61%	58%	58%	55%	59%	n.a.	59%	n.a.	n.a.	61%	59%	59%	56%	n.a.	58%	57%	59%	57%	58%	n.a.	58%	59%	60%	**58%**
TOTAL - 2010	%	60%	36%	41%	60%	55%	43%	42%	38%	52%	86%	42%	47%	53%	66%	51%	38%	53%	51%	52%	70%	57%	47%	45%	56%	56%	**52%**
TOTAL - 2020	%	70%	46%	50%	63%	64%	52%	53%	45%	64%	83%	47%	51%	62%	64%	55%	38%	61%	61%	58%	66%	60%	54%	49%	63%	73%	**58%**
TOTAL - 2030	%	75%	56%	54%	72%	67%	56%	60%	55%	65%	77%	53%	63%	64%	72%	55%	41%	68%	65%	62%	65%	62%	59%	53%	66%	75%	**62%**
Share of corresponding gross consumption																											
Electricity - 2010	%	10%	2%	8%	15%	6%	8%	4%	3%	6%	0%	3%	11%	5%	12%	4%	2%	6%	21%	6%	9%	31%	1%	20%	8%	7%	**7.2%**
Electricity - 2020	%	8%	5%	9%	20%	8%	12%	5%	7%	5%	0%	3%	12%	7%	17%	5%	3%	10%	24%	15%	20%	43%	1%	33%	12%	6%	**10.2%**
Electricity - 2030	%	9%	5%	12%	16%	9%	16%	7%	8%	7%	0%	3%	10%	8%	16%	9%	2%	11%	25%	18%	27%	44%	1%	44%	17%	9%	**12.7%**
Heat - 2010	%	8%	1%	4%	9%	6%	1%	3%	1%	4%	1%	1%	4%	6%	18%	3%	1%	4%	13%	4%	23%	24%	5%	3%	6%	7%	**4.3%**
Heat - 2020	%	24%	2%	7%	17%	18%	6%	7%	3%	10%	1%	2%	6%	15%	24%	6%	1%	12%	40%	12%	35%	62%	10%	12%	17%	29%	**10.8%**
Heat - 2030	%	44%	5%	8%	29%	31%	11%	11%	8%	14%	2%	3%	11%	19%	47%	11%	1%	23%	59%	21%	45%	67%	10%	23%	38%	46%	**18.4%**
Transport - 2010	%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0.0%**
Transport - 2020	%	6%	0%	0%	0%	3%	2%	3%	0%	3%	0%	0%	0%	3%	3%	3%	0%	0%	23%	0%	13%	26%	0%	3%	3%	1%	**2.6%**
Transport - 2030	%	6%	0%	2%	9%	5%	2%	10%	0%	9%	0%	0%	2%	11%	6%	1%	0%	3%	28%	6%	22%	45%	0%	11%	5%	2%	**5.1%**
Additional generation cost (as share of corresponding reference generation cost)																											
Electricity - 2030	% of ref.	48%	-13%	3%	35%	91%	19%	3%	3%	-18%	-39%	6%	-6%	-5%	34%	51%	-77%	17%	27%	14%	80%	70%	-70%	-4%	130%	37%	**20%**
Electricity - average	*% of ref.*	*29%*	*28%*	*11%*	*42%*	*66%*	*25%*	*26%*	*20%*	*3%*	*-26%*	*29%*	*15%*	*14%*	*41%*	*49%*	*-64%*	*32%*	*41%*	*22%*	*53%*	*58%*	*-41%*	*10%*	*87%*	*19%*	***28%***
Heat - 2030	% of ref.	36%	20%	10%	17%	24%	26%	-8%	17%	1%	-38%	-10%	6%	-13%	31%	22%	7%	13%	25%	-9%	3%	12%	-4%	-10%	17%	23%	**15%**
Heat - average	*% of ref.*	*67%*	*10%*	*29%*	*22%*	*53%*	*37%*	*22%*	*14%*	*21%*	*-12%*	*19%*	*21%*	*5%*	*61%*	*51%*	*20%*	*24%*	*53%*	*9%*	*42%*	*39%*	*25%*	*5%*	*48%*	*33%*	***40%***
Transport - 2030	% of ref.	60%	n.a.	63%	58%	49%	35%	19%	n.a.	21%	n.a.	n.a.	25%	24%	116%	38%	n.a.	12%	13%	6%	15%	26%	n.a.	6%	77%	170%	**30%**
Transport - average	*% of ref.*	*88%*	*n.a.*	*7%*	*72%*	*85%*	*66%*	*39%*	*n.a.*	*64%*	*n.a.*	*n.a.*	*31%*	*53%*	*109%*	*69%*	*n.a.*	*34%*	*45%*	*30%*	*45%*	*49%*	*n.a.*	*28%*	*62%*	*106%*	***41%***
TOTAL - 2010	% of ref.	46%	25%	1%	26%	50%	24%	51%	15%	17%	3%	25%	24%	17%	46%	70%	-47%	32%	42%	17%	54%	34%	3%	16%	30%	23%	**33%**
TOTAL - 2020	% of ref.	65%	21%	35%	29%	69%	47%	26%	21%	40%	-17%	30%	14%	23%	61%	55%	-48%	37%	60%	23%	49%	64%	-9%	14%	96%	47%	**44%**
TOTAL - 2030	% of ref.	39%	7%	11%	23%	36%	23%	3%	12%	3%	-38%	-2%	4%	-2%	36%	35%	-62%	14%	23%	0%	20%	28%	-34%	-5%	39%	28%	**18%**
TOTAL - average	*% of ref.*	*56%*	*26%*	*19%*	*31%*	*54%*	*31%*	*27%*	*19%*	*18%*	*-12%*	*24%*	*18%*	*14%*	*53%*	*53%*	*-46%*	*29%*	*45%*	*15%*	*45%*	*40%*	*-5%*	*9%*	*51%*	*31%*	***35%***
GHG emissions - CO_2-eq.																											
Net avoided direct & LCA emissions																											
Electricity - 2030	Mt/year	2.6	1.4	1.7	6.3	23.3	36.6	3.5	0.9	9.5	0.0	1.1	2.3	10.9	10.3	12.2	0.1	2.8	1.0	4.3	1.2	3.3	0.0	54.2	4.2	0.5	**194.0**
Heat - 2030	Mt/year	18.6	2.8	2.1	15.4	76.5	51.1	4.8	1.8	31.5	0.1	3.0	4.7	29.7	35.8	25.7	0.0	10.6	2.9	6.7	2.8	6.6	0.0	31.6	6.9	4.0	**375.5**
Transport - 2030	Mt/year	1.7	0.0	0.4	1.4	9.1	3.9	2.8	0.0	9.4	0.0	0.0	0.5	11.7	1.9	2.2	0.0	0.4	0.7	1.1	0.8	3.4	0.0	5.6	0.7	0.2	**57.8**
TOTAL - 2010	Mt/year	7.0	0.8	2.6	12.1	32.6	40.7	2.9	0.5	16.4	0.0	2.0	4.3	14.6	22.2	13.2	0.1	5.3	2.0	2.8	1.8	3.5	0.0	32.5	3.1	1.4	**224.2**
TOTAL - 2020	Mt/year	15.0	2.7	3.2	17.2	71.3	63.1	5.6	1.6	35.6	0.1	2.9	5.7	35.5	34.5	26.5	0.1	8.9	3.7	7.5	3.5	9.9	0.0	65.3	6.1	3.1	**428.4**
TOTAL - 2030	Mt/year	22.9	4.2	4.1	23.0	108.9	91.6	11.1	2.7	50.4	0.1	4.1	7.5	52.2	48.0	40.0	0.1	13.8	4.5	12.1	4.8	13.2	0.0	91.4	11.7	4.7	**627.4**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	78%	67%	69%	83%	77%	73%	77%	67%	81%	74%	59%	70%	81%	83%	58%	92%	71%	77%	82%	81%	80%	91%	79%	86%	77%	**76%**
Heat - 2030	%of gross	96%	97%	98%	97%	97%	96%	95%	98%	96%	97%	98%	97%	95%	97%	96%	99%	96%	94%	94%	95%	94%	97%	94%	95%	96%	**96%**
Transport - 2030	%of gross	94%	n.a.	117%	88%	83%	79%	75%	n.a.	58%	n.a.	n.a.	72%	65%	104%	79%	n.a.	78%	79%	95%	79%	90%	n.a.	80%	114%	131%	**74%**
TOTAL - 2010	%of gross	90%	66%	89%	90%	90%	91%	86%	76%	89%	97%	75%	87%	86%	94%	84%	92%	90%	86%	87%	93%	87%	92%	93%	92%	92%	**90%**
TOTAL - 2020	%of gross	91%	84%	85%	91%	91%	88%	79%	82%	88%	96%	79%	85%	88%	93%	81%	92%	89%	87%	89%	90%	86%	93%	87%	91%	93%	**88%**
TOTAL - 2030	%of gross	93%	84%	85%	92%	91%	85%	83%	85%	83%	95%	83%	85%	83%	94%	79%	92%	89%	87%	89%	88%	89%	94%	83%	93%	95%	**87%**
Air pollutants - SO_2																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-0.9	-0.8	-0.5	-0.1	-5.0	-2.2	1.4	-0.4	-2.6	0.0	-0.2	-0.5	2.3	0.1	-7.2	0.1	-1.0	-0.1	-0.3	-0.2	-0.5	0.0	9.1	0.2	-0.2	**-9.8**
Heat - 2030	kt/year	-4.2	-0.6	0.1	0.5	-26.7	-9.5	1.4	0.0	-15.7	0.0	0.4	0.9	-13.0	41.2	-14.2	0.0	-4.4	-0.4	-5.8	-1.3	-3.0	0.0	-31.6	-4.3	0.9	**-89.1**
Transport - 2030	kt/year	0.7	0.0	0.2	0.5	3.1	1.3	0.6	0.0	0.8	0.0	0.0	0.0	0.0	0.6	0.7	0.0	0.1	0.2	0.3	0.3	1.1	0.0	2.0	0.2	0.1	**12.7**
TOTAL - 2010	kt/year	0.2	-0.4	0.6	4.3	10.8	15.0	6.6	0.1	19.5	0.0	1.5	7.0	8.0	11.0	2.2	0.2	1.1	1.8	3.2	0.2	0.2	0.0	141.6	4.6	5.7	**245.2**
TOTAL - 2020	kt/year	-1.3	-1.0	-0.3	1.7	-8.9	0.5	5.0	-0.1	-2.5	0.0	1.3	1.5	1.0	27.9	-7.0	0.2	-2.9	0.0	-0.5	-0.2	-2.6	0.1	104.6	1.4	1.4	**119.2**
TOTAL - 2030	kt/year	-4.3	-1.4	-0.2	0.9	-28.6	-10.4	3.3	-0.4	-17.5	0.0	0.3	0.3	-10.7	41.9	-20.7	0.1	-5.3	-0.4	-5.8	-1.2	-2.4	0.1	-20.5	-3.9	0.8	**-86.1**

Key results by country

Case: 100% exploitation of the biomass potential, cross-sectoral least cost in terms of avoided CO_2, PRIMES LCEP

