# How can each sector contribute to 2C?

**Background Paper**

# RECIPE

**THE ECONOMICS OF DECARBONIZATION**

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# 1 Introduction

In the RECIPE project model based analyses of the economics of decarbonization – with a focus on the energy system – were carried out. For these analyses, three models were used: IMACLIM-R, REMIND-R and WITCH (see Jakob et al., 2009a, 2009b and Luderer et al., 2009). The following sectoral disaggregation of greenhouse gas emissions in the policy cases (450 ppm[1] C&C[2] and 410 ppm C&C, both compared to the baseline (BAU) levels) is the result of the model runs.

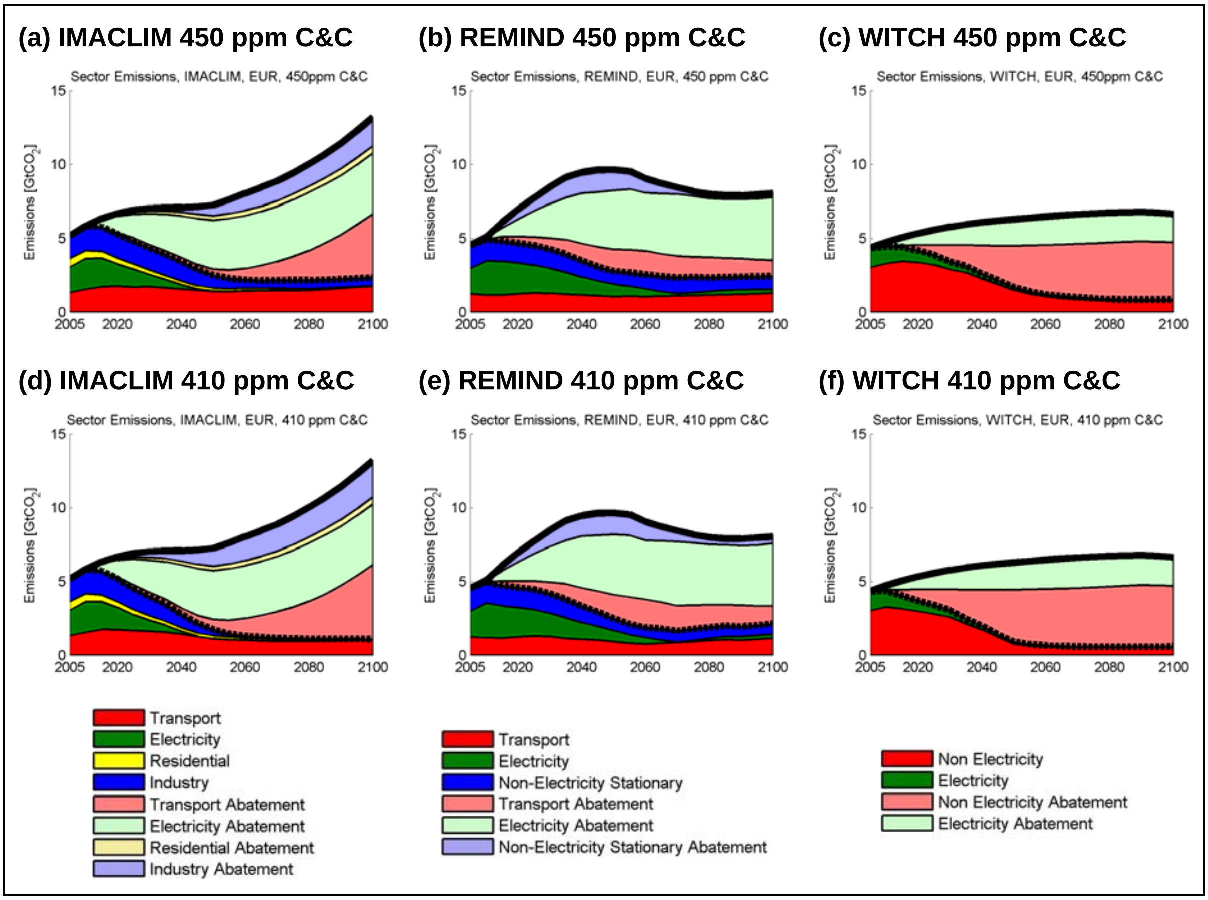


**Figure 1-1: European $CO_2$ emissions decomposed by different sectors for the three models IMACLIM-R, REMIND-R and WITCH for the 450 ppm C&C and the 410 ppm C&C scenario. The upper solid line indicates baseline emissions. The dashed line indicates the emission trajectory in the climate policy scenarios. The emissions abatement – the area between the baseline and policy emissions – can be attributed to the different sectors (light colors). Note that the sectoral breakdown differs between models.**

These top-down analyses were complemented by four in-depth bottom-up sectoral studies for Europe until 2030. The following sectors have been covered: (i) power and heat, (ii) transport, (iii) industry (iron and steel, cement) and (iv) agriculture. The aim is to show implications for the sectors in more detail that the models – due to their top-down approach –

[1] Both policy scenarios reflect $CO_2$-only concentrations.

[2] C&C: Contraction and Convergence (Meyer, 2004)

are not able to deliver. For each sector key mitigation options are analyzed, specific barriers are investigated and policy instruments targeting the sector are explored.

# 2 Power and heat sector

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- **Electricity generation is a key sector to consider in a policy aimed at mitigation of greenhouse gases. Although the share of emissions from the power generation sector has been reduced since 1990, it still accounts for more than 1/3 of total emissions. These emissions have increased in absolute terms and they are expected to do so until 2030 in the baseline scenario.**
- **On the other hand, a wide array of (mature and immature) mitigation technologies with significant abatement potential is and will be available at moderate costs in this sector. The sector has a significant potential to make a significant contribution to overall GHG emissions mitigation in the EU. A basket of low-carbon technologies will be needed to reach the mitigation targets.**
- **Albeit currently more expensive than their conventional, fossil-fired counterparts, most low-carbon technologies have a significant potential for cost reductions, if the appropriate policies are in place to encourage their development and diffusion. Apart from price barriers, non-price barriers also play a key role in this sector.**
- **Public policies are the major driver behind the uptake of low-carbon technologies and the decarbonization of the European power sector. A policy mix is needed. This refers to the need to combine instruments which tackle economic and non-economic barriers and instruments adapted to the maturity levels of mitigation technologies. Therefore, both demand-pull and supply-push policies are needed to facilitate the development of emerging technologies and the diffusion of the currently mature ones, respectively. More specifically, a carbon price signal and targeted RD&D support are crucial policies in this regard.**
- **Apart from combining instruments, other major aspects of policies aimed at encouraging low-carbon technologies in this sector include appropriate timing of instruments, appropriate design elements within specific instruments and a focus on the stability and continuity of policy, providing certainty for investors.**

## *2.1 Introduction*

Electricity generation is a key sector to consider in a policy framework aimed at mitigation of greenhouse gases. On the one hand, although the share of emissions from the power generation sector has been reduced since 1990 by a couple of percentage points, it still accounts for more than one third of total emissions. These emissions have increased in absolute terms and they are expected to do so until 2030 in all reference scenarios.

On the other hand, there is a high perceived feasibility of emissions reductions in this sector, given the existence of comparatively low cost technological alternatives and the possibility to pass the higher costs of mitigation policy into electricity prices. This is related to the traditionally low level of international competitiveness in this sector, as a result of being a local industry with generally low levels of interconnections between European countries. Simulation studies expect a significant reduction in emissions in a policy scenario (i.e., with additional policies to those considered in the reference scenario) in the order of 35 % to 47 %, indicating the potential of the sector to make a significant contribution to overall GHG emissions.

Albeit currently more expensive in private cost terms than their conventional, fossil-fired counterparts, the expected shares of low carbon technologies in 2030 increase even in a reference scenario. This is a result of their higher cost-competitiveness due to their large potential for cost reductions. In addition, both climate change mitigation as well as other benefits from these technologies (notably, the security of supply in terms of a reduction in the external energy dependency), and particularly renewables, will justify the maintenance (and improvement) of support schemes (both for R&D and deployment), which will ensure their market penetration. Political backing for a decarbonization of the economy is required to encourage investments in low-carbon technologies in this as well as in other sectors.

Notwithstanding, the 2030 generation mix will still be dominated by conventional generation alternatives due to their cost-competitiveness as well as to the inertia in complex energy systems, including the costs of changing a long-lasting capital stock

The general aim of this chapter is to provide an analysis of the electricity and heat sector with respect to the modeling work carried out in RECIPE. In particular, three more specific objectives are:

1. To provide a consistency check on the assumptions (mostly with respect to investment costs) and results of the RECIPE models (focusing on emissions, electricity generation, activity level per technology and investment flows required),

2. To provide complementary insights to those which are not provided by the models,

3. To identify a set of policy implications deriving from the analysis with respect to RECIPE model results and the aforementioned complementary insights.

The following section analyzes past, current and expected dynamics of the sector. Section 2.3 provides a consistency check on the assumptions and the results of the RECIPE models taking into account the existing literature and other non-RECIPE simulation exercises. Section 2.3.3 discusses several aspects not directly covered by modeling work. The chapter closes with an analysis of mitigation policies in this sector, including the investment flows required.

The timeframe for this analysis is 2030 and the focus is on the EU. This short report provides statements and data which are detailed in a longer version, from which this short report draws.

## *2.2 Past, current and expected dynamics of the sector*

### 2.2.1 Past and the current situation

Generation data for the EU in the 1990-2006 period shows distinct situations for fossil-fuel sources. Whereas coal has remained constant in absolute terms, oil has been substantially reduced and gas has experienced a three-fold increase (cf. Figure 2-1).

Low-carbon generation technologies have increased in the period, although at different rates. Those with the highest increase are also the ones starting from the lowest base (wind, solar and biomass). The greatest absolute and relative increase has been in wind electricity (from 1 TWh in 1990 to 82 TWh in 2006). In turn, the growth rates of nuclear and hydro are more modest, but their current shares in total electricity generation are quite significant. Low carbon technologies represent 43 % of total generation, approximately the same than in 1990[3]. The loss of share of nuclear and hydro in the period (currently 28 % and 9.5 %, respectively) has been offset by a larger share of biomass and wind (3 % and 2.5 %, respectively).

Therefore, in spite of the rise of low-carbon technologies, the EU generation mix is currently dominated by fossil fuels (57 %). Compared to 1990, fossil-fuel generation has remained constant, although with a greater share of a lower-carbon technology (gas) and a lower share of a dirtier source (coal).

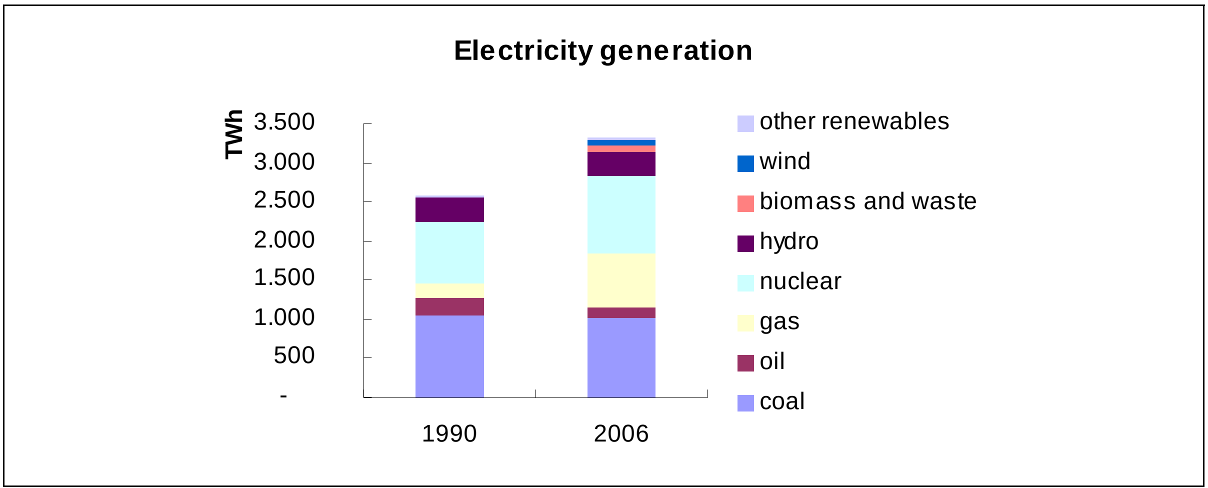



**Figure 2-1: Electricity generation in the EU-27 in 1990 and 2006 (TWh/year)** Source: IEA (2008a)

Regarding heat, the data show an increasing share of renewable energy sources of heat (RES-H) in the 1990-2005 period in the countries analyzed (table), with the exceptions of France, Spain and Sweden[4]. This corresponds to significant growth rates in the period. The greatest share can be observed in Austria and the three Nordic countries. In contrast, several countries have experienced low (and even negative) growth rates in the period and the share of RES-H is negligible (Spain, U.K., Greece, Ireland and Portugal). Per RES-H source, there is a general reduction in the share of geothermal heat in most countries in the period, although growth rates are positive. With some exceptions, the shares of solar thermal and biomass heat are generally greater in 2005 compared to 1990, Penetration rates of RES-E are greatest for Hungary and Italy regarding geothermal heat, U.K., Greece and Portugal with respect to solar thermal heat and Luxembourg, Finland, Poland and Sweden concerning biomass heat.

[3] Great changes can be observed in the share of fossil-fuel technologies during the period. Whereas the share of coal has significantly reduced from 41 % to 31 %, the share of gas has increased from 7 % to 21 %. These trends have contributed to the decarbonization of the EU electricity sector.

[4] IEA data have been used for this analysis (IEA 2008c). Only data for 19 of the 27 EU countries is provided (OECD-EU). According to IEA (2008c), data availability is problematic in the RES-H sector because official government statistics only capture the commercially traded fuel inputs to heat production as well as the commercial sale of heat by contracts to a third party use. However, heat production in non-grid connected and decentralized systems such as ground-source heat pumps and domestic solar thermal for hot water and swimming pool heating is not included in official statistics.

| | Renewable energy commercial heat production (TJ) | | | Share of RE commercial production in total production | | Share of geothermal in total RE heat production | | | Share of solar thermal heat in total RE heat production | | | Share of biomass heat in total RE heat production | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 2005 | Growth 1990-2005 | 1990 | 2005 | 1990 | 2005 | Growth 1990-2005 | 1990 | 2005 | % Growth 1990-2005 | 1990 | 2005 | % Growth 1990-2005 |
| **Austria** | 2056 | 14009 | 581 % | 7,2 % | 24,4 % | 15,3 | 4,5 | -71 % | 22 | 21,1 | -4 % | 68,3 | 88 | 29 % |
| **Belgium** | 120 | 1437 | 1098 % | 1,2 % | 6,4 % | 21,7 | 3,2 | -85 % | 17,7 | 7,1 | -60 % | 0 | 10,6 | |
| **Czech Republic** | 0 | 3851 | | 0 % | 2,8 % | 0 | 0 | n.a. | 0 | 2,6 | | 0 | 59,6 | |
| **Germany** | 10874 | 35835 | 230 % | 2,4 % | 2,8 % | 2,5 | 11,1 | 344 % | 4 | 20,6 | 415 % | 0 | 51,6 | |
| **Denmark** | 16095 | 39885 | 148 % | 17,4 % | 31,3 % | 0,3 | 0,2 | -33 % | 0,6 | 1 | 67 % | 46,6 | 53,7 | 15 % |
| **Spain** | 42 | 0 | -100 % | 15,8 % | 0 % | 0 | 11,1 | n.a. | 0 | 89 | | 0 | 0 | |
| **Finland** | 0 | 34779 | | 0 % | 21,3 % | 0 | 0 | n.a. | 100 | 0,1 | -100 % | 0 | 94,6 | |
| **France** | 9999 | 13187 | 32 % | 50 % | 7 % | 30 | 27,8 | -7 % | 5,3 | 4,8 | -9 % | 0 | 0 | |
| **Great Britain** | 0 | 0 | | n.a. | 0 % | 7,2 | 2,6 | -64 % | 92,8 | 97,4 | 5 % | 0 | 0 | |
| **Greece** | 0 | 0 | | n.a. | 0 % | 4,4 | 1,1 | -75 % | 95,6 | 99 | 4 % | 0 | 0 | |
| **Hungary** | 399 | 1078 | 170 % | 0,5 % | 1,7 % | 90 | 79,6 | -12 % | 0 | 1,8 | | 60,2 | 42,2 | -30 % |
| **Ireland** | 0 | 0 | | n.a. | 0 % | 50 | 9,6 | -81 % | 50 | 90,4 | 81 % | 0 | 0 | |
| **Italy** | 0 | 7974 | | n.a. | 4,1 % | 97,7 | 50,3 | -49 % | 2,3 | 4,8 | 109 % | 0 | 62,4 | |
| **Luxembourg** | 0 | 156 | | n.a. | 6,1 % | 0 | 0 | | 0 | 3,1 | | 0 | 100 | |
| **Netherlands** | 2059 | 4818 | 134 % | 13,7 % | 2,8 % | 0 | 0 | | 4,1 | 14 | 242 % | 12,3 | 25,7 | 109 % |
| **Poland** | 11014 | 3704 | -66 % | 1,5 % | 1,1 % | 0 | 9,3 | | 0 | 0 | | 100 | 100 | 0 % |
| **Portugal** | 0 | 0 | | 0 % | 0 % | 0 | 4,3 | | 100 | 95,7 | -4 % | 0 | 0 | |
| **Slovakia** | 0 | 2056 | | 0 % | 3,9 % | 0 | 9,3 | | 0 | 0 | | 0 | 88 | |
| **Sweden** | 16965 | 104869 | 518 % | 21,7 % | 57,9 % | 0 | 0 | | 0,8 | 0,2 | -75 % | 70,7 | 91,8 | 30 % |

**Table 2-1 Shares and growth rates of RES-H in the 1990-2005 period.** Source: Own elaboration from IEA (2008c)

### 2.2.2 The future

Future trends per technology will depend on technology characteristics (degree of maturity, trends in investment costs, resource potentials), market trends (evolution of fuel prices), several policy goals (climate change mitigation, security of supply, other environmental goals) and other factors, which will result in different types of policy strategies and instruments. The resulting picture will be one with different drivers and barriers per technology.

The opinion of experts regarding likely technology mixes which are based on own judgments on the technoeconomic potential of the different technologies and the evolution of other variables affecting deployment is another relevant source of information. Three sources of expert opinions have been taken into account: articles in the literature (and particularly, papers in the most important international journals on energy, energy policy and climate policy), a few expert interviews carried out by the author of this chapter and the results of the EurEnDel project[5].

A lot of insight can be derived from existing simulation models[6]. They all provide data for Europe in the 2005-2030 period, although relying on different assumptions, with different degrees of aggregation per technology and sometimes with different base years.

The analysis is carried out for three scenarios, a baseline and two policy scenarios (450 ppm C&C and 410 ppm C&C). Whereas the former usually includes already implemented climate policies which will likely continue in the future like the EU ETS, the policy scenario is assumed to have more stringent emissions targets and, thus, more ambitious policies[7].

Table 2-2 summarizes the assessment regarding possible trends per electricity generation technology. The discussion is based on expert judgments and the results of simulation models. Whereas some energy sources for electricity generation are either stagnant or experience a reduction (hydro and oil, respectively), other technologies show a clear upward trend (CCS, wind and solar). Finally, the trends of other technologies are uncertain during the period. For example, whereas nuclear is unlikely to increase its share in the short term, it may do so after 2020, stimulated by several factors. A re-emergence of coal by the end of the period, especially in the baseline scenario, is also likely. In contrast, whereas gas will keep on showing strong dynamics in the short-term, increasing gas prices may make it lose share by the end of the period.

5 EurEnDel is a European Union research project funded under the 5th RTD Framework Programme. It provides a Europe-wide Delphi study on future developments in the energy sector. The ultimate objective of the project was to provide advice on energy R&D priorities, based on sound expert knowledge (see Wehnert, T. (2004) for further details).

6 The non-RECIPE simulation studies considered in this paper are: the PRIMES model (EU Commission, 2008d), the POLES model (Russ et al., 2007), the International Energy Outlook (U.S. EIA/DOE, 2008), the WETO study (EU Commission, 2003 and 2006b), the World Energy Outlook, 2007 and 2008 editions (IEA, 2007 and IEA, 2008a) and the IEA Energy Technology Perspectives (IEA, 2008b).

7 However, in REMIND, there is no implementation of climate policies at all in the baseline scenario.

| | Baseline scenario | Policy scenarios |
|---|---|---|
| **Electricity generation** | Significant increase, encouraged by increasing demand as a result of economic and population growth and in spite of some increase in the energy efficiency of electricity production and consumption as a result of improvements in transmission, conversion efficiency and more efficient electric appliances. | Lower increase than in baseline as a result of higher carbon prices resulting in higher electricity prices, but unlikely to experience a much lower increase, given the inelasticity of demand and the increasingly low-carbon electricity substitutes for more carbon-intensive carriers (cf. 2.4). For this, very high carbon prices would be needed. |
| **Coal without CCS** | Reduced use in the first half of the period (given the efficiency of CCGTs and the EU ETS prices). But re-emergence later as it becomes more competitive with significantly increasing gas prices and new coal plants are more energy-efficient. Concerns over the security of supply could further encourage coal at the expense of gas.<br><br>Share in 2050 with respect to 2030: further increase. | Reduced use during the period, leading to a reduction in the share (i.e., no re-emergence, as in the baseline). Main factor: high carbon prices, partially offset by new coal vintage plants with greater conversion efficiencies. Improbable reductions in investment costs. |
| **Gas** | It will continue to experience significant growth rates given the attractiveness of relatively efficient, flexible and low-carbon intensive CCGTs. But experiences a reduction sometime in the middle of the period following increasing gas prices. | Increasing shares, since less affected than coal by higher carbon prices and CCGTs continue to have high efficiencies. Partially offset by increasing gas prices and security of supply concerns. |
| **Oil** | Share further reduced to become insignificant. Increasing oil prices and low efficiency make it an expensive energy source to produce electricity. | No significant changes with respect to baseline, since oil would have a very low share anyway (further reduction of negligible shares). More affected by high carbon price than gas. |
| **Nuclear** | Reduction until the middle of the period, as existing, second generation plants (built in the 80s) are decommissioned. Likely comeback after 2020, leading to a constant share in the period. This re-emergence is due to security of supply concerns leading to a reduction in social rejection of this technology, increasing fuel prices and improved security of operation of new plants (Generation 3 and 4). Improvements in management and load factors in existing plants may also take place during the period, increasing activity levels.<br><br>Commercial application of fusion: expected after 2050. | Higher carbon prices encourage the renewal of the license of existing plants. Increase in the construction of new plants (generation 3 and 4) since the middle of the period, encouraged by higher carbon prices than in baseline and by factors common to the baseline (security of supply, increasing fuel prices and a greater social acceptability of this technology). |

| | | |
|---|---|---|
| **Energy efficiency in electricity generation** | Encouraged by carbon prices and inherently greater conversion efficiency of capital stocks of new generation plants (fossil fuel and nuclear) | Higher carbon prices make electricity generation efficiencies more attractive and encourage the earlier substitution of existing plants and their replacement by new plants with greater conversion efficiencies. |
| **CCS** | Not foreseen before 2020, becoming more important by the end of the period, as demonstration plants unveil their economic and technical potential (i.e., the technology matures and its feasibility is fully demonstrated), coal re-emerges and carbon prices stimulate use of CCS. All in all, the share of CCS can not be expected to be large. | Same as baseline until 2020. Greater uptake of CCS by the end of the period.<br>This is due to more aggressive policies to advance their technoeconomic feasibility and attractiveness (demonstration projects, more R&D…). In addition, higher carbon prices make a fully demonstrated, mature, technology more attractive. |
| **Hydro** | Constant share during the period, with a small increase in absolute terms. Comparatively low resource potential and social rejection to new dam construction. Investment costs unlikely to be reduced. An increase is even possible (EU Commission, 2008d). Carbon prices unlikely to provide a sufficient incentive to offset those barriers. | Higher carbon prices are unlikely to make this technology much more attractive, given its investment costs and low social acceptability of new dam construction. There is limited technical potential left. |

| | | |
|---|---|---|
| **Wind** | Significant increase in absolute terms, leading to a higher share. Stimulated by significant investment cost reductions as a result of learning economies, increasing fuel prices, promotion schemes, relatively high unexploited potential (especially for wind off-shore), carbon prices in the EU ETS, improved resource prediction methods for grid integration, better grid management and increased inter-country connections. Security of supply concerns, other local socioeconomic and environmental benefits and intense lobbying effort by the coalition of forces benefiting from wind make the continuation of promotion schemes likely. However, as it becomes competitive with conventional sources by the end of the period, promotion schemes will be removed, at least for wind on-shore, although this is unlikely to be the case for off-shore.<br><br>Shadows on the road: possible increasing price of materials (steel), administrative hurdles, NIMBY effects, required back-up capacity and grid access and instability (limiting its share, i.e., 30 %). | Higher carbon prices could provide an additional boost to this technology, especially by the end of the period, if promotion schemes for wind on-shore (but not for off-shore) are phased out. Additional policies on grid integration could support a greater wind share. |
| **Solar** | Substantial absolute increases. Share increases, albeit from a very low base.<br><br>Drivers: Promotion schemes, large resource potentials and significant investment cost-reductions. However, it won’t be cost-effective during the period. Other obstacles: required back-up capacity and grid integration. | Higher carbon prices unlikely to provide a significant incentive for centralized solar electricity, given its high cost differentials with other sources, although this case is very different from decentralized solar electricity. However, more stringent targets could make the adoption of more aggressive policies for the uptake of PV more likely (i.e., regulations requiring the integration in buildings, higher FIT levels, greater uptake in official buildings…). |
| **Biomass** | Significant growth rates in the period although behind other renewables (except hydro). Learning rates are significant (especially in the case of co-firing, less so in the case of combustion) but non-price barriers should be removed (logistics…). | Higher carbon prices could provide an additional boost to this technology, but, as for the baseline, non-price barriers should be removed (logistics, sustainability discussions…). It is logic to expect that former coal plants will be bought and rebuilt to biomass plants as is currently seen in the US. This can have a significant impact on future biomass combustion. |

| | | |
|---|---|---|
| **Other RES (ocean, geothermal)** | Increase during the period, although from a close-to-cero base. Share negligible during the period. Non-maturity and/or high relative (investment) costs. | Higher carbon prices and other policies (R&D, demonstration, support schemes for deployment) unlikely to make a large difference with respect to deployment in the baseline. |
| Source: Own elaboration. | | |

**Table 2-2: Electricity generation per technology - Expected trends in the period (2005-2030) in the scenarios**

Regarding heat, the data shows significant remaining potentials for renewable sources of heat (Table 2-3), either compared to RES-E potentials (6) or to the total achievable potential in the 2005-2020 period[8]. The columns (6) and (7) show that in many countries 100 % of the achievable potential for geothermal and solar thermal heat remains to be exploited, meaning that the already achieved potential in RES-H is negligible. Significant achievements to date with respect to the achievable potential can only be observed for geothermal heat for the cases Bulgary and Hungary and for Austria and Greece for the case of solar thermal.

[8] The additional potential in 2005-2020 is defined in IEA (2008c) as the total realisable potential in 2020-2005 less the achieved potential (cumulative installed capacity) by 2005.

| | Additional realisable mid-term RES-H potentials (TWh) | | | | (5) RES-H additional potential as a percentage of RES-E additional potential | Additional realisable potential as a share of achievable potential in 2020-2005. | |
|---|---|---|---|---|---|---|---|
| | (1) Geothermal heat | (2) Solar thermal heat | (3) Biomass heat | (4) Total RES-H potentials | | (6) Geothermal | (7) Solar thermal |
| Austria | 9,3 | 6,6 | n.a. | 15,9 | 75 % | 97,9 % | 85,7 % |
| Belgium | 13,1 | 9,6 | n.a. | 22,7 | 148 % | 100,0 % | 100,0 % |
| Denmark | 9,4 | 5,3 | n.a. | 14,7 | 67 % | 100,0 % | 98,1 % |
| Finland | 5,9 | 7,7 | n.a. | 13,6 | 44 % | 100,0 % | 100,0 % |
| France | 47,9 | 68,5 | n.a. | 116,4 | 54 % | 97,0 % | 99,7 % |
| Germany | 86,7 | 74,1 | n.a. | 160,8 | 86 % | 98,2 % | 96,2 % |
| Greece | 5,7 | 9,2 | n.a. | 14,9 | 51 % | 100,0 % | 88,5 % |
| Ireland | 3,5 | 3,6 | n.a. | 7,1 | 40 % | 100,0 % | 100,0 % |
| Italy | 55 | 70,1 | n.a. | 125,1 | 132 % | 95,8 % | 99,6 % |
| Luxembourg | 0,2 | 0,1 | n.a. | 0,3 | 43 % | 100,0 % | 100,0 % |
| Netherlands | 14,1 | 14,7 | n.a. | 28,8 | 80 % | 100,0 % | 98,7 % |
| Portugal | 3,3 | 9,7 | n.a. | 13 | 36 % | 100,0 % | 97,0 % |
| Spain | 14,9 | 38,5 | n.a. | 53,4 | 33 % | 99,3 % | 98,0 % |
| Sweden | 11 | 9,3 | n.a. | 20,3 | 43 % | 100,0 % | 98,9 % |
| United Kingdom | 53,7 | 55,8 | n.a. | 109,5 | 56 % | 100,0 % | 99,5 % |
| Cyprus | 7,1 | 6,5 | n.a. | 13,6 | 850 % | 100,0 % | 94,2 % |
| Czech Republic | 5,3 | 5 | n.a. | 10,3 | 71 % | 100,0 % | 100,0 % |
| Estonia | 0,7 | 0,7 | n.a. | 1,4 | 21 % | 100,0 % | 100,0 % |
| Hungary | 6,6 | 5 | n.a. | 11,6 | 75 % | 86,8 % | 100,0 % |
| Latvia | 1,1 | 1,1 | n.a. | 2,2 | 31 % | 100,0 % | 100,0 % |
| Lithuania | 2,2 | 1,9 | n.a. | 4,1 | 58 % | 100,0 % | 100,0 % |
| Malta | 0 | 0,2 | n.a. | 0,2 | 40 % | n.a. | 100,0 % |
| Poland | 20,2 | 20,6 | n.a. | 40,8 | 79 % | 99,5 % | 100,0 % |
| Slovakia | 4,2 | 2,5 | n.a. | 6,7 | 108 % | 100,0 % | 100,0 % |
| Slovenia | 2,1 | 1,4 | n.a. | 3,5 | 43 % | 91,3 % | 93,3 % |
| Bulgaria | 2,1 | 4,2 | n.a. | 6,3 | 23 % | 80,8 % | 97,7 % |
| Romania | 12,7 | 14,2 | n.a. | 26,9 | 78 % | 94,1 % | 100,0 % |
| *EU-27* | *398* | *446* | *n.a.* | *844* | *65 %* | *97,9 %* | *98,2 %* |

**Table 2-3: Potentials in RES-H technologies.** Source: Own elaboration based on IEA (2008c)

The extent to which these RES-H potentials are exploited will mainly depend on the removal of the barriers to their deployment and the implementation and fine-tuning of support schemes[9]. Whereas there are some instruments in place, the heating and cooling sector is

9 According to IEA (2008c), the barriers for geothermal heat include cost, complex planning and permission procedures and the distance between deep geothermal resources and centres of heat demand whereas the main barriers to the deployment of solar thermal heat include inadequate planning guidelines, lack of consistent economic incentives,

weakly covered under current schemes RES-H promotion is in an early stage. As argued by Neuhoff et al. (2009) support is based mainly on investment loans and grants but is not strong enough to drive a successful development as in the case of RES-E.

## 2.3 Reflection on modeling results from sector perspective

The RECIPE models provide insights on total electricity generation, primary energy per generation technology and emissions over the next two decades as well as the emissions that will be reduced and the investment flows that will be required. These results will be discussed in this section.

The aim of this section is to assess the assumptions and results of the models, taking into account the existing literature, expert opinions and simulation models. Since the range of possible values for key parameters and, thus, the results of the models, is wide, the analysis performed in this section does not pretend to say whether the assumptions and results of the models are "right" or "wrong". It rather illustrates whether those assumptions and results are within the ranges observed in the literature.

### 2.3.1 Assumptions

Several key assumptions influence the results of simulations, including economic and demographic growth rates and fuel prices (oil, coal and gas). However, all of these have been harmonized in the RECIPE models. Therefore, the key assumption of the analysis (investment costs) is considered, which has a direct impact on the trend and share of different electricity generation technologies. These costs assumptions have been assessed according to the existing literature: The main conclusion is that they are generally within the ranges identified/estimated/expected in the relevant literature, with some exceptions.

### 2.3.2 Main results

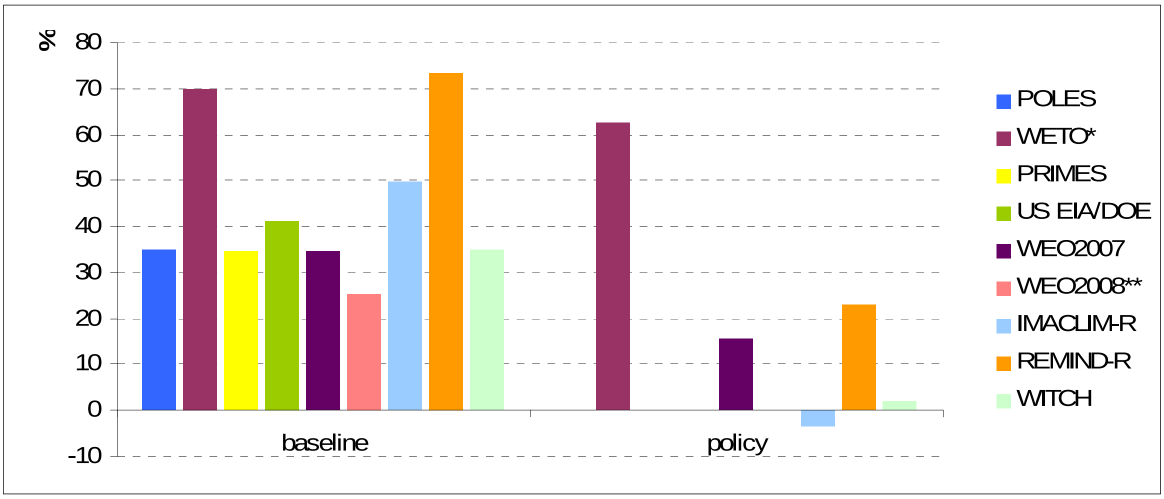
In this section the results of the models are analyzed for total electricity generation, primary energy per generation technology and emissions, taking into account the possible and expected evolution of their determinants and the results of other model simulations[10]. First, the results in the reference scenario are assessed. Then, an analysis of the results of policy scenarios (with a focus on the 450 ppm C&C policy scenario) with respect to the baseline scenario is carried out.

#### 2.3.2.1 Activity levels (total generation)

In the baseline scenario, all RECIPE models expect a moderate increase in electricity generation. This can be explained, given the rates of economic and population growth and the fact that the electricity intensity of the economy is unlikely to experience a large reduction, in spite of the adoption of more electricity-efficient technologies (appliances) and the implementation of policies aimed at energy efficiency in electricity demand. Other simulation models also envisage moderate increases in electricity generation in the baseline scenario (cf. Figure 2-2).

awareness programs and training opportunities. For a detailed analysis on the barriers in the EU heating and cooling sector, see the K4RES-H project. www.erec.org/projects/finalised-projects/k4-res-h.html

[10] A fourth key result of the models (required investment flows) is analyzed in the Section 2.4.




* 2001-2030

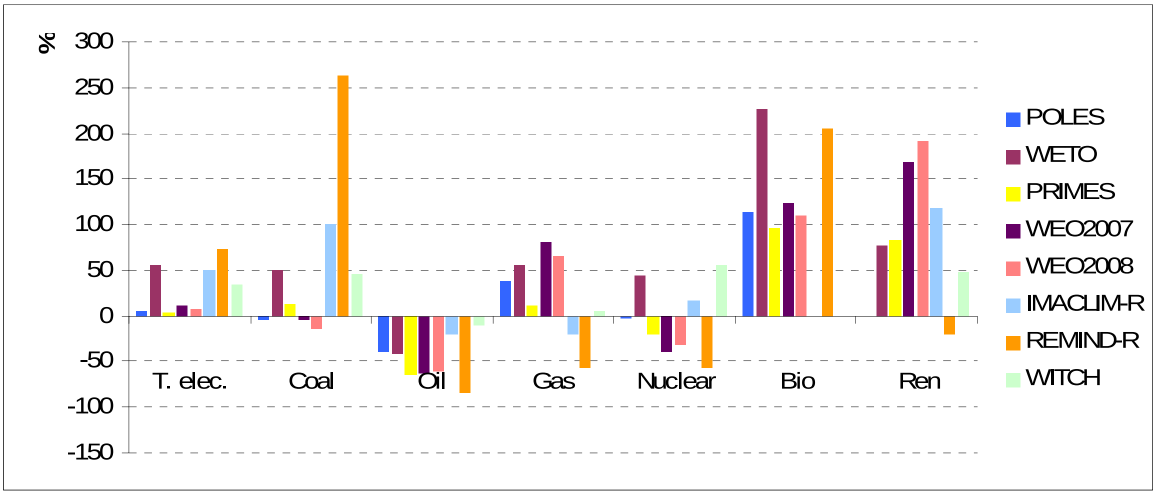
** 2006-2030

**Figure 2-2: Electricity generation - % Growth (2005-2030)**

In the policy scenario (450 ppm C&C), electricity generation experiences a reduction in IMACLIM-R and an increase in the other two models. Some simulation models (WEO2007 and WETO) show a greater increase in electricity generation in the baseline scenario than in the alternative scenario.

#### 2.3.2.2 Activity levels (primary energy per generation technology)

The trends in activity levels in the period can be analyzed per model (RECIPE and non-RECIPE), scenario (baseline and policy scenarios) and technologies (cf. Figure 2-3 and Figure 2-4). Significant increases in the baseline scenario for biomass and other renewables, substantial reductions in oil and mixed results for coal, gas and, especially, nuclear are expected.

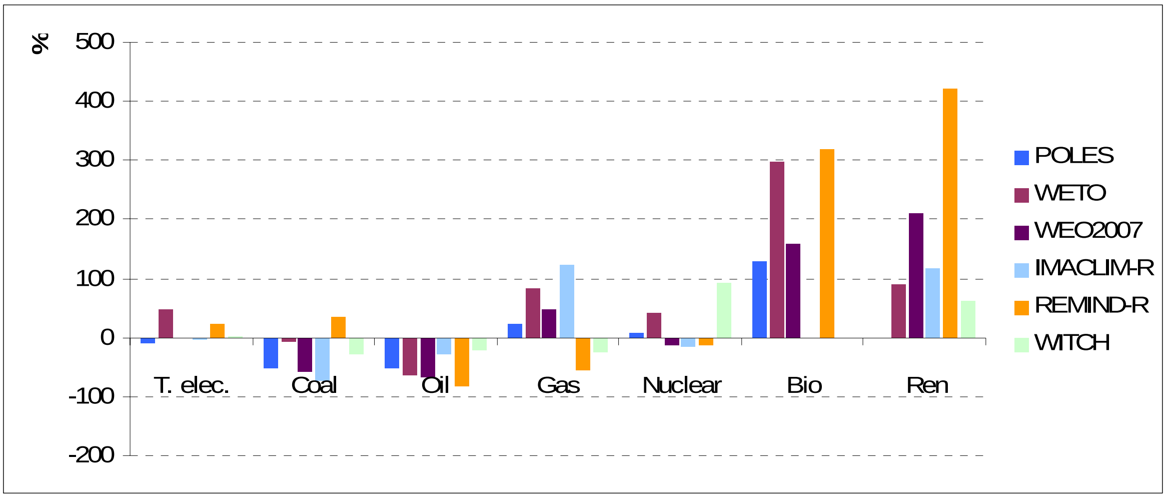



* POLES: Biomass and renewables are aggregated.

