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Deliverable M1.2

Report of the Reference and 2°C Scenario for Europe

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0 Executive Summary

Objectives and methodological approach of M1

The core objective of Work Package Mitigation 1 (M1) of the ADAM project is *to simulate* the possible development corridor between adaptation and *mitigation options and their related costs for Europe until 2050 and 2100, respectively*. As Europe obviously forms part of global emission activities, the analysis of Workpackage M1 also depends on the economic and policy assumptions and results of Workpackage M2 (covering the rest of the world), the results of the Work Package Scenarios (impacts of climate change) and the Work Domain Adaptation (WP A1 and A2) regarding the impacts of and adaptation to climate change of the European energy system. The methodology used here in this workpackage makes it possible to *quantify the adaptation costs of the European energy system* until the middle of this century which are reported in this deliverable, but also the mitigation costs of the European energy system to be published in May 2009.

The European countries are presently at different stages in their techno-economic development. Whereas some countries have highly developed infrastructures, few basic industries, and more than two thirds of their GDP generated by services, some of the central European countries are still lagging behind this development. Nevertheless, the expected economic growth and related use of energy may not necessarily involve a related increase in energy demand, since the efficiency of energy use in these countries is relatively low in many cases at present.

The *objective of this deliverable* is to report on the findings of two scenarios of future European greenhouse gas emissions until 2050 in a *Reference Scenario and – to a limited extent - a 2°C Scenario.*

- The *Reference Scenario* is an explorative scenario, which assumes constant present policy trends in energy and a moderate climate policy resulting in a 4°C average surface temperature increase during this century. It reflects the adaptation costs of the European energy system due to climate change by comparing the cost of energy demand and supply between the Reference Scenario and a Base Case Scenario - which assumes the same boundary conditions (e.g. population, economic growth) as the Reference Scenario but with no climate change at all. The Reference Scenario also represents the reference line for calculating the mitigation cost of the 2°C Scenario.
- The *2°C Scenario* is a mitigation scenario reflecting extensive mitigation policies at the global – and European - level, targeting the stabilisation of atmospheric CO_2 concentrations. Two variants are considered: Variant 1 assumes stabilisation of atmospheric CO_{2e} concentration at 450 ppm (50 % probability of reaching an average global surface temperature increase of 2°C) and Variant 2 assumes stabilisation of the CO_{2e} concentration at 400 ppm (80% probability of reaching +2°C).

The methodology chosen to analyse and project the potentials, costs, and impacts of possible adaptation and mitigation options is a *hybrid model system (HMS)* (see Deliverable M1.1; Chapter 2, Jochem et al. 2007). This system has three different macroeconomic models used for different time horizons (2000 to 2030, 2030 to 2050, and 2050 to 2100), and several bottom-up models at the process-oriented level which cover individual sectors in detail, technologies like renewables or power plants, or some sectors together at a higher level of aggregation. Finally, a material flow model as well as a forest model were applied to simulate the production of energy-intensive basic products at the physical level and to explore the limits of wood use in Europe (for an overview of the hybrid model system, see Figure 2-2).

Boundary conditions of the Reference Scenario

The boundary conditions of the macroeconomic models were partly taken as a given external development adopted from Work Package Scenarios (WP S) and partly calculated by one of the models, e.g. energy prices on the world markets by POLES. The European population projections were taken from WP S; they project a stagnating *population* between 2015 and 2030 and a 4 % reduction in 2050 compared to the year 2000 (see Table 0-1).

Table 0-1: Population of Europe (EU27 + CH and N), all scenarios, 2000 to 2050 [1000 person]

	2000	2015	2030	2050
Population (without Bulgaria and Romania)	464,449	477,190	476,800	455,350
Population (including BG and RO)	496,420	506,300	502,230	477,200

Source: Figures taken from Work Package Scenarios of ADAM

The economic development expressed using the *Gross Domestic Product (GDP*) in constant prices of 2000 increases, but at a declining rate from 2.2 % yearly for the first 15 years then 1.8 % for 2015 to 2030 and 1.3 % per year for 2030 to 2050 (see Table 0-2). Economic growth of the manufacturing sector reflects almost the average of the European GDP growth, while agriculture is below average and the service sector above average; this means the share of the servce sector in GDP will continue to increase in the future. The overall growth in GDP per capita in Europe amounts to 570 € per capita and year between 2000 and 2050. This figure has also been observed over the last 50 years in the EU-15 countries.

Table 0-2: Gross Domestic Product (GDP) and value-added of European economic sectors, Base Case and Reference Scenarios, 2000 to 2050, in $€_{2000}$

Sector	2000	2015	2030	2050	2015/ 2000 %/a	2030/ 2015 %/a	2050/ 2030 %/a
Total GDP	**9 541 928**	**13 252 090**	**17 277 160**	**22 369 700**	**2.2**	**1.8**	**1.3**
-agriculture	297 021	315 020	353 660	468 680	0.4	0.8	
-manufacturing	1 691 195	2 316 350	3 107 510	4 400 670	2.15	1.9	
-services	6 701 862	9 733 110	12 641 410	18 117 330	2.19	1.62	

Source: Results from E3ME for 2000 to 2030 and from ASTRA for 2030 to 2050

Global *oil prices* were projected by the POLES model (and converted to nominal prices assuming a 2 % annual global inflation rate). The price of world nominal crude oil rises from \$70 to \$120 per barrel in 2030. In real terms, however, the oil price remains almost constant over the period until 2030, then increases to 100 $\$_{2005}$ per barrel in 2050. This assumption raises some questions given the debate about the mid-point depletion of oil within the next 10 to 20 years (IEA 2008).

Results on final energy demand of Europe until 2050

Final energy demand in Europe calculated by the bottom up models will increase slightly until around 2035 (+8.6 %) to 53,100 PJ, before it starts slowly declining due to decreasing European population (see Table 0-1). However, the change of total final energy demand changes unevenly among European regions and sectors:

- Except for west European countries, the other three regions will still increase their total final energy demand by some 20 % until 2050, mostly driven by above-average economic growth. The decline of the final energy demand of west Europe determines overall development, although its share is declining from 56.4 % in 2005 to 51.4 % in 2050.
- While the transport sector will reduce its demand after 2020, the residential and service sectors start reducing later, after 2035, and the industrial sector will still slightly increase its demand until 2050 by 20 %, reaching almost 18,300 PJ in 2050 or more than 51 % of total European final energy demand.
- Final energy intensity of industry decreases from 8.15 GJ/1,000 € value added in 2005 to 4.15 GJ/1,000 € in 2050, representing an average energy productivity increase of 1.5 % per year. Energy intensity per GDP decreases from 4.7 GJ/1,000 € in 2005 to 2.5 GJ/1,000 € in 2050 at a similar rate of improvement. This is due to technical efficiency improvements (about 1 % per year), structural changes within industry (about 0.4 % per year) and to a small extent climate change (0.08 % per year).

Table 0-3: Final energy demand per demand sector of EU27+2 and in four European regions, PJ per year, Reference Scenario and influence of adaptation, 2005 – 2050

	2005	2020	2035	2050	2020-2005	2035-2020	2050-2035	2050-2005	Influence of adaptation
Residential	12,870	12,585	12,784	12,212	-2.0%	1.6%	-4.5%	-4.8%	**-10%**
Service	6,415	8,063	9,016	8,662	25%	10%	12%	33%	**-5%**
Industry	15,293	16,615	17,296	18,260	8.6%	4.1%	6.1%	20%	**-1%**
Transportation	14,322	14,793	14,018	13,840	3.3%	-5.3%	1.3%	-3.4%	**+1.9%**
TOTAL Europe	**48,899**	**52,060**	**53,110**	**52,980**	**6.5%**	**2.0%**	**-0.3%**	**8.3%**	**-3.3%**
North	3,978	4,461	4,712	4,904	12%	5.6%	4.1%	23%	**-2.0%**
West	27,585	28,197	28,306	27,257	2.2%	0.4%	-3.7%	-1.2%	**-4.3%**
Central-east	5,299	5,978	6,134	6,358	13%	2.6%	3.6%	20%	**-3.8%**
South	12,037	13,421	13,963	14,455	12%	4.0%	3.5%	20%	**-1.7%**
Non-Energy	*4,505*	*5,330*	*6,177*	*7,140*	*18%*	*16%*	*16%*	*59%*	*n.a.*

Source: derived from bottom up models from Chapter 6 of this report

The growth of final energy demand projected in parallel by the (more aggregated) POLES model is steadily increasing from 51,500 PJ in 2000 (including non-energy use) to 67,800 PJ in 2050; this implies a slightly smaller increase in final energy productivity of 1.2 % yearly compared to the results of the bottom up models. The difference can be explained by slightly different assumptions in inter-industrial structural change and slightly different assumptions on energy efficiency improvements in several sectors.

The impact of adaptation on final energy demand

Due to the warmer climate in the Reference Scenario (+4°C global average temperature above pre-industrial climate), the final energy demand of Europe is reduced by some 1,800.PJ or about 3.3 % in 2050 relative to the Base Case Scenario (without any climate change[1]). This decline is the net effect of less heating demand and more electricity demand for air conditioning and cooling (see Table 0-3). The modelling results indicate a decrease in energy demand of 10 % in the residential sector until 2050 as a European average, of 5 % in the service sector (where additional air conditioning plays a larger role than in the residential sector), and a small 1 % effect in industry. In the transportation sector, climate change even increases fuel demand by 1.5 % until 2050 due to additional air conditioning as well as more traffic jams due to extreme events.

There is, however, a regional impact of climate change: while in the west and central-east European region one can expect a decrease of final energy demand between 4.3 % and 3.8 % respectively, north and south Europe can only count on a slight decrease of between 2 % and 1.7 % respectively (see Table 0-3). Econometric analyses for several European countries and different climatic conditions conclude that higher incomes result in a higher demand for heating and cooling. This effect has been taken into account in the model calculations.

Net electricity demand is expected to decrease slightly in Nordic and Baltic countries (if all other influences remain constant), particularly where electricity accounts for a substantial share of heating energy (e.g. Norway or Sweden). In terms of heating expenses, climate change will thus bring more energy-related benefits than costs in northern Europe. The opposite is the case for southern Europe: here a 7 % increase in electricity demand is expected for cooling in the Reference Scenario in 2050.

The regional impact of climate change is more pronounced when the changing energy cost and additional investments for air conditioning and cooling are considered (see Table 0-4 and Table 0-5). While total energy cost will drop in Europe by some 16 billion. € in 2035 and more than 27 billion € in 2050, the reduction is relatively small in countries south of the Alps (0.7 billion € in 2020 and 2.3 billion € in 2050); it also turns into cost for the Mediterrainean countries if the yearly investments are added (see Table 0-5).

Table 0-4: Change in energy costs (fuels and electricity) for final energy between Base Case and Reference Scenario, in Mill. €, European regions, 2005– 2050

	Fuels				Electricity			
Country group	**2010**	**2020**	**2035**	**2050**	**2010**	**2020**	**2035**	**2050**
North	-238	-515	-1077	-1651	-90	-121	-161	-245
West	-2657	-5845	-13285	-21753	85	513	1200	1214
Central-east	-359	-780	-1809	-3159	20	97	224	268
South	-1198	-2477	-5311	-8419	806	2187	4618	6082
Total Europe	**-4,453**	**-9,617**	**-21,483**	**-34,981**	**822**	**2676**	**5881**	**7318**

Source: CEPE, ETH Zurich, results from bottom up models

[1] The Reference Scenario assumes that the global average temperature will rise by 4°C compared with pre-industrial levels (Van Vuuren et al., 2007).

Total additional yearly investments in air conditioning and cooling in Europe will exceed 8 billion € in 2050, where the burden is mostly on west and south Europe. This may lead – besides other adaptation impacts on electricity transmission lines, agriculture, forestry, tourism - to transnational compensation systems being needed (i.e. EU funds) to balance the inequitable effects of adaptation. Another impact may be that additional amounts of electricity in summer for air conditioning, cooling, irrigation have to be transmitted from the northern to the southern European countries.

Table 0-5: Adaptation investments due to more air conditioning and cooling in the final energy sectors, European regions, Reference Scenario , 2010– 2050

Country group	Yearly investment in billion €			
	2010	2020	2035	2050
North	0.1	0.1	0.2	0.4
West	1.0	1.9	2.9	4.4
Central-east	0.1	0.2	0.3	0.5
South	1.5	2.0	2.7	3.2
Total Europe	**2.7**	**4.3**	**6.2**	**8.4**

Source: CEPE, ETH Zurich [last updated 3 February 2009].

Electricity demand and generation

Electricity demand for the final energy sectors is projected by the POLES model to increase from 9,100 PJ in 2000 to 19,400 PJ (or 5,400 TWh) in 2050 and by the bottom up models from 10,270 PJ in 2005 to 15,400 PJ (or 4,300 TWh) in 2050 (see Table 0-6). This difference in model results can also be expressed by the improvement of electricity productivity which amounts to 10 % until 2050 in the POLES model and to 30 % in the bottom up models. Again, this suggests that the assumptions on inter-industrial structural change and efficiency improvements differ between the two model systems. This difference may be caused by the more detailed structure of the bottom up models but also by more optimistic assumptions of the technical progress of electricity efficiency and less demand of electricity-intensive products.

Given the differences in electricity demand projections of the final energy sectors, electricity generation has in addition structural differences. These may be due to the different types of models: while the POLES model uses more simulation as the projecting method, the EuroMM model is an optimisation model. The projections for the renewables and the year 2050 are rather comparable at 1,360 TWh (PowerAce) and 1,480 TWh (POLES).

Total final electricity demand in Europe will increase by around 50% between 2005 and 2050 in the Reference Scenario of which slightly 1.7 % are due to the additional demand for air-conditioning and cooling which is not fully compendsated by decreased heat demand. While the north European countries even benefit from climate change in the Reference Scenario (-0.5%), south Europe has the highest increase in electricity demand (+5 %; see Table 0-6).

Table 0-6: Electricity demand of final energy sectors and its change between Base Case and Reference Scenario, European regions, 2005– 2050.

Country group	Electricity demand in PJ					Impact of warmer climate		
	2005	2020	2035	2050	2050-2005	2020	2035	2050
North	1210	1341	1488	1593	32%	-0.3%	-0.3%	-0.5%
West	5547	6391	7251	7694	39%	0.3%	0.5%	0.5%
Central-east	908	1249	1462	1683	85%	0.3%	0.7%	0.7%
South	2608	3384	3970	4431	70%	2.1%	4.0%	4.9%
Total Europe	**10,272**	**12,365**	**14,172**	**15,402**	**50%**	**0.7%**	**1.4%**	**1.7%**

Source: CEPE, ETH Zurich, results of all bottom up models

The generation of electricity follows the demand of electricity of the final energy sectors. Small additional demand for the losses from transmission, distribution and generation due to higher ambient temperatures has to be expected (in the order of 1% of total electricity generated). While electricity generation expands by some 41 % to almost 4,800 TWh in the bottom up models' projection in 2050 (see Table 0-7), the generation growth is higher (+87 %) in the POLES results. It is interesting to see that the two models, PowerAce and POLES, point to similar developments of the renewables in total, but POLES and EuroMM develop quite different future pictures on coal-fired and natural gas-fired thermal power plants.

Table 0-7: Electricity generation by primary energy source, Europe, results of Bottom up Models (left row) and of POLES model (right row), Reference Scenario, 2005 to 2050

Energy Conversion Technology	TWh	TWh		
	2005	2020	2030	2050
Total	**3360**	**3840 – 4370**	**4225 – 5085**	**4780 – 6320**
- Coal	720	970 – 1450	1250 – 1810	1470 – 2050
- Nuclear	1030	920 – 870	1100 – 975	1360 – 1020
- Gas	430	260 – 685	150 – 770	130 – 660
- CHP	640	920 – n.a.	765 – n.a.	460 – n.a.
Renewables	**488**	**770 – 845**	**960 – 1060**	**1360 – 1450**
- Wind	71	202 – 300	327 – 390	638 – 510
- Hydropower	336	367 – 387	366 – 395	365 – 405
- Biowaste	10	24	25	28
- Biomass	49	94 – 148	98 – 208	104 – 208
- Biogas	15	46	70	103
- Geothermal	5	8	8	8
- Solar	1	25 – 38	51 – 71	78 – 650
- Waved Tide	0	3	10	35

Sources: results from bottom up models and POLES, described in chapters 3 and 7

The low gas share in electricity generation projected by EuroMM may be due to several factors, but certainly is mostly determined by assumptions on gas and coal prices in this optimisation model. The figures may be too low given the high contribution of fluctuating electricity supply from renewables. The largest difference between projected electricity generation among the renewables is solar power, which may need more analysis on assumptions like cost decreases and favourable conditions of investments for solar electricity generation in European countries.

The impact of adaptation on the energy conversion sector

A changing climate could affect several components of the European energy supply system:

- Decreased precipitation and warmer temperatures in summer will have a negative impact on thermal power plants, the majority of the European power generation, where rivers provide cooling water. Slightly lower efficiencies of thermal power plants is to be expected, as well as shut downs when water temperatures exceed certain thresholds. The additional investment for conventional thermal generation is approximately 12 % (or almost 1 billion € per year) higher in 2050 compared to the Base Case Scenario.
- There will be increased risks of electricity supply disruptions, associated with extremes (icy storms, floods and heat waves). To avoid theses risks, autonomous or planned adjustments will be made (e.g. decentralisation of generation, investments in transmission and distribution grids). No quantitative calculations have been made on this issue.
- Rising precipitation in countries north of the Alps and in Portugal, as well as melting glaciers in the Alps, will increase run-off water and increase the potential for hydro electricity generation. Less precipitation in Mediterranean countries will reduce hydro power generation. But the net effect of these changes will be small on investments in hydro power. In some countries with larger hydropower generation, more frequent floods will result in minor hydro electricity production cuts.
- Higher temperatures and increased precipitation north of the Alps will add to the growth of biomass. This will favour wood fuel use and agricultural crops as renewable energies. However, reduced water availability and extreme events (droughts, heat waves) in Southern Europe will have detrimental effects on crop yields and forest productivities.

Smaller impacts can be expected such as increasing average wind velocities improving the output of wind converters or higher temperatures slightly increasing electricity transmission losses. To conclude: a few impacts of extreme events on the energy conversion sector could be quantified leaving many questions unanswered with regard to damage costs of the Reference Scenario.

The development of energy-related CO_2 emissions

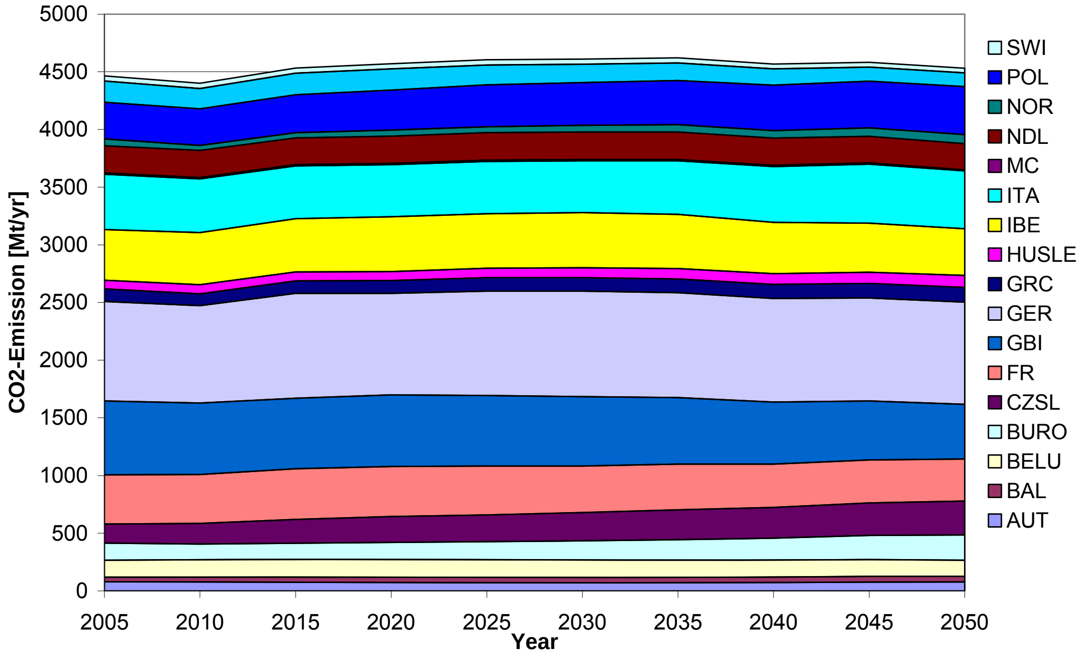
The direct CO_2 emissions stemming from the final energy sectors are slightly but constantly reduced in the Reference Scenario (see Table 0-8). Given the slight increase in final energy demand, the decarbonisation of the final energy sector is almost 0.5 % per year, due to the increasing share of electricity in final energy use.

Total *energy-related CO_2 emissions* (including those of the conversion sector) increase from around 4.2 billion tonnes CO_2 in 2000 to a peak of around 4.65 billion tonnes (i.e. 11 % higher) in 2035, before declining slightly to 4.6 billion tonnes towards the end of the period (see Figure 0-1).

Table 0-8: **Direct CO_2 emissions of the final energy sector, in million t CO_2 per year, European regions, Reference Scenario, 2005 – 2050**

Country group	CO_2 Mill. t					Impact of warmer climate		
	2005	2020	2035	2050	2050-2005	2020	2035	2050
North	135	131	130	138	2%	-0.2%	-0.3%	-0.1%
West	1,426	1,349	1,257	1,156	-19%	-1.7%	-3.4%	-5.0%
Central-east	263	272	264	268	2%	-1.4%	-2.7%	-3.8%
South	628	637	619	613	-2%	-1.4%	-2.4%	-3.3%
Total Europe	**2,452**	**2,389**	**2,270**	**2,176**	**-11%**	**-1.5%**	**-2.9%**	**-4.1%**

Sources: results from bottom up models in chapter 6



Source: own calculations by Power Ace and EuroMM

Figure 0-1: CO_2 emissions from fuel combustion in Europe, Reference Scenario, 2000 – 2050

Macro-economic impacts of adaptation

The major two macro-economic indicators, GDP and employment, are also negatively affected by adaptation in the Reference Scenario. For the EU27 the annual loss of GDP in 2020 is close to zero and amounts to about 50 billion € in 2035 and about 240 billion € in 2050, i.e. in the fifteen years between 2020 and 2035 the loss increases by 50 billion €, while in the subsequent fifteen years period from 2035 to 2050 the loss increases by 190 billion € or four times more than in the first 15-year period. This reflects the exponential development of economic impact of adaptation, which should be even more dramatic after 2050. The corresponding loss of employment amounts to about 1 million persons in 2050 for EU27.

Despite a positive direct impulse of adaptation investment the net investment impulse in the Reference Scenario is negative due to the second round effects occurring in the economy. These occur because GDP is reduced - in particular due to damages to capital stock, as a consequence of lower efficiencies and of lower yearly operating hours in case of extreme events and higher temperatures – and the second round effects of reduced GDP decrease investment. Primarily electronics and a very limited range of metal products increase their production of investment goods because they benefit most from the investments in air conditioning and adaptation of the power generation and distribution. The other sectors loose about 15 billion € in demand for investment goods in 2050.

The changes in energy demand, in particular the reduction of heating demand, will reduce energy imports of the EU27+2 by 10 billion € until 2035 and by about 22 billion € until 2050. The loss of employment is about 380,000 jobs until 2035 and 1 million until 2050 due to lower GDP as a consequence of the adaptation to climate change in a 4°C scenario. With regard to regional losses, the loss of employment is highest in the eastern countries with more than -0.3% in 2035 and in 2050 it is highest in the southern countries with more than -0.9% of employment.

Conclusions

The impact of climate change at 4°C temperature increase during this century on the European energy system is small, particularly until 2030, and affects mostly air conditioning, cooling, electricity generation and distribution. The impacts on the macro economy seem to be limited as well. However, the impacts of extreme events and related damage costs to the energy system could not be included into the analysis due to lacking quantitative knowledge of these influences.

The *efforts of adaptation are not equally distributed over Europe*. Countries or regions with maritime climates will experience less change in heating and air-conditioning, while the net effect of a warmer climate is likely to hit the Mediterranean countries most.

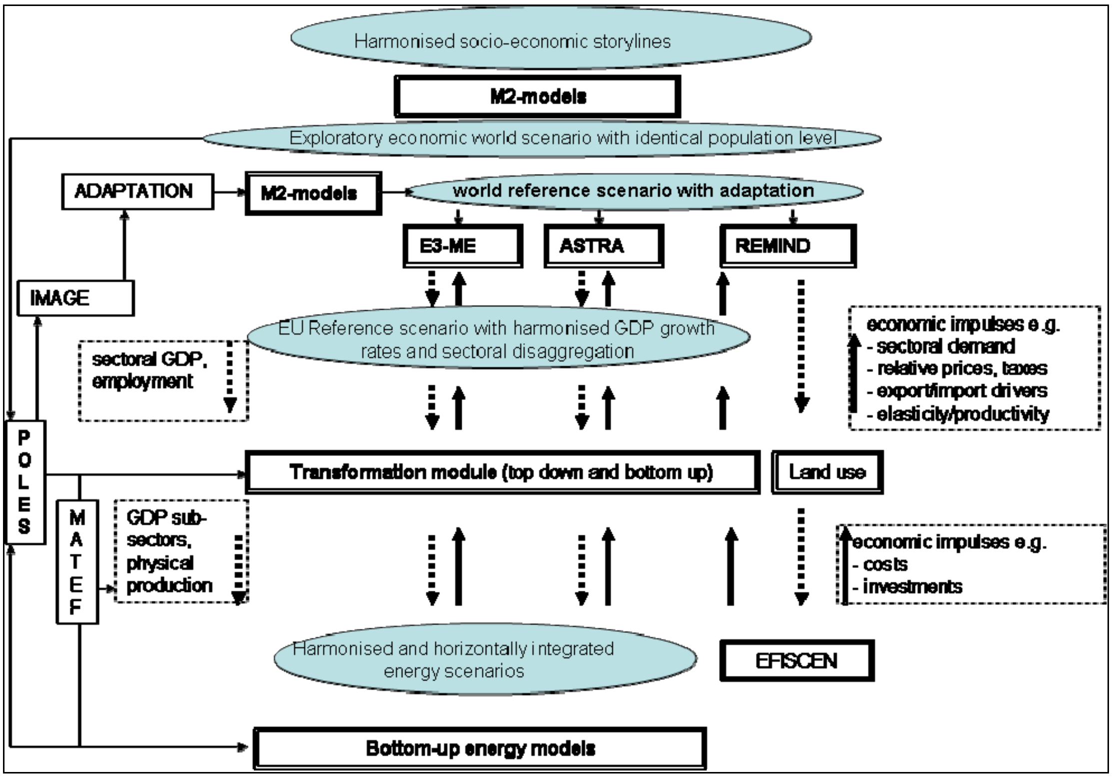
The CO_2 emissions per GDP of Europe decrease on average by 1.8 % per year in this Reference Scenario which seems to be a success. However, as the industrialised countries have to reduce their greenhouse gas emissions by some 60 to 80 % in absolute terms relative to the 1990 emissions until 2050 in order to limit the temperature increase to 2°C by the end of this century, the energy–related CO_2 emissions of the Reference Scenario demonstrate how substantial the change in the European capital stock has to be in the coming decades: in addition to what would happen in the Reference Scenario under constant trends of energy and climate policies, in a 2°C scenario the CO_2 emissions of Europe have to be reduced at a yearly rate of 2 % to 3.5 % in absolute terms which is an extreme challenge.

This target can only be achieved by substantial changes of all greenhouse gas-emitting sources. It includes the better use of energy-intensive materials, their partial substitution by biomass-based materials, improved energy efficiency and substantial increases in the use of renewables. In addition, carbon capture and storage from large coal-using plants and a contribution from nuclear energy may be needed. The first results of the 2°C Scenario by the POLES model (chapter 4) are presently being complemented by the sectoral bottom up models from the authors of this deliverable. The detailed results of the 2°C Scenario will be available by July 2009.

There is some evidence that adaptation costs are presently underestimated in Europe due to lack of knowledge, particularly in the area of extreme events. The extent to which adaptation will be implemented in the European energy system will also depend on the present and *near future global policy efforts and successes in mitigation*. The more governments of industrialised and emerging countries postpone mitigation policies and the more likely global greenhouse gas emissions will not be curbed by 2020 to 2030, the greater the tendency of European policy makers and investors to invest more in adaptation. There is a risk that the adaptation strategy will gain attention as it can be easily implemented at the national level, particularly in industrialised regions such as Europe.

1 Introduction

Work Package Mitigation 1 (M1) has the **core objective of simulating mitigation options and their related costs for Europe until 2050 and 2100 respectively**. As Europe obviously forms part of global emission activities, the analysis of M1 also depends on the economic and policy assumptions and results of Work Package M2 (covering the rest of the world), and also on the results of Work Package Scenarios (impacts of climate change) and on Work Domain Adaptation (WP A1 and A2) regarding the impacts of and adaptation to climate change by the European energy system. The analysis between 2050 and 2100 for Europe will be covered by the POLES model which also simulates the energy system and its emissions from the rest of the world in M2 (see Figure 1-1). The more detailed sectoral bottom up models will cover the time span until 2050, also offering a comparison between their results and those of POLES.



Source *Working Paper on the models used in this work package*

Figure 1-1: Overview of the model system of WP Mitigation 1 and its context of other ADAM work packages Mitigation 2, Adaptation 1 and 2, Scenarios

The work on the M1 model system also has the **objective of including a quantitative analysis of the adaptation of the energy system**, in particular concerning the adaptation of energy-related activities and sectors (e.g. reduced energy for heating demand and more energy for increased air conditioning in Europe, higher cost of dry cooling towers of thermal power stations).

There are *three major methodological challenges in WP M1* (see Chapter 2.1):

- The integration of economic and technical developments in Europe into global development. This is handled by two models used in the mitigation domain of this project, i.e. the integrated energy model POLES and a global econometric model E3MG. Soft links have been used for taking up the results of other work packages mentioned above;
- the economic and technical development within Europe, with the presently quite different conditions of the capital stock and economic performance in Western, Southern, and Eastern Member States of the European Union and the two other states covered in this analysis (Norway and Switzerland); and
- finally, differences in natural resources (such as renewable or fossil energies) which suggest different mitigation and adaptation policies in the European Countries.

This report covers the analysis and results of the Reference Scenario, which tries to identify the impact of climate change of 4°C average global surface temperature increase on the European energy system by the end of this century. For this purpose the results of the Base Case Scenario (reflecting the same demographic and economic development, but no climate change) were used (see Deliverable M1.1 of September 2007, Jochem et al. 2007).

1.1 Problematics

Economic and technical developments and *global climate change in Europe are part of the global economic and technical developments and related greenhouse gas emissions.* In order to design possible future adaptation and mitigation scenarios, therefore, a global context has to be simulated. This was achieved by the Work Package Scenarios where climate change is simulated with the techno-economic development of the rest of the world and the associated greenhouse gas emissions and the atmospheric concentrations are calculated for the period 2000 to 2100.

The *European countries are presently at different stages of techno-economic development*. Whereas some countries have almost fully complete infrastructures, few basic industries, and more than two thirds of their GDP generated by services (e.g. Switzerland, Denmark, Norway), some of the Central European countries have little developed infrastructures, relatively low incomes per capita, a relatively high share of GDP generated by agriculture, and a low degree of motorisation and automation.

Because of the *different population densities and climates*, European countries have a different wood production per capita or additional felling potentials in the next decades which offer opportunities for reducing energy-related greenhouse gases by using more wood as a fuel or by using forests as carbon stores or in long-lasting wood uses (e.g. houses and buildings).

From the perspective of methods to be usable for long term perspectives, macroeconomic models have an advantage in simulating the cycles of goods and money, but they are not able to simulate new technological developments in any detail. On the other hand, *sectoral, process-oriented bottom-up models* that can simulate technical and organisational innovations cannot adequately simulate the indirect impact of the energy system on the total national economy or foreign trade patterns. This dilemma can be solved by hybrid model systems consisting of macroeconomic and bottom-up models which exchange the results among one another. This solution was implemented by the authors and is reported in this deliverable.

1.2 Objectives of this deliverable

This deliverable *reports on the results of the Reference Scenario for Europe. It is* an explorative scenario and – in contrast to the Base Case Scenario - considers climate change of a projection that leads to a 4°C increase of global average surface temperature at the end of this century. In particular, this deliverable D2 of WP M1 reports on the following aspects:

- yearly energy-related CO_2 emissions of all European countries for the period 2000 to 2100, particularly for the period 2005 to 2050,
- the underlying assumptions on boundary conditions such as population, economic development, energy prices, energy demand and supply, and related technologies, which are similar to the Base Case Scenario, but have as an additional boundary condition: the changes in climate,
- the cost for adaptation in the Reference Scenario at the micro- and macroeconomic level, and
- the differences in the results of models used in parallel to identify uncertainties stemming from the modelling approach and related different exogenous assumptions.

1.3 Structure of this report

This report initially was characterized as internal document to the ADAM project. Since, in the final deliverable also substantial references to this report are made it is decided to make it publicly available, though one should take into account that the Reference Scenario of this D2 slightly differs from the revised Reference Scenario in D3 due to model improvements made to run the mitigation scenarios in D3. As an internal document also the formatting and quality review process (e.g. native speaker check) was less strict.

Chapter 2 gives an overview of the methodology used in the analyses of this report and some comments on data availability, of particular interest to the bottom-up models with their demand for detailed technical and cost information as well as the links to the macro-economic models.

Chapter 3 presents the assumptions and results of the Reference Scenario of the rather aggregated bottom-up energy model, POLES, which has the advantage of covering the 21st century and all European countries and country regions of the world. It serves to compare the results with the more detailed bottom-up models which are described in Chapter 6 and 7.

Chapter 4 reports on the first results of a 2°C Scenario (the variant of a 450 ppm CO_{2e} concentration level). This analysis is also performed by the other bottom up models, but the results will be reported in the third deliverable planned for end of May 2009.

Chapter 5 covers several aspects of boundary conditions, i.e. the availability of wood from European forests until 2050 (see Chapter 5.1), the demands of energy-intensive products (such as steel, paper, or aluminium; see Chapter 5.2), and the specific aspect of new forms of wood energy-use taking into account the demand for paper wood and other industrial wood as well as wood wastes that can be used for modern energy forms, i.e. pellets and chips.

Chapter 6 reports on the assumptions and results of the sectoral bottom up models, i.e. for the residential, service, industrial, and transport sector, as well on the use of renewables in the final energy sectors. In addition to final energy demand, the results include — the changes of energy use and energy cost as well as investments due to adaptation to climate change under the conditions of this scenario (+4°C temperature incease).

Chapter 7 looks at the options for generating final energy by primary energy in its different forms (fossil and nuclear fuels as well as renewables). The results also include changes in cost due to climate change.

Chapter 8 reports on the macro-economic results of the adaptation to climate change of the European energy system calculated by the ASTRA model. This is the first time that the changing cost and investments of the sectoral bottom up models could be calculated in the hybrid model system (HMS) developed in the ADAM project. It will also be used for calculating the macro-economic impacts of the 2°C Scenario.

Chapter 9 reflects policy conclusions on the basis of the results as well as methodological issues that could be pursued further in the future.

2 Methodological approach and data availability

The development of a reference scenario is essential for the overall consistency of the policy analysis, for adaptation as well as mitigation. The *Reference Scenario* – as designed here in Work Package M1 of the ADAM project - aims to integrate the most up-to-date information and expectations about demographic growth, its regional distribution, major economic and technology trends (in GDP trends, sectoral allocation of production, technological progress, R&D investment) and the availability of depletable resources. From this limited set of exogenous trends, the models used in this analysis project

- the relevant energy and environmental variables by various sectors and technologies up to 2050, and even up to 2100 with the POLES model,
- the benefits and costs of an adaptation scenario, selected to be a +4°C; this scenario has been labelled as the *"Reference Scenario"* because it forms the basis for calculating the mitigation costs of
- the *"2°C Scenario",* which describes the benefits and costs of two different mitigation scenario variants (one assuming a final atmospheric CO_{2e} concentration of 450 ppm at the end of this century and one assuming 400 ppm concentration; the latter seems extremely ambitious given the fact that CO_{2e} concentrations already reached 387 ppm in 2008).

2.1 Calculating the impact of climate change and adaptation costs for the energy system

Comparing the results of this Reference Scenario with those of the Base Case Scenario allows the adaptation costs of the energy system to be quantified in principle. These are calculated for all sectors and include identification of the related economic impacts at the macroeconomic level (see Chapter 8). However, it has to be stressed that the knowledge about changes in extreme events is highly limited, so that only changing temperatures and to some extent changing precipitation could be taken into account in this analysis, but not changing intensities or frequencies of heavy storms, heat waves, or droughts. This means that the adaptation costs calculated here are smaller than those to be expected from an real 4°C increase in the global average surface temperature by the end of this century.

It is assumed that a warmer climate in the future will affect energy demand in buildings (including office buildings and factories) in two ways: First, the share of cooled floor area is assumed to increase and, secondly, the specific energy demand of cooled floor area is assumed to increase. To estimate this impact for the tertiary (service), industrials and the residential sectors at the European level, their energy demand is modelled for 29 European (EU27+2) countries for two different scenarios: the Base Case Scenario assuming past climate conditions and the Reference Scenario assuming a warmer climate. The difference in temperature was calculated, depending on country and month, by the IMAGE model within the Work Package Scenarios of the ADAM project (Isaac, M. et al., 2008).

2.1.1 Impact of a warmer climate at the level of individual buildings

In the first stage, the specific energy demand for lighting, ventilation, cooling, appliances, heating and other thermal applications is modelled for different building types and locations in Europe. 14 locations (see Table 6-1) are chosen to cover both the relevant regions in terms of the energy demand of the residential and tertiary sector and the range of climate conditions in Europe.

Energy demands (and indoor climate conditions) are estimated with a dynamic building simulation model (IDA-ICE). Simulation results differentiate between the main types of energy services, namely lighting, ventilation, cooling, heating and other thermal applications, and will reveal the impact of climate change on the specific energy demand and the need for adaptation measures in buildings to ensure an acceptable level of comfort for their occupants. The impact estimated by our own building model simulation is backed up by evidence from the literature, particularly from Rivière, Adnot et al. (2008), Cartalsi, Synodinou et al. (2001), Frank (2005) and Aebischer et al. (2007).

2.1.1.1 Impact of a warmer climate at the sectoral level

In the second stage, the energy demand of the residential and tertiary sector was modelled for the two scenarios (Base Case and Reference) up to 2050. In the case of the service sector, the bottom-up model differentiates five main sectors, namely finance, retail, education, health/hotels/restaurants and a residual sector. Likewise, the residential sector model differentiates various building types and different construction periods (see Jochem et al. 2007a, b for more details). The main drivers are the conditioned (heated and possibly cooled) floor area and the specific energy demand for different types of energy services. The basic structure of the bottom-up modelling approach for the service sector can be described as follows:

$$Energy\ demand = \sum_{i,k,e} FA_{i,k,e} \cdot specific\ energ\ demand_{i,k,e} \qquad \text{(equ. 6-1)}$$

where *FA* denotes the conditioned floor area, *i* the economic sector or sub-sector, *k* the energy type and *e* the type of energy service (e.g. heating, cooling), respectively. Both floor area and specific energy demand change over time. The floor area, i.e. the building stock of the service sector, is further differentiated into buildings with different levels of energy services (e.g. with or without central or room air conditioning). Specific energy demand input data are derived from both historical data and from the results of the first stage as described above.

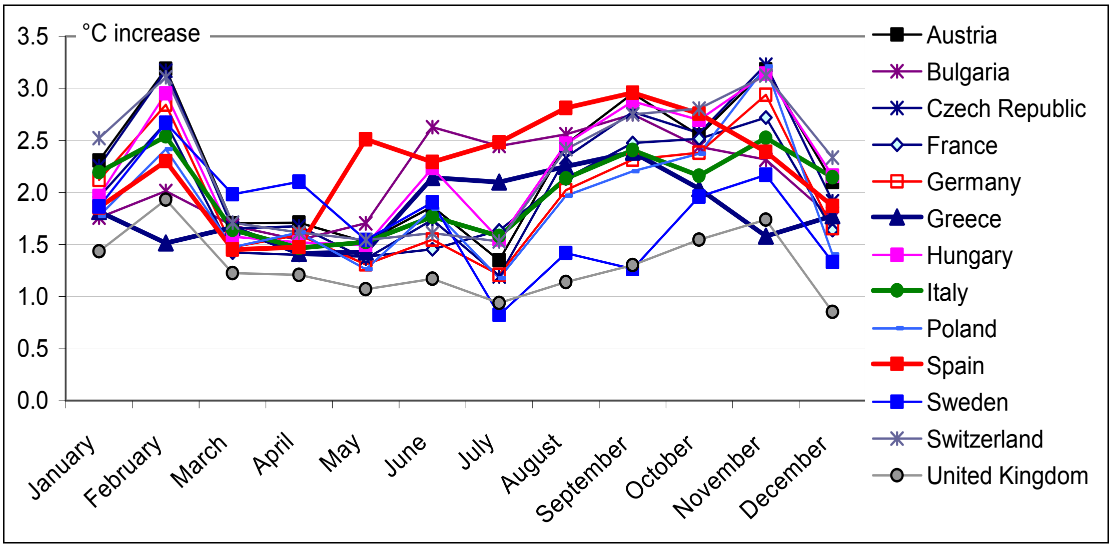
The relationship between climate and share of cooled floor area is based on market data and projections of the cooling market in Europe, on the findings of a study for the DGTREN of the EC (Adnot et al., 2003) and on preparatory studies of the ECODESIGN Lot 10 (Rivière, Adnot et al. 2008), particularly on the Draft report of Task 2-V5 October 2007: Economic and Market analysis.