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Air pollutants - SO_2																											
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-275%	-469%	-108%	-15%	-146%	-26%	68%	-525%	-520%	-1433%	-22%	-280%	43%	3%	-763%	76%	-367%	-49%	-33%	-73%	-83%	72%	31%	14%	-652%	**-17%**
Heat - 2030	%of gross	-83%	-130%	10%	7%	-235%	-43%	17%	-5%	-73%	-488%	32%	22%	-47%	75%	-353%	92%	-126%	-31%	-306%	-188%	-94%	80%	-307%	-383%	32%	**-46%**
Transport - 2030	%of gross	95%	n.a.	109%	73%	64%	59%	34%	n.a.	11%	n.a.	n.a.	-8%	0%	82%	59%	n.a.	49%	59%	71%	59%	70%	n.a.	65%	98%	125%	**38%**
TOTAL - 2010	%of gross	5%	-213%	36%	64%	49%	68%	87%	25%	67%	-1%	56%	83%	41%	62%	28%	85%	27%	69%	59%	16%	7%	91%	95%	82%	93%	**75%**
TOTAL - 2020	%of gross	-24%	-230%	-23%	25%	-48%	2%	52%	-10%	-10%	-366%	45%	37%	3%	76%	-81%	81%	-93%	-2%	-10%	-8%	-52%	86%	72%	32%	50%	**34%**
TOTAL - 2030	%of gross	-70%	-221%	-17%	9%	-146%	-32%	28%	-69%	-61%	-542%	12%	7%	-26%	72%	-335%	78%	-133%	-17%	-168%	-88%	-44%	77%	-48%	-153%	26%	**-30%**
Air pollutants - NO_X																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-2.7	-1.9	-3.2	-2.3	-16.8	-35.5	-1.1	-1.5	-5.2	0.0	-4.2	-1.5	-3.5	-9.5	-29.9	0.1	-3.9	-1.3	-4.4	-0.9	-3.2	0.0	-43.6	-2.9	-0.6	**-179.5**
Heat - 2030	kt/year	-3.0	-0.3	0.5	0.3	-16.5	0.5	0.0	-0.2	1.3	0.0	0.4	0.4	-0.1	-0.4	0.1	0.0	0.8	-0.3	-0.5	0.0	-0.9	0.0	-1.7	-0.6	0.0	**-20.1**
Transport - 2030	kt/year	-0.2	0.0	-0.5	-0.3	3.2	1.9	-2.6	0.0	-7.8	0.0	0.0	-0.2	-8.4	-1.5	1.0	0.0	0.1	0.3	-0.5	0.4	-1.7	0.0	0.7	-0.4	-0.1	**-16.7**
TOTAL - 2010	kt/year	-1.8	-1.4	-1.4	-2.5	-6.9	-2.3	1.0	-0.6	0.0	0.0	-4.4	-0.3	-3.2	-6.3	-10.0	0.2	-1.0	0.1	-0.3	-0.4	-0.9	0.0	73.9	0.8	0.7	**33.0**
TOTAL - 2020	kt/year	-4.2	-1.9	-2.7	-4.8	-24.3	-17.0	-0.5	-1.3	-6.1	0.0	-4.6	-2.4	-3.0	-9.9	-12.1	0.2	-2.7	-1.0	-1.6	-0.2	-4.4	0.0	39.6	-1.2	-0.7	**-66.9**
TOTAL - 2030	kt/year	-5.9	-2.2	-3.1	-2.3	-30.1	-33.1	-3.7	-1.7	-11.7	0.0	-3.8	-1.3	-12.0	-11.4	-28.8	0.1	-3.0	-1.3	-5.5	-0.6	-5.8	0.0	-44.6	-4.0	-0.7	**-216.3**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-90%	-93%	-194%	-33%	-58%	-97%	-33%	-142%	-47%	-174%	-12878%	-43%	-26%	-129%	-213%	39%	-114%	-128%	-118%	-62%	-89%	34%	-94%	-95%	-103%	**-92%**
Heat - 2030	%of gross	-21%	-13%	33%	2%	-30%	2%	0%	-16%	5%	-12%	22%	10%	0%	-2%	1%	65%	9%	-14%	-8%	-1%	-17%	-40%	-7%	-10%	1%	**-7%**
Transport - 2030	%of gross	-13%	n.a.	-219%	-24%	33%	42%	-78%	n.a.	-54%	n.a.	n.a.	-25%	-52%	-76%	42%	n.a.	16%	43%	-51%	43%	-52%	n.a.	11%	-73%	-95%	**-24%**
TOTAL - 2010	%of gross	-24%	-90%	-53%	-19%	-18%	-6%	19%	-92%	0%	-19%	-632%	-5%	-16%	-33%	-70%	64%	-20%	5%	-9%	-23%	-21%	51%	74%	20%	32%	**10%**
TOTAL - 2020	%of gross	-31%	-56%	-93%	-28%	-36%	-29%	-6%	-81%	-15%	-25%	-396%	-32%	-7%	-37%	-46%	50%	-32%	-29%	-20%	-6%	-45%	26%	33%	-20%	-27%	**-14%**
TOTAL - 2030	%of gross	-31%	-54%	-90%	-11%	-32%	-45%	-37%	-74%	-22%	-28%	-204%	-16%	-22%	-36%	-81%	40%	-22%	-32%	-50%	-12%	-48%	11%	-58%	-40%	-17%	**-39%**
Air pollutants - Particulate matter																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-0.2	-0.1	-0.1	-0.1	-0.6	-1.1	0.2	0.0	-0.2	0.0	-0.1	-0.1	0.1	-0.3	-1.5	0.0	-0.2	-0.1	-0.1	-0.1	-0.1	0.0	-0.8	0.2	0.0	**-5.3**
Heat - 2030	kt/year	0.2	0.0	0.1	0.3	0.6	2.5	0.3	0.1	0.8	0.0	0.2	0.1	0.9	1.7	0.5	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.9	0.0	0.1	**9.6**
Transport - 2030	kt/year	0.1	0.0	0.0	0.1	0.5	0.2	0.0	0.0	-0.3	0.0	0.0	0.0	-0.5	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.0	**0.9**
TOTAL - 2010	kt/year	0.0	0.0	0.1	0.3	1.5	2.4	0.4	0.0	1.4	0.0	0.0	0.4	0.9	0.5	0.3	0.0	0.3	0.2	0.2	0.1	0.1	0.0	12.7	0.8	1.1	**23.6**
TOTAL - 2020	kt/year	0.1	-0.1	0.0	0.0	0.5	1.7	0.5	0.0	0.8	0.0	0.0	0.1	1.3	1.2	0.3	0.0	0.1	0.1	0.2	0.2	0.0	0.0	10.4	0.6	0.1	**18.2**
TOTAL - 2030	kt/year	0.1	0.0	0.0	0.2	0.5	1.7	0.5	0.0	0.3	0.0	0.0	0.0	0.5	1.4	-0.8	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.4	0.2	0.1	**5.2**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-178%	-131%	-75%	-31%	-58%	-52%	56%	-119%	-53%	-335%	-516%	-114%	11%	-73%	-307%	72%	-154%	-131%	-55%	-79%	-84%	62%	-15%	46%	-173%	**-42%**
Heat - 2030	%of gross	22%	34%	67%	45%	19%	76%	86%	55%	53%	19%	83%	55%	61%	74%	51%	98%	43%	33%	24%	29%	36%	39%	58%	-4%	46%	**53%**
Transport - 2030	%of gross	96%	n.a.	71%	80%	86%	85%	7%	n.a.	-31%	n.a.	n.a.	-30%	-52%	59%	85%	n.a.	53%	87%	57%	86%	56%	n.a.	72%	62%	65%	**21%**
TOTAL - 2010	%of gross	10%	-104%	31%	40%	55%	70%	76%	-1%	69%	56%	-39%	70%	57%	38%	40%	91%	62%	58%	67%	65%	43%	83%	93%	91%	95%	**74%**
TOTAL - 2020	%of gross	7%	-76%	-10%	5%	16%	43%	72%	-6%	37%	15%	-10%	25%	51%	51%	25%	85%	23%	28%	47%	57%	7%	71%	72%	71%	46%	**50%**
TOTAL - 2030	%of gross	6%	-28%	0%	23%	10%	31%	56%	4%	11%	-7%	10%	3%	15%	50%	-49%	74%	7%	8%	-3%	12%	10%	54%	5%	31%	29%	**15%**
Avoided fossil fuels																											
Avoided fossil fuels - by fuel in energetic terms																											
Hard coal - 2030	TWh/year	0.7	0.0	1.6	1.5	11.1	42.1	1.8	0.0	0.4	0.0	0.0	0.0	1.6	9.1	0.1	0.0	0.1	0.6	0.0	0.0	3.5	0.0	84.9	0.3	0.0	**159.4**
Lignite - 2030	TWh/year	0.0	0.0	0.0	3.9	0.0	1.7	3.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	4.6	0.3	0.0	0.0	35.4	3.8	0.0	**54.5**
Oil - 2030	TWh/year	21.6	2.3	2.6	18.7	94.3	167.8	29.5	3.4	93.9	0.0	9.3	9.9	113.1	123.7	31.5	0.4	7.7	5.6	7.1	5.7	18.9	0.1	62.5	3.8	5.3	**839.0**
Gas - 2030	TWh/year	67.1	17.1	20.1	81.0	359.5	172.3	6.3	8.3	125.8	0.3	9.4	22.9	113.7	61.4	175.3	0.0	54.3	14.0	40.6	17.1	38.4	0.0	193.7	39.3	12.2	**1650.2**
Avoided fossil fuels - by sector in energetic terms																											
Electricity - 2030	TWh/year	16.8	9.2	14.9	37.5	147.8	197.0	13.2	6.1	50.8	0.0	9.6	14.2	60.4	66.1	98.5	0.3	20.2	6.1	23.1	8.0	22.6	0.1	236.5	18.3	3.9	**1081.3**
Heat - 2030	TWh/year	66.7	10.2	8.3	62.4	280.4	170.6	15.9	5.8	116.0	0.3	9.2	16.2	108.1	121.9	99.3	0.0	40.4	11.7	25.6	11.9	25.7	0.1	116.8	26.9	13.2	**1363.6**
Transport - 2030	TWh/year	5.9	0.0	1.1	5.3	36.7	16.4	12.2	0.0	53.3	0.0	0.0	2.4	60.0	6.2	9.2	0.0	1.7	2.8	3.7	3.3	12.5	0.0	23.2	1.9	0.4	**258.2**
TOTAL - 2010	TWh/year	32.9	6.0	12.6	53.4	167.9	161.9	11.9	3.1	78.5	0.1	11.8	17.1	69.8	112.0	68.8	0.3	24.1	8.4	13.2	9.2	19.4	0.1	120.4	12.2	5.4	**1020.6**
TOTAL - 2020	TWh/year	58.8	13.7	18.0	80.6	300.7	261.8	22.3	7.3	146.5	0.3	14.8	24.4	146.9	140.9	127.7	0.4	40.3	16.2	31.7	16.8	46.4	0.1	234.8	23.7	10.9	**1786.1**
TOTAL - 2030	TWh/year	89.4	19.4	24.3	105.1	464.9	383.9	41.3	11.9	220.1	0.3	18.8	32.8	228.4	194.3	207.0	0.4	62.3	20.6	52.4	23.2	60.8	0.1	376.6	47.2	17.5	**2703.1**
Avoided fossil fuels - by sector in monetary terms																											
Electricity - 2030	M€/year	283	158	237	578	2403	2853	166	101	870	1	165	244	1020	1025	1688	7	343	92	341	139	349	1	2637	267	67	**16036**
Heat - 2030	M€/year	1197	183	146	1117	5010	3481	331	111	2131	5	190	304	2042	2522	1780	1	712	211	449	207	461	1	2126	467	244	**25431**
Transport - 2030	M€/year	124	0	23	110	764	341	255	0	1111	0	0	50	1249	130	191	0	36	59	78	68	261	0	484	40	9	**5382**
TOTAL - 2010	M€/year	415	77	136	610	2023	1421	135	36	1028	2	157	185	897	1363	860	5	212	84	156	117	245	1	884	110	58	**11218**
TOTAL - 2020	M€/year	923	211	259	1171	4671	3554	330	109	2364	5	239	335	2378	2008	2012	7	579	231	465	264	716	2	2531	317	175	**25853**
TOTAL - 2030	M€/year	1603	341	407	1805	8177	6675	752	213	4112	6	356	598	4312	3677	3659	8	1091	362	868	414	1071	3	5247	774	320	**46849**

Avoided air pollution case

Case: 100% exploitation of the biomass potential, cross-sectoral least cost in terms of avoided air pollutant, PRIMES LCEP — Page 1 of 2