** No biomass is expected to be deployed in the period in IMACLIM-R and WITCH.

**Figure 2-3: Activity trends in 2005-2030 (% growth) - Baseline scenario**

The results for the policy scenario (450 ppm C&C) show that, with respect to the baseline scenario, a stringent climate policy would encourage the uptake of some technologies (nuclear, biomass, renewables and CCS) and discourage investments in others (coal). Mixed results can be observed for gas, with a positive effect of climate policy envisaged by some models (POLES, WETO, WEO 2007 and IMACLIM-R) and a negative impact expected by others (REMIND-R and WITCH).




* POLES: Biomass and renewables are aggregated.

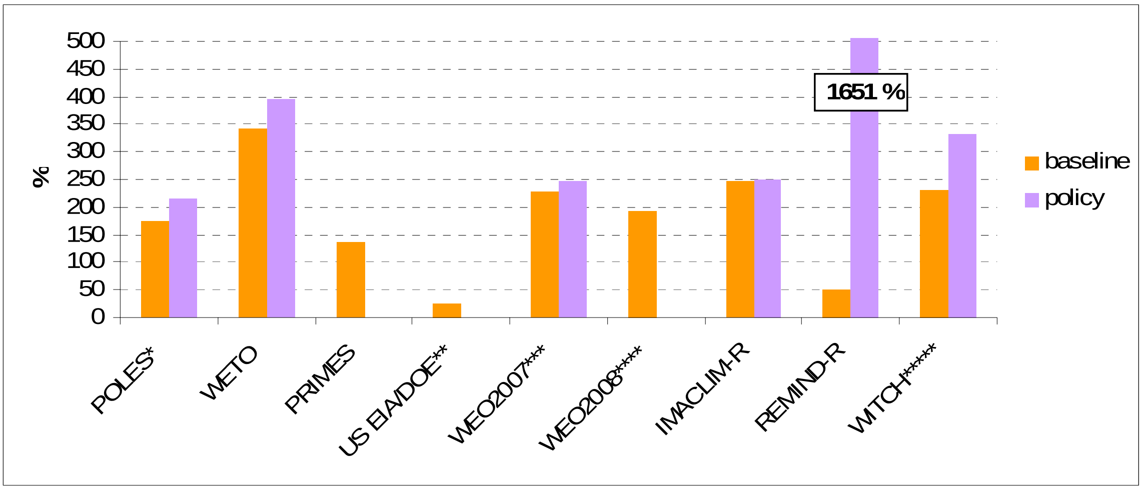
** No biomass is expected to be deployed in the period in IMACLIM-R and WITCH.

**Figure 2-4: Activity trends in 2005-2030 (acc. %) - Policy scenario**

A somehow striking result of RECIPE models (except for REMIND-R), which contrasts to non-RECIPE models, is the lack of deployment for biomass in, both, the baseline and policy scenarios. Biomass is likely to increase during the period, due to the existence of RES-E support schemes, given the targets of the new renewables directive and politically justification for climate and non-climate change benefits (security of supply, creation of a local industry, local development opportunities) even in the absence of a strong climate policy. Investment costs are expected to be reduced substantially and increasing fuel prices add another incentive. A carbon policy could be expected to provide an additional incentive for the diffusion of biomass technologies.

The following paragraphs provide a closer examination of the trends of other low-carbon technologies (wind, solar and nuclear). This is all the more important given that the above data provide aggregate results for a whole bunch of low-carbon technologies, renewables, which have different dynamics.

Regarding **wind**, the models expect a large increase in 2010-2030 in the baseline scenario. IMACLIM-R and WITCH are within the ranges of existing models, closer to the lower bound. REMIND-R is above the upper bound (cf. Figure 2-5).




* Includes all renewables except hydro.

** All RES

*** 2010 data calculated with lineal interpolation (2005 and 2015)

****2010 data calculated with lineal interpolation (2006 and 2015)

***** Includes wind and solar.

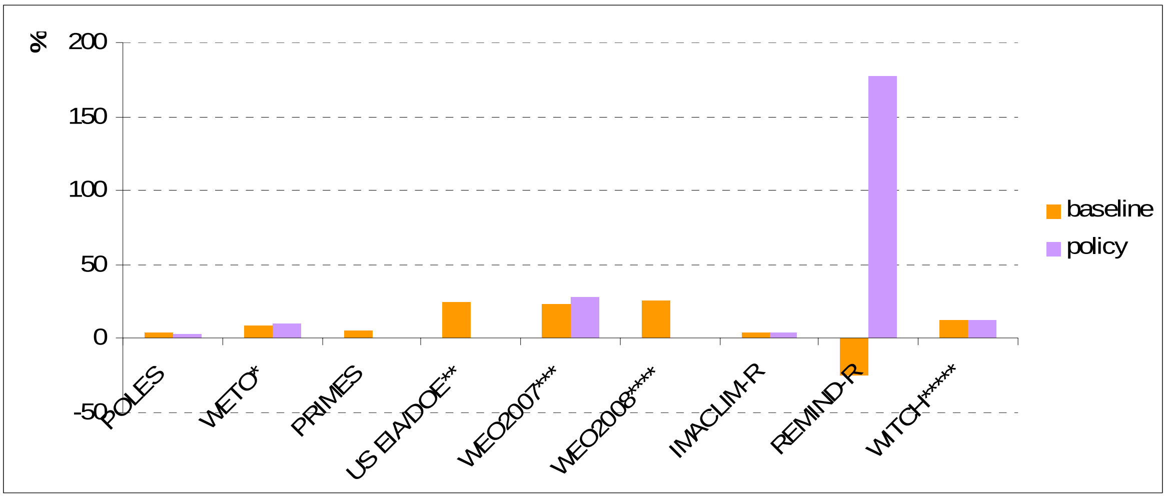
**Figure 2-5: Wind - Accumulated percentage variation in 2010-2030**

This increase is deemed feasible due to the greater competitiveness of this energy source versus others as a result of the carbon price, the expected reduction in investment costs due to learning effects, the existence of a large and booming industry in Europe and non-climate policy goals which will result in the continuation of RES-E support schemes for these technologies. In addition, the expected share of wind in total generation (between 5 and 7 % in 2030, according to WITCH) does not pose great challenges to the stability of the grid, which could be a barrier for much higher percentages (i.e., 30 % and above).

Although the trends in wind energy are similar for the three RECIPE models (with the aforementioned exception), the level of activity in the wind energy field differs between the models, even by orders of magnitude.

In the policy scenario (450 ppm C&C), the three models foresee an increase of wind throughout the period. The reduction in IMACLIM-R between 2025 and 2030 can be explained by the fact that an ambitious climate policy encourages the occupation of the best locations first which, thus, are exhausted by the end of the period. Therefore, the currently high dynamism of this sector would lead to a fast exploitation of the cheapest places and result in cost increases by the end of the period, which discourage investments by then.

Regarding **hydro**, very small increases are envisaged by IMACLIM-R and WITCH in the baseline scenario, whereas a significant rise is foreseen by REMIND-R. In the policy scenario (450 ppm C&C) the models expect even a lower increase compared to the baseline. A very small increase is predicted by non-RECIPE model simulations as well (cf. Figure 2-6).




* Hydro + geothermal

** All RES

*** 2010 data calculated with lineal interpolation (2005 and 2015)

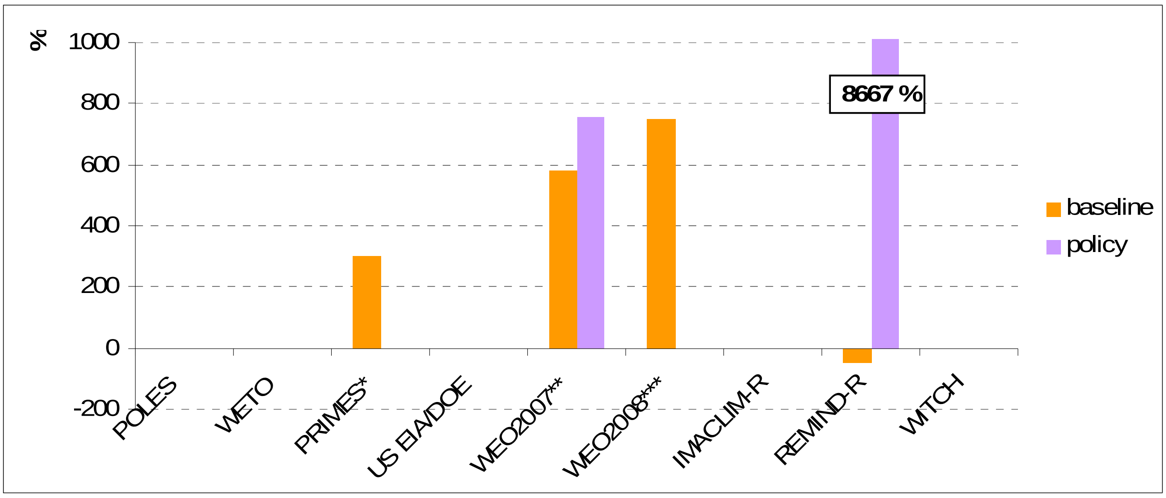
****2010 data calculated with lineal interpolation (2006 and 2015)

**Figure 2-6: Hydro - Accumulated percentage variation in 2010-2030**

There is little reason to expect large increases in hydro. The resource potentials (especially for large hydro) are limited and social acceptability factors play a major role in the exploitation of the remaining potential. In addition, investment costs will not be significantly reduced[11]. A carbon-constrained future will not push hydro, given that it would have a negligible effect on its relative competitiveness. Although a carbon price would improve its competitiveness, the aforementioned key factors would not be much affected. Other carbon-free energy sources are more competitive and take precedence to meet climate reduction targets.

[11] Indeed, according to EU Commission (2008d) learning rates for hydro are expected to be negative (-0.5 % per year for large hydro and -1.2 % per year for small hydro).

**Solar**: Only REMIND-R provides individual data for solar[12]. Solar plays a negligible role during the whole period. This can be expected, given its comparatively high investment costs. However, the fact that it experiences an absolute reduction in the baseline scenario by the end of the period is striking and is certainly at odds with other model simulations (cf. Figure 2-7). The picture for REMIND-R changes completely for the policy scenario where a large increase is expected. The sector is booming in certain countries with a large potential (i.e. Spain), as a result of generous promotion policies. But large unexploited potential, increasing fuel prices and substantial expected cost reductions make it difficult to foresee an absolute reduction in the baseline scenario, i.e., even in the absence of a strong climate policy[13].




* Solar and others, thermal uses included.

** 2010 data calculated with lineal interpolation (2005 and 2015)

*** 2010 data calculated with lineal interpolation (2006 and 2015)

**** (division by zero). Electricity generation increases from 0 TWh in 2010 to 17 TWh in 2030 in the baseline scenario and from 0 to 29 TWh in the policy scenario.

**Figure 2-7: Solar - Accumulated percentage variation in 2010-2030**

**Nuclear**: The trends widely differ across RECIPE models: WITCH expects a significant increase in the baseline scenario, REMIND-R envisages a large reduction and IMACLIM-R is in the middle (i.e., a small increase). It is particularly difficult to predict the future role of nuclear in the European electricity sector, because the attitude of governments towards nuclear is currently very different between countries and it is hard to predict how it will evolve as a result of the influence of key variables, i.e., concern about security of supply, GHG mitigation and social support. While some forces pull in one direction, others (investor risks associated with political and economic factors, high investment costs and social concerns on security aspects) pull in the opposite direction. What currently can be see is a

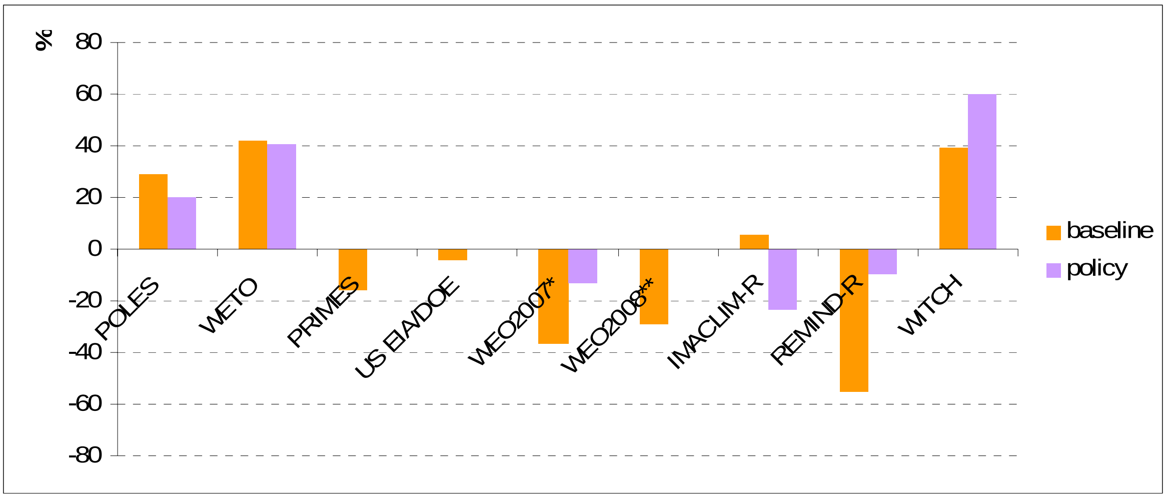
[12] WITCH aggregates solar data with wind data, which certainly limits the comparability of results, because wind is dominating the combined data for primary energy.

[13] This reduction is explained by the fact that, since no subsidies for solar are envisaged in the baseline scenario, no penetration of solar technologies is considered, which in turn reinforces the lack of deployment, because cost reductions as a result of learning effects are not allowed to unfold, keeping investment costs at a high level.

reopening of the nuclear power debate in some countries (e.g. Spain, Bulgaria), mostly fuelled by security of supply concerns.

Non-RECIPE models reflect this uncertainty: they expect either a reduction (PRIMES, EIA/DOE, WEO2007 and WEO2008) or a small increase (POLES and WETO) in the next decades, although they agree that the share of nuclear in the power generation mix will be reduced.

Does a stringent climate policy provide an additional boost to nuclear? The results of the models (both RECIPE and non-RECIPE) in the policy scenario (450 ppm C&C) are not unanimous in this regard, reflecting current uncertainties about the prospects for this technology (related to economic costs and political support)[14]. Whereas some envisage a greater level in the policy scenario than in the baseline scenario (WEO2007 and WITCH), others do not (POLES, WETO, IMACLIM-R and REMIND-R)[15]. Again, this is a reflection of the aforementioned uncertainties.




* 2010 data calculated with lineal interpolation (2005 and 2015)

**2010 data calculated with lineal interpolation (2006 and 2015)

**Figure 2-8: Nuclear - Accumulated percentage variation in 2010-2030**

#### 2.3.2.3 Emissions

The following figure shows the trends in emissions in the three RECIPE models in the 2005-2030 period. In the baseline (BAU) scenario, the three models expect an increase in emissions, ranging from a modest (WITCH) to a significant one (IMACLIM-R and REMIND-R). Indeed, emissions double in REMIND-R. The trends are very similar in the two policy scenarios (450 and 410 ppm C&C) for IMACLIM-R and REMIND-R. An increase until 2010 is envisaged, followed by a reduction, which is much greater in the case

[14] This is basically due to the different assumptions regarding government position on nuclear energy. As far as we know, only PRIMES makes the assumption about this policy explicit.

[15] "A greater level" means that, in the case both scenarios lead to a reduction in nuclear, the reduction is lower in the policy scenario than in the baseline scenario (i.e., the case of WEO2007).

of IMACLIM-R. In contrast, WITCH expects a sustained reduction in the whole period, ending up at much lower emission levels than the other two models.

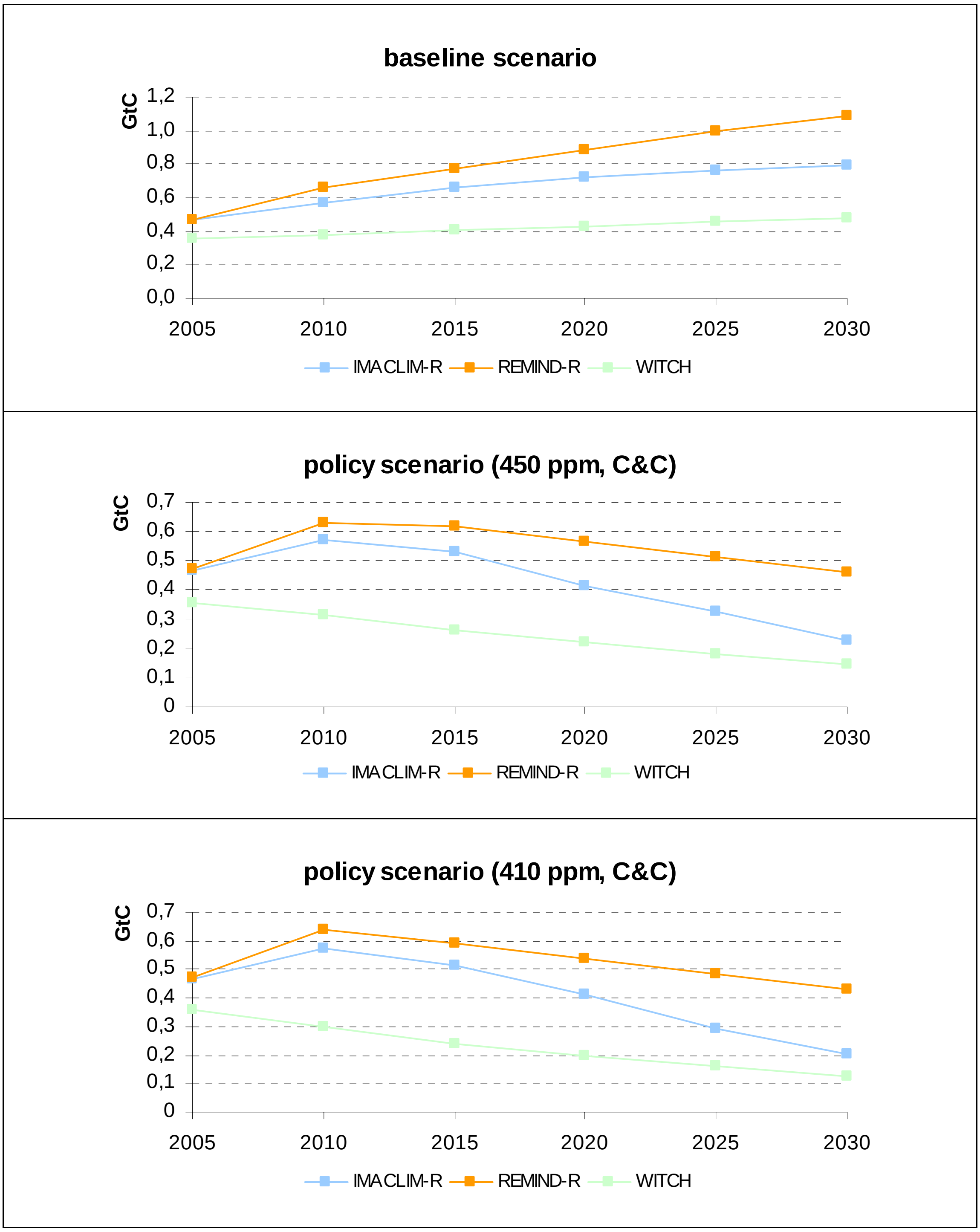



**Figure 2-9: Comparing emission trends across models and scenarios**

$CO_2$ emissions trends in the 2005-2030 period are very similar in the three models in the baseline scenario, although at different levels. The substantial increase expected in those emissions is higher than in other simulation models (Figure 2-9). Those emissions are significantly reduced in the policy scenarios, although to a different extent. WITCH and IMACLIM-R expect a significant reduction, above or in line with other models. Emissions are modestly reduced in REMIND-R.

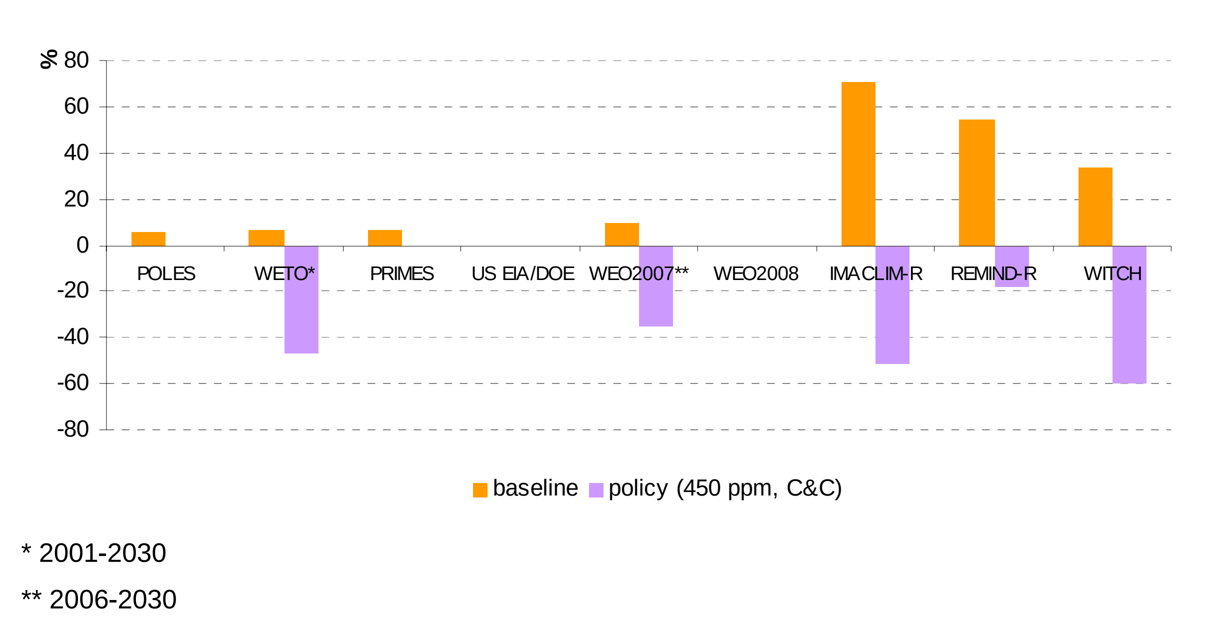



**Figure 2-10: Emissions in the electricity sector - % Growth (2005-2030) (baseline and 450 ppm C&C policy scenario)**

This emissions reduction in the policy scenarios are the a result of:

**1.** A reduction in electricity generation due to the implementation of energy efficiency measures. However, this is only the case in IMACLIM-R.

2. The greater uptake of low-carbon technologies (especially wind and nuclear) in this scenario.

In IMACLIM-R, the increase in emissions in the baseline scenario is greater than the increase in activity levels, indicating that factor one above more than compensates the impact of the low-carbon technology factor (mostly resulting from a greater penetration of wind), leading to a carbonization of the electricity sector.

In contrast, a significant degree of decarbonization can be observed in the policy scenarios, as a result of a greater uptake of carbon-free energy sources and energy efficiency. Both factors are clearly visible in IMACLIM-R, which experiences a reduction in electricity generation (see Figure 2-2) and a reduction in emissions per unit of generation (technology-specific factor, i.e., a growing share of less carbon intensive generation technologies). The increase in electricity generation in REMIND-R and WITCH does not lead to higher emissions because the technological factor dominates the reduction of electricity generation factor.

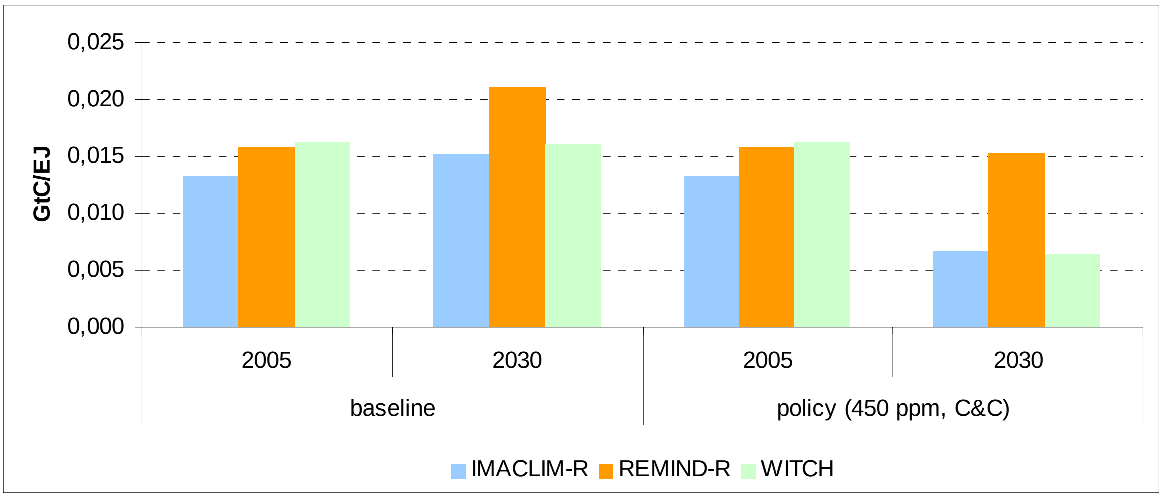



**Figure 2-11: Carbon intensity of European electricity generation**

### 2.3.3 Beyond the insights from models

Some relevant issues affecting mitigation of emissions in this sector and, particularly, the choice of electricity generation technologies but which are not directly grasped by modeling work are considered in this subsection. The following are worth mentioning.

1. Other barriers (apart from cost). Costs barriers have received most attention in the literature and they are one of the most important parameters in modeling work. However, low-carbon technologies sometimes suffer from other barriers (i.e., non-price barriers) which at the end of the day have a cost implication and could be even more important for their uptake. A case in point is administrative procedures for some renewable electricity technologies, particularly hydro, which can result in significant lead times. These delays result in significant risks for investors. Another example is the impediments to access the grid. The EU-funded project GreenNet suggest several policy measures to enable large scale grid integration of renewable electricity into the European electricity systems: implementation of correct unbundling, setting up markets in system operation to mitigate intermittency risk of renewables generation and consideration of the grid operators´ point of view (Auer et al., 2006)

2. Related to the previous aspects is the issue of risk, which should be another relevant criteria for the analysis of instruments. As in any investment process, risks for investors significantly raise the costs of financing and affect the profitability of projects involving the application of electricity technologies. Reducing the risks for investors is a critical aspect not only to enhance the probability of uptake of a specific technology, as usually considered (i.e., effectiveness criteria), but, equally important, in order to maintain the costs of financing (risk premium) within reasonable and affordable limits. This issue applies particularly to nuclear and renewable energy technologies. In the former case, it has been stressed that, for the new reactors being built worldwide (incl. the Finnish reactor), risks have significantly pushed up the costs of financing. In the case of renewable energy technologies, the volatility of support introduced by quota with tradable green certificate schemes has empirically been shown to be a clear deterrent for investment in renewable electricity (see Mitchell et al., 2006 for an analysis of the U.K. case). This contrasts with the certainty on the support levels provided by feed-in tariffs, entailing a lower risk premium. The message here is that policy makers should be particularly careful not only to implement an appropriate instrument, but also to reduce

the potential risks for investors. For technologies which need public support to be competitive with others, public support is a crucial source of risk. The continuation of support schemes, i.e., without major discontinuities, but with the sufficient flexibility to allow for some changes in response to changing circumstances would be a key element to reduce the risks for investors, with a simultaneous positive effect on the effectiveness and cost-effectiveness criteria. In the case of support for renewable energy, this has proven to be the case of feed-in tariffs schemes (del Río, 2008). These issues are further tackled in Neuhoff et al. (2009).

3. The links between electricity technologies. In general, modeling analysis usually focus on the substitution between these technologies. However, the complementary relationship has not received a comparable attention. However, this is hardly a unique shortcoming of modeling and should be regarded rather as an empty space in the literature on electricity generation and mitigation. Regarding the conflict relationship it would be interesting to know the extent to which investments in one particular technology crowds out investments in another. An in-depth analysis of the compatibility between different mitigation technologies should be performed in the future. Are they complementary or mutually exclusive? How successful is their combination? For example, this analysis has only been carried out, albeit on a bilateral basis, by Verbruggen (2008) for renewable and nuclear power.

4. Attaining the emissions reductions envisaged in the models with the deployment of new, low-carbon emissions technologies will require a significant volume of investments (see below). However, it is unclear whether those funds will be available in practice and where will they come from. Are the opportunity costs of investing in this sector's technologies above or below the costs of investing in other productive alternatives?

5. Other factors are critical in analyzing the competitiveness between electricity technologies. For example, in the case of renewables, the low availability factors for technologies like wind and solar (of 20 to 30 %) are also critical in comparing the costs of technologies[16]. Furthermore the need for back-up capacity in the case of renewables could add significantly to system costs.

6. A crucial issue that will affect investments in electricity generation technologies in Europe is the market liberalization process. Although, even according to the European Commission, liberalization is currently proceeding at a slow pace, it could show momentum in the 2030 timeframe. Liberalization seems to benefit certain technologies at the expense of others. For example, several authors suggest that CCGTs may have been favored (for example, see IEA, 2008a) by electricity liberalization processes around the world, whereas other technologies with longer write-off periods and often lower returns (including nuclear power plants) are not always being made due to the need to maximize value for short-term shareholders (for example, see IPCC, 2007, p.258)[17].

[16] Since data in the RECIPE models (both investment and O&M costs) are provided in $/KW (i.e., no actual generation), and there is no information on capacity factors, it is unclear the extent to which these aspects have been taken into account in the analysis.

[17] For example, Toke and Fragaki (2008) show the way the liberalized electricity market operates in the UK effectively may discriminate against small CHP plant selling their electricity to the grid and proposes several. Nevertheless, the authors suggest several rules that could make both issues (liberalization and CHP promotion) compatible.

7. Cross-cutting issues and interactions with other sectors will be increasingly important. In particular, increasing electricity demand can be expected from other sectors. For example, the WETO-H2 study shows that electricity consumption in the alternative policy scenario (or carbon-constrained case) is not much lower than in the Reference case, because the increasingly low-carbon electricity substitutes for fossil fuels and achieves a cost-advantage in new markets, especially transport, partially offsetting the increase in efficiency in the end-uses of electricity (see Chapter 3). This issue can be expected to be relevant in 2050, although probably not in the 2030 timeframe.

8. Investment flows are not taking into account R&D investments (except in WITCH), i.e., the investments that will be needed over the period 2010-2030 to enhance the quality and reduce the costs of currently immature and high costs low-carbon electricity generation technologies. However, an estimate of this sort is highly difficult to obtain anyway (within or outside modeling work) and, indeed, there are few estimates of this sort in the literature (Gielen, 2009)[18]. On the other hand, the amount of investments in CCS, expected to be significant, is not provided.

## *2.4 Sectoral policy issues and options*

### 2.4.1 Policy instruments

In order to achieve emissions reductions in this sector support policies are and will be needed. What will be the likely trend in mitigation policy measures in this sector? What lessons for the implementation of policies can be drawn from this analysis? The aim of this section is to respond to these questions, outlining the main policy options.

Cross-sectoral mitigation measures are likely to have a significant impact in this sector. Furthermore, since this is already (and it is likely to continue to be) a highly regulated sector regarding mitigation measures, some instruments affect all technologies in the sector. The EU ETS is worth mentioning in this regard. Electric utilities now face and will continue to face the cost of $CO_2$ emissions as another input cost. Therefore, it provides an on-going incentive to adopt all types of measures, especially the most mature. Some of these are more incremental at the level of the plant, such as energy efficiency in electricity generation, while others are more strategic at the level of the whole firm affecting new investments and eventually encouraging the substitution of carbon-intensive generation by low-carbon technologies.

In addition, some measures will directly affect only specific types of technologies (i.e., promotion schemes for the deployment of renewables). The underlying problem is that carbon policies may be relatively ineffective (yet necessary) to tackle the technological externality[19], i.e., a carbon price is not sufficient to encourage the development or uptake of technologies which are either immature (CCS) and thus need to go through the demonstration

[18] See Section 2.3.3 in this regard.

[19] The economic rationale for the public promotion of technological change in the climate mitigation realm is related to the "double externality problem" (Rennings et al., 2000, Jaffe et al., 2005, Newell, 2008): 1) The environmental externality. If firms do not have to pay for the damages caused by their GHG emissions, then these emissions will be too high and innovation in low-carbon technologies will not need to be encouraged. 2) The technological externality, due to the public good nature of technological innovation. This is related to spillover effects enabling copying of innovations, which reduces the gains from innovative activity for the innovator without full compensation and, thus, the incentives to innovate and to create radical systemic changes.

stage or are at or nearly at a commercial stage but are currently very expensive even though they have a large cost-reduction potential (solar PV)[20]. In the first case, a carbon price is not sufficient to facilitate the transition from an immature to a mature technology.

In the second case, the carbon price should be set at too high a level to encourage a greater diffusion which would allow this technology to advance along its learning curve and reduce its costs (and, thus, put a downward pressure on carbon prices). A very high carbon price would have other detrimental and distortionary effects on the economy as a whole (i.e., effects on competitiveness, carbon leakage (cf. Section 4.4)).

Complementary instruments are needed to address the “technological externality” and facilitate that those technologies reach the “break-even” point given by the carbon price, in which case those technology-specific instruments will no longer be needed and the carbon price will be sufficient to encourage the uptake of these technologies. Three of these policies for low-carbon technologies in this sector are discussed below.

1) R&D support for enhanced geothermal systems (EGS). R&D support is a must for certain technologies. For example, this is the case of EGS. According to IEA (2008b), EGS costs need to be reduced by 80 % to make EGS economical without feed-in tariffs or subsidies. This requires more cost-effective deep-well drilling and construction, more effective reservoir fracturing and stimulation techniques, and tailored surface-conversion technologies. This can be attained with focused R&D support, possibly in demonstration projects as is currently the case in the United States, Australia and Europe.

2) Demonstration projects for CCS. Government support is needed for the larger-scale demonstration of new technology, reducing the risks of the first stage of commercialization, improving the technical quality of the technologies and reducing their costs, allowing them to mature and later compete with other technologies in the carbon market. In particular, given its expected significant role in mitigation, full-scale deployment of CCS requires a significant effort in demonstration and the development of a suitable infrastructure (IEA, 2008b). Development of the legal and regulatory frameworks, $CO_2$ reduction incentive pricing, financial support for RD&D, and public outreach are needed to enable CCS.

3) R&D support and deployment support for solar PV. In general, R&D support improves the quality of the technology and encourages cost reductions. In the case of solar PV, R&D is expected to help improve current silicon-based PV technology and also favor the two-stage technology shift from present silicon-based to thin film to novel PV devices[21]. On the other hand, deployment support in the form of feed-in tariffs (FITs) allows PV to advance along its learning curve, reducing its costs through learning effects and economies of scale. Although PV costs have in the past decreased with a learning rate of

[20] For immature technologies the insufficiency of a carbon price to encourage low-carbon technology investments occurs even if this price is high and stable. Low or volatile carbon prices would affect both mature and immature technologies. A carbon tax or a sufficiently high carbon price in an ETS might be difficult to reach due to political economy reasons (del Rio and Labandeira 2009, see also Neuhoff, 2009). Or the price could be too volatile (in an ETS), although caps and floors (as implemented for FITs in Spain) could be adopted.

[21] According to IEA (2008b), the key technology developments needed for PV are: to increase the efficiency and reduce the material intensity and costs of crystalline silicon modules; to increase the efficiency and lifespan of thin film modules; and to guarantee sufficient public and private R&D funding for the development of third-generation novel devices (ultra-high efficiency and ultra-low cost cells).

15 to 20 % (Neji, 2007), investment costs are still the main barrier for the uptake of this technology and, thus, further cost reductions are needed. Both instruments may be needed in the short to medium term to make solar PV competitive with other electricity generation technologies and compete in electricity retail markets with the existence of a carbon price.

The above suggests that deployment support should be granted even with the existence of a carbon price if there are significant potential learning effects which make currently expensive technologies cheaper in the future. The additional support (to a carbon price) can be fully justified in the case of very immature technologies (in the form of R&D), whereas such additional support loses legitimation as technologies progress along the different steps of the technological change process. Fully mature technologies should only be supported with a carbon price. The reason is that for mature technologies only the aforementioned GHG externality (but not the technological externality) is relevant and justifies support.

Accordingly, the following figure illustrates the combination of general incentives (ETS, carbon taxes, quota with TGCs without banding) suitable for encouraging the most mature technologies and technology-specific instruments which are more appropriate for the immature technologies[22]. The more mature the technologies, the more suitable are these "general" (i.e., technology-neutral) instruments. The more immature, the greater the need for technology-specific measures.

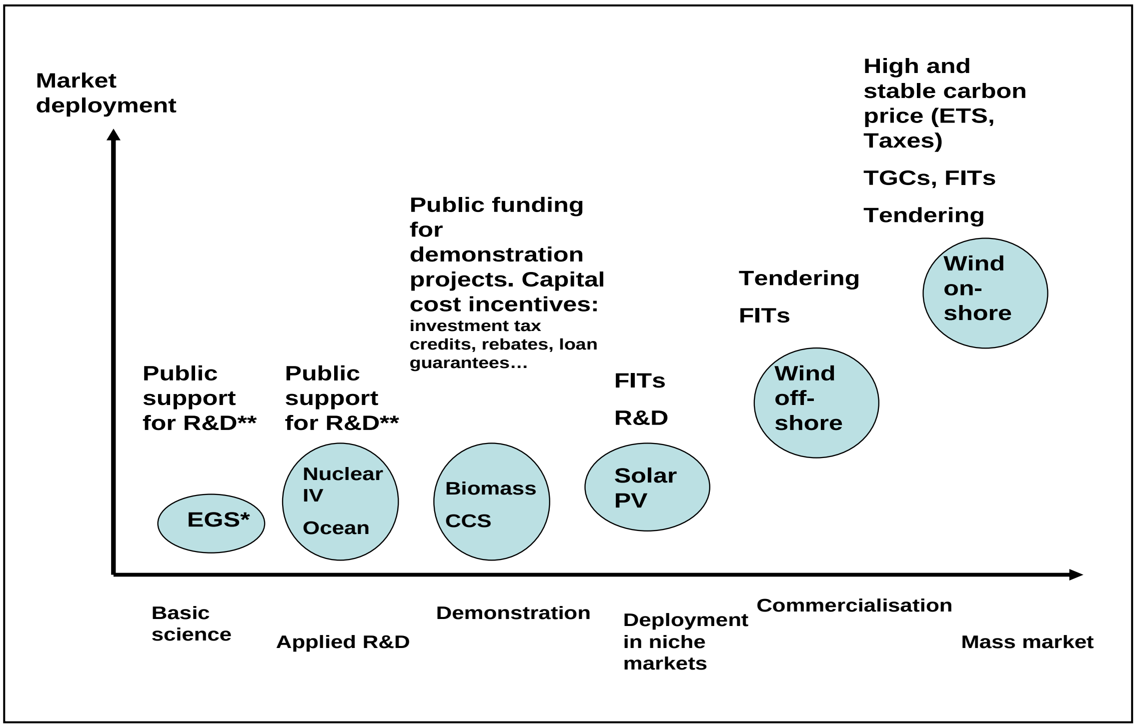



**Figure 2-12: Combining instruments according to the maturity level of low-carbon power-generation technologies.** Source: Own elaboration based on Newell (2008), IEA (2008b) and IEA (2008c). Lay-out based on IEA (2008c). * EGS = Enhanced geothermal system; ** R&D support can take different forms: research contracts and grants, tax credits and inducement prizes. The realization of the supported R&D activities can

[22] Nevertheless, the actual optimal mix of incentive schemes will depend on national circumstances (including renewable potential, existing policy framework, existence of non-economic barriers, degree of market liberalization and energy system infrastructure. (IEA, 2008c).

take place in either public or private research centres and organizations and involve public and private partnerships (Newell, 2008).