As the specific approach differs slightly between the residential and the tertiary sectors, more details are given in the subsequent sections.

2.1.1.2 Temperature and degree days of the two underlying climate scenarios

Two climate scenarios were defined: a Base Case Scenario (BC, assuming no climate change at all) and the Reference Scenario (warmer climate: WC scenario). HDD and CDD of the Base Case Scenario were calculated for 39 locations[2] in 23 different countries using typical meteorological year (TMY)[3] hourly data from IWEC weather stations (as published on the website http://www.equaonline.com/iceuser/). Each of the EU27+2 countries is represented by one or a weighted average of several IWEC weather stations.

HDD and CDD of the Reference Scenario are calculated using hourly temperature T data of the Base Case Scenario to which monthly average T differences between the considered modelling year (2005 to 2050) and the average of 1980 to 2000 were added for each country individually. These monthly T differences stem from simulation results of the climate model IMAGE. The underlying simulation runs were performed by Isaac et al. (2008) within the ADAM project. All of these monthly differences are positive for all countries and all months and vary mostly between 1.5°C and 3°C for 2050. For almost all European countries, the increase is lowest in spring (see Figure 2-1). In southern Europe, the largest increase is in late summer whereas in central Europe the largest increase tends to be in winter.



Source: own representation (based on Isaac et al., 2008: increase between 2050 and average 1980-2000)

Figure 2-1: Assumed increase of monthly temperature T in the Reference Scenario for 2050 (selected European countries)

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2 Vienna (AT), Brussels (BE), Copenhagen (DK), Helsinki (FI), Paris, Marseille (FR), Berlin, Bremen, Frankfurt, Munich, Koeln, Stuttgart (DE) Athens, Thessaloniki (GR), Dublin, Kilkenny (IE), Milan, Rome, Naples (IT), Nancy (FR, also used for LU), Amsterdam (NL), Coimbra (PT), Madrid, Sevilla (ES), Stockholm (SE), Birmingham, London (UK), Larnaca (CY), Prague (CZ), Debrecen (HU), Kaunas (LI), Warsaw (PL), Bratislava (SK), Ljubljana (SL), Bergen, Oslo (NO), Geneva (CH), Bucharest (RO), Sofia (BG).

3 Up to 18 years of weather data for the period 1982–1999 were processed by ASHARE using Hall's method, see ASHRAE (2002).

The assumptions of the Reference Scenario are summarised below:

- Building physics simulations are based on hourly T data.
- Over the average of all hours within a month, T increase is uniform within each month, but different between different months and for each country (see Figure 2-1).
- Monthly increases are superposed by an additional daily variation of the temperature, assuming a sin function of the form $0.5 * \sin\left\{\left(\frac{t+6}{24}\right)2\pi\right\}$ °C (equ. 6-2)
- No change in direct and global radiation (it is unclear in climate models whether radiation would decrease due to more clouds or increase) and relative humidity.

First it is interesting to note that the impact of the above temperature change assumptions do not have a linear impact on either heating or cooling degree days, neither in relative nor absolute terms. In relative terms, HDD and CDD change increasingly with lower initial values following a concave course. HDD decrease by about 25 % to 30 % in southern Europe, and by about 15 % to 20 % in the rest of Europe (see Table 2-1). In relative terms, CDD are affected most strongly in Scandinavian and northern climates (up to +100% or more), but much less so in southern Europe (+35% to 62%).

Table 2-1: Heating degree days (HDD) and cooling degree days (CDD), Reference Scenario, in Centigrade, 2005 - 2050

Country or country group	HDD 2005	HDD 2020	HDD 2035	HDD 2050	HDD 2050-2005	CDD 2005	CDD 2020	CDD 2035	CDD 2050	CDD 2050-2005
Austria	3025	2874	2676	2495	-18%	248	287	343	408	65%
Baltic States	4018	3886	3698	3505	-13%	69	79	95	115	67%
Belgium/Luxembourg	2823	2666	2480	2287	-19%	108	127	155	190	76%
Bulgaria	2890	2762	2609	2467	-15%	278	336	417	506	82%
Czech Republic	3545	3370	3143	2936	-17%	90	109	137	169	88%
Denmark	3492	3380	3219	3044	-13%	26	31	39	49	90%
Finland	4691	4499	4259	4031	-14%	30	36	47	58	94%
France	2220	2092	1936	1776	-20%	298	338	397	464	56%
Germany	3155	3002	2798	2606	-17%	120	139	169	204	70%
Greece	1306	1229	1127	1032	-21%	993	1078	1189	1304	31%
Hungary	2993	2854	2669	2489	-17%	314	363	430	504	60%
Ireland	2940	2834	2695	2549	-13%	4	6	9	14	221%
Italy	1882	1766	1624	1476	-22%	564	628	714	805	43%
Malta/Cyprus	642	601	533	425	-34%	1270	1350	1461	1576	24%
Netherlands	2861	2730	2540	2363	-17%	62	70	83	100	61%
Norway	4040	3902	3710	3512	-13%	27	32	41	52	95%
Poland	3484	3342	3149	2958	-15%	98	114	140	172	74%
Portugal	1067	967	846	717	-33%	510	599	721	849	66%
Romania	2883	2764	2611	2442	-15%	425	489	577	668	57%
Slovakia	2887	2741	2577	2408	-17%	278	322	384	455	63%
Slovenia	3166	3010	2804	2603	-18%	187	226	282	346	85%
Spain	1553	1459	1327	1203	-23%	766	851	971	1099	43%
Sweden	4177	4017	3837	3647	-13%	33	39	51	68	107%
Switzerland	2783	2619	2429	2241	-19%	225	257	304	360	60%
United Kingdom	2890	2777	2634	2480	-14%	25	30	41	55	125%

Source: own categorisation and calculations using data from http://www.equaonline.com/iceuser/ (based on ASHRAE 2002) and from Isaac et al. (2008).

Heating and cooling degree data can be categorised into different regions within Europe. Five regions can be discerned for CDD (see Table 2-1). Regarding HDD, the regions south-east and mid-west could be summarised, but north (Scandinavian) and north-west (Ireland and U.K.) should still need to be distinguished. These results will be used to calculate the changes in heating and cooling demand in all final energy sectors (see Chapter 6) and also their impact on the conversion efficiencies of energy converting technologies (see Chapter 7).

Econometric analyses for several European countries and different climatic conditions conclude that rising incomes bring about a higher demand for heating and cooling. This effect is also taken into account (see Chapters 6.2 and 6.3).

For the industrial sector, the same impacts for heating and cooling demand were applied taking the changes in energy demand of the service sector for each industrial sector into account.

2.1.2 Impact of a warmer climate in the transport and energy conversion sector

A qualitative analysis of the impacts of climate change in the *transport sector* was a first step. In order to quantify the effects of climate change on a country's transportation system, both the geographical structure and the climate zone were evaluated to compile a matrix indicating the effects on both the transport times and the expected investments. Four main characteristics of impacts were used in this matrix: mountains, rivers, heat waves, snow fall.

These analytical steps lead to country-specific assumptions on factors quantifying the expected rise of transport times and investments due to climate change for all European countries. In 2010, no changes were assumed compared to the base case. As the impact is still scarcely known, sensitivities were assumed for several runs. The transport times were thereby estimated to rise between 0.05 % and 0.3 % around 2025, as well as between 0.25 % and 1.75 % in 2050. Investments were estimated to rise between 0.1 % and 0.7 % around 2025 to around 0.5 % and 3.5 % in 2050 respectively (see Chapter 6.7).

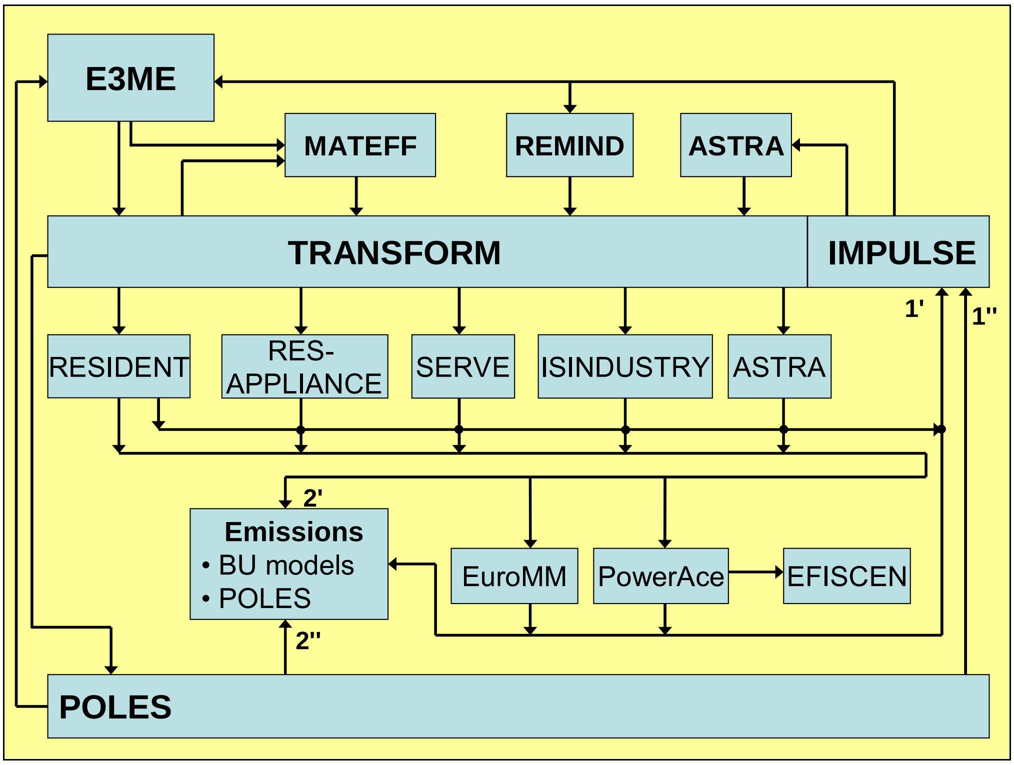
The quantification of climate change impacts on the use of *renewable energies (RES)* presents a challenging task. Impacts have to be quantified using input from climate data predicted commonly by general circulation models (GCM). However, uncertainties related to the GCM-predicted changes in global climate imply that derived results are only of an exploratory character. Furthermore, the resolution of climate models is often too coarse to model their impact on the availability of RES at the level of European countries, regarding for instance the prediction of wind speeds. The refinement or local downscaling of GCM output represents one approach towards improving geographical resolution, but this task remains to be done. Therefore, the analytical work focused on a literature analysis and made some estimates on changing technical potentials of the various renewables in the European countries (see Chapter 7.1).

Finally, the impact on the generation and transmission of electricity was restricted to temperature changes of rivers and cooling water, which was available at the country level (see Chapter 7.2). Other impacts of extreme events could not be taken on board since the quantification by the general circulation models is still insufficient for the quantitative analysis of the impacts of climate change.

2.2 Linking the adaptation and mitigation costs to the macro-economic models

One of the major challenges of the Working Package M1 tasks was the implementation of the planned hybrid model system, i.e. the linkage of the input and output of the bottom up models (RESIDENT, RESAPPLIANCE, SERVE, ISINDUSTRY, ASTRA, PowerACE, and EuroMM) with the inputs and outputs of the two macro-economic models in order to evaluate the adaptation and mitigation efforts of the different scenarios at the macroeconomic level.

The analysis started with the macroeconomic drivers calculated by the two macroeconomic models E3ME and ASTRA (see Figure 2-2). These economic drivers had been used to convert them into drivers for the bottom up models (see Chapter 6) to calculate the energy demand in all final energy sectors in Europe as well as the appropriate energy supply (see Chapter 7). The EFISCEN model delivered the maximum availability of wood from European countries, and the MATEFF model calculated the development of the energy-intensive basic products and the use of wood from forests and waste wood (see Chapter 5). Finally, the comparison between the results of the Base Case Scenario and the Reference Scenario identified the adaptation cost in terms of changed investments and changed energy cost in Chapter 6 and 7).



Source: Working Paper M1-1, Jochem et al., 2007a

Figure 2-2: Overview of the hybrid model system used by Working Package M1

These changes in investments, energy cost and programme cost had to be collected for all sectors in the IMPULSE model (see Chapter 8.1 and 8.2) and fed into the ASTRA model in order to calculate the impacts on economic growth and employment. Results from the E3ME model, the second macroeconomic model, were not available, but will be included in the final deliverable.

2.3 Data availability

Data availability is a crucial point for any quantitative modelling of national energy systems. Specific data problems and how they were (or will be) handled in the ongoing work of Work Package M1 are described in the following chapters (Chapter 3 to 8). However, there are some general observations on data availability which are briefly mentioned here:

- Data availability for the *base year (2004 or 2005)* was much better for the old EU Member countries (EU-15), Norway, and Switzerland than the new EU Member countries and Turkey. The major data sources used were Eurostat, ODYSSEE, and MURE.
- In some cases, *international statistics* such as those from the IEA or UN deviated from the national statistics of European sources for the base year and the past. In these cases, the data were taken from European data sources unless there was a reason to prefer the national statistics (e.g. in wood energy use, where Eurostat data only cover firewood and not the use of modern forms of fuel wood such as pellets and chips).
- Data on *technical information was often only available for some European countries* and had to be estimated for some other countries based on this. In many cases, this was possible based on the assumption that the technological know-how or the technologies sold and used are similar in neighbouring European countries due to trade and shared knowledge and also because of similar climates and related building traditions, etc.
- This data problem was more pronounced regarding *future technical developments* in European countries in the next five decades. This issue was treated in a similar way based on the arguments of intensified trade and an intensified exchange of technical knowledge due to the common market, an increased exchange of students and labour, large European companies, and many other drivers and trends of harmonisation within Europe. The basic assumption here was a *convergence of technical parameters* in the next decade. Minor differences may remain between Member States, but these will probably be smaller than is the case today.
- Finally, the lack of quantitative information on extreme events for the Reference Scenario, i.e. the climate change of a 4°C increase of global surface temperature, was a major drawback of the analysis which leads to an unknown underestimate of the macro-economic results of the Reference Scenario reported in Chapter 8.

Some of the models had to be simplified due to low data availability, particularly in the new Member states regarding building and electrical appliance stock or the use of renewables. Further, more detailed comments on data availability are given in the chapters of each sector (see Chapters 3 to 8) and deviations due to data availability and use will also be discussed in the final deliverable.

Recommendations on how data availability could be improved by the European Commission or its Member States are not given in this deliverable M.1-2, but will be made at the end of the project in February 2009.

2.4 References

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3 Assumptions and results of the POLES model – Reference Scenario

The POLES reference projection in the ADAM study illustrates the energy scene up to 2100 which would result if the on-going trends and structural changes in the world economy were to continue. The modelling system provides a tool for the simulation and economic analysis of world energy scenarios under environmental constraints. A partial equilibrium model is used with a dynamic recursive simulation process. By identifying the drivers and constraints in the energy system, the model describes the pathways for energy development, fuel supply, greenhouse gas emissions, international and end-user prices from today until 2050 and also – as aggregated bottom-up model - until the end of this century.

The approach combines a relatively high degree of detail in the key components of the energy systems with economic consistency, since all the changes in these key components are largely determined by relative price changes at sectoral level. The model identifies 47 regions of the world with 22 energy demand sectors and about 40 energy technologies – now including generic "very low energy" end-use technologies.

The main exogenous inputs to the Reference Scenario relate to world population and economic growth as the main drivers of energy demand, oil and gas resources as critical constraints on supply, and the future costs and performance of energy technologies that define feasible and cost-effective solutions. In all cases, the projected trends extrapolate existing structural changes; this in no way implies a uniform development of the global economic and energy system, as illustrated below.

An important aspect of the projections performed with the POLES model is that they rely on a framework of permanent inter-technology competition with dynamically changing attributes. The expected cost and performance data for each key technology are gathered and examined in a customised database that organises and standardises the information in a manner appropriate to the task (see model description in Working Paper of M1 Jochem/Schade et al. 2008).

Although the model does not calculate the indirect macroeconomic impacts of mitigation scenarios (which is done by the two macroeconomic models E3ME and ASTRA, see Chapter 8), it does produce micro-economic assessments based on the sectoral costs of implementing new technologies, which benefit from a rigorous examination of the engineering and scientific fundamentals.

Finally, in the ADAM Reference Scenario, for the first time, the impacts of climate change on the energy system for building heating and cooling are introduced as endogenous variables in the POLES model. Further adaptation effects are projected in the sectors of industry, transport, renewables, and thermal power plants (see Chapters 6 and 7).

3.1 Assumptions and methods of the Reference Scenario

The assumptions about major drivers of the energy system are the same as in the Base Case Scenario – which does not assume any climate change during this century. The only major changes in assumptions concern the adaptation effects in the European energy system due to climate change. However, as the information for projecting extreme events is still very limited, most of the additional assumptions made tend to rely only on changes in temperature. This Reference Scenario assumes the increase of global average surface temperature to be 4°C above pre-industrial levels by the end of this century. There are no quantitative assumptions about changes in extreme events for this Scenario; this implies that the adaptation cost of the energy system calculated in the following chapters is still too low.

3.1.1 Major assumptions

The assumptions on population and economic growth are briefly revised here to avoid constant references to the first deliverable M1.1 of this work package and the results on the Base Case Scenario.

Population and economic growth

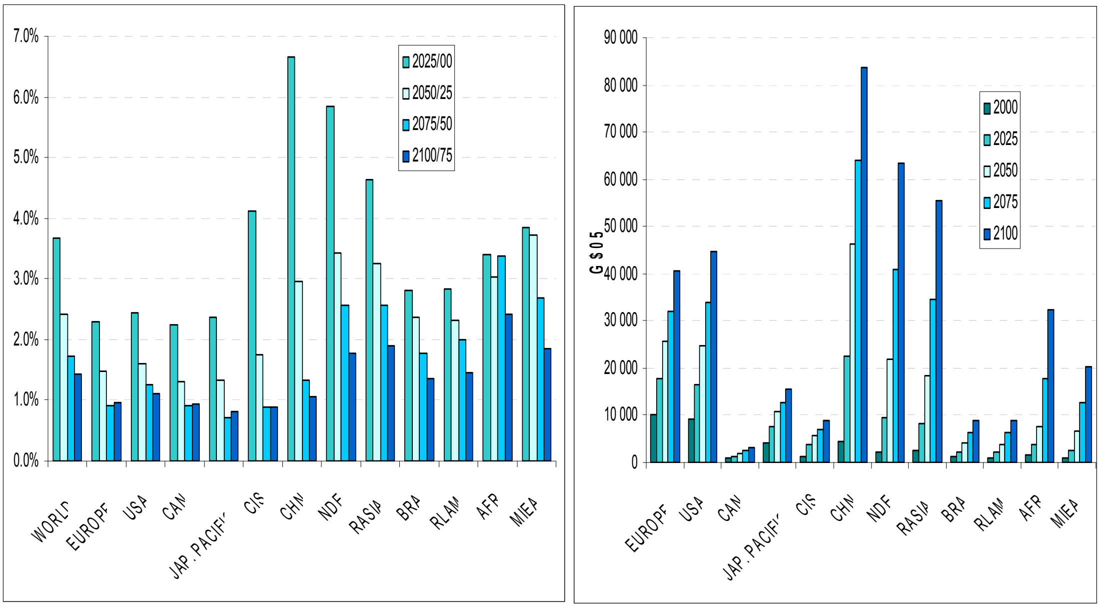
By the end of the century, the world population is expected to stabilise at 9.2 billion people. In this study, global GDP is projected to increase by a factor of 4 up to 2050, then again by 2.2 up to 2100 to almost 400 trillion $ (see Table 3-1). This means that the world economy is projected to grow at 3%/year until 2050 and then to slow down to an average of 1.6%/year between 2050 and 2100. The lower rate in the second part of the century is the combined consequence of a slow down in population growth – or even a declining population in some regions – and lower per capita GDP growth in all regions except the Middle East and Africa (see Table 3-1).

Table 3-1: World population and global gross domestic product (GDP), Reference Scenario, 2000 to 2050

	2000	2025	2050	2075	2100	Annual % change 2050/00	2100/50	2100/00
Key Indicators								
Population (Millions)	6078	7896	9066	9367	9203	0.8%	0.0%	0.4%
GDP (G$05)	40903	100157	181215	277702	395724	3.0%	1.6%	2.3%
Per capita GDP ($05/cap)	6729	12684	19988	29646	42998	2.2%	1.5%	1.9%

Source: POLES Reference Scenario ADAM

The rate of future economic growth is similar across industrialised regions, around 2.3 %/year from 2000 to 2025 and 1 %/year from 2075 to 2100. As expected, economic growth is faster in emerging and developing regions: between 3 and 4 %/year in Africa and the Middle East over the period and somewhat smaller in Latin America. Because of the rapidly increasing absolute GDP level of Asia, there is a steep decline in its growth rate from the current 6.7 % for China and 4.6 %/year for the Rest of Asia to 1.9 % to 1.1 %/year between 2075 and 2100, respectively (see Figure 3-1). This reflects the end of the rapid catching-up process currently being experienced by Asian economies, the linear per capita economic growth patterns of industrialised countries as well as the economic slowdown related to the rapid ageing of the population in China. European GDP grows on average by around 2.3 %/year in until 2025, by 1.5 %/year until 2050 and 1 %/ year thereafter until the end of the century. The average growth rate of Europe is slightly higher than that of Canada and Japan-Pacific (+1.3%/year), but remains lower than the USA (1.6%/year) due to greater immigration to North America compared with Europe.



Source: POLES Reference Scenario ADAM

Figure 3-1: **Economic growth rates (left) and regional GDP (right), world and world regions, Reference Scenario, 2025 to 2100**

National growth rates vary substantially in Europe, particularly during the 2000/20 period and range from 1.8 %/year for Italy and Germany to 4.9 %/year for the Baltic countries. During the second half of the century, the growth rates converge to around 0.8 to 1.1 %/yr (see Table 3-2).

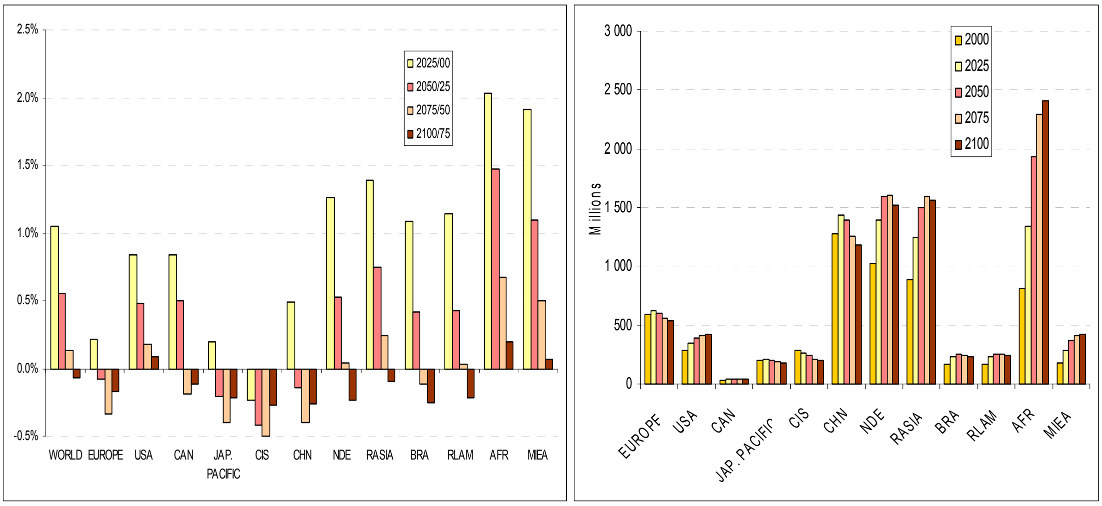
Table 3-2: **Europe, EU27, and 4 European regions – GDP (in billion $$_{2005}$), 1990 to 2100**

								Annual % change		
	1990	2000	2010	2020	2030	2050	2100	2000/20	20/50	50/100
Austria	163	206	245	300	344	400	593	1.9%	1.0%	0.8%
Baltic States	52	57	109	149	183	244	362	4.9%	1.7%	0.8%
Belgium & Luxemburg	213	269	330	406	483	624	927	2.1%	1.4%	0.8%
Bulgaria	56	47	73	94	116	168	292	3.6%	2.0%	1.1%
Cyprus, Malta and Slovenia	35	30	44	55	64	80	119	3.0%	1.3%	0.8%
Czech Republic	126	129	194	242	294	401	697	3.2%	1.7%	1.1%
Denmark	114	143	176	214	251	310	460	2.0%	1.3%	0.8%
Finland	102	123	153	188	224	293	435	2.1%	1.5%	0.8%
France	1157	1392	1711	2124	2540	3345	4966	2.1%	1.5%	0.8%
Germany	1632	1975	2327	2839	3262	3969	5892	1.8%	1.1%	0.8%
Greece	130	164	232	297	360	483	717	3.0%	1.6%	0.8%
Hungary	106	115	163	203	249	353	523	2.9%	1.8%	0.8%
Ireland	50	101	162	199	239	316	469	3.5%	1.6%	0.8%
Italy	1141	1337	1599	1909	2133	2389	3547	1.8%	0.8%	0.8%
Netherlands	297	396	469	592	704	889	1320	2.0%	1.4%	0.8%
Norway and Switzerland	285	146	179	225	269	339	503	2.2%	1.4%	0.8%
Poland	249	356	508	682	887	1392	2067	3.3%	2.4%	0.8%
Portugal	122	160	185	233	274	349	518	1.9%	1.4%	0.8%
Romania	142	118	192	258	331	514	894	4.0%	2.3%	1.1%
Slovakia	54	56	88	116	147	219	380	3.7%	2.1%	1.1%
Spain	567	738	954	1220	1455	1850	2747	2.5%	1.4%	0.8%
Sweden	168	204	266	328	386	498	739	2.4%	1.4%	0.8%
United Kingdom	1067	1352	1714	2123	2555	3460	5136	2.3%	1.6%	0.8%
Rceu	47	82	125	173	229	371	645	3.8%	2.6%	1.1%
Turkey	4842	5663	7653	10661	14171	22407	61208	3.2%	2.5%	2.0%
EU27	7743	9468	11895	14770	17482	22547	33802	2.2%	1.4%	0.8%
Europe	12917	15358	19851	25829	32151	45663	96158	2.6%	1.9%	1.5%
B4	4997	6056	7351	8995	10490	13163	19540	2.0%	1.3%	0.8%
SE	854	1093	1416	1806	2154	2763	4102	2.5%	1.4%	0.8%
NE	1229	1381	1735	2151	2557	3270	4854	2.2%	1.4%	0.8%
EE	995	1165	1697	2217	2780	4060	6454	3.3%	2.0%	0.9%

Source: POLES Reference ADAM

Note : the European countries are divided into four main economic/geographical areas : the Big Four – B4 (Germany, Italy, France, the United Kingdom), Southern Europe - SE (Spain, Portugal, Greece, Cyprus, Malta & Slovenia), Northern Europe – NE (Belgium & Luxembourg, Denmark, Finland, Ireland, the Netherlands, Sweden, Norway and Switzerland), Eastern Europe – EE (Austria, Baltic States, Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia).

Regional variations in economic growth world-wide derive in part from the underlying population dynamics (see Figure 3-2). By 2025, the growth in population is negative in Europe, the Pacific OECD and the CIS-countries. North and Latin America and Asia have low positive growth rates. After 2025, Africa and the Middle East are the only regions where population growth exceeds 1 %/year.



Source: POLES Reference Scenario ADAM

Figure 3-2: Population growth, world and main regions, 2025 to 2100

Within Europe, the biggest changes concern Eastern Europe where there is an acceleration of the population decrease after 2010 (see Table 3-3).

Table 3-3: Population development, Reference Scenario, Europe, EU27, and four areas -

	1990	2000	2010	2020	2030	2050	2100	Annual % change 2000/20	20/50	50/100
Austria	8	8	8	8	8	8	7	0.1%	-0.1%	-0.3%
Baltic States	8	7	7	7	6	5	5	-0.4%	-0.7%	-0.3%
Belgium & Luxemburg	10	11	11	11	11	11	10	0.2%	0.0%	-0.1%
Bulgaria	9	8	7	7	6	5	4	-0.8%	-1.0%	-0.6%
Cyprus, Malta and Slovenia	3	3	3	3	3	3	3	0.3%	-0.1%	-0.4%
Czech Republic	10	10	10	10	10	8	7	-0.2%	-0.5%	-0.5%
Denmark	5	5	6	6	6	6	6	0.3%	0.1%	-0.1%
Finland	5	5	5	5	5	5	5	0.2%	0.0%	-0.1%
France	57	59	62	63	64	63	59	0.3%	0.0%	-0.1%
Germany	79	82	83	82	82	79	73	0.0%	-0.1%	-0.2%
Greece	10	11	11	11	11	11	8	0.1%	-0.1%	-0.5%
Hungary	10	10	10	10	9	8	7	-0.3%	-0.5%	-0.4%
Ireland	4	4	4	5	5	6	5	1.3%	0.5%	-0.2%
Italy	57	58	58	57	55	51	38	-0.1%	-0.4%	-0.6%
Netherlands	15	16	17	17	17	17	16	0.3%	0.0%	-0.1%
Norway and Switzerland	11	12	12	13	13	13	11	0.3%	0.1%	-0.3%
Poland	38	39	38	38	36	32	25	-0.1%	-0.6%	-0.5%
Portugal	10	10	11	11	11	11	9	0.3%	-0.1%	-0.4%
Romania	23	22	21	20	19	17	14	-0.4%	-0.7%	-0.4%
Slovakia	5	5	5	5	5	5	4	0.0%	-0.5%	-0.4%
Spain	39	41	44	44	44	43	33	0.4%	-0.1%	-0.5%
Sweden	9	9	9	9	10	10	9	0.3%	0.2%	-0.1%
United Kingdom	58	59	61	63	65	67	66	0.3%	0.2%	-0.1%
Rceu	24	24	24	24	23	22	18	0.0%	-0.3%	-0.3%
Turkey	272	386	598	925	1330	2268	5724	4.5%	3.0%	1.9%
EU27	472	483	492	493	490	471	411	0.1%	-0.2%	-0.3%
Europe	779	906	1126	1455	1857	2774	6165	2.4%	2.2%	1.6%
B4	250	258	263	265	266	260	236	0.1%	-0.1%	-0.2%
SE	62	65	69	70	69	67	53	0.4%	-0.1%	-0.5%
NE	59	62	64	66	68	68	63	0.3%	0.1%	-0.2%
EE	136	134	132	129	124	110	90	-0.2%	-0.5%	-0.4%

Source: POLES Reference Scenario ADAM

The second key driver of economic growth is the growth in per capita GDP that increases the mobilisation of labour and global productivity in the long term. The average growth rate in per capita GDP slowly decreases over the period world-wide. This trend is consistent with studies of long-term economic growth which point to a secular trend of 1.5-2 %/year for average productivity growth. Although the per capita GDP continues to increase up to $100,000/capita in North America (the highest throughout the period), the slowdown in per capita GDP growth is most noticeable here and in Asia, where per capita GDP growth is more than halved from the present impressive 3.2 - 6.1 %/year (see Table 3-4).

This pattern of economic and demographic growth mitigates the inequalities in income across the world in the long run. In spite of the decline in growth rates, China's per capita GDP catches up with that of Western Europe by the end of the century. Africa remains the most backward region; by 2100, its per capita GDP is 13 % of that of the USA, which is still an improvement on today's 6 %. In 2100, the average per capita income in all developing regions except Africa is above € 36 000.

Table 3-4: Per capita GDP, by world region (€$_{2005}$ ppp/year), 2000 to 2100

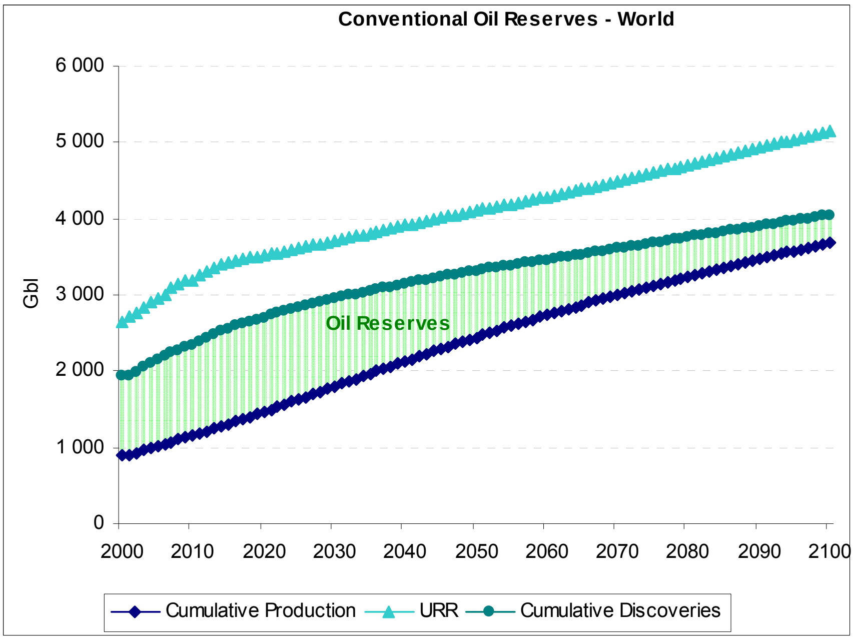
						Annual % change			
	2000	2025	2050	2075	2100	2025/00	2050/25	2075/50	2100/75
WORLD	6729	12684	19988	29646	42998	2.6%	1.8%	1.6%	1.5%
EUROPE	17160	28612	42033	57301	76070	2.1%	1.6%	1.2%	1.1%
USA	32018	47484	62801	82151	105782	1.6%	1.1%	1.1%	1.0%
CAN	26003	36831	45012	59208	76754	1.4%	0.8%	1.1%	1.0%
JAP. PACIFIC	20820	35624	52108	68782	89063	2.2%	1.5%	1.1%	1.0%
CIS	4775	13883	23828	33609	44990	4.4%	2.2%	1.4%	1.2%
CHN	3499	15501	33166	50929	70953	6.1%	3.1%	1.7%	1.3%
NDE	2220	6721	13671	25408	41892	4.5%	2.9%	2.5%	2.0%
RASIA	3002	6595	12192	21649	35527	3.2%	2.5%	2.3%	2.0%
BRA	6542	9984	16115	25721	38324	1.7%	1.9%	1.9%	1.6%
RLAM	6234	9604	14897	24044	36301	1.7%	1.8%	1.9%	1.7%
AFR	1957	2731	3993	7757	13401	1.3%	1.5%	2.7%	2.2%
MIEA	5923	9450	17962	30839	48006	1.9%	2.6%	2.2%	1.8%

Source: POLES Reference Scenario ADAM

World fossil fuel resources

The assumptions about oil and gas resources are critical because present market behaviour and a series of studies on resource availability suggest that the supply development necessary to meet future increases in demand may face increasing difficulties. Any energy outlook for the long term has to deal with the ineluctability of an "oil peak" and a "gas peak", the date of which remains uncertain, but which some geologists expect in the not too distant future. The consequent increase in fuel prices may profoundly influence the development of competing energy technologies and reshape the future energy system at a global level. The POLES model provides a high level of detail for evaluating oil and gas resources and reserves, while all the assumptions concerning the ultimate recoverable resources (URS), discoveries, reserves and cumulative production and recovery rates have been reviewed by the Institut Français du Pétrole (IFP).

The cumulative production of conventional oil today is around 835 billion barrels. The assumption in the ADAM POLES study is that 1 820 billion bl remain to be produced at current recovery rates, of which almost 1 037 billion bl have already been discovered.



Source: POLES Reference Scenario ADAM

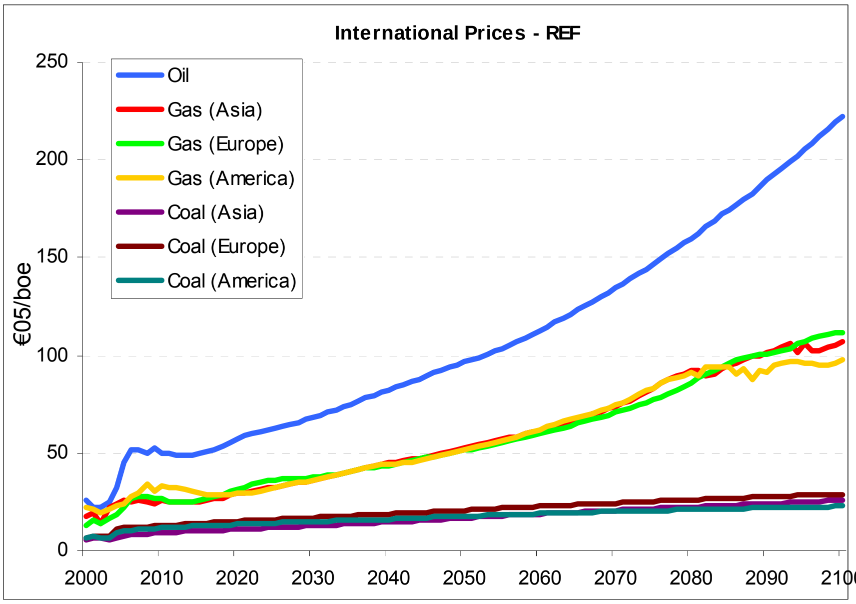
Figure 3-3: Ultimate Recoverable Resources, cumulative discoveries and production of crude oil, 2000 to 2100

The volume of ultimately recoverable resources increases in the period because of improved recovery rates, while cumulative discoveries depend on exploration efforts (Figure 3-3). The dynamic process for the development of reserves is visible in the Figure, because reserves represent the difference between total cumulative discoveries and cumulative production. This process of reserve development and extension explains how the total ultimate recoverable resources estimated by the USGS are extended from 2 600 G bl today to nearly 5 000 G bl in 2100; this of course has a major influence on the supply and demand balance for oil up to 2100.

The geo-political and climate policy context

Assuming there is no additional climate policy, the Reference Scenario represents a projection study where the investment and consumption decisions of economic agents are not modified by additional environmental regulations. Some limited geopolitical constraints on world oil development are taken into account in this scenario. It adopts the view that recent developments in the oil market – with prices between $ 70 and 140/bl in 2008 – not only reflect a conjunction of exceptionally high demand with limited supply, but also signal important and permanent changes in resource accessibility and market behaviour. There are no longer any significant reserve margins of production capacity, suggesting that the tightness in supply will persist. This is not a consequence of insufficient reserves in the short term, but of restricted access to new developments and of growing scarcity in the longer term. Access is constrained in the oil rich OPEC countries by inadequate investments in producing and converting capacity and in non-OPEC countries by unexpected technical and political obstacles and reaching mid depletions points of their major producing fields.

Examining the policies for oil development and foreign investment in the OPEC countries indicates that, although there are still highly profitable opportunities, access is constrained in practice. The constant and significant increase in the oil production capacities of OPEC, which is needed to balance the world energy system in the next decades, will not be easy to achieve. This should even induce, in the medium term, stronger price volatility than the Reference Scenario exhibits. As a consequence, one can expect successive price shocks to limit demand and encourage alternative energy developments leading to oil prices at 100 €/bl in 2050 and over 200 €/bl. by the end of this century (see Figure 3-4).



Source: POLES Reference Scenario ADAM

Figure 3-4: Prices of oil and gas in the Reference projection (€/bl), 2000 to 2100

However, a full description of unstable price behaviour is hard to incorporate in a long-term model. An approximate representation in the Reference Scenario assumes a low responsiveness of capacity development in OPEC to any increase in the price of oil. With the mechanisms of oil price formation included in the model, this low responsiveness leads to higher prices than would otherwise occur. Figure 3-4 illustrates the resulting trajectory of prices: the price of crude oil is expected to stabilise between 2008 and 2015 at a level of 50 $€_{2005}$/bl (i.e. approximately 70 $\$_{2005}$/bl) and then increase again to almost 100 €/bl in 2050 and to around 220 €/bl in 2100 as the resource constraints become tighter and tighter. This price level is needed, not so much to stimulate supply alternatives, which are in most cases already competitive, but to curb the trend in world oil demand, which would otherwise be clearly unsustainable.