Key results by country	Country:	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Energy output	[Unit]																										
Electricity - 2030	TWh/year	17	7	4	21	101	148	7	3	51	0	5	8	38	29	77	0	15	5	14	4	10	0	145	13	3	**724**
Heat - 2030	TWh/year	28	8	6	44	172	85	13	6	67	0	9	16	91	110	60	0	28	8	18	8	22	0	57	17	10	**883**
Transport - 2030	TWh/year	18	0	4	5	43	16	13	0	47	0	1	2	52	2	10	0	2	3	5	3	10	0	22	1	0	**260**
TOTAL - 2010	TWh/year	21	4	6	27	78	68	6	2	41	0	8	9	41	56	40	0	10	4	6	4	10	0	42	6	3	**494**
TOTAL - 2020	TWh/year	44	10	10	48	202	154	16	5	97	0	10	17	107	88	97	0	25	10	21	10	27	0	120	14	7	**1140**
TOTAL - 2030	TWh/year	63	15	14	70	315	249	33	9	164	0	14	27	181	142	147	0	44	16	37	15	43	0	224	31	13	**1867**
Conversion efficiency																											
Electricity - 2030	%	49%	42%	40%	55%	49%	42%	44%	39%	43%	37%	37%	48%	45%	51%	41%	39%	44%	46%	44%	53%	53%	38%	43%	49%	50%	**44%**
Heat - 2030	%	80%	64%	63%	78%	76%	75%	69%	71%	72%	82%	70%	74%	75%	82%	68%	43%	79%	77%	76%	78%	78%	71%	59%	73%	78%	**74%**
Transport - 2030	%	57%	n.a.	49%	54%	58%	57%	59%	n.a.	58%	n.a.	49%	60%	57%	53%	55%	n.a.	56%	57%	57%	58%	57%	n.a.	60%	57%	n.a.	**57%**
TOTAL - 2010	%	67%	36%	37%	52%	46%	41%	41%	39%	44%	86%	52%	44%	50%	59%	45%	37%	44%	49%	41%	51%	58%	47%	42%	51%	47%	**47%**
TOTAL - 2020	%	65%	49%	49%	60%	58%	50%	50%	48%	50%	81%	53%	51%	57%	65%	52%	37%	54%	55%	54%	60%	64%	54%	43%	52%	57%	**54%**
TOTAL - 2030	%	62%	51%	51%	67%	62%	50%	58%	55%	57%	77%	53%	63%	61%	73%	50%	40%	61%	60%	58%	65%	65%	59%	47%	60%	69%	**57%**
Share of corresponding gross consumption																											
Electricity - 2010	%	7%	2%	9%	17%	9%	9%	4%	5%	8%	0%	2%	10%	6%	13%	4%	2%	11%	22%	9%	28%	30%	1%	21%	10%	10%	**8.6%**
Electricity - 2020	%	11%	5%	8%	19%	11%	12%	6%	7%	11%	0%	2%	12%	8%	16%	7%	3%	12%	36%	14%	30%	36%	1%	41%	19%	19%	**12.2%**
Electricity - 2030	%	19%	6%	8%	22%	14%	23%	8%	8%	12%	0%	3%	10%	10%	16%	13%	2%	16%	46%	22%	31%	51%	1%	56%	26%	18%	**17.1%**
Heat - 2010	%	11%	1%	3%	6%	3%	1%	2%	1%	2%	1%	2%	3%	5%	15%	2%	1%	1%	11%	1%	9%	19%	5%	1%	4%	3%	**2.7%**
Heat - 2020	%	17%	2%	6%	13%	12%	4%	6%	4%	3%	1%	2%	6%	10%	25%	5%	1%	7%	22%	7%	21%	42%	10%	5%	7%	14%	**7.1%**
Heat - 2030	%	20%	3%	6%	23%	19%	6%	9%	8%	9%	2%	3%	11%	17%	48%	7%	1%	17%	45%	16%	33%	62%	10%	12%	27%	36%	**12.7%**
Transport - 2010	%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	6%	0%	0%	0%	0%	**0.2%**
Transport - 2020	%	10%	0%	2%	8%	4%	2%	3%	0%	5%	0%	0%	0%	5%	3%	3%	0%	4%	23%	8%	17%	28%	0%	0%	3%	1%	**3.4%**
Transport - 2030	%	19%	0%	7%	10%	6%	2%	11%	0%	9%	0%	0%	2%	10%	2%	1%	0%	3%	28%	8%	25%	40%	0%	11%	2%	0%	**5.4%**
Additional generation cost (as share of corresponding reference generation cost)																											
Electricity - 2030	% of ref.	104%	18%	-13%	102%	133%	42%	4%	3%	42%	-38%	14%	-3%	28%	57%	76%	-75%	46%	55%	33%	80%	89%	-70%	2%	187%	154%	**46%**
Electricity - average	*% of ref.*	*48%*	*43%*	*8%*	*86%*	*117%*	*44%*	*29%*	*35%*	*49%*	*-25%*	*16%*	*18%*	*25%*	*69%*	*71%*	*-56%*	*62%*	*61%*	*34%*	*84%*	*79%*	*-41%*	*16%*	*137%*	*118%*	***54%***
Heat - 2030	% of ref.	32%	19%	18%	11%	37%	23%	-7%	24%	-7%	-38%	-10%	5%	-10%	32%	21%	7%	11%	34%	-11%	3%	16%	-4%	-1%	14%	17%	**17%**
Heat - average	*% of ref.*	*75%*	*17%*	*39%*	*18%*	*47%*	*34%*	*24%*	*34%*	*-1%*	*-12%*	*52%*	*9%*	*22%*	*53%*	*37%*	*4%*	*15%*	*44%*	*6%*	*27%*	*61%*	*25%*	*2%*	*27%*	*16%*	***41%***
Transport - 2030	% of ref.	116%	n.a.	71%	57%	51%	34%	19%	n.a.	18%	n.a.	75%	24%	20%	60%	42%	n.a.	12%	13%	7%	17%	23%	n.a.	4%	65%	n.a.	**33%**
Transport - average	*% of ref.*	*140%*	*n.a.*	*111%*	*91%*	*112%*	*85%*	*39%*	*n.a.*	*59%*	*n.a.*	*89%*	*62%*	*88%*	*86%*	*67%*	*n.a.*	*46%*	*45%*	*44%*	*76%*	*58%*	*n.a.*	*19%*	*57%*	*n.a.*	***79%***
TOTAL - 2010	% of ref.	81%	25%	-7%	47%	92%	34%	50%	49%	29%	3%	61%	18%	44%	56%	82%	-48%	57%	45%	27%	53%	71%	3%	17%	40%	32%	**51%**
TOTAL - 2020	% of ref.	82%	44%	45%	58%	111%	55%	32%	39%	67%	-18%	32%	19%	44%	68%	65%	-49%	57%	74%	38%	71%	82%	-9%	22%	168%	118%	**63%**
TOTAL - 2030	% of ref.	71%	18%	23%	36%	66%	37%	6%	15%	18%	-38%	4%	4%	7%	38%	56%	-60%	25%	38%	11%	25%	35%	-34%	2%	71%	43%	**32%**
TOTAL - average	*% of ref.*	*81%*	*39%*	*33%*	*50%*	*88%*	*46%*	*31%*	*43%*	*36%*	*-12%*	*41%*	*16%*	*30%*	*57%*	*64%*	*-46%*	*49%*	*53%*	*27%*	*55%*	*60%*	*-5%*	*15%*	*83%*	*59%*	***51%***
GHG emissions - CO_2-eq.																											
Net avoided direct & LCA emissions																											
Electricity - 2030	Mt/year	6.1	1.9	1.1	8.6	36.1	52.0	3.6	0.9	17.0	0.0	0.9	2.3	12.9	10.6	17.1	0.1	4.4	1.9	5.3	1.5	4.0	0.0	68.9	6.4	1.1	**264.9**
Heat - 2030	Mt/year	8.4	2.0	1.6	13.3	48.0	27.3	4.0	1.9	19.7	0.1	3.0	4.7	27.0	37.5	15.4	0.0	7.9	2.2	5.0	2.1	6.1	0.0	15.5	4.8	3.2	**260.5**
Transport - 2030	Mt/year	7.3	0.0	1.2	1.4	12.1	4.0	2.9	0.0	6.6	0.0	0.2	0.6	7.2	0.6	2.7	0.0	0.5	0.7	1.6	0.9	2.9	0.0	5.7	0.3	0.0	**59.2**
TOTAL - 2010	Mt/year	7.8	0.8	2.6	12.5	31.1	43.0	2.9	0.7	15.4	0.0	2.2	4.1	14.1	20.7	10.5	0.1	6.3	2.0	2.7	1.7	3.3	0.0	32.8	3.0	1.4	**221.6**
TOTAL - 2020	Mt/year	14.9	2.8	3.0	17.3	63.3	56.9	5.6	1.6	28.2	0.1	2.6	5.8	31.5	34.6	24.6	0.1	7.9	3.6	6.8	3.3	8.1	0.0	64.9	5.6	2.4	**395.4**
TOTAL - 2030	Mt/year	21.7	3.8	4.0	23.3	96.2	83.3	10.5	2.8	43.3	0.1	4.1	7.5	47.1	48.7	35.2	0.1	12.8	4.8	12.0	4.4	12.9	0.0	90.1	11.5	4.3	**584.6**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	83%	68%	68%	84%	81%	75%	78%	67%	81%	74%	50%	70%	80%	84%	59%	91%	75%	82%	82%	87%	84%	91%	78%	86%	78%	**77%**
Heat - 2030	%of gross	96%	97%	98%	97%	98%	96%	95%	98%	97%	97%	98%	97%	96%	97%	96%	99%	96%	95%	95%	96%	94%	97%	97%	96%	97%	**97%**
Transport - 2030	%of gross	131%	n.a.	100%	84%	89%	79%	71%	n.a.	44%	n.a.	100%	79%	43%	84%	83%	n.a.	86%	79%	104%	80%	87%	n.a.	80%	95%	n.a.	**72%**
TOTAL - 2010	%of gross	92%	66%	89%	92%	87%	92%	86%	84%	87%	97%	81%	86%	85%	93%	73%	92%	92%	86%	88%	90%	86%	92%	92%	91%	89%	**89%**
TOTAL - 2020	%of gross	95%	84%	87%	91%	89%	87%	78%	82%	79%	96%	81%	85%	84%	94%	79%	91%	86%	87%	88%	89%	88%	93%	85%	87%	88%	**86%**
TOTAL - 2030	%of gross	100%	80%	88%	91%	90%	81%	81%	85%	77%	95%	82%	85%	77%	94%	73%	92%	87%	87%	90%	89%	89%	94%	81%	90%	91%	**84%**
Air pollutants - SO_2																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-1.2	-0.8	-0.5	-0.1	-3.6	0.5	1.4	-0.4	-3.7	0.0	0.0	-0.6	2.8	0.3	-6.0	0.1	-1.1	0.1	-0.1	0.0	0.0	0.0	8.6	0.5	-0.3	**-3.8**
Heat - 2030	kt/year	-1.1	-0.4	0.0	7.2	-13.7	-4.5	2.0	0.0	-1.5	0.0	0.4	1.0	-1.8	43.4	-8.2	0.0	-2.9	-0.1	-3.9	-1.1	-2.0	0.0	-6.3	-2.8	1.3	**5.0**
Transport - 2030	kt/year	5.9	0.0	0.6	0.3	3.8	1.3	1.1	0.0	2.7	0.0	0.1	0.0	3.2	0.2	0.9	0.0	0.2	0.2	0.6	0.3	1.0	0.0	1.9	0.1	0.0	**24.3**
TOTAL - 2010	kt/year	1.9	-0.4	0.6	4.9	19.6	18.4	6.9	0.4	29.6	0.0	1.6	7.3	14.5	11.0	3.5	0.2	4.1	2.0	5.9	1.9	1.4	0.0	154.5	5.0	8.3	**303.1**
TOTAL - 2020	kt/year	2.1	-1.0	-0.2	6.7	-3.0	5.8	6.7	0.0	16.6	0.0	1.0	2.4	14.1	28.4	-4.2	0.2	-1.4	0.9	1.8	0.7	0.3	0.1	149.3	4.2	1.3	**232.9**
TOTAL - 2030	kt/year	3.6	-1.2	0.1	7.5	-13.5	-2.6	4.5	-0.4	-2.5	0.0	0.4	0.5	4.3	43.9	-13.3	0.1	-3.8	0.2	-3.5	-0.9	-1.1	0.1	4.3	-2.2	1.0	**25.5**

Key results by country

Case: 100% exploitation of the biomass potential, cross-sectoral least cost in terms of avoided air pollutant, PRIMES LCEP