Furthermore, in addition to the aforementioned combination of instruments other measures tackling the non-economic barriers to the development and uptake of low-carbon mitigation technologies should be implemented.

Finally, a stable policy is key to reduce investment risks and to the effective and cost-effective deployment of low-carbon technologies.

Table 2-4 provides some insights on the possible trends of mitigation policies for power sector technologies, distinguishing between sector measures (affecting all generation technologies) and technology-specific measures.

| Technologies | Possible trends |
|---|---|
| **All technologies (sector measures)** | Continuation of the EU ETS, with allowances being auctioned to the firms in the sector. |
| **Coal technologies** | The introduction of an Emission Performance Standard is currently discussed at EU-level and introduced in Norway. |
| **Shift from coal to gas** | No direct mitigation policy (except the EU ETS) can be expected. Substitution will continue to depend on fuel (gas, oil and coal) and carbon prices. |
| **Nuclear** | Heterogeneous situation depending on countries: some have decided to have no or phase out nuclear power (Belgium, Germany, Austria, Cyprus, Denmark, Estonia, Greece, Italy, Ireland, Latvia, Luxembourg, Malta and Portugal) whereas others have made firm decisions about commissioning new nuclear plants (Bulgaria, Finland, France, Lithuania and Romania).<br>Possible reopening of the nuclear debate in some countries, following concerns on security of supply or climate change mitigation (i.e., Spain). |
| **Renewables** | The Renewable Energy Directive includes compulsory targets up to 2020 (for electricity, transport and heating/cooling). A follow-up Directive can be expected in the future with targets for 2030 or 2050.<br>Trend is toward a greater cooperation/collaboration between Member States regarding the fine-tuning of their promotion schemes.<br>Member States can retain their domestic support schemes. |
| **Energy Efficiency in power generation** | No direct mitigation policy. On-going incentive provided by the EU ETS towards a greater uptake of energy efficiency in power generation. |
| **Cogeneration** | More harmonized framework for the support of cogeneration. Compulsory targets at the EU and MS levels. |
| **CCS** | Support for demonstration projects<br>Inclusion of CCS in the EU ETS.<br>Inclusion of CCS in CDM? |

**Table 2-4: Outlining the main mitigation policies in the EU power sector up to 2030.** Source: own analysis

On the other hand, four major aspects of these policies can be highlighted: complementarities in instrument choice and timing of policies, appropriate design elements within specific instruments and a focus on the stability and continuity of policy, which provides certainty for investors.

Regarding the first aspect, an intertemporal climate mitigation effort and the potential role to be played by technologies at different stages of maturity will make it likely that a carbon price will provide a necessary albeit not sufficient incentive for the development of a technology mix which will be capable of attaining more stringent targets at reasonable costs. A predictable carbon price signal is necessary to internalize the $CO_2$ externality and provides for an on-going incentive to develop and adopt low-carbon technologies. However, this will need to be complemented with technology-specific support schemes (in the form of investment or production subsidies, as is the case of feed-in tariffs for renewable electricity, or support for research, development, including demonstration projects, as is the case of CCS) for those technologies which are expected to have a large cost-reduction potential but which are currently more expensive and for which a carbon price does not make them sufficiently attractive for potential adopters, impeding them to reach the commercialization stage. Once mature and commercial, learning investments are no longer justifiable and technologies previously supported with a technology-specific promotion scheme should be allowed to compete with other technologies only based on the incentive provided by the carbon price.

The price signal provides a continuous incentive for technological change which is particularly suitable to change behaviors by firms and consumers in a market economy. It is particularly fit for mature technologies but its effectiveness in encouraging currently immature technology has not been proven. While technology policy instruments are certainly needed in a long-term perspective, economic instruments are needed in a short and long-term perspective.

Given the long-lasting capital stock in this sector, this short-term price incentive (combined with long-term emission targets which ensure that there will also be a carbon price in the long-term) will facilitate substitution by less carbon-intensive infrastructures and technologies and mitigate to some extent the lock-in problem. Policies need to be implemented now in order to avoid lock-in in long-lasting infrastructures which may make the achievement of more stringent mitigation targets much more difficult (and costlier) given the long lifetimes of power plants.

Technology policy measures ensure that in the medium and long terms, when other plants will reach the end of their useful lives, they can be replaced by mature and low-cost technologies. Demonstration projects, support for R&D and creation of protected niches for currently promising, immature and high-cost technologies will hopefully allow the improvement and cost reductions in those technologies and put them “on the shelf” to replace the old ones. If they have not been allowed to reduce their cost and remain uncompetitive, such substitution will take place at a much greater cost.

Finally the issue of timing of these complementary policies also calls for the elimination of subsidies involved in technology policy instruments once they will no longer be needed, i.e., once the supported technology is cost-competitive. Ideally, support for technologies should be tailored to the advances along the learning curve, i.e., it should be reduced as costs go down and, eventually, eliminated once the “substitution price” has been reached. Degressive FITs, as applied in several Member States, show that this adjustment of support to the costs of the technologies is possible and desirable in order to avoid an excessive burden on the consumer/taxpayer. Learning investments, however, should have a limit, because there is clearly a trade-off between long-term and short-term efficiency. This difficult balance requires the combination of different policies.

Therefore, economic instruments (ETS, carbon taxes) should be combined with technology policy measures (support for R&D, demonstration projects). Intersectoral-wide as well as sector-wide instruments should be combined with other instruments targeted at specific technologies, taking into account relevant technoeconomic characteristics of those technologies and, in particular, their different maturity levels.

On the other hand, as important as the choice of instruments is the choice of their design elements. For example, experience with renewable electricity support schemes shows that the success of instruments depends to a large extent on their specific design. Although the literature has focused on the discussion of the advantages and drawbacks of different promotion schemes (namely feed-in tariffs and quotas with tradable green certificates), the truth is that it is possible to identify successful as well as poorly functioning schemes in both categories, depending on which design choices were made.

Furthermore, as with other investments, investments in low-carbon technologies take place when there is sufficient security for investors. Given the dependence of the competitiveness of these technologies on support schemes, a changing regulatory framework is a significant source of uncertainty and risk. Therefore, stability of support schemes for low-carbon technologies is an important condition for their effectiveness but also for their cost-effectiveness. A significant risk of policy changes leads to higher risk premiums, increasing the cost of financing by lending institutions and making investments more expensive. Table 2-5 provides an illustration of appropriate measures per technology.

| **Mitigation option** | **Instruments** |
|---|---|
| Whole sector | A price instrument (ETS, carbon taxes) or an emissions performance standard |
| Fuel switching (coal to gas) | - BAU trends (depending on the price of gas, the carbon price and concerns on security of supply)<br>- Economic instruments internalising the negative externalities of coal (carbon taxes and tradable permits for power plants) may be necessary in so far as gas prices are increasing |
| Renewable energy sources (general) | - FITs<br>- Market mechanisms for mature technologies (FITs, TGCs in supranational schemes)<br>- Immature technologies; RD&D (including basic research)<br>- Appropriate international grid management of intermittent renewables |
| Biomass | FITs |
| Hydropower (small) | FITs |
| Wind | - Quotas with TGCs<br>- FITs |
| Solar | - Investment subsidies<br>- Feed-in tariffs<br>- RD&D |
| Other renewables for electricity | RD&D |
| Renewable energy for heat | - Investment incentives<br>- tax measures (investment-based and fuel-based)<br>- low-interest loans<br>- Bonus model |

| | |
|---|---|
| Cogeneration | FITs/Certificates |
| Nuclear | - Strategic public RD&D funding is required for additional technology development<br>- Loan guarantees<br>- Production tax credits<br>- Public risk coverage for investments<br>- International research cooperation (regarding advanced nuclear energy systems)<br>- Information dissemination on the advantages of this technology (to enhance public acceptability) |
| Energy efficiency in electricity generation | - Carbon prices (taxes/permits)<br>- Power plant minimum efficient standards<br>- Best available Technologies prescriptions<br>- Information and education campaigns |
| CCS | - Carbon prices (taxes/permits)<br>- RD&D<br>- Information dissemination on the advantages of this technology (to enhance public acceptability) |

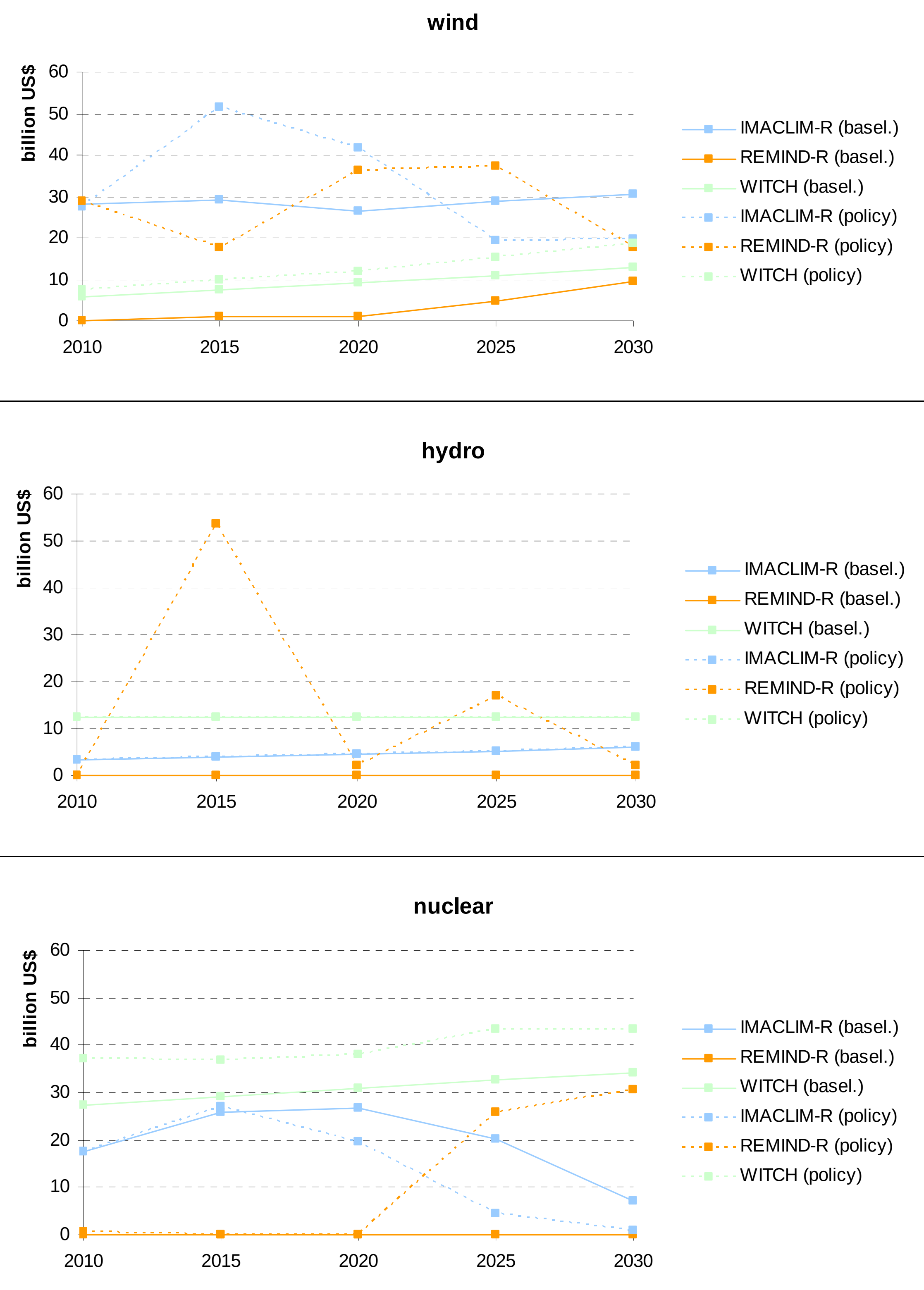
**Table 2-5: Summary of possible instruments in the EU electricity sector.** Source: Own elaboration

Finally, in addition to specific instruments being applied, some of the contextual conditions for these technologies could be created and some of the barriers removed. More specifically, administrative procedures leading to delays and grid-connection aspects should be improved.

## 2.4.2 Required investment flows

### 2.4.2.1 Results of RECIPE

The following figures show the investment flows in the RECIPE models for wind, hydro and nuclear in, both, the baseline and policy scenario (450 ppm C&C) for the 2010-2030 period. Unfortunately, an overall figure of total investment flows is not available in any of the models.




Note: Both scenarios in each model are represented by the same colors. (baseline scenario: solid line; policy scenario (450 ppm C&C): dashed line)

* Data for WITCH (wind) includes wind and solar.

**Figure 2-13: Investment flows in the 2010-2030 period**

In general, wind experiences a high dynamism, whereas the trends in hydro are much more flat and results for nuclear widely differ across the models. With some exceptions, investment flows in these low-carbon technologies are greater in the policy scenario than in the baseline scenario, since climate policy encourages the uptake of all these technologies (to a greater or lesser extent). Differences between the investment flows across the models as well as across technologies are a reflection of uncertainties about the possible evolution of the drivers and barriers for these technologies, already discussed in the previous sections. Notwithstanding, some of these issues are taken up again in the discussion of differences between the models for specific technologies. The following paragraphs provide a brief discussion per energy source.

**Wind**: A moderate increase in wind investments in the period could be expected a priori, especially in the policy scenario (450 ppm C&C), given that activity levels for wind generally increase during the period. However, there are several forces at play here.

In general, the amount of investments flows results from multiplying the installed capacity in the period by investment costs. Generation capacity is likely to increase substantially in the period (see Section 2.2), whereas investment costs are expected to be reduced substantially, due to learning effects (see above). The increase in capacity is likely to be greater than the reduction in investment costs and, thus, a sustained increase in investment flows in wind energy can be expected. This clearly seems to be the case in WITCH. The increase is greater in the policy scenario (450 ppm C&C) compared to the baseline scenario, indicating that a climate policy provides an additional push for this technology.

However, the trends in the other two models show fluctuating and inverted-U shapes (REMIND-R and IMACLIM-R, respectively). This suggests several issues. On the one hand, the reduction in investment costs may be higher or lower than capacity additions. On the other hand, it can also be the case that decreasing returns play a role here as well, i.e., once the best locations have been occupied, the next ones will induce higher costs, discouraging further investments.

To sum up, despite uncertainties on investment cost reductions, the evolution of fossil fuel prices, evolution of national support schemes grid improvements and potential NIMBY effects possibly resulting in bottlenecks and delays or even rejection in administrative procedures, the future looks bright for this technology, especially in the presence of an ambitious climate policy.

**Hydro**: No large increases in investment flows are expected in hydro in the three RECIPE models, although they differ regarding the trends in those flows: A sustained but modest increase is expected by IMACLIM-R, a strong reduction is foreseen by REMIND-R and a constant flow is envisaged in WITCH.

Hydro capacity is likely to experience a very small increase throughout the period, for the reasons already mentioned in Section 2.2. Investment costs are likely to stay constant or even increase (EU Commission, 2008d)[23]. Therefore investment flows in the period are likely to be modest and to experience a small increase in both scenarios.

[23] According to EU Commission (2008d), expected learning rates in the period would be -1.2 % per year for small hydro and -0.5 % per year for large hydro.

Investment flows in the policy scenario (450 ppm C&C) do not experience any difference with respect to the baseline two of the models (IMACLIM-R and WITCH), suggesting that an ambitious climate policy is unlikely to have any influence on hydro capacity investments (see Section 2.2).

To sum up, in contrast to wind (and nuclear), there are unlikely to be major sources of uncertainty affecting this technology, a result of the technology having reached a saturation stage. Everything affecting this technology is likely to be too plain to make it attractive. Therefore, low uncertainty, but probably also low returns for investment can be expected in Europe.

**Nuclear:** Investment flows related to nuclear activity widely differ across the models, probably suggesting a large uncertainty on the drivers and barriers for this technology. This reflects the expectations on capacity additions regarding nuclear in the three models. Modeling of nuclear faces high uncertainty on several fronts, but especially on the economics (evolution of investment costs) and politics (social rejection or a reopening of the nuclear debate due to security of supply concerns and climate change mitigation issues). Therefore, either an increase or a reduction in capacity and investment flows can occur depending on such assumption.

With respect to the baseline scenario, nuclear experiences a greater reduction in the period in the policy scenario (450 ppm C&C) in IMACLIM-R, whereas the increase is similar in WITCH, although at significantly greater investment volumes. This is consistent with capacity data (and constant investment costs for nuclear). In terms of capacity, IMACLIM-R shows the same increase in both scenarios, whereas such increase is much higher in the policy scenario (450 ppm C&C) in WITCH and REMIND-R. Therefore, the models only provide partial evidence that a more ambitious climate policy would have a greater influence on nuclear.

#### 2.4.2.2 Results of other simulations

Major investments in the energy-supply chain, conversion technologies and infrastructure will be required in the electricity generation sector in the timeframe and location considered here (2006-2030, European Union). Some data sources provide information on these flows. The problem is that these data are usually aggregated, i.e., not differentiated per generation technology. Therefore, these data are complemented with own calculations using data from WEO 2008 (IEA, 2008a) and the Energy Technology Perspectives, Scenarios & Strategies to 2050 (IEA, 2008b). Table 2-6 summarizes the calculations of investment flows. It can be observed that estimates differ widely, depending on the different assumptions, including the distinct territorial coverage in each study.

| | Maximum estimate | Minimum estimate | Some assumptions affecting the results |
|---|---|---|---|
| **Aggregate data in WEO 2007 (IEA, 2007a)** | 1728 | 1728 | 2006 dollars, Europe |
| **Aggregate data in WEO 2008 (IEA, 2008a)** | 1505 | 1505 | 2007 dollars., OCDE-Europe |
| **Own technology-specific calculations based on WEO 2008 (IEA, 2008a)** | 826 | 782 | 2007 dollars, European Union |
| **Energy Technology Perspectives (IEA, 2008b)** | 750 | 625 | 2005 dollars, OCDE-Europe |

**Table 2-6: Summary of the investment flows calculations (bn US$)**

The other models show an important effect of energy-efficiency measures on power sector investments encouraged by a drastic climate policy (i.e., WEO 2007). They also show that investments in transmission and distribution might be significant, accounting for about one-third of overall investments in the sector in the 2007-2030 period in the EU, according to WEO 2008[24]. Investments in power generation plants are expected to increase substantially, by more than two-fold. This is mostly related to the fact that some of the electricity generation capital stock (plants) reaches the end of its useful life by 2020.

Regarding the insights on investment flows per technology, calculations using the data in WEO 2008 (baseline scenario), show that low-carbon technologies are highly dynamic, with significant flows associated to wind and solar and, to a lesser extent, hydro, biomass and gas. A comparison of the Reference Scenario (RS) and Alternative Policy Scenarios (APS) in WEO 2007 suggests and confirms that an ambitious climate policy would significant encourage investments in low-carbon technologies[25].

Apart from investment flows related to deployment of the technologies, the investment flows associated to research, development and demonstration (RD&D) of low-carbon technologies can be substantial. For example, the Energy Technologies Perspectives (IEA, 2008b) shows that research, development, demonstration and deployment investment costs in the 2005-2030 period for OCDE-Europe are between 625 and 750 bn dollars[26]. The largest investment flows per technology are related to wind, followed by nuclear and cleaner coal technologies.

#### 2.4.2.3 Trade

In contrast to other sectors (i.e. industry), trade effects are not very relevant in this sector, given its “local” character, i.e., the fact that electricity flows across and outside Europe are not very relevant, with the notable exception of the Scandinavian countries. This is due to the insufficiently developed system of trans-border grid connections (Wehnert, 2004), which

[24] Obviously, investments in power generation plants accounts for the other 2/3.

[25] This is specially so for tidal and wave (generation is 107 % higher in the APS compared to the RS in 2030) and nuclear, geothermal and solar (between 45 % and 33 % higher), to a lower extent for wind and biomass (around 15 % higher) and much lower for hydro (around 5 %).

[26] Note that RD&D investments are not differentiated from deployment investments,

prevent those flows. The creation of the common market for electricity is one of the priorities in the energy sector in the European Union.

The situation might be different in the future as security of supply concerns and the fact that a greater share of renewable generation can be better managed in a wider electricity market. Some argue that trans-border electrical power networks will be expanded mainly due to energy safety reasons and due to the need to create a common market for electricity (Wehnert, 2004).

In the future, electricity inflows from outside Europe could take place with respect to solar plants (concentrated solar power (CSP)) in the North of Africa. Electricity to less-sunny neighboring areas (e.g. Southern Europe) could be provided at a cost that is competitive with other solar options, the transmission costs being more than offset by the lower cost of production (IEA, 2008b)[27]. But, given the costs of CSP (even considering cost reductions) and the relatively unexploited potential in the South of Europe, this is unlikely to occur in the 2030 horizon, although it should not be discarded for some time after.

[27] According to the German Aerospace Center, with modern DC lines, exporting electricity from Northern Africa to Europe would cost 30 US$/MWh, less than the cost difference of solar electricity between both zones (DLR, 2006).

# 3 Transport

Authors: Agnieszka Markowska, Huib van Essen, Bettina Kampman

- **Without policy intervention, $CO_2$ emissions from transport will continue to increase strongly. GDP growth, removal of trade barriers, cost reduction and a shift to faster transport modes are the main drivers for growth.**
- **The future development of low-carbon technologies in the transport sector like electrification, hydrogen and advanced biofuels is highly uncertain.**
- **The short-term priority for the transport sector lies in research, development and demonstration in order to assess the viability of alternative options, to reduce uncertainties and to bring costs down.**
- **The economic availability of $CO_2$ neutral fuels, specifically biofuels and hydrogen from renewable sources, will be limited for a long time. Policies promoting the use of biofuels should take the well-to-wheel energy efficiency and greenhouse gas emissions of the production of these fuels into account.**
- **For the transport sector to contribute to ambitious long term targets in an economically efficient manner, inclusion of transport into emissions trading is unlikely to be sufficient. A combination of complementary policy tools addressing specific market failures and consumer behavior is required, e.g. transport-reducing spatial planning, the provision of public transport systems and efficiency standards.**

## *3.1 Introduction*

The transport sector in Europe is growing. Although improvements in fuel efficiency have been achieved and non-fossil fuels have been introduced, ever increasing transport demand is outweighing these benefits. Consequently, GHG emissions from transport keep growing. The main subsectors responsible for this trend are passenger cars and lorries as well as passenger aviation and maritime shipping. In the next decades, these trends are expected to continue, unless policy interventions curb these trends.

## *3.2 Past current and expected dynamics in the transport sector*

In this chapter the main trends in transport demand and modal split in both passenger and freight transport (Section 3.2.1) are discussed. The next section (3.2.2) focuses on the trends in energy consumption and $CO_2$ emissions. Finally, in Section 3.2.3 the main trends and key challenges are summarized.

### 3.2.1 Transport demand and modal split

Since 1970, both freight and passenger transport volumes more than doubled. In the category of passenger transport this growth is almost completely due to the growth of road transport while in the category of freight transport both road transport and shipping exhibit very fast growing trends.

The (expected) trends in transport demand from 1990 till 2030 for the EU-25 are depicted in Figure 3-1 and Figure 3-2. They show that transport in general is steadily growing and expected to keep on growing during the next two decades, however with a somewhat decreasing pace. By far the highest share of passenger transport can be attributed to passenger cars. The highest growth is occurring in the subsector of passenger cars and air transport. Air passenger travel between 1995 and 2004 grew by 49 % (EU-25, domestic and intra-EU aviation only) (EEA, 2008a).

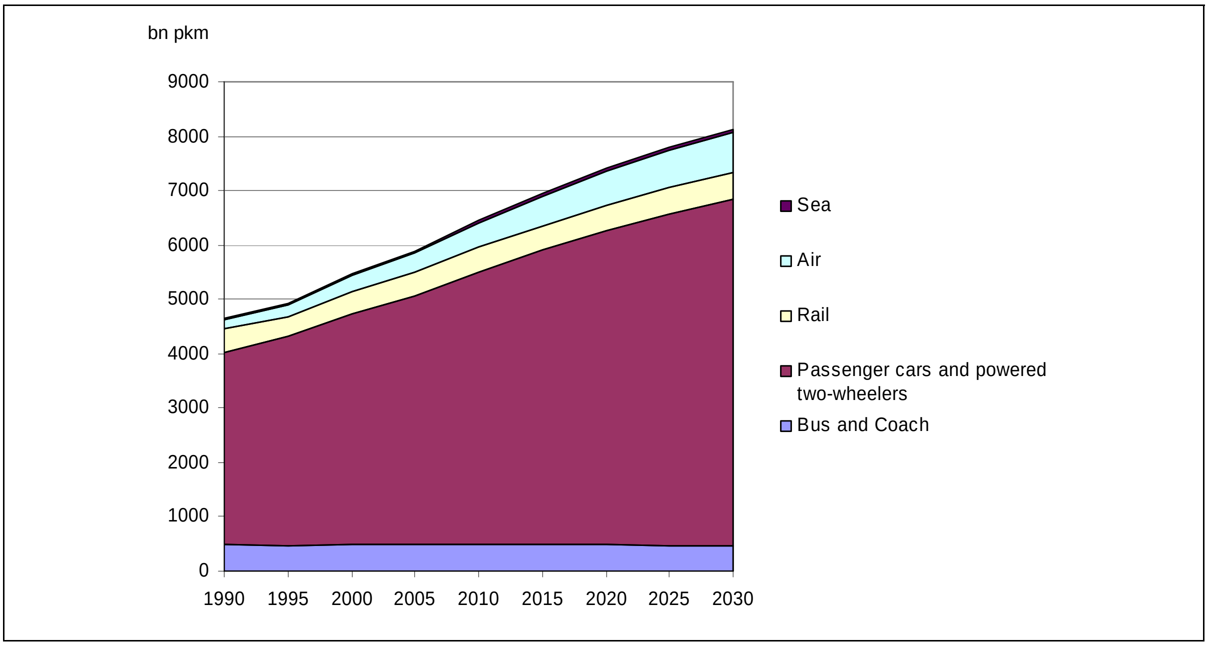



**Figure 3-1: Forecast of development of passenger transport in EU-25 until 2030** Source: DG TREN, 2005

Growth in freight transport (Figure 3-2) will be higher than in passenger transport and be largest in road transport (lorries). Road transport has the highest share in transport of goods. Road transport is currently responsible for 73 % of inland goods transport, railways for 17 %, inland waterways for 5 %, and pipelines also for 5 % (DG TREN, 2008a).

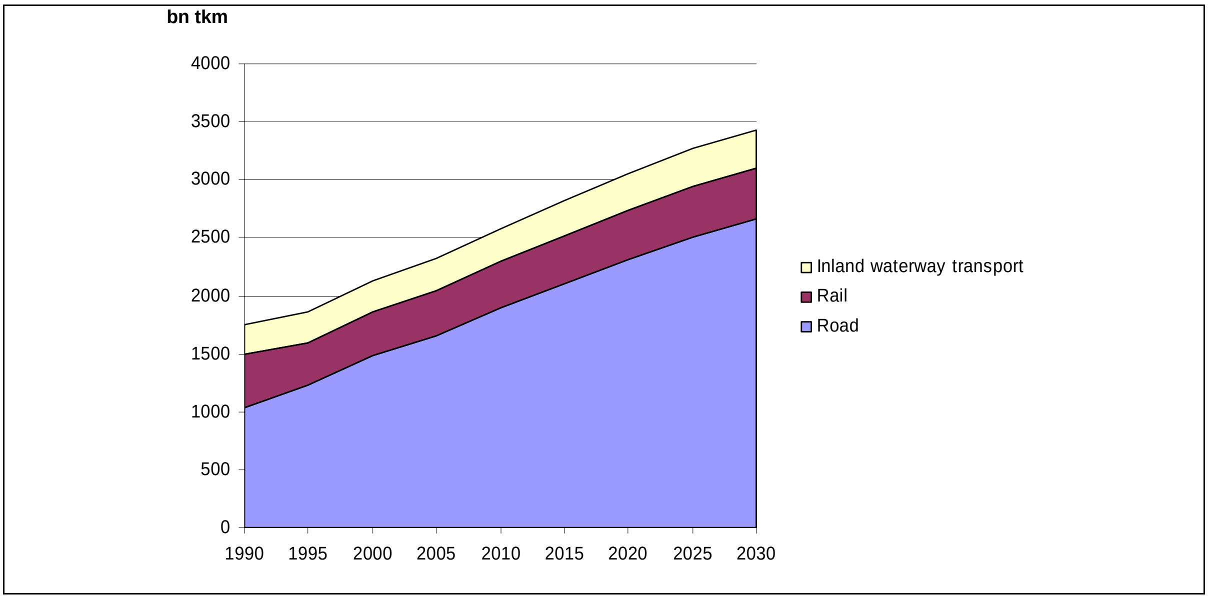
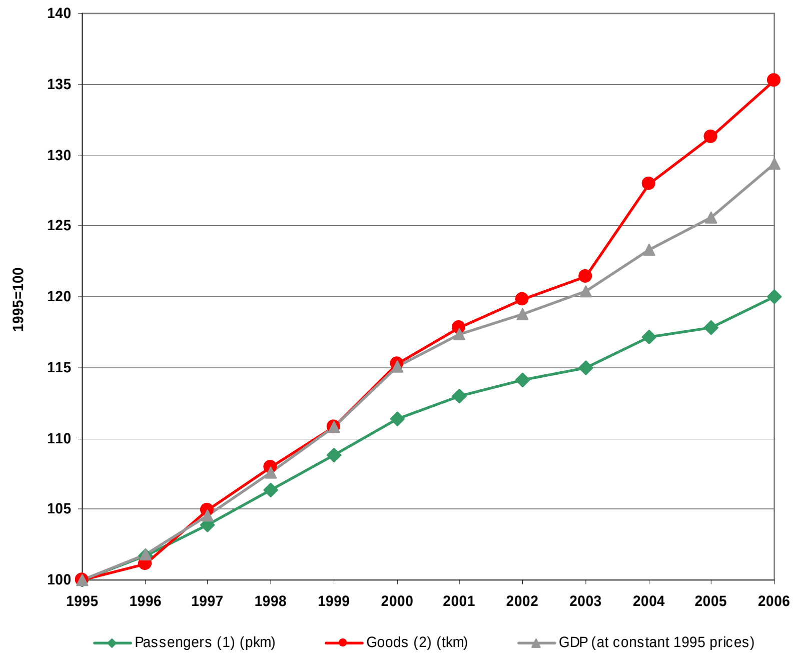



**Figure 3-2: Forecast of development of freight transport in EU-25 until 2030.** Source: DG TREN, 2005

Note that sea transport is not included in the DG TREN statistics shown here. Other statistics show that sea shipping (intra-EU) contributes to about 37 % of total freight transport, compared to 46 % for road. In 2005, world seaborne trade in tkm grew by more than

5 % compared to the previous year, which shows a high potential of growth in this sector. In the same year, the world's merchant fleet expanded by 7.2 % (IPCC, 2007). CE et al. (2006) states, that the growth in maritime transport for the coming years is expected to continue, but with no more than 4 % per annum. GHG emissions from this sector will rise at a slower, albeit unknown, rate.

GDP growth and, in the case of freight transport, the removal of trade barriers is an important driver for transport growth. Figure 3-3 shows the dynamic of transport growth in comparison with GDP growth in EU-27. As can be seen from the graph, growth in the passenger transport from 1997 on stays below the rate of GDP growth, while increase in freight transport is more intensive than GDP growth. So freight transport was growing more intensively than passenger transport. Especially high growth rates of freight transport can be observed after the year 2003, which is related to accession of a large group of New Member States to the EU (EEA, 2007).




Notes: (1): passenger cars, powered two-wheelers, buses & coaches, tram & metro, railways, intra-EU air, intra-EU sea.

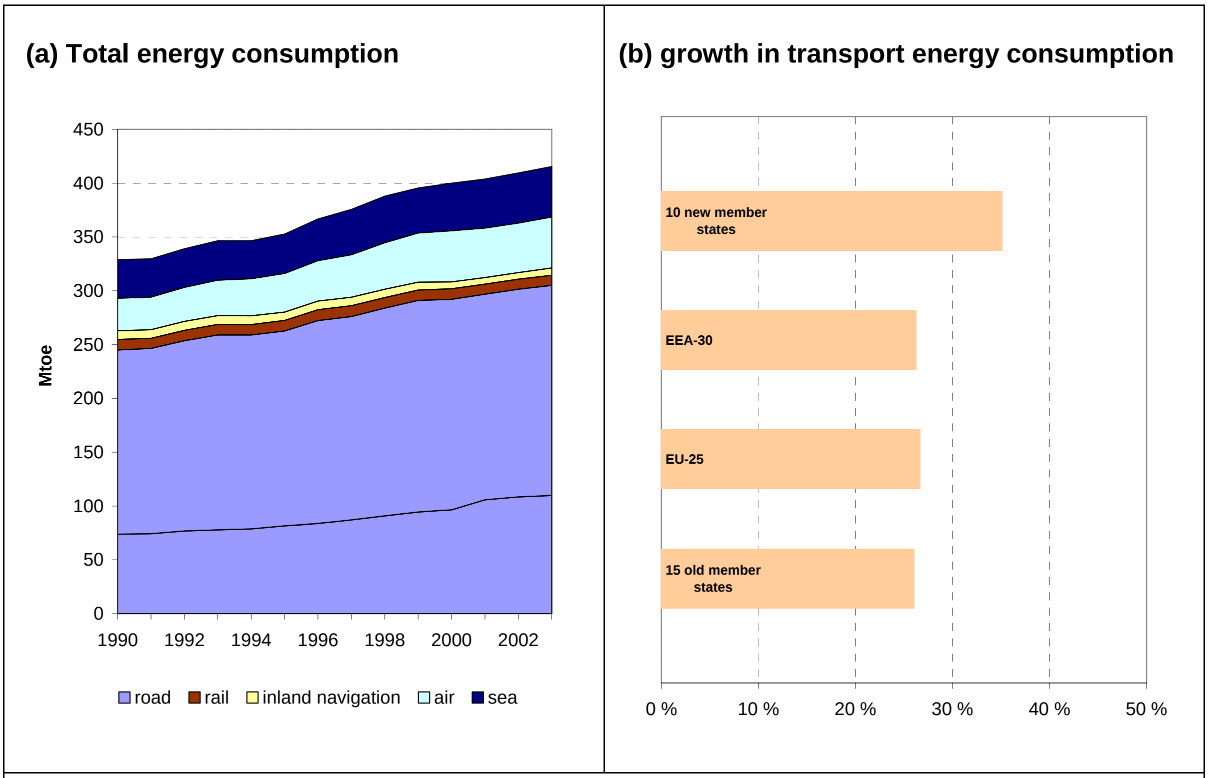
(2): road, rail, inland waterways, oil pipelines, intra-EU air, intra-EU sea.

**Figure 3-3: Dynamic of transport growth vs. GDP in EU-27 between 1995 and 2006.** DG TREN, 2008a

## 3.2.2 Energy use and $CO_2$ emissions

### 3.2.2.1 Energy use

During the last three decades of the twentieth century, the energy consumption of transport worldwide has almost doubled. In Europe a similar trend is visible. Trends in energy consumption of various transport modes in Europe are shown in Figure 3-4. It is clear that the growth is dominated by road transport. Among the 30 countries which were members of the European Environmental Agency (EEA) in 2005, new Member States of the EU exhibited the highest growth rate in energy consumption of the transport sector (about 30 % during the period 1990-2003, which is about 10 % more than average).




Note: Inland navigation includes transport on inland waterways and coastal transport. The line dividing road transport distinguishes the share of freight (*lower part*) from passenger (*upper* part) transport. The division is based on information from the 25 EU countries. Transport by pipelines is excluded, as its contribution is far less than 1 % of total energy consumption by transport. EU-25 refers to the 25 EU member states as of May 2004. EEA-30 refers to EU-25 plus Norway, Iceland, Bulgaria, Romania, and Turkey.

**Figure 3-4: (a) Total energy consumption in transport (EEA-30), 1990-2003 (Mtoe) and (b) growth in transport energy consumption by region between 1990-2003.** CE et al. (2006); based on Eurostat data and EEA, 2005

After very high growth rates in the 1990s, the pace of increase of energy use in transport in the EU is somewhat slowing down, which reflects the decreasing growth rates of passenger and freight transport. Nevertheless, transport energy demand in 2030 is projected to be 28 % higher than in 2005 (DG TREN, 2008b).

Due to the expected fuel efficiency improvements, in particular in passenger transport, energy demand in the transport sector is expected to grow less than overall transport activity.

On the other hand, fuel efficiency improves somewhat less than expected a few years ago. The fuel efficiency standards for passenger cars will be introduced at a slower pace than was assumed by DG TREN (2008b). Hence the forecast for the GHG emissions growth of transport may be an underestimation.

#### 3.2.2.2 $CO_2$ emissions

In Europe, the highest growth rate of $CO_2$ emissions can be observed in aviation. In the European Union, $CO_2$ emissions of land transport between 1990 and 2005 increased by 26 %, while $CO_2$ emissions of international aviation and maritime shipping increased by as much as 66% (EEA, 2008b).

Historical development of GHG emissions in EU-27 is depicted in Figure 3-5. While total GHG emissions (from all sectors) have recently stabilized at the level of approximately 5.5 bn tons of $CO_2$eq, emissions from transport keep rising and are currently at the level of 1.3 bn tons of $CO_2$eq. In 2006, transport was responsible for almost 24 % of GHG emissions in EU-27, and over 70 % of these emissions could be attributed to road transport.