This trend in the prices of oil and gas creates a structural cost advantage for coal. Coal resources are much larger than those of oil and gas; they are also more dispersed and often located in large energy consuming countries. Consequently, the absolute increase in coal prices, when expressed in terms of oil equivalent, is expected to be far less than for hydrocarbons. In the Reference Scenario, coal prices roughly double from the current level, which is similar to the relative change expected for oil; but in terms of oil equivalent, the price of coal is still only 15 €/bl in 2050 and 21 €/bl in 2100, creating a huge cost advantage for coal compared with crude oil and natural gas.

3.1.2 Methods used to reflect climate change[4]

This work aims to assess the changes in energy use for heating and air conditioning due to climate change. In order to do so, it was necessary to adapt existing demand equations, taking into account the available data on the fundamental drivers of energy demand for heating and air conditioning in the residential and service sectors in a world where the average temperature may increase by +3.7°C during this century compared to pre-industrial times.

Modelling the impacts of climate change on heating demand

First of all, we isolate the demand for heating from the demand for substitutable energy (heating, cooking and sanitary hot water) in the residential sector. Final demand of substitutable energy in the residential sector (**FCSENRES**) is split into two parts: on the one hand, the demand that remains unaffected by climate change (**FCSENRESW**) and on the other hand, the demand that will be affected (**FCSENRESH**):

$$\mathbf{FCSENRES_{[ALLC]} = FCSENRESW_{[ALLC]} + FCSENRESH_{[ALLC]}}$$

The share (SHRES) of the part of heating demand in residential energy demand, computed from data found in the existing literature, helps to accomplish this separation:

$$\mathbf{FCSENRESH_{[ALLC]} = FCSENRES_{[ALLC]} * SHRES_{[ALLC]}}$$

$$\mathbf{FCSENRESW_{[ALLC]} = FCSENRES_{[ALLC]} * (1\text{-}SHRES_{[ALLC]})}$$

In the second stage we estimate the climate change impact on heating demand (**FCSENRESHCC**). The main drivers are heating degree days (HDD) provided by Timer/IMAGE. These data correspond to the Reference Scenario (770 ppmv in 2100, +3.7°C since pre-industrial ages).

$$\mathbf{FCSENRESHCC_{[ALLC]} = FCSENRES_{[ALLC]} * SHRES_{[ALLC]} * \frac{HDD_{[ALLC]}}{HDD_{2002}}}$$

In this way, the new demand for substitutable energy taking climate change into account is:

$$\mathbf{FCSENRESCC_{[ALLC]} = FCSENRESW_{[ALLC]} + FCSENRESHCC_{[ALLC]}}$$

The same methodology is used for the service sector, but no specific adaptation to climate change was done for industry and transport.

The data for **SHRES** and **SHSER** for the base year (2002) for each POLES region are compiled using several sources such as Enerdata and Eurostat 2005 for temperature correction. Then a logarithmic regression is applied between **SHRESH** and **HDD** and **GDP** (assuming the equivalence between spatial and temporal regression):

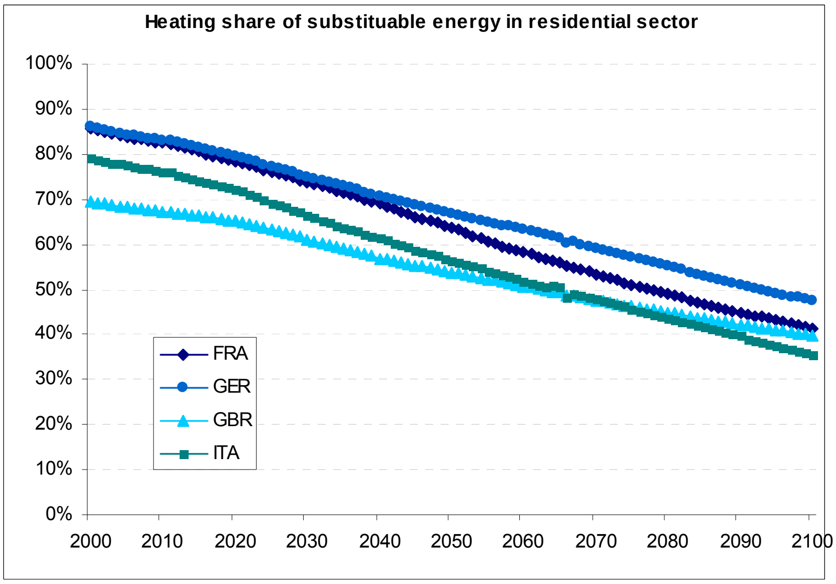
$$\mathbf{SHRES_{[ALLC,T]} = SHRES_{[ALLC,T-1]} * \left(\frac{GDPPOP_{[ALLC,T]}}{GDPPOP_{[ALLC,T-1]}}\right)^{0.06} * \left(\frac{HDD_{[ALLC,T]}}{HDD_{[ALLC,T-1]}}\right)^{1.58}} \qquad ([5])$$

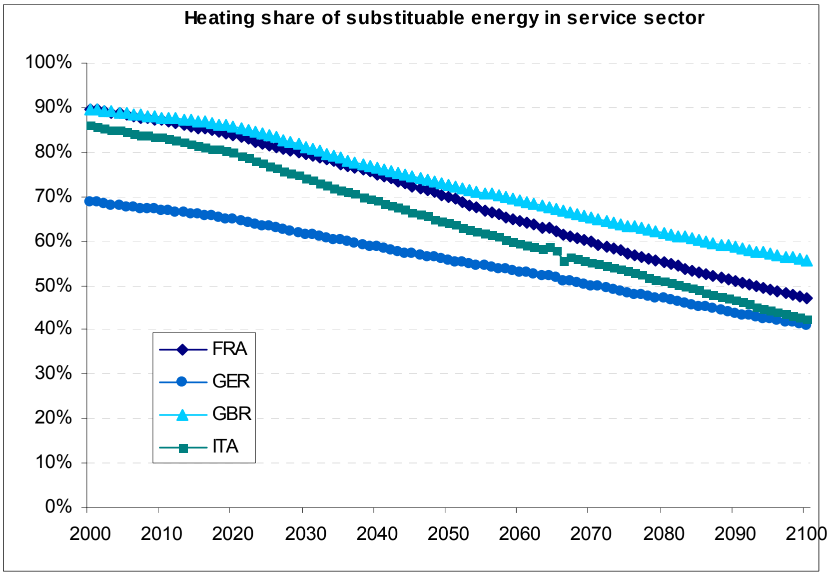
---

4 This section has been written taking into account the work by Julien MOREL

$$\mathbf{SHSER}_{[ALLC,\,T]} = \mathbf{SHSER}_{[ALLC,\,T-1]} * \left(\frac{\mathbf{GDPPOP}_{[ALLC,T]}}{\mathbf{GDPPOP}_{[ALLC,T-1]}}\right)^{0.02} * \left(\frac{\mathbf{HDD}_{[ALLC,T]}}{\mathbf{HDD}_{[ALLC,T-1]}}\right)^{1.47}$$

A substantial decline of heating share in substitutable energy can be observed during the whole century for both sectors, the residential and service sector, as demonstrated for the "Big Four" EU countries (see Figure 3-5).





Source: POLES Reference Scenario ADAM

Figure 3-5: Heating shares of substitutable energy in the residential and service sectors in the Big Four European countries, 2000 to 2100

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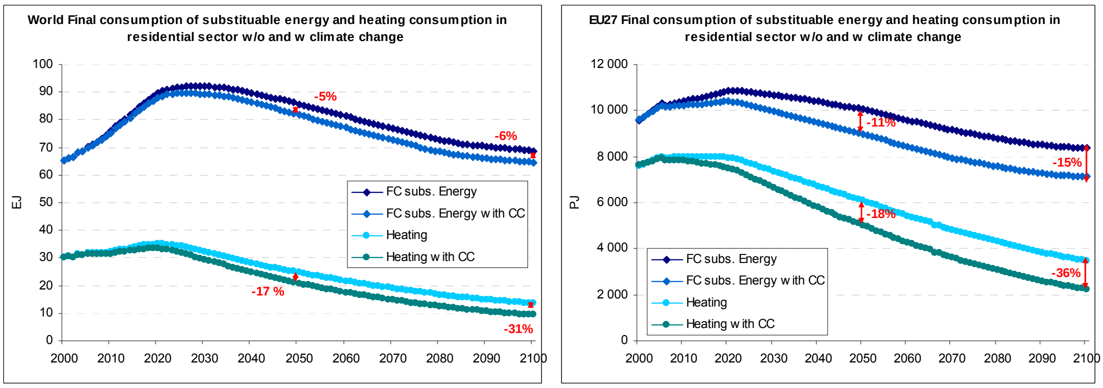
[5] The coefficient of determination is 0.85 and 0.82 for the residential and service sectors, respectively.

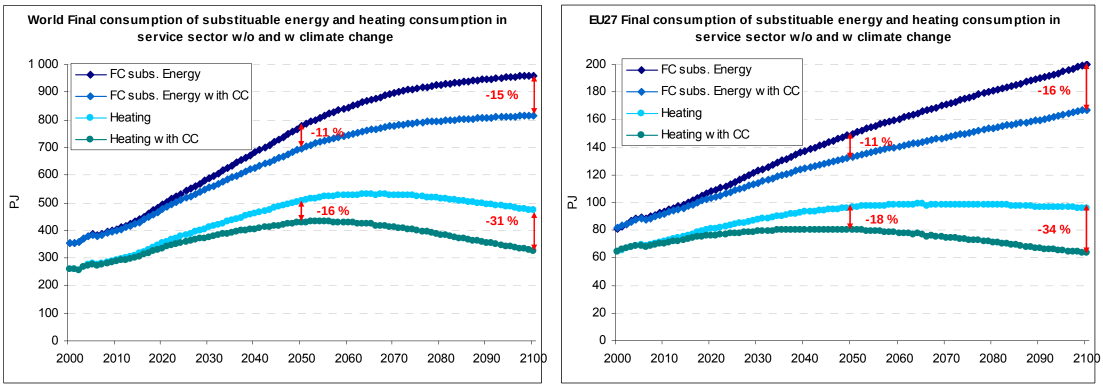
Results

The increase in temperature clearly curtails the heating demand. Comparing the heating demand in the residential sector with and without climate change impacts reveals a gap which widens over time from -17 % by 2050 to -31 % by 2100 at world level and from -18 % to -36% for the EU27 level (see Figure 3-6). The drop in heating demand translates into a reduction of the substitutable energy demand by -5 % at world level and -11 % at EU27 level by 2050 and by -6 % and -15 %, respectively, by 2100. There are comparable results in the service sector.



Source: POLES Reference Scenario ADAM

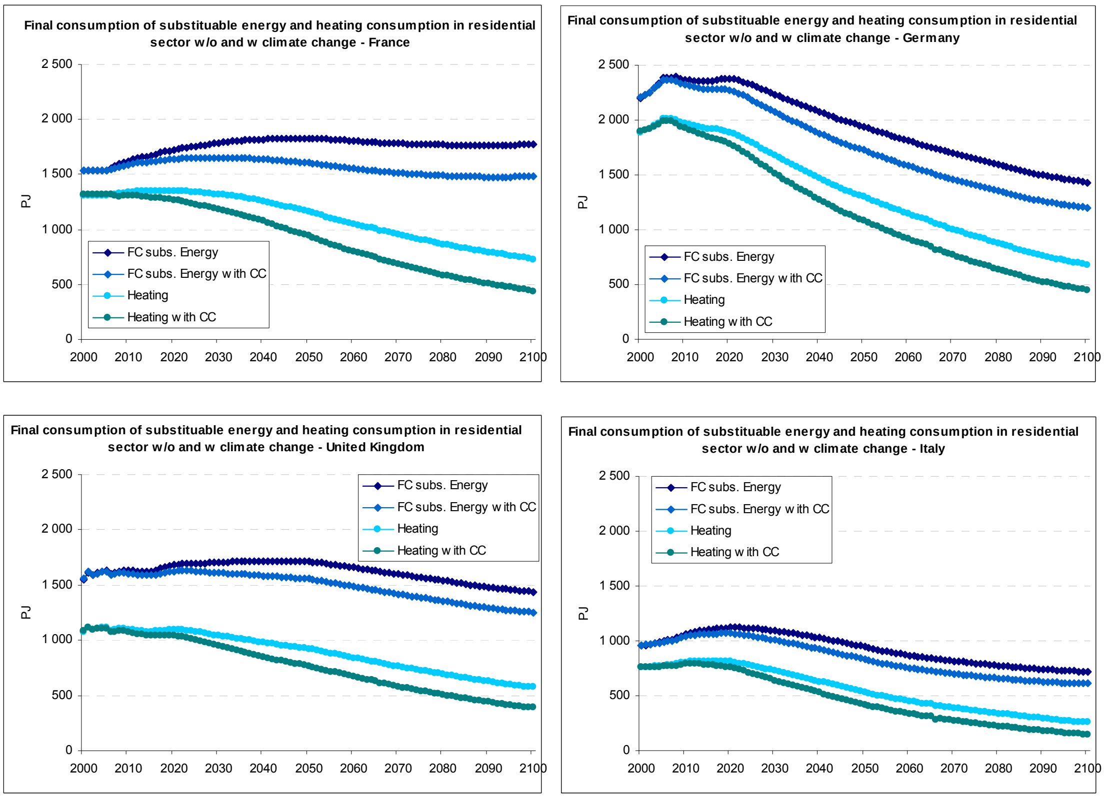
Figure 3-6: Final consumption of substitutable energy and heat demand in the European residential sector with and without climate change, 2000 to 2100



Source: POLES Reference Scenario ADAM

Figure 3-7: Final consumption of substitutable energy and heat demand in the European service sector with and without climate change, Reference Scenario, 2000 to 2100

Some examples of the impact of climate change on heating and substitutable energy demand in the residential sector at country level are presented in the following figure.



Source: POLES Reference Scenario ADAM

Figure 3-8: Final demand of substitutable energy and heating demand in the residential sector with and without climate change, Reference Scenario, 2000 to 2100

Modelling the impacts of climate change on cooling demand

The method proposed to model the impact of climate change on residential cooling demand is based on the paper by McNeil and Letschert. We model the impact in two steps, first modelling air conditioning equipment and then modelling the average baseline unit energy consumption (UEC).

Step 1: Modelling air conditioning equipment

The air-conditioning equipment rate (ACER) is the multiplication of the climate maximum saturation rate (CMAX) by the air-conditioning availability (AVRES). Climate maximum saturation depends on the number of cooling degree days (CDD). For example, for the US, the climate maximum saturation (**CMAX)** can be calculated with the following equation:

$$\mathbf{CMAX = 1 - 0.949 * e^{(-0.00187*CDD)}}$$

Residential air conditioning availability (**AVRES)** is dependent on revenues following a logistic S-curve: $\mathbf{AVRES = 1 / (1+ e^{(3.77610543)} * e^{(-0.22537608*GDPPOP)})}$ ([6])

Then saturation is: **ACER = CMAX * AVRES**

Step 2: Modelling unit energy consumption of residential sector (per dwellings)

6 Model refitted with POLES data. $R2 = 0.66$

The air-conditioning unit energy consumption (AC**UEC)** depends on the number of cooling degree days, but there is a significant dependence on income as well. The following equation was refitted with POLES data:

$$\mathbf{ACUEC=CDD*(a * \ln(GDPPOP) + b)}$$

The equation is proposed in the paper by Morna Isaac and Detlef Van Vuuren, which is derived from McNeil. The logarithm takes into account saturation for high income levels.

$$\mathbf{ACUEC_{(t)} = ACUEC_{(t-1)} * \frac{CDD_{(t)}}{CDD_{(t-1)}} * \frac{(a * \ln(GDPPOP_{(t)}) + b)}{(a * \ln(GDPPOP_{(t-1)}) + b)}}$$

Where: $a = 7.2651*10^{-0.8}$, $b= 8.7398 * 10^{-0.5}$

Finally, the air conditioning electricity consumption with climate change impact (**FCCELRESC**) is calculated as the product of climate maximum saturation (**CMAX),** residential air conditioning availability (**AVRES),** the air-conditioning unit energy consumption (**ACUEC)** and the number of dwellings (**DWL**):

$$\mathbf{FCCELRESC_{[ALLC]} = CMAX_{[ALLC]} * AVRES_{[ALLC]} * ACUEC_{[ALLC]} * DWL_{[ALLC]}}$$

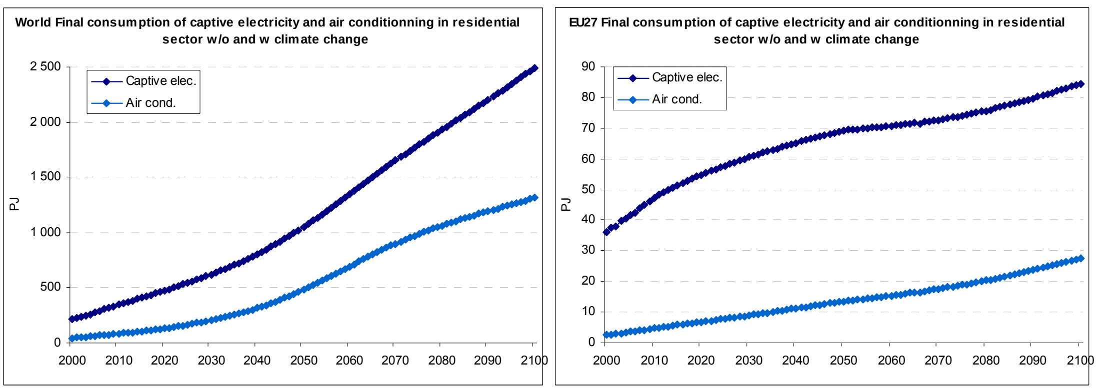
And the total captive electricity including air conditioning:

$$\mathbf{FCCELRESTOT_{[ALLC]} = FCCELRES_{[ALLC]} - FCCELRESC_{[ALLC]}2000 + FCCELRESC_{[ALLC]}}$$

Data

The cooling degree days (**CDD**) come from Timer/IMAGE for the Reference Scenario (771 ppmv in 2100, +3.7°C). The air conditioner saturation data and the unit energy consumption data are from the paper by McNeil and Letschert. The GDP per capita and number of dwellings are from POLES: GDPPOP, DWL.

Results



Source: POLES Reference Scenario ADAM

Figure 3-9: World and EU27 final energy demand for captive electricity and air conditioning in the residential sector, Reference Scenario, 2000 to 2100

The net effect of climate change on global energy use and emissions is relatively small, as the increases in cooling are compensated for by the decreases in heating. However, the impacts on heating and cooling in specific different countries and world regions are considerable in the Reference Scenario, with heating energy demand decreasing by 31 % world-wide by 2100 as a result of climate change, and air conditioning energy demand increasing by 72 %. At a regional level, considerable impacts can be seen, particularly in South Asia, where the energy demand for residential air conditioning could increase by around 50 % due to climate change in the Reference Scenario compared to the situation without climate change (Base Case Scenario).

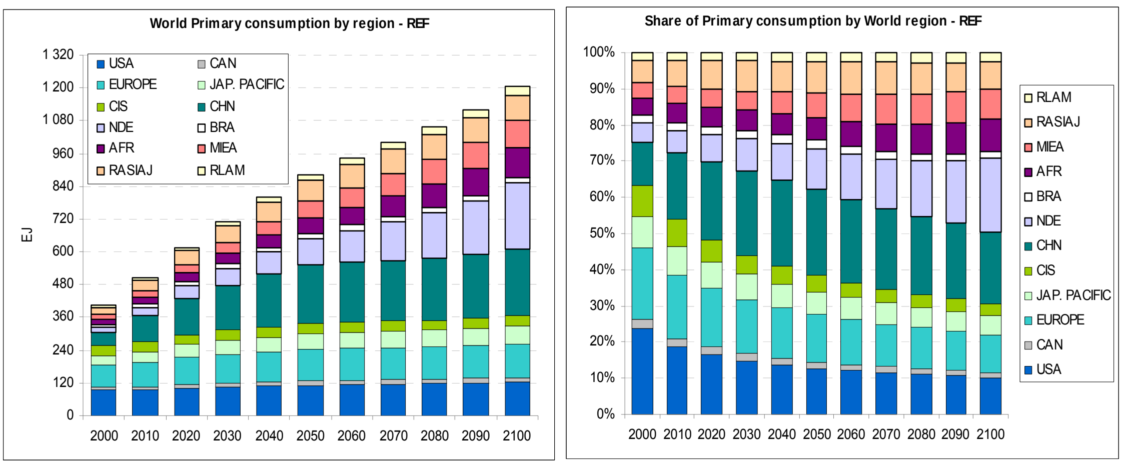
3.2 Energy balances and emission profiles in the Reference Scenario

3.2.1 Primary energy balance

World GDP quadruples between now and 2050, and is ten times higher in 2100 in spite of the relatively low economic growth rates towards the end of the period. The energy intensity of the world GDP in 2050 falls to about half of its 2000 value and further by 38 % in the second half of this century due to structural change, autonomous efficiency improvements and higher prices. Consequently, world energy demand roughly doubles from 414 EJ today to about 965 EJ in 2050 and triples by 2100 compared to 2000, reaching 1,230 EJ.

The 0.4%/year increase in world primary energy demand to 2100 appears low, but the cumulative consequences are large, particularly at the regional level. By 2050, the primary energy demand of today's industrialised countries (including the CIS countries) increases by a factor of 1.3 and 1.4 by 2100. In the developing world, demand increases by a factor of 3.7 and 5.6, respectively. Shortly after 2020, the energy demand of the developing countries exceeds that of the present industrialised countries (Figure 3-10).

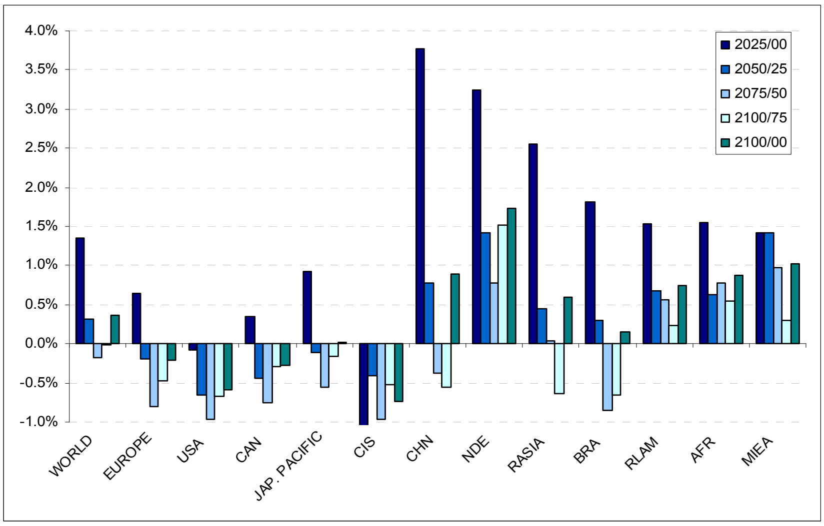
The role of industrialised countries or that of the European region in world primary energy demand is estimated to halve during this century (respectively from 62 % to 30 % for industrialised countires and from 19 % to 10 % for Europe). The primary energy demand in Europe increases moderately over the period from 78 EJ today to only 113 EJ in 2100 (Figure 3-12). This is one of the lowest growth rates in the world regions (0.4%/year).



Source: POLES Reference Scenario ADAM

Figure 3-10: World primary energy demand in the Reference Scenario by world regions, 2000 to 2100

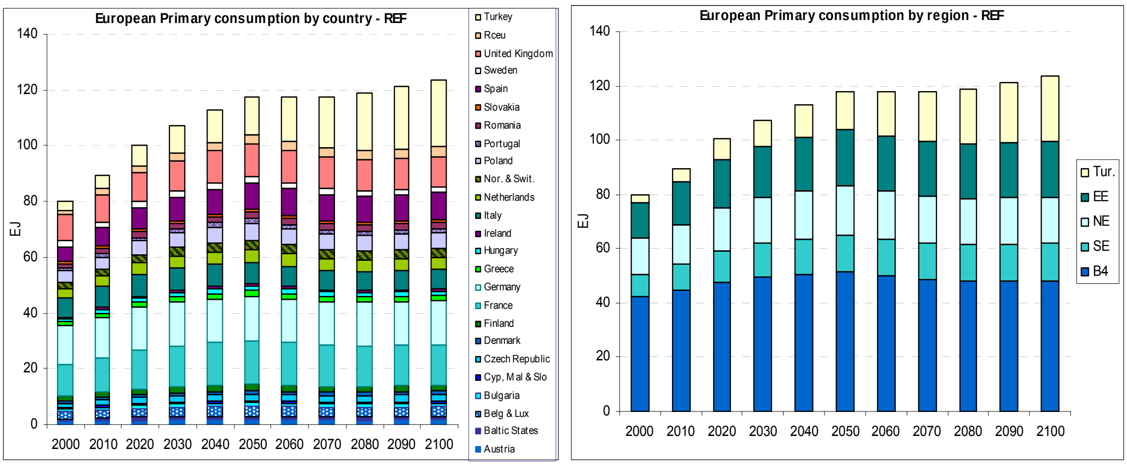
Analysing the resulting world energy system reveals the significant structural changes that are needed to accommodate the constraints on fossil fuel resources as well as sustantuial improvements in eefficient energy use. This development is clearly reflected in the energy intensity of GDP of the world economy, which falls throughout the period and is reduced to one-fifth by 2100 relative to the year 2000.



Source: POLES Reference Scenario ADAM

Figure 3-11: Growth rates of primary energy demand by world regions, Reference Scenario, 2000 to 2100

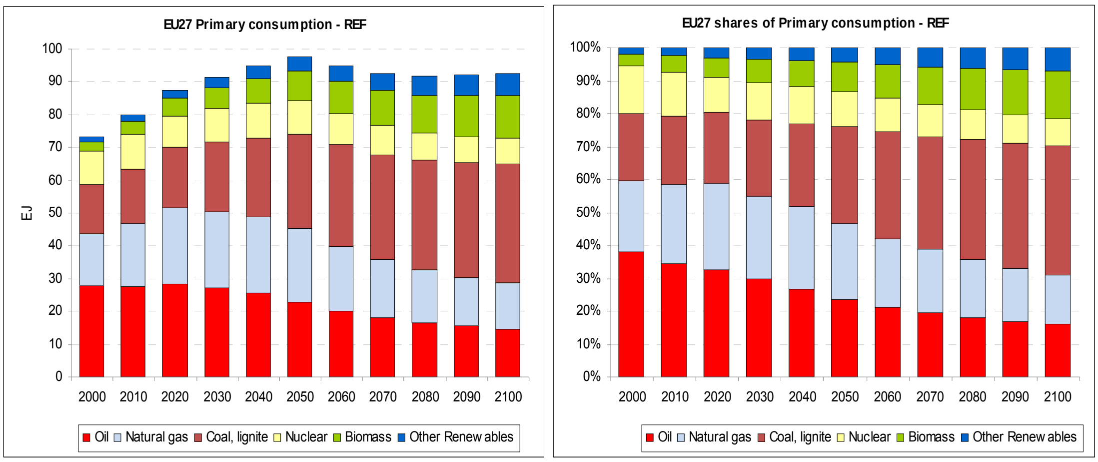
The primary energy demand of the Big Four European countries increases slightly from 42 EJ at present to 51 EJ by 2050 and drops to 48 EJ by 2100. However, the share of these countries in the total primary demand of Europe decreases steadily from 55 % in 2000 to 47 % and 42 % in 2050 and 2100, respectively. Turkey's energy demand increases rapidly, while the demand of other countries remains relatively stable (see Figure 3-12).



Source: POLES REF ADAM

Figure 3-12: European primary energy demand by country and region, 2000 to 2100

The contribution of fossil energy sources decreases from 80% at the beginning of the century to 76% by 2050 and represent 70 % by the end of the period (see Figure 3-13). The demand of oil and gas is restricted by high prices, in particular after 2020. By 2030, the demand of oil and gas in Europe is less than in 2000. During the century, coal use more than doubles, providing slightly less than 30 EJ by 2050 and 36 EJ by 2100. Compared to the current 15 EJ, the figure is impressive. It reflects the relative abundance of coal and the resulting price advantage in the long term. Renewables increase steadily over the period, representing 21% of primary energy demand by 2100. Nuclear contribution is expected to diminish, from 10.5 EJ today to 7.7 EJ by 2100.



Source: POLES Reference Scenario ADAM

Figure 3-13: EU27 primary energy demand by energy carriers, Reference Scenario, 2000 to 2100

These trends have a clear impact on Europe's level of energy self-sufficiency (see Table 3-5):

1. The ratio of primary production to primary consumption is currently 53 %.
2. This ratio falls to 46 % between 2025 and 2050 because of falling oil and gas production in the North Sea and despite the modest increase in demand.
3. After 2050, the upward trends in renewable energies compensate for the falling production of hydrocarbons; in 2100, the self-sufficiency ratio recovers to 49 %.

Table 3-5: European energy self-sufficiency ratio, Reference Scenario, 2000 to 2100

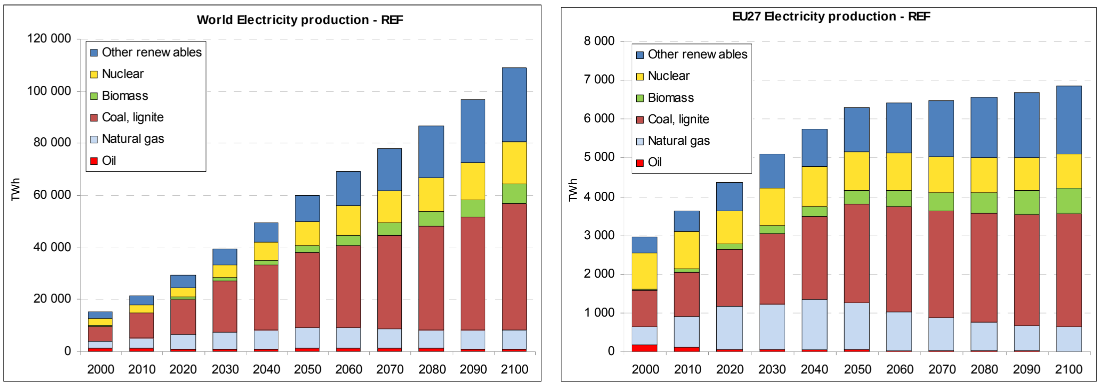
	2000	2025	2050	2075	2100
Primary Production (Mtoe)	936	1022	1073	1071	1083
Primary Consumption (Mtoe)	1750	2139	2328	2198	2212
P. prod/P. cons (%)	53%	48%	46%	49%	49%

Source: POLES Reference Scenario ADAM

3.2.2 The development of global electricity generation

The generation of electricity worldwide increases nearly fourfold, from 15,200 TWh/year today to 60,100 TWh/year by 2050, and then almost doubles, reaching 109 000 TWh/year by 2100 (Figure 3-14).

In the EU27, electricity generation more than doubles during the first half of the century and remains relatively stable after 2050, reaching 7 100 TWh/year by 2100 (see Table 3-6). The evolution at country level is estimated to be similar for the Big Four and faster for other European countries. For example, in southern European countries, electricity generation increases fivefold over the 10 decades considered.



Source: POLES Reference Scenario ADAM

Figure 3-14: World and EU27 electricity generation, Reference Scenario, 2000 to 2100

Table 3-6: Electricity generation by country in Europe, Reference Scenario, 2000 to 2100

	1990	2000	2010	2020	2030	2050	2100	Annual % change 2000/20	20/50	50/100
Austria	50	62	67	82	97	118	136	1.5%	1.2%	0.3%
Baltic States	34	24	45	54	62	77	89	4.1%	1.2%	0.3%
Belgium & Luxemburg	72	85	97	119	146	190	233	1.7%	1.6%	0.4%
Bulgaria	42	40	50	60	67	78	96	2.1%	0.9%	0.4%
Cyprus, Malta and Slovenia	16	19	28	35	41	51	61	3.1%	1.3%	0.4%
Czech Republic	63	73	94	113	128	156	185	2.2%	1.1%	0.3%
Denmark	26	36	52	62	72	87	99	2.8%	1.1%	0.3%
Finland	54	70	83	108	128	165	179	2.2%	1.4%	0.2%
France	421	541	630	759	878	1072	1154	1.7%	1.2%	0.1%
Germany	550	567	655	766	862	1005	1146	1.5%	0.9%	0.3%
Greece	35	52	72	93	109	134	167	2.9%	1.2%	0.4%
Hungary	28	35	45	55	67	92	97	2.2%	1.8%	0.1%
Ireland	15	24	31	38	48	65	71	2.3%	1.8%	0.2%
Italy	217	233	320	368	417	467	459	2.3%	0.8%	0.0%
Netherlands	72	89	108	140	177	229	262	2.3%	1.6%	0.3%
Norway and Switzerland	159	214	223	257	292	334	436	0.9%	0.9%	0.5%
Poland	136	145	184	234	278	393	387	2.4%	1.7%	0.0%
Portugal	29	44	60	75	90	113	133	2.8%	1.4%	0.3%
Romania	64	52	63	81	97	134	164	2.3%	1.7%	0.4%
Slovakia	24	31	38	45	52	68	90	1.9%	1.4%	0.6%
Spain	152	221	321	411	486	621	796	3.2%	1.4%	0.5%
Sweden	146	145	166	182	190	218	228	1.1%	0.6%	0.1%
United Kingdom	320	377	422	489	595	790	892	1.3%	1.6%	0.2%
Rceu	61	64	109	145	175	239	304	4.2%	1.7%	0.5%
Turkey	58	125	207	352	550	963	2212	5.3%	3.4%	1.7%
EU27	2413	2965	3633	4368	5088	6322	7121	2.0%	1.2%	0.2%
WEUR	2845	3367	4172	5123	6104	7859	10073	2.1%	1.4%	0.5%
B4	1507	1719	2027	2382	2752	3334	3649	1.6%	1.1%	0.2%
SE	231	336	482	614	726	920	1157	3.1%	1.4%	0.5%
NE	544	662	761	907	1053	1288	1507	1.6%	1.2%	0.3%
EE	504	525	695	868	1024	1354	1547	2.5%	1.5%	0.3%

Source: POLES Reference Scenario ADAM

The share of thermal generation increases until 2030 - 2040 (up to 69 % at the world level and 64 % for EU27) because other sources cannot match the growth in demand, but it drops to 59 % by 2100 (see Table 3-7). This represents a significant structural change for a reference projection. The role of thermal generation varies from country to country. Currently, in eastern and southern European countries, respectively 65 % and 63 % of electricity generation is provided by thermal power plants. This is expected to remain relatively stable over the entire period in these countries, decreasing slightly at the end of the period (to slightly more than 60 %). The role of thermal generation becomes more important in the Big Four countries and the northern European countries from currently 51 % and 33 %, respectively, to 64 % and 49 % by 2050, and to 58 % and 44 % by 2100.

Table 3-7: The share of thermal generation in total electricity generation, Europe and European regions, Reference Scenario, 2000 to 2100

	2000	2010	2020	2030	2050	2100
EU27	54%	59%	64%	64%	66%	59%
WEUR	52%	57%	61%	61%	63%	57%
B4	51%	57%	63%	62%	64%	58%
SE	63%	66%	63%	66%	70%	60%
NE	33%	38%	46%	49%	49%	44%
EE	65%	66%	65%	65%	66%	62%

Source: POLES Reference Scenario ADAM

Within the thermal generation sector, advanced technologies will progressively gain ground until they have the lion's share. In 2100 in the EU27 region, more than 60 % of coal-based power generation is from advanced coal technologies and 67 % of gas-based electricity is from combined cycles or co-generation. Heating oil disappears almost entirely from the electricity sector (see Table 3-8).

Table 3-8: EU27 electricity generation by technology, Reference Scenario 2000 to 2100

								Annual % change		
	2000	2010	2020	2030	2040	2050	2100	2000/20	20/50	50/100
Electricity Production (TWh)	2965	3633	4368	5088	5757	6322	7121	2.0%	1.2%	0.2%
Thermal, of which :	1614	2125	2778	3258	3752	4151	4220	2.8%	1.3%	0.0%
Coal, lignite	925	1135	1455	1809	2129	2548	2933	2.3%	1.9%	0.3%
of which advanced coal	0	45	550	1125	1483	1613	1546	51.9%	3.6%	-0.1%
Gas	506	785	1113	1194	1303	1201	630	4.0%	0.3%	-1.3%
of which combined cycle	278	389	685	769	807	663	216	4.6%	-0.1%	-2.2%
of which cogeneration (industry)	49	105	144	179	220	262	207	5.6%	2.0%	-0.5%
Oil	181	125	63	46	52	59	13	-5.1%	-0.2%	-3.0%
Biomass	41	81	148	208	268	343	644	6.7%	2.8%	1.3%
Nuclear	945	967	869	974	1016	1017	868	-0.4%	0.5%	-0.3%
of which new design	0	0	0	0	45	154	529	na	na	2.5%
Hydro (large)	341	330	339	345	350	354	373	0.0%	0.1%	0.1%
Hydro (small)	41	45	48	49	49	50	51	0.9%	0.1%	0.1%
Wind	22	158	298	390	454	513	695	13.8%	1.8%	0.6%
Solar	0	7	36	71	130	219	656	33.3%	6.2%	2.2%

Source: POLES Reference Scenario ADAM

World generation from renewable resources grows strongly - by a factor of 5 in 2050 and 13 in 2100. The development of renewable electricity in the EU27 almost meets the EU's target of 20 % of total power generation by 2020. This share is maintained and even increased in the future to 23 % by 2050 and 34 % by 2100.

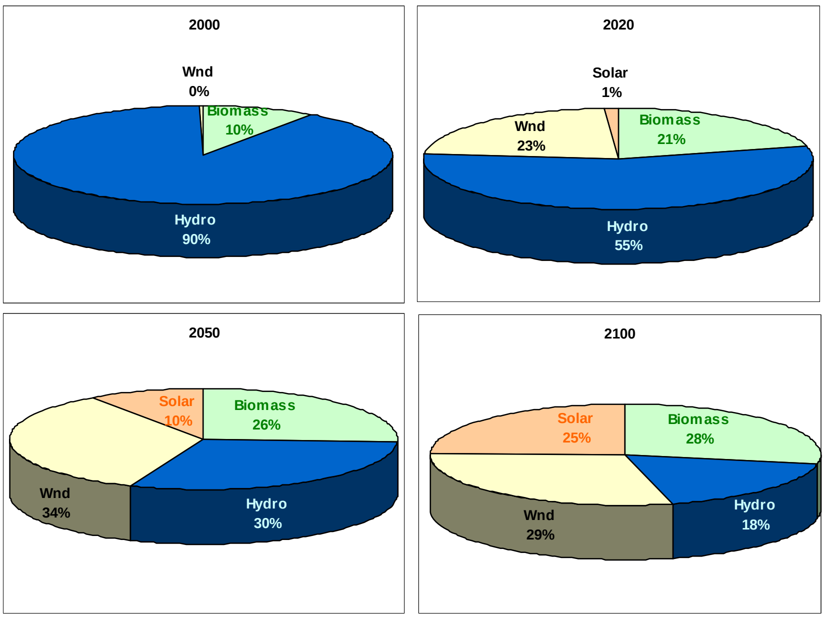
The contribution of renewables by country in the total electricity generation is projected to be larger in northern European countries due to the high shares here of hydropower and later wind power (currently 47 %, 42 % by 2020, 45 % by 2050 and 60 % by 2100, see Table 3-9). In the Big Four countries it seems that, without climate policies, the role of renewables will remain at a relatively low level: 17 % in 2020, 21 % in 2050 and 29 % in 2100. Other European countries are in-between the northern European countries and the Big Four: 21 % by 2020 and 33 % by 2100.