Page 2 of 2

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Air pollutants - SO_2																											
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-164%	-358%	-162%	-6%	-72%	5%	68%	-541%	-398%	-1418%	-4%	-289%	44%	14%	-460%	75%	-265%	13%	-10%	-3%	-6%	72%	23%	29%	-450%	**-5%**
Heat - 2030	%of gross	-47%	-154%	-1%	59%	-216%	-39%	30%	-4%	-9%	-493%	27%	26%	-7%	75%	-321%	92%	-107%	-10%	-256%	-231%	-68%	80%	-123%	-360%	52%	**3%**
Transport - 2030	%of gross	257%	n.a.	100%	42%	65%	59%	62%	n.a.	42%	n.a.	100%	11%	45%	60%	61%	n.a.	63%	59%	89%	54%	67%	n.a.	61%	70%	n.a.	**68%**
TOTAL - 2010	%of gross	37%	-223%	36%	79%	75%	79%	88%	69%	86%	-1%	58%	88%	75%	68%	48%	85%	84%	75%	90%	81%	56%	91%	96%	88%	97%	**86%**
TOTAL - 2020	%of gross	33%	-229%	-14%	66%	-18%	26%	70%	-2%	65%	-374%	42%	59%	48%	76%	-51%	81%	-51%	49%	41%	33%	9%	86%	87%	78%	64%	**63%**
TOTAL - 2030	%of gross	67%	-243%	8%	52%	-78%	-10%	43%	-63%	-10%	-546%	19%	11%	11%	73%	-253%	77%	-113%	9%	-99%	-69%	-21%	77%	9%	-80%	38%	**9%**
Air pollutants - NO_X																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-1.1	-1.9	-2.2	-0.5	-10.9	-30.5	-1.1	-1.5	-15.9	0.0	-3.8	-1.9	-9.2	-7.9	-26.4	0.1	-4.0	-1.0	-3.5	0.1	-0.2	0.0	-55.7	-3.3	-1.1	**-183.4**
Heat - 2030	kt/year	-0.2	0.3	0.3	-0.4	0.3	0.9	0.0	0.0	4.4	0.0	0.3	0.4	3.2	0.4	0.8	0.0	1.1	-0.1	0.4	0.1	-0.6	0.0	5.4	0.6	0.3	**18.0**
Transport - 2030	kt/year	-1.5	0.0	0.9	0.4	1.1	1.9	-3.0	0.0	-4.3	0.0	0.1	0.0	-3.6	0.2	0.8	0.0	-0.1	0.3	-1.1	0.4	-1.0	0.0	1.0	-0.1	0.0	**-7.7**
TOTAL - 2010	kt/year	-2.0	-1.4	-1.3	2.1	4.4	1.1	1.1	-0.3	-0.2	0.0	-3.4	-0.1	-1.7	0.0	-7.0	0.2	0.3	0.3	0.5	0.6	0.2	0.0	80.6	0.8	1.2	**76.2**
TOTAL - 2020	kt/year	-3.2	-1.5	-2.0	-0.1	-6.0	-10.5	-0.5	-1.1	-8.8	0.0	-3.5	-2.0	-0.9	-1.2	-9.6	0.2	-2.0	-0.2	-0.8	0.7	-0.1	0.0	46.9	-0.7	-0.2	**-7.4**
TOTAL - 2030	kt/year	-2.7	-1.7	-1.0	-0.5	-9.4	-27.7	-4.1	-1.5	-15.8	0.0	-3.4	-1.6	-9.7	-7.4	-24.8	0.1	-2.9	-0.8	-4.2	0.6	-1.8	0.0	-49.4	-2.8	-0.8	**-173.2**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-16%	-73%	-196%	-5%	-26%	-60%	-33%	-146%	-81%	-182%	-12516%	-56%	-57%	-106%	-136%	36%	-77%	-56%	-75%	7%	-5%	34%	-94%	-70%	-88%	**-69%**
Heat - 2030	%of gross	-2%	17%	23%	-4%	1%	5%	1%	-3%	27%	-12%	15%	10%	14%	2%	7%	67%	16%	-5%	10%	8%	-12%	-40%	46%	14%	11%	**9%**
Transport - 2030	%of gross	-27%	n.a.	100%	25%	9%	42%	-81%	n.a.	-32%	n.a.	100%	-3%	-24%	34%	28%	n.a.	-12%	43%	-82%	39%	-35%	n.a.	15%	-26%	n.a.	**-10%**
TOTAL - 2010	%of gross	-26%	-91%	-51%	15%	10%	3%	20%	-35%	-1%	-19%	-318%	-2%	-8%	0%	-49%	64%	5%	12%	12%	21%	5%	51%	75%	21%	44%	**23%**
TOTAL - 2020	%of gross	-23%	-45%	-76%	-1%	-9%	-19%	-7%	-69%	-22%	-26%	-275%	-27%	-2%	-5%	-37%	50%	-23%	-6%	-11%	16%	-1%	26%	35%	-11%	-7%	**-2%**
TOTAL - 2030	%of gross	-15%	-41%	-32%	-2%	-11%	-38%	-42%	-67%	-32%	-29%	-170%	-19%	-18%	-23%	-74%	38%	-23%	-18%	-40%	14%	-15%	11%	-64%	-30%	-19%	**-32%**
Air pollutants - Particulate matter																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-0.3	-0.1	-0.1	-0.2	-0.8	-1.1	0.2	0.0	-0.8	0.0	-0.1	-0.1	-0.2	-0.4	-1.6	0.0	-0.2	-0.1	-0.1	0.0	-0.1	0.0	-1.8	0.4	-0.1	**-7.7**
Heat - 2030	kt/year	0.2	0.1	0.0	0.3	1.0	1.5	0.2	0.1	0.8	0.0	0.2	0.1	1.0	1.8	0.4	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.6	0.0	0.1	**9.1**
Transport - 2030	kt/year	0.7	0.0	0.1	0.1	0.6	0.2	0.1	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.3	0.0	0.0	**3.3**
TOTAL - 2010	kt/year	0.2	0.0	0.1	0.2	1.6	2.7	0.4	0.0	1.5	0.0	0.0	0.4	0.9	0.1	0.0	0.0	0.5	0.2	0.3	0.3	0.1	0.0	13.7	0.9	1.7	**25.7**
TOTAL - 2020	kt/year	0.4	-0.1	0.0	0.0	0.5	1.6	0.5	0.0	0.7	0.0	0.0	0.1	1.3	1.1	0.2	0.0	0.0	0.1	0.2	0.2	0.1	0.0	11.9	0.8	0.1	**20.0**
TOTAL - 2030	kt/year	0.6	-0.1	0.0	0.2	0.9	0.6	0.5	0.0	0.3	0.0	0.0	0.0	1.1	1.4	-1.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	-0.9	0.4	0.0	**4.6**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-115%	-147%	-145%	-36%	-47%	-40%	55%	-121%	-127%	-340%	-527%	-116%	-33%	-88%	-248%	68%	-137%	-95%	-46%	-43%	-35%	62%	-26%	46%	-187%	**-46%**
Heat - 2030	%of gross	53%	74%	74%	52%	58%	87%	87%	72%	77%	22%	82%	56%	73%	76%	70%	98%	58%	42%	49%	41%	41%	39%	80%	23%	55%	**70%**
Transport - 2030	%of gross	201%	n.a.	100%	75%	83%	85%	46%	n.a.	34%	n.a.	100%	37%	36%	84%	83%	n.a.	53%	87%	56%	84%	61%	n.a.	70%	58%	n.a.	**69%**
TOTAL - 2010	%of gross	31%	-108%	31%	22%	50%	73%	77%	54%	69%	56%	28%	63%	58%	10%	2%	91%	74%	58%	74%	74%	44%	83%	94%	90%	97%	**73%**
TOTAL - 2020	%of gross	47%	-54%	-6%	1%	17%	47%	68%	26%	32%	13%	26%	29%	54%	47%	18%	85%	12%	29%	51%	61%	30%	71%	70%	75%	47%	**52%**
TOTAL - 2030	%of gross	62%	-45%	13%	20%	22%	13%	63%	19%	12%	-6%	16%	11%	37%	50%	-71%	69%	-3%	-1%	6%	24%	23%	54%	-11%	42%	13%	**13%**
Avoided fossil fuels																											
Avoided fossil fuels - by fuel in energetic terms																											
Hard coal - 2030	TWh/year	1.3	0.0	1.1	2.0	16.3	58.7	1.8	0.0	0.7	0.0	0.0	0.0	2.0	9.3	0.2	0.0	0.0	1.0	0.0	0.0	4.0	0.0	107.6	0.4	0.0	**206.5**
Lignite - 2030	TWh/year	0.0	0.0	0.0	5.3	0.0	2.4	3.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	5.7	0.4	0.0	0.0	45.2	5.9	0.0	**70.1**
Oil - 2030	TWh/year	26.7	1.4	5.3	27.4	78.1	94.8	28.3	3.9	83.5	0.0	10.0	9.8	104.8	125.8	25.5	0.4	6.7	5.0	8.1	6.0	17.1	0.1	46.4	2.5	4.6	**722.2**
Gas - 2030	TWh/year	57.0	18.0	14.2	69.4	350.6	226.7	6.3	7.8	129.0	0.3	8.7	23.0	120.7	62.3	180.2	0.0	55.7	16.0	38.9	15.2	39.7	0.0	181.6	39.4	13.8	**1674.3**
Avoided fossil fuels - by sector in energetic terms																											
Electricity - 2030	TWh/year	36.9	11.9	10.1	50.9	218.1	274.7	13.5	5.9	91.5	0.0	8.9	14.1	73.1	67.2	135.5	0.3	30.8	10.9	28.4	9.4	26.0	0.1	301.6	28.4	8.0	**1456.1**
Heat - 2030	TWh/year	29.4	7.5	6.4	47.7	181.6	91.0	13.2	6.0	72.2	0.3	9.2	16.4	99.5	127.8	59.6	0.0	30.0	9.0	19.2	8.6	23.8	0.1	55.7	18.9	10.4	**943.6**
Transport - 2030	TWh/year	18.6	0.0	4.0	5.5	45.2	16.8	13.6	0.0	49.5	0.0	0.6	2.4	54.9	2.5	10.6	0.0	2.0	2.8	5.1	3.7	10.9	0.0	23.6	0.9	0.0	**273.4**
TOTAL - 2010	TWh/year	31.8	6.3	12.9	53.5	178.4	161.3	12.1	3.5	77.8	0.1	12.5	16.6	69.5	105.0	62.0	0.3	27.6	7.0	14.1	9.9	18.6	0.1	119.4	12.0	6.0	**1018.4**
TOTAL - 2020	TWh/year	55.3	14.3	15.8	76.6	287.7	239.1	22.3	7.5	139.1	0.3	11.9	24.7	139.7	138.8	124.4	0.4	39.1	15.6	29.4	16.2	36.9	0.1	234.7	22.3	10.9	**1703.2**
TOTAL - 2030	TWh/year	84.9	19.4	20.5	104.1	445.0	382.6	40.3	11.9	213.2	0.3	18.7	32.8	227.5	197.5	205.8	0.4	62.8	22.8	52.7	21.6	60.7	0.1	380.8	48.2	18.4	**2673.1**
Avoided fossil fuels - by sector in monetary terms																											
Electricity - 2030	M€/year	619	204	160	784	3545	3979	170	99	1567	1	154	242	1234	1042	2322	7	524	165	420	162	401	1	3362	413	138	**21716**
Heat - 2030	M€/year	530	133	114	898	3226	1844	274	117	1354	5	191	306	1882	2644	1073	1	531	162	338	150	426	1	1018	328	194	**17742**
Transport - 2030	M€/year	388	0	84	115	942	351	284	0	1031	0	13	51	1145	52	221	0	41	59	107	76	228	0	491	19	0	**5697**
TOTAL - 2010	M€/year	409	81	138	596	2069	1369	135	40	996	2	170	178	885	1269	772	5	212	66	149	116	236	1	814	111	56	**10876**
TOTAL - 2020	M€/year	882	220	230	1137	4415	3145	314	113	2237	5	196	340	2268	1999	1950	7	559	210	439	255	571	2	2238	288	169	**24189**
TOTAL - 2030	M€/year	1538	337	358	1797	7713	6175	728	216	3952	6	358	599	4261	3738	3616	8	1096	387	865	388	1055	3	4871	760	332	**45155**

Biofuel prioritisation (domestic use)

Key results by country

Case: **100% exploitation of the biomass potential, prioritisation of the transport sector** (10% biofuels by 2020 - without international trade), **PRIMES LCEP**