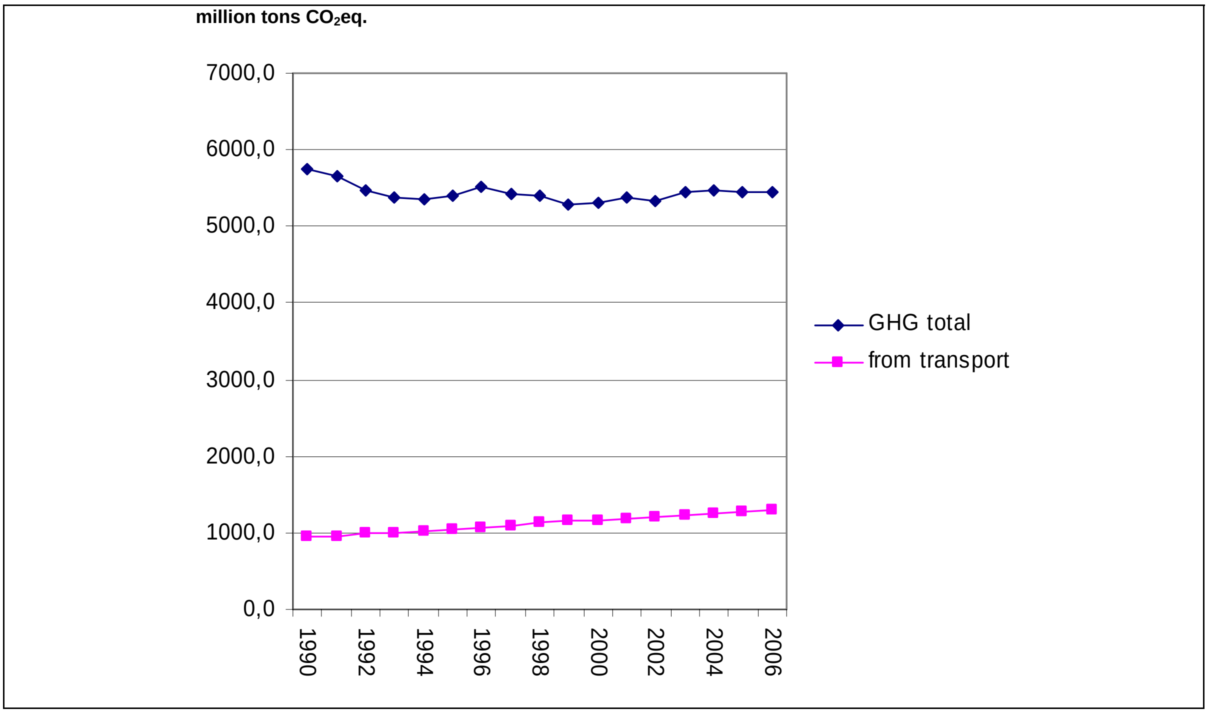



**Figure 3-5: Development of GHG emissions in EU-27 during the period 1990-2006.** Source: DG TREN, 2008a based on EEA statistics

In Figure 3-6 various sectors in EU-27 are compared on their development in $CO_2$ emissions. This again shows the fact that unlike other sectors, transport still shows a rapid growth in $CO_2$ emissions.

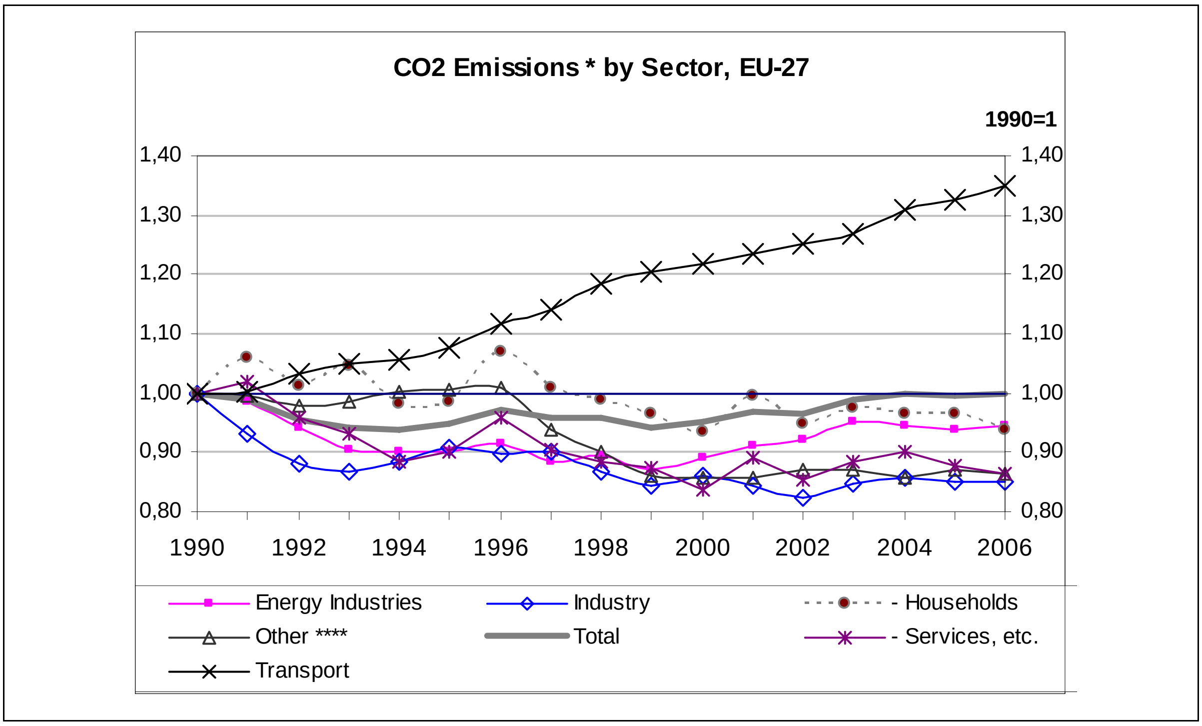



**Figure 3-6: Relative change in GHG emissions in EU-27 for various sectors, during the period 1990-2006.**
Source: DG TREN, 2008a

Like the energy consumption, $CO_2$ emissions in the transport sector are expected to grow less than overall transport activity, due to the expected fuel efficiency improvements, in particular in passenger transport.

Another measure that can contribute to decouple the trends in GHG emissions from transport and transport volumes is an increase in the share of biofuels[28]. Significant fuel switching in the transport sector is expected as a result of implementation of the biofuels Directive (2003/30/EC) and the recent Renewable Energy Directive. In 2010, the share of biofuels is expected to reach 4 %, increasing further to 9.5 % in 2030.

Table 3-1 shows the forecasted trends of energy consumption in road transport until 2030. The share of biofuels is expected to grow over time at the expense of the share of gasoline, while diesel and LPG are going to remain more or less on a stable level (with slight increase of LPG). The share of gas and electricity in total energy consumption in road transport is expected to stay below 1 %.

[28] There are doubts about the GHG reduction potential of biofuels in general and the current so-called first generation types of biofuels in particular. This issue is further discussed in Section 3.4.2.1.

| % change per year | 1990-2000 | 2000-2005 | 2005-2010 | 2010-2020 | 2020-2030 |
|---|---|---|---|---|---|
| **Gasoline** | -0.3 | -2.8 | -0.4 | -0.2 | -0.3 |
| **Diesel** | 4.0 | 4.2 | 1.4 | 1.0 | 0.4 |
| **LPG** | 3.0 | 4.5 | 4.6 | 1.9 | 0.8 |
| **Biofuels** | | 38.7 | 30.9 | 7.7 | 2.8 |
| **Gas** | 5.3 | 7.1 | 5.0 | 3.2 | 2.0 |
| **Electricity** | | | | 12.8 | 5.1 |
| **Total Road** | 1.8 | 1.3 | 1.3 | 1.0 | 0.4 |
| **Shares in %** | **1990** | **2005** | **2010** | **2020** | **2030** |
| **Gasoline** | 57.7 | 38.4 | 35.2 | 31.4 | 29.3 |
| **Diesel** | 41.1 | 58.8 | 58.9 | 58.9 | 58.9 |
| **LPG** | 1.2 | 1.5 | 1.8 | 2.0 | 2.1 |
| **Biofuels** | 0.0 | 1.1 | 3.9 | 7.4 | 9.4 |
| **Gas** | 0.1 | 0.2 | 0.2 | 0.3 | 0.3 |
| **Electricity** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**Table 3-1: Trends of energy consumption in road transport.** Source: DG TREN, 2008b

### 3.2.3 Conclusions and key challenges

While greenhouse gas emissions of many other sectors stabilized or even decreased over the last decades, the $CO_2$ emissions of the transport sector kept on growing. This growth is directly related to the growth in the overall transport volume, particularly driven by growing volumes of road transport, aviation and maritime transport due to GDP growth, removal of trade barriers and reduction of cost. An additional driver is a shift to faster transport modes, in particular aviation.

There are four main options for changing the trend of growing GHG emissions in transport:

- Improvement of fuel efficiency,
- Cleaner fuels,
- Limitation of the transport growth (or even volume),
- Changes in the modal split.

While the first two options are mainly technology oriented, the third and fourth fully depends on changes in trade flows and consumer behavior. The first two options require strong technological innovation and a market for fuel efficient and low-carbon fuelled vehicles and technology. The key challenge in the transport sector is to create market conditions that stimulate all stakeholders (notably consumers, fuel companies, vehicle manufacturers, the power generation and agricultural sectors, businesses) to take action (King, 2007). Limitation of transport growth and changes in modal split are mainly driven by infrastructure and spatial developments and policy as well as pricing measures.

## 3.3 Reflection on modeling results from sector perspective

The forecasts presented in the previous section were all based on official EU-projections until 2030. In this section the RECIPE model results for the period until the year 2100 are analyzed (baseline scenario and the two policy scenarios (450 and 410 ppm C&C)). The modeling work carried out within RECIPE builds on three models: WITCH, REMIND-R and IMACLIM-R. The first model does not present separate results for transport. Therefore, the following discussion is limited to the results of REMIND-R and IMACLIM-R.

Model results show the overall energy consumption for the whole economy and the transport sector, both in Europe and worldwide. The results do also include projections for the energy mix for each sector.

### 3.3.1 Results for Europe

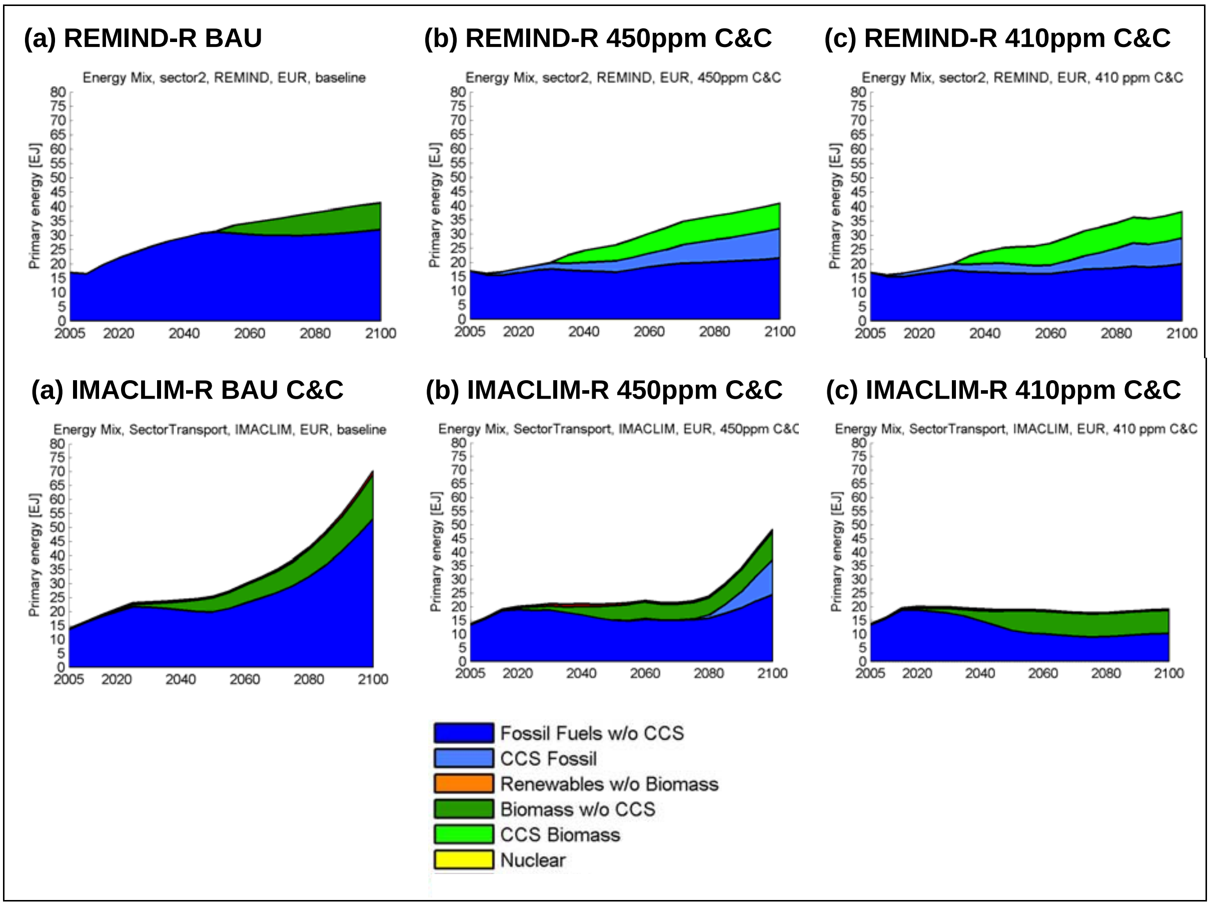



**Figure 3-7: Model results (REMIND-R and IMACLIM-R) for transport energy use Europe**

The baseline scenarios for Europe of both models for the short term (towards 2030) are in line with the projections of DG TREN. Only the downward trend between 2005 and 2010 from REMIND-R is not in line with what is expected by DG TREN.

According to REMIND-R, the growth in energy consumption of transport in Europe slows further down after 2030. In this period, the growth rate of aviation is an important factor that determines the growth in transport energy use. REMIND-R seems to assume a less strong growth of particularly aviation after 2050 than in the period until 2050.

The baseline scenario in IMACLIM-R is more or less similar until the mid of the century. After then, the energy use increases rapidly and ends about 50 % higher than in REMIND-R.

In the policy (450 ppm C&C) scenario, both models show a more or less constant fossil fuel consumption (without CCS). This means that the $CO_2$ emissions in transport are reduced less than in other sectors, resulting in increasing share of transport in overall $CO_2$ emissions

In IMACLIM-R emission reduction is reached by efficiency improvements, volume reduction and a shift to electricity. This implies that volume reduction and/or fuel efficiency improvements are important. This requires important changes in infrastructural and spatial developments and/or a very strong pricing policy. REMIND-R does not assume much reduction of energy use, but relies heavily on CCS.

For passenger road transport, electric or fuel cell technology are generally expected to play an important role in the long term. For lorries, shipping and aviation, electric propulsion is not likely to gain an important share, while biofuels could well be an important part of the solution. The IMACLIM-R approach seems to reflect these trends somewhat better than REMIND-R, but it should be emphasized that at this stage the technology forecasts are still very uncertain.

An important difference between the two models is the level of energy reduction that is assumed in the policy scenarios. In IMACLIM-R, energy saving is an important element, while in REMIND-R, the energy use in the policy scenarios is not much lower than in the baseline. This would only be likely to occur if energy saving additional to the baseline would be much more expensive than the alternative fuels. These two contrasting views can also be observed within the community of transport experts: some believe that the climate change problem with transport can be solved by technological improvements, without reduction of transport demand growth and down-sizing, while others believe that technological improvements will not be sufficient and need to be accompanied by limiting energy use in various ways, including limiting transport growth and vehicle downsizing.

Both models agree on a lower $CO_2$ reduction in transport compared to other sectors. This is in line with the general view among experts and can be explained by the higher cost in transport for reaching high emission reduction levels.

### 3.3.2 Results for the whole world

Figure 3-8 shows the worldwide results of IMACLIM-R and REMIND-R for the transport sector. The main trends and differences between the two models are rather similar to those for Europe. In REMIND-R, the share of biofuels and CCS in the policy scenarios is higher than in Europe, implying that these innovations will particularly take place outside Europe. The reason for this is unclear.

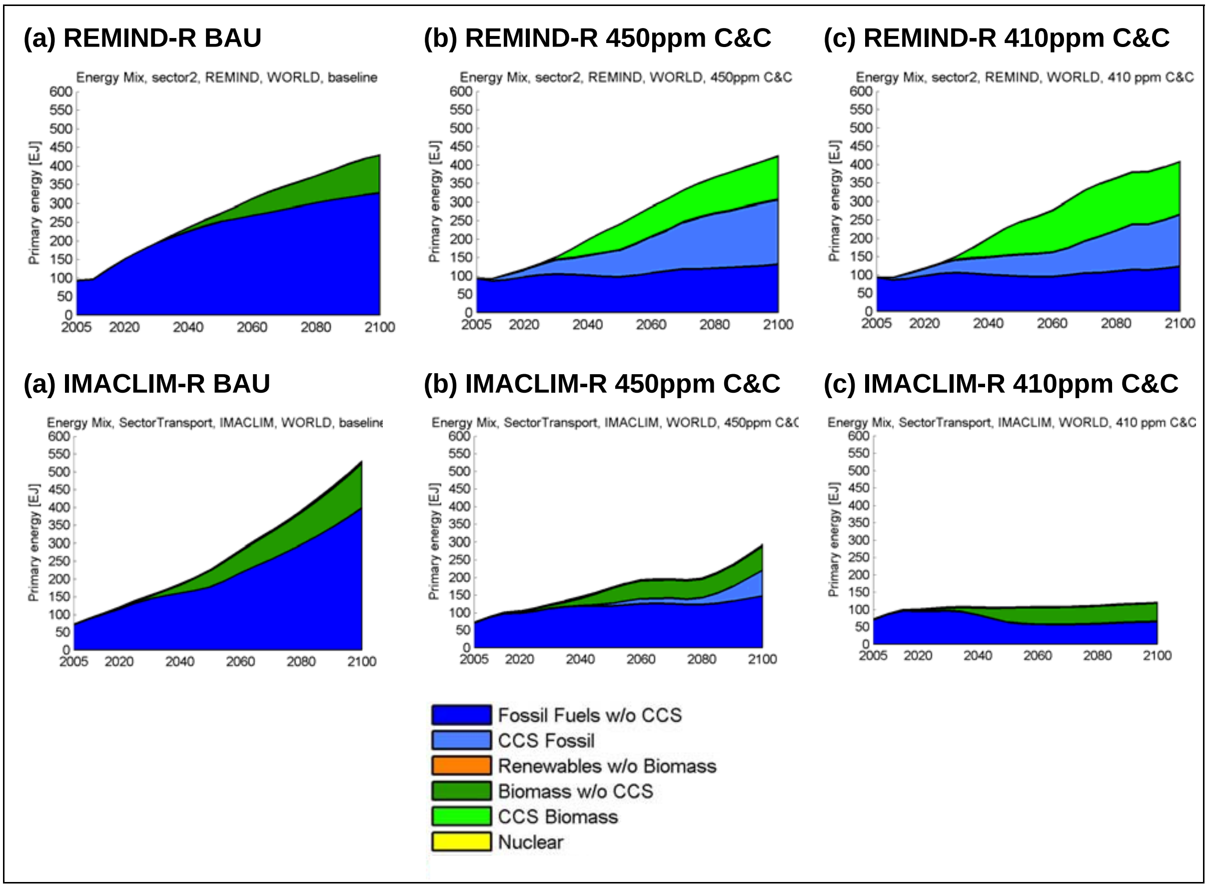



**Figure 3-8: Model results (REMIND-R and IMACLIM-R) for the whole world**

### 3.3.3 Likeliness of some of the assumptions

The 410 and 450 ppm C&C scenarios of the two models discussed here differ significantly. The main differences seem to be:

- Assumptions on fuel efficiency improvements of vehicles,
- Assumptions on transport growth,
- The share of biofuels, both in the EU and globally.

#### 3.3.3.1 Role of hydrogen, electricity and CCS

A large scale shift to hydrogen or electric transport may be a realistic option for the longer term. The potential, cost and feasibility may become large enough to reach the high share, but are yet uncertain. A disadvantage of the hydrogen route is the relatively low energy efficiency over the whole chain. The GHG reduction in the transport sector in REMIND-R is completely achieved by CCS. Also this is still a technology that needs to be developed, which makes this option very uncertain.

In the REMIND-R scenarios, the fossil fuel consumption of the transport sector keeps on growing. In the 410 and 450 ppm C&C scenarios of IMACLIM-R the dependency on fossil fuel is considerably lower (up to a factor six in the 410 ppm C&C scenario). This means that in the IMACLIM-R world, GHG emissions reduction is combined with a reduction in dependency on fossil fuels. Given the (political) importance of limiting the dependency on fossil fuel, this is an important advantage over the purely CCS-based world modeled by

REMIND-R.

#### 3.3.3.2 Vehicle efficiency and transport growth rates

There is evidence that there is very much room for improving the energy efficiency of particularly passenger cars exists (King, 2007). IMACLIM-R seems to rely stronger on this than REMIND-R. In the 410 and 450 ppm C&C scenarios, IMACLIM-R also assumes some type of limitation of transport volumes. With very fuel efficient vehicles there is a high chance for rebound effects. These rebound effects can be limited by very strong infrastructure, spatial and pricing policies. In the world modeled by IMACLIM-R these elements are important for achieving the GHG reduction. Since detailed data on transport volume developments in the scenarios are not available, it is impossible to assess this in more detail.

#### 3.3.3.3 Biofuels

In both models, biofuels have a large share in the total energy use of transport in 2100 in most scenarios. To assess the likeliness of the share of biofuels assumed, the total amount of biofuels that is assumed for the whole economy has to be exlored. This can be obtained from Figure 3-9 that shows the overall energy mix for all sectors (not just transport) according to both REMIND-R and IMACLIM-R.

These numbers can be compared with recent estimates of global sustainable biomass energy potential from the German Advisory Council on Global Change (WBGU) (2008) and Smith et al. (2007a). WBGU (2008) estimates the global technical potential for bio-energy from waste and residues in 2050 to be 80 EJ per year (or rather 50 EJ per year taking into account sustainability criteria, especially soil protection). The global potential for cellulose-based energy plants is estimated to be 30-120 EJ per year, if forests, peat lands and wetlands are excluded from use. This gives in total a range of 80-170 EJ per year in 2050. Smith et al. (2007a) estimate a global mitigation potential from bioenergy production equivalent to 50-200 EJ per year in 2030.

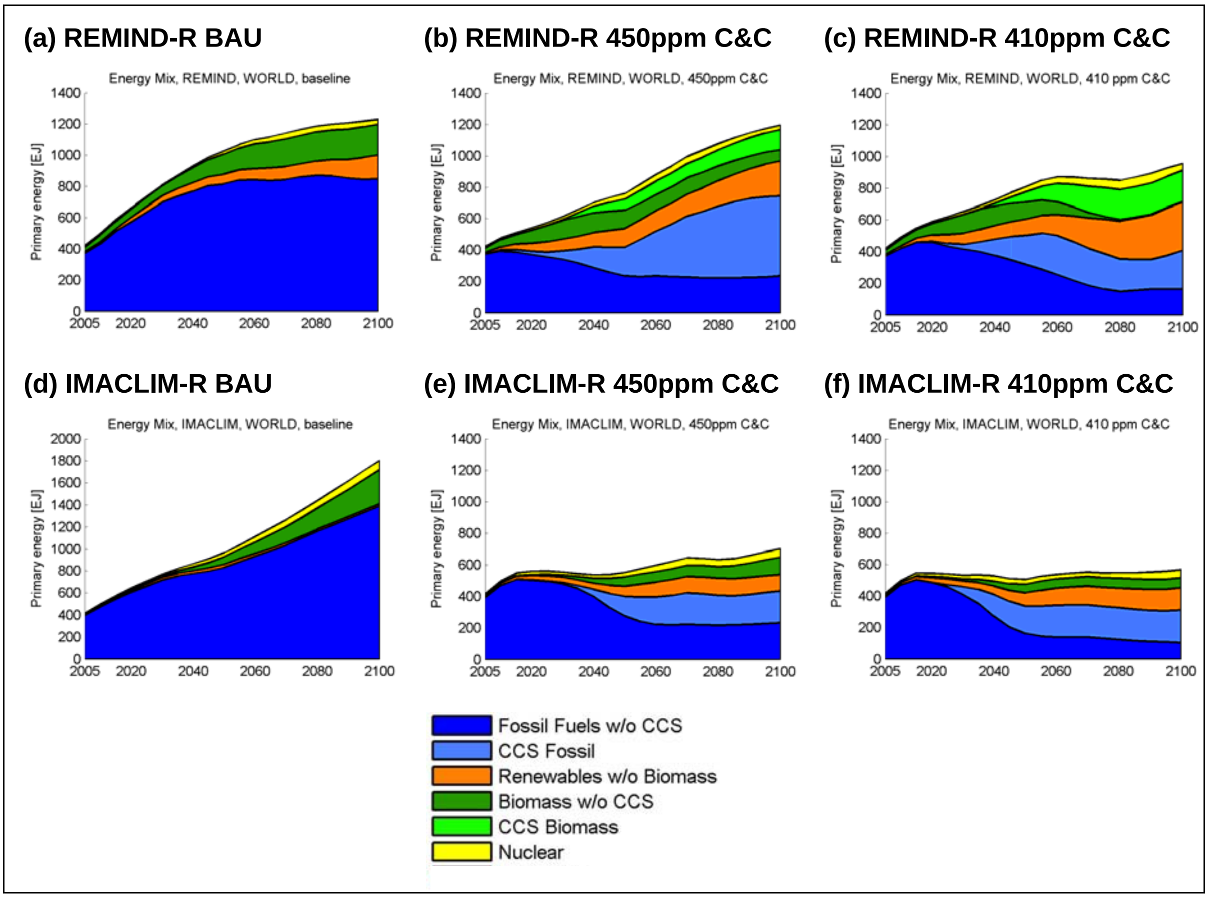



**Figure 3-9: Model results (REMIND-R and IMACLIM-R) for all sectors and the whole world**

In REMIND-R, biofuels are combined with CCS. This implies that biofuels are used in electricity or hydrogen plants to produce transport fuels like hydrogen or electricity, instead of using them directly as transport fuel. For the long term, both options (direct use of biofuels in the transport sector and indirect application of biofuels by producing hydrogen or electricity) are still open at the moment and seem equally likely.

### 3.3.4 Conclusion

The two models that are discussed assume very different scenarios for reaching GHG reduction in transport: A technological solution as modeled by REMIND-R versus a combined technology, energy saving approach by IMACLIM-R. These two visions reflect well the debates among transport experts.

The IMACLIM-R scenarios have the advantage that in addition to $CO_2$ reduction also the dependency on fossil fuels is reduced. It requires technological innovation like fuel effiency improvements of vehicles and the development of second generation biofuels. In addition it requires policies and measures that reduce transport growth. Recent history has shown that it is extremely difficult to limit transport growth. Pricing measures or emission trading are instruments that can help to limit transport growth. To be effective these type of measures should be accompanied by infrastructure and spatial policy that limit the transport demand.

## *3.4 Sectoral policy issues and options*

As shown in the previous section, vehicle efficiency improvements and a shift to alternative fuels both play a key role in the long term scenarios for the transport sector, within the scope of ambitious $CO_2$ reduction targets. This requires significant technical innovation. In addition, also limitation of the growth of transport is likely to be needed. Particularly in the transition modeled by IMACLIM-R these types of measures are required.

This chapter describes various options for policy instruments for the short and medium term to reduce GHG emissions in the transport sector. Not all types of possible measures are discussed but a few major types are in the focus:

- Biofuel policy,
- Fuel efficiency standards for road transport,
- Carbon-based fuel taxes,
- Cap and trade systems.

Before discussing these types of policy, a general discussion on policy types is included.

The final subsection of this section gives a brief overview of mitigation cost and investment flows for GHG reduction

### 3.4.1 Generic and specific policy

Policy instruments aiming to reduce energy use and GHG emissions can be grouped into generic and specific instruments.

Generic instruments create generally favorable conditions that promote various types of GHG reduction measures. For instance, they may set overall fuel consumption or $CO_2$ reduction goals to be met irrespective of the technology used. Transport users can then choose whether they will meet these goals with, e.g., improved fuel efficiency, with alternative fuels, or by driving less. They do not stimulate a specific technical or non-technical option. Generic instruments usually also target a wide range of stakeholders. They contribute to overcoming barriers related to cost and consumer behavior. In addition, this type of instruments may reduce the volume growth of transport. Examples of generic instruments are emission trading and $CO_2$ differentiated taxation. They are generally market-based.

Specific policy instruments promote specific measures or actions from specific stakeholders. In this way, the policies help to overcome barriers related to certain mitigation options. They can be regulation, communication or market-based. Biofuel and $CO_2$-regulations, subsidies for hybrid cars, $CO_2$ labeling and government campaigns promoting eco-driving are all examples of specific measures. Within the context of generic policy instruments, additional specific instruments may be used to correct market imperfections or to create temporary incentives for specific technologies.

Both for generic and specific instruments, national governments are the primary actors. However, some measures require supranational agreements, such as within and international bodies like the European Union, IATA (International Air Transport Association) or IMO (International Maritime Organization).

## 3.4.2 Biofuels

### 3.4.2.1 GHG reduction potential of biofuels

Production and use of biofuels have strongly been rising in recent years, both in the EU and globally. The current biofuels industry is composed of two main sectors: biodiesel and bioethanol. In the EU, biodiesel production is 10 times higher than bioethanol production, which is reverse to the global ratio. This has to do with government policies of various Member States, the rapeseed production potential of the EU (rapeseed oil is one of the main raw materials that can be converted to biodiesel) and the relatively high share of diesel in EU fuel sales. In 2005, 3.9 million tons of biofuel was produced in the European Union, marking a 65.8 % growth compared to 2004. Production of bioethanol is much lower in the EU, but also increased significantly, by 70.5 % between 2004 and 2005, according to EurObserver (van Essen, 2008).

Biofuels have the advantage that the $CO_2$ that is emitted during combustion is equal to the $CO_2$ that is taken up by the biomass during cultivation. However, they still contribute to climate change because of greenhouse gas emissions during cultivation of the biomass ($N_2O$ emissions mainly, due to fertilizer use), transport and production of the biofuel. More recently, it has been realized also in the policy making area that significant GHG emissions can also occur due to land used changes caused by the increase of biomass production. These land use change emissions may be caused directly, when, for example, forests are converted to agricultural land for biofuel feedstock cultivation. Alternatively, indirect land use change emissions may also occur when the biofuel feedstock is cultivated on existing agricultural land, as this will still lead to an overall increase of global agricultural area, and displace the food or feed crops that were cultivated there previously.

Currently in the European Union, biofuels are thought to achieve, on average, well-to-wheel greenhouse gas reduction percentages between 30 and 60 % as compared to fossil diesel and petrol (JRC, concawe, EUCAR (2007)) – if no significant land use change emissions occur. Some biofuels, such as ethanol produced from Brazilian sugar cane, can achieve much higher GHG reduction, 80-90 %. New biofuel products are currently under development that may be produced from non-food feedstock such as agricultural residues or woody biomass, also with expected greenhouse gas reduction potential of 80-90 %. In the coming years, these second-generation biofuels will undergo further development, but large scale deployment is not yet expected before 2015. Taking into account a relatively small percentage of biofuels in total fuel use, the $CO_2$ reduction potential in the road vehicles sector can be estimated in the range of 10-20 % (assuming a GHG reduction of 80-90%, and a maximum biofuels share of 10-20 %).

Recently, however, doubts have risen about both the actual GHG emission reduction of biofuels, and the potential of sustainable biofuel and bioenergy production, following the realization of the impact of land use change on GHG emissions mentioned above. Now that biofuels demand has increased so significantly, it is considered likely that this leads to an increase of agricultural land demand. This expansion of agricultural land can lead to very significant GHG emissions, especially when it is created by converting forest land or other types of land with high carbon content in its vegetation and soil. In some cases, these GHG emissions may more than cancel out any GHG savings achieved with the biofuel, even when assuming 20 or 30 years of biofuel production on that land. In various reports from, for example, the OECD, JRC and the UK Gallagher Review it is therefore concluded that it is very uncertain whether current biofuel policies actually reduce GHG emissions.

Even if biofuels reduce greenhouse gas emissions, they may also have disadvantages. First of all, the cost of most biofuels is higher than that of fossil fuels. The only exception is bioethanol from Brazil, that started stimulating the use of this fuel in the 1970s. Likewise, costs from European biofuels may come down in the future due to learning effects. However prices will also depend on demand and supply which can to a certain extent be stimulated with specific policies (see Chapter 3.4). Estimates of current cost effectiveness of biofuels for GHG mitigation vary significantly in the literature. Taking the GHG reduction estimates mentioned above as a starting point (i.e., excluding emissions due to land use change), GHG mitigation with biofuels cost about €600 to €1100 per ton $CO_2$eq. according to OECD (2008), but only 100 - 250 €/ton $CO_2$eq. according to JRC, concawe and EUCAR (2007). These costs could be even (much) higher if emissions due to land use change were included.

Secondly, various reports have claimed that the recent strong increase in (global) biofuels demand is one of the reasons for the high food prices. There is still debate on how large this effect is (see, e.g., Gallagher (2008), OECD (2008) and World Bank (2008)), and the results will vary between crops, but there seems to be a general consensus that biofuels are a contributing factor to the current food crisis. As the second generation biofuels currently under development will use non food crops such as agricultural residues and lignocellulosic biomass as feedstock, this impact is expected to reduce once these advanced biofuels replace the current generation.

Thirdly, concerns about the potential negative effect of biofuels on biodiversity are growing. The substantial rise of the demand for biomass from both the biofuel and bioenergy sector puts additional pressure on farmland and forest biodiversity, as well as on soil and water resources (see, e.g., MNP et al., 2008, Howarth, R.W., S. Bringezu, 2009). It may also counteract other current and potential environmental policies and objectives, such as waste minimization or environmentally oriented farming (EEA, 2006). Many recent studies confirm that the biofuel potential is certainly not unlimited, due to constraints regarding biodiversity, food production, water availability, etc. (see e.g. Howarth, R.W., S. Bringezu, 2009, Dornburg et al., 2008, WWI, 2006). A number of initiatives are therefore ongoing around the world to develop sustainability criteria for biofuels (e.g., the Global Bioenergy Partnership (GBEP), and sustainability criteria in the EU Renewable Energy Directive). These criteria enable both policy makers and industry to distinguish between sustainable and unsustainable biofuels, although it is expected to be difficult to capture indirect land use change effects in these type of criteria (see e.g., Howarth, R.W., S. Bringezu, 2009). Global policies such as forest and biodiversity protection, as debated in the context of the climate and biodiversity protection negotiations (in the FCCC and CBD), can also be an effective means to reduce the negative impacts of indirect land use change effects.

The long term potential of biofuels thus depends on a number of factors. One of the main challenges is to develop technologies to convert other, non food types of biomass (i.e., lignocellulosic biomass, waste and residues) to a transport fuel, in other words to prevent the conversion of land and competition with food. This can be done either by developing new biofuel conversion processes (the second generation biofuels), or by increasing the use of electricity in transport, and increasing the volume of biomass in the electricity sector. In both cases, the biofuel potential will depend on the availability of (sustainably produced) biomass. As this will be the same type of biomass that is used for electricity and heat generation from biomass, these applications will compete for the total biomass volume that can be sustainably produced.

#### 3.4.2.2 Biofuel policy

Governments can promote the application of biofuels in various ways. The directive on promotion of the use of biofuels or other renewable fuels (2003/30/EC) sets indicative targets for minimum proportion of biofuels placed on the markets of the Member States with reference values for 2005 and 2010 being equal to 2 % and 5.75 %, respectively. The target for 2005 has not been achieved (the average percentage for EU-25 in 2005 was approximately 1 %) and it is doubtful if the target for 2010 will be reached (EU Commission, 2007b). Nevertheless, the directive has created a very significant increase of biofuel production and consumption in the EU.

Among the EU countries, only Germany and Sweden reached the reference value for 2005 (3.8 % and 2.2 %, respectively). Both countries have been active in this field for several years, Germany concentrating mostly on biodiesel and Sweden on bioethanol.

Tax exemptions were one of the main instruments used to support biofuels sector but several Member States (Austria, Slovenia, Czech Republic, Germany, the Netherlands and the UK) have implemented a new form of support: biofuel obligations. These require fuel suppliers to include a given percentage of biofuels in their total supply of fuel on the market. Some Member States are using the obligations as a complement to tax exemptions, others as an alternative. In addition, other incentives can be found throughout Europe, such as reduced congestion charging and parking tariffs for ethanol vehicles in Sweden, and policies to increase the number of petrol stations that offer high percentage biofuel blends such as E85 (which contains 85 % ethanol and 15 % petrol).

In December 2008, the EU has agreed on a 10 % target for alternative fuels in 2020, and a number of biofuels sustainability criteria. The latter are aimed at, among other things, ensuring a minimum amount of GHG emission reduction, and preventing areas of high natural value and high carbon content to be converted to biomass production. A methodology on how to included indirect effects will be further developed in the coming years. Because of the doubts about the sustainability of current biofuels, the 2020 target will be reviewed in 2014.

Currently, EU biofuel policy thus tends to both increase the share of biofuel use, and guarantee the sustainability of the biofuels used. This is the result of studies that showed that particularly the so-called first generation of biofuels have many negative side effects and hardly reduce GHG emissions, and may significantly increase GHG emissions as well as other negative environmental and socio economic effects when indirect land use change impacts are taken into account.

### 3.4.3 Vehicle regulation

Setting regulatory emission limits is a policy instrument that forces manufacturers to improve the energy efficiency of vehicles. Regulatory limits can be set on various levels. In analogy to emission limits for air polluting exhaust gases, $CO_2$ emission limits (in g/km) can be set at the vehicle level. Targets, however, can also be set at the level of manufacturers. Manufacturers could be obliged to realize a certain sales averaged $CO_2$ emission (in g/km) or fuel consumption value (in l/100km). Targets at the vehicle as well as manufacturer level can be set in different ways:

- A fixed or uniform target,

- A percentage reduction target compared to a baseline situation,
- A utility-based target, in which the allowed $CO_2$ emission is a function of objectively measurable parameters of the vehicle that relate to the functionality of the car as perceived by users (in essence e.g. bigger or more powerful cars are allowed to emit more $CO_2$ or to consume more fuel).

In the case of targets at the manufacturer level the above definitions are applied in relation to the sales averaged emissions or fuel consumption, or as a mix of the above options. Targets set at the level of manufacturers can be accompanied by the possibility to bank or trade $CO_2$ credits.

In 2008, the European Union has decided on binding fuel efficiency targets for passenger cars. A target of 130 g/vkm for 2015 is combined with an indicative long term target of 95 g/km for 2020. Also several US states and the federal US government are planning to introduce fuel efficiency standards for passenger cars. Standards although considerably lower than in the EU also exist in Japan and China.

This type of vehicle regulation has the advantage that it guarantees improvement of the fuel efficiency of the fleet, and is therefore regarded as a key element in GHG policy for transport. Long term targets can help car manufacturers to invest in time in technological innovation (King, 2008).

### 3.4.4 Fuel taxes

Fiscal and other pricing measures can be effective instruments to improve fuel efficiency of vehicles and reduce transport demand. The relatively high level of taxes on vehicles and fuels in Europe has convincingly led to a more fuel efficient vehicle fleet compared to e.g. the USA and other countries.