Table 3-9: The share of renewable electricity generation by country and European regions, Reference Scenario, 2000 to 2100

	1990	2000	2010	2020	2030	2050	2100	Annual % change 2000/20	20/50	50/100
Austria	65%	73%	77%	78%	82%	81%	80%	0.3%	0.1%	-0.03%
Baltic States	9%	15%	9%	10%	11%	15%	28%	-1.8%	1.4%	1.2%
Belgium & Luxemburg	2%	4%	8%	13%	17%	26%	61%	5.7%	2.4%	1.7%
Bulgaria	4%	7%	9%	10%	13%	20%	31%	1.7%	2.2%	0.9%
Cyprus, Malta and Slovenia	21%	21%	18%	19%	21%	28%	43%	-0.4%	1.3%	0.9%
Czech Republic	2%	4%	5%	8%	8%	10%	13%	3.6%	0.6%	0.6%
Denmark	2%	17%	21%	23%	26%	30%	51%	1.6%	0.9%	1.1%
Finland	20%	34%	26%	26%	30%	41%	70%	-1.3%	1.5%	1.1%
France	14%	14%	13%	16%	17%	21%	34%	0.6%	1.0%	1.0%
Germany	4%	7%	13%	16%	17%	19%	23%	3.8%	0.7%	0.4%
Greece	6%	9%	11%	13%	14%	21%	34%	2.0%	1.6%	1.0%
Hungary	1%	1%	6%	8%	10%	15%	22%	12.2%	2.0%	0.8%
Ireland	7%	6%	10%	14%	18%	27%	45%	4.1%	2.2%	1.0%
Italy	18%	23%	22%	28%	28%	31%	42%	1.0%	0.3%	0.6%
Netherlands	0%	5%	10%	10%	11%	17%	32%	3.7%	1.8%	1.2%
Norway and Switzerland	99%	87%	78%	71%	66%	67%	66%	-1.0%	-0.2%	0.0%
Poland	2%	3%	6%	8%	9%	15%	24%	4.9%	2.2%	0.9%
Portugal	33%	31%	30%	33%	32%	34%	56%	0.4%	0.1%	1.0%
Romania	18%	29%	27%	24%	23%	24%	34%	-0.9%	0.0%	0.7%
Slovakia	10%	16%	15%	16%	17%	19%	25%	0.1%	0.5%	0.6%
Spain	17%	17%	22%	20%	18%	15%	27%	0.7%	-1.0%	1.2%
Sweden	50%	57%	52%	65%	70%	72%	79%	0.6%	0.3%	0.2%
United Kingdom	2%	3%	9%	14%	16%	16%	22%	7.3%	0.4%	0.7%
Rceu	38%	45%	31%	33%	35%	38%	42%	-1.5%	0.4%	0.2%
Turkey	40%	25%	22%	19%	19%	22%	32%	-1.2%	0.4%	0.7%
EU27	12%	15%	17%	20%	21%	23%	34%	1.4%	0.5%	0.7%
WEUR	18%	21%	21%	23%	23%	26%	35%	0.5%	0.4%	0.6%
B4	8%	11%	14%	17%	19%	21%	29%	2.4%	0.6%	0.7%
SE	18%	18%	21%	21%	19%	19%	32%	0.7%	-0.3%	1.1%
NE	45%	47%	41%	42%	41%	45%	60%	-0.6%	0.3%	0.6%
EE	16%	20%	19%	21%	23%	26%	33%	0.2%	0.7%	0.5%

Source: POLES Reference Scenario ADAM

The structure of the renewable electricity mix varies over time. In the case of the EU27, the share of hydro decreases from 90 % in 2000 to 55% in 2020, 30 % in 2050 and only 18 % in 2100 reflecting the present largely exploited potential of this renewable energy source (see Figure 3-15). Biomass, wind and solar energy will increase their contributions throughout the period examined, and attain nearly equal shares by 2100.



Source: POLES Reference Scenario ADAM

Figure 3-15: EU27 share of the different energy sources in total renewable generation, Reference Scenario, 2000 to 2100

Table 3-10: Nuclear electricity generation by European country, Reference Scenario, 2000 to 2100

	2000	2010	2020	2030	2050	2100	Annual % change 2000/20	20/50	50/100
Austria	0	0	0	0	0	0	na	na	na
Baltic States	8	19	20	15	13	9	4.3%	-1.5%	-0.7%
Belgium & Luxemburg	48	43	33	26	16	4	-1.8%	-2.5%	-2.5%
Bulgaria	18	17	17	16	14	11	-0.3%	-0.5%	-0.6%
Cyprus, Malta and Slovenia	5	7	10	12	10	7	3.7%	0.0%	-0.7%
Czech Republic	14	33	33	29	26	23	4.6%	-0.8%	-0.3%
Denmark	0	0	0	1	11	11	na	21.8%	0.1%
Finland	23	35	36	37	33	16	2.4%	-0.3%	-1.4%
France	415	439	427	483	390	268	0.1%	-0.3%	-0.7%
Germany	170	128	9	0	0	0	-13.6%	-100.0%	na
Greece	0	0	7	15	18	17	na	3.1%	-0.1%
Hungary	14	17	19	18	18	13	1.4%	-0.2%	-0.7%
Ireland	0	0	0	0	0	0	na	-2.5%	na
Italy	0	0	0	2	30	66	na	na	1.6%
Netherlands	4	13	25	46	65	51	9.7%	3.2%	-0.5%
Norway and Switzerland	26	36	56	71	79	77	3.8%	1.2%	-0.1%
Poland	0	1	13	43	72	55	na	5.8%	-0.5%
Portugal	0	0	7	15	19	14	na	3.3%	-0.6%
Romania	5	6	9	14	16	15	2.5%	1.9%	-0.1%
Slovakia	17	19	16	13	11	9	-0.2%	-1.3%	-0.4%
Spain	62	59	86	79	73	83	1.6%	-0.6%	0.3%
Sweden	57	64	22	0	0	0	-4.7%	-100.0%	na
United Kingdom	85	69	80	109	185	196	-0.3%	2.8%	0.1%
Rceu	0	5	22	31	33	28	na	1.3%	-0.3%
Turkey	0	0	29	83	145	255	na	5.5%	1.1%
EU27	945	967	869	974	1017	868	-0.4%	0.5%	-0.3%
WEUR	972	1007	977	1158	1274	1228	0.0%	0.9%	-0.1%
B4	670	636	516	595	604	530	-1.3%	0.5%	-0.3%
SE	67	66	110	120	119	121	2.5%	0.3%	0.0%
NE	158	190	173	181	204	160	0.4%	0.6%	-0.5%
EE	76	115	149	179	202	162	3.4%	1.0%	-0.4%

Source: POLES Reference Scenario ADAM

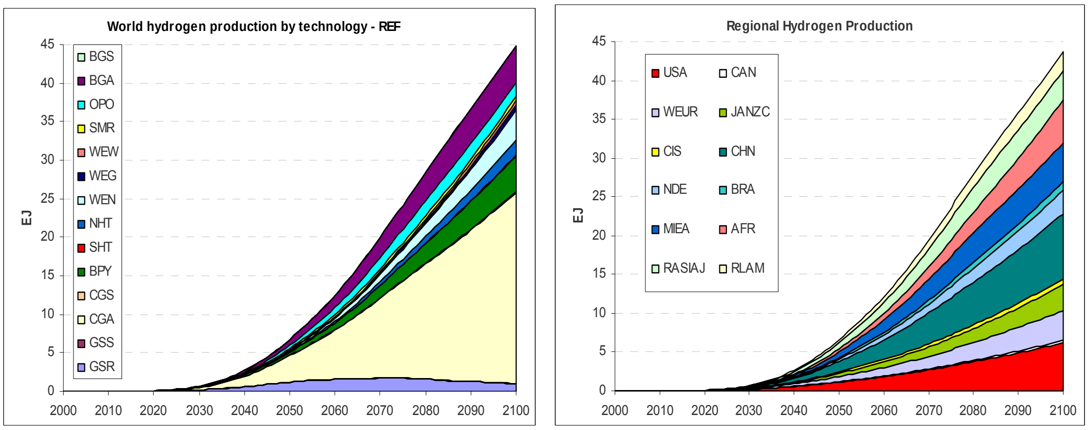
The absolute contribution and the share of nuclear electricity both decrease until 2020 as some second-generation plants are retired. World electricity generation in nuclear plants revives after this point, with the rapid introduction of third- and fourth-generation plants which quadruple by 2050 and are 10 times higher by 2100. In the EU27, the contribution of nuclear energy remains relatively stable (see Table 3-10). However, 12 % of electricity in the EU27 will come from nuclear energy by 2100.

In Europe, France, the United Kingdom and Turkey play a major role in nuclear generation. While nuclear generation in France decreases after 2030, it will increase in the United Kingdom and Turkey.

3.2.3 Hydrogen production

In the Reference Scenario, hydrogen production remains limited at world level (6.6 PJ in 2050 and 44 PJ in 2100). In 2050, it represents only 1.2 % of total final energy demand and only 6 % in 2100 – equivalent to 4 % and 13 % respectively of final electricity demand. In the EU27 the contribution of hydrogen is even lower: only 0.8 % of total final energy demand and 4.5 % in 2100 – equivalent to 2.8 % and 13 % of the final electricity demand in 2050 and 2100, respectively.

Hydrogen is mainly produced using coal (see Figure 3-16). Hydrogen production from the steam reforming of natural gas is limited by increasing gas prices and costs more than coal gasification. World hydrogen production has a relatively balanced profile across regions.

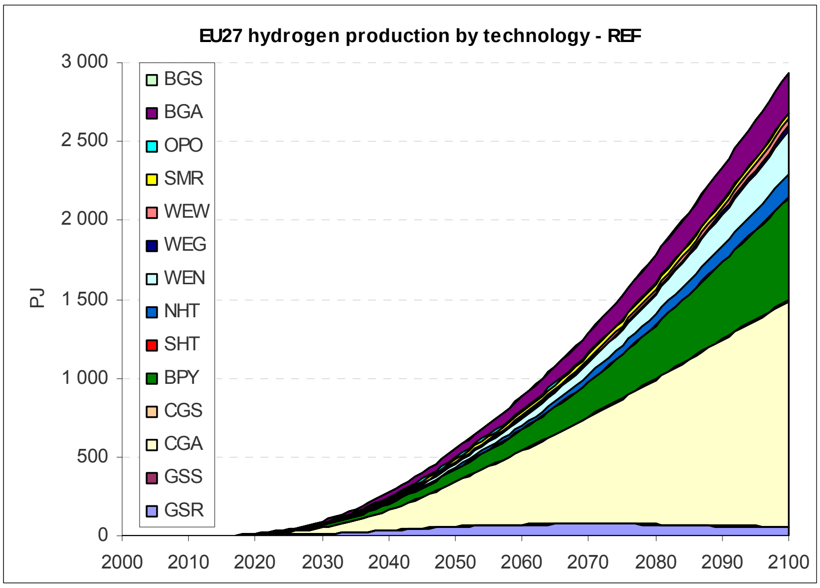


Source: POLES Reference Scenario ADAM

Figure 3-16: Hydrogen energy production by technology and world region, 2000 to 2100

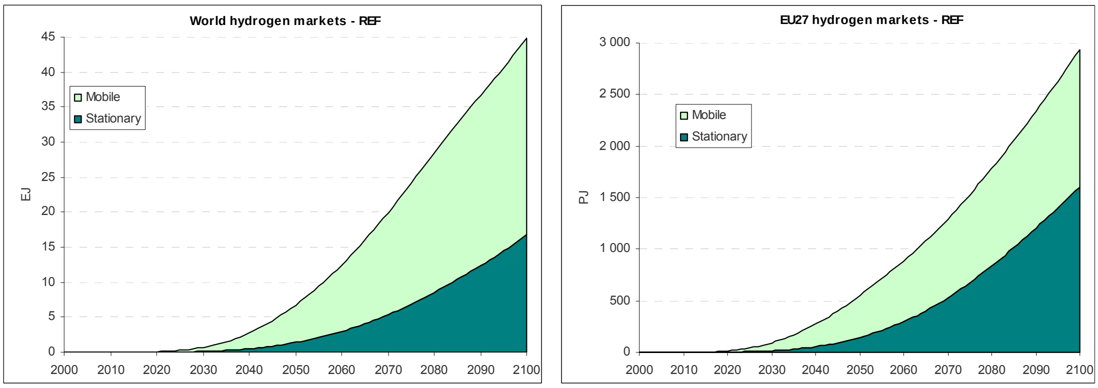
The amount of hydrogen produced for energy purposes is very limited in Europe until 2030 after which it begins to penetrate the market and total production reaches 3 EJ by 2100. This is equivalent to 16 % of the total final demand of electricity (see Figure 3-17). The share in European final demand is of course lower and equals 7 % of final demand compared to a world average of 8 %.

Nearly two thirds of the globally produced hydrogen are used for mobility purposes in the transport market, which represent 79 % of the total in 2050 and 63 % in 2100. In the EU27 countries these figures represent 74 % of the total hydrogen used in the transport sector by 2050 and 45 % by 2100. Stationary use is mostly small fuel cell applications in decentralised co-generation plants.



Source: POLES Reference Scenario ADAM

Figure 3-17: Hydrogen production in Europe by technology, Reference Scenario, 2000 to 2100



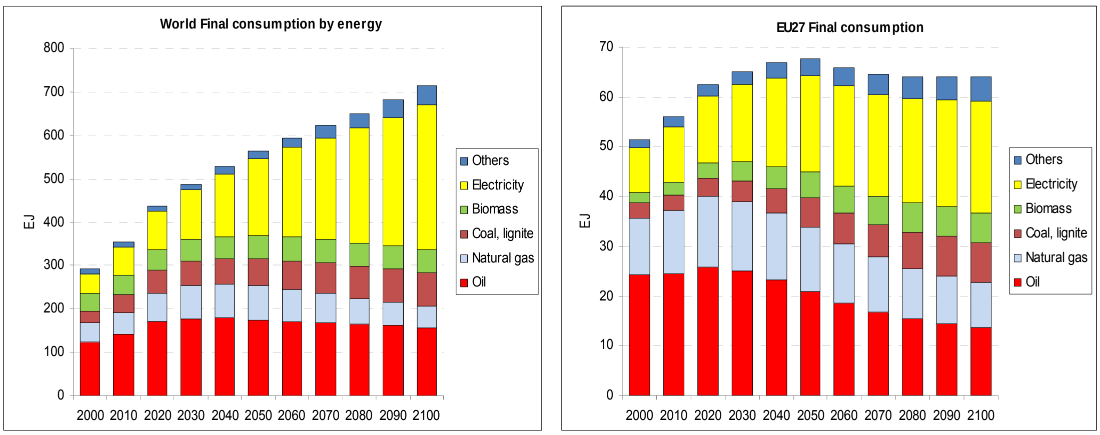
Source: POLES Reference Scenario ADAM

Figure 3-18: World and EU27 hydrogen markets, Reference Scenario, 2000 to 2100

3.2.4 Trends in final energy demand

Expected world final energy demand almost doubles by 2050, but then increases more slowly, with only a 30 % increase between 2050 and 2100. Final electricity demand increases significantly faster, at a rate of more than 2 %/year which is equivalent to an increase from 45 EJ in 2000 to 335 EJ in 2100.

The final consumption of energy in the EU27 increases during the first half of the century at an average rate of 0.55 %/year and decreases slightly (-0.1 %/year) over the second half. This tendency is seen in all European countries, albeit at different paces - lower in the Big Four and northern countries and faster in the rest of Europe.



Source: POLES Reference Scenario ADAM

Figure 3-19: World (left) and EU 27 final energy demand (right) by energy carrier, Reference Scenario, 2000 to 2100

EU27 final electricity demand increases at a faster pace than final energy consumption - by more than 0.9 %/year - but much more slowly than the world average for electricity. At country level, given that the fastest increase of electricity demand occurs in the southern and eastern European countries, the share of the Big 4 and other northern countries decreases from 73 % currently to 61 % by 2050 and 53 % by 2100.

Table 3-11: Final energy demand by European countries, Reference Scenario, 2000 to 2100

	2000	2010	2020	2030	2050	2100	Annual % change 2000/20	20/50	50/100
Austria	1.0	1.2	1.3	1.4	1.3	1.3	1.3%	0.0%	-0.1%
Baltic States	0.4	0.6	0.7	0.8	0.8	0.8	2.5%	0.5%	-0.1%
Belgium & Luxemburg	2.1	2.1	2.4	2.5	2.5	2.3	0.6%	0.2%	-0.2%
Bulgaria	0.4	0.5	0.7	0.7	0.7	0.8	2.3%	0.3%	0.1%
Cyprus, Malta and Slovenia	0.3	0.4	0.4	0.4	0.5	0.5	1.4%	0.5%	0.0%
Czech Republic	1.1	1.3	1.5	1.6	1.7	1.7	1.6%	0.4%	0.0%
Denmark	0.6	0.7	0.8	0.8	0.8	0.8	1.1%	0.2%	0.0%
Finland	1.0	1.2	1.4	1.5	1.6	1.5	1.5%	0.6%	-0.2%
France	7.1	7.6	8.6	9.3	10.1	9.8	0.9%	0.6%	-0.1%
Germany	10.3	10.7	11.7	11.9	11.8	11.2	0.6%	0.0%	-0.1%
Greece	0.8	0.9	1.1	1.1	1.2	1.3	1.4%	0.5%	0.1%
Hungary	0.7	0.9	1.0	1.1	1.2	1.0	1.6%	0.5%	-0.2%
Ireland	0.5	0.6	0.6	0.6	0.6	0.6	1.4%	0.1%	-0.2%
Italy	5.6	6.0	6.4	6.4	5.9	5.2	0.7%	-0.3%	-0.2%
Netherlands	2.5	2.8	3.1	3.3	3.4	3.3	1.1%	0.3%	-0.1%
Norway and Switzerland	1.8	1.9	2.1	2.3	2.4	2.6	0.8%	0.4%	0.2%
Poland	2.5	2.8	3.3	3.5	4.0	3.6	1.3%	0.6%	-0.2%
Portugal	0.8	0.9	1.0	1.1	1.1	1.1	0.7%	0.5%	-0.1%
Romania	1.0	1.3	1.5	1.5	1.6	1.6	1.9%	0.3%	0.0%
Slovakia	0.5	0.6	0.6	0.7	0.7	0.7	1.2%	0.3%	0.1%
Spain	3.8	4.6	5.5	5.9	6.2	6.1	1.9%	0.4%	0.0%
Sweden	1.5	1.5	1.6	1.7	1.8	1.6	0.4%	0.4%	-0.2%
United Kingdom	6.8	6.9	7.4	7.6	8.0	7.1	0.4%	0.2%	-0.2%
Rceu	0.7	1.3	1.6	1.8	2.1	2.2	3.9%	1.0%	0.0%
Turkey	2.4	3.3	5.0	6.2	8.1	13.5	3.7%	1.6%	1.0%
EU27	51.5	56.1	62.5	65.2	67.8	64.2	1.0%	0.3%	-0.1%
WEUR	56.4	62.5	71.2	75.5	80.4	82.5	1.2%	0.4%	0.1%
B4	29.8	31.2	34.1	35.2	35.8	33.4	0.7%	0.2%	-0.1%
SE	5.7	6.8	8.0	8.5	9.1	9.0	1.7%	0.4%	0.0%
NE	10.1	10.7	12.1	12.7	13.3	12.8	0.9%	0.3%	-0.1%
EE	8.4	10.5	12.1	12.9	14.1	13.7	1.8%	0.5%	-0.1%

Source: POLES Reference Scenario ADAM

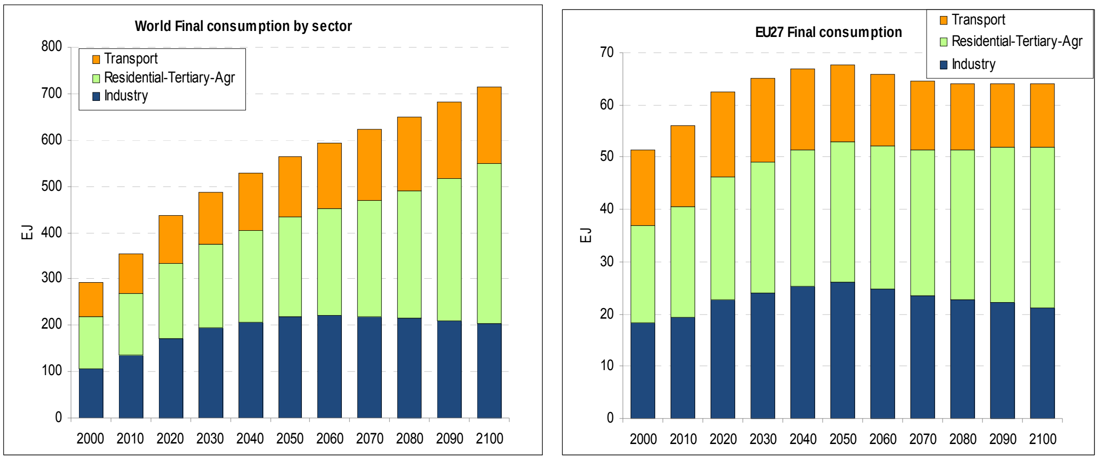
Table 3-12: Final electricity demand by European country, Reference Scenario, 2000 to 2100

	2000	2010	2020	2030	2050	2100	Annual % change 2000/20	20/50	50/100
Austria	0.2	0.2	0.3	0.3	0.4	0.5	2.0%	1.2%	0.3%
Baltic States	0.1	0.1	0.1	0.2	0.2	0.2	4.3%	1.3%	0.4%
Belgium & Luxemburg	0.3	0.4	0.4	0.5	0.7	0.8	1.8%	1.4%	0.4%
Bulgaria	0.1	0.1	0.1	0.2	0.2	0.2	2.3%	1.0%	0.5%
Cyprus, Malta and Slovenia	0.1	0.1	0.1	0.1	0.2	0.2	2.8%	1.4%	0.4%
Czech Republic	0.2	0.2	0.3	0.3	0.4	0.5	2.5%	1.3%	0.4%
Denmark	0.1	0.1	0.2	0.2	0.2	0.3	1.7%	1.3%	0.4%
Finland	0.3	0.3	0.4	0.5	0.6	0.7	2.1%	1.3%	0.2%
France	1.4	1.7	2.1	2.5	3.1	3.4	2.1%	1.3%	0.2%
Germany	1.8	2.0	2.3	2.6	3.1	3.7	1.4%	1.0%	0.3%
Greece	0.2	0.2	0.3	0.3	0.4	0.5	2.9%	1.3%	0.5%
Hungary	0.1	0.1	0.2	0.2	0.3	0.3	2.1%	1.7%	0.2%
Ireland	0.1	0.1	0.1	0.2	0.2	0.2	2.8%	1.8%	0.2%
Italy	1.0	1.2	1.3	1.5	1.7	1.7	1.6%	0.8%	0.0%
Netherlands	0.4	0.4	0.5	0.6	0.8	0.9	1.8%	1.5%	0.3%
Norway and Switzerland	0.6	0.7	0.8	0.9	1.1	1.4	1.5%	0.9%	0.5%
Poland	0.3	0.4	0.6	0.7	1.0	1.0	2.4%	1.9%	0.0%
Portugal	0.1	0.2	0.2	0.3	0.4	0.4	2.8%	1.4%	0.4%
Romania	0.1	0.2	0.2	0.3	0.4	0.5	2.7%	1.8%	0.5%
Slovakia	0.1	0.1	0.1	0.1	0.2	0.3	2.3%	1.5%	0.6%
Spain	0.7	1.0	1.3	1.5	1.9	2.5	3.1%	1.4%	0.5%
Sweden	0.5	0.5	0.5	0.6	0.7	0.7	0.8%	0.6%	0.1%
United Kingdom	1.2	1.3	1.5	1.9	2.5	2.9	1.3%	1.6%	0.3%
Rceu	0.2	0.3	0.4	0.5	0.7	0.9	3.9%	1.6%	0.5%
Turkey	0.3	0.6	1.1	1.7	3.0	6.9	5.8%	3.5%	1.7%
EU27	9.1	11.0	13.3	15.5	19.4	22.4	1.9%	1.3%	0.3%
WEUR	10.2	12.7	15.6	18.6	24.2	31.5	2.1%	1.5%	0.5%
B4	5.3	6.2	7.3	8.5	10.4	11.7	1.6%	1.2%	0.2%
SE	1.0	1.5	1.9	2.2	2.9	3.7	3.0%	1.4%	0.5%
NE	2.2	2.5	3.0	3.5	4.3	5.0	1.6%	1.2%	0.3%
EE	1.4	1.8	2.3	2.8	3.7	4.3	2.7%	1.6%	0.3%

Source: POLES Reference Scenario ADAM

In sectoral terms (Figure 3-19), the fastest increase in world final energy demand is in the residential and service sector (1.2 %/year), followed by transport (0.8 %/year) and industry (0.6 %/year). Figure 3-19 reveals a long-term stabilisation of final energy demand in the transport sector at world level, while a slight slowdown is noted for the EU27 countries. This is a significant change in the pattern of demand. Over the past thirty years, a long-lasting decoupling of "energy services" from GDP has only been observed for stationary uses of fuels and only temporarily for transport, i.e. in the USA after the first oil shock and the introduction of the CAFE standards. There are several possible explanations for this new trend in transport including: saturation in equipment and in the time budget for personal transport, significant oil price increases; the impact of more severe technological standards. In this respect, the Reference Scenario already includes significant structural change.

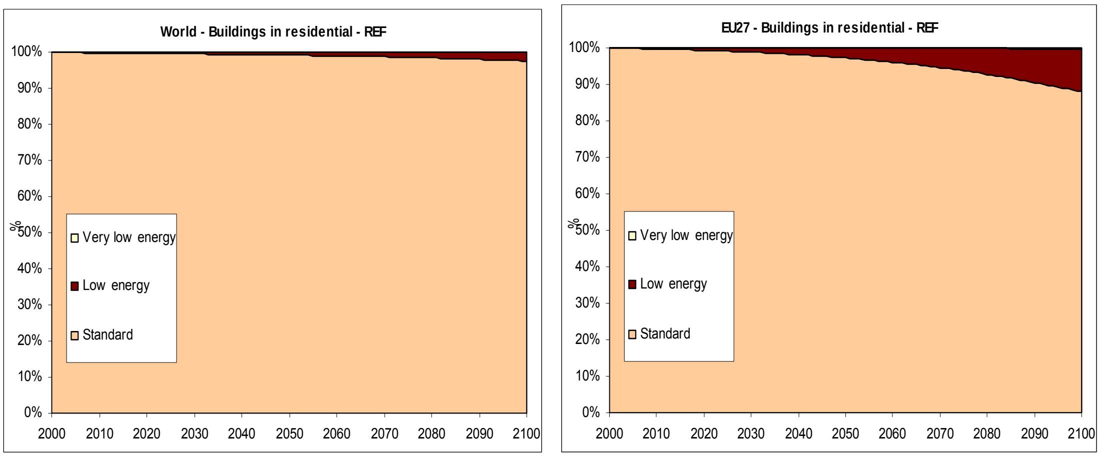
Changes in the transport sector suggest that the EU27 may have already entered a second phase of energy decoupling, with electricity remaining the only energy carrier or service for which demand continues to grow. The third and final phase of decoupling – that of electricity, if it ever happens – is not visible before the 2050 horizon.



Source: POLES Reference Scenario ADAM

Figure 3-20: World (left) and EU27 (right) final energy demand by sector, Reference Scenario, 2000 to 2100

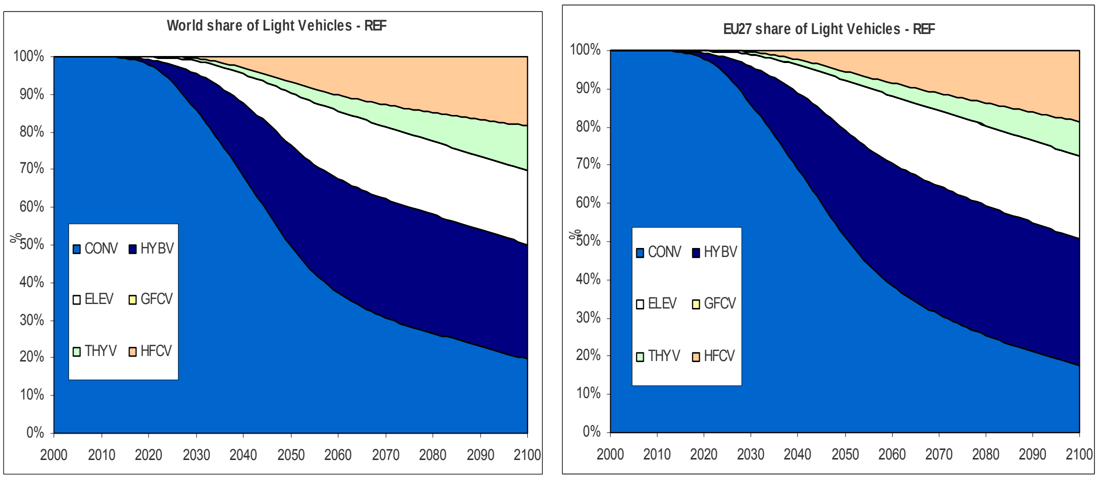
The version of the POLES model used in ADAM incorporates the diffusion of new low energy or very low energy (VLE) buildings, which consume only one half or one quarter respectively of the average consumption rate in existing buildings in each region. The VLE building concept reflects the current efforts in many countries to develop zero or even positive energy buildings with integrated solar PV panels. In the Reference Scenario, while price increases do encourage greater energy efficiency in buildings, they are still insufficient to overcome the building stock inertia and trigger a significant development of low and VLE buildings: in 2100 their world and EU27 market only amounts to 2 % and 12 %, respectively.



Source: POLES Reference Scenario ADAM

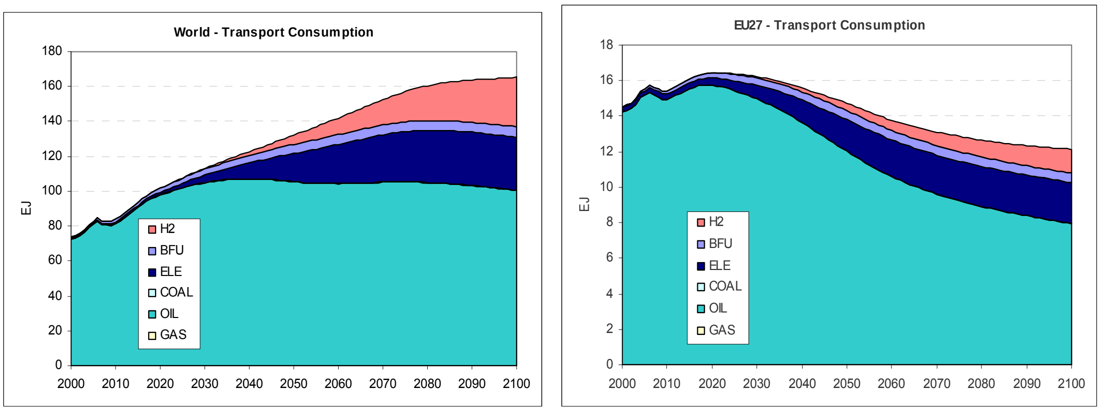
Figure 3-21: World (left) and EU27 (right) buildings by shares of different efficiencies in the residential sector, Reference Scenario, 2000 to 2100

Similarly, in the transport sector, different types of technologies take into account the efforts of many actors to develop cleaner and more efficient cars. Here, stock effects and inertia are lower and the impact of oil prices stronger, so that conventional cars steadily lose market shares and hybrid, electric, hydrogen ICE and hydrogen fuel cell technologies progressively increase their market shares after 2020 (see Figure 3-22). This is why, while world transport energy demand continues to expand and stabilises only after 2080 at 165 EJ, the role of electricity and hydrogen in transport fuels expands significantly. In the EU27, light vehicle energy demand peaks much earlier, between 2015 and 2035, and then decreases to 12 EJ by the end of the period (see Figure 3-23).



Note: CONV: conventional cars; ELEV: electric vehicles; THYV and HYBV: Hybrid cars; GFCV and HFCV: fuel cell driven vehicles
Source: POLES Reference Scenario ADAM

Figure 3-22 : World (left) and EU27 (right) share of light vehicles, Reference Scenario, 2000 to 2100

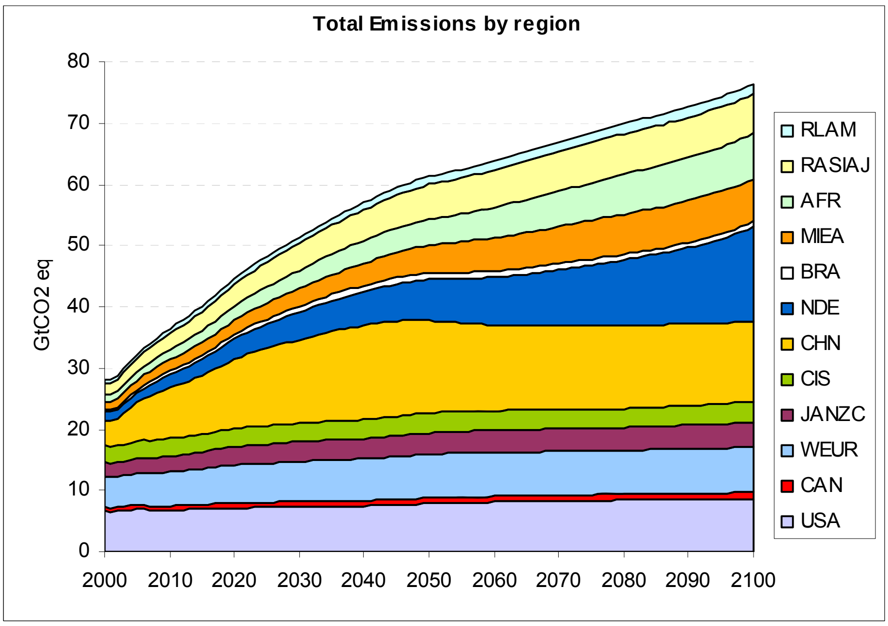


Source: POLES Reference Scenario ADAM

Figure 3-23: World (left) and EU27 (right) transport energy demand, Reference Scenario, 2000 to 2100

3.2.5 GHG emissions

World GHG emissions from energy and industrial activities double until 2050 and continue to increase by 25 % until 2100. This is a disturbing result, because its trajectory would lead to a concentration of about 1000 ppmv CO_{2e} by the end of the century and therefore to a temperature increase of about 4°C as early as 2100. Unambitious energy and climate policies with limited scope will not be able to combat the climate change problem. The combined effect of all the structural and technological changes in the Reference Scenario is that GHG emissions are 2.4 times higher in 2100 than in 2005.

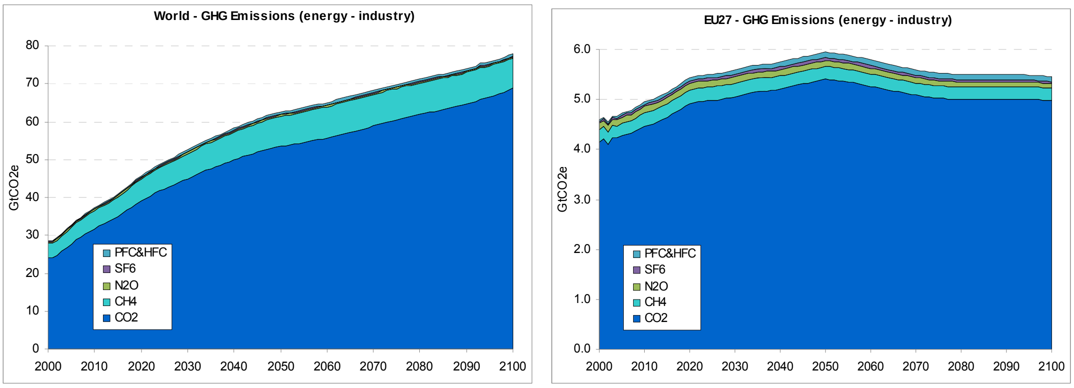


Source: POLES Reference Scenario ADAM

Figure 3-24: World GHG emissions by regions, Reference Scenario, 2000 to 2100

The GHG emissions of Annex B countries increase slowly from 15 Gt CO_{2e} in 2005, to 19 Gt CO_{2e} by 2050 and 21 Gt CO_{2e} by 2100. The increase in non-Annex B regions is more dramatic; emissions are 17 Gt CO_{2e} in 2005, but climb to 55 Gt CO_{2e} by 2100 and are equivalent to two thirds of the world's total (see Figure 3-24). This reflects the magnitude of energy needs in the developing world, which are only partly contained by price increases, and are also increasingly met by coal in the context of relatively expensive oil and gas.

As for Europe, the level of GHG emissions from energy and industrial activities peaks at 5.9 Gt CO_{2e} in 2050 and then decreases to 5.4 Gt CO_{2e} at the end of the period, which corresponds to the emission level in 2020. This is a consequence of low population growth, or even declining population in some regions, the high price of energy and low economic growth rates relative to increases in energy productivity due to autonomous efficiency improvements during re-investments.



Source: POLES Reference Scenario ADAM

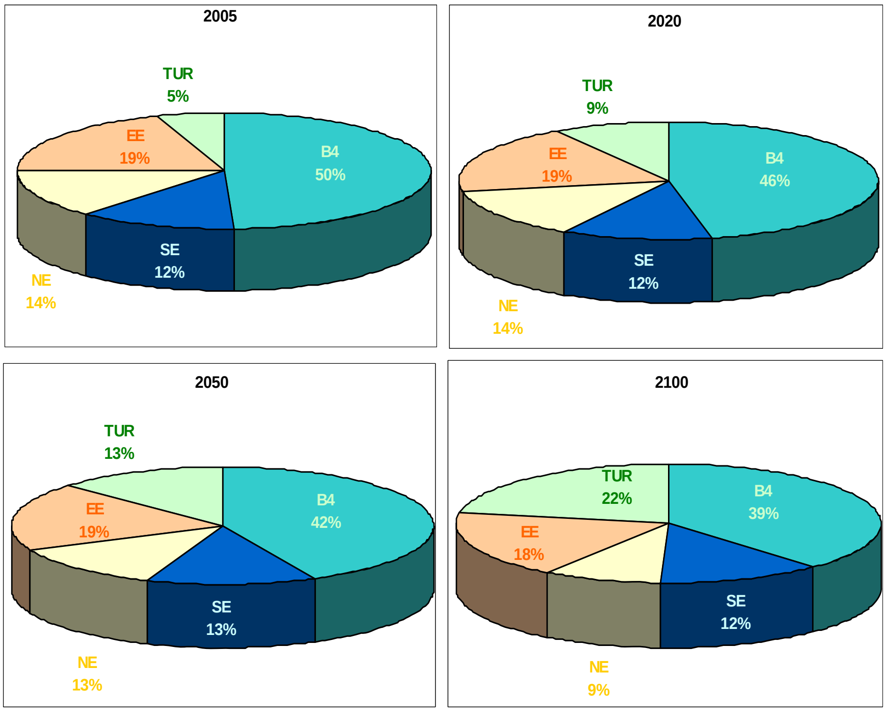
Figure 3-25: World (left) and EU27 (right) - GHG emissions (energy and industry related), Reference Scenario, 2000 to 2100

Table 3-13: CO_2 emissions by European country (in $MtCO_2$), Reference Scenario, 2000 to 2100

							Annual % change		
	2000	2010	2020	2030	2050	2100	2000/20	20/50	50/100
Austria	66	67	70	66	61	49	0.2%	-0.5%	-0.4%
Baltic States	29	39	49	56	65	64	2.5%	1.0%	0.0%
Belgium & Luxemburg	148	144	170	183	187	125	0.7%	0.3%	-0.8%
Bulgaria	51	66	72	72	72	83	1.8%	0.0%	0.3%
Cyprus, Malta and Slovenia	31	38	39	38	43	40	1.1%	0.4%	-0.2%
Czech Republic	117	126	138	146	159	173	0.8%	0.5%	0.2%
Denmark	54	66	71	72	64	40	1.3%	-0.3%	-0.9%
Finland	67	68	74	79	88	57	0.5%	0.6%	-0.9%
France	400	457	534	550	682	630	1.5%	0.8%	-0.2%
Germany	837	864	1006	1022	1045	1031	0.9%	0.1%	0.0%
Greece	88	101	110	115	119	119	1.1%	0.3%	0.0%
Hungary	51	61	71	79	91	84	1.7%	0.8%	-0.2%
Ireland	46	52	57	59	59	45	1.1%	0.1%	-0.5%
Italy	429	438	441	436	393	336	0.1%	-0.4%	-0.3%
Netherlands	180	187	205	211	213	188	0.6%	0.1%	-0.2%
Norway and Switzerland	81	85	95	102	99	94	0.8%	0.1%	-0.1%
Poland	327	341	350	331	368	337	0.3%	0.2%	-0.2%
Portugal	62	59	67	72	80	64	0.4%	0.6%	-0.4%
Romania	85	103	114	112	129	142	1.5%	0.4%	0.2%
Slovakia	37	46	51	55	62	74	1.6%	0.6%	0.4%
Spain	308	369	429	482	575	599	1.7%	1.0%	0.1%
Sweden	55	54	73	87	94	65	1.5%	0.8%	-0.7%
United Kingdom	565	595	585	594	612	531	0.2%	0.1%	-0.3%
Rceu	84	149	146	149	180	201	2.8%	0.7%	0.2%
Turkey	218	316	486	605	826	1468	4.1%	1.8%	1.2%
EU27	4031	4340	4775	4914	5260	4877	0.9%	0.3%	-0.2%
WEUR	4414	4891	5503	5770	6366	6640	1.1%	0.5%	0.1%
B4	2231	2353	2567	2601	2731	2528	0.7%	0.2%	-0.2%
SE	489	567	645	706	817	822	1.4%	0.8%	0.0%
NE	630	656	745	791	805	613	0.8%	0.3%	-0.5%
EE	847	998	1060	1067	1187	1209	1.1%	0.4%	0.0%

Source: POLES Reference Scenario ADAM

The evolution of CO_2 emissions in Europe varies among Member States, which display changing dynamics over the century. The contribution of the Big Four and northern European countries to European CO_2 emissions decreases from 50 % and 14 % in 2005, to 42 % and 13 % by 2050, and 39 % and 9 % by 2100 respectively. The role of eastern European countries remains relatively stable, while that of Turkey rises sharply from 5 % in 2005 to 22 % by 2100 due to its assumed population and economic growth.