Page 1 of 2

Country:	[Unit]	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Energy output																											
Electricity - 2030	TWh/year	13	4	5	18	88	100	7	3	35	0	5	8	29	31	54	0	9	3	9	3	9	0	116	8	2	**558**
Heat - 2030	TWh/year	42	10	6	39	132	86	10	5	56	0	9	12	82	88	50	0	26	10	20	11	22	0	73	18	9	**815**
Transport - 2030	TWh/year	13	2	4	12	113	69	16	2	77	0	1	5	71	16	44	0	10	3	8	3	13	0	48	6	2	**538**
TOTAL - 2010	TWh/year	18	5	7	32	87	81	6	2	53	0	8	13	41	57	46	0	12	4	7	6	10	0	49	7	3	**555**
TOTAL - 2020	TWh/year	44	10	10	50	227	170	16	5	118	0	11	18	125	80	97	0	27	12	23	12	33	0	142	16	9	**1256**
TOTAL - 2030	TWh/year	68	16	15	69	332	256	32	9	168	0	15	25	183	135	148	0	45	15	38	17	43	0	236	33	13	**1911**
Conversion efficiency																											
Electricity - 2030	%	47%	41%	43%	53%	44%	43%	44%	42%	42%	38%	40%	48%	47%	52%	42%	40%	46%	43%	46%	44%	45%	38%	42%	45%	48%	**44%**
Heat - 2030	%	82%	69%	63%	79%	72%	61%	66%	62%	77%	83%	66%	70%	75%	81%	56%	41%	75%	76%	72%	76%	70%	71%	66%	78%	80%	**71%**
Transport - 2030	%	58%	52%	59%	57%	57%	57%	58%	59%	57%	n.a.	54%	55%	58%	57%	57%	n.a.	56%	57%	57%	58%	58%	n.a.	58%	58%	56%	**57%**
TOTAL - 2010	%	55%	37%	41%	58%	48%	45%	42%	39%	49%	81%	41%	49%	48%	59%	46%	37%	52%	51%	49%	64%	53%	47%	49%	54%	54%	**49%**
TOTAL - 2020	%	62%	45%	44%	60%	57%	48%	50%	44%	57%	81%	46%	47%	60%	59%	47%	37%	57%	60%	58%	62%	56%	54%	49%	59%	65%	**54%**
TOTAL - 2030	%	67%	56%	54%	66%	58%	51%	56%	53%	58%	77%	54%	59%	62%	69%	50%	40%	63%	63%	60%	64%	59%	59%	50%	62%	67%	**57%**
Share of corresponding gross consumption																											
Electricity - 2010	%	9%	2%	8%	15%	7%	7%	4%	3%	5%	0%	3%	11%	4%	15%	3%	2%	5%	21%	5%	12%	33%	1%	16%	8%	7%	**6.8%**
Electricity - 2020	%	13%	4%	11%	21%	10%	12%	5%	5%	6%	0%	3%	13%	6%	19%	6%	3%	8%	24%	9%	24%	45%	1%	32%	12%	10%	**10.6%**
Electricity - 2030	%	15%	4%	9%	18%	12%	15%	7%	7%	8%	0%	3%	10%	7%	17%	9%	2%	10%	26%	15%	26%	44%	1%	45%	17%	12%	**13.2%**
Heat - 2010	%	6%	1%	4%	8%	4%	2%	3%	1%	2%	1%	1%	3%	3%	13%	1%	1%	3%	13%	3%	18%	19%	5%	4%	5%	6%	**3.1%**
Heat - 2020	%	17%	2%	4%	13%	13%	4%	5%	4%	6%	1%	2%	3%	12%	18%	3%	1%	9%	38%	11%	31%	51%	10%	11%	14%	21%	**7.8%**
Heat - 2030	%	30%	4%	6%	21%	15%	6%	7%	6%	7%	2%	3%	8%	16%	39%	6%	1%	16%	55%	17%	46%	61%	10%	15%	28%	31%	**11.7%**
Transport - 2010	%	4%	1%	1%	4%	2%	2%	0%	1%	3%	0%	0%	3%	3%	2%	3%	0%	4%	0%	4%	4%	3%	0%	4%	3%	1%	**2.4%**
Transport - 2020	%	9%	1%	2%	8%	7%	5%	5%	1%	8%	0%	0%	5%	8%	6%	5%	0%	9%	23%	9%	13%	32%	0%	9%	5%	7%	**6.1%**
Transport - 2030	%	13%	1%	8%	23%	16%	8%	14%	3%	14%	0%	0%	4%	14%	17%	6%	0%	15%	28%	14%	23%	48%	0%	23%	17%	13%	**11.1%**
Additional generation cost (as share of corresponding reference generation cost)																											
Electricity - 2030	% of ref.	72%	-18%	-9%	34%	83%	18%	0%	20%	-16%	-39%	4%	-9%	-7%	22%	49%	-75%	14%	53%	14%	84%	105%	-70%	-4%	105%	48%	**21%**
Electricity - average	*% of ref.*	*65%*	*25%*	*11%*	*46%*	*70%*	*25%*	*25%*	*28%*	*2%*	*-2%*	*29%*	*13%*	*10%*	*50%*	*54%*	*-55%*	*29%*	*58%*	*22%*	*58%*	*71%*	*-41%*	*7%*	*88%*	*42%*	***32%***
Heat - 2030	% of ref.	29%	18%	9%	16%	25%	18%	-7%	5%	-4%	-39%	-11%	11%	-15%	33%	8%	3%	9%	15%	-7%	3%	5%	-4%	-8%	17%	9%	**10%**
Heat - average	*% of ref.*	*46%*	*10%*	*10%*	*18%*	*46%*	*22%*	*22%*	*7%*	*9%*	*-12%*	*3%*	*21%*	*-1%*	*42%*	*10%*	*2%*	*19%*	*41%*	*4%*	*39%*	*27%*	*25%*	*9%*	*38%*	*21%*	***26%***
Transport - 2030	% of ref.	119%	77%	65%	65%	104%	71%	22%	68%	38%	n.a.	75%	45%	26%	95%	75%	n.a.	48%	13%	18%	15%	26%	n.a.	-4%	79%	178%	**58%**
Transport - average	*% of ref.*	*119%*	*130%*	*102%*	*81%*	*137%*	*99%*	*54%*	*131%*	*65%*	*n.a.*	*125%*	*70%*	*37%*	*113%*	*98%*	*n.a.*	*75%*	*45%*	*54%*	*54%*	*61%*	*n.a.*	*28%*	*104%*	*180%*	***82%***
TOTAL - 2010	% of ref.	52%	48%	7%	33%	58%	36%	50%	42%	25%	5%	28%	33%	20%	35%	60%	-48%	34%	40%	24%	52%	30%	3%	18%	33%	26%	**37%**
TOTAL - 2020	% of ref.	80%	33%	33%	36%	91%	53%	37%	35%	43%	-17%	29%	36%	19%	67%	67%	-49%	41%	61%	28%	55%	68%	-9%	14%	108%	64%	**51%**
TOTAL - 2030	% of ref.	53%	11%	18%	29%	66%	31%	8%	20%	11%	-39%	-2%	11%	1%	38%	45%	-63%	19%	24%	5%	20%	33%	-34%	-5%	48%	44%	**26%**
TOTAL - average	*% of ref.*	*61%*	*37%*	*22%*	*36%*	*69%*	*40%*	*33%*	*35%*	*23%*	*-12%*	*22%*	*28%*	*15%*	*49%*	*58%*	*-47%*	*34%*	*43%*	*22%*	*46%*	*42%*	*-5%*	*10%*	*58%*	*41%*	***39%***
GHG emissions - CO_2-eq.																											
Net avoided direct & LCA emissions																											
Electricity - 2030	Mt/year	4.4	1.1	1.4	7.2	30.9	36.4	3.3	0.7	12.3	0.0	0.9	2.3	9.3	11.0	12.3	0.1	2.5	1.0	3.3	1.1	3.3	0.0	56.3	4.3	0.8	**206.3**
Heat - 2030	Mt/year	12.3	2.5	1.6	11.0	36.4	28.1	2.9	1.3	15.7	0.1	2.9	3.4	24.3	29.5	12.6	0.0	7.3	2.6	5.6	2.9	5.7	0.0	19.4	4.9	2.6	**235.5**
Transport - 2030	Mt/year	5.0	0.7	1.5	3.8	43.8	27.9	3.7	0.8	16.4	0.0	0.3	1.3	13.5	5.2	18.0	0.0	3.5	0.7	2.9	0.8	3.6	0.0	17.1	2.5	0.9	**173.9**
TOTAL - 2010	Mt/year	5.6	1.0	2.7	12.1	29.8	36.8	2.9	0.7	14.7	0.0	2.0	4.7	10.0	21.2	9.0	0.1	4.6	2.0	2.2	1.6	3.2	0.0	29.0	2.9	1.4	**200.2**
TOTAL - 2020	Mt/year	14.2	2.7	3.0	17.2	72.4	61.1	5.2	1.5	32.9	0.1	2.7	6.0	31.4	31.7	25.7	0.1	8.1	3.5	7.0	3.4	9.3	0.0	67.2	5.8	3.0	**415.2**
TOTAL - 2030	Mt/year	21.8	4.3	4.5	21.9	111.1	92.3	9.9	2.8	44.3	0.1	4.1	6.9	47.1	45.7	42.9	0.1	13.3	4.3	11.9	4.8	12.6	0.0	92.8	11.7	4.3	**615.7**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	80%	63%	75%	85%	80%	78%	78%	64%	85%	74%	56%	70%	75%	84%	60%	92%	66%	79%	73%	79%	80%	91%	80%	88%	82%	**78%**
Heat - 2030	%of gross	95%	97%	97%	97%	97%	97%	95%	97%	96%	97%	98%	97%	95%	97%	97%	99%	96%	94%	95%	95%	94%	97%	94%	95%	96%	**96%**
Transport - 2030	%of gross	124%	129%	113%	100%	123%	126%	73%	147%	67%	n.a.	145%	79%	59%	104%	129%	n.a.	116%	79%	111%	79%	90%	n.a.	112%	123%	130%	**102%**
TOTAL - 2010	%of gross	78%	72%	90%	87%	84%	85%	86%	79%	74%	96%	75%	78%	65%	91%	60%	92%	84%	85%	76%	88%	82%	92%	89%	88%	91%	**82%**
TOTAL - 2020	%of gross	91%	85%	82%	90%	93%	88%	79%	80%	83%	96%	77%	81%	74%	92%	82%	91%	86%	86%	86%	89%	85%	93%	89%	90%	96%	**87%**
TOTAL - 2030	%of gross	97%	88%	93%	93%	99%	94%	80%	93%	80%	95%	85%	83%	78%	95%	91%	92%	92%	87%	91%	88%	89%	94%	87%	97%	98%	**90%**
Air pollutants - SO_2																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-1.6	-0.7	-0.4	-0.1	-5.9	-5.6	1.3	-0.4	-1.7	0.0	-0.2	-0.5	1.7	0.4	-7.5	0.1	-1.0	-0.1	-0.5	-0.2	-0.9	0.0	10.9	0.2	-0.3	**-13.1**
Heat - 2030	kt/year	-3.2	-0.6	-0.1	0.5	-9.6	2.5	1.1	-0.1	-1.8	0.0	0.3	1.3	-0.8	34.5	-2.6	0.0	-2.4	-0.5	-3.2	-1.2	-3.0	0.0	-13.2	-2.9	0.1	**-4.9**
Transport - 2030	kt/year	3.6	0.3	0.6	1.4	16.6	11.0	1.7	0.3	7.5	0.0	0.1	0.5	6.2	1.7	7.2	0.0	1.2	0.2	1.1	0.3	1.2	0.0	10.5	0.9	0.4	**74.6**
TOTAL - 2010	kt/year	-0.9	-0.3	0.7	3.3	12.7	12.3	6.7	0.2	22.3	0.0	1.5	7.4	9.5	10.5	1.8	0.2	0.7	1.8	2.8	0.4	0.1	0.0	112.0	4.2	6.2	**216.2**
TOTAL - 2020	kt/year	-0.3	-0.8	0.1	1.3	-2.5	6.4	5.0	0.0	8.7	0.0	1.0	1.6	6.7	23.1	-0.8	0.2	-2.0	-0.1	-0.3	0.1	-2.3	0.1	106.7	1.7	1.1	**154.7**
TOTAL - 2030	kt/year	-1.3	-1.1	0.2	1.8	1.1	7.9	4.1	-0.2	4.0	0.0	0.2	1.3	7.2	36.6	-2.9	0.1	-2.2	-0.4	-2.7	-1.2	-2.7	0.1	8.2	-1.8	0.2	**56.6**

Key results by country

Case: **100% exploitation of the biomass potential, prioritisation of the transport sector** (10% biofuels by 2020 - without international trade), **PRIMES LCEP**