Increasing fuel excise duties will influence consumers to buy more efficient vehicles, will promote a fuel efficient driving style and will have an effect on transport volume. The increase can be related to the $CO_2$ emissions resulting from the use of the fuels or to the well-to-wheel GHG emissions (if these emissions are measured and monitored). This type of carbon-based fuel taxes may provide incentives to use fuels with lower GHG emissions, e.g. to biofuels from waste or residues, or electricity from renewable energy. This can be an important part of a long term policy aimed at climate-neutral transport fuels.

Like other generic instruments, fuel taxes have the advantage that they give incentives for all types of $CO_2$ reduction. Besides a shift to cleaner fuels this includes a shift to more fuel efficient vehicles and limitation of transport growth rates. Particularly at the long term, fuel taxes have an impact on the vehicle fleet and mobility patterns. Economic analysis has shown that on average a fuel price increase of 10 % results in a 6 to 8 % decrease in overall fuel consumption of passenger cars (Hanly et al., 2002; Graham and Glaister, 2002). The much higher average fuel efficiency of passenger cars in Europe compared to the US can for a large part be explained by the much higher fuel excise duties in Europe.

A major problem related to increasing fuel taxes for road transport is the lack of public support. This makes implementation of this policy very difficult. $CO_2$-differentiation of taxes are likely to be less controversial, and in modes that do not yet face fuel taxes (aviation and shipping), public support may also be less of a problem. However, various types of international treaties make that the latter type of taxes difficult to implement. Implementing an excise duty on kerosene would help to make the price of air travel more consistent with its relative environmental performance, especially compared to other modes.

### 3.4.5 Cap and trade systems

Another way to regulate emissions in the transport system is the definition of a cap on the overall emissions. In order to allow stakeholders to meet this cap in the most cost effective way, such an approach needs to be accompanied by some form of emissions trading system. Parties involved are allocated emission allowances (for example based on historic trends - grandfathering option), or can buy them at an auction. Over time the cap on overall emissions (i.e. the number of emission allowances allocated or auctioned) can then be reduced. The price of traded emission allowances will generally be determined by the marginal costs of abatement measures in those sectors where these abatements are the most cost-effective. This type of policy has already been implemented in the EU Emission Trading System, that caps the emissions of the EU industry and electricity sectors.

This is a generic policy in which governments do not prescribe which technological or other measures are to be used, but allows consumers, transport companies, car manufacturers and other stakeholders to choose those reduction measures that best suit their individual situation. Financial aspects will be important in this choice but also other aspects such as comfort and travel time can play a role. The market itself is best able to make these choices.

Transport sectors which are dealing with heavy international competition, such as aviation and shipping, can best be incorporated in the EU Emission Trading System ETS. In these sectors a limited number of relatively large companies is active, so that an effective trading system can easily be set up under the condition that a feasible $CO_2$ monitoring system can be designed and implemented (see e.g. CE (2005) for the case of aviation). In July 2008 the European Parliament agreed on inclusion of aviation in the EU ETS from 2012 onwards. Possibilities of including sea shipping are currently being explored.

The price of $CO_2$ emission allowances under the EU ETS in 2008-2009 is in the range of 10 to 25 €/ton. Given the relatively high costs of many abatement options in the transport sector, the question is whether incorporation into the ETS will lead to implementation of efficiency improvement and $CO_2$ reduction measures in the transport sector itself. If this is not the case, then still the transport sector will help to reach overall reduction goals by buying emission allowances from other sectors and as such financing reduction measures taken in these sectors. A drawback of the situation, however, would be that is does not contribute to reduction of the dependence on imported oil nor to the innovative strength of the transport sector. To deal with these problems, additional policy may need to be implemented (Kampman et al, 2008).

Freight transport by road can be incorporated into the ETS by allowing transport companies to trade emission allowances or by implementing a trading system at the level of fuel suppliers. The former would lead to a large number of companies involved; many smaller ones generate relatively small emissions. This would lead to high costs both for the trading system as such and for the administrative actions needed at the level of transport companies. Also, the difference in size between large industries under ETS and some smaller transport companies may be inappropriate. A trading system at the level of fuel producers/suppliers would have fewer trading parties. Such a system would also allow passenger road transport to be included.

Fuel producers can influence $CO_2$ performance of their fuels by blending biofuels into petrol and diesel, by creating niches for pure biofuels or by implementing other alternatives with lower $CO_2$ emissions. Fuel producers, however, do not have a direct influence on the efficiency with which these fuels are used. A closed trading system at the level of fuel suppliers, nevertheless, does seem a feasible option. Incorporation of the price of emission allowances in the fuel price will then lead to increased consumer/user demand for fuel efficient vehicles and alternative fuels and to increased supply of these technologies by car manufacturers. The main advantage of this system is the limited number of trading parties and the price transparency for other stakeholders (users and car manufacturers).

Such a trading system at the level of fuel suppliers can, at some stage, be incorporated in the ETS, but could also be implemented independently. The advantage of the latter is that the emission cap for the included transport sectors will provide incentives for GHG reduction measures in the sector itself, so that meeting a $CO_2$ reduction goal also helps to meet energy security goals and stimulates innovation in the sector. A separate system will also not affect the price of the emission allowances in the EU ETS, whereas inclusion of transport in the ETS may increase the price. A stand alone trading system, however, may lead to less cost effective GHG reduction than an integrated system. In addition, the trade price in a closed system may become much higher than in the case of inclusion in the current ETS.

The introduction of some kind of cap and trade system for road transport will face some of the same problems mentioned for fuel taxes. An effective cap and trade system will result in relatively high fuel prices, which generally results in low public support. Finally, transaction costs of trading schemes may be high and do heavily depend on the design of the system.

### 3.4.6 Mitigation potential and related investment flows in the transport sector

In the previous sections various types of policy measures were discussed. For any GHG policy in transport, mitigation cost and investments needed for reaching ambitious GHG reduction are important data. This section summarizes results from IPCC and UNFCCC on mitigation potentials and related investment costs in the transport sector. Both reduction potential and reduction costs can only be estimated in broad ranges, with huge uncertainties regarding technological development options, market development and psychological factors. Therefore, investment flows related to the specific mitigation options can only be estimated very roughly.

#### 3.4.6.1 Mitigation potential and cost according to IPCC Fourth Assessment report

The IPCC Fourth Assessment report discusses three other recent studies – the International Energy Agency's (IEA) World Energy Outlook (IEA, 2004a) and IEA Technology Brief (IEA, 2004b), and the World Business Council on Sustainable Development's Mobility 2030 (WBCSD, 2004) – that also examined worldwide GHG mitigation potential (IPCC, 2007).

The World Energy Outlook defines a scenario in which vehicle fuel efficiency in the United States and Canada is nearly 20 % higher than in the reference scenario and hybrid and fuel-cell powered vehicles make up 15% of the stock of light-duty vehicles in 2030. Average fuel efficiency in this 'alternative scenario' in developing and transition economies is 10-15 % higher than in the reference scenario. Measures to reduce traffic growth and move to more efficient modes reduce road traffic by 5 % in the EU and by 6 % in Japan. Road freight is reduced by 8 % in the EU and 10 % in Japan.

The net reductions in $CO_2$ emissions during the period 2002-2030 within this scenario are 997 MtC, or 11.4 % in comparison to the reference scenario. This is due to reduction in the annual growth rate of energy consumption in transport from 2.1 % to 1.3 %, which is a significant accomplishment but still allows transport energy to grow by 57 % during the analyzed period. $CO_2$ emissions grow a bit less because of a shift to fuels with less carbon intensity, such as natural gas and biofuels.

IEA (2004b) examined also a simple scenario for reducing the world GHG emissions from the transport sector, where deployment of fuel-cell vehicles would aim for a 10 % share of light-duty vehicle sales by 2030 and 100% by 2050, with a 75 % per-vehicle reduction of GHG emissions by 2050 as compared to gasoline vehicles. Other assumed measures in this scenario include improvement of fuel efficiency ranging from 15 % by 2020 to 35 % by 2050. Hybrid vehicle sales would increase by 50 % of sales by 2040 and market penetration of biofuels would reach 25 %, with 50 % lower well-to-wheel GHG emissions per km than gasoline. Furthermore, the demand for travel by 2050 would be reduced by 20 % as compared to the reference case.

According to this scenario, penetration of fuel-cell vehicles by itself would allow bringing GHG emissions back to their 2000 levels. Combined measures would result in GHG emissions peaking in 2020 at the level of about 3 Gt of $CO_2$eq. and retreating to half of their 2000-level (i.e. to about 1.5 Gt of $CO_2$eq.) by 2050.

The Mobility 2030 study (WBCSD, 2004) examines a scenario postulating a very large increase in the penetration of fuel efficient technologies in the road vehicle sector. The scenario assumes among others (i) that diesels make up 45 % of light-duty vehicles and medium trucks by 2030, (ii) that half of vehicle sales in these vehicle classes are hybrids (also by 2030) (iii) that one-third of all motor vehicle liquid fuels are biofuels by 2050, (iv) that half of LDV and medium truck vehicle sales are fuel cells by 2050, with the hydrogen beginning as fossil-based but gradually moving to 80 % carbon-neutral by 2050, (v) that better traffic flow and other efficiency measures reduce GHG emissions by 10 % and (vi) that consumer preference for size and power is reduced. In this scenario, GHG emissions are curbed to 2000-level by 2050.

The authors of the Mobility 2030 study make it clear that such a mixed scenario would be very difficult to achieve and a lot of obstacles would have to be overcome, including huge reductions in costs of fuel cells and improvements in hydrogen storage and delivery network.

The IPCC (2007) provides an overall overview of mitigation potential at various cost levels for light duty road vehicles (passenger cars and vans), aviation and biofuels. The results for the first two categories are presented in Table 3-2. The mitigation potential for biofuels is estimated at 600-1500 $MtCO_2$ at prices less than 25 US$/$tCO_2$.

| | Mitigation potential at various cost levels ($MtCO_2$) | | | |
|---|---|---|---|---|
| **Mitigation measure** | **0 US$/t $CO_2$** | **20 US$/t $CO_2$** | **50 US$/t $CO_2$** | **100 US$/t $CO_2$** |
| **Light duty road vehicles** | 369-697 | 669-718 | 689-718 | 718-766 |
| **Aircraft** | | | 150 | 280 |

**Table 3-2: Global mitigation potentials at various cost levels.** Source: IPCC, 2007

#### 3.4.6.2 Estimates for overall investment flows from UNFCCC

An overview of estimates of investment flows is provided by the UNFCCC (2007). Global transport sector investments under the reference scenario (transport emissions increasing from about 5.5 GT $CO_2$ in 2005 to 8.7 Gt $CO_2$ in 2030, with petrol being the dominant source of energy for transportation and share of biofuels of 3 %) are estimated following the OECD ENV-Linkages model at the level of 1138 bn US$. This is almost 30 % higher than costs reported for 2000. Investments in motor vehicles contribute to about half of total costs. In 2030, total global transport sector investments in this scenario are expected to exceed 4 trillion US$, with the investments in motor vehicles at the level of 209 bn US$.

Another scenario assessed in the UNFCCC report is the mitigation scenario, which relies on increased use of hybrid electric vehicles and biofuels and further vehicle efficiency improvements. Under this scenario, the share of hybrid vehicles rises from 18 % in the reference scenario to 60 %, along with doubling of biofuel use and further improvements of efficiency of internal combustion engine. As a result, transport $CO_2$ emissions in 2030 would be 2 Gt lower than under the reference scenario. Most of the reductions would be achieved in developing countries, where transport is growing with the fastest pace, and in OECD North America, which has the largest stock of vehicles. The total additional investment in transport in 2030 under the mitigation scenario is estimated at the level of 88 bn US$, of which 9.2 bn is for biofuel production and the rest mostly for more costly hybrid electric vehicles. Of the total additional investment within the mitigation scenario, developing countries and OECD countries would account for approximately 40 % and 54 %, respectively.

## *3.5 Conclusions*

The transport sector as well as its GHG emissions keep growing. The main subsectors responsible for this trend are road vehicles and passenger aviation. The energy consumption by the transport sector in Europe is also expected to grow significantly over the next decades. Due to fuel efficiency improvements, energy use and GHG emissions will grow less fast than transport volumes.

Strong policies will be necessary if the transport sector is to provide a contribution to reaching future global $CO_2$ reduction goals. For reaching ambitious long term goals for $CO_2$ reduction, a strong combination of efficiency improvement, $CO_2$ neutral fuels and volume measures is likely to be necessary.

Improving the energy efficiency of all types of vehicles, in particular passenger cars, lorries and aircraft, should be a dominant element in the energy policy for the transport sector for the next decades. Regulation of $CO_2$ emissions, either by means of emission limits at the vehicle level or by setting binding targets per manufacturer to the sales-averaged $CO_2$ emissions of new vehicles, is a specific policy instrument to promote efficiency improvement.

The availability of $CO_2$ neutral fuels, specifically biofuels and hydrogen from renewable sources, will be limited for a long time. In the short to medium term use of renewable energy in other sectors offers more cost effective options for $CO_2$ reduction than use as transport fuels. Policies promoting the use of biofuels should take account of the Well-to-Wheel energy efficiency and greenhouse gas emissions of the production of these fuels.

Overall reduction of the energy consumption and $CO_2$ emissions of (road) transport may be achieved through more generic policy instruments such as differentiated fuel taxes or a cap & trade system. The latter measure sets a limit to the overall emissions and allows stakeholders to reach this limit in the most cost-effective way by trading of emission allowances. Trading systems can be closed, i.e. within a single sector or group of stakeholders, or open, i.e. involving various sectors and a wide range of stakeholder groups. To be effective, emission trading or fuel taxes should be accompanied with spatial and infrastructure policy that limit transport growth, particularly is the least energy efficient transport modes.

# 4 Industry

Authors: Stéphanie Monjon, Renaud Crassous-Doerfler, Henri Waisman

- **In the absence of climate policy, the industry sector's primary energy mix will be dominated by fossil fuels, in particular coal, directly and via the coal used for electricity generation. In presence of climate policy the total energy mix is decarbonized mainly because more electricity is used and is generated by a very low carbon intensive mix.**
- **The industry sector holds significant potential for energy efficiency improvements.**
- **A key barrier to mitigation is the low rate of capital turnover in energy intensive industry (cement, steel, aluminium, glass, refineries). In Europe, emission reductions in the near to medium term will not be implemented by investing in new installations but rather by improving technologies of existing installations as only a few new installations are scheduled for construction in the mid-term. After 2020, this capital turnover constraint is less binding since new equipment vintages will have to be installed.**
- **This opens a window of opportunity for more ambitious decarbonization after 2020 and raises the concerns about geographical relocation of these industries in case of persisting asymmetry of carbon constraints and carbon prices over the world. The risk of carbon leakage (due to higher imports from non carbon constrained countries) is real for a few sectors (i.e. cement, iron and steel, aluminium, refineries and fertilizers), but it is limited over the short term. It is more significant after 2020 but limited to some segments of these industry.**
- **The leakage concerns in case of symmetric carbon prices have been invoked to legitimate full free allowance allocation to most industry sectors. But although it responds the problem of the equity value of the company, this option does not respond the short term (and limited) competitiveness disadvantage due to a higher production price. It creates investment uncertainty and may limit incentives for low-carbon innovation, investment and substitution.**
- **Border adjustments are efficient against price competitiveness but raise serious concerns about discrimination or trade sanctions. This distortions in price competitiveness are of second order in the short term, these adjustments should be used in a very cautious manner as a component of a global negotiation package. But these border adjustments do not really help to shift from free allocation to full auctioning. Indeed, since the new capacities are at stake, the incentive to invest in a country with a low carbon content will persist in case of auctioned allowances even with border taxes. This means that the challenge is to have a global architecture for the energy intensive industry after 2020.**
- **For the time being and due to the long-lived nature of the production capital, reliability is of key importance even more than distortions in international competition. Industry thus needs a stable, transparent policy regime to encourage investments in more expensive but more carbon-efficient technology; this raises the issue of the evolution of the design of the EU-ETS or of any successor.**

## 4.1 Introduction

While energy-intensive industries have already performed large energy efficiency gains in the last decades to tackle successive increases of energy prices[29], they have been targeted first by the new European GHG regulations, along with energy utilities. Actually they are responsible for 21 % of total GHG emissions in the EU-27 and emissions can be attributed to a clear number of installations. This facilitates the implementation of a regulatory system, compared to other sectors such as transportation, buildings or agriculture, in which the set-up of climate policies is much more intricate.

Reducing emissions further in the energy-intensive sectors – especially in the cement, iron, steel and aluminium industries – can be achieved by two channels:

- Technological change on the supply side, first with *already mature technologies*, with incremental investment in capital and technologies that can lead to lower emissions (advanced furnaces, fuel switch, gas recovery, etc.), then with *possible technological breakthrough* through technologies that are not yet mature (CCS, ULCOS[30] technologies, etc.).

- Material substitutions toward less GHG-intensive materials in all sectors on the demand side, for example in buildings, vehicles, infrastructures, etc.

These two channels can be activated through an increasing carbon price signal, but it produces well known adverse effects on domestic employment, and emission leakage in case of asymmetric constraints (see Neuhoff et al., 2009). Depending on the potential pass-through of the carbon price in the final price of materials, complementary policy measures could be possible and necessary to compensate part of these adverse effects.

The models used in the RECIPE project provide no detailed information about each industrial sector, which does not allow a comprehensive consistency check between macro modeling results and bottom-up information. This part focuses on the results of the IMACLIM-R model, which is the only model to represent energy – intensive industry as a single sector, while it is embedded in a non-energy sector in the two other models. Details about sub-sectors such as steel, cement, glass or aluminium are not explicitly represented in the models but some indicators that allow to analyze the demand side can still be extracted from the scenarios.

## 4.2 Past, current and expected dynamics of the sectors

The iron and steel sector is the largest emitter of direct energy and process $CO_2$. In 2005, it accounted for 20 % of world industrial energy use and 30 % of energy and process $CO_2$ emissions. Around 70 % of energy $CO_2$ emissions come from direct fuel combustion and the remaining from electricity and heat (WRI, 2005).

The non-metallic minerals sector (including cement) accounts for more than 26 % of the world industrial energy and process $CO_2$ emissions. 50 % of these emissions come are

[29] For example, decreases in energy use and $CO_2$ emissions per ton of finished steel has been respectively 47 % and 50 % between 1975 and 2000 (source: Eurostat).

[30] Ultra - low $CO_2$ Steelmaking

process-related. The emissions of the cement sector come from process emissions (52 %), from fuel combustion (43 %) and from electricity and heat (5 %) (WRI, 2005).

In the baseline scenarios developed by IEA (2008b), from 2005 to 2050, the direct $CO_2$ emissions of the iron and steel industry are expected to increase of +114 % for a production increase of +134 % and an energy use increase of +123 %, while the direct $CO_2$ emissions of the non-metallic minerals sector are expected to increase of +76 % for a production increase of +84 % and an energy use increase of +85 %.

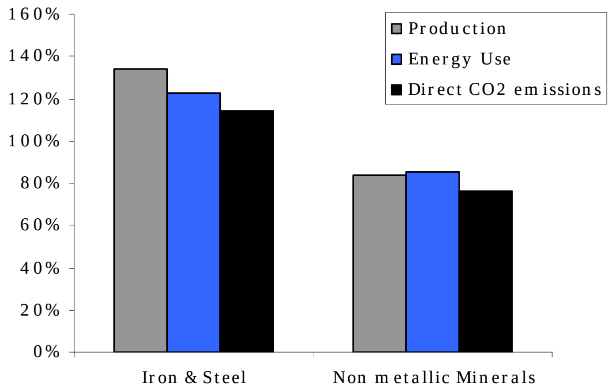



**Figure 4-1: Increase of production, energy use and direct $CO_2$ emissions between 2005 and 2050**

### 4.2.1 Historical development and projections for production and consumption

Since 1970, the production of cement and of steel has grown extensively. Between 2005 and 2007, steel production increased by +17 % and cement production by +18 % (IISI, 2008a; USGS, 2008).

| | 1970-2005 Production increase (%) | 2005 Production level (Mt) | 2003 Share of the world production in developing countries (%) |
|---|---|---|---|
| **Iron & steel** | +84 | 1129 | 78 |
| **Cement** | +271 | 2200 | 42 |

**Table 4-1: World production of iron & steel and cement.** Source: IPCC (2007)

The growth is mainly due to rapid industrialization and infrastructure building in emerging and developing countries. In particular, China is already the world's largest producer and consumer of steel and cement, with a consumption growth that is far beyond all expectations (Sheehan et al., 2008).

#### 4.2.1.1 Steel

Global apparent steel demand[31] is estimated to have grown by 431.6 million tons during 2001-2007, to a level of 1208.5 million tons in 2007 (IISI, 2008a). Driven by rapid industrialization and migration to growing cities, China's steel consumption has more than doubled during this period, accounting for almost 60 % of the global consumption increase observed. In 2007, EU-27 accounted for around 16 % of the world's apparent steel consumption, China 34 % and the United States 9 %.

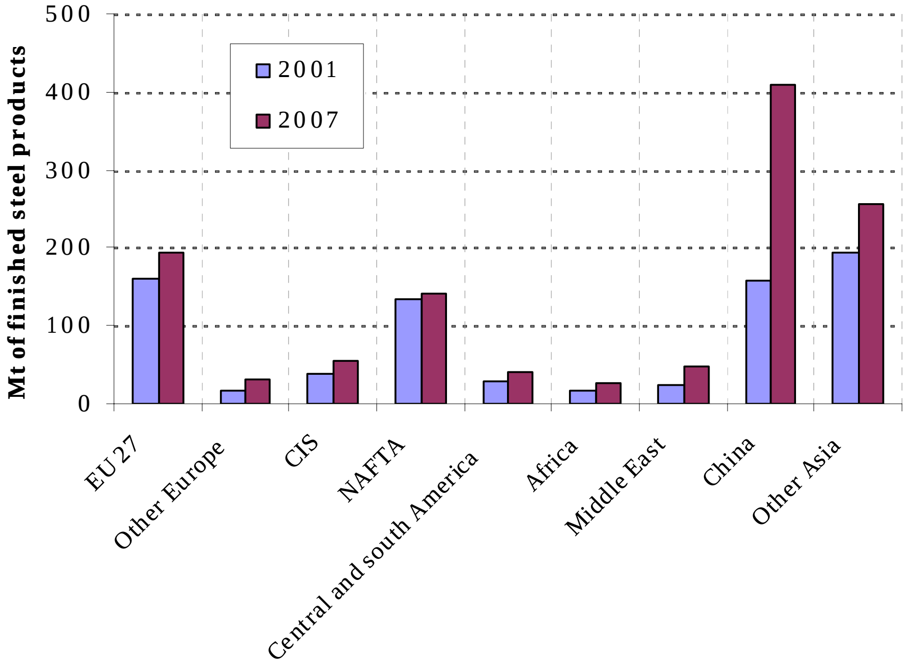



**Figure 4-2: Apparent steel production.** Source: IISI (2008a)

Steel consumption per capita depends largely on the level of infrastructure development of the economy. Despite the recent strong increase in Chinese demand for steel, per capita consumption is still lower than in EU-27, Japan or United States. In Brazil, Russia or India, potential growth is even more important.

China's apparent steel use should continue growing strongly, especially in the Russian market and in Brazil due to a strong growth in the automotive, construction and engineering sectors (IISI, 2008b). In the EU-27, the growth in steel demand should also continue but at a modest pace.

In 2007, the most important steel producers are China, EU-27, Japan, USA and Russia (see Table 4-2). World production capacities have been extended from 1024 Mt in 1997 to 1359 Mt in 2005 and 1474 Mt in 2007, with existing capacities fully used (OECD Secretariat, 2008). In China, the production capacities increased more than threefold between 1997 and 2007 (484 Mt).

[31] Apparent steel use reflects the deliveries of steel to the marketplace from the steel producers as well as from importers. This differs from real steel use, which takes into account steel delivered to or drawn from inventories.

In the EU-27, the steel production level has increased much less between 1997 and 2007, from 194 Mt to 210 Mt. The production capacities of primary steel in the EU-15 have increased slightly between 1997 and 2005 from 196.8 Mt to 203.5 Mt. In 2006, the production capacities of the EU-27 were about 243 Mt (OECD Secretariat, 2008).

| | Steel Production share (%) | |
|---|---|---|
| | **1997** | **2007** |
| **China** | 13.6 | 36.4 |
| **EU-27** | 24.3 | 15.6 |
| **Other Asia** | 11.9 | 10.8 |
| **NAFTA** | 16.1 | 9.8 |
| **CIS** | 10.1 | 9.2 |
| **Japan** | 13.1 | 8.9 |
| **Others (1)** | 8.8 | 7.0 |
| **Other Europe** | 2.1 | 2.3 |

Others (1) include Africa, Middle East, Central and South America, Australia and New Zealand.

Note: World total steel production in 1997 and in 2007 respectively: 799 and 1344 million metric tons of crude steel respectively. Source: IISI (2008a)

**Table 4-2: Shares of world steel production (1997 and 2007)**

The production of steel is assumed to decline in Western Europe throughout the period 2000-2030[32]. This results from the stagnation of consumption in the region and a continued trend towards net imports of finished steel products, but also from the displacement of steel production especially to countries with low energy prices and domestic iron ore reserves (Calleja et al., 2004).

In the long term, the sector could suffer from world overcapacities. Global demand is expected to increase strongly, in particular in the BRIC countries (Brazil, Russia, India and China). The world economic crisis that has begun in 2008 is likely to accelerate this process.

The production capacities which have been built worldwide during the last years and the potential excess of capacity which may appear, following a slow down in some key countries, are some of the main challenges for the EU steel sector. This excess may lead to drastic reduction of margins in the EU and market share losses.

#### 4.2.1.2 Cement

World consumption growth is expected to continue to be strong through the next 15 years. In the EU-15 the growth will be modest, while for “Other Europe”, the expected growth could be around +14 % in 2010-2015 and in 2015-2020 (Ocean Shipping Consultants, 2006).

[32] There are few figures publicly available, but for example, the recent report from the Vattenfall energy company assumed that in US and EU production is expected to decline with 22 % and 29 % respectively between 2005 and 2030.

China has almost half the world's cement production capacity, manufacturing an estimated 1300 Mt in 2007 (50 % of global production), followed by India with a production of 160 Mt in 2007 (6 % of global production).

| | Cement Production share (%) | |
|---|---|---|
| | 1995 | 2007 |
| **China** | 30 | 48.7 |
| **Japan** | 7 | 2.4 |
| **Other Asia** | 23 | 19 |
| **EU-27** | | 9.7 |
| **EU-15** | 12 | |
| **Other Europe** | 6 | 2.4 |
| **CIS** | 4 | 3.4 |
| **United States** | 5 | 3.4 |
| **Other America** | 8 | 6.2 |
| **Others (2)** | 5 | 4.8 |
| Note: World total cement production in 1995 and 2007 respectively: 1420 and 2770 million tons. | | |

**Table 4-3: Shares of world cement production (1995 and 2007).** Source: CEMBUREAU (1997, 2008)

Production capacities are generally sized to satisfy local demand: there are only few capacities built in order to export (Demailly, 2008). Excess capacities in a country may result from an imperfect anticipation of local demand. They may also emerge in countries with a rapidly growing consumption where producers oversize their investment to fit future demand (Demailly and Quirion, 2005). A lack of capacity may notably result from the anticipation of a transitory boom in consumption which does not incite local producers to invest in new capacities. According to many experts, the balance of consumption and capacity in the rest of the world is crucial to determine the international pressure to which EU cement manufacturers are subjected.

In Europe, the recent evolution of cement sector is different among countries. France, Germany, Italy and Spain are the biggest producers of cement in the EU. In Italy and Spain where demand has been increasing strongly in recent years, cement production has increased significantly between 1997 and 2007, while clinker production capacities were extended as well but in a smaller proportion. During the same period, in France, cement production and clinker capacities have been relatively stable, while in Germany, cement production has decreased a little ( -8 %) and clinker capacities a lot (-45 %).

| | Cement production (Mt) | | Clinker capacity (Mt) | |
|---|---|---|---|---|
| | 1997 | $2007^e$ | 1997 | $2007^e$ |
| **France** | 19 | 21 | 24 | 22 |
| **Germany** | 37 | 34 | 41,9 | 23 |
| **Italy** | 33,7 | 44 | 45,7 | 46 |
| **Spain** | 27,6 | 50 | 33,8 | 42 |

**Table 4-4: Cement production and clinker production capacities in some European countries.** Source: USGS (1998, 2008)

## 4.2.2 International trade

### 4.2.2.1 Steel

Trade plays a major role in the steel market. An increasing share of finished and semi-finished steel products has been traded (from 23 % of total world production in 1975 to 36.3 % in 2007, IISI, 2008a). A large part of the trade is at regional level. For instance, in 2007, only 21% of the exportations (24 % of the importations) of the EU-25 countries went to (came from) outside the EU-25.

The US has been a major net importer of steel for many years while the EU-25 has been a net exporter or a next importer depending on the year. China's position changed from a net importer to a net exporter in 2006. China became the largest single source of US steel imports in 2006.

According to Eurostat, during 2006 the EU-27 imported around 15 % and 25 % of its long and flat product consumption respectively, including semi-finished (semis) and finished products from non-EU countries. Two thirds of the imports go to five countries: Italy (almost one third of EU imports), Spain, Belgium, Germany and the UK. During 2006, the EU-25 exported around 9 % and 18 % of its long and flat production respectively abroad. Export ratios have been steadier than import ratios in the past years. Around ¾ of trade flows are in finished products.

China has decided to restrict exports due to concerns about the availability and price of iron ore. In May 2007, the government imposed export tariffs of 5 to 10 % on more than 80 steel products (e.g. steel wire, sheet and plate) and raised export tariffs from 10 to 15 % on primary commodities (steel billets, ingots and pig iron). More recently, China raised the export tax rate on steel billets and ingots from 15 % to 25 %.

The rise in EU imports may also be attributed to the increase in consumption in some EU countries which do not have the required capacity. This triggers higher trade flows both from inside and outside the EU. From IISI (2007), the EU-25 consumption has increased by more than 10 % between 2005 and 2006, and especially in Spain and Italy.

### 4.2.2.2 Cement

Cement is a heavy product relatively to its value added, hence very costly to transport especially on road. It costs around 10€ to transport one ton of cement over 100km on road, the cost decreasing with distance, whereas one ton is sold around 65€ – excluding transport costs – on average in the EU (Reinaud, 2004). Shipping costs are lower as it costs around 15€ to cross the Mediterranean Sea and around 4€ for loading and unloading. Hence, the larger a country and the less port infrastructures it has, the less sensitive to trade it is. Generally, one considers that the cement does not travel more than 200km on road from the plant to the consumer (Demailly and Quirion, 2005). This is an important barrier to trade and partly explains the significant price differences among countries, including European countries.

In 2005 around 16 % of the cement consumed in the EU was imported, about half of cement imports in the EU countries came from non-EU countries. Around three-quarters of these imports were actually clinker, the energy and $CO_2$ intensive intermediary product that entails lower transportation costs.

In 2006, around 95 % of imports from outside the EU went to six countries: Portugal, Hungary, Bulgaria, France, Italy and Spain. The latter two represent almost ¾ of all imports from outside the EU, and Spain itself more than half. But being the largest consumers in the EU, the non-EU import ratio of Spain and Itlay is not very high: 20 % and 10 % respectively.

In Spain and Italy, a high share of national consumption is located near the coast. North African countries traditionally supply most of the imports. The consumption in Spain has been surging over the past 10 years (+130 %) whereas domestic firms have "cautiously" invested – constantly fearing that the current rise is temporary and will eventually be followed by a decline in building activity. The situation is similar in Italy where consumption has been increasing by 60 % in the past 10 years.

## 4.2.3 Structure of the sector

### 4.2.3.1 Steel

In the 1970s and 1980s, steel industry has been facing a difficult situation and has undergone considerable restructuring to make the industry more competitive and more efficient. Quality and flexibility increased (van den Berg, 1996; Luiten and Blok, 2003). Since 1980, the iron and steel industry has been gradually consolidated in Western Europe and North America. As shown in Table 4-5 the share of top ten producers in the world reached 27 % of total production in 2007, coming from 21 % in 1980, although world crude steel production increased significantly. Nevertheless, the steel industry is less concentrated than cement and aluminium.

| 2007 | | | | 2006 | | |
|---|---|---|---|---|---|---|
| **Rank** | **Company** | **Production (Mt)** | **% of World** | **Rank** | **Production (Mt)** | **% of World** |
| 1 | Arcelor Mittal | 116.4 | 8,7 % | 1 | 117.2 | 9,4 % |
| 2 | Nippon Steel | 35.7 | 2,6 % | 2 | 34.7 | 2,8 % |
| 3 | JFE | 340. | 2,5 % | 3 | 32.0 | 2,6 % |
| 4 | POSCO | 31.1 | 2,3 % | 4 | 30.1 | 2,4 % |
| 5 | Baosteel | 28.6 | 2,1 % | 6 | 22.5 | 1,8 % |
| 6 | Tata steel | 26.5 | 2,0 % | 45 | 6.4 | 0,5 % |
| 7 | Ansham-Benxi | 23.6 | 1,7 % | 5 | 22.6 | 1,8 % |
| 8 | Jiangsu Shagang | 22.9 | 1,7 % | 17 | 14.6 | 1,2 % |
| 9 | Tangshan | 22.8 | 1,7 % | 9 | 19.1 | 1,5 % |
| 10 | US Steel | 21.5 | 1,6 % | 7 | 21.2 | 1,7 % |
| Notes: (1) Tata steel's production in 2007 includes Corus group's production bought in 2006; (2) World steel production in 2007 (resp. 2006): 1344 Mt (resp. 1244 Mt) | | | | | | |

**Table 4-5: Top steel producers, 2006 and 2007.** Source: IISI, 2008b

This consolidation trend has been driven mainly by national and regional mergers and acquisitions. Consolidation in the steel industry is likely to continue (OECD, 2007). There are several reasons for this. Firstly, the steel-producing companies want to produce finished steel near major consuming markets to avoid the costs of transportation, long delivery times, and currency fluctuations. Secondly, they also want to be closer to raw materials or in regions with low labor costs to produce semi-finished steel products. For instance, labor costs range from 3 % of the total cost in China to around 20 % in OECD countries (Watson et al., 2005).

Transnational firms may take advantage of cost differences across countries. They may trade semi-finished products between their various plants, although the share of semis in trade has remained constant over the past five years. Ultimately they may relocate part of their production capacities to low-cost countries. For the moment, this delocalization has been restricted by political concerns and management inertia (IEA, 2007b). But a slow down of the booming commodity market would certainly accelerate closures.

| | Production (Mt) | Share of the top 5 steel-producers |
|---|---|---|
| **China** | 423 | 24 |
| **EU-25** | 198 | 59 |
| **Japan & Korea** | 165 | 73 |
| **N. America** | 132 | 59 |
| **CIS** | 120 | 49 |

**Table 4-6: Industry concentration on a regional basis, 2006.** Source: IEA (2007b)

#### 4.2.3.2 Cement

Several EU cement producers are transnational firms which have plants outside the EU. Lafarge and Holcim for example operate in more than 70 countries (Vieillefosse, 2007). According to IEA (2007b), the big European cement producers dominate the global cement market. Moreover, all of them have established trading operations to supply countries with a lack of capacity. The ten largest cement firms in the world control about 70 percent of total cement exports. Cross-border investment in the cement sector is significant and growing.

| Company | World market share (%) | Country of origin |
|---|---|---|
| **Lafarge** | 5.5 | France |
| **Holcim** | 5.0 | Switzerland |
| **Cemex** | 4.3 | Mexico |
| **heidelbergCement** | 2.5 | Germany |
| **Italcementi** | 2.1 | Italy |
| **Taiheiyo** | 1.6 | Japan |

**Table 4-7: Leading cement companies, 2003.** Source: WRI (2005)

### 4.2.4 Future development

In both industries, modest expected demand growth in EU and large amounts of locked-in capital lead to the conclusion that continuous improvements of existing production units are more likely than investments into alternative technologies.

The existing production capacities in the EU will continue to supply local markets. Nevertheless, given the importance of transnational firms in these sectors, one may expect a partial relocation of semi-finished products in the cement and steel sectors.

#### 4.2.4.1 Steel

Today most steel plants are built to supply local markets. Except in a few countries, no capacities are explicitly built dedicated to exports. EU-25 steel production is divided into the blast furnace/basic oxygen units (BOF) route (59.5 %) and the electric arc furnaces (EAF) route (40.5 %). The EAF is going to be the preferred technology in the EU due to climate policies[33]. But a concern for the European industry is the availability of scrap for EAF technologies, as the scrap potentials seem already exploited today.

EAF plants in the EU mostly produce long products that have a lower import ratio than flat products. It is often explained with the low valued added of these products and their size which make them costly to transport. Another explanation for the lower import ratio may be that there is no clear operating costs advantage in developing regions (McKinsey, 2007). Neither is there a clear cost advantage when one includes capital costs. Finally, the raw material – scrap – is spread over the world and costly to transport. Finally, experts agree on the fact that EU EAF plants, i.e. the EU long steel industry, are not significantly subject to relocation.

BOF plants in the EU produce mostly flat products, which show a higher import ratio than long products. This may be explained with more important operating costs differences across countries. The low cost countries are mostly countries which benefit from close raw material sources. This lowers transportation costs for these materials and allows vertical integration, thus ensures access to iron ore and coal at stable prices. While product differentiation helps the EU flat steel industry to sustain profitability in the short term, it might not suffice to lead to new investment or to re-investment in existing plants in the long-run. Indeed, not only are operating costs significantly lower in developing countries than in the EU, but operating plus investment costs in some low cost countries are similar to operating costs in the EU (McKinsey, 2007). The main low cost countries candidates for relocation are Brazil, Ukraine and India.

However, analysis of costs does not give a complete picture. There are also trade barriers, the most important of them for flat products being the quality and service differentiation. Sector experts agree on the fact that the flat semi-finished products, for which differentiation is a less important issue and whose production cost differ widely across countries, may be subject to relocation whereas downstream production activities should remain close to consumers (Demailly, 2008). Trade of semis is likely to remain intra-firms trade, or at least with strong long-term partnership, given the significant cost of investment in downstream activities which require security of supply.

[33] According to IEA (2008b), the production of one ton of crude steel in the BF-BOF route generates around 1600 kg $CO_2$-eq, in the EAF route less 500 kg CO2-eq and in the DRI-EAF route between 1200 (based on gas) and 2500 (based on coal) kg $CO_2$-eq. The quantity of emissions can vary depending on the energy mix to produce the electricity.

If relocation of BOF semis should occur in the future, the intensity of this evolution is uncertain. Some experts argue that no new investment will take place in blast furnaces in the EU, leading to their closure in the medium term. Others argue that high cost plants might be relocated while the others are not. Such an analysis is coherent with the investment plan from Arcelor-Mittal. This plan forecasts the closure of inland plants, which suffer from transportation costs and are generally small scale, by 2020 and their relocation to Brazil. Finally, some experts point out the Arcelor-Mittal plans to bring back iron making to Liege, indicating that the steel industry is profitable enough to cope even with Belgian inland costs.

The relocation of a segment of the production chain makes it sensitive to new risks like the implementation of tariffs. Other risks are the fluctuations in exchange rates or in international transportation costs.