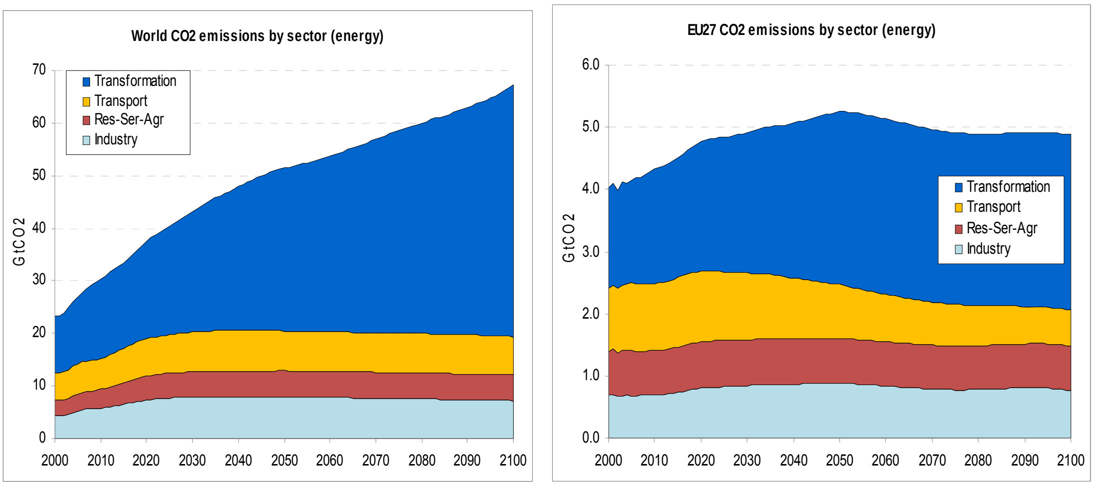


Source: POLES Reference Scenario ADAM

Figure 3-26: Share of different country groups in total European CO_2 emissions, Reference Scenario, 2000 to 2100

The combination of the different trends results in significant structural changes in the energy system in Europe, even in the Reference Scenario. These changes are mostly due to the modest increase in total final energy demand, while electricity demand still shows relatively high growth as described above. Associated with this penetration of electricity, the development of renewables and nuclear energy helps Europe's CO_2 emissions to stabilise by 2055 and even to achieve some reductions in the longer term (Figure 3-27).

This profile provides a consistent reference development for emission trends, in the Reference Scenario without significantly changed mitigation policies. This assumes little progress in international commitments that would adequately curb climate change. Instead, the industrialised countries prefer adaptation strategies with the consequence of high adaptation costs and high costs for the remaining resulting damages from extreme events during the coming centuries.



Source: POLES Reference Scenario ADAM

Figure 3-27: World (left) and EU27 CO_2 emissions (right) by sector (energy), Reference Scenario, 2000 to 2100

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4 Assumptions and results of the POLES model – the 2°C Scenario (at 450 ppmv CO_2 concentration)

The European Commission prefers the limitation of the increase of the global average surface temperature to 2°C above pre-industrial level until 2100. This target related to a CO_2 concentration of the atmosphere of 450 ppmv at a 50 % probability to meet the 2°C by the end of this century (IPCC 2007). There is an 80 % probability to reach 2°C at a CO_2 concentration of 400 ppmv which is considered as an extremely ambitious variant of a 2°C-Scenario.

Most critical questions of how to attain the EU climate policy targets still remain unanswered. The POLES model – and later in the next report, the more detailed bottom up models - and the two variants of the 2°C-Scenarios developed in the ADAM project introduce a more detailed treatment of new technology diffusion and thus provide better insights into the role of these technologies in climate change mitigation. They answer the following questions among others: At what rate can clean and high efficient energy technologies be deployed? How and to what extent could their diffusion be speeded up given re-investment cycles and the time needed by architects, planners and craftsmen to learn about these new technologies? What are the economic costs of the corresponding large-scale technological transitions of mitigation?

While some observers argue that radical technology breakthroughs will be required to achieve a 2°C target (Hoffert et al., 2003), others assert that existing technologies are sufficient to address the problem for the next half century (Pacala and Socolow, 2004). Most analysts seem to agree, however, on the need for significantly increased investment in energy technology research and development (National Commission on Energy Policy, 2003). However, there are large uncertainties associated with R&D, and any deterministic model will be limited in its ability to characterise the potential benefits, particularly for disruptive technologies. Deterministic models do not take into account changed preferences, unexpected structural changes, the uncertainty of future technology performances, and they do not endogenously simulate technological breakthroughs, which are by definition hard to forecast, if at all with any acceptable probability.

Given the capabilities of the POLES model in terms of energy technology description, the impacts of new and alternative technology pathways involving renewable energies, nuclear, hydrogen, carbon capture and storage (CCS), and highly energy efficient technologies in the final energy sectors have been examined in relation to their role in reaching the EU targets and in the dynamics of forming new technology paradigms.

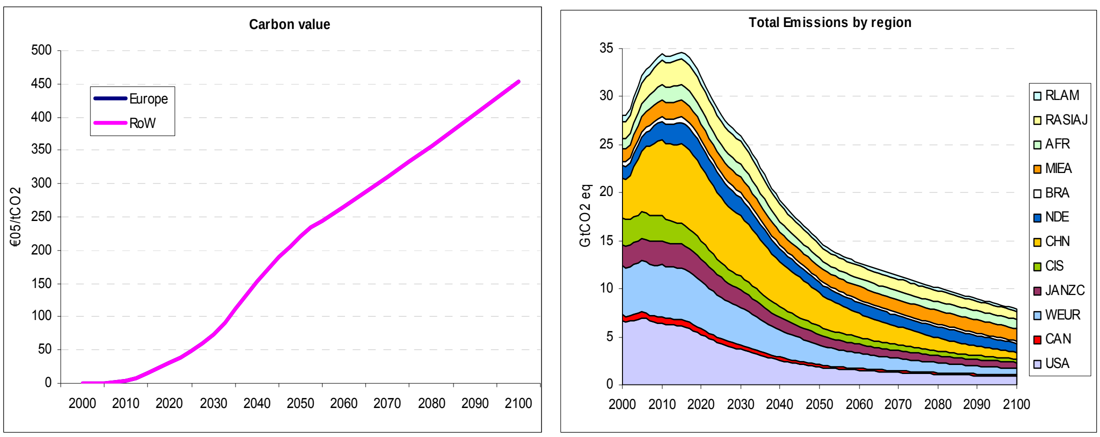
4.1 The 2°C Scenario: Assumptions and methods

The ADAM Reference Scenario presented above in Chapter 3 provides a plausible projection of future energy use and CO_2 emissions until 2100, assuming that the current main trends of population and economic growth continue and that the mitigation policies remain very modest at the national and international level. The Reference Scenario offers the methodological opportunity to calculate additional cost of mitigation by introducing clean and efficient energy technologies in addition to what has been assumed in the Reference Scenario. This additional scenario tries to restrict the European CO_2 emissions to such an extend that the 2°C target set by the European Commission can be achieved bar the end of this century. The maximum CO_2 emissions allowed to meet this target are taken from the results of the global model system TIMES calculated by Work package Scenarios of the ADAM project.

The 2°C Scenario follows a stringent GHG reduction profile over time, which implies a stabilisation of the CO_2 concentration level at 450 ppmv CO_{2e}. This means that global GHG emissions would peak around 2020, return to their current level before 2030 and end up at one third of their current level by 2100 (see Figure 4-1). Of course, one could also select a different reduction profile where maximum emissions occur around 2030, but this means a steep reduction in the following decades as the integral of all greenhouse gas emissions determines the final concentration in the atmosphere.

The 2°C-Scenario assumes the same development of world population and also the same economic grows in a first round as the Reference Scenario did. However, to reach the 2°C target, substantial differences have to be made by assuming a price the consumer has to pay for greenhouse gas emissions. Therefore, a carbon value is introduced to represent a synthesis of the various taxes, emissions quotas, policies and other measures that may be combined to put a price on carbon and to achieve the desired emission reductions in a "dose-response" type approach (see Figure 4-1). This carbon value is an economic "proxy variable", reflecting the stringency of the policy measures to be implemented not only at a national or European level, but as much as possible on the global level.

The results obtained for the carbon value provide two types of information that will be confirmed below in the detailed analysis of the model’s results. First, in order to achieve the significant reductions in emissions after the peak sometime between 2020 and 2030 ("the window of opportunity"), the model's response functions require a sharp increase in the carbon value since simulations with a moderate linear increase in the carbon value only induce a slowdown in emission growth.



Source: POLES 2°C Scenario (at 450 ppmv) ADAM

Figure 4-1: Carbon value necessary to achieve objectives and the corresponding emission profile, 2°C-Scenario, 2000 to 2100

Secondly, this sharp increase of the carbon value illustrates the fact that there seems to be no "backstop technology" in the energy system described in the model that would enable massive reductions once the carbon value reaches the threshold. Although all low-carbon technologies are to some degree economically feasible at the carbon values considered, the full development of their potential still has to respect re-investment cycles and diffusion time of new technologies. To our knowledge today it is therefore necessary to promote high carbon values to weigh on energy demand and to accelerate the diffusion of very low emission and very efficient technologies. The high carbon value reached – 450 $€_{2005}/tCO_2$ in 2100 – cuts GHG emissions by 54 % and by 77 % in 2050 and 2100, respectively, compared to 2005 at the global level.

This high level of carbon value seems to be quite high and the results of the more detailed bottom up models of the ADAM project that will be available in February 2009 may be used to check this result from the POLES model.

For companies in the power sector and energy-intensive industries, stricter greenhouse gas regulations designed to meet the 2°C target will mean a shift in the global business environment, probably even greater than the one triggered by the oil crisis in the 1970s. This may have a fundamental impact on key aspects of business strategy, such as production economics, cost competitiveness, investment decisions, and the value of different types of assets, but also on material efficiency and material substitution (see Chapter 5.2). Companies in these energy-intensive industries should therefore anticipate the effects of different types of greenhouse gas regulation, strive to adjust, and position themselves accordingly.

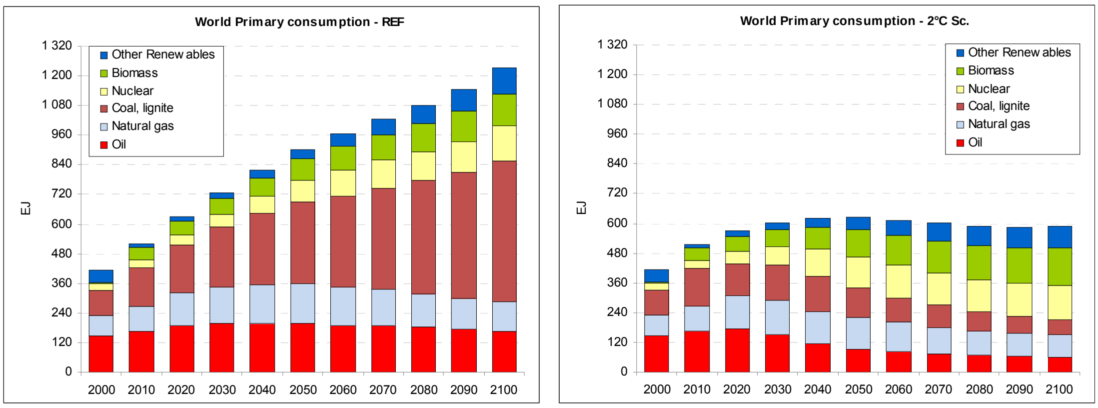
The first section below analyses the main consequences of this climate policy framework on energy supply and demand for Europe in a world context, while the second section deals with the resulting technological changes in the European power generation sector.

4.2 Results of the 2°C Scenario to 2050 and 2100

4.2.1 Impact on energy supply and demand

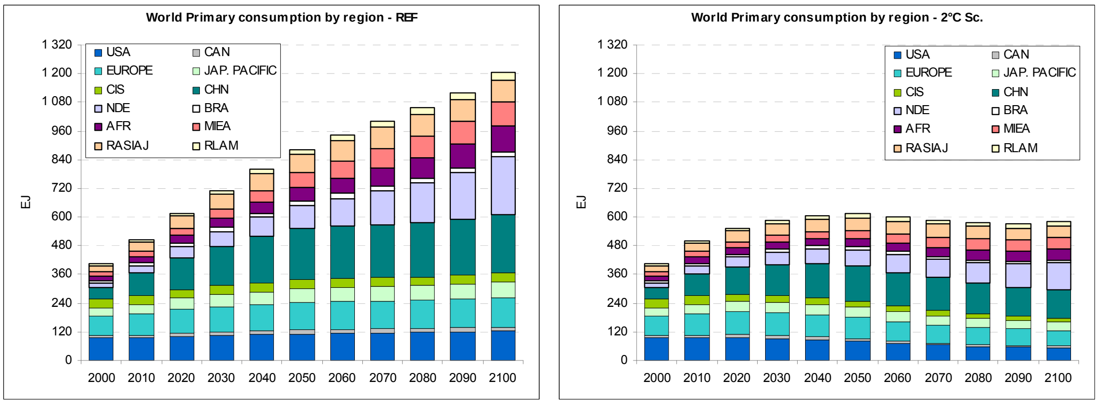
Unlike the Reference Scenario, where world primary energy demand is tripled in 2100 in comparison to 2000, in the 2°C Scenario, global primary energy demand stops increasing in 2050, then stabilises at about 51 % above 2000 levels, and begins to decrease after 2060. In 2100 primary energy demand is only 43 % higher than in 2005 (see Figure 4-2). This shows that one important answer to limit climate change is largely to be found on the demand side of the energy system. The introduction of a high carbon tax is particularly effective in reducing the demand for fossil fuels, which account for only one third of the primary energy balance in 2100, as renewable and nuclear energy technologies with zero CO_2 emissions become increasingly widespread.

In the regional analysis, the energy consumption of the industrialised countries increases slightly until 2020 and then falls to a level of 31 % below that of 2000. Although primary energy demand continues to increase in the developing countries throughout the period, this growth is much slower than in the Reference Scenario. Total energy demand of the developing countries nearly triples, rising from 280 to 400 EJ in 2100. This increase reflects the fact that access to modern energy sources remains essential for poverty reduction and human development, even in the case of strong environmental constraints as examined here.



Source: POLES-LEPII ADAM

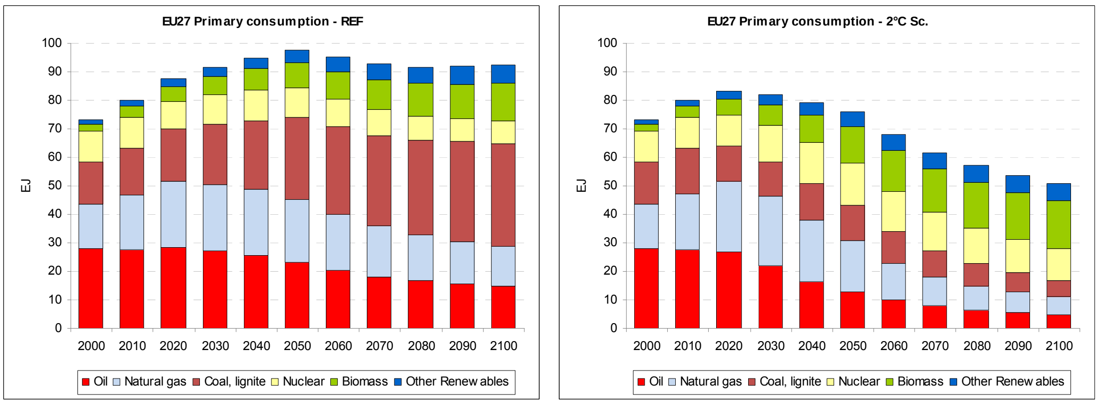
Figure 4-2: World primary energy demand by energy, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100



Source: POLES-LEPII ADAM

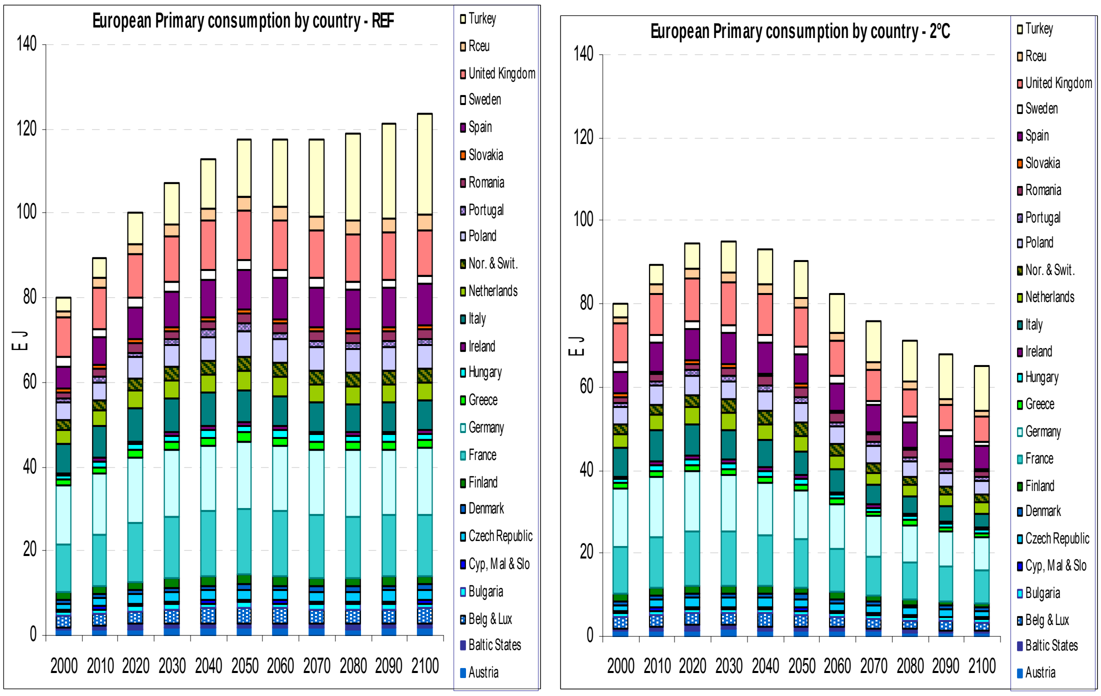
Figure 4-3: World primary energy demand by region, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

The carbon tax and stringent mitigation policies also have a significant impact on the level of primary energy demand in Europe. Energy demand of the 2°C Scenario is 25 % and 45 % lower in 2050 and 2100, respectively, compared to the Reference Scenario (see Figure 4-4). GHG emissions peak by 2020 and decrease considerably thereafter to only 30 % of the current level by the end of the century.



Source: POLES-LEPII ADAM

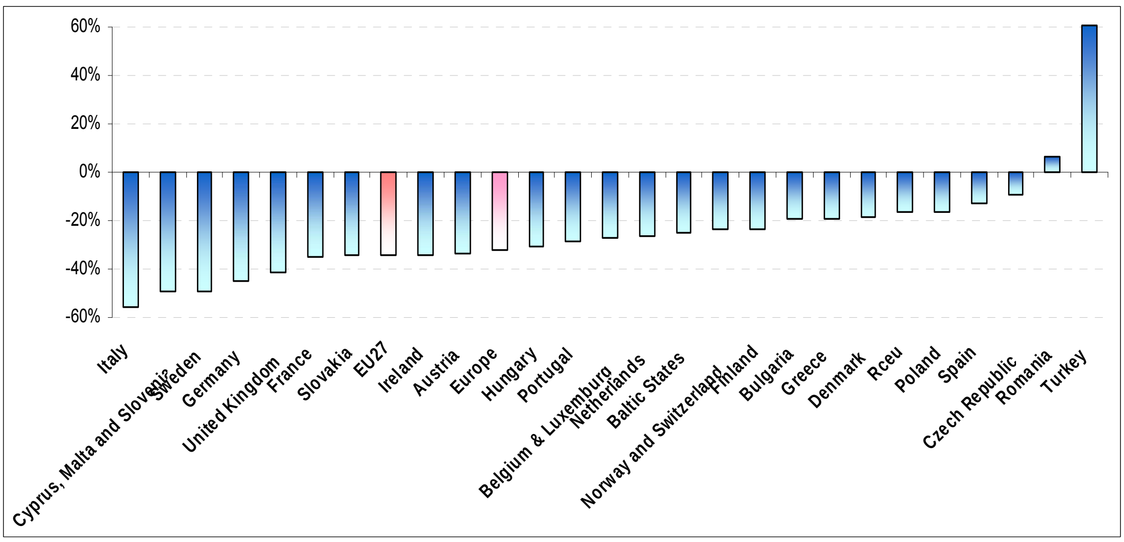
Figure 4-4: EU27 primary energy demand by energy, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100



Source: POLES-LEPII ADAM

Figure 4-5: European primary demand by country, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

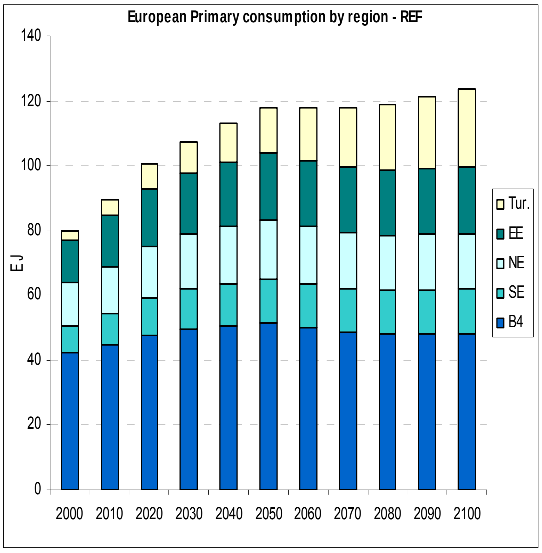
The impacts on energy demand and emissions vary from country to country. At the end of the period, countries like Italy, the Mediterranean countries, Sweden, and Germany seem much more affected than the European average due to relatively low additional economic growth and still substantial efficiency potentials. Countries like Turkey and Romania with low present per capita GDP still increase their energy demand in comparison with the current level (see Figure 4-6).

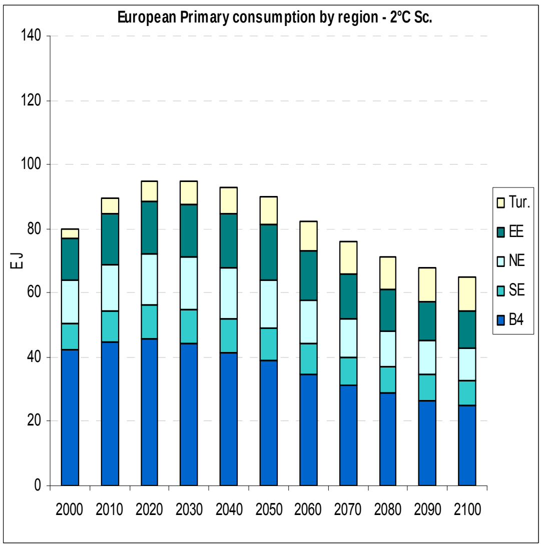


Source: POLES-LEPII ADAM

Figure 4-6: Change of European primary demand between 2005 and 2100 in %, 2°C Scenario

In the 2°C Scenario, the Big Four and northern European countries see their primary energy demand continue to increase until 2020, but decrease steadily thereafter down to 43 % (Big Four) and 29 % (northern Europe) below current levels in 2100 (see Figure 4-7, right).

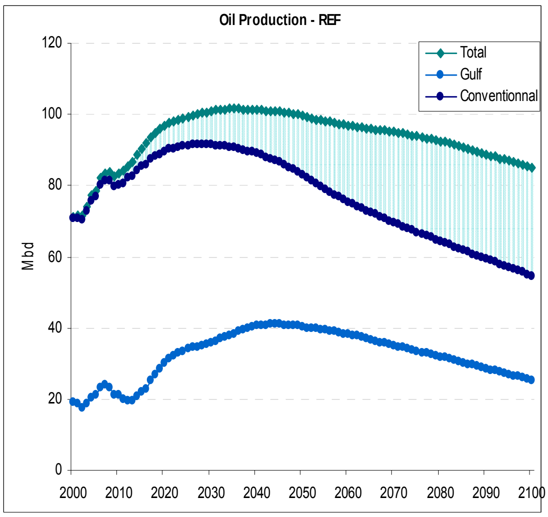


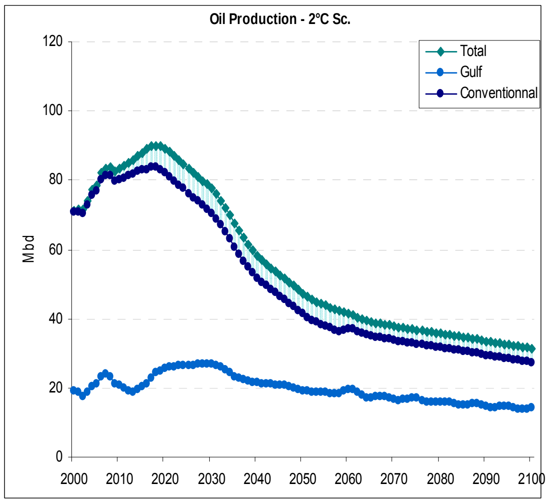


Source: POLES-LEPII ADAM

Figure 4-7: European primary demand by region, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

On the supply side, world crude oil production is similar to that of the Reference Scenario until 2015, since carbon taxes are roughly the same during this initial period. In the 2°C Scenario, crude oil production begins to decline in 2020 as the high and continuously rising carbon tax increasingly weighs on demand and more energy efficient technologies as well as substitution by renewable energies start increasing their shares (see Figure 4-8).

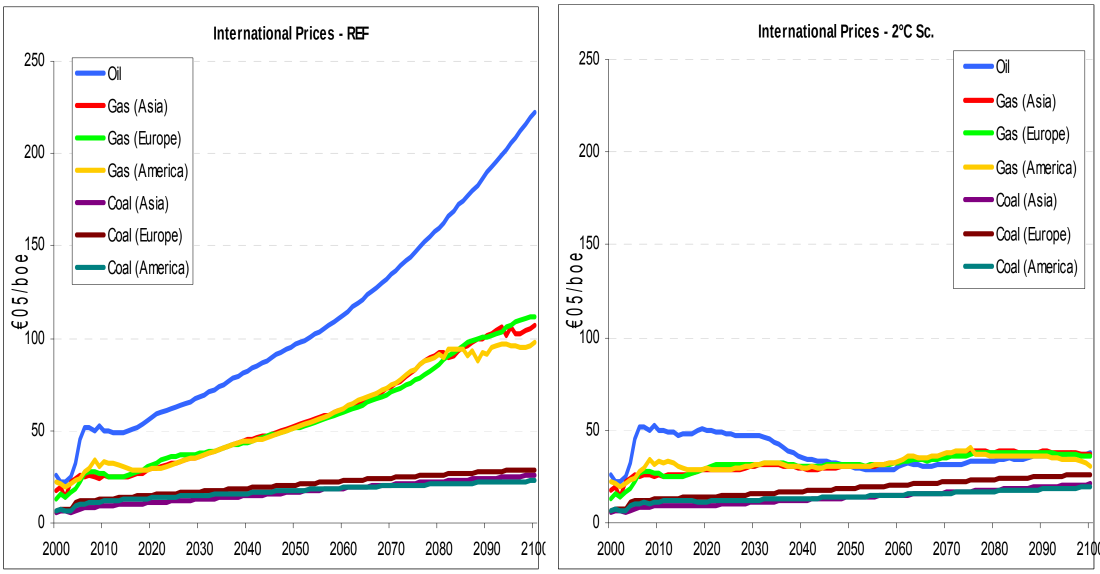




Source: POLES-LEPII ADAM

Figure 4-8: World oil production, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

After 2020, global crude oil and natural gas prices begin to be much lower in the 2°C Scenario than in the Reference Scenario (see Figure 4-9). However, it should be noted that these lower prices are only for oil and natural gas prices on the international markets or for import. This lower level is of course not reflected in the prices charged to end-users and consumers, since the carbon tax component of the final price increases sharply (see Figure 4-1).

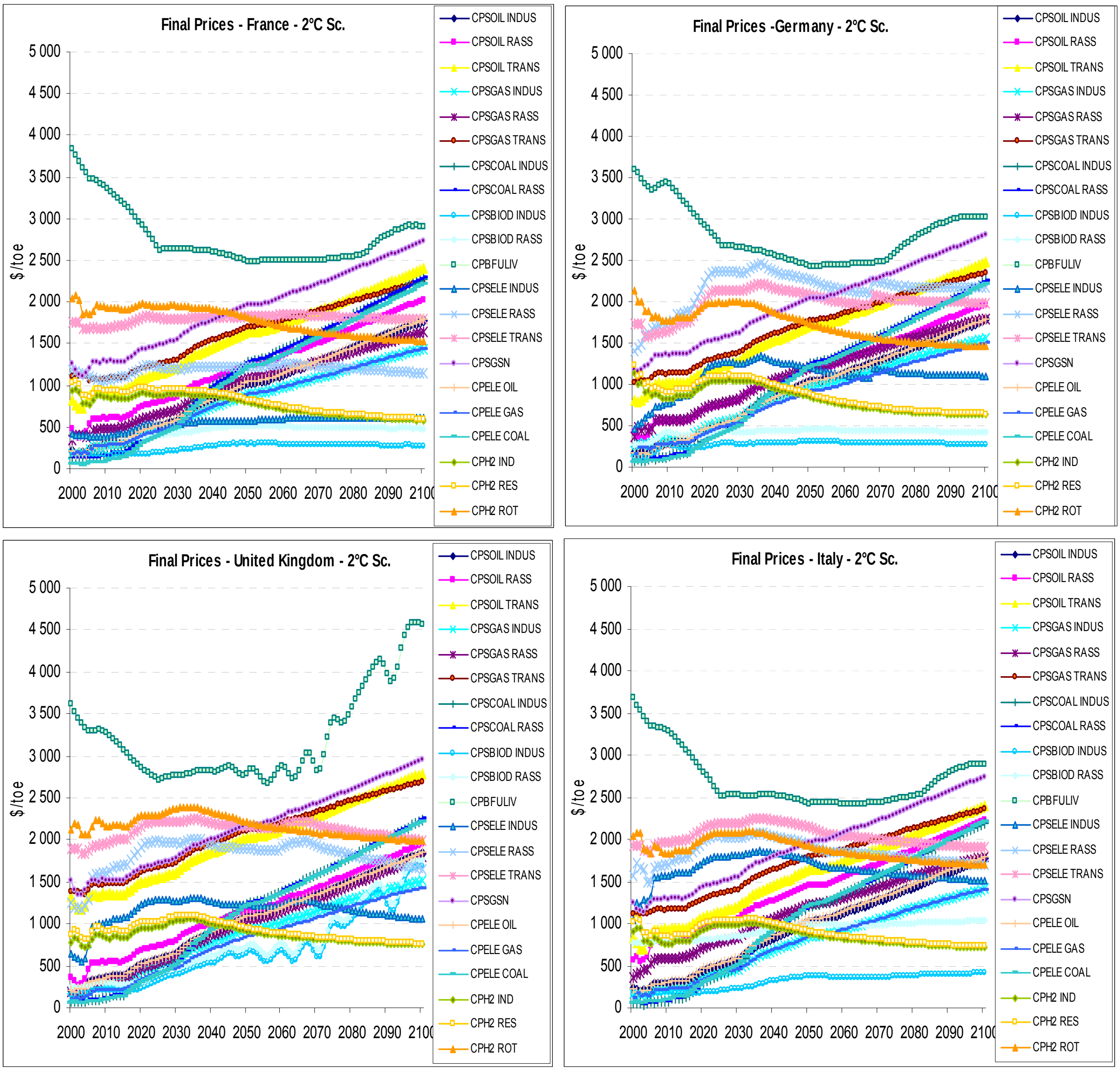


Source: POLES-LEPII ADAM

Figure 4-9: Energy prices of fossil fuels on international markets (without carbon tax), Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

Some examples of final energy prices for the Big Four show that prices of oil, gas and coal increase considerably (see Figure 4-10). On the contrary, the prices of hydrogen and electricity stabilise and even decrease slightly in the long term. However biofuel prices are not affected by the environmental tax, but remain very high for these countries. It is indeed the very high tax level that considerably reduces the demand for fossil fuel energies, alleviates pressure on oil and natural gas resources, and may even recreate an era of rather inexpensive oil and gas availability as the demand substantially decreases compared to the Reference Scenario.

One of the most noteworthy differences between the Reference Scenario and the 2°C Scenario is that, in the former, the increasing scarcity of crude oil only slightly reduces the growth in total primary energy consumption, as there is a considerable increase in coal use that would have dramatic impacts on the global climate. On the contrary, in the 2°C Scenario, oil actually becomes relatively more abundant and less expensive on world markets. This is probably one of the greatest "win-win" benefits for climate policies that have been identified so far.



Source: POLES-LEPII ADAM

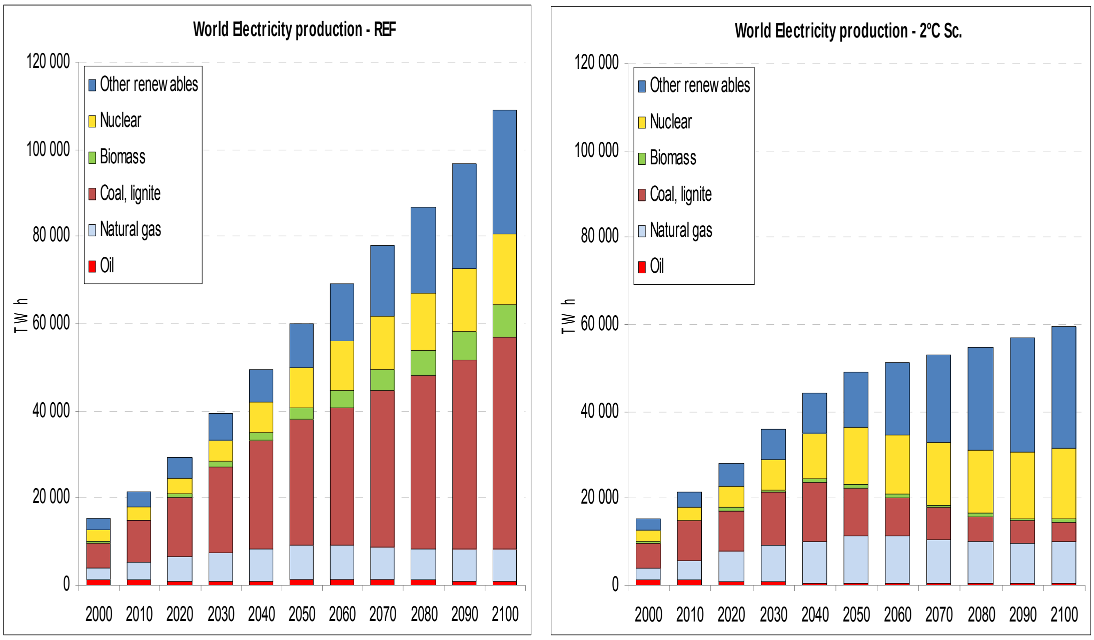
Figure 4-10: Examples of final energy prices for Big Four countries, 2°C Scenario, 2000 to 2100

4.2.2 Technological changes induced by the scenario

Substantial GHG emission reductions in the energy sector will be obtained both by reductions in the demand for energy and by modifying the corresponding supply-mix, in particular of electrical power. The first type of measures aiming at modifying the demand for energy includes the constant promotion of a high level of energy efficiency in all sectors and, in the longer term, the deployment of highly energy-efficient technologies and equipment in the construction, transportation and manufacturing sectors.

The second category of measures includes four different options for "decarbonising" the energy sector, in particular power generation. The first one simply concerns substituting crude oil and coal with natural gas. This takes advantage of the lower CO_2 content per unit of delivered energy of natural gas combustion. The other three options involve distinct families of technologies: renewable energies, nuclear power (using current technology reactors and new "fourth-generation" reactors) and finally, CO_2 capture and storage for large thermal power plants and other fossil fuel intensive production facilities such as cement kilns or coke ovens.

Although all of these mitigation options are used to achieve the CO_2 emissions reduction target in the 2°C Scenario, their respective contribution to emission reductions varies over time. Initially, the bulk of reductions are obtained by substituting natural gas for coal and crude oil in applications where this is easy and straightforward, in particular the generation of heat in the final energy sectors and the generation of electrical power. After this, cleaner power production technologies (renewable energy, nuclear power and carbon capture and storage) are sufficiently developed to achieve most of the reductions up to 2040. Towards the end of the period, the spread of "very low emission" energy demand technologies by passive houses and buildings in the residential sector, where the long re-investment cycle is a constraint to rapid deployment, make the greatest contribution to emission reductions.

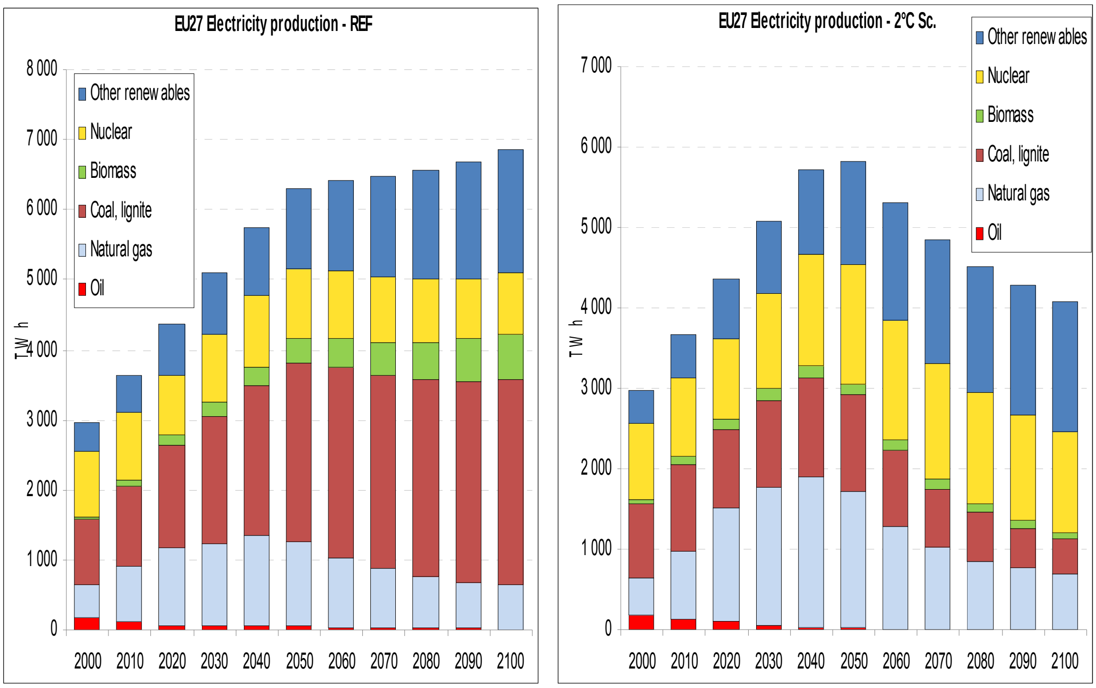


Source: POLES-LEPII ADAM

Figure 4-11: World electricity generation by energy carriers, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

It should be noted here that renewable energies and nuclear power make an increasingly large contribution to the reduction effort, whereas the impact of carbon capture and sequestration technologies diminishes at the end of the period, due to the increasing costs of storage sites and CO_2 losses upon capture, which ultimately make these technology options quite sensitive to the high carbon tax (see Figure 4-11).

EU27 electricity production in the 2°C Scenario peaks in 2050 and then drops to slightly more than 4 000 TWh by 2100 (see Figure 4-12). Fossil fuels inputs for electricity generation shrink to less than 30% by the end of the period.