Page 2 of 2

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Air pollutants - SO_2																											
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-294%	-515%	-120%	-6%	-135%	-71%	69%	-643%	-275%	-1430%	-29%	-277%	36%	17%	-819%	76%	-398%	-45%	-59%	-96%	-147%	72%	36%	17%	-494%	**-22%**
Heat - 2030	%of gross	-109%	-175%	-13%	10%	-201%	20%	23%	-21%	-17%	-489%	27%	45%	-3%	75%	-125%	91%	-96%	-37%	-193%	-182%	-113%	80%	-208%	-368%	4%	**-4%**
Transport - 2030	%of gross	211%	126%	104%	81%	108%	115%	76%	142%	71%	n.a.	146%	72%	63%	80%	118%	n.a.	93%	59%	92%	58%	69%	n.a.	158%	112%	133%	**101%**
TOTAL - 2010	%of gross	-33%	-93%	38%	53%	55%	59%	88%	35%	77%	-1%	55%	81%	65%	66%	24%	85%	21%	68%	62%	30%	4%	91%	90%	80%	93%	**74%**
TOTAL - 2020	%of gross	-7%	-146%	7%	23%	-13%	25%	64%	0%	35%	-369%	42%	45%	21%	76%	-8%	81%	-63%	-6%	-6%	4%	-51%	86%	76%	40%	50%	**47%**
TOTAL - 2030	%of gross	-24%	-143%	12%	22%	5%	27%	46%	-24%	18%	-546%	11%	34%	19%	72%	-31%	78%	-54%	-21%	-72%	-88%	-55%	77%	19%	-64%	9%	**21%**
Air pollutants - NO_X																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-4.1	-1.8	-1.8	-1.5	-15.1	-34.1	-0.4	-1.2	-2.3	0.0	-4.1	-1.3	-6.1	-8.0	-27.0	0.1	-3.8	-1.2	-5.1	-1.2	-3.6	0.0	-38.0	-2.5	-0.7	**-164.8**
Heat - 2030	kt/year	-1.3	0.1	0.3	0.6	-1.5	4.8	0.0	-0.4	0.0	0.0	0.3	0.5	0.8	0.1	3.0	0.0	1.1	-0.6	0.8	-0.1	-1.4	0.0	-0.7	-0.2	0.2	**6.6**
Transport - 2030	kt/year	-1.3	-0.4	-1.8	-3.6	-27.1	-21.9	-4.4	-0.7	-17.4	0.0	-0.3	-1.2	-11.6	-5.6	-14.7	0.0	-2.8	0.3	-2.9	0.4	-2.2	0.0	-8.2	-2.0	-0.7	**-130.0**
TOTAL - 2010	kt/year	-2.6	-1.2	-1.3	-1.7	-4.3	-5.1	1.0	-0.5	-1.9	0.0	-4.4	-0.8	-5.5	-4.4	-9.8	0.2	-1.5	0.1	-0.8	-0.3	-0.8	0.0	56.7	0.4	0.8	**12.4**
TOTAL - 2020	kt/year	-4.6	-1.8	-2.6	-4.3	-27.8	-26.2	-1.3	-1.2	-9.2	0.0	-4.9	-2.9	-9.7	-8.5	-20.5	0.2	-3.7	-1.2	-2.3	-0.2	-5.1	0.0	39.4	-1.5	-0.9	**-100.9**
TOTAL - 2030	kt/year	-6.6	-2.1	-3.3	-4.4	-43.7	-51.2	-4.8	-2.3	-19.7	0.0	-4.1	-2.0	-17.0	-13.5	-38.7	0.1	-5.5	-1.4	-7.2	-0.8	-7.2	0.0	-47.0	-4.7	-1.2	**-288.2**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-83%	-104%	-140%	-19%	-41%	-99%	-13%	-136%	-17%	-173%	-13719%	-38%	-50%	-103%	-198%	39%	-116%	-112%	-158%	-79%	-102%	34%	-80%	-82%	-79%	**-80%**
Heat - 2030	%of gross	-13%	6%	28%	7%	-6%	27%	1%	-49%	0%	-11%	17%	19%	4%	1%	33%	50%	17%	-27%	16%	-3%	-30%	-40%	-5%	-3%	8%	**4%**
Transport - 2030	%of gross	-32%	-95%	-198%	-110%	-83%	-113%	-98%	-158%	-77%	n.a.	-206%	-89%	-57%	-113%	-121%	n.a.	-99%	43%	-127%	42%	-61%	n.a.	-59%	-98%	-90%	**-84%**
TOTAL - 2010	%of gross	-35%	-70%	-48%	-13%	-11%	-14%	19%	-69%	-8%	-25%	-636%	-10%	-30%	-22%	-69%	64%	-32%	5%	-23%	-15%	-18%	51%	67%	11%	33%	**4%**
TOTAL - 2020	%of gross	-33%	-58%	-86%	-24%	-39%	-45%	-20%	-86%	-23%	-27%	-436%	-36%	-23%	-33%	-76%	50%	-45%	-34%	-32%	-6%	-53%	26%	34%	-25%	-31%	**-21%**
TOTAL - 2030	%of gross	-36%	-52%	-95%	-23%	-45%	-72%	-50%	-106%	-40%	-28%	-205%	-26%	-32%	-44%	-111%	40%	-43%	-36%	-68%	-18%	-61%	11%	-62%	-49%	-30%	**-54%**
Air pollutants - Particulate matter																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-0.3	-0.1	-0.1	-0.1	-0.8	-1.2	0.2	0.0	0.0	0.0	-0.1	-0.1	0.0	-0.3	-1.5	0.0	-0.2	-0.1	-0.1	-0.1	-0.1	0.0	-0.2	0.3	0.0	**-4.8**
Heat - 2030	kt/year	0.1	0.1	0.0	0.2	0.6	1.6	0.2	0.0	0.3	0.0	0.1	0.1	0.7	1.5	0.4	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.5	0.0	0.1	**6.8**
Transport - 2030	kt/year	0.4	0.0	0.0	0.1	1.6	0.9	0.1	0.0	0.6	0.0	0.0	0.0	0.6	0.1	0.6	0.0	0.1	0.0	0.1	0.1	0.1	0.0	1.3	0.1	0.0	**7.1**
TOTAL - 2010	kt/year	-0.1	0.0	0.1	0.3	1.6	1.8	0.4	0.0	1.1	0.0	-0.1	0.4	0.6	0.2	-0.1	0.0	0.2	0.2	0.1	0.1	0.1	0.0	10.2	0.7	1.2	**18.9**
TOTAL - 2020	kt/year	0.1	-0.1	0.0	0.1	0.7	1.1	0.4	0.0	1.1	0.0	-0.1	0.1	1.2	1.1	-0.1	0.0	0.1	0.1	0.2	0.2	0.0	0.0	10.9	0.6	0.1	**17.9**
TOTAL - 2030	kt/year	0.3	0.0	0.0	0.3	1.4	1.3	0.5	0.0	0.9	0.0	0.0	0.1	1.3	1.4	-0.5	0.0	0.1	0.0	0.0	0.0	0.1	0.0	1.6	0.4	0.1	**9.1**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-148%	-162%	-97%	-16%	-55%	-63%	64%	-148%	-11%	-335%	-559%	-115%	6%	-53%	-320%	73%	-168%	-124%	-77%	-91%	-78%	62%	-3%	53%	-127%	**-37%**
Heat - 2030	%of gross	28%	58%	68%	52%	42%	87%	86%	47%	37%	21%	77%	67%	56%	78%	74%	97%	52%	27%	46%	27%	30%	39%	51%	11%	49%	**60%**
Transport - 2030	%of gross	172%	91%	66%	53%	78%	72%	46%	97%	45%	n.a.	107%	45%	44%	47%	74%	n.a.	45%	87%	34%	86%	52%	n.a.	147%	57%	59%	**71%**
TOTAL - 2010	%of gross	-30%	-56%	33%	32%	55%	56%	76%	12%	55%	48%	-48%	61%	44%	17%	-17%	91%	45%	58%	43%	62%	39%	83%	90%	87%	96%	**64%**
TOTAL - 2020	%of gross	7%	-56%	-2%	10%	20%	30%	68%	-8%	46%	10%	-37%	31%	46%	47%	-6%	85%	22%	27%	48%	54%	8%	71%	77%	73%	53%	**49%**
TOTAL - 2030	%of gross	30%	-7%	9%	27%	29%	26%	63%	8%	34%	-8%	4%	15%	42%	50%	-30%	74%	11%	5%	3%	10%	8%	54%	22%	44%	26%	**26%**
Avoided fossil fuels																											
Avoided fossil fuels - by fuel in energetic terms																											
Hard coal - 2030	TWh/year	1.0	0.0	1.3	1.7	14.2	39.7	1.7	0.0	0.5	0.0	0.0	0.0	1.5	9.6	0.1	0.0	0.0	0.6	0.0	0.0	3.4	0.0	86.3	0.2	0.0	**161.8**
Lignite - 2030	TWh/year	0.0	0.0	0.0	4.4	0.0	1.6	3.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	4.0	0.3	0.0	0.0	36.1	3.8	0.0	**54.7**
Oil - 2030	TWh/year	22.9	3.5	5.4	22.2	143.7	156.4	27.5	4.2	102.3	0.0	9.0	11.0	118.6	116.7	58.0	0.4	14.4	5.5	11.8	5.8	18.8	0.1	76.6	8.3	5.0	**948.2**
Gas - 2030	TWh/year	63.2	15.6	15.9	71.1	289.6	153.8	5.9	6.5	99.4	0.3	9.5	19.8	99.3	61.4	132.0	0.0	42.7	13.4	34.1	17.1	36.3	0.0	164.6	32.9	12.0	**1396.4**
Avoided fossil fuels - by sector in energetic terms																											
Electricity - 2030	TWh/year	27.8	7.9	11.9	42.1	189.4	185.6	12.4	5.1	63.1	0.0	8.8	13.8	56.1	69.6	95.6	0.3	19.3	6.1	19.8	7.8	22.5	0.1	241.1	18.5	5.6	**1130.2**
Heat - 2030	TWh/year	45.7	9.6	6.5	44.6	139.4	92.8	9.5	4.1	57.6	0.3	9.2	11.6	88.1	101.3	48.4	0.0	27.9	10.9	21.3	12.0	22.8	0.1	71.7	20.0	9.1	**864.5**
Transport - 2030	TWh/year	13.5	1.7	4.3	12.6	118.8	73.1	16.7	1.7	81.5	0.0	0.6	5.4	75.2	16.8	46.1	0.0	10.2	2.9	8.8	3.4	13.3	0.0	50.7	6.8	2.3	**566.3**
TOTAL - 2010	TWh/year	32.5	7.1	13.5	55.4	180.5	166.2	12.3	4.0	77.6	0.2	11.9	20.6	62.9	111.4	66.3	0.3	23.0	8.6	13.2	9.0	18.8	0.1	111.3	11.4	5.5	**1023.5**
TOTAL - 2020	TWh/year	59.4	13.2	17.9	81.3	304.4	251.5	20.6	6.7	144.5	0.3	14.5	27.0	151.9	133.8	122.1	0.4	36.9	15.7	29.4	16.7	44.3	0.1	236.3	22.4	11.3	**1762.6**
TOTAL - 2030	TWh/year	87.0	19.1	22.6	99.3	447.5	351.4	38.6	10.9	202.2	0.3	18.6	30.7	219.4	187.7	190.1	0.4	57.4	19.9	49.9	23.2	58.6	0.1	363.6	45.3	17.0	**2561.0**
Avoided fossil fuels - by sector in monetary terms																											
Electricity - 2030	M€/year	467	135	189	648	3077	2688	155	84	1081	1	152	238	948	1080	1637	7	329	93	293	135	347	1	2688	269	96	**16840**
Heat - 2030	M€/year	815	171	114	799	2474	1895	198	79	1057	5	187	217	1664	2104	870	1	492	197	375	209	408	1	1306	347	165	**16151**
Transport - 2030	M€/year	281	35	89	263	2476	1524	347	36	1698	0	12	112	1568	349	962	0	212	59	183	71	277	0	1057	142	48	**11803**
TOTAL - 2010	M€/year	414	93	150	631	2199	1640	139	50	1047	2	158	239	833	1334	868	5	224	84	161	113	238	1	919	107	59	**11709**
TOTAL - 2020	M€/year	929	207	256	1180	4756	3425	303	104	2383	5	232	380	2510	1829	1954	7	548	222	456	262	683	2	2635	299	180	**25747**
TOTAL - 2030	M€/year	1563	341	393	1711	8027	6107	701	200	3836	6	351	567	4180	3533	3469	8	1033	349	851	415	1032	3	5051	758	310	**44793**

Alternative scenario

Key results by country — Case: **100% exploitation of the biomass potential, prioritisation of the transport sector** (10% biofuels by 2020 - without international trade), **PRIMES LCEP** — *Page 2 of 2*