#### 4.2.4.2 Cement

According to experts, today there are no or very few capacities built in order to export, in particular to the EU. Exports come from domestic excess capacities, generally transitory. This remains true within firms: intra-firms trade is used to balance supply and demand on a given market, taking advantage of capacities on other markets.

The process of significantly increasing export capacities despite the existing relocation barriers would be driven by transnational firms. To date, these firms have already invested in low cost countries in order to supply local demand. These countries generally exhibit a fast growing consumption, reducing the risk of building extra capacity that would have to be reallocated to exports. If the opportunity to export disappears, following for example a shock on transport costs, the excess capacity may be rapidly absorbed by the rise in local consumption. These transnational firms face lower barriers than independent importers.

It seems that one may fear a partial relocation of clinker production to the Mediterranean Basin. Indeed, despite the previous barriers, some EU firms are considering the possibility to relocate part of their production. Until now however, it seems that there is globally no clear advantage in relocating. Such an advantage may only exist under some particular conditions. Italcementi for example had already developed the transportation of cement from South Italy to Northern Italy by ship, in response to limited availability of raw material in the North. Given that it has become a large producer in Egypt, it turned out that most of the logistics are already in place to transport cement from Egypt to Italy. Some cement sector experts speculate that Italcementi may be the first mover in the relocation process. However, the recent implementation of a severe export tax in Egypt, which has highlighted one of the risks of relocation, may well damp this process down.

## *4.3 Reflection on modeling results from sector perspective*

IMACLIM-R is the only model to provide disaggregated data for industry. Therefore the results analyzed in this section come from simulations with IMACLIM-R.

This section draws three main lessons from the modeling results:

(i) Industry has a very significant margin of growth in the future decades, essentially because of the huge demand for industrial goods in emerging and developing countries. Some growth of output of high value added finished products will occur in Europe but most of the growth will probably occur in Asia.

(ii) Even in the absence of mitigation policies, industry seems to be able to achieve significant efficiency gains because of the increase of oil and gas prices, but an increasing share of coal in power generation could maintain a high carbon intensity.

(iii) A global climate policy would not affect industrial output in Europe, while it could be significantly decreased in other countries that could suffer from high transition costs.

(iv) An asymmetric constraint would provoke some temporary emission leakage between 2010 and 2030 but the picture in 2030 shows that this situation is reversible within one decade.

### 4.3.1 Growth of industrial output

In the baseline scenario, the index of physical output of energy-intensive sectors is steadily increasing up to 2050, even if its growth is supposed to slowdown progressively at the global level, from 3 % per year between 2010 and 2030 to 2 % per year between 2030 and 2050. IMACLIM-R projects industrial output as a whole to increase further during the next decades, at a rather constant rate around 1 % per year. Nevertheless output of steel and cement, that are only subsectors of the aggregate industry sector in the model, may experience a decrease in output. The OECD environmental outlook does not project any decrease of the European industrial output between now and 2030, too.

Globally, the world is likely to be split into two categories of regions, with a 0.3 to 2 % growth rate in the OECD countries and higher mean growth rates reaching 7 % in the emerging and developing countries. The growth of industrial value added will occur everywhere in the world: developing countries are responsible for 51 % of total growth, of which 15 % occur in China and 9 % in India, while USA (13 %) and Europe (8 %) contribute a significant part. These figures are not essentially based on 'tons' of materials, especially in OECD countries that could get more specialized in higher value-added products.

| | 2010-2030 | 2030-2050 | 2050-2100 |
|---|---|---|---|
| **USA** | 2.0 % | 1.5 % | 1.1 % |
| **Canada** | 1.5 % | 1.3 % | 1.0 % |
| **Europe** | 1.6 % | 1.1 % | 1.1 % |
| **OECD Pacific** | 1.0 % | 0.3 % | 0.8 % |
| **CIS** | 1.5 % | 0.4 % | 1.6 % |
| **China** | 5.1 % | 2.6 % | 1.2 % |
| **India** | 6.9 % | 4.1 % | 2.6 % |
| **Brazil** | 5.1 % | 2.0 % | 1.5 % |
| **Middel-East** | 3.3 % | 3.7 % | 2.9 % |
| **Africa** | 6.6 % | 4.4 % | 2.7 % |
| **Rest of Asia** | 5.8 % | 3.3 % | 2.2 % |
| **Rest of Latin America** | 4.9 % | 2.4 % | 2.3 % |
| **World** | 3.0 % | 2.0 % | 1.6 % |

**Table 4-8: Mean annual growth rate of physical industrial output (all regions, IMACLIM-R)**

Growth of industrial output is dominantly driven by domestic consumption, domestic consumers buy most of the domestic production. In emerging country the share of domestic output consumed domestically will increase (from 80 % to 87 % in China, from 83 % to 94 % in India), while it will decrease in OECD countries (from 87 % to 83 % in Europe and from 78 % to 67 % in Japan). Nonetheless, because of higher growth in developing countries, they will have an increasing market share on the international market for industrial goods (from 37 % to 50 %), which grows almost six times in constant monetary terms between 2005 and 2100.

These results strongly depend on the assumptions made about the demand side. One critical assumption adopted in the scenarios is that the material input of buildings and productive capacity remains approximately constant, so that demand for products from energy-intensive industries is sustained by the need for new buildings, new productive capacities, new urban and transportation infrastructures. On the supply side, there is no consideration of primary resource limitation, whereas this can be relevant for some minerals. Two solutions may counterbalance this: (i) for some minerals, recycling provides a huge potential for tackling depletion of primary resources and (ii) there might be many opportunities for substitution among materials that would not affect the global output of energy intensive aggregates as represented in the model.

### 4.3.2 Energy efficiency and carbon intensity

In the absence of ambitious climate policies, direct $CO_2$ emissions from energy-intensive industries increase three times between 2005 and 2100, from 5.6 $GtCO_2$ in 2005 to 16.6 $GtCO_2$ in 2100.

In Europe, direct emissions increase 1.5-fold until 2050 and 1.9-fold until 2100 compared to the level in 2005. Indirect emissions from intermediate electricity consumption (computed with the mean carbon intensity of power supply) are increasing 2.6-fold until 2100, because of an increasing share of coal in power generation. The scenario is in line with what is usually shown in the literature since aggregate industry is projected with continuous energy efficiency gains and almost no decoupling between energy use and $CO_2$ emissions. However the energy intensity decreases at a mean rate of -0.9 % per year until 2050 and -0.5 % afterwards. This a rather optimistic projection compared to many experts' views on the steel and cement sub-sectors, where the energy efficiency improvements are likely to slowdown, as the 1 % annual rate that was quite stable in the past decades would not be sustainable in the future. The direct carbon intensity has a very flat profile, first decreasing and then increasing again after 2050. It is projected to reach 84 % of its 2005 value in 2100, while the indirect carbon intensity has a flat concave profile that never goes below the 2005 level (cf. Figure 4-3).

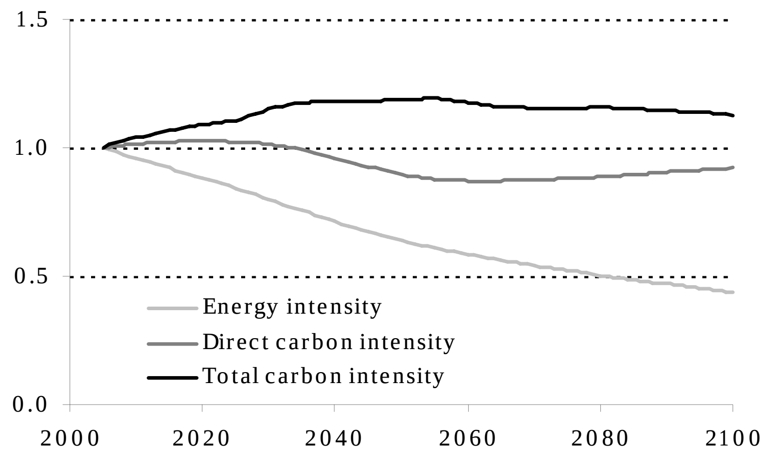



**Figure 4-3: Trends of the energy intensity of output and of the carbon intensity of the energy mix – Europe, baselines scenario, IMACLIM-R model**

At the global level, energy efficiency of industrial production is improving continuously (-1 % per year to 2050 and -0.75 % per year beyond 2050) especially due to pervasive market signals of increasing fossil fuel prices and progressive technical leapfrogging in emerging and developing countries. In the meantime, the ‘direct’ carbon intensity, which is the ratio between direct emissions and energy consumption, decrease at a -0.5 % mean rate between 2035 and 2060, and increase again beyond 2060 to reach 92 % of the current intensity in 2100. Looking at indirect emissions, carbon intensity is also likely to be higher than the current value because of the increasing share of coal in power generation at the global level, because coal as a large competitiveness margin in a context of rising prices for oil and gas. The total carbon intensity follow a flat concave profile, with a slow increase up to 2030, a stabilization during 20 years and a very slow decrease beyond 2050.

Globally, the baseline scenario shows a continuous relative decoupling of direct and indirect emissions from output in the industrial sector, mainly due to energy efficiency improvements. This leads to two important remarks: *first*, one can question the plausibility of such a continuous energy efficiency improvement, only due to an increasing scarcity of oil and gas (see Pielke et al., 2008) and *second*, the profiles of direct and indirect carbon intensities may be critically dependent on the availability of large quantities of non conventional fuels and coal during the whole century, which is also controversial.

### 4.3.3 Contraction and Convergence

In the standard policy scenario (450 ppm C&C) with common participation as soon as 2010, industry appears to be a major contributor to global mitigation, since its emissions feature a 80 % decrease in Europe and a 86 % decrease in the world from 2005 to 2100.

On the long run, these large reductions are not related to output reductions, even if there may be some changes in the regional repartition of output, in favor of the countries that were disadvantaged in the baseline scenario because of their still higher salaries, namely OECD countries. Production in Europe in not affected significantly by climate policies. Most striking is the impact of the emissions constraint in the next decades, with significant transition costs in many regions, especially in emerging countries whose economic growth in the baseline scenario is significantly based on industrial growth, such as China, India or Russia (CIS). In fact over the next two decades, carbon constraints and carbon prices weigh heavily on energy-intensive sectors while the inertia of capital and technologies prevent them to lower their carbon intensity rapidly. On the long run, Middle-East and Russia have a competitive advantage compared to the baseline scenario because their exchange rates are much lower in order to compensate the decreases of oil and gas exports.

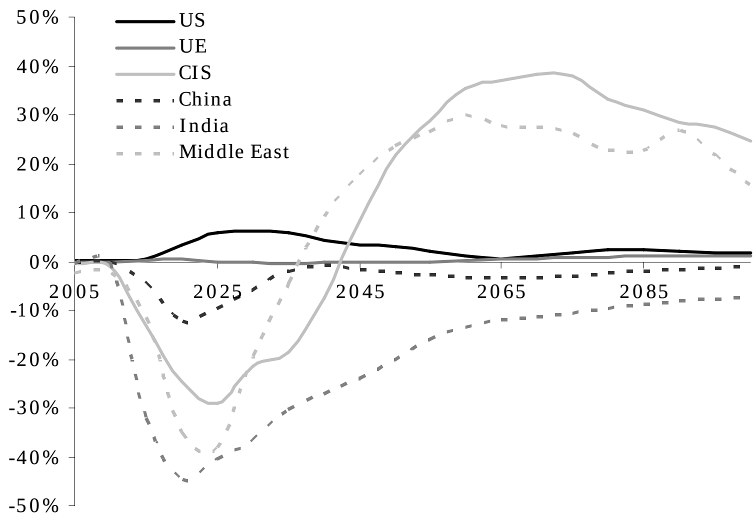



**Figure 4-4: Variations of industrial output in the policy scenario (450 ppm C&C) compared to the baseline scenario**

During the transition, the carbon tax interplays with the higher energy efficiency of industry in OECD countries in favor of their competitiveness, which explains why industrial output increases in the US and is constant in the EU in spite of their own carbon burden. Obviously, those results depend on the assumptions on the level of pass-through of the carbon price (high in these simulations) and on the demand elasticity (very low because the material content of equipments and infrastructures is not supposed to be reduced significantly in IMACLIM-R).

Mitigation of emissions in the industry sector is partly due to faster and deeper energy efficiency gains, partly to a decarbonization of the energy mix in the industry sector itself and partly due to the generation of carbon-free electricity. At the global level, energy intensity would decrease much faster during the first half of the century at a -2.3 % annual rate instead of -1 % in the baseline scenario; total carbon intensity would decrease first thanks to the decarbonization of electricity consumed by industry and later because of massive electrification of the energy mix in the industry sector (Table 4-9).

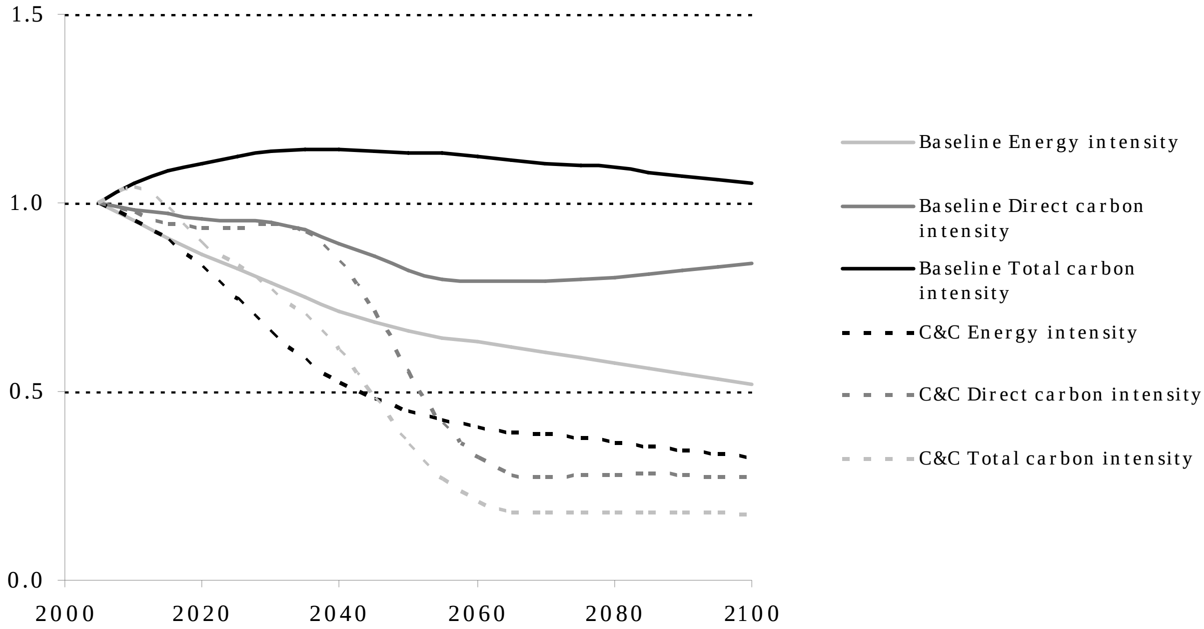



**Figure 4-5: Variations of energy intensity, direct carbon intensity and total carbon intensity, Europe, policy scenario (450 ppm C&C) compared to the baseline, IMACLIM-R**

| | 2005 | 2020 | 2050 | 2100 |
|---|---|---|---|---|
| **Coal** | 16 % | 17 % | 15 % | 9 % |
| **Oil** | 35 % | 14 % | 5 % | 2 % |
| **Gas** | 26 % | 48 % | 42 % | 24 % |
| **Electricity** | 23 % | 21 % | 39 % | 65 % |

**Table 4-9: Energy Mix of the European industry, policy scenario (450 ppm C&C)**

### 4.3.4 Delayed participation of developing countries and carbon leakage

When Europe is supposed to adopt major climate policies alone, while the rest of the world delays commitment beyond 2020, the long run picture of a world-wide low carbon industry is not different, but the transition during the first two decades is different in Europe. First Europe has to reach its target alone, without the flexibility to adjust its marginal abatement cost with the world carbon price. Compared to the policy scenario (450 ppm C&C) mentioned above, a scenario with delayed participation of other developing countries shows a much steeper carbon price profile is necessary for Europe to achieve 100 % of its reductions domestically. Second, there is a temporary asymmetry of carbon constraints during the period when the rest of the world is not taking stringent commitments.

Therefore, leakage can effectively be observed in Europe, since its industry sector would be deeply disadvantaged and would have a strong incentive to move to other countries with no carbon regulation, even if such regulation is expected to happen one decade later.

In this scenario with delayed policies outside EU, physical industrial output is 12 % lower in Europe in 2020 when compared to the two other scenarios, but value added is 30 % lower because of profit shrinking. The 'missing' output is compensated by industrial production in all other countries but the lower value added in Europe is compensated by an increased value added in the rest of the world (cf. Figure 4-6), even if the world price for the industrial good is not significantly different. This is mainly a transition effect, since the outcome in 2030 is much less negative for the EU (cf. Figure 4-7)

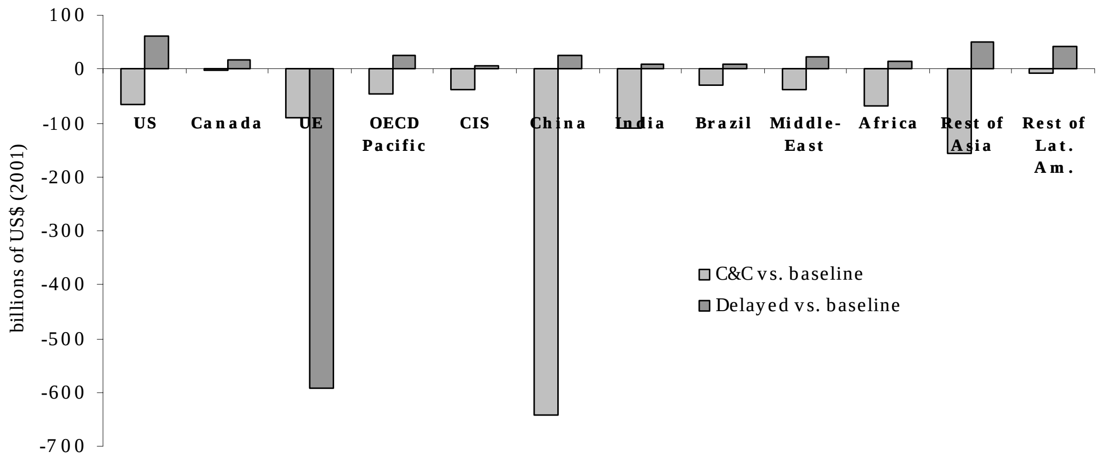



**Figure 4-6: Industrial value added in 2020 in the policy scenarios (C&C and delayed participation) compared to the baseline scenario**

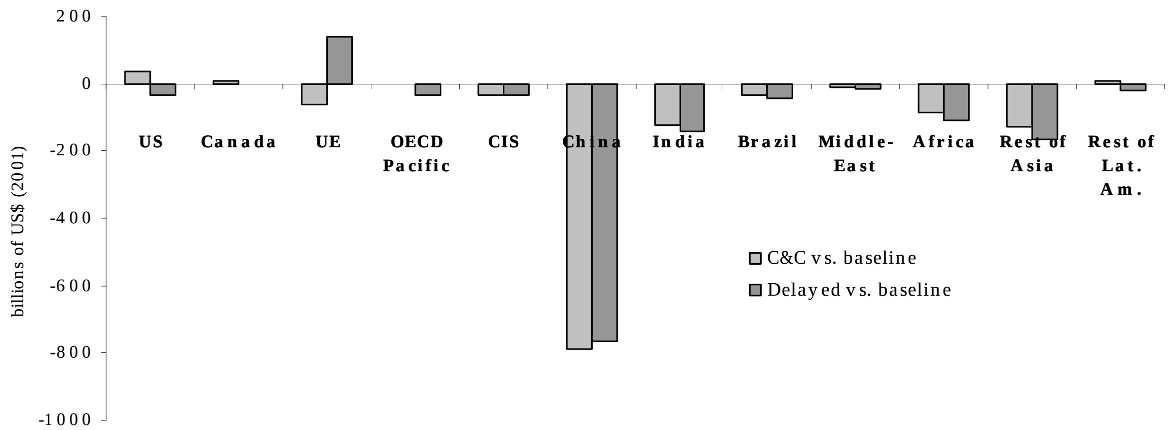



**Figure 4-7: Industrial value added in 2030 in the policy scenarios (C&C and delayed participation) compared to the baseline scenario**

Actually, the impact of carbon leakage on emissions is not negligible: in the 'delayed participation' scenario emissions outside Europe increase steadily between 2010 and 2020 compared to the baseline scenario. The maximum of leakage is reached in 2020 with additional 660 Mt $CO_2$, of which 20 % occur in in North America, 35 % in Asia, 30 % in the Middle East region.

It is worth noting that these simulations have some limits that could change the overall picture of leakage and costs: (i) no representation of carbon capture and storage for the industrial sectors, (ii) no consideration of spatial heterogeneity of the exposure to terrestrial transport costs and (iii) no information about the large shift that could be envisaged on the demand side, with a replacement of carbon-intensive materials by low carbon materials and some change in upstream drivers of material demands (infrastructures, buildings, cars, etc.). It has been underlined by Crassous et al. (2007) that mitigation policies would not necessarily lower material demand and could even raise temporarily this demand because of large renovation programs in the building sector and in infrastructure. Therefore industries such as steel and cement could gain large opportunities on the demand side, even if they are forced to contribute significantly and rapidly to global mitigation efforts.

## *4.4 Sectoral policy issues and options*

### 4.4.1 Climate policy and carbon leakage

In 2005 EU has implemented an Emission Trading Scheme (EU ETS) to limit the emissions of the energy-intensive industries. EU ETS covers around 45 % of European $CO_2$ emissions and is a masterpiece of Europe's climate policy defined in order to comply with its commitment in the Kyoto protocol and its objectives for 2020.

The scheme specifies a global quantity of emissions not to exceed, which defines the stringency of the policy and determines its environment efficiency. 12000 energy-intensive plants across the EU are included in the EU ETS, covering about 40 % of the EU's total $CO_2$ emissions. The trading of the $CO_2$ permits allows decreasing the global cost of compliance to the environmental target and guarantees the cost-effectiveness of the instrument.

Installations for the production of pig iron or steel (primary or secondary fusion) including continuous casting, with a capacity exceeding 2.5 tons per hour and installations for the production of cement clinker in rotary kilns with a production capacity exceeding 500 tons per day are included in the EU ETS.

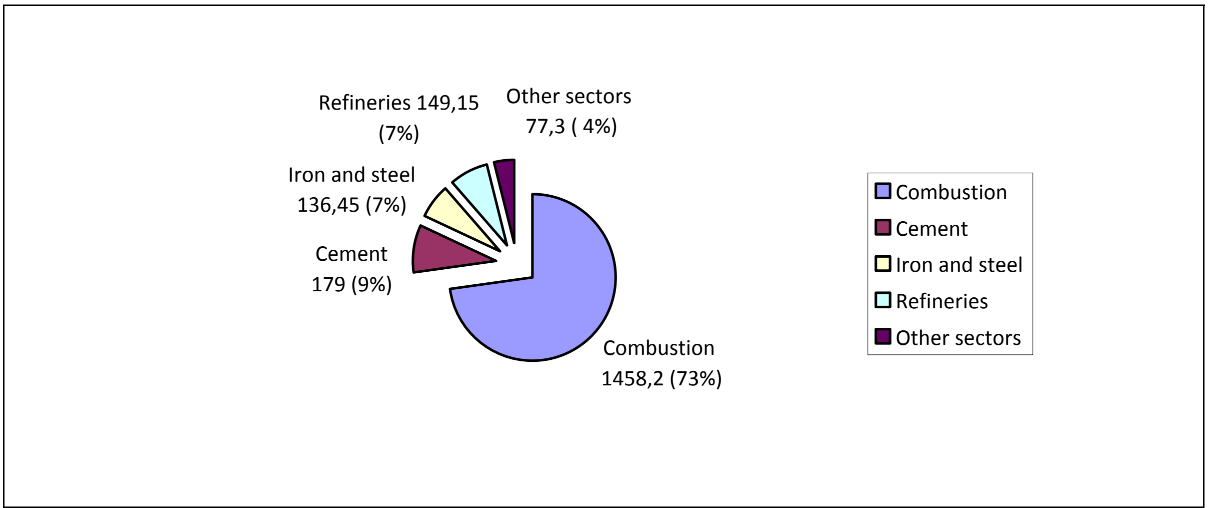



**Figure 4-8: EU ETS sectors emission in 2005-2006 (average): in volume (Mt) and percentage (%).** Source: Alberola et al. (2008)

Due to unilateral $CO_2$ prices, concerns about the loss of industrial competitiveness and leakage of $CO_2$ emissions are discussed and taken into account in the current process of review of the scheme for the post-Kyoto phase.

In theory, a persistent $CO_2$ price differential may change trade patterns and induce carbon leakage, thus lowering the environmental efficiency of the EU ETS. The scheme increases the production cost of European producers in GHG intensive sectors, some of which are exposed to international competition. If European producers pass-through the costs to consumers, they may loose some market shares to foreign producers. If they do not pass through costs on the other hand, then their market share may be unaffected at least in the short-run, but their profit will shrink due to their lower ability to generate revenues and in the long run investments may be relocated outside of Europe. European industry will then lose some market shares in both European and foreign markets, with two main consequences: job losses and an increase in GHG emissions in non-European countries increase, i.e. carbon leakage.[34]

Two carbon leakage channels exist due to loss of competitiveness following asymmetric climate policy costs: immediate loss of market share for carbon-constrained industrial products, to the benefit of non carbon constrained countries (i.e. decreases of exports and increases of imports) and relocation of energy-intensive industries to countries with a less stringent climate policy (Reinaud, 2008). These channels are also called the 'competitiveness leakage channel' (Demailly and Quirion, 2007).

This channel of leakage has two components: operational leakage and investment leakage (Graichen et al., 2008). Operational leakage is a short-term concern, which comes from the production decrease in existing installations. Investment leakage is due to the redirection of investments from Europe to regions without similar climate policies. It takes place in the longer run but it could be more important than operational leakage in capital-intensive industries like primary aluminium or steelmaking.

### 4.4.2 Carbon Leakage in an economy-wide perspective

Model results allow investigating the relative role of the two channels of the carbon leakage mechanism. First, the operational channel is active instantaneously as soon as a carbon price is set in one or several regions, because it induces a direct increase of the producer price of industrial goods. Figure 4-9 compares the domestic price of industrial goods in Europe to the world price of industrial goods on the international market, which provides a proxy of the competitiveness of European industry. In the policy scenario (450 ppm C&C), Europe gains from the setting of a uniform world-wide carbon price, because of its pre-existing energy efficiency superior to the rest of the world. In case of unilateral policies during ten years, the loss of competitiveness of industry is noticeable but the price index is only 5 % greater than in the baseline scenario, which does not dominate other reasons for variations in production costs (exchange rates, raw material price fluctuations, inflation, wages and other regulations).

[34] Carbon leakage is not limited to this "GHG-intensive industry channel". Moreover in most general equilibrium models the larger part of leakage occurs through the "energy prices channel". This means, climate policies decrease the international prices of oil, gas and coal hence increase their use in countries without a climate policy.

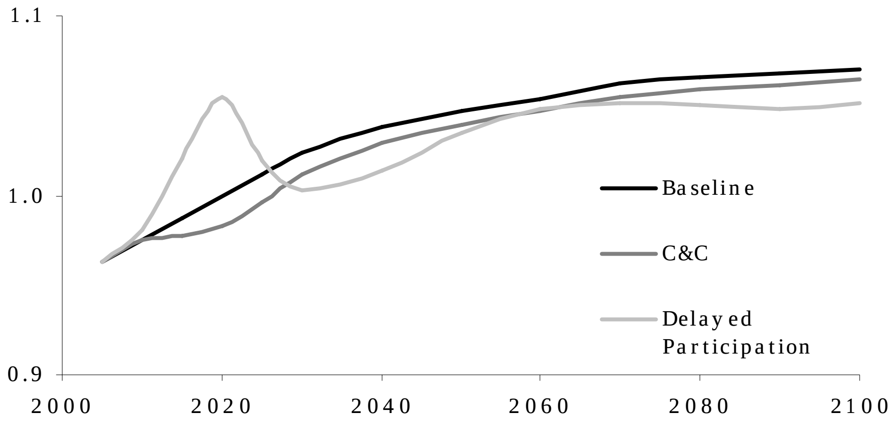



**Figure 4-9: Ratio between the EU domestic price and the international price of industrial goods in the policy scenarios and the baseline scenario**

One effect which is generally missing in discussions with policymakers is that the short-run cost increase due to the unilateral carbon value is partially compensated by a significant decrease of the exchange rate of the European currency. Surely, this compensation depends on the exchange rate policy. But it has to be noted that – in the simulations at least – the loss of competitiveness of the European industry is followed by a decrease of exports (minus 19 %) and an increase of imports of industrial goods (plus 29 %). This imbalance of commercial flows has feedback effects, either on capital flows (central bank reserves or increase of national debt) to maintain the exchange rate, or on the exchange rate, which will decrease enough to induce an opposite commercial flow for some other goods. In the simulations that were analyzed[35], the second flexibility is the only channel to compensate the variations of flows of industrial goods. The variation of the exchange rate in the delayed participation scenario compared to the two other scenarios is even larger then the increase of the domestic industrial price shown above (Figure 4-10). Indeed in IMACLIM-R the trade elasticity of industrial goods is one of the highest elasticities compared to other goods because these markets are supposed to be highly competitive and globalized. As other markets are less fluid, a larger exchange rate variation is necessary to reach an equivalent shift of commercial flows with non industrial goods.

[35] The model ran under the assumption of a stabilized capital balance.

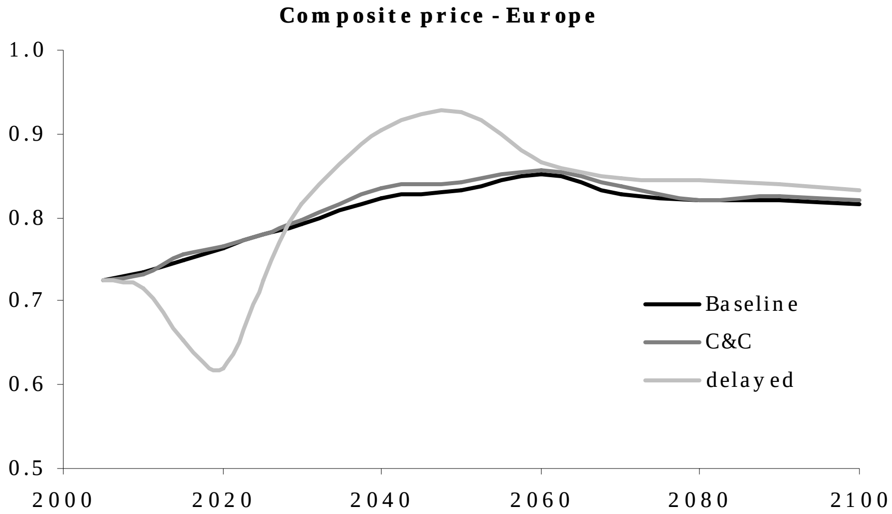



**Figure 4-10: Variations of the composite price in the policy scenarios (C&C and delayed participation) and baseline scenario**

As a consequence, the variation of commercial flows for the composite good is very significant, with a +91 % increase of exports and a minus 39 % of imports in 2020, when the carbon value differential is maximum.

| | Industry | Composite |
|---|---|---|
| **Exports** | -19 % | 91 % |
| **Imports** | 29 % | -39 % |

**Table 4-10: Variations of exports and imports in the delayed participation scenario compared to the C&C scenario in 2020**

This picture would suggest that carbon leakage is not necessary a pure loss for the region adopting a unilateral climate policy. Nevertheless, if a general equilibrium effect may partially compensate – at the state level – the adverse effects of an asymmetric carbon constraint, this would probably have macroeconomic costs, because it has not be expected by investors or decision-makers, because other monetary or debt policies would work against this exchange rate adjustment.

The second channel of carbon leakage has longer lasting effects because its consequences in terms of domestic industrial underinvestment may last for decades, far beyond the ‘globalization’ of the carbon constraint. As shown in Figure 4-11 (black line for EU), cumulated investment in the industrial sector since 2000 diverges a lot from the baseline scenario, as the underinvestment is likely to increase and reach -17 % in 2020, catching-up only very slowly to end of the century. In 2020, the industrial capacity is 10 % lower in the ‘delayed participation scenario’ than in the baseline scenario. The missing investment goes everywhere in the world, but especially to regions where the increasing European demand for imports increase the capacity needs. The demand for additional capacity only affects the period when carbon prices are asymmetric, as shown in Figure 4-11.

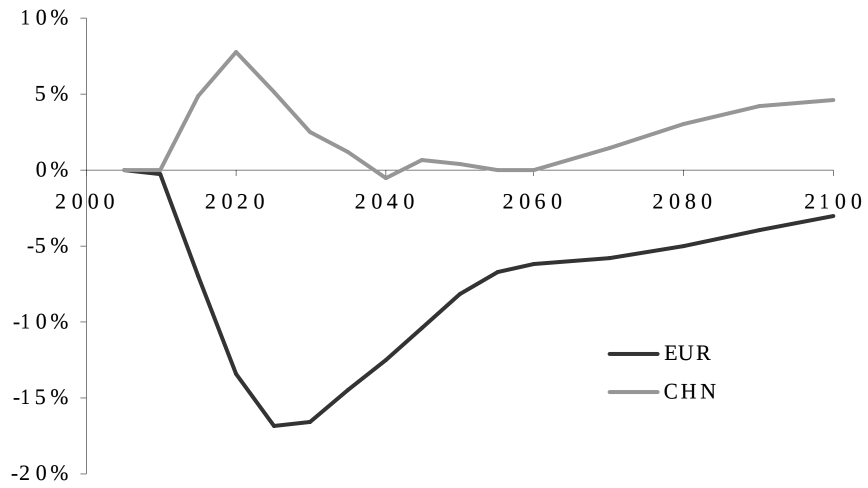



**Figure 4-11: Variations of cumulated investment in the industrial sector, in the policy scenario (delayed participation) compared to the baseline scenario, for Europe and China.**

Eventually, one can look at the employment indicator to summarize the resulting impact of an asymmetric carbon constraint, taking into account all general equilibrium effect. The variation of the unemployment rate[36] shows that an asymmetric constraint would raise unemployment of 5 % in 2020, faster than a global carbon constraint such as in the policy scenario (450 ppm C&C), in which additional unemployment peaks at 2.5 % close to 2030[37].

[36] In Imaclim-R, employment is demand-driven and real wages are linked to the unemployment rate through a global 'wage curve' in each region.

[37] This unemployment is not only due to leakage and changes in the sector competitiveness and in the terms of trade because Europe, but also to the higher carbon price which is necessary in Europe to make it achieve its emission constraint *alone*. To disentangle both effects, an intermediate scenario has been produced replacing the carbon price of Europe during the period of asymmetric constraint by the carbon price of the policy scenario (450 ppm C&C). It shows that the unilateral commitment of Europe is responsible for 23 % of the additional unemployment, while the rest is due to the higher carbon price because Europe cannot use allowance trading.

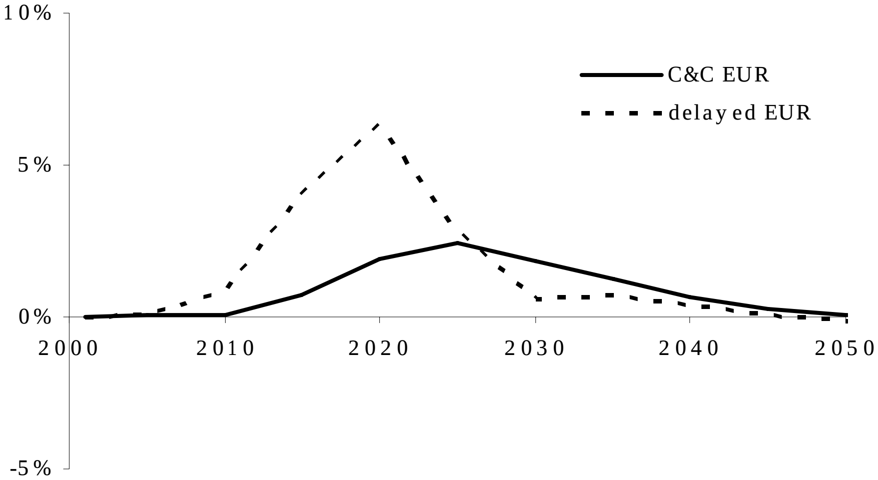



**Figure 4-12: Variations of unemployment rate, policy scenarios (C&C and delayed participation) compared to the baseline scenario**

In the past, production capacities of steel and cement industries have been generally sized to satisfy local demand: there have been few capacities built in order to export, even for the intermediary products. This picture might be changing in the future. For instance, in the long run, one may fear a significant relocation of semi-finished products of cement and blast furnaces steel if the full cost of emissions is internalized. The high uncertainty concerning the permanence of the asymmetry of the carbon constraint reduces the expected cost differential across countries and the incentive to relocate, but once the relocation is done, there is a big inertia.

As shown by simulations, the consequences of relocated investment in case of delayed participation of the non-European countries are characterized by a relatively strong inertia of the decrease of the industrial production in Europe. From the moment where all countries participate in multilateral climate policy, 15 years are necessary to recover an industrial production level in Europe close to the one of the policy scenario (450 ppm C&C). This is due to the long life of the installations in the heavy industry. For instance, in the steel industry, the average life of the production materials is from 10 to 15 years with a continuous retrofitting, and a blast furnace is generally constructed for 40 years.

### 4.4.3 Tackling carbon leakage

Some options could prevent climate policies from negatively impacting European industry's competitiveness. Those options are described extensively in Neuhoff et al. (2009). The European Commission is committed to take appropriate action to limit carbon leakage in the draft for the revision of the EU ETS Directive (EU Commission, 2008b). Continued free allowance allocation to the “energy-intensive industries which are determined to be exposed to a significant risk of carbon leakage” or “an effective carbon equalization system […]” to put “installations from the Community which are at a significant risk of carbon leakage and those from third countries on a comparable footing […]” are mentioned as possible measures to address leakage concerns. For this last option, the text of the draft adds: “such a system could apply requirements to importers that would be no less favourable than those applicable to installations within the EU, for example by requiring the surrender of allowances” (EU Commission, 2008b, p. 8), referring to a border adjustment. Other options are also discussed among experts, such as state aid and sectoral agreements.

### 4.4.4 Investments in few new installations in mid-term

New investments will be located uppermost close to demand centres or where resources (in labor or raw materials) are cheaper. In the EU, few new production capacities should be installed, at least in the next decade. Emission reductions will not implemented with new technologies but rather by improvement of existing installations. Climate policy must take into account this element. In particular, the stringency of the carbon constraint applied to the industry must be defined with this element.

For the long term (after 2020), more radical innovations could be implemented with the renewal of the production capacities. After this date, if the carbon constraint has been implemented worldwide, the new installations could remain in the EU and radical innovations may be finalized.