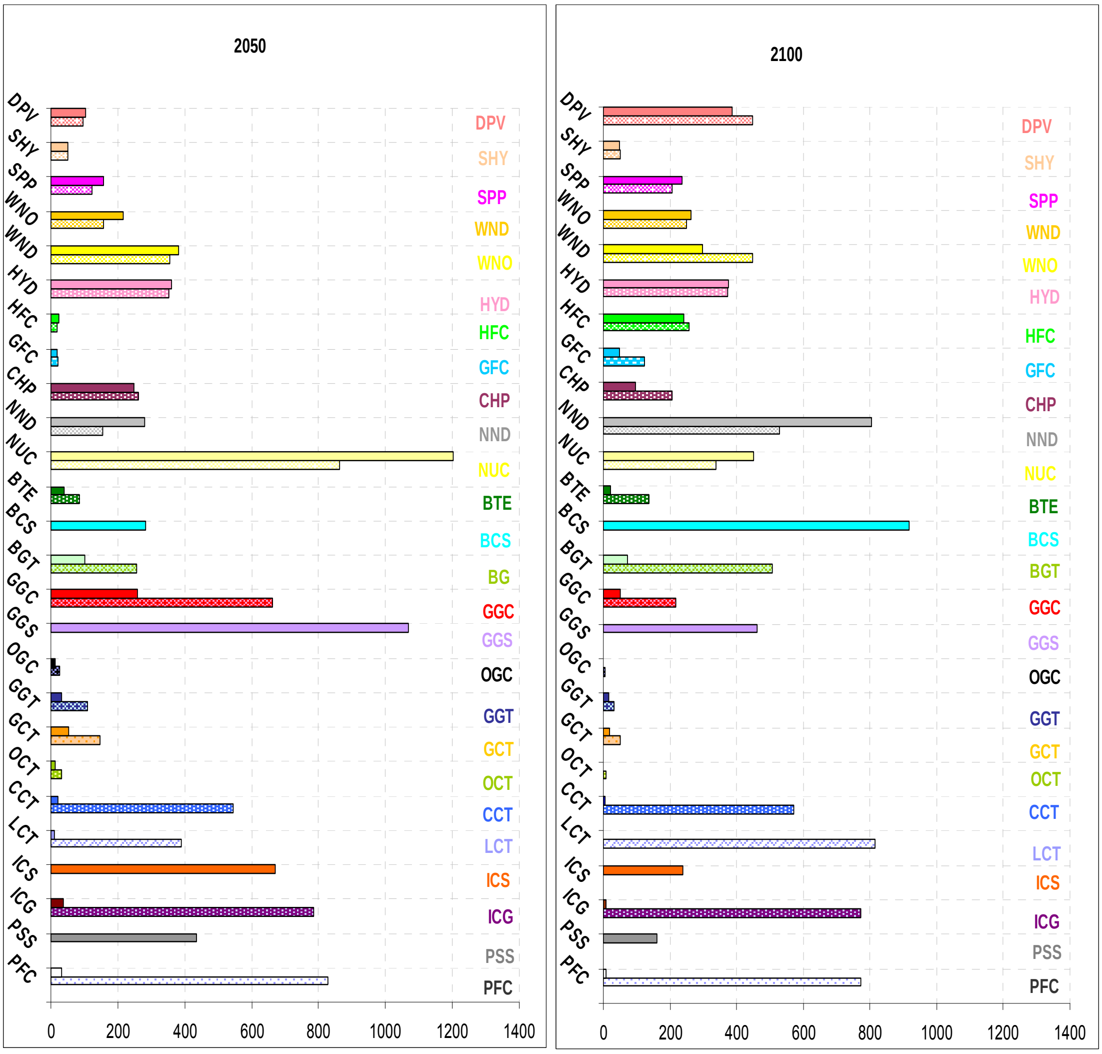


Source: POLES-LEPII ADAM

Figure 4-12: EU27 electricity production, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

Explanation of the abbreviations:

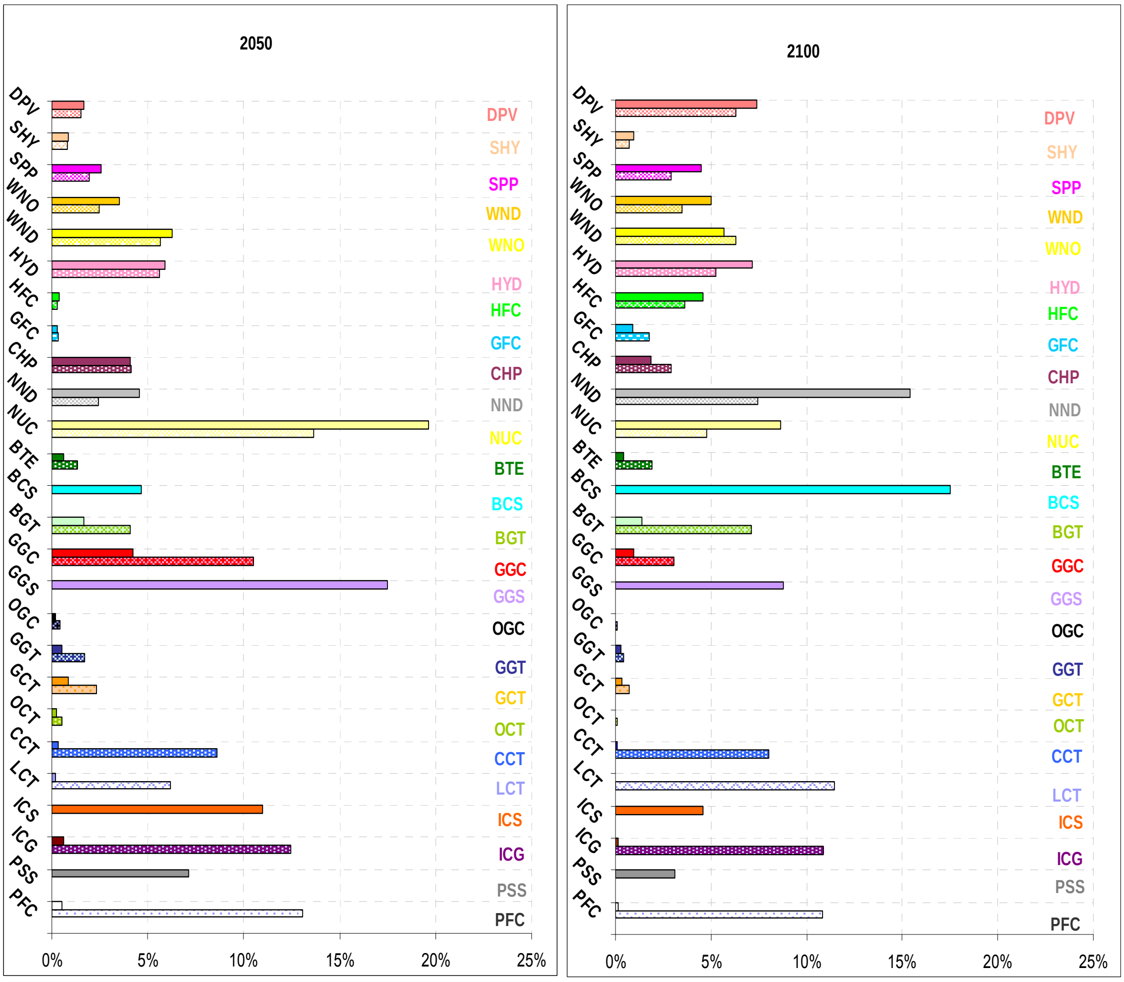
DPV:	decentralised photovoltaics	BGT:	Biomass gasification for electricity production in gas turbine
SHY:	Small hydro power plants	GGC:	Gas-powered Gas turbine in combined cycle
SPP:	solar power plants (thermal technologies for network electricity production)	GGS:	Gas-powered Gas turbine in combined cycle with sequestration
WNO:	wind offshore	OGC:	Oil-powered Gas turbine in combined cycle
WND:	wind onshore	GGT:	Gas-powered turbine
HYD:	hydro power	GCT:	Gas-powered conventional thermal
HFC:	hydrogen fuel cell	CCT:	Coal-powered conventional thermal
GFC:	gas fuel cell	LCT:	Lignite-powered conventional thermal
CHP:	cogeneration	ICS:	integrated coal gasification with combined cycle with sequestration
NND:	New Nuclear design	ICG:	integrated coal gasification with combined cycle
NUC:	Conventional Light-Water nuclear reactor	PSS:	Pressurised coal supercritical with sequestration
BTE:	Biomass for thermal electricity	PFC:	Pressurised coal supercritical
BCS:	Biomass for thermal electricity with sequestration		



Source: POLES-OGC: LEPII ADAM

Figure 4-13: EU27 electricity production by technology in 2°C Scenario (top bar) and Reference Scenario (bottom bar), 2050 and 2100 in TWh

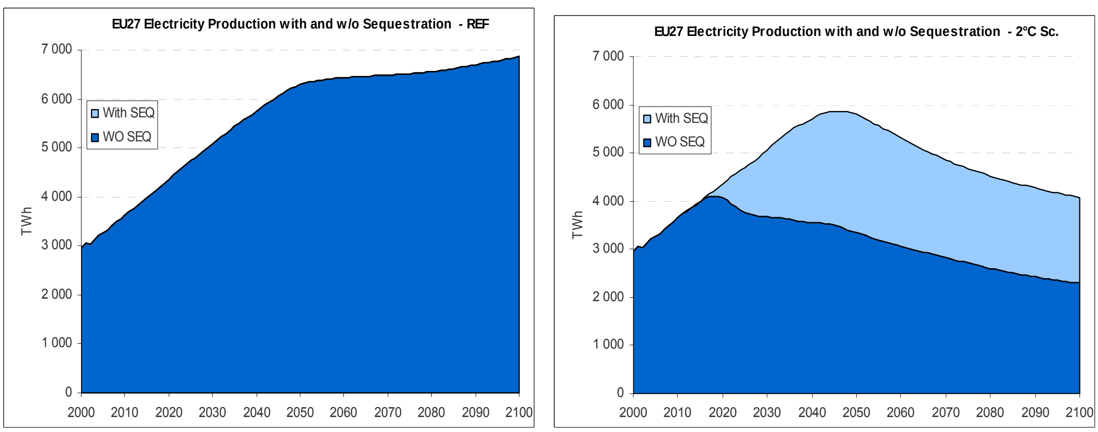
The impact of mitigation policy on the diffusion of different technologies is summarised in Figure 4-14 for the year 2050 and 2100. By 2050, the most strongly affected technologies are nuclear and CCS technologies, which represent 65 % of the total EU27 electricity generation compared to 16 % in the Reference Scenario. By 2100, the diffusion of biomass gasification with sequestration becomes the winning technology, with 920 TWh. Nuclear power continues to provide 24 % of electricity, but the role of the fourth generation is much more important than in 2050.



Source: POLES-LEPII ADAM; abbreviation see below Figure 4-12

Figure 4-14: EU27 share of electricity production by technology in 2°C (top bar) and Reference Scenario (bottom bar,) in 2050 and 2100 (in % of total electricity generation)

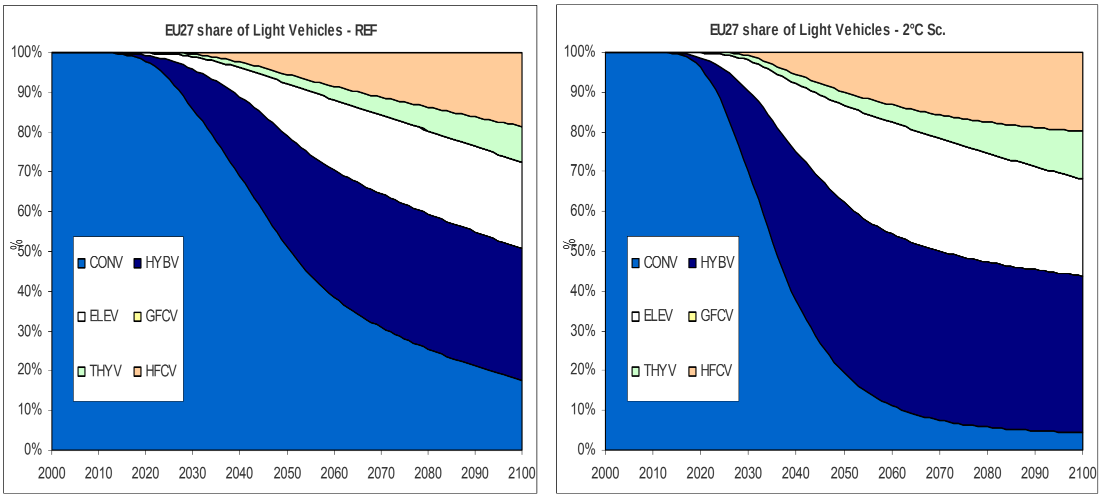
In the 2°C Scenario, 42 % and 44 % respectively of the electricity production in 2050 and 2100 are provided by fossil generation technologies with sequestration (see Figure 4-15).



Source: POLES-LEPII ADAM

Figure 4-15: EU27 electricity production with and without sequestration, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

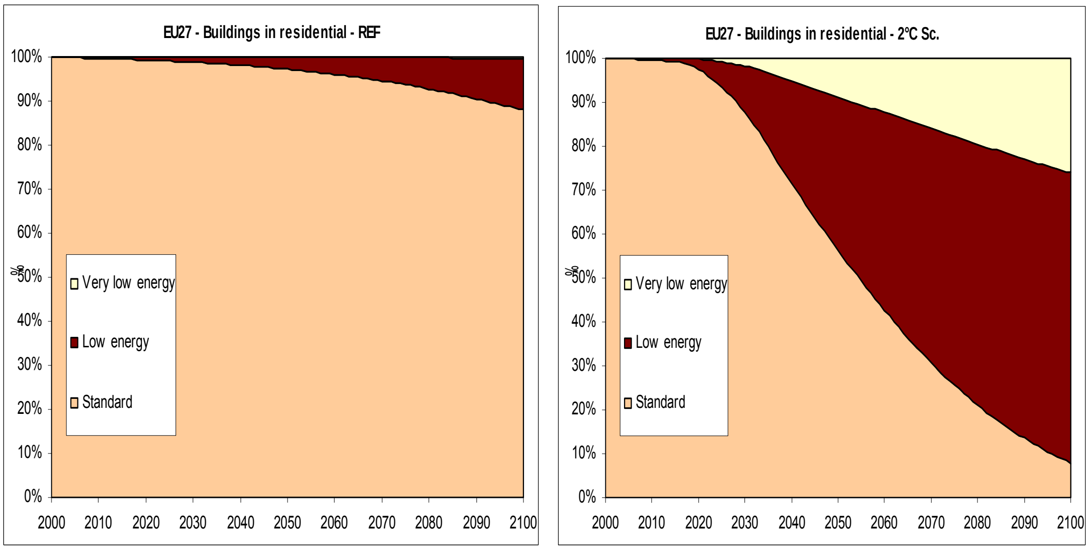
As indicated above, the 2°C Scenario has an impact not only on the diffusion of cleaner supply and conversion technologies, but also on accelerating the diffusion of new types of energy-consuming applications or infrastructures. Some key dimensions of this evolution are the development of very low energy, passive or positive energy buildings and new low energy/emission road vehicles. The shares of electric and hybrid vehicles in the stock of cars rise by 13 % and 28 % respectively by 2050 in the Reference Scenario, and by 25 % and 42 % respectively in the 2°C Scenario. After 2060, conventional vehicles (with an internal combustion engine) have almost disappeared from the vehicle stock in the 2°C Scenario (see Figure 4-16.

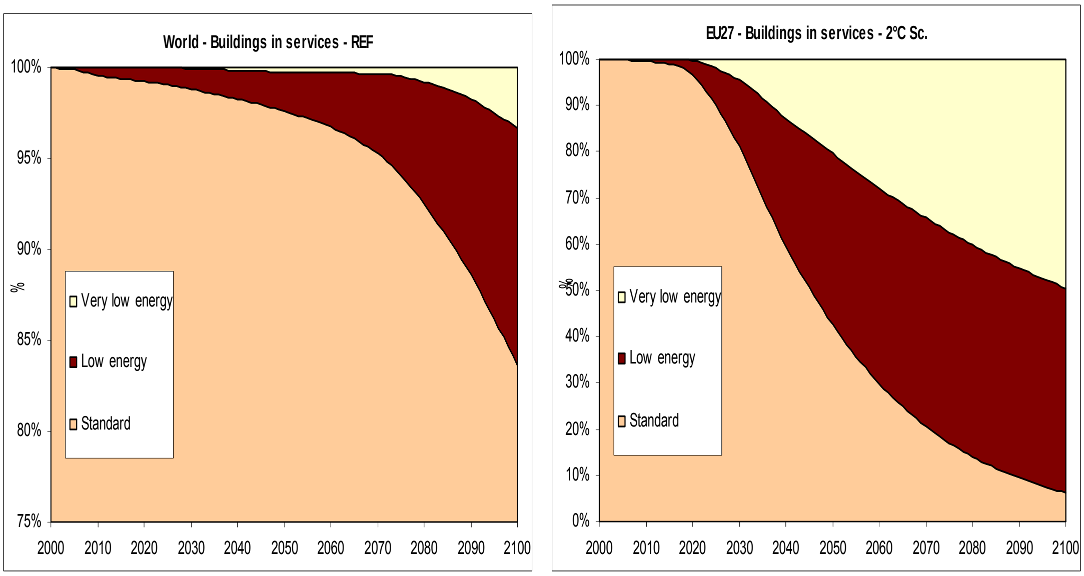


Source: POLES-LEPII ADAM

Figure 4-16: EU27 diffusion of different types of vehicles, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

In the 2°C Scenario, the share of low and very low energy buildings represents more than 40 % of the building stock in Europe in 2050 and more than 90 % in 2100 in both the residential and service sector (see Figure 4-17).

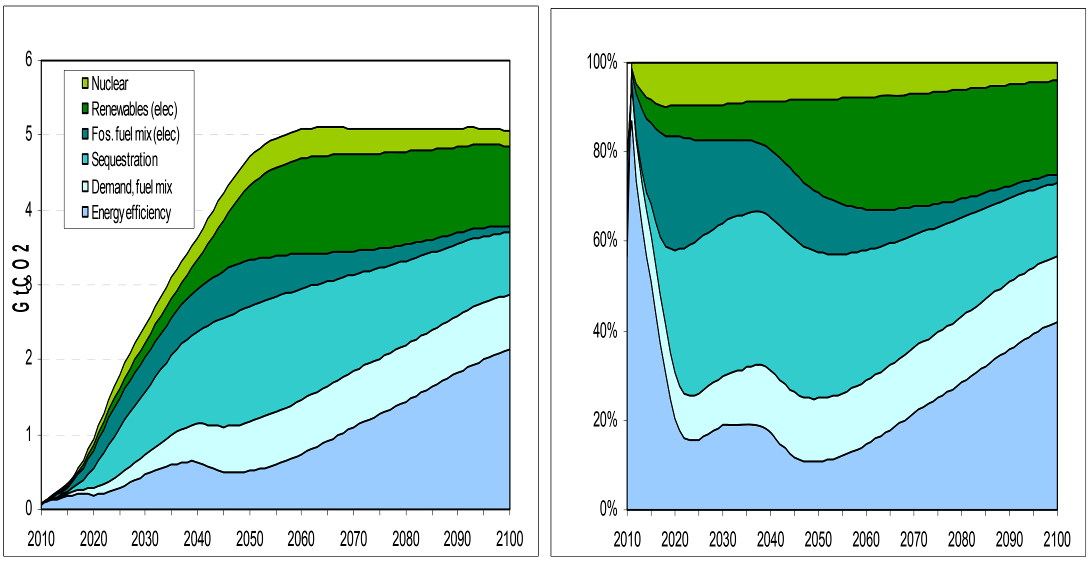




Source: POLES-LEPII ADAM

Figure 4-17: EU27 diffusion of different types of buildings in the residential sector (upper figures) and the service sector (lower figures), Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

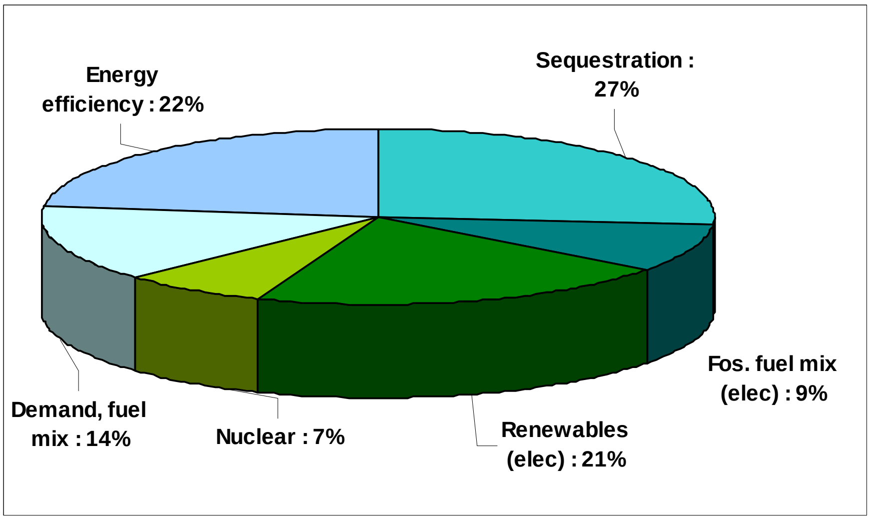
In order to analyse the relative weight of the different options examined above, the contribution of six major options to emission reductions can be traced throughout the projection period (see Figure 4-18): (1) Energy-efficiency and very low emission buildings and vehicles, (2) Changes in the fuel-mix at the demand level, (3) Changes in the fuel-mix in the electricity sector, (4) Renewable energies, (5) Nuclear energy, (6) Carbon capture and storage (CCS).



Source: POLES-LEPII ADAM

Figure 4-18: EU27 annual contribution of various actions to reduce CO_2 emissions, in billion tonnes per year (left) and in % (right), 2°C Scenario, 2000 to 2100

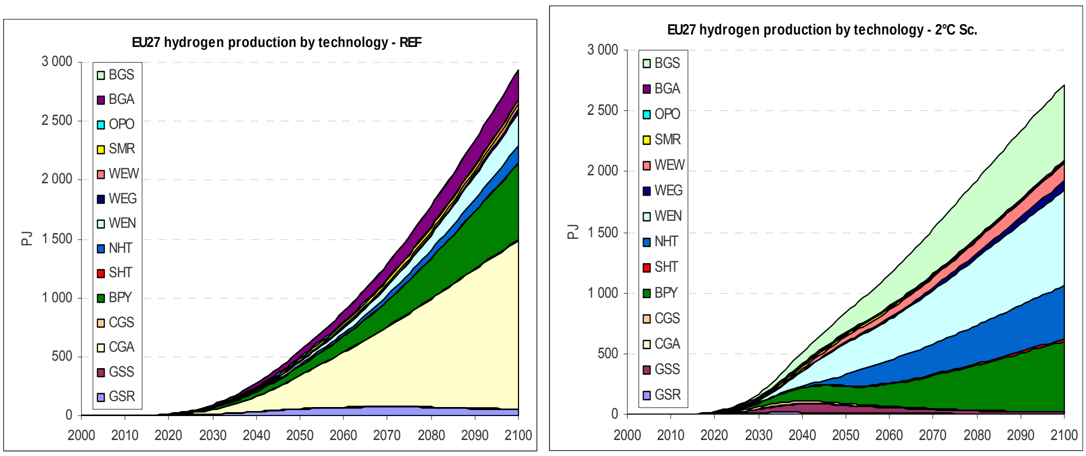
A look at the cumulative contributions of the various actions to reduce carbon emissions from 2010 to 2050 shows that demand-related actions play the biggest role, followed by carbon capture and storage, developing renewable energies, and in equal proportions, increasing nuclear power production and fossil-fuel substitution (see Figure 4-19). It should be noted that these contributions are measured with respect to the trend projection, which explains why the incremental contribution of carbon capture and storage is relatively large (it is very low in the trend projection) and why the renewable energy contribution exceeds that of nuclear power, whereas the absolute contribution of nuclear power to the global energy balance slightly exceeds that of renewable energies in both cases.



Source: POLES-LEPII ADAM

Figure 4-19: Cumulative contributions of CO_2 emission reduction measures in %, 2°C Scenario – 2000-2100)

As far as hydrogen production is concerned, the volume does not vary much from one scenario to the other, while the role of the different hydrogen production technologies changes significantly (see Figure 4-20).



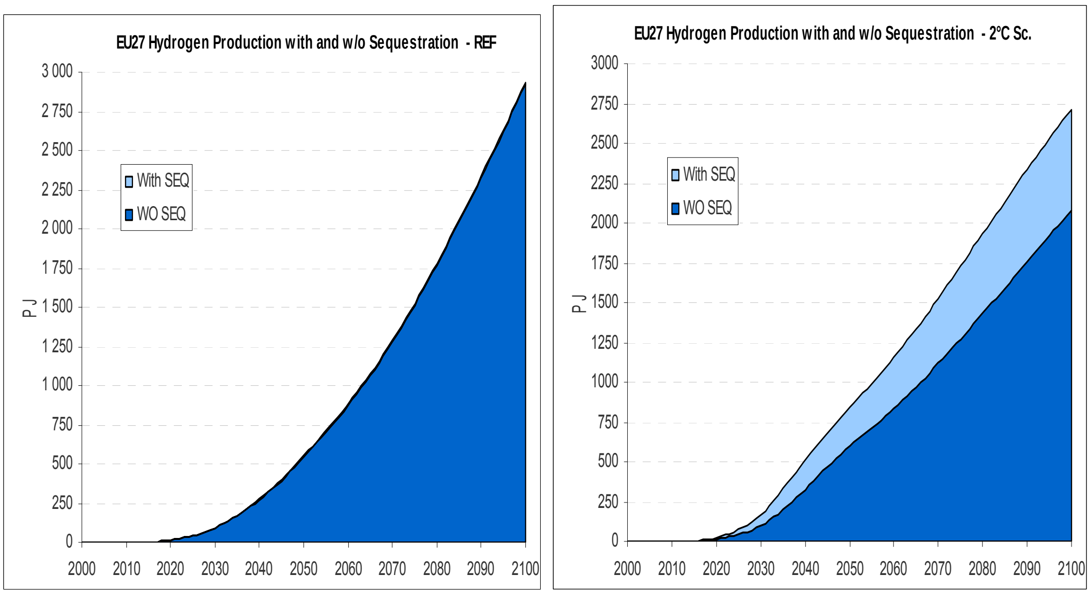
Source: POLES-LEPII ADAM

Figure 4-20: Hydrogen production by primary energy source in PJ, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

In the 2°C Scenario, the winning technologies at the world level are based on nuclear and biomass: hydrogen from water electrolysis nuclear dedicated (WEN), nuclear thermal high-temperature thermolysis (NHT), biomass gasification with sequestration (BGS) and biomass pyrolysis (BPY). Hydrogen production by these technologies represents 78 % by 2050 and 89 % by 2100 (see Figure 4-21).

Figure 4-21: Share of EU27 hydrogen production by technology in 2°C (top bar), Reference Scenario (low bar), in 2050 (left) and 2100 (right) at the world level

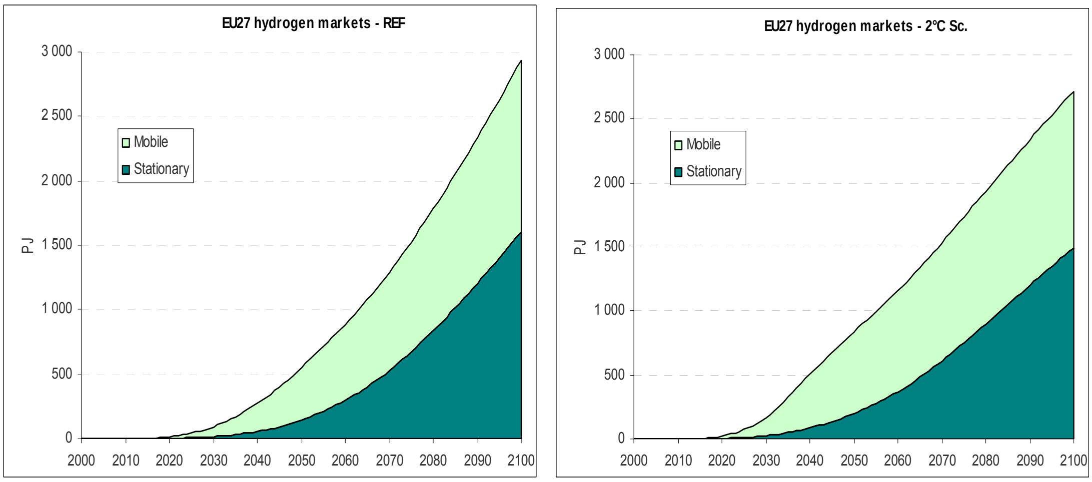
In the 2°C Scenario in Europe, 29 % of hydrogen production by 2050 and 23 % by 2100 are provided by fossil fuel based technologies with sequestration (see Figure 4-22).



Source: POLES-LEPII ADAM

Figure 4-22: EU27 Hydrogen production with and without sequestration, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

Hydrogen markets are also very similar in both scenarios (74-76 % for mobile uses by 2050 and 45 % by 2100) in spite of the fact that the share of fuel cell and thermal hydrogen vehicles is higher in the 2°C Scenario (see Figure 4-23).



Source: POLES-LEPII ADAM

Figure 4-23: EU27 hydrogen application, Reference Scenario (left) and 2°C Scenario (right), 2000 to 2100

4.3 Conclusions

As preliminary conclusions, the comparison of the Reference Scenario with the 2°C Scenario shows that the necessary drastic reduction in greenhouse gas emissions by 2050 and 2100 at the global and European level is only possible if very active mitigation policy measures are implemented. This will require on the one hand a high carbon value to be established, which is likely to have to increase quite rapidly over the period of this century and thus enables the massive development of both very energy efficient demand technologies and low and zero CO_2 energy supply options. In addition to the high carbon value on fossil energies, substantial sectoral and technology oriented measures have to be very soon taken by governments at the national, European and multinational level. These measures are only likely to be accepted if other measures (e.g. social policies, exemptions for energy-intensive basic product industries) are implemented to reduce the impacts of the necessary price signal and make this burden tolerable for both consumers and the business community.

Even though this 2°C Scenario is still exploratory, it shows that no major technological mitigation option can be neglected if mankind is to reduce total greenhouse gas emissions to a level compatible with the stabilisation of atmospheric concentrations consistent with Europe's climate objective. These major options are: "very energy-efficient and very low emissions" technologies in the residential, service, transportation and manufacturing sectors, the massive deployment of renewable energies, third- and fourth-generation nuclear power and carbon capture and storage.

The price of carbon has a direct impact not only on greenhouse gas emissions, but also on the price of energy resources, and in particular on that of hydrocarbons, crude oil and natural gas.

The 2°C Scenario results in a crude oil price that is one half less than that of the Reference Scenario in 2050 and 2100, stabilising approximately at today's levels. A very high carbon tax reduces the demand for all fossil fuels: coal, of course, but also crude oil and natural gas. Consequently, the pressure on conventional oil and gas resources is reduced in comparison with the Reference Scenario. This also significantly decreases the global energy dependency on major fossil fuel exporting regions.

It can thus be seen that an ambitious active mitigation policy scenario seeking to limit climate change also deals with the problem of global hydrocarbon resource depletion. The analysis has shown that sustainable energy development depends largely on the level of ambition and of course the effectiveness of mitigation policy measures that will be selected and intelligently implemented as policy bundles including policies that increase the acceptance of this 2°C target.

Naturally, there are limits to what could be analysed by the existing model. The first has to do with the fact that the POLES model does not measure the carbon constraint's reciprocal impact on the economy, since it is a partial equilibrium model that does not illustrate the macroeconomic impact of ambitious climate policies. The second limitation is the inability to fully account for the impact of the structural changes resulting from the adoption of a low-emission profile on the overall economy, technologies and behaviours. Efforts are currently being made to improve the understanding of both these limitations by establishing closer links between sector-based models and macroeconomic models (which is implemented by the hybrid model system with macro-economic models, see Chapter 8 of this deliverable as well as the final deliverable (M1.3) which will be published in July 2009) and by trying to describe the potential characteristics of a "Factor 4 society" in greater detail and with greater accuracy (see Chapter 5 to 7 of this deliverable and of the final deliverable in July 2009).

4.4 References

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5 Assumptions and results of the forest and material demand model – Reference and 2°C Scenario

5.1 Assumptions and results of forest model EFISCEN – Reference and 2°C Scenario 2000 to 2050

The forests of the EU27+2 countries[7] comprise some 156 million ha, or 34 % of the available land area. Since only about 60 % of their increment harvested, a vast resource of stemwood growing stock has developed over the last decades. This and the generally good accessibility of European forests means that biomass from existing forests is seen as a potentially significant source of raw material for bio-energy purposes. Here we quantify the future technical potential supply of biomass from existing European forests, taking into consideration assumptions of climate change effects on forest growth rate.

Forestry projections for the Reference and 2°C Scenarios were produced using the European Forest Information SCENario model (EFISCEN, see also Annex). EFISCEN can be used to make projections of wood production and carbon stock changes in tree biomass in European forests down to the forest type and NUTS2 level (Nabuurs et al. 2007, Schelhaas et al. 2007). EFISCEN consists of a whole tree biomass module, a soil module and a wood products module. Projections made with EFISCEN are initialised using detailed national forest inventories (see Table 5-1; Schelhaas et al. 2006) that were specifically gathered for this purpose from national forest inventory institutes.

For each European country, projections are made by forest types. Forest types are distinguished using four characteristics: the tree species, the site quality, the region where the forest is situated (mostly NUTS2 regions) and the owner of the forest. Information from EFISCEN can be aggregated to any level. For this analysis, data was aggregated on a country level. We provide projections on the wood available for the paper and conventional wood industries and the wood available for bio-energy. In the Reference and 2°C Scenarios, nature-oriented management in forestry or the adaptation of forest management to climate changes were not considered. Climate change effects on forest growth were incorporated via the process-based model chain SMART-SUMO-WATBAL (Wamelink et al., 2008), which was applied to intensive forest monitoring level plots in mid and high latitudinal Europe (Pussinen et al., 2008). For southern Europe, expected impacts were based on a literature survey.

EFISCEN is an area-based matrix model that simulates the dynamics of the stemwood volume in a forest (Schelhaas et al. 2007). For other tree organs such as leaves, branches and roots, a detailed biomass expansion database is incorporated. A separate matrix is set up for each forest type distinguished in the input data (which may be according to species, region, site class and owner). One matrix consists of 60 age classes of 5 year width and 10 volume classes with widths that vary depending on the forest under study.

[7] = EU27 plus Switzerland and Norway

Table 5-1: Overview of national inventories used to parameterise EFISCEN for different countries

Country	forest areas 1000 ha (Verburg et al. 2006, 2007, WUR/MNP)	FAWS 1000 ha (UN-ECE/FAO 2000)	EFISCEN areas 1000 ha (Schelhaas et al. 2006, Nabuurs et al. 2007)	Year of forest inventory
Austria	3,764	3,352	2,978	1992-96
Baltic States	n.a.	n.a.	n.a.	
Estonia	2,104	1932	2074	1999-2001
Latvia	2,717	2,413	2,804	2000
Lithuania	1,898	1,686	1,960	2000
Belgium/Luxembourg				
Belgium	701	639	725	1997-199
Luxembourg	Na	85	71	1989
Bulgaria	3,491	3,123	3,295	2000
Czech Rep.	2,555	2,559	2,493	2000
Denmark	394	440	442	1990
Finland	19,771	20,675	19,752	1986-1994
France	14,526	14,470	13,729	1988-2000
Germany	10,396	10,142	9,979	1986-1990/1993
Greece	n.a.	n.a.	n.a.	n.a.
Hungary	1,738	1,702	1,860	2000
Ireland	296	580	329	1992-1993
Italy	7,908	6,013	3,831	1985
Malta/Cyprus	n.a.	n.a.	n.a.	n.a.
Netherlands	314	314	307	1995-1999
Norway	n.a.	6,609	6,644	1996-2000
Poland	9,241	8,300	6,019	1993
Portugal	2.438	1,897	2,133	1997-1998
Romania	7,017	5,617	6,211	80s
Slovakia	1,940	1,706	1,909	1994
Slovenia	1,139	1,035	1,152	2000
Spain	9,209	10,479	13,905	1986-1995
Sweden	25,379	21,236	20,967	1996-2000
Switzerland	n.a.	1,060	1,140	1994
Un. Kingdom	2,004	2,108	2,202	1995-2000
Total Europe*	**136,173**	**131,862**	**128,911**	

* Excluding Greece, Malta, Cyprus

Ageing of the forest is simulated by moving the area to a higher age class, while growth is simulated by moving the area to a higher volume class. Transition chances are derived from increment figures from the input data, or from growth and yield tables. These transitions can be changed over time to simulate changes in growing conditions, in this case, climate change.

Thinning in the model is simulated by moving area one volume class down. The user can specify an age range where thinning can be carried out. Whether thinning will be carried out depends on the actual demand for thinnings. A user-defined fraction of the area that has been subjected to thinning will be moved up one volume class to simulate the growth response after a thinning.

Final fellings are simulated by deducting the area from a certain cell. Final felling chances can be set by the user as a function of age class. The fraction that is actually harvested depends on the actual demand for wood from final fellings. The fraction of residues from thinnings and fellings (branches, tops and roots) extracted from the forest can be specified as well (see Table 5-2). Within ADAM, these extraction coefficients are based on a study that quantified the maximum fraction of residues able to be extracted in an ecologically sustainable way (Lindner et al. 2005, EEA).

Table 5-2: Maximum ecologically sustainable extraction shares for each country based on the distribution of the different suitability classes in each European country

Suitability class (associated maximum extraction share)	**High (75%)**	**Moderate (50%)**	**Marginal (15%)**	**Unsuitable (0%)**	
Country	Distribution of FAWS over the different classes (%)				Weighted average share (%)
Austria	15	35	29	21	33
Baltic states					
Estonia	16	7	12	65	17
Lithuania	38	34	4	24	46
Latvia	31	30	31	8	43
Belgium/Luxembourg	20	40	12	28	37
Bulgaria	n.a.	n.a.	n.a.	n.a.	n.a.
Czech Republic	18	70	10	2	50
Denmark	38	43	6	14	51
Finland	2	69	0	29	36
France	46	34	11	9	53
Germany	38	51	6	6	55
Greece	n.a.	n.a.	n.a.	n.a.	n.a.
Hungary	46	29	9	15	50
Ireland	15	39	31	14	35
Italy	21	34	25	20	37
Malta/Cyprus	n.a.	n.a.	n.a.	n.a.	n.a.
Netherlands	20	70	5	6	51
Norway	n.a.	n.a.	n.a.	n.a.	n.a.
Poland	17	53	13	17	41
Portugal	30	36	8	26	42
Romania	n.a.	n.a.	n.a.	n.a.	n.a.
Slovakia	38	27	31	4	47
Slovenia	29	37	28	6	44
Spain	30	13	12	46	31
Sweden	1	87	2	9	45
Switzerland	n.a.	n.a.	n.a.	n.a.	n.a.
United Kingdom	17	27	11	45	28
Total Europe*	**20**	**51**	**9**	**20**	**42**

Lindner et al. 2005, EEA 2005

* Excluding Greece, Malta, Cyprus, Norway and Switzerland – values from Austria are used for Norway and Switzerland

Area deducted from the matrix is placed in a separate class, the non-stocked area. Regeneration is simulated as movement from the non-stocked area into the lowest age and volume class of the matrix. Natural mortality is simulated by moving a fraction of the area in a certain cell one volume class down. This fraction can be set by the user as a percentage of the growing stock, varied by age class. The actual fraction of the area moved down then depends on the average volume before, and the difference between the volume classes. Only an area that has not recently been thinned can be subjected to natural mortality.

Basic outputs of the model include developments of area, growing stock, increment, standing dead wood, harvest level and age class distribution over time. These are provided on different aggregation levels (per species, regions, and total). Furthermore, the model can provide information on carbon stocks in biomass and soil if the corresponding modules are parameterised.