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Air pollutants - SO_2																											
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-294%	-515%	-120%	-6%	-135%	-71%	69%	-643%	-275%	-1430%	-29%	-277%	36%	17%	-819%	76%	-398%	-45%	-59%	-96%	-147%	72%	36%	17%	-494%	**-22%**
Heat - 2030	%of gross	-109%	-175%	-13%	10%	-201%	20%	23%	-21%	-17%	-489%	27%	45%	-3%	75%	-125%	91%	-96%	-37%	-193%	-182%	-113%	80%	-208%	-368%	4%	**-4%**
Transport - 2030	%of gross	211%	126%	104%	81%	108%	115%	76%	142%	71%	n.a.	146%	72%	63%	80%	118%	n.a.	93%	59%	92%	58%	69%	n.a.	158%	112%	133%	**101%**
TOTAL - 2010	%of gross	-33%	-93%	38%	53%	55%	59%	88%	35%	77%	-1%	55%	81%	65%	66%	24%	85%	21%	68%	62%	30%	4%	91%	90%	80%	93%	**74%**
TOTAL - 2020	%of gross	-7%	-146%	7%	23%	-13%	25%	64%	0%	35%	-369%	42%	45%	21%	76%	-8%	81%	-63%	-6%	-6%	4%	-51%	86%	76%	40%	50%	**47%**
TOTAL - 2030	%of gross	-24%	-143%	12%	22%	5%	27%	46%	-24%	18%	-546%	11%	34%	19%	72%	-31%	78%	-54%	-21%	-72%	-88%	-55%	77%	19%	-64%	9%	**21%**
Air pollutants - NO_X																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-4.1	-1.8	-1.8	-1.5	-15.1	-34.1	-0.4	-1.2	-2.3	0.0	-4.1	-1.3	-6.1	-8.0	-27.0	0.1	-3.8	-1.2	-5.1	-1.2	-3.6	0.0	-38.0	-2.5	-0.7	**-164.8**
Heat - 2030	kt/year	-1.3	0.1	0.3	0.6	-1.5	4.8	0.0	-0.4	0.0	0.0	0.3	0.5	0.8	0.1	3.0	0.0	1.1	-0.6	0.8	-0.1	-1.4	0.0	-0.7	-0.2	0.2	**6.6**
Transport - 2030	kt/year	-1.3	-0.4	-1.8	-3.6	-27.1	-21.9	-4.4	-0.7	-17.4	0.0	-0.3	-1.2	-11.6	-5.6	-14.7	0.0	-2.8	0.3	-2.9	0.4	-2.2	0.0	-8.2	-2.0	-0.7	**-130.0**
TOTAL - 2010	kt/year	-2.6	-1.2	-1.3	-1.7	-4.3	-5.1	1.0	-0.5	-1.9	0.0	-4.4	-0.8	-5.5	-4.4	-9.8	0.2	-1.5	0.1	-0.8	-0.3	-0.8	0.0	56.7	0.4	0.8	**12.4**
TOTAL - 2020	kt/year	-4.6	-1.8	-2.6	-4.3	-27.8	-26.2	-1.3	-1.2	-9.2	0.0	-4.9	-2.9	-9.7	-8.5	-20.5	0.2	-3.7	-1.2	-2.3	-0.2	-5.1	0.0	39.4	-1.5	-0.9	**-100.9**
TOTAL - 2030	kt/year	-6.6	-2.1	-3.3	-4.4	-43.7	-51.2	-4.8	-2.3	-19.7	0.0	-4.1	-2.0	-17.0	-13.5	-38.7	0.1	-5.5	-1.4	-7.2	-0.8	-7.2	0.0	-47.0	-4.7	-1.2	**-288.2**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-83%	-104%	-140%	-19%	-41%	-99%	-13%	-136%	-17%	-173%	-13719%	-38%	-50%	-103%	-198%	39%	-116%	-112%	-158%	-79%	-102%	34%	-80%	-82%	-79%	**-80%**
Heat - 2030	%of gross	-13%	6%	28%	7%	-6%	27%	1%	-49%	0%	-11%	17%	19%	4%	1%	33%	50%	17%	-27%	16%	-3%	-30%	-40%	-5%	-3%	8%	**4%**
Transport - 2030	%of gross	-32%	-95%	-198%	-110%	-83%	-113%	-98%	-158%	-77%	n.a.	-206%	-89%	-57%	-113%	-121%	n.a.	-99%	43%	-127%	42%	-61%	n.a.	-59%	-98%	-90%	**-84%**
TOTAL - 2010	%of gross	-35%	-70%	-48%	-13%	-11%	-14%	19%	-69%	-8%	-25%	-636%	-10%	-30%	-22%	-69%	64%	-32%	5%	-23%	-15%	-18%	51%	67%	11%	33%	**4%**
TOTAL - 2020	%of gross	-33%	-58%	-86%	-24%	-39%	-45%	-20%	-86%	-23%	-27%	-436%	-36%	-23%	-33%	-76%	50%	-45%	-34%	-32%	-6%	-53%	26%	34%	-25%	-31%	**-21%**
TOTAL - 2030	%of gross	-36%	-52%	-95%	-23%	-45%	-72%	-50%	-106%	-40%	-28%	-205%	-26%	-32%	-44%	-111%	40%	-43%	-36%	-68%	-18%	-61%	11%	-62%	-49%	-30%	**-54%**
Air pollutants - Particulate matter																											
Net avoided direct & LCA emissions																											
Electricity - 2030	kt/year	-0.3	-0.1	-0.1	-0.1	-0.8	-1.2	0.2	0.0	0.0	0.0	-0.1	-0.1	0.0	-0.3	-1.5	0.0	-0.2	-0.1	-0.1	-0.1	-0.1	0.0	-0.2	0.3	0.0	**-4.8**
Heat - 2030	kt/year	0.1	0.1	0.0	0.2	0.6	1.6	0.2	0.0	0.3	0.0	0.1	0.1	0.7	1.5	0.4	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.5	0.0	0.1	**6.8**
Transport - 2030	kt/year	0.4	0.0	0.0	0.1	1.6	0.9	0.1	0.0	0.6	0.0	0.0	0.0	0.6	0.1	0.6	0.0	0.1	0.0	0.1	0.1	0.1	0.0	1.3	0.1	0.0	**7.1**
TOTAL - 2010	kt/year	-0.1	0.0	0.1	0.3	1.6	1.8	0.4	0.0	1.1	0.0	-0.1	0.4	0.6	0.2	-0.1	0.0	0.2	0.2	0.1	0.1	0.1	0.0	10.2	0.7	1.2	**18.9**
TOTAL - 2020	kt/year	0.1	-0.1	0.0	0.1	0.7	1.1	0.4	0.0	1.1	0.0	-0.1	0.1	1.2	1.1	-0.1	0.0	0.1	0.1	0.2	0.2	0.0	0.0	10.9	0.6	0.1	**17.9**
TOTAL - 2030	kt/year	0.3	0.0	0.0	0.3	1.4	1.3	0.5	0.0	0.9	0.0	0.0	0.1	1.3	1.4	-0.5	0.0	0.1	0.0	0.0	0.0	0.1	0.0	1.6	0.4	0.1	**9.1**
Net vs. gross avoided direct & LCA emissions																											
Electricity - 2030	%of gross	-148%	-162%	-97%	-16%	-55%	-63%	64%	-148%	-11%	-335%	-559%	-115%	6%	-53%	-320%	73%	-168%	-124%	-77%	-91%	-78%	62%	-3%	53%	-127%	**-37%**
Heat - 2030	%of gross	28%	58%	68%	52%	42%	87%	86%	47%	37%	21%	77%	67%	56%	78%	74%	97%	52%	27%	46%	27%	30%	39%	51%	11%	49%	**60%**
Transport - 2030	%of gross	172%	91%	66%	53%	78%	72%	46%	97%	45%	n.a.	107%	45%	44%	47%	74%	n.a.	45%	87%	34%	86%	52%	n.a.	147%	57%	59%	**71%**
TOTAL - 2010	%of gross	-30%	-56%	33%	32%	55%	56%	76%	12%	55%	48%	-48%	61%	44%	17%	-17%	91%	45%	58%	43%	62%	39%	83%	90%	87%	96%	**64%**
TOTAL - 2020	%of gross	7%	-56%	-2%	10%	20%	30%	68%	-8%	46%	10%	-37%	31%	46%	47%	-6%	85%	22%	27%	48%	54%	8%	71%	77%	73%	53%	**49%**
TOTAL - 2030	%of gross	30%	-7%	9%	27%	29%	26%	63%	8%	34%	-8%	4%	15%	42%	50%	-30%	74%	11%	5%	3%	10%	8%	54%	22%	44%	26%	**26%**
Avoided fossil fuels																											
Avoided fossil fuels - by fuel in energetic terms																											
Hard coal - 2030	TWh/year	1.0	0.0	1.3	1.7	14.2	39.7	1.7	0.0	0.5	0.0	0.0	0.0	1.5	9.6	0.1	0.0	0.0	0.6	0.0	0.0	3.4	0.0	86.3	0.2	0.0	**161.8**
Lignite - 2030	TWh/year	0.0	0.0	0.0	4.4	0.0	1.6	3.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	4.0	0.3	0.0	0.0	36.1	3.8	0.0	**54.7**
Oil - 2030	TWh/year	22.9	3.5	5.4	22.2	143.7	156.4	27.5	4.2	102.3	0.0	9.0	11.0	118.6	116.7	58.0	0.4	14.4	5.5	11.8	5.8	18.8	0.1	76.6	8.3	5.0	**948.2**
Gas - 2030	TWh/year	63.2	15.6	15.9	71.1	289.6	153.8	5.9	6.5	99.4	0.3	9.5	19.8	99.3	61.4	132.0	0.0	42.7	13.4	34.1	17.1	36.3	0.0	164.6	32.9	12.0	**1396.4**
Avoided fossil fuels - by sector in energetic terms																											
Electricity - 2030	TWh/year	27.8	7.9	11.9	42.1	189.4	185.6	12.4	5.1	63.1	0.0	8.8	13.8	56.1	69.6	95.6	0.3	19.3	6.1	19.8	7.8	22.5	0.1	241.1	18.5	5.6	**1130.2**
Heat - 2030	TWh/year	45.7	9.6	6.5	44.6	139.4	92.8	9.5	4.1	57.6	0.3	9.2	11.6	88.1	101.3	48.4	0.0	27.9	10.9	21.3	12.0	22.8	0.1	71.7	20.0	9.1	**864.5**
Transport - 2030	TWh/year	13.5	1.7	4.3	12.6	118.8	73.1	16.7	1.7	81.5	0.0	0.6	5.4	75.2	16.8	46.1	0.0	10.2	2.9	8.8	3.4	13.3	0.0	50.7	6.8	2.3	**566.3**
TOTAL - 2010	TWh/year	32.5	7.1	13.5	55.4	180.5	166.2	12.3	4.0	77.6	0.2	11.9	20.6	62.9	111.4	66.3	0.3	23.0	8.6	13.2	9.0	18.8	0.1	111.3	11.4	5.5	**1023.5**
TOTAL - 2020	TWh/year	59.4	13.2	17.9	81.3	304.4	251.5	20.6	6.7	144.5	0.3	14.5	27.0	151.9	133.8	122.1	0.4	36.9	15.7	29.4	16.7	44.3	0.1	236.3	22.4	11.3	**1762.6**
TOTAL - 2030	TWh/year	87.0	19.1	22.6	99.3	447.5	351.4	38.6	10.9	202.2	0.3	18.6	30.7	219.4	187.7	190.1	0.4	57.4	19.9	49.9	23.2	58.6	0.1	363.6	45.3	17.0	**2561.0**
Avoided fossil fuels - by sector in monetary terms																											
Electricity - 2030	M€/year	467	135	189	648	3077	2688	155	84	1081	1	152	238	948	1080	1637	7	329	93	293	135	347	1	2688	269	96	**16840**
Heat - 2030	M€/year	815	171	114	799	2474	1895	198	79	1057	5	187	217	1664	2104	870	1	492	197	375	209	408	1	1306	347	165	**16151**
Transport - 2030	M€/year	281	35	89	263	2476	1524	347	36	1698	0	12	112	1568	349	962	0	212	59	183	71	277	0	1057	142	48	**11803**
TOTAL - 2010	M€/year	414	93	150	631	2199	1640	139	50	1047	2	158	239	833	1334	868	5	224	84	161	113	238	1	919	107	59	**11709**
TOTAL - 2020	M€/year	929	207	256	1180	4756	3425	303	104	2383	5	232	380	2510	1829	1954	7	548	222	456	262	683	2	2635	299	180	**25747**
TOTAL - 2030	M€/year	1563	341	393	1711	8027	6107	701	200	3836	6	351	567	4180	3533	3469	8	1033	349	851	415	1032	3	5051	758	310	**44793**

Key results by country

Case: 100% exploitation of the biomass potential, cross-sectoral least cost in terms of primary energy, PRIMES baseline

Air pollutants - SO_2

Net vs. gross avoided direct & LCA emissions

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	%of gross	20%	28%	45%	30%	26%	58%	77%	-94%	55%	-2763%	44%	56%	89%	78%	33%	75%	75%	82%	5%	-9%	-170%	72%	58%	58%	97%	59%
Heat - 2030	%of gross	-127%	-30%	30%	59%	-84%	-328%	-1403%	12%	14%	-1372%	-61%	15%	-435%	54%	-404%	75%	-47%	-290%	-192%	-261%	-174%	80%	-159%	-194%	-2%	-64%
Transport - 2030	%of gross	148%	n.a.	109%	77%	90%	95%	74%	n.a.	51%	n.a.	n.a.	44%	55%	88%	79%	n.a.	55%	59%	70%	60%	68%	n.a.	83%	117%	129%	76%
TOTAL - 2010	%of gross	2%	32%	45%	82%	70%	58%	87%	56%	75%	-1047%	59%	85%	63%	69%	46%	85%	37%	71%	67%	-52%	-90%	90%	67%	80%	95%	68%
TOTAL - 2020	%of gross	13%	-3%	54%	69%	38%	36%	58%	28%	43%	-1240%	48%	60%	23%	70%	12%	81%	39%	42%	-8%	-64%	-122%	86%	66%	54%	88%	47%
TOTAL - 2030	%of gross	-35%	9%	40%	57%	-7%	26%	10%	-20%	24%	-1469%	25%	30%	1%	64%	-17%	75%	43%	11%	-99%	-78%	-85%	77%	-8%	-30%	83%	13%