For instance, in the steel sector, European companies have invested in the program ULCOS (Ultra-Low $CO_2$ Steel making). The goal of ULCOS is to develop a steel making technology that reduces $CO_2$ emission by at least 50 %. The technologies being evaluated, including CCS, biomass and hydrogen reduction, show a potential for controlling emissions to 0.5 to 1.5 $tCO_2$/t (0.14 to 0.41 tC/t) steel (Birat, 2005).

The evaluation of the carbon leakage risk must also take into account the policies implemented by countries which could host new capacities to serve the EU market. Even if these last ones do not participate i a multilateral climate agreement, they could be reluctant to host plants dedicated to export. For instance, China already has some concerns about their dependency toward foreign energy or raw material sources but also the pollution produced by industrial installations. Moreover, the supply of the domestic market has become a priority in some industries, like steel. It is why the authorities have implemented export tariffs or lowered export rebates for high energy-consuming, high-polluting and resource-intensive products since 2005.

# 5 Agriculture

Authors: Hermann Lotze-Campen, Steffen Noleppa, Silke Spielmans, Alexander Popp, Benjamin Bodirsky

- **A range of mitigation options for the agricultural sector is available at low, zero or even negative costs, but considerable non-price-related barriers have to be overcome.**
- **Due to potentially high transaction costs, an expansion of the emission trading system to the agricultural sector may not be the most efficient way to fully use the available mitigation potentials.**
- **A climate change mitigation strategy in European agriculture should be part of a wider policy approach towards sustainable agriculture and rural development, consistent with related goals in environment policy and development policy.**

## *5.1 Introduction*

World population will continue to grow. It was 6.1 bn in 2000 and reached 6.6 bn in 2007 (PRB, 2007). In 2030, already 8 bn people will live on earth and are projected to rise to 9.3 bn in 2050 (PRB, 2007; United States Census Bureau, 2008). The situation in the EU is rather different: here population is projected to remain stagnant or slightly decline (PRB, 2007).

Sustained growth in per-capita income is another key driver for growth in world agricultural demand. The trend of long-term global economic growth is expected to continue (USDA, 2007; OECD and FAO, 2007), although the recent economic crisis has increased the uncertainty regarding long-term growth projections. In the EU income growth until recently has been projected at around 2 % per year (Nowicki et al., 2006; EU Commission, 2008). Economic prosperity goes hand in hand with the trend of urbanization. Schmidhuber and Shetty (2005) expect that the rate of urbanization will accelerate. By 2030 virtually all population growth will be urban and by 2050 two thirds of all people will live in cities (Cohen, 2006). Both economic growth and urbanization tend to raise per-capita food consumption and change food preferences. Demand increase will be most pronounced in dairy, meat, and processed foods (Brown, 1995, Mittal, 2006). By and large, it can be expected that, due to population growth and changing diets accompanied by an overall increase of calorie intake, global agricultural demand will double in the first half of the 21st century (von Witzke et al., 2008).

## *5.2 Past, current and expected dynamics of the sector*

### 5.2.1 Market trends

The necessary increase in agricultural production to meet growing world food, feed and bio-energy demand must come from an increased productivity on land already farmed (Runge et al., 2003; FAPRI, 2008; FAO, 2008; OECD, 2008; USDA, 2008). Limits are obvious:

- The acreage that may be added in future is probably less productive than the land that is already used by farmers.
- Another significant constraint for an increased agricultural production is water. In the

past, an increase in agricultural production was always associated with growing water use for farming. However, the resource is becoming ever scarcer and thus more expensive (von Witzke et al., 2008), which will also tend to slow down productivity growth.

- Environmental concerns could limit additional productivity since an intensification of agricultural production may cause trade-offs with respect to other societal objectives, e.g. it may negatively affect biodiversity.
- Sustained high energy prices and, thus, prices for fertilizers and fuels may negatively affect agricultural production and productivity growth.
- Organic farming – typically less productive than conventional farming – is becoming more and more important at a global scale.
- Finally, annual growth rates in autonomous productivity (technological progress due to breeding programs, new technologies etc.) have been in decline since the Green Revolution of the 60th and 70th of the past century. In fact, annual productivity in world agriculture has declined from around 4 % in 1961-1990 to about 2 % in the last decade of the 20th century. It is currently at around 1 % (von Witzke et al., 2008).

In the absence of major breakthroughs in technology, a rather slow productivity growth is expected to continue (Ruttan and von Witzke, 1988; FAO, 2008, 2006). According to FAPRI (2008), annual growth rates in yields will be close to or even below 1 % at a global scale in the upcoming decade and probably less in the EU assuming conventional breeding programs and implying constant crop management practices.

Finally, the special importance of bio-energy shall be highlighted. The high demand for bio-energy is influencing agricultural markets and, hence, agricultural production. This holds true for the EU as well (OECD, 2008). Recent projections (OECD and FAO, 2008; von Witzke et al, 2008) show that bio-ethanol as well as bio-diesel production will still increase in upcoming years. Compared to 2008, OECD and FAO (2008) – assuming no major importance of cellulose-based technologies – expect that the production of bio-ethanol will triple by 2017, whereas the production of bio-diesel will double. Such an increase would require devoting a major share of oilseed production in the EU as well as a substantial share of grain production to bio-energy production (von Witzke et al., 2008, Bamiere et al., 2007). This may not be a sustainable strategy (Bringezu et al., 2007), especially not if food-security aspects are taken into account. Hence, rather strong uncertainties are associated with the future development of crop production for bio-energy purposes in the EU. The future development heavily depends on the availability of cellulose-based (second generation) technologies and on policy changes. Current support schemes of bio-energy production in the EU and other OECD regions are not only costly, but also have limited impacts on reducing greenhouse gases and improving energy security (OECD, 2008a). The role of bioenergy in the transport sector is further discussed in Section 3.4.2.

The underlying developments will surely have significant implications on world and EU agricultural markets. Market effects are already visible. Today, it can be stated that the trend of declining world market prices has ended and that world market prices for agricultural goods have increased. Although the observed price hikes in 2008 cannot be expected to sustain, it is reasonable to anticipate an overall trend of (possibly much) higher prices for agricultural raw products than in the past decades.

### 5.2.2 Policy trends

There are two major political and institutional factors which have to be considered when assessing current and future trends from the perspective of the further development of the EU agricultural sector: The EU Common Agricultural Policy (CAP) and the WTO negotiations.

During the past 15 years several reforms of the CAP have been undergone. A recent milestone in this process was the reform from 2003 (Henning, 2008). By applying a so-called "Health check" in 2008 this most recent reform from 2003 and the entire CAP were assessed in order to streamline and modernize the agricultural policy setting in the EU again. This evaluation process led to new proposal on how to modify the CAP. The various reforms, including the recent "Health check" proposals, followed a rather consistent path: Less market interventions (i.e. more market liberalization) on the one hand, and increased support for farmers (via decoupled and direct payments) as well as for rural areas (via rural development funds) on the other hand.

The 2008 "Health check" cannot be considered a 'true' reform. Instead, it aimed at identifying necessary steps to amend the CAP until 2013 and beyond. Consequently, a debate on the role of the CAP beyond 2013 has already started. Although there is rarely a consistent view on the future of the CAP in the various EU member states and within the CAP stakeholder community, main 'guidelines' on how the CAP may move forward can already be identified (see also Raad voor het Landelijk Gebied, 2008):

- Based on principles of economic policy-making and fairness towards developing countries, further market orientation in agriculture is desirable. A partly or full elimination of price support, export refunds, production quota mechanisms, and other interventionist market support measures is proposed by the majority of EU member states.
- A full decoupling and gradual phase-out of direct payments to farmers is seen as important as trade liberalization (see also below the discussion of the WTO issue).
- The CAP is more and more seen as an instrument for supporting and developing the functions and structures of European rural areas including agriculture but not exclusively focused on farming. A broader based territorial approach while applying agricultural policy interventions is emphasized in many EU member states taking into account economic needs (diversification of rural income, regional economic development) and the need to deliver public goods such as landscape, biodiversity, cultural heritage, ecosystem services, etc.

A new CAP has to comply with WTO agreements (Henning, 2008). The 'guidelines' developed above seem to be associated with potential outcomes of current WTO negotiations. The current Doha Round of negotiations recommended signing a new WTO agreement on agriculture in 2005. This ambitious objective was not achieved, and it is still being negotiated. Despite the fact that the so-called Falconer proposal (WTO, 2007) initiated new discussions and negotiations, the Doha-Round has collapsed because of a major dispute between a few important negotiation parties, namely India, China and the United States.

### 5.2.3 Main sources of GHG emissions in the EU agricultural sector

Agricultural emissions in GHG inventories include, for methodological reasons, neither $CO_2$ emissions from land use and land use change, nor emissions from on-farm energy use, nor emissions from the upstream and downstream agro-food sectors, such as fertilizer and pesticide manufacturing, transportation and processing. Land use, land use change and forestry (LULUCF) is regarded as a sector in itself. That is why agricultural GHG emissions in GHG inventories are limited to non-$CO_2$ ($CH_4$ and $N_2O$) emissions. $CO_2$ emissions from agricultural soils account for less than 1 % of GHG emissions globally, emissions from land use change for about 15 %.

Globally, non-$CO_2$ agricultural emissions account for 10-12 % of total anthropogenic GHG emissions and for about 85 % of $N_2O$ and 47 % of $CH_4$ emissions (Smith et al., 2007c). On average, for industrialized countries the share of the agricultural sector is smaller: 8 % of total anthropogenic GHG in OECD countries (69 % of $N_2O$ and 43 % of $CH_4$ emissions, OECD, 2008) and 9 % in the EU-15 (EEA, 2008c).

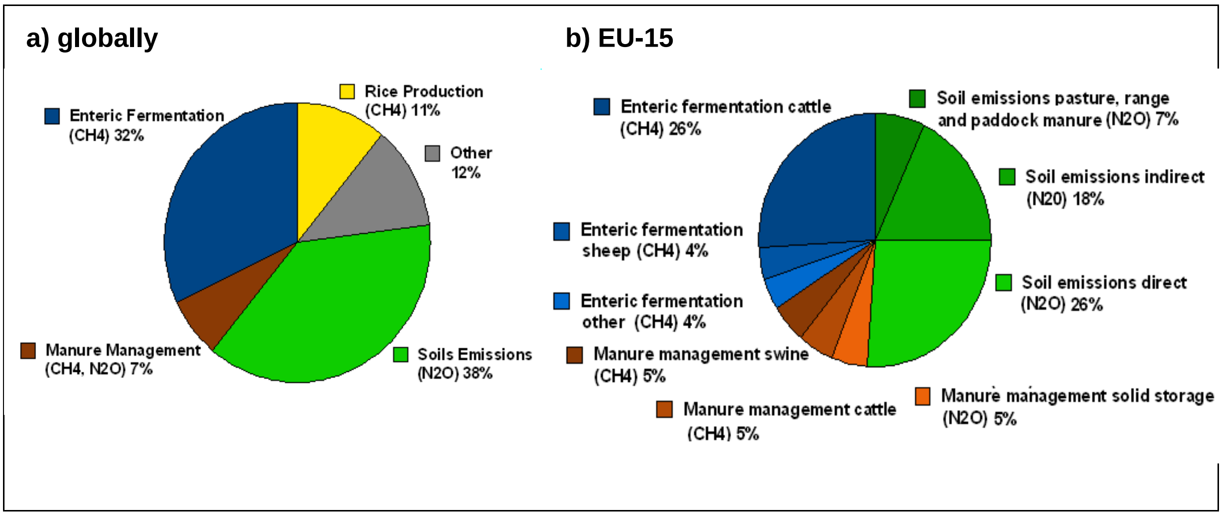



**Figure 5-1: Share of key source categories in the agricultural sector for non-$CO_2$ emissions in 2005.** Data from Smith et al., 2007c and Adapted from EEA, 2008c

Globally the main sources, as shown in Figure 5-1, are 38 % soils emissions ($N_2O$), 32 % enteric fermentation ($CH_4$), 7 % manure management ($CH_4$, $N_2O$), 11 % rice production ($CH_4$) and 12 % other, mainly biomass burning ($CH_4$, $N_2O$).

In the EU-15 $N_2O$ and $CH_4$ emissions from the agricultural sector contribute about 5 % and 4 % of total GHG emissions respectively (EEA, 2008c). The main sources of GHG emissions in the EU-15 are 34 % enteric fermentation from ruminants, 15 % manure management, 51 % emissions from agricultural soils. Emissions from biomass burning and rice production are negligible in the EU.

**$CH_4$ (Methane):** $CH_4$ emissions in the EU are nearly exclusively associated with livestock production, the number of livestock being the major driver. Roughly 73 % of agricultural $CH_4$ emissions derive from enteric fermentation and 27 % from manure management (EEA, 2008c). Enteric fermentation from cattle form the largest part of $CH_4$ emissions, accounting for 2.4 % of total and for 25 % of agricultural GHG emissions of EU-15 in 2006. Enteric fermentation from sheep is of minor importance. $CH_4$ emissions from manure management account for roughly 1 % of total GHG emissions. Emissions from rice cultivation are negligible.

**$N_2O$ (Nitrous Oxide):** Roughly 90 % of agricultural $N_2O$ emissions derive from agricultural soils and 10 % from manure management. The main source category for $N_2O$ emissions from manure management is “solid storage, dry lot”. In this category the share of new member states is remarkably high. Agricultural soils emissions account for nearly 5 % of total GHG emissions. The main source is direct soils emissions with 2.5 % of total GHG emissions. In the EU-15, Germany (24.3 %) and France (22.5 %) are responsible for nearly half of emissions from this source. Emissions from pasture, range and paddock manure account for 0.6 % of total GHG emissions. Indirect (=off-site) $N_2O$ soil emissions account for 1.6 % of total GHG emissions in the EU-15.

## Trends since 1990

In 1990 agriculture was responsible for 11 % of total GHG emissions (Bates, 2001) in the EU-15. Since then emissions have steadily decreased and are predicted to decrease further. According to US-EPA, "Western Europe" is the only world region where these emissions are predicted to decrease. Globally non-$CO_2$ agricultural GHG emissions have increased by 17 % from 1990 to 2005 and are predicted to increase further.

Since 1990 there has been a shift in livestock production in the EU, which led to decreased $CH_4$ emissions from enteric fermentation and manure management. In the EU-15 $CH_4$ emissions from enteric fermentation declined by 11 %, to a large extend associated with declining number of cattle. In the EU-27 emissions from enteric fermentation from cattle declined by 21 %, and in the new member states even by 49 %. While $CH_4$ emissions from cattle manure management have also declined, an increasing pig sector in the EU led to increasing emissions from swine manure. Over the period 1990-2006, $CH_4$ emissions from swine manure increased by 22 %, while swine population increased only by 5 %. With the exception of Poland (+17 %) the new MOE member states did not participate in this growth, their emissions from this source decreased by 28 %.

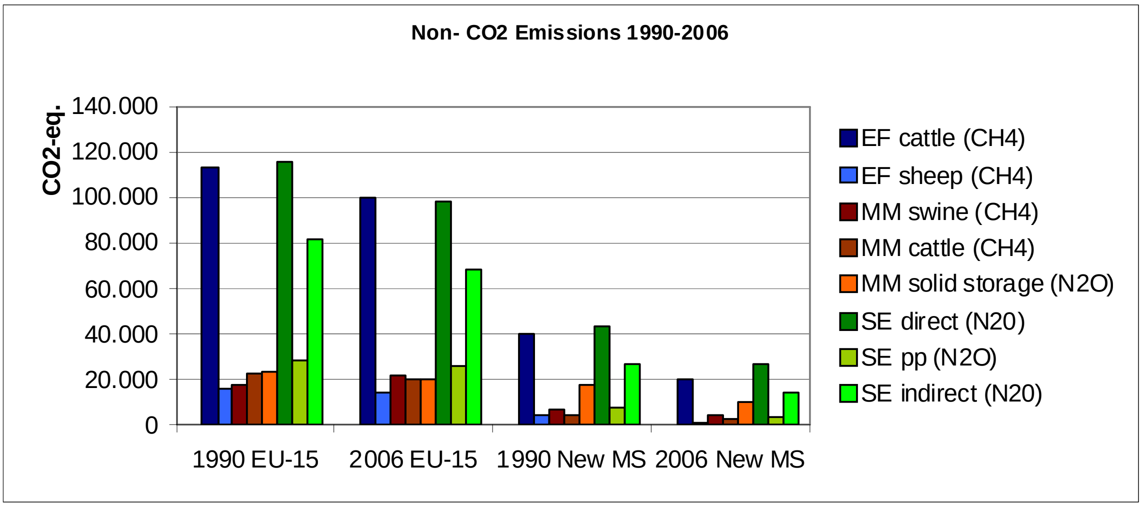



**Figure 5-2: Emissions trends in agriculture for non-$CO_2$ emissions 1990-2006**

### 5.2.4 Main mitigation options in the EU agricultural sector

Given the variety of agricultural structures, farming systems and site conditions, there can be no “one-fits-all” priority list at the EU-level. The effectiveness of most measures depends on regional and local conditions and for mountain areas in Greece it will be necessary to focus on other priorities than e.g. in the Netherlands or Denmark. It must also be taken into consideration whether there should be lower mitigation objections for the new Central and Eastern European member states, given the fact that these countries need to recover from a sharp decrease in production due to economic transformation. Moreover, it must be taken into account that a measure can have a certain mitigation potential in one region while it induces higher emissions elsewhere (leakage). So the possible impacts for measures in the EU have to be considered at the global level, e.g. with regard to shifts in land use.

But even if the mitigation potential could be quantified exactly, this could not be the only criterion for selection. The measures with the highest potential per ha are those that lead to a sharp decline in production (converting cropland to grassland, afforestation, restoration of peat soils, bioenergy crops), which makes them rather costly (opportunity costs). Without incentives they cannot be implemented. But if high prices for emissions are to be expected in the future, this would lead to a competition between food production on the one hand and climate change mitigation on the other and will act as another driver for higher food prices.

The following chapter gives an overview of estimations for the mitigation potentials at different cost levels. These estimates vary, some studies are global, some regional, some cover a wide range of measures, others just a small selection. Some have tried do cover the problem of leakage, some have more ore less ignored it. That is why it is not possible to give reliable estimations for the above described measures in t $CO_2$eq. per year for the EU-27, as would be desirable.

By far the highest mitigation potential has been estimated for various types of bio-energy production, mainly from cellulose-based feedstocks. Improved energy efficiency also seems to offer great mitigation potential in the EU. But this is not ascribed to the agricultural sector.

$CO_2$ sequestration is also a very promising mitigation measure, or rather a set of measures. Frelih-Larsen et al. (2008) distinguish between preservation of existing carbon stocks (permanent grasslands, forests, soils with high organic matter content like peat lands, bogs and wetlands) and carbon sequestration in mineral soils. They suggest setting the first as a priority in EU agricultural mitigation strategy. They argue that, inter alia, carbon losses from organic soils would be far higher than gains in mineral soils and sequestration would be difficult to monitor. The preservation of existing carbon stocks should not be restricted to more ore less intact areas with natural wetland vegetation, but include restoration of degraded peat lands and bogs. Drained organic soils, even if the first draining measures where taken centuries ago, nowadays are still acting as large sources of $CO_2$, due to continuing oxidation of organic matter. GHG inventories do not reveal this properly, as they do not contain a category for $CO_2$ emissions from drained organic soils. This is somehow “hidden” in the LULUCF-sector, in the categories “cropland remaining cropland” and “grassland remaining grassland”. The guidelines for GHG inventories should be redesigned to better reflect this high mitigation potential.

With regard to existing carbon stocks in peat soils, it is important to include drained peat soils that have been transferred to cropland or intensively managed grassland in the past, and to investigate the feasibility of their restoration. Barz et al. (2007) assume that of the 830,000 ha of peat lands in Northern Germany about one quarter could be restored and returned into carbon sinks. As a site-adapted and sustainable use of restored peat lands they suggest biomass production. So the restoration of these peat lands could have a double mitigation effect (soil carbon sequestration and biomass production). Barz et al. (2007) regard yields of about 10 t/ha or about 2 Million t of biomass annually as realistic. Such cultivation of biomass on restored peat lands is called by some authors “padiculture” (Wichtmann and Joosten, 2008). It is important to note that biomass cultivation on still more ore less intact and yet not heavily drained peat lands does not produce the described benefits and should in fact, as Wichtmann and Joosten suggest, be banned completely for biomass cultivation.

Restoration of peat soils, maintenance of peat soils, improved water management via high groundwater tables and protection of grassland are of course overlapping measures. Their potential per area is high, but they are naturally limited to certain areas (peat soils and wetlands). There are no reliable figures available in the literature for the overall potential of these measures in the EU. The potential for emissions reduction is estimated roughly at 15 t $CO_2$/ha. (Wichtmann, 2008). But there is great variation over different sites and locations. Couwenberg et al. (2008) describe type, thickness and trophic state of the peat soil, mean water level and water level fluctuation, present vegetation and local climate conditions as main parameters which determine the net GHG balance of restored peat lands. They found that $CO_2$-emissions decline with mean water levels rising close to the surface, while those of methane rise sharply. The net balance can be positive or negative, depending of site conditions. As emission data from restored peat lands is rather scarce and there are no long-term observations, there still is large uncertainty concerning long-term emission behavior of formerly drained and restored peat lands (especially under climate change conditions). But as drained peat lands of temperate Europe constitute an important source of GHG emissions (Couwenberg et al. (2008) describe them as a “global hotspot”), more attention in research should be paid to the question, whether peat land restoration could be included in an emissions trading system.

Other measures for $CO_2$ sequestration are afforestation and agroforestry. The first offers high mitigation potential per area, but is associated with a loss in agricultural production. The mitigation potential for the EU is moderate. The latter allows the combination of sequestration and sustainable food production. But the estimated potential for agroforestry in the EU is rather marginal. Certain bio-energy crops like short-rotation trees and perennial grasses do also offer potential for $CO_2$ sequestration, in addition to the substitution of fossil fuels.

$CO_2$ sequestration in mineral soils via cropland management measures (reduced tillage, diversified crop rotation systems and monitoring of carbon balances) offer less potential per area, but are not to be neglected, as they are applicable on all cropland and thus amount to a high overall potential. They offer co-benefits in terms of agronomy, biodiversity and soil protection, but they suffer from specific problems and barriers of implementation, i.e. non-permanence, uncertainty, additionality and high monitoring costs. $CO_2$ sequestration in mineral soils is partly overlapping with measures to reduce $N_2O$ emissions from soils, which also can be implemented widespread and offer many co-benefits for water protection and biodiversity. The effectiveness of these measures is rather uncertain, as they are depending much on site and weather conditions and management skills of the farmer. With regard to the abatement potential for $N_2O$ from legume crops, there is little consensus in the literature. They can lead to both reduced and increased $N_2O$ emissions. The mitigation potential is rather low compared to $CO_2$ sequestration.

The abatement potential in the livestock sector (mainly manure management and feeding practices) is estimated to be much higher, compared to $N_2O$ abatement via crop management, but significantly lower than the potential for $CO_2$ sequestration. Some measures are rather costly and afford investment, some are available at low cost. They may be more suitable for integration into incentive schemes for emission reduction than both reduction of $N_2O$ soil emissions and enhancing $CO_2$ removals, because costs and mitigation effect are more predictable and non-reversible. However, the data base so far is relatively weak, and this should be considered for further research.

### 5.2.5 Assessing mitigation potential and costs

Abatement in agriculture plays a key-role in mitigating greenhouse gases. 10-40 % of global mitigation across sectors in the next century may come from agricultural abatement and biomass (Rose et al., 2007). The main conclusion from investigating a large number of studies on mitigation potentials is that high uncertainties and clear needs for further research prevail.

Despite the large number of publications on this subject, the literature is heavily interlinked and self-referential. For instance, all studies of non-$CO_2$ mitigation covered here (except De Cara et al., 2005) are directly or indirectly based on Bates (2001), Gerbens (1998) or both. These two studies investigate a rather small number of case studies. Even though subsequent studies corrected or enlarged the original investigations, there is still an enormous lack of cost-benefit analysis on the ground. Furthermore, existing analyses are incomprehensive. Often only the main GHG-emissions are covered, and other emission impacts neglected. Many measures, like combating erosion, exhibit large positive externalities in addition to GHG mitigation. Finally, the efficiency of mitigation measures largely depends on the local context. The same measure often leads to different, sometimes even negative outcomes, depending on where it is implemented. Models with high regional diversification or even differentiation of farm-types could therefore give more precise results.

The cheapest mitigation options comprise mainly instruments which are already in line with best practices in agricultural production, such as no-tillage or conservation tillage, precision fertilization, manure management or changes in livestock diet. However, currently most of these management options are not compulsory. At higher emission prices, shifts in production and land use may occur, and bio-energy becomes more profitable (Smith et al., 2007c).

The methodology for deriving mitigation potentials is different among all models. Some studies like GAINS or AGROPA-GHG have high regional resolution, others like US-EPA (2006) or Smith et al. (2007a) are able to put the European abatement potential into a global context. However, not a single study included transaction costs and price changes into their final assessment of mitigation potentials. Also technological progress was often neglected, weakly implemented, or only qualitatively taken into account.

As technical mitigation potentials often include only known mitigation measures, they tend to underestimate future potentials. Thus, while early studies still assumed a technical mitigation potential of 21 Mt $CO_2$eq./yr (Bates, 2001), new estimates range up to 800 Mt $CO_2$eq./yr (Smith et al., 2007a), not including bio-energy.

Economic potentials for non-$CO_2$ emissions in 2020 are estimated at 2-35Mt $CO_2$eq./yr at negative costs, at 30-40 Mt $CO_2$eq./yr at 20 US$/t $CO_2$eq., and 40-50 Mt $CO_2$eq/yr at 50 US$/t $CO_2$eq. Beyond, more than 70 Mt $CO_2$eq./yr could probably be sequestered at reasonable costs. Holistic economic potentials for all GHG-mitigation options comprising also bio-energy were not found for the European level.

## *5.3 Reflections on modeling results from sector perspective*

### 5.3.1 Overall assessment of the model results

The economy-energy models IMACLIM-R, WITCH and REMIND-R have a strong focus on energy use and carbon emissions from combustion of fuels and industrial sources. The models currently neglect non-$CO_2$ emissions, which are the main contribution to climate change from the agricultural sector. Hence, agricultural emissions can only be reflected in the three models to a very limited extent. Moreover, in the literature the highest potential for mitigation in the agricultural sector is assumed for carbon sequestration related to land use and land use changes. Different pathways of carbon emissions from land use and land use change are not integrated in the model calculations. Therefore the strongest link between the agricultural sector and the models is the use of biomass energy.

Although population growth is regarded to be a major driver for energy demand and combustion of fuels, the models do not analyze interactions between demand for feed and food, food and oil prices and food consumption patterns. They further neglect interactions between the use of biomass energy and carbon emissions due to land use change (deforestation, conversion of grassland to arable land, drainage of peat lands) and emissions of non-$CO_2$ GHG due to intensified agricultural production and/or extension of agricultural area. This is a shortcoming in all of the applied models in the RECIPE project. As they have not been designed for a thorough analysis of the agricultural and land use sector and do not describe interactions between biomass energy use, land use and land use change, their usefulness to describe the mitigation potential of agriculture is necessarily limited. This certainly would require more specific modeling approaches. Further research is strongly recommended in this area, as appropriate policy choices for agricultural mitigation could, at the same time, lower agricultural emissions and improve rural development and food security in the long run.

### 5.3.2 Bioenergy production in the baseline and policy scenario

Until the year 2030, the three models project similar levels of total energy consumption at about 750-800 EJ in the baseline, and 500-600 EJ in the policy scenario. Major differences occur only after 2050. The level of primary energy production from biomass is shown in Figure 5-3.

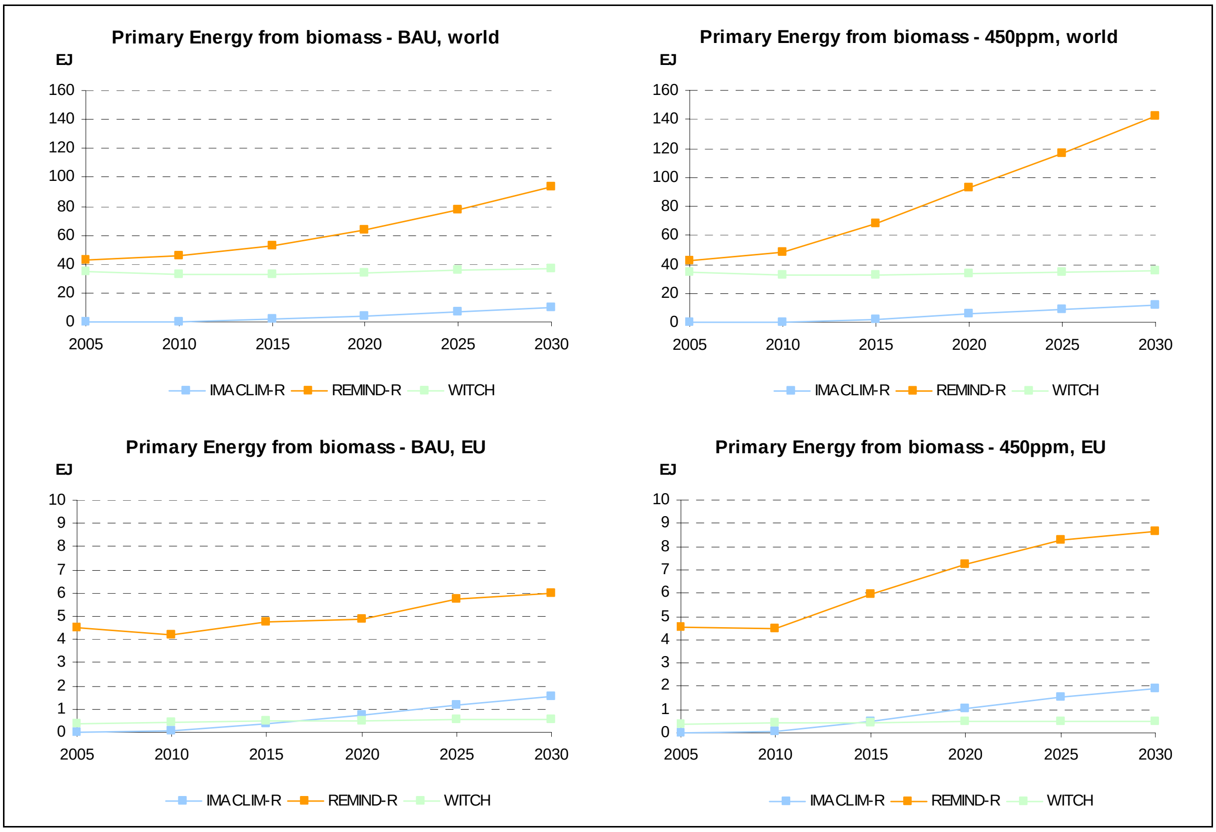



**Figure 5-3: Primary energy production from biomass in the three models (baseline and policy scenario (450 ppm C&C))**

REMIND-R shows the highest share of bioenergy in primary energy supply in the baseline and the policy scenario in 2030. The lowest levels of bioenergy are projected by IMACLIM-R. IMACLIM-R and WITCH show no significant difference in biomass production between the baseline and the policy scenario. In REMIND-R, biomass production in 2030 increases to 145 EJ per year in the policy scenario, compared to 93 EJ in the baseline scenario.

These numbers can be compared with recent estimates of global sustainable biomass energy potential from the German Advisory Council on Global Change (WBGU, 2009) and Smith et al. (2007a). WBGU (2009) estimates the global technical potential for bio-energy from waste and residues in 2050 to be 80 EJ per year (or rather 50 EJ per year taking into account sustainability criteria, especially soil protection). The global potential for cellulose-based energy plants is estimated to be 30-120 EJ per year, if forests, peat lands and wetlands are excluded from use. This gives in total a range of 80-170 EJ per year in 2050. Smith et al. (2007a) estimate a global mitigation potential from bioenergy production equivalent to 50-200 EJ per year in 2030.

IMACLIM-R projects global bioenergy production at 10-12 EJ per year in 2030, and EU production at around 2 EJ. This level is rather low and is not expected to put any serious pressure on agricultural production or land-use change. WITCH projects global bioenergy production at around 36 EJ per year in 2030, and EU production around 0.5 EJ per year. These estimates are very low for the EU, and at the lower end of global figures in the references cited above (WBGU, 2009, Smith et al., 2007a). These numbers would affect agricultural production, but would probably not add serious pressure to agricultural resource use. REMIND-R projections for the baseline scenario are still in the lower range of the reference numbers for world totals, but already fairly high for the EU, compared to current levels and different estimates in literature. REMIND-R projections for the policy scenario for 2030 are at the higher end of WBGU estimates (given that these are for 2050 only) and of the range given by Smith et al. (2007a). Again, REMIND-R projections for EU are relatively high, but still within the range of other sources.

In the baseline scenario, the REMIND-R projections for 2030, bioenergy contributes around 12 % to total energy use worldwide and around 5 % in Europe. In the REMIND-R policy scenario, biomass contributes around 24 % to total energy consumption worldwide, and around 10 % in Europe. Given the estimates in literature and modest assumptions about future technological change in agricultural production, these numbers are not expected to put serious pressure on agricultural production systems in Europe and worldwide.

### 5.3.3 Additional assessment of the policy scenarios

#### 5.3.3.1 Contraction and Convergence (C&C)

In this scenario, IMACLIM-R shows a sharp rise of carbon prices up to 350 US$/t$CO_2$ until 2030. Although there is so far considerable uncertainty about abatement costs for carbon sequestration in soils, prices of several hundred dollars could be a sufficient incentive to engage a lot more in this. Although this is not covered by the models, it can be assumed that an increase in carbon prices would probably result in a rise of food prices, especially for meat and dairy products, if the agricultural sector would be included in emission reduction schemes. This would most likely be associated with structural changes in the livestock sector in the EU. Carbon prices in the REMIND-R stabilization scenario remain low during the whole period. Hence, it is unlikely that there would be strong incentives to integrate carbon sequestration in soils in an emission trading scheme. Carbon prices in the WITCH stabilization scenario start to increase strongly from 2030 on. In 2050 they would be around 500 US$/t$CO_2$. This should be an incentive for carbon sequestration in soils, and also for forest and peat land preservation as well as further GHG mitigation, but only if the international community finds a way to adequately integrate this into climate mitigation policies. Of course, the inclusion of land-use related emissions into a global climate policy regime also depends on many other factors and objectives, not just the level of carbon prices.

#### 5.3.3.2 Intensity targets

If emission allowances were allocated in proportion to GDP share, this would lead to very high economic losses in India, China and other NAI countries. This would hardly be in line with UN development goals like poverty reduction and food security and should not be regarded as an option.

#### 5.3.3.3 Global tax regime

In all three models, with a global tax regime China would be better off compared to the C&C scenarios, but India and the rest of NAI countries would lose. As these are the most vulnerable regions with regard to food security, this scenario would also worsen the state of global food security, compared to the C&C scenario.

#### 5.3.3.4 Technological vetoes

There is a wide range of biomass crops and technologies available to produce energy from biomass (open fireplaces, first-generation biofuels, biogas from residues for electricity generation, BtL etc.). They vary considerably with regard to their positive or negative impact on global warming, and also have diverging impacts on other societal objectives such as biodiversity and food security. Hence, an overall veto on biomass is not very targeted and seems unlikely. On the other hand, it is unlikely that all technical options could be realized without severe consequences for biodiversity and food security. Differentiated and globally accepted regulations for land-use change in general, and biomass production in particular, are needed.

##### 5.3.3.5 Delayed participation

This is unlikely to have direct implication for the agricultural sector.

### 5.3.4 Required investment flows to achieve the potentials

For the agricultural sector no emission reduction requirements have been directly derived from the policy scenarios of the models. Indirectly, these could be derived from the amount of biomass energy use, which to a large amount would have to be produced within agricultural and agro-forestry production systems.

Large scale investment – comparable to investment amounts e.g. in the energy sector – is not to be expected for biomass energy production. Investments for small scale, on-farm biomass energy production and investment for biomass plant production could be provided by slightly reshaping investment support schemes already in place, e.g. within the second pillar of the Common Agricultural Policy.

The policy scenarios do not consider measures to reduce non-$CO_2$ GHG emissions as well as measures for carbon sequestration in soils. However, these issues have been covered by this sector study and show the wide potential of existing, often low-cost options.

High-cost mitigation options are associated with land-use change and the related opportunity costs. As an example, this may be described for the restoration of peat soils and wetlands. If this would be done on a large scale in Europe, it would require the purchase of huge areas of land and compensation payments to the former land owners/users and, therefore, large public investment flows. Indeed, the mitigation potential per area for the restoration of peat soils is high, but naturally limited to certain areas, with great variations among regions in the EU. Currently, there are no reliable figures available in the literature to calculate the overall potential of this measure in the EU. For Germany, a recent study (Hirschfeld et al., 2008) estimated the mitigation potential of the restoration of peat soils at 36.9 Mt $CO_2$eq. per year, assuming all peat soils would be included. This would be about 4 % of total GHG emissions in Germany. While it would certainly not be technically feasible to restore all peat soils, at least this shows a considerable potential with large co-benefits. This issue is recommended for further research.

For most of the described mitigation options within the EU agricultural sector there is no or only limited need for major investment flows that would exceed usual investment rates in agricultural holdings. Transaction costs and other non-monetary barriers are of higher significance than investment constraints.

## *5.4 Sectoral policy issues and options*

### 5.4.1 Assessment of current policy instruments

Besides climate policy in the context of the UNFCCC there is a range of other EU policies with significant impacts on climate change mitigation in agriculture. Those with the strongest link are energy policy, environment policy (water, air, soil) and agricultural policy.

#### 5.4.1.1 Energy policy (objective for biofuels)

The major concern of EU energy policy is energy security. The biomass action plan (EU Commission, 2005) intends to more than double the use of biomass in heating, electricity and transport by 2010. In 2007 the Commission proposed further targets, with a 20 % target for all renewables by 2020 (EU Commission, 2007a) and 10 % for biofuels. These targets have been confirmed in the “climate change and renewable energy packet” of January 2008. The target for biofuels has been challenged and heavily criticized by stakeholders and NGOs, because of possible negative impacts on sustainability goals connected with biofuels. To address these concerns the Commission intends to introduce sustainability standards for bioenergy crops and biofuels.

#### 5.4.1.2 Environment policy: water quality, air quality, soil conservation

**Water Quality:** The **Nitrate Directive** aims to protect water bodies against nitrate pollution from agricultural sources. It was adopted in 1991, in 2002 all member states had transposed it into national law, but it still lacks full implementation and proper application. The **Water Framework Directive** (WFD, entering into force in 2005) was designed to improve the management of water bodies and to achieve “good chemical and ecological status” of all water bodies until 2015. Member states have identified river basin districts, set up monitoring programs and are currently working on management plans and programs. These may include measures for aquatic ecosystems and associated wetlands. The implementation of the WFD is highly relevant for mitigation strategies, as wetland soils contain large amounts of organic matter and the management of wetlands determines their function as a carbon source or sink.

**Air quality:** In 2005, the EU defined health and environmental objectives to improve air quality and set emission targets for main pollutants. These include a reduction of $NO_x$ by 60 % and of $NH_3$ by 27 % by 2020 compared with the year 2000. $NO_x$ and $NH_3$ emissions are interconnected with $N_2O$ emissions via N-fluxes. They have the same sources, and instruments to reduce these air pollutants have direct impacts on climate change mitigation.