5.1.1 Assumptions on forest area and policies in Europe in the Reference and 2°C Scenarios

For the results presented in this chapter, the standard EFISCEN management routine database (Nabuurs et al. 2007) was used, but with a number of adjustments to increase the accuracy of the projections. Small deviations exist between the forest area covered in the database and the area of forest available for wood supply (FAWS) according to UN-ECE/FAO (2000, see Table 5-1), due to the fact that country correspondents were not always able to provide detailed data for the whole FAWS area. Within the ADAM study, we used the projections of the IMAGE/CLUE model chain (Verburg et al. 2006, 2007, WUR/MNP 2007) for the development of the future forest area under the B2 storyline scenario as laid down by the IPCC (2000). Therefore, initial forest area per country in EFISCEN was corrected to match the initial area specified in the IMAGE/CLUE projections. Projected future changes in forest area were taken into account via the afforestation and deforestation options in EFISCEN. No projections were available for Norway or Switzerland. The area of forest available for wood supply (FAWS) as provided by UN-ECE/FAO (2000) was used to correct the initial forest area, and current changes in forest area (UN-ECE/FAO, 2000) were projected into the future. We assume that changes in forest area are the same under the Base Case Scenario, the Reference Scenario and the 2°C Scenario, i.e. we assume there are no specific policy changes to promote afforestation. Although afforestation could be one of the mitigation options in the 2°C Scenario, we assume that any available land will be preferably used to produce bio-fuels.

In the Base Case Scenario, no climate change effects on forest dynamics were incorporated, since zero climate change was assumed by definition in this scenario. However, in the Reference Scenario and the 2° Scenario, climate changes are assumed. Climate change can influence forest dynamics in various ways. Increased CO_2 concentration might have a positive effect on forest growth (Bergh et al, 2003; Rathgeber et al., 2003). In northern countries, the growing season may be prolonged, leading to increased growth (Bergh et al., 2003). Increased temperature may increase productivity if current temperatures are sub-optimal for photosynthesis, but may also lead to increased respiration (Bergh et al., 2003; Jump et al., 2007). If precipitation remains the same or decreases, the forest might suffer from increased drought stress, which might lead to decreased growth and increased mortality (Ogaya and Peñuelas, 2007). In the longer term, these altered circumstances will affect the tree species composition of the forest via altered competition between species. Another effect of climate change may be the increased chance of extreme events, like forest fires or storms (Whitlock et al., 2003, Moriondo et al., 2006, Meehl et al., 2007).

Although these events can have a large impact on the forest, they are not taken into account within this mitigation module because the quantification of the probability of extreme events and their level in the future is still too uncertain. In the adaptation module (A2), extreme events are considered in more detail. For the mitigation study and the Reference Scenario, we only took into account expected short-term (i.e. several decades) effects of climate change on forest growth. Climate change effects on forest growth were based on the process-based model chain SMART-SUMO-WATBAL (Wamelink et al., 2008), which was applied to intensive forest monitoring level plots in mid and high latitudinal Europe (Pussinen et al., 2008). As an average over the age classes for Europe, the growth changes were 19 %, 28 %, 29 %, and 59 % respectively in 2010, 2030, 2050, and 2070. More detailed analyses of process-based modelling, including more details per tree species and region of Europe, can be found in Wamelink et al. (2008).

For southern Europe, not enough long-term monitoring sites were available for detailed analysis, so a literature survey was conducted. Some of the literature on climate change effects on forests in southern Europe expects increment to decline due to prolonged drought effects (Olesen et al., 2007). Others expect increased increment, mainly due to increased precipitation in winter which mitigates expected droughts (Rathgeber et al., 2003; Magnani et al., 2004; Eggers et al., 2008). In the study by Wamelink et al. (2008), the plots in the Mediterranean region of France actually showed decreased increment, so we chose to rely on the first type of studies. Information was only available for a few species, so we had to use the same factors for all tree species. We assumed a 5 % decrease in increment by 2015 and a 10 % decrease by 2040.

The influence of climate change on forest productivity is very uncertain. Studies are usually based on process-based models applied to a small selection of sites. There is a huge variability in responses to climate change between the different models. Furthermore, such studies take a very long time. It was therefore not possible to differentiate between climate impacts in the Reference Scenario and the 2° Scenario.

An important driver for forest dynamics in EFISCEN is the total required national fellings. The EFISCEN model is designed to match these nationally required fellings by harvesting wood using management routines per forest type (Nabuurs et al., 2007). In this case conventional management routines were used to estmate final fellings, thinning chances and regeneration rates per forest type.

To calculate the potential supply of wood for bio-energy, two different projections of required felling were used up to 2050. A business-as-usual required felling projection (BAU) was used to make projections of wood supply for the conventional wood industry. A maximum required fellings projection (MAX) was used to make projections of the potential supply of wood for bio-energy or intensified use of wood as a substitution material in the 2°C Scenario.

The amount of wood available for bio-energy was calculated as the difference between the projections for the amount of wood harvested under BAU and that harvested under MAX. This difference can be seen as the extra harvest due to complementary fellings for biomass production. The BAU and MAX projections were based on FAOSTAT data from 1990-2005 (FAOSTAT 2007). For BAU, a 5 year running average was used to make projections into the future beyond 2005. For MAX, a 10 % increase in required fellings every 5 years was assumed, which levelled off, however, before the growing stock fell below the initial value.

Besides stemwood from complementary fellings, logging residues from wood harvesting for the conventional wood industry can also be used for bio-energy. The efficiency of extracting these residues (tops and branches) from harvesting sites depends on the suitability of a site. Four different suitability classes are distinguished for tops and branches, each associated with different extraction efficiencies (see Table 5-2). For each country the extraction efficiency was calculated as a weighted efficiency over the different suitability classes. For roots and existing dead wood, it was assumed that they are not extracted at all.

5.1.2 Results on wood supply from forests, landscape wood, and demolition wood for the two scenarios - 2000 to 2050

Data were grouped into the same four European regions as for the Base Case Scenario (see Deliverable 1 Jochem et al. 2008): Central/Western Europe, Eastern Europe, Scandinavia and the Mediterranean (see Table 5-3).

Table 5-3: Division of European countries into four European regions

Central\Western Europe	Austria
	Belgium/Luxembourg
	France
	Germany
	Ireland
	Netherlands
	Switzerland
	United Kingdom
Mediterranean	Italy
	Portugal
	Spain
Scandinavia	Denmark
	Finland
	Norway
	Sweden
Eastern Europe	Bulgaria
	Czech Republic
	Baltic states
	Hungary
	Poland
	Romania
	Slovakia
	Slovenia

5.1.2.1 Wood supply potential from forests by country – 2000 to 2050

The EFISCEN projections based on the above assumptions are presented in Table 5-4. Time series are also plotted for the four regions (see Figure 5-1). For both Ireland and Spain, the harvests for the MAX felling projections were lower than the harvests for the BAU felling projections in some years. This is possible when high harvest levels in certain years reduce the availability of wood in subsequent years to below the required level of felling. For the years where the wood harvest of the MAX projections was below that for the BAU projections, only biomass from residue extraction under the MAX projection was assumed to be available for bio-energy, while the roundwood removed under this projection was assumed to be used for the conventional wood industry.

Under the BAU fellings, wood harvests show only a small increase of 3.2 % over the total time frame of 45 years, except for the Mediterranean region, which shows an irregular trend. This region also shows an inconsistent trend for biomass availability compared with the other regions. A possible explanation is that the initial datasets are less suitable for the EFISCEN model for some of the Mediterranean countries. For example, in Portugal, short rotation Eucalyptus plantations form an important part of national forest inventories. These plantations typically have a rotation of five years. One single time step in EFISCEN is also 5 years, making it difficult to properly simulate forest development for these types of forestry projects.

In general, the required felling projections used predict a large increase in biomass availability for bio-energy from forest harvests. From the current availability of 18.1 Mt C per year, the potential rises to 104.5 Mt C per year in 2050 (see Table 5-4). Under the Base Case, the potential was calculated to be 87.1 Mt C per year in 2050, i.e. an increase of 20 %. The potential for residues (tops and branches) comprises 31 % of the total potential, while in the Base Case this was 35 %. These outcomes suggest that the potential of the European forest as a whole for bio-energy production would increase under a climate change scenario. However, we did not take into account other potential effects of climate change, like increased mortality and the occurrence of extreme events. Furthermore, the increase was distributed unevenly over Europe. In the Mediterranean region, the potential decreased by 5 %, while it increased by 49 % in the Scandinavian region. Eastern Europe and central/western Europe experience a more moderate increase, by 9 and 14 %, respectively.

The state of the forests is described as the average growing stock per hectare, shown in graph B in Figure 5-1. The average growing stock is fairly stable in all regions, showing that an increase in harvest could stop the currently observed trend of increasing standing stocks in European forests (UN-ECE\FAO 2005).

The increase in production projected in this study is realised over an increasing area as a result of the afforestation projected by data from UNECE\FAO (2005) and IMAGE\CLUE (Verburg et al. 2006, 2007, WUR/MNP 2007). The total forest area increased in our study from 139 million ha in 2005 to 184 million ha in 2050. Increases in forest area may not have an immediate effect on production, but within the period used in this study (50 years), they do contribute to increase harvests.

Table 5-4: **Harvested stemwood under Max and BAU scenarios, extracted residues (Res), and the total available biomass (Tot) (1000 t C yr^{-1}) for each country in 2005, 2025 and 2050.**

Country	2005				2025				2050			
	Max	BAU	Res	Tot	Max	BAU	Res	Tot	Max	BAU	Res	Tot
Austria	3666	3666	533	533	5286	3771	822	2337	8418	3824	1267	5862
Baltic States	6117	6117	1187	1187	8650	6311	1632	3971	9079	6689	1679	4070
Belgium/Luxembourg	976	976	171	171	1310	1177	222	355	1239	1046	221	415
Bulgaria	1368	1368	300	300	2004	1463	430	971	2262	1408	475	1329
Czech Republic	3583	3583	785	785	4622	3640	995	1977	4770	3662	1144	2252
Denmark	415	415	102	102	542	436	129	236	590	397	129	321
Finland	12502	12502	1612	1612	16801	12538	2195	6458	18921	12726	2452	8647
France	9713	9713	2449	2449	14111	9406	3419	8124	18590	9332	4521	13779
Germany	12122	12122	2987	2987	17273	12720	4318	8871	24128	12753	6055	17429
Greece	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Hungary	1658	1658	426	426	1936	1592	491	835	2369	1623	598	1344
Ireland	350	350	50	50	422	412	56	66	498	485	71	84
Italy	2424	2425	214	214	3505	2416	293	1382	5734	2451	493	3776
Malta/Cyprus	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Netherlands	165	165	40	40	321	259	75	137	472	263	112	321
Norway	2090	2090	251	251	3054	2112	370	1311	4918	2116	600	3402
Poland	7211	7211	1381	1381	10439	7500	1951	4890	12087	7554	2266	6799
Portugal	1774	1774	498	498	1122	1151	315	315	1619	1740	455	455
Romania	4005	4005	653	653	5839	4077	976	2738	9485	4108	1625	7003
Slovakia	1847	1847	397	397	2717	2010	615	1322	3079	2025	724	1777
Slovenia	659	659	137	137	877	685	185	376	1246	691	298	853
Spain	3980	3980	694	694	2395	2503	432	432	4054	3744	731	1041
Sweden	16836	16836	2763	2763	24573	17964	4082	10691	32174	18039	5429	19565
Switzerland	1296	1296	191	191	1901	1294	297	904	3033	1297	476	2212
United Kingdom	2039	2039	290	290	2841	2035	398	1205	3259	1925	426	1760
Total Europe*	96798	96798	18112	18112	132539	97472	24697	59902	172024	99899	32250	104496

Legend: Max - wood availability for the maximum required felling projection; BAU - wood availability for the business as usual required felling projection; Res - the extraction of residues under the maximum required felling scenario; Tot - the total amount of wood biomass available for bioenergy (Tot = Res +(Max-Bau)) *excluding Greece, Malta, Cyprus

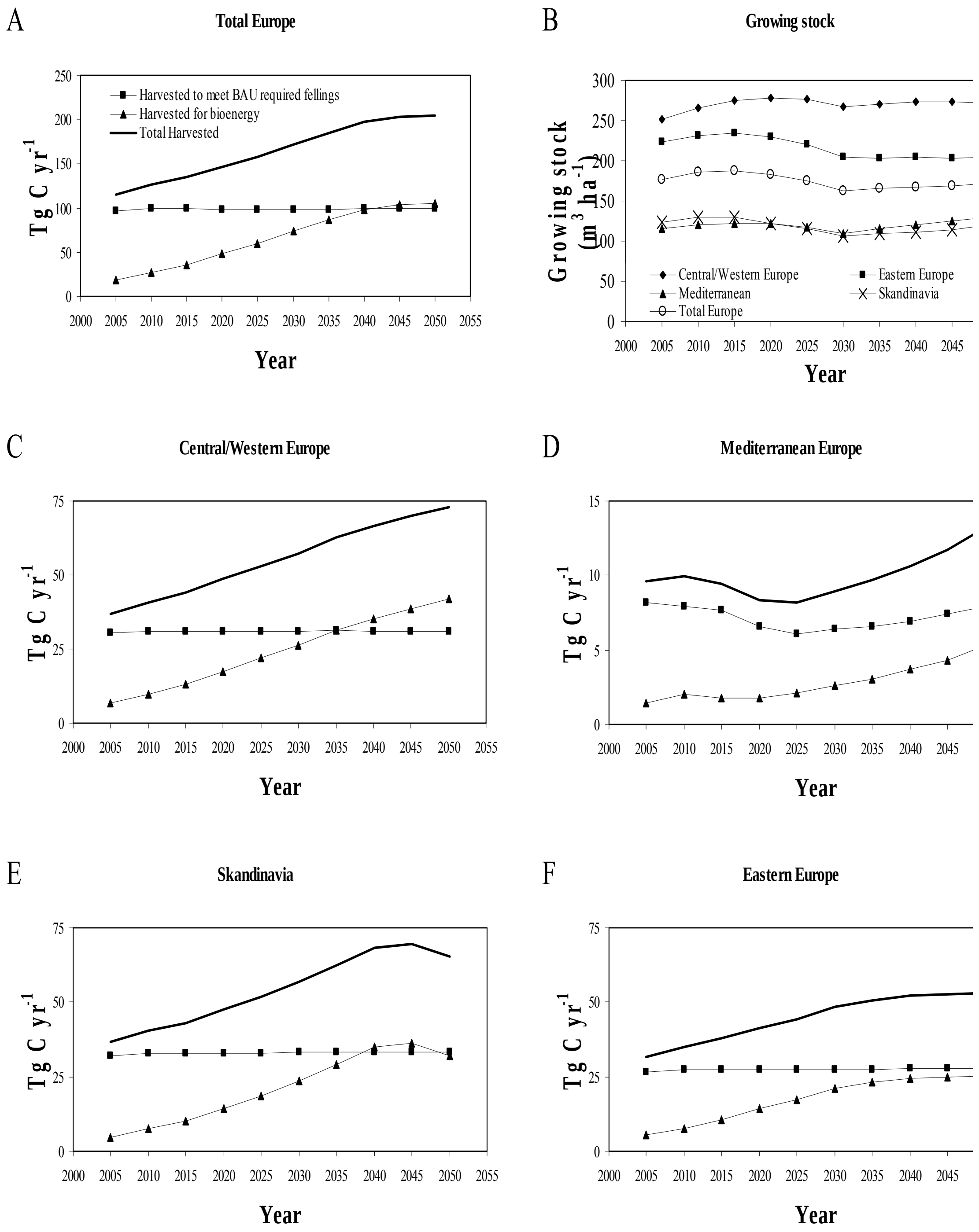

Figure 5-1: Harvested biomass for Europe for the conventional wood industry (Mt C), for bio-energy and the total amount harvested (A), the growing stock development displaying the state of the forest per region under the MAX scenario (B), and the same variables as in A but per region (C-F)

The biomass available for bio-energy is also converted into million tonnes of oil equivalents (Mtoe) in order to be able to compare our projections with other studies (see Table 5-5). For the conversion we used constants proposed by the EEA (2006). In total, almost 93 Mtoe could be produced from the forests, about 5 % of the current primary energy demand of these countries.

Table 5-5: Projections on energy available from forestry projects in Mtoe per year, Reference and 2°C Scenarios, 2005-2050.

Total bio-energy	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Austria	0.47	0.75	1.13	1.59	2.08	2.55	3.09	3.69	4.38	5.21
Baltic States	1.05	1.60	2.17	2.94	3.53	3.97	4.23	3.46	3.54	3.62
Belgium/Luxemb.	0.15	0.19	0.19	0.23	0.32	0.29	0.28	0.28	0.33	0.37
Bulgaria	0.27	0.35	0.49	0.67	0.86	1.06	1.27	1.23	1.20	1.18
Czech Republic	0.70	1.05	1.45	1.89	1.76	2.32	2.70	2.59	2.57	2.00
Denmark	0.09	0.11	0.13	0.19	0.21	0.18	0.17	0.22	0.30	0.29
Finland	1.43	2.68	3.07	4.49	5.74	7.32	9.03	11.24	12.19	7.68
France	2.18	3.41	4.57	5.82	7.22	8.73	10.37	12.19	12.19	12.24
Germany	2.65	3.39	4.68	6.19	7.88	9.64	11.49	11.99	13.99	15.49
Greece	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Hungary	0.38	0.42	0.47	0.55	0.74	0.97	1.15	1.30	1.01	1.19
Ireland	0.04	0.05	0.06	0.07	0.06	0.05	0.07	0.07	0.07	0.07
Italy	0.19	0.41	0.65	0.92	1.23	1.57	1.95	2.38	2.85	3.35
Malta/Cyprus	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Netherlands	0.04	0.05	0.06	0.08	0.12	0.18	0.24	0.28	0.28	0.29
Norway	0.22	0.42	0.64	0.89	1.17	1.47	1.80	2.17	2.57	3.02
Poland	1.23	1.75	2.53	3.38	4.34	5.44	5.36	6.22	6.11	6.04
Portugal	0.44	0.38	0.32	0.29	0.28	0.30	0.31	0.34	0.37	0.40
Romania	0.58	0.92	1.38	1.89	2.43	3.05	3.71	4.32	5.02	6.22
Slovakia	0.35	0.45	0.64	0.89	1.17	1.49	1.62	1.98	1.83	1.58
Slovenia	0.12	0.18	0.25	0.34	0.33	0.38	0.51	0.61	0.71	0.76
Spain	0.62	1.00	0.63	0.39	0.38	0.42	0.45	0.56	0.62	0.92
Sweden	2.46	3.46	5.16	7.23	9.50	12.00	14.69	17.44	17.28	17.38
Switzerland	0.17	0.32	0.46	0.63	0.80	0.96	1.20	1.43	1.68	1.97
United Kingdom	0.26	0.44	0.65	0.88	1.07	1.04	1.24	1.49	1.52	1.56
Total Europe*	**16.09**	**23.77**	**31.79**	**42.43**	**53.22**	**65.38**	**76.94**	**87.49**	**92.59**	**92.84**

Conversion coefficients: 1 Gg biomass = 18.6 TJ & 1 toe = 41.87 GJ; *excluding Greece, Malta, Cyprus

The presented estimates of wood use are close to the physical potential of the forest. The projections did not take into account economic or social constraints that may reduce the projected harvests. Possible private forest owners may not be willing to harvest wood for bio-energy production, given the current relatively low energy prices. If prices for energy rise, this may interfere with the prices of raw materials and that will affect the paper and conventional wood industries. These kinds of dynamic interactions are not taken into account in this study, but may have a significant effect on the availability of wood for bio-energy (see Chapter 5.3). With rising energy prices, the amount of wood harvested for bio-energy will probably also rise, while there may be an associated drop in the wood demand for conventional industry. This may further increase the potential amount of wood available for bio-energy.

Because EFISCEN is primarily designed to make projections concerning potentials of roundwood, these are well tested and validated. However, estimations on the available amount of branches are less certain. The amount of branches is calculated using biomass expansion factors (BEFs). The calculation of the amount of branch biomass present in a forest based on the amount of roundwood present in a forest depends strongly on the quality of the estimated BEFs. Although there are many studies giving estimated BEF values, these vary widely (Zianis et al. 2005); therefore our predictions about the extraction of wood from residues should be interpreted with caution.

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5.2 Assumptions and results of the MATEFF model – Reference (4°C Scenario) and 2°C Scenarios - 2000 to 2050

The model used for simulating energy-intensive materials and products is called MATEFF. The production of such energy-intensive products and materials is an important driver of industrial energy demand. It is difficult to relate the development of these energy-intensive products to the economic production value if the value added of these basic materials increases substantially over time; this is often the case due to quality improvements or additional services of the related industrial sector. It is important, therefore, to relate the specific energy demand of materials to their physical production and not to gross or net production values. The assumptions for the development of the physical production of energy-intensive materials were based on two alternative methods:

- Trend estimates of per capita production of the energy-intenisve basic products is one option, particularly if saturation effects can be observed in the past or anticipated for the future, or
- the use of an statistically estimated relation between the economic production figures of the basic material industries projected by the macroeconomic models and the physical production of the basic products often representing the trends to higher value added, higher material quality and improved properties.

The following sub-chapters briefly describe the assumptions and method used for the main basic materials such as steel, aluminium, glass, paper, cement, and plastics. The assumptions and results concerning the different industrial sectors are identical in the Base Case Scenario (see Deliverable M1.1: Report of the Base Case Scenario for Europe) and the Reference Scenario (4°C Scenario; see Chapter 5.2.1.1). In contrast, the assumptions of the 2°C Scanario are quite different by assuming fast progress in material efficiency in oder to resuce industrial energy demand in the basic product industries (see Chapter 5.2.2.1).

A few of the projections on energy-intensive products presented in Deliverable M1.1 have been revised due to new data. The assumptions and results of the "Reference Scenario (4°C Scenario)" and the 2°C Scenario are described in the following sections.

5.2.1 Assumption on the demand of energy-intensive products

5.2.1.1 Reference Scenario (4°C Scenario) – 2000 to 2050

Assumptions on the drivers of steel production in Europe

Steel is a much valued basic material with numerous uses as a raw material, half-finished product, finished product, transformed product or processed product. An enormous increase in competitiveness (improvement of energy and resource efficiency, minimisation of CO_2 emissions, new steel grades, innovative and efficient steel production technologies) is apparent in every field of steel production.

World steel production has been increasing continuously at high rates since 1970. In 1970 world crude steel production equalled 595 million tonnes. In 2006, 1,240 million tonnes of crude steel were produced globally, worth around 670 billion €. China and India, in particular, demonstrate rapid growth in steel production. For example, 422.7 million tonnes of crude steel were produced in China in 2006, which translates to about 324 kg/capita and year.

By comparison, the EU-27 produced 206.8 million tonnes of steel in 2006 even though the European Union (485 million inhabitants) is a leading steel market (426 kg/cap. per year). In 2006 in the EU-27, the share of oxygen steel was 59.6 % and the share of electric steel 40.1 %. Electric steel is made out of steel scrap, whereas oxygen steel is mainly produced as a primary material from iron ore in blast furnaces. There is a large share of electric steel in the highly industrialised countries of Europe with large capital stocks, which will continue to increase in the future.

Based on the production of oxygen steel and electric steel in the year 2005, the development of steel production was estimated for EU-27 (+ Norway, Switzerland, Turkey) by projecting the steel production per capita of the European countries in the years 2020, 2030, 2040 and 2050 (see Table 5-6 und Table 5-7). The data between these reference points of the development were calculated as a linear increase or decrease. When estimating per capita steel production, two different trends have to be considered for the next decades:

- The older the capital stock of an industrialised country, the more steel scrap becomes available. This increases the potential for electric steel production in the country considered.

- The more industrial goods with steel parts are imported into a country, the more likely it is for steel production to be reduced, particularly oxygen steel.

As a result of these basic trends, increasing shares of electric steel production can be expected, especially in the smaller European countries where crude steel production in blast furnaces is no longer economically feasible. In these cases, the share of electric steel production may reach 100 % like in Denmark or Ireland in the year 2000. At present (and expected to remain that way in the future), Greece, Norway, and Switzerland also only produce electric steel, which means the crude steel production of these countries matches their electric steel production (Table 5-17 and Table 5-18). In contrast, the Baltic States produce exclusively crude steel. Latvia is the leading steel manufacturer among the Baltic States. Portugal (at present), Slovenia (at present), Spain (from 2015) and Italy (from 2030) produce a very high share of electric steel. The percentage of electric steel in these countries averages more than 80 % of total steel production and their electric steel production grows by 0.3 % per year.

Malta/Cyprus do not produce stell at all, neither oxygen steel production nor an electric steel production. Denmark does not produce any crude steel at present either. Denmark's oxygen steel plants were closed in 1980 and electric steel ceased to be produced here in 2003. Ireland stopped producing crude steel in 2002 (oxygen steel before 1990 and electric steel in 2002).

Table 5-6: Estimated production of crude steel in tonnes per capita in EU27 + Norway, Switzerland and Turkey, Reference Scenario 2005 – 2050

Country or Country group	2005	2030	2050
Austria	0.86	0.60	0.50
Baltic States	0.24	0.20	0.20
Belgium/Luxembourg	5.72	5.50	4.95
Bulgaria	0.26	0.30	0.30
Czech Republic	0.61	0.50	0.45
Denmark	–	–	–
Finland	0.90	0.70	0.60
France	0.32	0.30	0.25
Germany	0.54	0.56	0.56
Greece	0.20	0.17	0.24
Hungary	0.20	0.20	0.20
Ireland	–	–	–
Italy	0.50	0.45	0.40
Malta/Cyprus	–	–	–
the Netherlands	0.42	0.40	0.40
Norway	0.15	0.15	0.15
Poland	0.22	0.30	0.27
Portugal	0.13	0.10	0.11
Romania	0.29	0.30	0.30
Slovakia	0.80	0.65	0.41
Slovenia	0.29	0.36	0.30
Spain	0.42	0.40	0.40
Sweden	0.63	0.55	0.50
Switzerland	0.14	0.18	0.20
United Kingdom	0.22	0.22	0.20
Turkey	0.29	0.50	0.45

Source: BSR Sustainability GmbH

The basic assumption made about crude steel production in European countries is that it declines after a peak due to the industrialisation and motorisation of a country. Therefore, Eastern European countries either exhibit a still growing or stagnating pattern of steel production, while Western European countries all have declining trends in steel production in physical terms. However, as increasing amounts of steel scrap become available, these serve as secondary material for the electric arc process which has increasing or stagnating trends. The overall result is that the per capita crude steel production is declining slightly in most EU-15 countries; However, in some Eastern European countries and Turkey per capita production is still increasing until 2030 (see Table 5-6).

Per capita electric steel production of many European countries (Austria, Belgium/-Luxembourg, Finland, France, Germany, the Netherlands, Sweden, United Kingdom, the Czech Republic, Hungary, Poland, Slovakia, Romania and Turkey) increases by an average of 0.6 % per year.

Table 5-7: Estimated production of electric steel in tonnes per capita in EU27 + Norway, Switzerland and Turkey, Reference Scenario 2005 – 2050

Country or Country group	2005	2030	2050
Austria	0.08	0.09	0.10
Baltic States	–	–	–
Belgium/Luxembourg	0.45	0.49	0.54
Bulgaria	0.10	0.14	0.19
Czech Republic	0.06	0.07	0.09
Denmark	–	–	–
Finland	0.27	0.30	0.35
France	0.12	0.13	0.15
Germany	0.17	0.20	0.23
Greece	0.20	0.22	0.24
Hungary	0.03	0.04	0.05
Ireland	–	–	–
Italy	0.30	0.36	0.42
Malta/Cyprus	–	–	–
Netherlands	0.01	0.01	0.01
Norway	0.15	0.15	0.15
Poland	0.09	0.11	0.14
Portugal	0.07	0.09	0.11
Romania	0.08	0.10	0.14
Slovakia	0.07	0.08	0.10
Slovenia	0.30	0.36	0.43
Spain	0.31	0.34	0.37
Sweden	0.20	0.21	0.23
Switzerland	0.14	0.18	0.20
United Kingdom	0.05	0.05	0.05
Turkey	0.21	0.19	0.19

Source: BSR Sustainability GmbH

Assumptions on the drivers of aluminium production in Europe

Aluminium is a young material compared to steel. Its specific weight is considerably less than steel which is the major reason it is often preferred to steel in mobile applications when lightweight solutions are necessary (e.g. airplanes, elevators, packaging, car wheels or even cars and windows). However, the production of primary aluminium is very electricity-intensive due to its electrolytic production process and it is also costly compared to steel. Therefore, aluminium is in stiff competition with steel as well with plastics, as plastics also have low specific weight and similar properties to aluminium (such as no corrosion, recyclable (polymers), and similar prices).

Aluminium can easily be recycled by melting aluminium scrap. Because of the high price per ton of primary aluminium (about 2,000 € / t), the production of secondary aluminium is very attractive and recycling a widespread practice. As aluminium is a young material, the share of secondary aluminium in total aluminium production should be rather low. However, as primary aluminium is so electricity-intensive, much of it is produced in countries with cheap electricity (like Canada or Australia).

Austria, the Baltic States, Belgium/Luxembourg, Bulgaria, Denmark, Finland, the Czech Republic, Ireland, Malta/Cyprus and Portugal do not have any *primary aluminium production*. Based on primary aluminium production in the year 2005, the development of primary aluminium production was estimated for EU27 (+ Norway, Switzerland, Turkey) using the following basic considerations:

- Most of the increases in primary aluminium demand in Europe will be satisfied by imports from countries with cheap electricity prices.
- In many European countries, existing production capacities will be maintained (but not enlarged) and mostly re-invested (but not in Germany or in other European countries in cases of re-investments in the next decades).
- The production data between the estimated values of each decade were calculated as linear increases or decreases.

The primary aluminium production of France, Hungary, Romania and Spain remains constant after 2030 (see Table 5-20). Most other countries (Greece, Italy, the Netherlands, Poland, Slovakia, Slovenia, Sweden and Switzerland) maintain a constant level of aluminium production after 2020. The United Kingdom shows a constant level of primary aluminium production for the entire period.

Only Norway and Turkey feature increasing primary aluminium production throughout the period 2005 to 2050 due to the inexpensive electricity from hydropower in Norway and the high domestic demand in Turkey with new efficient power stations. Over the same period, the primary aluminium production in Germany decreases by about 45 %.

Belgium/Luxembourg, Ireland and Cyprus/Malta do not have any *secondary aluminium production*. Belgium stopped producing secondary aluminium in 2005 and Switzerland in 2002.

Based on the production of *secondary aluminium* in the year 2005, the development of secondary aluminium production was estimated for EU-27 (+ Norway, Switzerland, Turkey). Again, the development of production between the estimated values for each decade is calculated as a linear increase or decrease.

The data concerning the secondary aluminium production of the eastern European countries (the Baltic States, Slovakia, Slovenia and Turkey) are not specified (see Table 5-8). It is estimated that Turkey starts producing secondary aluminium in 2020, which may be a rather conservative estimate.

Assumptions on the drivers of cement production in Europe

Cement is an important construction material, not only for houses and buildings, but also for the transportation infrastructure of a country such as bridges, tunnels, roads or airports. This means that the development of a country's population, country size and topography and transportation infrastructure are major determinants when estimating the cement demand of an industrialised country. It also means that each country experiences a maximum cement demand per capita during its phase of building its capital stock of an industrialised country. This per capita cement demand decreases afterwards to a lower cement demand per capita for fully industrialised countries when only re-investments have to be made. This consideration leads to the conclusion that per capita estimates would be the best method, assuming that cement cheap to produce and expensive to transport over long distance so that changing trade patterns are unlikely in the future.

Table 5-8: Estimated development of secondary aluminium production in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario 2005 – 2050

Country or Country group	2005	2020	2030	2040	2050
Austria	151	2005-2030: + 1.5% per year	2030-2050: + 1% per year		
Baltic States	not specified				
Belgium/Luxembourg	–	–	–	–	–
Bulgaria	8	20			40
Czech Republic	40		60		70
Denmark	20	20	20	20	20
Finland	35		44	44	44
France	222		270	270	270
Germany	712	2005-2050: + 7.5 per year			
Greece	9		11		13
Hungary	20		50		60
Ireland	–	–	–	–	–
Italy	654	2005-2030: + 6 per year	2030-2050: + 2 per year		
Malta/Cyprus	–	–	–	–	–
Netherlands	50	60	60	60	60
Norway	362		500		600
Poland	7	30		70	80
Portugal	18	2005-2030: + 0.5 per year	2030-2050: + 0.2 per year		
Romania	7	25		50	60
Slovakia	not specified				
Slovenia	not specified				
Spain	243		350		400
Sweden	32	2005-2030: + 0.0003 per year	2030-2050: + 0.0001 per year		
Switzerland	–	–	–	–	–
United Kingdom	205	2005-2030: + 1 per year	2030-2050: constant level		
Turkey	not specified	50			80

Source: BSR Sustainability GmbH

The relevant economic branch "non-metal minerals", simulated by the E3ME and the ASTRA model, show moderate growth for the EU15 countries plus Norway and Switzerland and generally higher growth rates for Eastern European countries. Although the non-metal minerals cover many more industrial products than just cement (e.g. lime, bricks, glass (see Chapter 5.2.4) and ceramics), the economic development of this branch has been used as an indicator to differentiate the per capita estimates.

Based on the production of cement per capita in the year 2000, the development was estimated by country for the years 2020, 2030, 2040, and 2050 for EU27 (+ Norway, Switzerland, Turkey) (see Table 5-9). The data between reference points were calculated as linear increases or decreases.

The figures for Austria, Denmark, Germany, the Netherlands and Norway show a constant level of cement production per capita throughout the whole period. In contrast, the cement production per capita increases to start with in Belgium/Luxembourg, the Czech Republic and Hungary and then levels out after 2040 (see Table 5-9). All other countries have a constant level of cement production per capita after 2030. The cement production per capita in Turkey gradually decreases from 2000 until 2050 assuming that the most intensive phase of construction occurred during 2000 to 2010.

Table 5-9: Estimated cement production in tonnes per capita in EU27 + Norway, Switzerland and Turkey, Reference Scenario 2005 – 2050

Country or Country group	2000	2020	2030	2040	2050
Austria	0.48	0.48	0.48	0.48	0.48
Baltic States	0.25			0.35	0.35
Belgium /Luxembourg	0.80		0.60	0.60	0.60
Bulgaria	0.30		0.38	0.38	0.38
Czech Republic	0.35	0.45		0.35	0.35
Denmark	0.38	0.38	0.38	0.38	0.38
Finland	0.25		0.35	0.35	0.35
France	0.34		0.38	0.38	0.38
Germany	0.40	0.40	0.40	0.40	0.40
Greece	1.42		0.50	0.50	0.50
Hungary	0.36	0.45		0.35	0.35
Ireland	0.96		0.40	0.40	0.40
Italy	0.75		0.60	0.60	0.60
Malta / Cyprus	2.10		1.50	1.50	1.50
Netherlands	0.20	0.20	0.20	0.20	0.20
Norway	0.40	0.40	0.40	0.40	0.40
Poland	0.30		0.35	0.35	0.35
Portugal	0.89		0.50	0.50	0.50
Romania	0.30		0.35	0.35	0.35
Slovakia	0.60		0.50	0.50	0.50
Slovenia	0.70		0.55	0.55	0.55
Spain	1.00		0.60	0.60	0.60
Sweden	0.30		0.38	0.38	0.38
Switzerland	0.55		0.50	0.50	0.50
United Kingdom	0.22		0.28	0.28	0.28
Turkey	0.50				0.40

Source: BSR Sustainability GmbH

Assumptions on the drivers of paper production in Europe

Paper is a natural material based on wood, recycled paper and additives. The average annual paper and board production growth was 3.3 % per year between 1980 and 1997 in Western Europe (Competitiveness Study of the European Pulp, Paper and Board Manufacturing Industry 1998, Confederation of European Paper Industries CEPI). This development was not actually expected by many experts in the 1990s as it was a widespread belief that the increasing use of computers and telecommunications would reduce paper demand growth in the near future.

As paper production is quite energy- and resource-intensive, a new European declaration on paper recycling covers a total of 29 European countries aiming to ensure that the recycling rate hits 66 % by 2010.

The paper production of the EU27 + Norway and Switzerland is calculated based on the following categories: production and net import of pulpwood (in metric tonnes), net import of pulp (in metric tonnes), insertion quotas of recycled paper (in %) and insertion quotas of additives (in metric tonnes). The following equation was used for paper production (see Equ. 5.2.1-1):

Production of paper =

(net import of wood pulp/pulp in tonnes
+ net import of pulpwood in tonnes
+ production of pulpwood in tonnes)
/ (1 – (additives in % of paper production
+ quotas of insertion of recycled paper in %)

Equation 5.2.1-2

The economic data of the E3ME- and ASTRA-model form the basis used to define the main development trend concerning the wood and paper sector. The development of different wood-classes therefore follows the progression of the E3ME-sector "wood and paper" from 2005 until 2030 as well as the ASTRA-sector "paper" from 2030 to 2050. It should be noted that the ASTRA-sector "paper" combines the two E3ME-sectors "wood and paper" and "printing and publishing".

In the rich Western European countries, the elasticity factor - the relation between physical growth and economic growth - was selected as 40 % of the annual economic increase *from 2005 to 2030*. In some Eastern European countries (Estonia, Latvia, Lithuania, Slovakia, Slovenia, Bulgaria, Romania), the elasticity factor was estimated as 50 % between 2005 and 2030, because their industry sector "wood and paper" was assumed to grow faster. The remaining annual economic increase is not due to increasing physical paper production, but due to improved paper quality, wood products, and printing as well as publishing activities which all add to the growth in value added of the sector.

In the period *2030-2050,* the richer countries (Austria, Belgium/Luxembourg, Denmark, France, Finland, Germany, Greece, Ireland, Italy, the Netherlands, Spain, Portugal, Sweden, United Kingdom, Cyprus, Hungary, Poland, Norway, Switzerland) are calculated with lower elasticities of annual economic growth as are the Central European countries (Czech, the Baltic States, Malta, Slovakia, Slovenia, Bulgaria, Romania). It is estimated that the growth of paper production will slow down in the last decade even more in some countries. In

Belgium/Luxembourg, Finland, France, Greece, Portugal, Norway and Switzerland, the elasticity is fixed at 10 % of the annual economic increase from 2040 on. The elasticity is reduced to 20 % of the annual economic growth in the Czech Republic, Estonia, Slovakia, Slovenia, Bulgaria and Romania. In contrast, some countries (Austria, Denmark, Germany, Ireland, Italy, Spain, Sweden, United Kingdom, Cyprus, Hungary, and Poland) show a constant level of paper industry growth.

Bulgaria, Latvia, Lithuania, Cyprus and Malta are exceptions, which do not follow the developed paper production formula:

- Malta has no paper production.
- Cyprus (which started producing paper in 2003), Latvia and Lithuania do not seem to produce wood pulp or pulp according to the statistics. Therefore, these countries only produce paper on the basis of recycled paper and imported wood pulp or imported pulp.
- The paper production of Cyprus is at a constant level of 5,000 tonnes per year from 2005 to 2030. Afterwards, paper production increases by about 100 tonnes per year for the next twenty years.
- Latvia: Paper production grows at a rate of 0.5 % per year from 2005 to 2030. For 2030-2050, the growth factor is 1 % per year.
- Lithuania: Paper production remains constant until 2030. Thereafter it grows at 0.4 % per year.
- Bulgaria: Paper production shows a constant increase of 2 % per year from 2005 to 2030. Between 2030 and 2050, the growth factor is only 1 % per year.

For the European countries, assumptions had to be made about the development of recycled paper, pulp and additives. These estimates were based on past developments of the composition of new paper (recycled paper, pulp, additives, mechanical pulp; see Table 5-10 based on the example of Germany) as well as on national sources projecting future shares of recycled paper.

Table 5-10: Consumption of the paper industry in Germany in percent (VDP, 2004)

Year	Recycled paper	pulp	additives	mechanical pulp
1985	39.0	30.0	18.0	13.0
2004	56.6	19.6	17.1	6.6

Source: BSR Sustainability GmbH

The insertion quota of additives is assumed to be 18.0 % in 2005. This quota decreases to 17.0 % in 2030 and 16.5 % in 2050. In countries which already have a high insertion quota of recycled paper of about 80 % (Denmark, Ireland, Spain, United Kingdom, Cyprus and Lithuania), the insertion quota of additives is estimated to be 15 % in 2005. This quota decreases to 14.4 % in 2030 and 14.0 % in 2050. The insertion quotas of recycled paper are taken from the German Association of the Paper Industry VDP or national sources. In countries with a high insertion quota of recycled paper (Denmark, Ireland, United Kingdom, Cyprus, Hungary, Latvia, Lithuania, Bulgaria and Switzerland), the maximum insertion quota was estimated to be constant at about 80 %.

Assumptions on the drivers of glass production in Europe

The glass industry is very heterogeneous, with a wide variety of products and applications (food industry, construction industry, beverage industry, automotive industry, etc.). But the glass industry in Europe only consists of a very limited number of companies. Where glass production is restricted to just two or three national manufacturers, production data are confidential. Therefore there are few publicly available statistics of glass production in Europe. Only global production figures by glass types are available at EU level.