Air pollutants - NO_X

Net avoided direct & LCA emissions

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	kt/year	-2.3	-2.0	-2.5	-1.7	-21.9	-36.7	-1.3	-1.6	-6.0	0.0	-4.8	-1.6	-3.0	-4.0	-25.5	0.1	-3.0	-0.5	-5.8	-1.6	-5.5	0.0	-33.3	-2.1	1.0	-165.6
Heat - 2030	kt/year	-4.2	0.2	0.6	-0.2	-12.9	3.4	0.6	-0.1	-0.9	0.0	0.3	0.6	2.7	-0.6	2.8	0.0	1.2	-1.4	0.4	0.2	-1.8	0.0	1.7	0.6	0.0	-6.9
Transport - 2030	kt/year	-0.7	0.0	-0.2	-1.1	-5.1	-5.5	-4.1	0.0	-6.6	0.0	0.0	-0.2	-7.6	-7.5	-0.6	0.0	-0.7	0.3	-0.4	0.3	-2.3	0.0	-1.8	-1.3	-0.5	-45.4
TOTAL - 2010	kt/year	-2.3	-1.1	-1.2	-1.1	-5.6	-5.5	1.6	-0.5	-0.4	0.0	-4.5	-0.4	-4.1	-6.7	-8.3	0.1	-0.9	0.4	-0.3	-0.6	-0.8	0.0	16.1	0.1	0.8	-25.4
TOTAL - 2020	kt/year	-4.1	-1.6	-2.2	-4.6	-27.4	-19.0	-0.5	-1.4	-5.4	0.0	-5.1	-1.8	-6.7	-10.5	-13.3	0.1	-2.0	0.0	-1.7	-0.6	-5.1	0.0	29.9	-0.6	0.2	-83.6
TOTAL - 2030	kt/year	-7.2	-1.8	-2.0	-3.0	-39.8	-38.8	-4.7	-1.7	-13.5	0.0	-4.5	-1.2	-7.9	-12.1	-23.4	0.1	-2.4	-1.5	-5.9	-1.1	-9.6	0.0	-33.5	-2.8	0.5	-217.9

Net vs. gross avoided direct & LCA emissions

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	%of gross	-47%	-72%	-103%	-22%	-61%	-77%	-43%	-152%	-41%	-179%	-2214%	-40%	-19%	-28%	-98%	42%	-29%	-29%	-142%	-114%	-118%	34%	-79%	-56%	39%	-66%
Heat - 2030	%of gross	-39%	9%	34%	-2%	-27%	17%	26%	-7%	-4%	-14%	22%	14%	10%	-3%	20%	-22%	30%	-63%	6%	7%	-34%	-42%	5%	11%	-1%	-3%
Transport - 2030	%of gross	-25%	n.a.	-219%	-53%	-29%	-59%	-95%	n.a.	-45%	n.a.	n.a.	-26%	-43%	-103%	-17%	n.a.	-100%	43%	-47%	35%	-62%	n.a.	-22%	-86%	-93%	-47%
TOTAL - 2010	%of gross	-31%	-59%	-42%	-8%	-14%	-16%	27%	-72%	-2%	-34%	-574%	-7%	-21%	-34%	-53%	64%	-21%	19%	-10%	-51%	-21%	48%	38%	3%	38%	-10%
TOTAL - 2020	%of gross	-30%	-49%	-60%	-25%	-36%	-33%	-6%	-87%	-14%	-30%	-518%	-24%	-16%	-38%	-44%	50%	-23%	0%	-25%	-21%	-54%	26%	31%	-10%	5%	-18%
TOTAL - 2030	%of gross	-39%	-40%	-46%	-15%	-39%	-50%	-48%	-70%	-26%	-29%	-260%	-14%	-13%	-32%	-54%	40%	-16%	-33%	-52%	-24%	-70%	10%	-39%	-26%	8%	-37%

Air pollutants - Particulate matter

Net avoided direct & LCA emissions

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	kt/year	0.0	0.1	0.1	0.0	0.4	1.2	0.3	0.0	0.6	0.0	0.0	0.1	1.3	0.8	0.3	0.0	0.7	0.0	-0.1	0.0	-0.3	0.0	1.8	0.3	1.7	9.3
Heat - 2030	kt/year	0.0	0.1	0.1	0.5	1.1	0.7	0.0	0.1	1.2	0.0	0.1	0.1	0.3	0.7	0.4	0.0	0.2	0.0	0.1	0.0	0.1	0.0	1.4	0.1	0.1	7.4
Transport - 2030	kt/year	0.2	0.0	0.0	0.1	0.9	0.4	0.1	0.0	0.3	0.0	0.0	0.0	0.5	0.2	0.2	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.5	0.1	0.0	3.9
TOTAL - 2010	kt/year	0.0	0.0	0.1	1.1	2.8	1.6	0.4	0.0	2.0	0.0	0.0	0.5	1.0	0.2	0.2	0.0	0.3	0.2	0.2	0.0	0.1	0.0	4.0	0.6	1.4	16.7
TOTAL - 2020	kt/year	0.2	0.0	0.1	0.7	2.4	2.3	0.4	0.0	2.1	0.0	0.0	0.3	1.6	1.3	0.8	0.0	0.6	0.2	0.2	0.1	-0.1	0.0	9.3	0.8	1.4	24.8
TOTAL - 2030	kt/year	0.2	0.1	0.1	0.6	2.5	2.4	0.5	0.0	2.1	0.0	0.0	0.2	2.2	1.7	0.8	0.0	0.9	0.1	0.1	0.0	-0.1	0.0	3.7	0.5	1.7	20.5

Net vs. gross avoided direct & LCA emissions

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	%of gross	-14%	30%	36%	6%	17%	27%	70%	-31%	54%	-338%	-5%	34%	72%	52%	11%	77%	64%	14%	-25%	-51%	-144%	62%	30%	61%	96%	35%
Heat - 2030	%of gross	8%	65%	64%	59%	36%	66%	64%	57%	63%	5%	63%	57%	36%	62%	57%	92%	73%	-12%	44%	35%	23%	36%	60%	44%	34%	50%
Transport - 2030	%of gross	131%	n.a.	71%	68%	83%	75%	48%	n.a.	36%	n.a.	n.a.	29%	43%	53%	81%	n.a.	-9%	87%	56%	85%	50%	n.a.	85%	63%	63%	62%
TOTAL - 2010	%of gross	4%	28%	44%	68%	67%	55%	77%	37%	77%	-3%	7%	69%	58%	15%	18%	92%	60%	75%	67%	26%	30%	82%	76%	87%	97%	63%
TOTAL - 2020	%of gross	18%	5%	44%	47%	43%	49%	67%	18%	65%	-7%	3%	45%	54%	53%	39%	87%	68%	58%	48%	38%	-22%	71%	82%	81%	92%	59%
TOTAL - 2030	%of gross	21%	42%	45%	42%	36%	38%	62%	24%	54%	-24%	19%	42%	55%	56%	25%	77%	63%	19%	15%	16%	-20%	53%	41%	56%	91%	43%

Avoided fossil fuels

Avoided fossil fuels - by fuel in energetic terms

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Hard coal - 2030	TWh/year	7.4	6.2	6.4	49.4	89.2	103.7	1.2	3.0	23.9	0.0	4.7	8.1	18.5	49.7	66.4	0.0	44.0	0.1	6.2	1.8	2.8	0.0	216.3	13.3	2.0	724.3
Lignite - 2030	TWh/year	0.0	0.0	0.0	6.3	0.0	89.3	9.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	6.4	2.6	0.1	0.0	0.0	40.6	2.5	1.5	159.1
Oil - 2030	TWh/year	19.3	3.6	2.8	22.4	156.4	55.4	17.5	3.2	134.9	0.0	2.7	9.2	81.3	60.1	24.2	0.2	3.0	3.7	7.6	4.3	17.7	0.1	57.4	5.1	4.2	696.3
Gas - 2030	TWh/year	55.2	10.1	13.7	31.1	222.0	138.0	13.2	5.6	58.3	0.4	12.3	16.9	128.6	62.3	117.0	0.0	13.7	12.2	32.9	15.5	44.0	0.0	78.7	24.2	8.4	1114.3

Avoided fossil fuels - by sector in energetic terms

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	TWh/year	22.3	10.7	13.2	41.3	164.5	248.3	15.2	5.3	59.4	0.0	11.8	15.7	57.1	66.7	122.7	0.2	40.6	7.7	20.1	6.8	24.7	0.1	191.9	16.9	4.5	1167.8
Heat - 2030	TWh/year	50.5	9.1	9.4	60.4	241.1	103.9	10.1	6.8	104.2	0.3	8.0	16.1	105.7	82.7	71.8	0.0	17.8	11.9	25.8	11.4	26.3	0.1	170.7	23.7	9.8	1177.6
Transport - 2030	TWh/year	9.1	0.0	0.3	7.5	61.9	34.1	15.8	0.0	53.5	0.0	0.0	2.4	65.5	22.7	13.0	0.0	2.6	2.9	3.4	3.5	13.6	0.0	30.5	4.6	1.8	348.7
TOTAL - 2010	TWh/year	29.0	7.0	13.3	61.0	177.6	144.1	12.4	3.1	71.3	0.1	13.4	18.5	67.8	121.9	67.6	0.2	20.8	6.4	11.0	7.4	15.4	0.1	87.5	11.1	4.8	972.9
TOTAL - 2020	TWh/year	55.7	12.1	18.5	84.3	318.6	239.6	22.9	7.0	139.4	0.3	16.2	25.2	144.4	114.5	126.9	0.2	35.0	14.4	26.9	14.0	42.2	0.1	230.6	24.2	10.1	1723.6
TOTAL - 2030	TWh/year	81.9	19.9	22.9	109.2	467.6	386.4	41.0	12.1	217.1	0.4	19.7	34.2	228.3	172.1	207.5	0.2	60.9	22.5	49.4	21.7	64.5	0.1	393.1	45.2	16.0	2694.0

Avoided fossil fuels - by sector in monetary terms

Country:		Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Slovakia	Slovenia	European Union 25
Electricity - 2030	M€/year	413	156	209	830	2577	2721	200	101	1061	1	197	240	1071	837	1784	7	377	77	358	126	521	2	1705	214	51	15835
Heat - 2030	M€/year	1193	225	224	731	5890	2491	229	144	2817	7	197	403	2444	2045	1698	0	281	272	577	262	618	2	2813	471	237	26270
Transport - 2030	M€/year	264	0	9	220	1809	996	461	0	1564	0	0	70	1914	662	378	0	75	85	100	102	397	0	891	133	51	10183
TOTAL - 2010	M€/year	478	102	181	737	2739	1728	164	47	1353	2	211	295	1162	1725	1017	5	219	87	172	133	286	2	909	128	62	13946
TOTAL - 2020	M€/year	1062	209	271	1085	5823	3424	385	122	2914	6	273	437	2965	1446	2081	6	387	237	497	280	858	3	3130	354	171	28426
TOTAL - 2030	M€/year	1870	381	442	1782	10276	6208	890	244	5442	8	394	713	5429	3543	3860	7	733	434	1035	490	1536	4	5408	818	339	52287

Annex 9 Emissions legislation used to check whether modelled plant would meet emissions limits

Table 8.10 Emissions legislation used to check modelled plant would meet stringent emissions limits

Fuel	Pollutant	Country	Legislation
Wood and other biomass	Particulates	Germany	1st BImSchV — Ordinance on Small and Medium Combustion Plants
		Germany	DIN 18891
		Germany	DIN 18895
		Germany	TA Luft 5.4.1.2.1
		Europe	EN303-5
		Nordic area	Nordic Swan
		France	Aretes of 20 June 2002 modified and 30 July 2003 modified
		EC	Large Combustion Plant Directive
	Nitrogen oxides	Germany	DIN 18891
		Germany	DIN 18895
		Germany	TA Luft 5.4.1.2.1
		France	Aretes of 20 June 2002 modified and 30 July 2003 modified
		EC	Large Combustion Plant Directive
Liquid fuel	Particulates	–	–
	Nitrogen oxides	UNECE	Gothenberg Protocol
Landfill gas	Particulates	Switzerland	LRV 1985 (2000)
		UNECE	Gothenberg Protocol
	Nitrogen oxides	Switzerland	LRV 1985 (2000)
		UNECE	Gothenberg Protocol
Woodgas	Particulates	UNECE	Gothenberg Protocol
		EC	Large Combustion Plant Directive
	Nitrogen oxides	UNECE	Gothenberg Protocol
		EC	Large Combustion Plant Directive
Waste	Particulates	EC	Waste Incineration Directive
	Nitrogen oxides	EC	Waste Incineration Directive

European Environment Agency

Maximising the environmental benefits of Europe's bioenergy potential

2008 — 94 pp. — 21 x 29.7 cm

ISBN 978-92-9167-375-9
EEA Technical report series: ISSN 1725-2237
DOI 10.2800/49213

TH-AK-08-009-EN-N
DOI 10.2800/49213

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99

Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

ISBN 978-92-9167-375-9

Publications Office

European Environment Agency