**Soil directive:** A recent Commissions proposal (EU Commission, 2006a) addresses the problem of soil degradation and erosion. Member states would be obliged to identify areas of risk for erosion, organic matter decline, compaction, salinization and landslides, and to take measures to reduce these risks. One major concern addressed by the soil directive is low organic matter content of cultivated soils. Therefore, its successful implementation could be a central part of a mitigation strategy.

#### 5.4.1.3 Common Agricultural Policy (CAP)

Some of the existing CAP instruments, although designed for other purposes, do already promote mitigation as a side effect, others lead to higher emissions. Instruments that promote mitigation are e.g. agri-environment measures (AEM), payments for modernization of agricultural holdings and machinery, and cross compliance (CC) obligations. Current instruments that counteract mitigation are coupled payments for livestock, export subsidies for animal products and indirect incentives for conversion of grassland to cropland. Most decoupled payments are still insufficiently linked to environmental standards.

As **AEM** are not especially targeted for climate change mitigation, their effects vary and not all necessarily reduce GHG emissions. The ones that have been targeted for soil conservation purposes like reduced tillage or erosion prevention through soil cover will most likely have positive effects on C balances. Others that are clearly targeted towards endangered species may have positive effects on mitigation, especially when targeted at wetlands. Support for organic farming systems offers potential benefits (Fliessbach et al., 2007, Küstermann, 2007, Niggli et al., 2008, Freyer, 2008), as synthetic fertilizers are banned, crop rotation schemes are more diverse and generally include perennial legumes, and maintenance of soil fertility through high soil carbon content is a central objective.

**Payments for modernization of agricultural holdings and machinery** can be used for energy saving technologies, for improved manure management and N-application technologies etc. **Cross compliance (CC) obligations** have been introduced to improve compliance with existing standards and prevent negative side effects of decoupling like abandonment. While the first referred to existing legislation, the latter was newly introduced and consists of rather imprecise language like “minimum soil cover” or “appropriate machinery use”, and therefore is of limited effectiveness. Despite these shortcomings, the introduction of cross compliance has helped to enforce existing legislation, e.g. the nitrate directive. The impact on climate change mitigation remains unclear.

**Coupled payments for livestock production** lead to larger numbers of sheep and cattle and therefore contribute to higher $CH_4$ emissions. **Export subsidies** lead to more intensive livestock production and therefore contribute to higher $CH_4$ and $N_2O$ emissions. **Indirect incentives for conversion of grassland to cropland** have been given in 1992 with the introduction of per-area payments for cropland, and again in 2005 when the single-payment scheme was established, with payment entitlements for cropland being much higher than those for “permanent pasture”.

## 5.4.2 Suggestions for future promotion policies

### 5.4.2.1 Further reform of the Common Agricultural Policy (CAP)

The Common Agricultural Policy has recently undergone an assessment (“health check”). It was decided to shift more financial means into rural development measures (the so-called "second pillar"). The responsibility for implementation is with the member states. The original goal was to adjust the CAP to meet new challenges in the fields of climate change, renewable energies, water management and biodiversity. However, as the health check has led to little additional funding for these new priorities and has not set mandatory objectives for emission reduction or $CO_2$ removals, it is not to be seen as a general shift in rural development measures towards mitigation of climate change. Full use of the mitigation potential in the agricultural sector would require a general screening of existing instruments in both pillars. Further and more fundamental reform of the CAP, possibly including a phase-out of direct payments, may be forthcoming with the beginning of the new programming period from the year 2014 onwards. This would be the appropriate time to fully integrate mitigation measures into the CAP and to reduce current incentives for GHG emissions. AEM could be clearly targeted for climate change mitigation with a result-oriented approach.

### 5.4.2.2 Enforcement of direct regulations

Setting stronger requirements in the framework of water policy (esp. nitrate directive) and soil conservation policy is an option for climate change mitigation, as these policies are very much interrelated and in line with climate change mitigation, but lack full implementation.

Cross compliance obligations can support implementation, but will become less effective with decreasing support levels. Regulations concerning “good agricultural and environmental conditions” also have high potential to promote climate change mitigation, but should be strengthened and transformed into legislation that is likely to prevail beyond existing direct payment schemes.

#### 5.4.2.3 Communication and capacity building

Enforcement of good agricultural practice through direct regulations is very unpopular and an effective monitoring system is costly. Therefore, communication and capacity building for low-emission farm management practices may be more effective. This should be true at least for those practices that support mitigation and at the same time offer benefits for the farmer and/or public goods. Soil-crop systems with their nitrogen and carbon fluxes are highly complex systems. Their management requires know-how and careful monitoring of field conditions for the implementation of best practices at different sites and in different cropping systems.

#### 5.4.2.4 Integrating agriculture in the EU Emission Trading System

Emission trading systems intends to create incentives for investment in emission reduction projects and use price mechanisms to promote abatement on the supply side. The EU $CO_2$ Emissions Trading System (ETS), based on UNFCCC, was introduced in January 2005. Until now, the ETS only covers a selected part of $CO_2$ emissions of relatively large emitters that are easy to monitor. In a communication from January 2007 (EU Commission, 2007a) the EU Commission suggested to strengthen the ETS and extend the scheme to other GHG and sectors. These suggestions have been further elaborated in a legislative proposal (EU Commission, 2008b) to amend the current ETS-directive. Yet, in that proposal the Commission explicitly excludes the agricultural sector from further extension of the ETS and does not allow for credits from carbon sinks (LULUCF projects). Instead, the commission suggests, in a proposal for the so-called “effort sharing decision” (EU Commission, 2008c), to cut overall emissions of sectors not yet included in the ETS by 10 % from 2005 levels by 2020. In relation to GDP, member states would have to fulfill different mandatory reduction obligations, ranging from 20 % reduction (Denmark, Ireland, Luxembourg) to 20 % increase (Bulgaria).

The proposed new ETS-directive would explicitly include $CO_2$ and $N_2O$ emissions from the production of N-fertilizer (nitric acid and ammonia). To extend the scope on N-fertilizer production would increase agricultural production costs. Higher prices for N-inputs could be an incentive for farmers to make use of more efficient nutrient management practices.

The modalities for a potential integration of the agricultural sector into the ETS are unclear and should be further explored. The complex structure of the agricultural sector (large number of relatively small producers, uncertainties in quantifying emissions, variety of sites and farming systems) makes this a challenging task. It has to be assessed whether the benefits outweigh the transaction costs for implementing such a system.

In fact, offset trading with Certified Emission Reductions (CER) from agriculture is already taking place. Globally, a range of agricultural projects which offer credits to farmers for GHG offsets do exist. Most of them are focused on reducing $CH_4$ from livestock wastes in North America (Canada, Mexico, US), Latin America (Brazil), China and Eastern Europe (Smith et al., 2007b). Some of these projects use the Clean Development Mechanism (CDM). Offset trading with carbon sequestration does also exist, but is currently not supported by

CDM. For $N_2O$ emissions there seem to be no projects yet, but in principle they could be included in existing schemes.

#### 5.4.2.5 Other marked oriented instruments

**Taxation and levies:** Similar to an emission trading system, a tax or levy on emission-intensive inputs or emissions would increase production costs and set price signals on the supply side to promote sustainable production and emission abatement. An EU-wide taxation of nitrogen has often been proposed by environmental NGOs to tackle the problem of nitrate leaching. It has never been realized at EU level, although in some European countries different nitrogen taxation policies are (or have been) in place. Taxation schemes may be applied to mineral fertilizers, N-surplus at the farm level, number of livestock units, or external feedstuff.

Market-oriented approaches are considered to be more efficient than direct regulation, although effectiveness depends on relative prices. With the implementation of the nitrate directive (see above) the non-marked approach currently dominates. With a large number of small producers (emitters), the administration of a tax would probably be much easier to manage at lower transaction costs compared to an emission trading system (Frelih-Larsen, 2008).

**Carbon labeling** addresses the issue from the demand side: As the “carbon footprint” of food products varies widely (von Koerber et al., 2007), consumption and dietary patterns (demand side) significantly influence the mitigation potential of the agricultural sector (supply side). Information and awareness-raising on the consumer side offers opportunities for a marked-oriented approach towards a climate-friendly agriculture and food chain (von Witzke, Noleppa, 2007).

Carbon labeling could be realized as a single issue labeling or integrated into a broader food labeling scheme, including other environmental impacts such as water use, waste production, or biodiversity. The PICCMAT-Project recommends the latter (Frelih-Larsen, 2008) and suggests connecting it with the existing standard and monitoring system for organic farming in the EU. Labeling schemes for climate impacts do already exist in the UK and Germany, and are forthcoming in Sweden, France and Japan. While first approaches focused on transport (e.g. “food miles”, “air miles”, campaigning for locally grown food), the new labeling initiatives, based on life cycle analysis (LCA), follow a holistic approach. This is highly relevant with regard to impacts on trade with developing countries (Shah, 2008).

Neufeld et al. (2008) analyzed the impacts of four different policy options (emission cap, emission tax, nitrogen tax, less intensive animal farming) on costs for farmers, macroeconomic costs, administrative costs and environmental benefits. They found that all options had advantages as well as disadvantages and suggest a mixed approach.

## *5.5 Possible lines of future research*

Future research on climate mitigation in agriculture should focus on the following four subjects: net-benefit of mitigation options, interplay between adaptation and mitigation, improvement of the available data base, and identification of policy constraints for mitigation in the agricultural sector.

**Net-benefit of mitigation options**

The net-benefit of many mitigation options in agriculture is difficult to estimate, because they cannot be assessed separately. They interact either with each other in terms of GHG emissions and cost of production, or do affect other sustainability goals such as poverty reduction, food security, or water and biodiversity conservation. For example, herd reduction, based on a shift in human diets, is seen as the most prominent mitigation strategy for $CH_4$ from ruminant livestock (Thorpe, 2008). However, it remains unclear to what extent a diet shift away from a ruminant products would increase pork and poultry consumption and, hence, the pressure on arable land, or how it would affect already over-exploited fish populations. The size of the net GHG effect of dietary shifts is a pressing research question.

The development of robust mitigation strategies also requires an in-depth analysis of risks associated with bioenergy. Bioenergy carriers will increase the competition for land, water, and other inputs. They contribute to increasing prices of food, may have negative impacts on landless populations and net-food buyers in developing countries, but they have positive effects for landowners. Therefore, concerns about the sustainability of bioenergy are growing, including land-use emissions and deforestation, water use and biodiversity issues. A careful and integrated assessment of such interlinked impacts is of key importance for an optimization of land-use related mitigation strategies.

### Interplay between adaptation and mitigation

There are many interactions between adaptation and mitigation in the agricultural sector. Climate change has a direct impact on crop yields, livestock health, and changes in soil carbon, resulting from microbial decomposition. Related adaptation measures, such as shifts in crop rotations and the crop mix, tillage practices, and irrigation will in turn alter GHG emissions and the mitigation potential of the agricultural sector. On the other hand, the introduction of new crop species for bioenergy production, especially perennials for short-rotation forestry, can increase adaptive capacity to climate extremes (droughts, floods) in many agricultural production systems. Therefore, relevant interactions between adaptation and mitigation, but also the impacts and side effects of such interplays on costs and other sustainability goals need to be identified, evaluated and properly addressed.

### Improvement of the available data base

The basis for detailed and profound recommendations for appropriate mitigation policies in the agricultural sector is the availability of sound data, especially on emission parameters and mitigation costs. Research on agricultural mitigation options is a relatively young topic. Rough global and (sub-)continental assessments are already available. However, details are missing at the regional and local level. Agricultural mitigation will only work effectively if the applied measures fit the local production conditions (structure and quality of soils, water availability, knowledge base of farmers, availability of technologies, etc.). For this, a much broader knowledge base than currently available is needed.

### Policy constraints

Various policy options are available to push agricultural mitigation of GHG emissions. However, all of these policies have advantages and disadvantage. Most of them are subject to potentially severe trade-offs. Less intensive farming practices, with lower nitrogen inputs and lower livestock density, could reduce agricultural emissions, but lower average yields would also increase the pressure to expand current cropland to fulfill rising global food demand. Increased bioenergy production would reduce the use of fossil fuels, but increased intensity in agricultural production will lead to higher emissions. Transaction costs for some policy measures may be especially high in the agricultural sector, and particularly in developing countries. From this perspective the agricultural sector may require special treatment. More integrated policy assessments are required at the regional and global level, including exercises in priority setting, in order to come up with a viable and socially acceptable policy mix for climate change mitigation in agriculture.

## *5.6 Conclusions*

There is a range of mitigation options for the agricultural sector available at low, zero or even negative costs. As non-price-related barriers form a considerable part of overall limitations, measures to overcome these barriers are crucial for a climate change mitigation strategy in agriculture. Due to potentially high transaction costs, an expansion of the emission trading system to the agricultural sector may not be the most efficient way to fully use the available mitigation potentials. In the past, emission reduction was already successfully driven by other policy instruments. But this is true only with regard to EU agriculture, not at the global level. The authors of this study confirm the recommendations of the PICCMAT-Project (Frelih-Larsen et al., 2008) that a strategy for climate change mitigation in European agriculture should be an integral part of a wider approach for promotion of sustainable agriculture and rural development. To guarantee coherence in overall EU policy, agricultural mitigation measures should be consistent with sustainability goals e.g. in environment policy and development policy. While many measures offer co-benefits with respect to other sustainability goals, some also have trade-offs and may lead to severe adverse effects. A mere technical and one-sided approach to mitigation options could therefore be misleading. Agriculture in the future may face a high demand for emission offsets, if it can verifiably mitigate GHG emissions at relatively low costs (Schneider and McCarl, 2003). However, ambitious mitigation efforts on large parts of the agricultural land would strongly affect agricultural production, prices, and welfare.

## References


Alberola, E., J. Chevallier and B. Chèze (2008): The EU Emissions Trading Scheme: Disentangling the Effects of Industrial Production and $CO_2$ Emissions on Carbon Prices. Economix Working Paper 2008-12.

Auer, H., C. Obersteiner, W. Prüggler, L. Weissensteiner, T. Faber and G. Resch (2006): Guiding a Least Cost Grid Integrtion of RES-Electricity in an extended Europe. GreenNet-Europe Action Plan. EU-funded project. http://www.greennet-europe.org

Bamiere, L., J. C. Bureau, L. Guinde, H. Guyomard, F. Jacquet and D. Treguer (2007): Prospects for EU Biofuel Production and Trade. TRADEAG Working Paper 07/12 Paris: INRA.

Barz, M., W. Wichtmann, M. Ahlhaus and T. Timmermann (2007): Utilisation of common reed as energy source. 15th European Biomass Conference Exhibition, 1-11 May, Berlin.

Bates, J. (2001): "Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in Agriculture in the EU: Bottom-up Analysis," Contribution to a Study for DG Environment, European Commission by Ecofys Energy and Environment, AEA Technology Environment and National Technical University of Athens.

van den Berg, J.C. (1996): The forces that drive research and development in the steel industry. Iron making and Steelmaking 23 (4), 309–316.

Birat J.-P. (2002): Innovation paradigm for the steel industry of the 21st century, future directions for the steel industry and climate change. Dr Manfred Wolf Symposium, May 10-11, Zürich, p. 102-28.

Bringezu, S., S. Ramesohl, K. Arnold, M. Fischedick, J. v. Geibler, C. Liedtke and H. Schütz (2007): What We Know and What We Should Know: Towards a Sustainable Biomass Strategy. Wuppertal Papers No. 163. Wuppertal: Wuppertal Institute.

Brink, C.; E. van Ierland, L. Hordijk and C. Kroeze (2005): Cost-effective emission abatement in agriculture in the presence of interrelations: cases for the Netherlands and Europe, Ecological Economics 53, pp 59– 74

Brown, L. R. (1995): Who Will Feed China? Washington, D.C.: World Watch Institute.

Calleja, I., L. Delgado, P. Eder, A. Kroll, J. Lindblom, C. van Wunnik, O. Wolf, F. Gouarderes and J. Langendorff (2004): Promoting environmental technologies: sectoral analyses, barriers and measures, Report from the Sustainable Production and Consumption Issue Group as a contribution to the Environmental Technologies Action Plan, Report EUR 21002 EN.

CE Delft, Germanischer Lloyd, MARINTEK and Det Norske Veritas (2006): Greenhouse Gas Emissions for Shipping and Implementation Guidance for the Marine Fuel Sulphur Directive

CE (2005): Giving wings to emission trading: Inclusion of aviation under the European Emission Trading System (ETS): Design and impacts; Delft

Cembureau (Association Européenne du Ciment) (2008): Activity report.

Cembureau (Association Européenne du Ciment) (1997): Activity report.

Cohen, B. (2006): Urbanization in Developing Countries: Current Trends, Future Projections, and Key Challenges for Sustainability. In: Technology in Society 28, p. 63-80.

Couwenberg J, J. Augustin, D. Michaelis and H. Joosten (2008): Emission reductions from rewetting of peatlands - Towards a field guide for the assessment of greenhouse gas emissions from Central European peatlands. Unpublished Report, RSPB, London. 28pp.

Crassous, R., O. Sassi, H. Waisman, J.-C. Hourcade, P. Criqui, P. Mima, and A. Kitous (2007): 'Prospects for Energy-Intensive Industries under a 450 ppm $CO_2$ constraint: lessons from an IMACLIM-POLES dialog', International Energy Workshop, 25-27 June 2007, Stanford University, Stanford, California

De Cara, S., M. Houzé and P.A. Jayet (2005): Methane and Nitrous Oxide Emissions from Agriculture in the EU: A Spatial Assessment of Sources and Abatement Costs. Environmental & Resource Economics 32: 551–583

Demailly D. (2008): Compétitivité et fuites de carbone dans l'industrie sous politique climatique asymétrique, thèse de doctorat, CIRED.

Demailly, D. and P. Quirion (2005): The competitiveness impacts of $CO_2$ emissions reductions in the cement sector, Report for the OECD, SMASH/CIRED

DG TREN (European Commission - Directorate-General for Energy and Transport) (2005): European Energy and Transport. Trends to 2030 - update 2005

DG TREN (European Commission - Directorate-General for Energy and Transport) (2008a): Pocketbook, statistical data from the website: http://ec.europa.eu/dgs/energy_transport/figures/pocketbook, site visit: 7 July 2008

DG TREN (European Commission - Directorate-General for Energy and Transport) (2008b): European Energy and Transport. Trends to 2030 - update 2007, http://ec.europa.eu/dgs/energy_transport/figures/trends_2030_update_2007/energy_transport_trends_2030_update_2007_en.pdf, site visit: 10 July 2008

DLR (German Aerospace Center) (2006): Trans-CSP - Trans-Mediterranean Interconnection for Concentrating Solar Power, Institute of Technical Thermodynamics, Stuttgart, Germany.

Dornburg, V., A. Faaij, P. Verweij, H. Langeveld, G. van de Ven, F. Wester, H. van Keulen, K. van Diepen, M. Meeusen, M. Banse, J. Ros, D. van Vuuren, G. J. van den Born, M. van Oorschot, F. Smout, J. van Vliet, H. Aiking, M. Londo, H. Mozaffarian and K. Smekens (2008): Biomass assessment – Assessment of global biomass potentials and their links to food, water, biodiversity, energy demand and economy; Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change (WAB)

EEA (European Environment Agency) (2005): TERM 2005 Fact Sheets; Copenhagen

EEA (European Environment Agency) (2006): Transport and environment: facing a dilemma, TERM 2005: indicators tracking transport and environment in the European Union, European Environmental Agency, EEA report No 3/2006; Copenhagen

EEA (European Environment Agency) (2007): Transport and environment: on the way to a new common transport policy – TERM 2006: TERM, indicators tracking transport and environment in the European Union, EEA; Copenhagen

EEA (European Environment Agency) (2008a): Climate for a transport change - TERM 2007: indicators tracking transport and environment in the European Union, Copenhagen: European Environment Agency, 2008

EEA (European Environment Agency) (2008b): Greenhouse gas emission trends (CSI 010) -

Assessment published in February 2008 http://themes.eea.europa.eu/IMS/ISpecs/ISpecification20040909113419/IAssessment1195226181050/view_content, site visit: 21 March 2008; Copenhagen

EEA (European Environment Agency) (2008c): “Annual European Community greenhouse gas inventory 1990-2006 and inventory report 2008”. Submission do the UNFCCC Secretariat EEA Technical report No 6/2008.Copenhagen.

van Essen, H. P. (2008): The environmental impacts of increased international road and rail freight transport - past trends and future perspectives, Delft

EU Commission(2003): World Energy Technology and Climate Policy Outlook 2030. EUR 20366.

EU Commission (2005): ”Communication from the Commission of 7 December 2005 - Biomass Action Plan”, Brussels.

EU Commission (2006a): Proposal for a European Parliament and Council Directive of 22 September 2006 setting out a framework for soil protection and amending Council Directive 2004/35/EC.

EU Commission (2006b): World Energy Technology Outlook 2050, WETO H2. EUR 22038.

EU Commission (2007a): Communication: "Limiting Global Climate Change to 2 degrees Celsius. The way ahead for 2020 and beyond", Brussels, 10. January 2007.EC 2006: “Proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC”, Brussels.

EU Commission (2007b): Communication from the Commission to the Council and the European Parliament. Biofuels progress report. Report on the progress made in the use of biofuels and other renewable fuels in the Member States of the European Union, COM(2006) 845 final, Brussels, 10.01.2007; Brussels

EU Commission (2008a): Prospects for agricultural markets and income in the European Union 2007 – 2014. Brussels: EC.

EU Commission (2008b): “Proposal for a Directive of the European Parliamnent and of the Council amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading system of the Community” Brussels, 23. January 2008.

EU Commission (2008c): “Proposal for a Decision of the European Parliament and of the Council on the effort of Member States to reduce their greenhouse gas emissions to meet the Community’s greenhouse gas emission reduction commitments up to 2020”, Brussels, 23. January 2008.

EU Commisssion (2008d): European energy and transport trends to 2030 - Update 2007. European Commission Directorate-General for Energy and Transport. Brussels.

FAO (Food and Agriculture Organization of the United Nations) (2006): World Agriculture towards 2030/2050: Interim Report. Rome: FAO.

FAO (Food and Agriculture Organization of the United Nations) (2008): FAOSTAT. Rome: FAO. (www.faostat.fao.org of 22/06/08)

FAPRI (Food and Agricultural Policy Research Institute) (2008): FAPRI Searchable Outlook Database. Ames: FAPRI. (www.fapri.iastate.edu/tools/outlook.aspx of 22/06/08)

Fliessbach, A., H.-R. Oberholzer, L. Gunst and P. Mäder (2007): Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. Agriculture, Ecosystems & Environment 118, S. 273–284.

Frelih-Larsen, A., A. Leipprand, S. Naumann and O.S. Beucher (2008): “PICCMAT backround paper for stakeholder consultation workshop in Brussels, June 25 2008: Climate change Mitigation in Agriculture - Policy options for the Future”, Ecologic, institute for International and European Environmental Policy, Berlin.

Freyer, B. (2008): The impact of different nutrition patterns and agricultural production sytems on greenhouse-gas emissions. In: Enita Clermont (Hrsg.), International scientific and professionnal conference; Organic agriculture and climate change, The contribution that organic agriculture and our dietry choices can make to the mitigation of global warming, International scientific and professionnal conference; Organic agriculture and climate change, 17.-18.04.2008, Enita Clermont Lempdes.

Gallager, E. (2008): The Gallagher Review of the indirect effects of biofuels production; Renewable Fuels Agency

Gerbens, S. (1998): Cost-effectiveness of methane emission reduction from enteric fermentation of cattle and buffalo, Draft Report, August 5, 1998, Department of Agricultural, Environmental and Systems Technology (AEST), Agricultural University Wageningen, the Netherlands.

Gielen, D. (2009): Energy Technology Perspectives. Presented at the IV Congress of the Spanish Association for Energy Economics. January 2009.

Graham, D.J. and S. Glaister (2002): The demand for automobile fuel - A survey of elasticities. Journal of Transport Economics and Policy. Volume 36, Part 1. p. 1-26

Graichen, V., K. Schumacher, F. Matthes, L. Mohr, V. Duscha, J. Schleich and J. Diekmann (2008): Impacts of the EU Emissions Trading Scheme on the industrial competitiveness in Germany, Environmental Research of the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, Research Report 3707 41 501.

Hanly, M., J. Dargay and P. Goodwin (2002): Review of income and price elasticities in the demand for road traffic - ESRC TSU publication 2002/13, ESRC Transport Studies Unit Centre for Transport Studies, University College, London.

Henning, C. (2008): The Health Check: A Starting Point of the End of the ’old CAP’?. In: Agrarwirtschaft 57, p. 149-154.

Hirschfeld, J., J. Weiß, M. Preidl, T. Korbun (2008): Klimawirkungen der Landwirtschaft in Deutschland. Schriftenreihe des IÖW (Institut für ökologische Wirtschaftsforschung) 186/08. Berlin.

Howarth, R.W. and S. Bringezu (2009): Biofuels: Environmental Consequences and Implications of Changing Land Use. Proceedings of the Scientific Committee on Problems of the Environment (SCOPE) International Biofuels Project Rapid Assessment, 22-25 September 2008, Gummersbach, Germany.

IEA (2004a): International Energy Agengy, World Energy Outlook 2004. In: IPCC (2007): IPCC Fourth Assessment report. Working Group III Report "Mitigation of Climate Change"; Cambridge University Press, Cambridge, United Kingdom

IEA (2004b): International Energy Agency, Energy Technologies for a Sustainable Future: Transport, Technology Brief. In: IPCC (2007): IPCC Fourth Assessment report. Working Group III Report "Mitigation of Climate Change"; Cambridge University

Press, Cambridge, United Kingdom

IEA (2007a): World Energy Outlook 2007. Paris.

IEA (2007b) Sectoral approaches to greenhouse gas mitigation: exploring issues for heavy industry, appendix 3 – Policy overview and key statistics for cement, aluminium, iron and steel.

IEA (2008a): World Energy Outlook 2008. Paris.

IEA (2008b): Energy Technology Perspectives 2008 - Scenarios and Strategies to 2050, OECD/IEA, Paris.

IEA (2008c): Deploying renewables. Principles for effective policies. Paris.

IISI (International Iron and Steel Institute) (2008a): World Steel in Figures 2008.

IISI (International Iron and Steel Institute) (2008b): IISI Short Range Outlook, Media release, 14 Apr 2008.

IISI (International Iron and Steel Institute) (2007): World Steel in Figures 2007.

IPCC (2007): Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jaffe, A.B., R. Newell and R. Stavins (2005): "A tale of two market failures: technology and environmental policy". Ecological Economics 54 (2–3), 164–174.

Jakob, M., H. Waisman, V. Bosetti, E. De Cian, M. Leimbach and L. Baumstark (2009a): Description of the RECIPE models. RECIPE Background Paper. Available online at http://www.pikpotsdam.de/recipe

Jakob, M., V. Bosetti, H. Weisman, E. De Cian, J. Steckel, M. Leimbach and L. Baumstark (2009b): The RECIPE reference scenarios. RECIPE Background Paper. Available online at http://www.pik-potsdam.de/recipe

JRC, concawe, EUCAR (2007): WELL-to-WHEELS Report Version 2c, March 2007 available online: http://ies.jrc.ec.europa.eu/WTW

Kampman, B., M. D. Davidson and J. Faber (2008): Emission trading and fuel efficiency in road transport – An analysis of the benefits of combining instruments; Swedish Environment Protection Agency, report 5896, November 2008

King, J. (2007): The King review of low carbon cars – Part I The potential for $CO_2$ reduction; UK Treasury, October 2007.

King, J. (2008): The King review of low carbon cars – Part II Recommendations for action; UK Treasury, March 2008.

von Koerber, K., J. Kretschmer and M. Schlatzer (2007): „Ernährung und Klimaschutz – wichtige Ansatzpunkte für verantwortungsbewusstes Handeln." In: ernährung im focus 7-05/07, aid, bonn.

Küstermann, B., M. Kainz and K.-J. Hülsbergen (2007): Modeling carbon cycles and estimation of greenhouse gas emissions from organic and conventional farming systems. Renewable Agriculture and Food Systems. 23: 1-16.

Luderer, G. ,V. Bosetti, J. Steckel, H. Waisman, N. Bauer, E. De Cian, M. Leimbach, O. Sassi and M. Tavoni (2009): The Economics of Decarbonization – A global perspective. RECIPE Background Paper. Available online at http://www.pikpotsdam.de/recipe

Luiten E. and K. Blok (2003): Stimulating R&D of industrial energy-efficient technology; the effect of government intervention on the development of strip casting technology. Energy Policy, 31, 1339–1356.

McKinsey (2007): Curbing Global Energy Demand Growth: The Energy Productivity Opportunity, Industrial Sector.

Meyer, A. (2004): Briefing: Contraction and Convergence. Engineering Sustainability (157). Issue 4, p. 189-192

Mitchell, C., D. Bauknecht and P. M. Connor (2006): “Effectiveness through risk reduction: a comparison of the renewable obligation in England and Wales and the feed-in system in Germany”. Energy Policy, 34(3), 297-305.

Mittal, S. (2006): Structural Shift in Demand for Food: Projections for 2020. Working Paper No. 184. New Delhi: Indian Council for Research and International Economic Relations.

MNP, UNEP-WCMC, UNEP-GRID Arendal, LEI-WUR (2008): Cross-roads of Planet Earth’s Life, Exploring means to meet the 2010 biodiversity target, Study performed for the Global Biodiversity Outlook 2. 2008.

Neij, L. (2007): “Cost Development of Energy Technologies – an Analysis Based on Experience Curves”. NEEDS (New Energy Externalities Developments for Sustainability), report prepared for the European Commission, www.needsproject.org

Neufeldt, H. and M. Schäfer (2008): Mitigation strategies for greenhouse gas emissions from agriculture using a regional economic-ecosystem model. Agriculture, Ecosystems and Environment, 123 (4), 305-316.

Neuhoff, K., S. Dröge, O. Edenhofer, C. Flachsland, H. Held, M. Ragwitz, J. Strohschein, A. Türk and A. Michaelowa (2009): Translating model results to economic policies, RECIPE Background Paper, available at http://www.pik-potsdam.de/recipe

Newell, R. (2008): A U.S. innovation strategy for Climate Change Mitigation. The Brookings Institution. Washington D.C.

Niggli, U., A. Fliessbach, P. Hepperly and N. Scialabba (2008): Low greenhouse gas agriculture: mitigation and adaptation potential of sustainable farming systems. FAO, Rome, 13 pages.

Nowicki, P., C. Weeger, H. van Meijl, M. Banse, J. Helming, I. Terluin, D. Verhoog, K. Overmars, H. Westhoek, A. Knierim, M. Reutter, B. Matzdorf, O. Margraf and R. Mnatsakanian (2006): SCENAR 2020: Scenario Study on Agriculture and the Rural World. Brussels: EC.

Ocean Shipping Consultants (2006): Cement: Consumption Growth Ahead, Press Release. (available at: http://www.osclimited.com/releases/cementto2020.pdf)

OECD (Organization for Economic Co-operation and Development) (2007): OECD Steel Committee sees favourable outlook for steel demand: the global steel industry faces important challenges, Statement by the chairman of the OECD Steel Committee, Istanbul, Turkey, 17-18 May 2007.

OECD (Organization for Economic Co-operation and Development) (2008): Economic Assessment of Biofuel Support Policies. Paris: OECD.

OECD (Organization for Economic Co-operation and Development) and FAO (Food and Agriculture Organization of the United Nations) (2007): OECD-FAO Agricultural Outlook 2007-2016. Paris: OECD.

OECD (Organization for Economic Co-operation and Development) and FAO (Food and Agriculture Organization of the United Nations) (2008): OECD-FAO Agricultural Outlook 2008-2017. Paris: OECD.

OECD Secretariat (2008): Steel committee crude steel making capacities developments.

Pielke Jr., R., T. Wigley and C. Green (2008): Dangerous Assumptions. Nature 452, 531-532

PRB (Population Reference Bureau) (2007): 2007 World Population Data Sheet. Washington, D.C.: PRB.

Raad voor het landelijk gebied (2008): The Implementation of the CAP and Visions of its Future Role across 27 EU Member States. Utrecht: RAAD

Reinaud, J. (2004): Industrial Competitiveness under the European Union Emissions Trading Scheme. IEA Information Paper: December 2004.

Rennings, K. (2000): Redefining innovation-eco-innovation research and the contribution from Ecological Economics. Ecological Economics 32, 319–332.

Del Río, P. and Labandeira, X. (2009): Barriers to the introduction of market-based instruments in climate policies: an integrated theoretical framework. Environmental Economics and Policy Studies 10: 41–68.

Rose, S., H. Ahammad, B. Eickhout, B. Fisher, A. Kurosawa, S. Rao, K. Riahi, and D. van Vuuren, (2007): Land in Climate Stabilization Modeling. Energy Modeling Forum Report, Stanford University.

Runge, C. F., Senauer, B., P. G. Pardey and M. W. Rosegrant (2003): Ending Hunger in Our Lifetime. Baltimore: Johns Hopkins University Press.

Russ, P., T. Wiesenthal, D. van Regemorter and J. C. Ciscar (2007): Global Climate Policy Scenarios for 2030 and beyond. Analysis of GHG Emission Reduction Pathway Scenarios with the POLES and GEM-E3 models. JRC Reference Reports. EUR 23032 EN.

Ruttan, V.W. and H. von Witzke (1988): International Agricultural Policy Coordination. In: Atlantic Community Quarterly 26, p. 321-329.

Schmidhuber, J. and P. Shetty (2005): The Nutrition Transition to 2030: Why Developing Countries are Likely to Bear the Major Burden. Paper presented at the 97th Seminar of the EAAE. Reading: University of Reading.

Schneider U.A. and B. A. McCarl (2003): Economic Potential of Biomass Based Fuels for Greenhouse Gas Emission Mitigation", Environmental and Resource Economics, volume 24, p. 291-312(22)

Shah, H. (2008): The Carbon Footprint in Agricultural Trade. Backround Paper for the stakeholder dialogue “The Future of Agriculture”, Barcelona, 30th/31th May 2008, WTO, University of Barcelona, International Centre for Trade and Sustainable Development (ICTSD) and International Food and Agricultural Trade Policy Council (IPC), ICTSD

Sheehan, P. and F. Sun (2008): Emissions and economic development: Must China choose?, in R. Garnaut, L. Song and Wing Thye Woo (eds), China’s Dilemma: Economic Growth, the Environment and Climate Change, jointly published by Asia Pacific

Press, Canberra, the Brookings Institution Press, Washington DC, and Social Sciences Academic Press (Chinese translation), Beijing.

Smith, P., D. Martino, Z. Cai, D. Gwary, H.H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, R.J. Scholes, O. Sirotenko, M. Howden, T. McAllister, G. Pan, V. Romanenkov, U. Schneider, S. Towprayoon, M. Wattenbach, and J.U. Smith (2007a): Greenhouse gas mitigation in agriculture. Philosophical Transactions of the Royal Society, B., 363. doi:10.1098/rstb.2007.2184.

Smith, P., D. Martino, Z. Cai, D. Gwary, H.H. Janzen, P. Kumar, B.A. McCarl, S.M. Ogle, F. O'Mara, C. Rice, R.J. Scholes, O. Sirotenko, M. Howden, T. McAllister, G. Pan, V. Romanenkov, U.A. Schneider and S. Towprayoon (2007b): Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. Agriculture, Ecosystems and Environment, 118, pp. 6-28.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes and O. Sirotenko (2007c): Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Thorpe A. (2008): Enteric fermentation and ruminant eructation: the role (and control?) of methane in the climate change debate. Climatic change (in press). DOI: 10.1007/s10584-008-9506-x

Toke, D. and A. Fragaki (2008): "Do liberalized electricity markets help or hinder CHP and district heating? The case of the UK". Energy Policy 36 (2008) 1448–1456.

USGS (U.S. Geological Survey) (2008): Mineral Commodity Summaries 2008.

USGS (U.S. Geological Survey) (1998): Mineral Commodity Summaries 1998.

UNFCCC (2007): Investment and financial flows to address climate change

United States Census Bureau (2008): Total Midyear Population for the World: 1950-2050. (www.census.gov/ipc/www/idb/worldpop.html of 25/06/08).

U.S. EIA/DOE (2008): International Energy Outlook 2008. Energy Information Administration Office of Integrated Analysis and Forecasting. U.S. Department of Energy Washington.

USDA (United States Department of Agriculture) (2007): USDA Agricultural Projections to 2016. Washington, D.C: USDA.

USDA (United States Department of Agriculture) (2008): USDA Agricultural Projections to 2017. Washington, D.C: USDA.

US-EPA (2006): Global Mitigation of Non-$CO_2$ Greenhouse Gases. United States Environmental Protection Agency, EPA 430-R-06-005, Washington, D.C. http://www.epa.gov/nonco2/econ-inv/downloads/GlobalMitigationFullReport.pdf accessed 26 March 2007.

Verbruggen, A. (2008): "Renewable and nuclear power: A common future?". Energy Policy 36, 4036-4047

Vieillefosse, A. (2007): Des Accords Sectoriels dans les Engagements Post-2012? Série Etudes 07-E02, Ministère de l'Ecologie et du Développement Durable, direction des études économiques et de l'évaluation environnementale.

Watson, C., J. Newman, R.H.T. Upton and P. Hackmann (2005): Can Transnational Agreements Help Reduce GHG Emissions? Round Table on Sustainable Development, OECD, Paris.

WBCSD (World Business Council for Sustainable Development) (2004): Mobility 2030: Meeting the Challenges to Sustainability. In: IPCC (2007): IPCC Fourth Assessment report. Working Group III Report "Mitigation of Climate Change"; Cambridge University Press, Cambridge, United Kingdom

WBGU (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltfragen) (2009): World in Transition – Future Bioenergy and Sustainable Land Use. Earthscan, London.

Wehnert, T. (2004): EurEnDel. Technology and Social Visions for Europe’s Energy Future - A Europe-wide Delphi Study. European Union research project funded under the 5th RTD Framework Programme

Wichtmann, W. (2008): Standortgerechte Landnutzung auf wiedervernässten Mooren. Presentation. Conference „Landnutzung und Klimawandel“, IÖW (Institut für ökologische Wirtschaftsforschung), 19.11.2008, Berlin, not published.

Wichtmann, W. and H. Joosten (2007): Padiculture: peat formation and renewable resources from rewetted peatlands. IMCG (International Mire Conservation Group) newsletter, issue 2007/3, pp. 24-28, Greifswald.

von Witzke H. and S. Noleppa (2007): Methan und Lachgas: Die vergessenen Klimagase. Wie die Landwirtschaft ihren Beitrag zum Klimaschutz leisten kann. Frankfurt am Main: WWF

von Witzke, H., S. Noleppa and G. Schwarz (2008): Global Agricultural Market Trends and Their Impacts on European Union Agriculture. Working Paper 84. Berlin: Humboldt-Universität zu Berlin.

World Bank (2008): Rising food prices: Policy options and World Bank response - Background note

WRI (World Resources Institute) (2005): Navigating the Numbers.

WTO (World Trade Organization) (2007): Draft Modalities for Agriculture. Geneva: WTO

WWI (Worldwatch Institute) (2006): Biofuels for transportation, global potential and implications for sustainable agriculture and energy in the 21st century; Washington