Europe is the most mature glass market and has the highest proportion of value-added products (Pilkington). About 30 million tonnes of glass are produced here each year. Container glass represents the largest share (~ 61 %) followed by flat glass (~ 26 %) and other glass (~ 13 %). Germany is the biggest manufacturer of glass (~ 24 %) followed by France (~ 18 %) and Italy (17 %). In 2005, the glass industry was run at around 90 percent capacity utilisation, globally (Pilkington).

The European glass industry shows a stable development of production with a marginal increase (~1 % per year) over the last few years. In contrast, the glass demand of the different countries has grown more quickly than their GDP over the last 20 years (Pilkington). Furthermore, the demand for value-added products is growing at a faster rate than the demand for basic glass.

The basic data defining the development of production in the glass sector are economic production data from the E3ME- and ASTRA-models, i.e., the development of the different glass categories (flat glass, container glass, other glass) follow the progression of the E3ME-sector "non-metallic mineral products" from 2005 until 2030 and of the ASTRA-sector "non-metallic mineral products" from 2030 to 2050.

In western European countries (Austria, Belgium/Luxembourg, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Sweden, United Kingdom, Norway and Switzerland), the elasticity between physical and economic growth is 40 % of the annual economic increase from 2005 to 2030. In the poorer western and Central European countries (Greece, Portugal, Spain, the Czech Republic, the Baltic States, Hungary, Poland, Slovakia, Slovenia, Bulgaria, Romania), the elasticity was estimated to be 50 % of the annual economic increase from 2005 until 2030 because the share of high value-added products in production is assumed to be less and because there is a substantial demand for glass due to the increasing consumption of private households, investments in buildings and retrofitting windows. Since 1992 the average glass production growth in Turkey has been 5 % per year. Therefore the glass industry in Turkey is estimated to increase by 3 % from 2005 till 2030. Subsequently, in the years 2030 – 2050, glass production growth is assumed to decline to 2 % per year. There is no glass production in Malta or Cyprus.

From 2030 to 2050, an elasticity of 20 % of the annual economic increase is assumed for the Western countries (Austria, Belgium/Luxembourg, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Sweden, United Kingdom, Norway and Switzerland) and 25 % for the Central European countries (Greece, Portugal, Spain, Czech Republic, the Baltic States, Hungary, Slovakia, Slovenia, Bulgaria, Romania).

If glass production data were not available for intermittent years or countries, the total glass amount was normally calculated as 26 % flat glass, 61 % container glass and 13 % other glass. Some countries show a different subdivision of total glass production. This production structure was adopted from an older study of the glass market in Europe (see Table 5-11).

Detailed historical data of physical glass production (2000 - 2005), which were collected from different sources, are available for Austria (some data were calculated for the years 2001 - 2003), Belgium, France, Germany, Italy and the Czech Republic. Only the total glass production of the year 2000 was found for the following countries: Denmark, Finland (flat glass: 8 %, container glass: 46 %, other glass: 46 %), Ireland, Luxembourg, Sweden (flat glass: 55 %, container glass: 29 %, other glass: 16 %), the Baltic States, Hungary, Slovakia, Slovenia and Norway (flat glass: 9 %, container glass: 81 %, other glass: 10 %).

In Bulgaria (flat glass: 5 %, container glass: 94 %, other glass: 1 %), most glass factories have been closed for a number of years (British Glass: Overview of Glass Container – Production in the EU: 2006). Until 2005, the entire demand of Bulgaria was satisfied by imports from Turkey, France, the Czech Republic, Germany and China. At present, Sisecam is in the process of building several factories for various types of glass (British Glass: Overview of Glass Container – Production in the EU: 2006).

Table 5-11: Historical basis data for future glass production estimates

Country or country group	Basis year of production	Subdivision of glass (%)		
		flat	container	other
Bulgaria	container glass 2005 & flat glass 2006	26	61	13
Greece	container glass 2005	26	61	13
Netherlands	container glass 2005 & total glass 2003	12	74	14
Portugal	container glass 2003-2006	11	76	13
Spain	container glass 2002-2006	26	67	7
United Kingdom	container glass 2003-2006 & other glass 2005	26	61	13
Poland	container glass 2005-2006	26	61	13
Romania	container glass 2005	34	52	14
Switzerland	total glass 2005	26	61	13
Turkey	container glass 2003-2006, total glass 2000-2003 & other glass 2003	45	28	27

Source: BSR Sustainability GmbH

5.2.1.2 Assumptions on material efficiency in the 2°C Scenario – 2000 to 2050

Compared to the Reference Scenario, improved material efficiency and substitution of energy-intensive materials is assumed for all industry sectors. From 2000 to 2009, the Reference Scenario and the 2°C Scenario have identical production results in the basic product industry sectors. From 2010 to 2050, production changes take place in energy-intensive products due to the assumed high energy prices (including energy taxes and emission certificates, see Chapter 4) and climate change policies that include material efficiency and substitution policies at national and at EU level, as well as in most other parts of the world. Similar technological improvements are estimated for all the European countries so that production changes are calculated using the same factors for all these countries.

Assumptions on the drivers of steel production in Europe

Crude steel production, which includes electrical as well as oxygen steel, decreases in this scenario until 2050 in comparison to the Reference Scenario (4°C Scenario) due to improved material efficiency and increased material substitution. Due to specific technical applications, the production of oxygen steel will not decline as much as electrical steel in the next 40 years (see Table 5-12).

Table 5-12: Production changes (in %) of electrical and oxygen steel in EU27 + Norway, Switzerland and Turkey compared to the Reference Scenario, 2000 – 2050

Energy-intensive product	2000-2010	2010-2020	2020-2030	2030-2040	2040-2050
	Production changes in % per year compared to Reference Scenario				
Electrical steel	0.0	- 0.5		- 0.6	
Oxygen steel	0.0	- 0.3	- 0.4	- 0.5	

Source: BSR Sustainability GmbH

Assumptions on the drivers of aluminium production in Europe

In line with the assumptions on the drivers of steel production, primary and secondary aluminium production is also assumed to fall continuously in the future (see Table 5-13).

Table 5-13: Production changes (in %) of aluminium in EU27 + Norway, Switzerland and Turkey compared to the Reference Scenario, 2000 – 2050

Energy-intensive product	2000-2010	2010-2020	2020-2030	2030-2040	2040-2050
	Production changes in % per year compared to Reference Scenario				
Primary aluminium	0.0	- 0.2		- 0.3	
Secondary aluminium	0.0	- 0.2		- 0.3	

Source: BSR Sustainability GmbH

Assumptions on the drivers of cement production in Europe

Similar to steel and aluminium production, cement production is assumed to decrease continuously in the future due to technological innovations and a global economic slowdown (see Table 5-14).

Table 5-14: Production changes (in %) of cement in EU27 + Norway, Switzerland and Turkey compared to the Reference Scenario, 2000 – 2050

Energy-intensive product	2000-2010	2010-2020	2020-2030	2030-2040	2040-2050
	Production changes in % per year compared to Reference Scenario				
Cement	0.0	- 0.5			

Source: BSR Sustainability GmbH

Assumptions on the drivers of paper production in Europe

Paper production in the 2°C Scenario is also reduced by between 0.5 % and 0.7 % per year in all European countries compared to the Reference Scenario (see Table 5-15). This development is due to the “paperless office” and technological innovations (like thin and flexible displays for books or newspapers, thinner paper types, etc.). The percentage of recycled paper does not change compared to the Reference Scenario.

Table 5-15: Production changes of paper (in %) in EU27 + Norway, Switzerland and Turkey compared to the Reference Scenario, 2000 – 2050

Energy-intensive product	2000-2010	2010-2020	2020-2030	2030-2040	2040-2050
	Production changes in % per year compared to Reference Scenario				
Paper	0.0	- 0.5	- 0.6	- 0.7	

Source: BSR Sustainability GmbH

Assumptions on the drivers of glass production in Europe

The glass production of other glass is identical to the results of the Reference Scenario. In contrast, container glass production is estimated to decrease by roughly -0.5 % to -1.0 % per year (see Table 5-16). For the same period, there is an increased production of flat glass compared with the Reference Scenario. This increase is due to rapidly growing photovoltaic cell production, window glass (for example triple glazing) and the demand of the automobile industry.

Table 5-16: Production changes of glass (in %) in EU27 + Norway, Switzerland and Turkey compared to the Reference Scenario, 2000 – 2050

Energy-intensive product	2000-2010	2010-2020	2020-2030	2030-2040	2040-2050
	Production changes in % per year compared to Reference Scenario				
Container glass	0.0	- 0.5	- 0.8	- 1.0	
Other glass	0.0				

	2000 -2010	2010 - 2013	2014 - 2020	2020 - 2026	2026 - 2036	2036 - 2048	2048 - 2050
	Production changes in % per year compared to Reference Scenario						
Flat glass	0.0	+ 1.3	+ 1.2	+ 1.1	+ 1.0	+ 0.9	+ 0.8

Source: BSR Sustainability GmbH

5.2.2 Production changes in energy-intensive products

5.2.2.1 Reference Scenario (4°C Scenario) – 2000 to 2050

Results for steel production in European countries – 2000 to 2050

The total crude steel production of EU27 plus Switzerland and Norway increases slightly from 195 Mt to 200 Mt, before slowly decreasing to about 191 Mt in 2030 (see Table 5-17). The decreasing population between 2030 and 2050 (-4.5 %) and increasing net imports of investment goods with steel components together have the effect of reducing crude steel production to 174 Mt in 2050, i.e. a drop of 9 % over two decades.

If Turkey's steel production is included, the peak in steel production is postponed to 2030, and production in 2050 is about 11 Mt higher than in 2000 (i.e. +5.5 %; see Table 5-17).

Relative to the gross production of the basic metal industry, which stagnates until 2030, the estimates of crude steel production do not contradict the economic development of the larger economic sector (basic metals).

Table 5-17: Production of crude steel in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	5,710	6,050	5,540	5,000	4,040
Baltic States	500	480	440	400	340
Belgium/Luxembourg	14,210	13,590	13,510	13,350	12,670
Bulgaria	2,020	2,090	1,990	1,870	1,520
Czech Republic	6,210	5,760	5,300	4,770	3,800
Denmark	800	–	–	–	–
Finland	4,100	4,420	4,150	3,820	3,200
France	20,980	19,690	19,520	19,110	15,780
Germany	46,380	47,140	46,630	46,380	46,380
Greece	1,090	2,350	2,150	1,930	2,570
Hungary	1,870	1,990	1,930	1,840	1,650
Ireland	360	–	–	–	–
Italy	26,760	28,100	26,640	24,920	21,000
Malta/Cyprus	–	–	–	–	–
Netherlands	5,670	6,640	6,800	6,920	6,860
Norway	680	710	740	800	820
Poland	10,500	10,740	10,940	10,880	8,620
Portugal	1,090	910	990	1,050	1,150
Romania	4,670	6,110	5,990	5,790	5,030
Slovakia	3,730	4,810	4,120	3,360	1,880
Slovenia	520	660	670	660	490
Spain	15,920	17,600	17,770	17,600	17,020
Sweden	5,230	5,350	5,370	5,370	5,030
Switzerland	1,000	1,200	1,280	1,350	1,460
United Kingdom	15,160	13,740	13,980	14,250	13,430
EU-27 + 2	**195,140**	**200,110**	**196,430**	**191,400**	**174,720**
Turkey	14,330	27,560	37,000	46,910	45,540
Total Europe	**209,460**	**227,670**	**233,430**	**238,300**	**220,270**

Source: BSR Sustainability GmbH

The development of *electrical steel* is more dynamic due to the basic assumption of increasing steel scrap. The electrical steel produced in EU27 plus Switzerland and Norway increases from around 80 Mt in 2000 to 95 Mt in 2050, i.e. by 19 % (see Table 5-18). This raises the share of electrical steel in total crude steel production from 41.3 % in 2000 to almost 55 % in 2050 (see Table 5-18). The trends are similar even if Turkish steel production is included. However, the trend is then more pronounced. The share of electrical steel in total crude steel production increases from 82 Mt (or by 39.4 %) in 2000 to 115 Mt in 2050 (i.e. by 52.4 %). This equals an average annual growth of almost 0.7 % per year.

Table 5-18: Production of electrical steel in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	560	640	680	720	810
Baltic States	–	–	–	–	–
Belgium/Luxembourg	5,300	4,950	5,190	5,440	5,980
Bulgaria	600	760	810	860	970
Czech Republic	520	580	610	650	730
Denmark	800	–	–	–	–
Finland	970	1,460	1,550	1,650	1,860
France	8,490	7,520	7,990	8,480	9,560
Germany	13,320	14,080	14,950	15,870	17,890
Greece	1,090	2,300	2,370	2,440	2,590
Hungary	230	330	350	370	420
Ireland	360	–	–	–	–
Italy	16,010	18,030	19,140	20,200	19,000
Malta/Cyprus	–	–	–	–	–
Netherlands	160	150	150	160	190
Norway	680	710	740	780	820
Poland	3,290	3,560	3,780	4,010	4,520
Portugal	500	780	870	970	1,130
Romania	1,330	1,780	1,890	2,010	2,260
Slovakia	290	380	400	420	480
Slovenia	520	660	670	660	700
Spain	11,670	13,880	14,430	14,860	15,780
Sweden	1,950	1,820	1,930	2,050	2,310
Switzerland	1,000	1,200	1,280	1,350	1,460
United Kingdom	3,640	2,780	2,950	3,130	3,530
EU-27 + 2	**73,280**	**78,330**	**82,730**	**87,090**	**92,980**
Turkey	9,090	15,450	16,400	17,410	19,620
Total Europe	**82,370**	**93,780**	**99,130**	**104,500**	**112,600**

Source: BSR Sustainability GmbH

Table 5-19: Production of crude steel (oxygen steel + electrical steel) in Europe in 1000 tonnes, Reference Scenario, 2000 – 2050

Country group	Production of	2000	2010	2020	2030	2050
EU-27 + 2	Oxygen steel	121,370	121,110	113,370	104,340	81,620
	Electrical steel	73,280	78,330	82,730	87,090	92,980
	Crude steel (oxygen steel + electrical steel)	**195,140**	**200,110**	**196,430**	**191,400**	**174,720**
Total Europe	Oxygen steel	126,600	133,230	133,960	133,840	107,550
	Electrical steel	82,370	93,780	99,130	104,500	112,600
	Crude steel (oxygen steel + electrical steel)	**209,470**	**227,670**	**233,430**	**238,300**	**220,270**

Source: BSR Sustainability GmbH

Results for aluminium production in European countries – 2000 to 2050

Total production of primary aluminium increases from 4 Mt in 2000 to 6.1 Mt in 2050 (+52 %) due to substantial production increases in Norway and small increases in the UK, some central European countries, and Turkey. Including Turkey does not significantly alter the figures of total European primary aluminium production (to 6.2 Mt in 2050, see Table 5-20).

Table 5-20: Production of primary aluminium in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	–	–	–	–	–
Baltic States	–	–	–	–	–
Belgium/Luxembourg	–	–	–	–	–
Bulgaria	–	–	–	–	–
Czech Republic	–	–	–	–	–
Denmark	–	–	–	–	–
Finland	–	–	–	–	–
France	440	450	460	470	470
Germany	640	620	550	490	360
Greece	160	170	170	170	170
Hungary	30	30	30	40	40
Ireland	–	–	–	–	–
Italy	190	200	200	200	200
Malta/Cyprus	–	–	–	–	–
Netherlands	300	340	350	350	350
Norway	1,030	1,580	1,990	2,400	3,000
Poland	50	60	60	60	60
Portugal	–	–	–	–	–
Romania	180	250	250	260	260
Slovakia	110	160	160	160	160
Slovenia	80	140	140	140	140
Spain	370	400	400	400	400
Sweden	100	110	110	110	110
Switzerland	40	50	50	50	50
United Kingdom	310	370	370	370	370
EU-27 + 2	**4,020**	**4,900**	**5,290**	**5,650**	**6,130**
Turkey	60	60	70	70	90
Total Europe	**4,090**	**4,960**	**5,350**	**5,720**	**6,220**

Source: BSR Sustainability GmbH

The total production of secondary aluminium increases a bit faster than that of primary aluminium, starting at 2.67 Mt in 2000 and reaching more than 4.1 Mt in 2050 (see Table 5-21). Starting from initial low values per capita, the highest growth is in Central European countries due to the expected modernisation of the capital stock here and also some shifting of production sites from Western Europe to Central European countries. The development in Western European countries reflects the declining growth here, particularly between 2030 and 2050 (see Table 5-21).

Looking at both types of aluminium, production increases significantly by more than 50 % from 2.7 Mt to slightly above 10 Mt (see Table 5-22).

Table 5-21: Production of secondary aluminium in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario 2000 – 2050

Country or Country group	2000	2010	2020	2030	2050
Austria	160	160	170	190	210
Baltic States			not specified		
Belgium/Luxembourg	1	–	–	–	–
Bulgaria	10	10	20	30	40
Czech Republic	40	40	50	60	70
Denmark	30	20	30	20	20
Finland	40	40	40	40	40
France	270	230	250	270	270
Germany	570	750	820	900	1.050
Greece	10	10	10	10	10
Hungary	40	30	40	50	60
Ireland	–	–	–	–	–
Italy	600	680	740	800	840
Malta/Cyprus			not specified		
Netherlands	100	50	60	60	60
Norway	260	390	450	500	600
Poland	10	20	30	50	80
Portugal	20	20	30	30	30
Romania	2	10	30	40	60
Slovakia			not specified		
Slovenia			not specified		
Spain	240	260	310	350	400
Sweden	30	30	30	30	30
Switzerland	10	–	–	–	–
United Kingdom	240	210	220	230	230
EU-27 + 2	**2,670**	**2,970**	**3,320**	**3,660**	**4,120**
Turkey	not specified	not specified	50	60	80
Total Europe	**not specified**	**not specified**	**3,370**	**3,720**	**4,200**

Source: BSR Sustainability GmbH

Table 5-22: Total production of aluminium (primary + secondary) in Europe in 1000 tonnes, Reference Scenario, 2000 – 2050

Country group	Production of	2000	2010	2020	2030	2050
EU-27 + 2	Primary aluminium	4,020	4,900	5,290	5,650	6,130
	Secondary aluminium	2,670	2,970	3,320	3,660	4,120
	Total aluminium	**6,690**	**7,870**	**8,610**	**9,310**	**10,250**
Total Europe	Primary aluminium	4,090	4,960	5,350	5,720	6,220
	Secondary aluminium	not specified	not specified	3,370	3,720	4,200
	Total aluminium	not specified	not specified	**8,720**	**9,440**	**10,420**

Source: BSR Sustainability GmbH

Results for cement production in European countries – 2000 to 2050

The total cement production of Europe is almost constant at around 240 Mt per year, but the long-term trend is a declining one: Cement production is reduced to 203 Mt in 2050 (see Table 5-23). This decline reflects the basic influence of population and the assumption that rich, industrialised countries have finished their building stock and infrastructure and only need cement for re-investments. Major contributions to the drop in cement production between 2000 and 2050 are from Italy (-12.8 Mt), Spain (-15.2 Mt), and Greece (-10.2 Mt).

If Turkey is included, European cement production stagnates one decade later, before also declining to 244 Mt in 2050, or by -12 % relative to the year 2000 (see Table 5-23).

Table 5-23: Production of cement in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario, 2000 – 2050

Country or Country group	2000	2010	2020	2030	2050
Austria	3,890	3,960	3,990	4,000	3,880
Baltic States	1,810	1,900	1,990	2,030	1,880
Belgium/Luxembourg	8,590	8,060	7,410	6,720	6,610
Bulgaria	2,400	2,440	2,430	2,370	1,930
Czech Republic	3,590	4,060	4,470	3,810	2,960
Denmark	2,030	2,090	2,140	2,190	2,220
Finland	1,290	1,500	1,710	1,910	1,860
France	20,140	21,720	23,060	24,190	23,960
Germany	32,940	33,080	32,910	32,610	31,510
Greece	15,580	12,470	9,050	5,560	5,370
Hungary	3,680	4,030	4,330	3,690	2,890
Ireland	3,650	3,420	2,870	2,100	2,300
Italy	43,290	40,720	37,140	33,250	30,550
Malta/Cyprus	2,470	2,450	2,380	2,230	2,400
Netherlands	3,180	3,320	3,400	3,460	3,430
Norway	1,800	1,890	1,980	2,080	2,170
Poland	11,610	12,160	12,580	12,700	11,180
Portugal	9,100	8,140	6,870	5,470	5,360
Romania	6,640	6,750	6,810	6,760	5,870
Slovakia	3,240	3,060	2,860	2,600	2,310
Slovenia	1,380	1,270	1,150	1,010	900
Spain	40,730	38,140	32,590	26,420	25,540
Sweden	2,670	3,000	3,360	3,720	3,820
Switzerland	3,940	3,890	3,800	3,700	3,620
United Kingdom	12,910	14,520	16,250	18,110	18,800
EU-27 + 2	**242,540**	**238,060**	**227,510**	**212,660**	**203,320**
Turkey	34,120	37,480	39,920	41,310	40,480
Total Europe	**276,650**	**275,540**	**267,430**	**253,960**	**243,810**

Source: BSR Sustainability GmbH

Results for paper production in European countries – 2000 to 2050

The data of this sector are subject to further revision after 2030 as the economic data of ASTRA have been re-calculated which was not able to be reflected in the figures of Table 5-24. Total paper production in Europe increases from 93.3 Mt in 2000 to 134 Mt in 2030 (or by almost 44 % or 1.2 % per year, see Table 5-24). In the last two decades, paper production totals 158 Mt, i.e. slows down to an annual increase of 0.8 %, which still represents a substantial per capita growth of almost 1.2 % per year due to the shrinking population.

Table 5-24: Production of paper in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	4,390	5,370	6,030	6,700	8,380
Baltic States	120	220	220	230	370
Belgium/Luxembourg	1,730	1,900	2,250	2,620	3,170
Bulgaria	140	360	440	540	650
Czech Republic	540	800	850	860	1,190
Denmark	260	410	500	540	630
Finland	13,510	13,010	14,840	15,730	17,850
France	10,010	10,430	11,560	11,800	13,970
Germany	18,180	23,370	23,170	25,360	28,260
Greece	500	550	590	670	810
Hungary	510	600	620	700	1,040
Ireland	40	50	50	50	60
Italy	9,130	11,390	14,180	17,560	20,740
Malta/Cyprus	–	10	10	10	10
Netherlands	3,330	3,630	3,870	4,140	4,450
Norway	2,300	2,180	2,340	2,520	2,820
Poland	1,930	2,830	3,040	3,020	4,300
Portugal	1,290	1,830	2,570	3,370	4,380
Romania	340	400	640	880	1,220
Slovakia	930	890	910	860	1,720
Slovenia	410	650	650	640	800
Spain	4,770	5,870	8,090	8,630	10,910
Sweden	10,790	13,210	16,550	18,110	19,930
Switzerland	1,620	1,730	1,840	1,820	2,470
United Kingdom	6,610	6,670	6,600	6,770	8,310
EU-27 + 2	**93,350**	**108,340**	**122,390**	**134,110**	**158,430**

Source: BSR Sustainability GmbH

Results for glass production in European countries – 2000 to 2050

The total glass production of Europe increases from 35 Mt in 2000 to 43.2 Mt in 2030 (or by almost 23.4 % or 0.7 % per year, see Table 5-25). In the final two decades, glass production reaches more than 47 Mt and production slows to an annual increase of 0.4 %, which still represents a significant per capita growth of 0.65 % per year due to the shrinking population. If the Turkish glass industry is included, the increase in glass production is more pronounced, starting from 36.6 Mt and growing with an annual rate of almost 0.9 % per year to 47.3 Mt in 2003 and to 53 Mt in 2050 (i.e. by 0.57 % per year).

Table 5-25: Production of total glass in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario, 2000 – 2050

Country or country group	Glass category	2000	2010	2020	2030	2050
Austria	Total Glass	480	500	530	560	620
Baltic States	Total Glass	70	80	80	80	90
Belgium/Luxembourg	Total Glass	1,760	1,890	2,050	2,170	2,310
Bulgaria	Total Glass	240	770	900	1,090	1,280
Czech Republic	Total Glass	1,200	1,750	1,850	1,900	2,250
Denmark	Total Glass	190	190	210	220	240
Finland	Total Glass	140	150	160	160	170
France	Total Glass	5,530	5,780	6,130	6,390	6,760
Germany	Total Glass	7,680	7,000	7,350	7,700	8,070
Greece	Total Glass	290	330	340	370	400
Hungary	Total Glass	960	1,060	1,060	1,080	1,260
Ireland	Total Glass	190	240	270	290	320
Italy	Total Glass	4,910	5,550	6,010	6,350	6,860
Malta/Cyprus	Total Glass	–	–	–	–	–
Netherlands	Total Glass	1,360	980	1,060	1,140	1,270
Norway	Total Glass	90	80	80	80	80
Poland	Total Glass	1,580	1,910	1,940	1,930	2,160
Portugal	Total Glass	1,140	1,480	1,720	1,940	2,040
Romania	Total Glass	280	340	360	390	410
Slovakia	Total Glass	170	190	200	200	220
Slovenia	Total Glass	120	140	130	130	150
Spain	Total Glass	2,940	3,380	3,850	4,290	4,860
Sweden	Total Glass	350	380	430	440	470
Switzerland	Total Glass	410	320	320	320	390
United Kingdom	Total Glass	2,960	3,560	3,750	4,030	4,400
EU-27 + 2	**Total Glass**	**35,020**	**38,060**	**40,790**	**43,230**	**47,080**
Turkey	Total Glass	1,600	2,240	3,010	4,050	6,010
Total Europe	**Total Glass**	**36,620**	**40,300**	**43,800**	**47,280**	**53,100**

Source: BSR Sustainability GmbH

5.2.2.2 2°C Scenario - 2000 to 2050

Results for steel production in European countries – 2000 to 2050

The total crude steel production of EU27 plus Switzerland and Norway increases slightly in the 2°C Scenario from 195 Mt to about 199 Mt in 2010, before slowly decreasing to about 138 Mt in 2050 (see Table 5-26). Electrical steel production of EU27 plus Switzerland and Norway decreases only slightly in the 2°C Scenario from around 73 Mt in 2000 to 71 Mt in 2050 (see Table 5-27). Therefore, the share of electrical steel (EU27 + 2) in total crude steel production rises from 38 % in 2000 to 51 % in 2050 (see Table 5-28). In the same time, the oxygen steel produced decreases from 121 Mt to 67 Mt (~-49 %). The total amount of crude steel production in EU27+2 in 2010 is only 1.4 Mt lower than in the Reference Scenario. This difference between Reference and 2°C Scenario of produced crude steel increases up to 36 Mt in 2050 (see Table 5-29) or from 0.4 Mt (2010) up to 21 Mt (2050) for electrical steel (see Table 5-30).

Table 5-26: Production of crude steel in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	5,710	6,030	5,340	4,590	3,280
Baltic States	500	0	0	0	0
Belgium/Luxembourg	14,210	13,540	12,930	12,120	10,090
Bulgaria	2,020	2,080	1,900	1,700	1,190
Czech Republic	6,210	5,740	5,110	4,380	3,090
Denmark	800	0	0	0	0
Finland	4,100	4,410	3,970	3,460	2,520
France	20,980	19,620	18,680	17,330	12,440
Germany	46,380	46,970	44,710	42,250	37,170
Greece	1,090	2,290	2,240	2,160	1,980
Hungary	1,870	1,990	1,850	1,690	1,340
Ireland	360	0	0	0	0
Italy	26,760	27,980	25,320	22,230	16,170
Malta/Cyprus	–	0	0	0	0
Netherlands	5,670	6,620	6,570	6,400	5,650
Norway	680	710	700	690	620
Poland	10,500	10,700	10,480	9,900	6,830
Portugal	1,090	770	820	860	860
Romania	4,670	6,090	5,740	5,280	4,010
Slovakia	3,730	4,800	3,970	3,090	1,520
Slovenia	520	650	630	590	540
Spain	15,920	17,520	16,850	15,670	13,080
Sweden	5,230	5,330	5,150	4,880	4,010
Switzerland	1,000	1,190	1,210	1,190	1,120
United Kingdom	15,160	13,690	13,440	13,060	10,860
EU27 + 2	**195,140**	**198,690**	**187,610**	**173,500**	**138,380**
Turkey	14,330	27,450	35,380	42,680	36,380
Total Europe	**209,460**	**226,140**	**222,980**	**216,180**	**174,750**

Source: BSR Sustainability GmbH

Table 5-27: Production of electrical steel in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	560	640	640	640	620
Baltic States	–	0	0	0	0
Belgium/Luxembourg	5,300	4,930	4,900	4,810	4,570
Bulgaria	600	760	760	760	740
Czech Republic	520	570	580	570	560
Denmark	800	0	0	0	0
Finland	970	1,460	1,470	1,460	1,420
France	8,490	7,480	7,540	7,490	7,300
Germany	13,320	14,010	14,110	14,030	13,670
Greece	1,090	2,290	2,240	2,160	1,980
Hungary	230	330	330	330	320
Ireland	360	0	0	0	0
Italy	16,010	17,940	18,070	17,860	14,520
Malta/Cyprus	–	0	0	0	0
Netherlands	160	150	150	150	140
Norway	680	710	700	690	620
Poland	3,290	3,540	3,560	3,540	3,450
Portugal	500	770	820	860	860
Romania	1,330	1,770	1,780	1,770	1,730
Slovakia	290	370	380	380	370
Slovenia	520	650	630	590	540
Spain	11,670	13,810	13,620	13,140	12,060
Sweden	1,950	1,810	1,830	1,820	1,770
Switzerland	1,000	1,190	1,210	1,190	1,110
United Kingdom	3,640	2,770	2,790	2,770	2,700
EU27 + 2	**73,280**	**77,940**	**78,100**	**76,990**	**71,040**
Turkey	9,090	15,370	15,480	15,390	14,990
Total Europe	**82,370**	**93,310**	**93,580**	**92,380**	**86,030**

Source: BSR Sustainability GmbH

Table 5-28: Production of crude steel (oxygen steel + electrical steel) in Europe in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country group	Production of	2000	2010	2020	2030	2050
EU27 + 2	Oxygen steel	121,370	120,750	109,510	96,510	67,340
	Electrical steel	73,280	77,940	78,100	76,990	71,040
	Crude steel (oxygen steel + electrical steel)	195,140	198,690	187,610	173,500	138,380
Total Europe	Oxygen steel	126,600	132,830	129,410	123,800	88,730
	Electrical steel	82,370	93,310	93,580	92,380	86,030
	Crude steel (oxygen steel + electrical steel)	209,460	226,140	222,980	216,180	174,750

Source: BSR Sustainability GmbH

Table 5-29: Differences in crude steel production between the Reference Scenario and the 2°C Scenario in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2000 – 2050

Country or Country group	2000	2010	2020	2030	2050
Austria	0	20	200	410	760
Baltic States	0	480	440	400	340
Belgium/Luxembourg	0	50	580	1,230	2,580
Bulgaria	0	10	90	170	330
Czech Republic	0	20	190	390	710
Denmark	0	-	-	-	-
Finland	0	10	180	360	680
France	0	70	840	1,780	3,340
Germany	0	170	1,920	4,130	9,210
Greece	0	60	-90	-230	590
Hungary	0	0	80	150	310
Ireland	0	-	-	-	-
Italy	0	120	1,320	2,690	4,830
Malta/Cyprus	-	-	-	-	-
Netherlands	0	20	230	520	1,210
Norway	0	0	40	110	200
Poland	0	40	460	980	1,790
Portugal	0	140	170	190	290
Romania	0	20	250	510	1,020
Slovakia	0	10	150	270	360
Slovenia	0	10	40	70	-50
Spain	0	80	920	1,930	3,940
Sweden	0	20	220	490	1,020
Switzerland	0	10	70	160	340
United Kingdom	0	50	540	1,190	2,570
EU27 + 2	**0**	**1,420**	**8,820**	**17,900**	**36,340**
Turkey	0	110	1,620	4,230	9,160
Total Europe	**0**	**1,530**	**10,450**	**22,120**	**45,520**

Source: BSR Sustainability GmbH

Table 5-30: Differences in electrical steel production between the Reference Scenario and the 2°C Scenario in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2000 – 2050

Country or Country group	2000	2010	2020	2030	2050
Austria	0	0	40	80	190
Baltic States	-	-	-	-	-
Belgium/Luxembourg	0	20	290	630	1,410
Bulgaria	0	0	50	100	230
Czech Republic	0	10	30	80	170
Denmark	0	-	-	-	-
Finland	0	0	80	190	440
France	0	40	450	990	2,260
Germany	0	70	840	1,840	4,220
Greece	0	10	130	280	610
Hungary	0	0	20	40	100
Ireland	0	-	-	-	-
Italy	0	90	1,070	2,340	4,480
Malta/Cyprus	-	-	-	-	-
Netherlands	0	0	0	10	50
Norway	0	0	40	90	200
Poland	0	20	220	470	1,070
Portugal	0	10	50	110	270
Romania	0	10	110	240	530
Slovakia	0	10	20	40	110
Slovenia	0	10	40	70	160
Spain	0	70	810	1,720	3,720
Sweden	0	10	100	230	540
Switzerland	0	10	70	160	350
United Kingdom	0	10	160	360	830
EU27 + 2	**0**	**390**	**4,630**	**10,100**	**21,940**
Turkey	0	80	920	2,020	4,630
Total Europe	**0**	**470**	**5,550**	**12,120**	**26,570**

Source: BSR Sustainability GmbH

Results for aluminium production in European countries – 2000 to 2050

The total production of primary aluminium increases from 4 Mt in 2000 to 5.4 Mt in 2050 (see Table 5-31). In contrast to the Reference Scenario, this means a decline of about 11.4 % for EU27+2 in the year 2050. The separate decline of primary aluminium production for all European countries is shown in Table 5-34. In comparison, the total production of secondary aluminium increases, starting at 2.7 Mt in 2000 and reaching 3.7 Mt in 2050 (see Table 5-32). In the same period, the total amount of aluminium produced in EU27+2 increases from 6.69 Mt in 2000 up to 9.13 Mt in 2050 (see Table 5-33).

A detailed view of the differences in aluminium production between the Reference Scenario and the 2°C Scenario is given in Table 5-34 and Table 5-35.

Table 5-31: Production of primary aluminium in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	–	0	0	0	0
Baltic States	–	0	0	0	0
Belgium/Luxembourg	–	0	0	0	0
Bulgaria	–	0	0	0	0
Czech Republic	–	0	0	0	0
Denmark	–	0	0	0	0
Finland	–	0	0	0	0
France	440	450	450	450	420
Germany	640	610	540	460	320
Greece	160	170	170	160	150
Hungary	30	30	30	30	30
Ireland	–	0	0	0	0
Italy	190	200	200	190	180
Malta/Cyprus	–	0	0	0	0
Netherlands	300	340	340	330	310
Norway	1,030	1,580	1,950	2,270	2,660
Poland	50	60	60	60	50
Portugal	–	0	0	0	0
Romania	180	250	250	250	230
Slovakia	110	160	160	150	140
Slovenia	80	140	140	130	120
Spain	370	400	390	380	360
Sweden	100	110	110	100	100
Switzerland	40	50	40	40	40
United Kingdom	310	370	360	350	330
EU27 + 2	**4,020**	**4,890**	**5,170**	**5,350**	**5,430**
Turkey	60	60	60	70	80
Total Europe	**4,090**	**4,950**	**5,230**	**5,420**	**5,510**

Source: BSR Sustainability GmbH

Table 5-32: Production of secondary aluminium in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	160	160	170	180	190
Baltic States			not specified		
Belgium/Luxembourg	1	0	0	0	0
Bulgaria	10	10	20	30	40
Czech Republic	40	40	50	60	60
Denmark	30	20	20	20	20
Finland	40	40	40	40	40
France	270	230	250	260	240
Germany	570	750	810	860	940
Greece	10	10	10	10	10
Hungary	40	30	40	50	50
Ireland	–	0	0	0	0
Italy	600	680	730	770	760
Malta/Cyprus			not specified		
Netherlands	100	50	60	60	50
Norway	260	390	440	480	540
Poland	10	20	30	50	70
Portugal	20	20	30	30	30
Romania	2	10	20	40	50
Slovakia			not specified		
Slovenia			not specified		
Spain	240	260	300	340	360
Sweden	30	30	30	30	30
Switzerland	10	0	0	0	0
United Kingdom	240	210	220	200	210
EU27 + 2	**2,670**	**2,960**	**3,250**	**3,510**	**3,700**
Turkey	not specified	not specified	50	60	70
Total Europe	**not specified**	**not specified**	**3,290**	**3,570**	**3,770**

Source: BSR Sustainability GmbH

Table 5-33: Production of aluminium (primary aluminium + secondary aluminium) in Europe in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country group	Production of	2000	2010	2020	2030	2050
EU27 + 2	Primary aluminium	4,020	4,890	5,170	5,350	5,430
	Secondary aluminium	2,670	2,960	3,250	3,510	3,700
	Total aluminium	**6,690**	**7,850**	**8,420**	**8,860**	**9,130**
Total Europe	Primary aluminium	4,090	4,950	5,230	5,420	5,510
	Secondary aluminium	not specified	not specified	3,290	3,570	3,770
	Total aluminium	not specified	not specified	**8,520**	**8,990**	**9,280**

Source: BSR Sustainability GmbH

Table 5-34: Decrease of primary aluminium production between the Reference Scenario and the 2°C Scenario in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	-	-	-	-	-
Baltic States	-	-	-	-	-
Belgium/Luxembourg	-	-	-	-	-
Bulgaria	-	-	-	-	-
Czech Republic	-	-	-	-	-
Denmark	-	-	-	-	-
Finland	-	-	-	-	-
France	0	0	10	20	50
Germany	0	10	10	30	40
Greece	0	0	0	10	20
Hungary	0	0	0	10	10
Ireland	-	-	-	-	-
Italy	0	0	0	10	20
Malta/Cyprus	-	-	-	-	-
Netherlands	0	0	10	20	40
Norway	0	0	40	130	340
Poland	0	0	0	0	10
Portugal	-	-	-	-	-
Romania	0	0	0	10	30
Slovakia	0	0	0	10	20
Slovenia	0	0	0	10	20
Spain	0	0	10	20	40
Sweden	0	0	0	10	10
Switzerland	0	0	10	10	10
United Kingdom	0	0	10	20	40
EU27 + 2	0	10	120	300	700
Turkey	0	0	10	0	10
Total Europe	0	10	120	300	710

Source: BSR Sustainability GmbH

Table 5-35: Decrease of secondary aluminium production between the Reference Scenario and the 2°C Scenario in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	0	0	0	10	20
Baltic States	-	0	0	0	0
Belgium/Luxembourg	0	-	-	-	-
Bulgaria	0	0	0	0	0
Czech Republic	0	0	0	0	10
Denmark	0	0	10	0	0
Finland	0	0	0	0	0
France	0	0	0	10	30
Germany	0	0	10	40	110
Greece	0	0	0	0	0
Hungary	0	0	0	0	10
Ireland	-	-	-	-	-
Italy	0	0	10	30	80
Malta/Cyprus	-	0	0	0	0
Netherlands	0	0	0	0	10
Norway	0	0	10	20	60
Poland	0	0	0	0	10
Portugal	0	0	0	0	0
Romania	0	0	10	0	10
Slovakia	-	0	0	0	0
Slovenia	-	0	0	0	0
Spain	0	0	10	10	40
Sweden	0	0	0	0	0
Switzerland	0	-	-	-	-
United Kingdom	0	0	0	30	20
EU27 + 2	0	10	70	150	420
Turkey	-	-	0	0	10
Total Europe	**-**	**-**	80	150	430

Source: BSR Sustainability GmbH

Results for cement production in European countries – 2000 to 2050

In the 2°C Scenario, substantial decreases in European cement production is assumed to several factors: the stagnation or sometimes even decreasing per capita cement consumption leading already in the Reference Scenario to a decrease of almost 40 Mt in 2050 is further decreasing by almost 42 Mt in the EU27+2 due to better design of buildings and built infrastructures, to substitution by other construction materials sch as metals, bricks, and wood, ot to higher cement quality (see Table 5-37). In total, EU27+2 countries produce 190 Mt in 2035 and only 162 Mt in 2050. Even in Turkey and some other EU-member countries, cement production starts declining after 2020 (see Table 5-36).

Table 5-36: Production of cement in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	3,890	3,940	3,770	3,580	3,080
Baltic States	1,810	1,890	1,880	1,810	1,490
Belgium/Luxembourg	8,590	8,010	7,010	6,010	5,260
Bulgaria	2,400	2,420	2,290	2,130	1,530
Czech Republic	3,590	4,040	4,220	3,410	2,350
Denmark	2,030	2,080	2,020	1,960	1,770
Finland	1,290	1,490	1,620	1,710	1,480
France	20,140	21,610	21,790	21,650	19,050
Germany	32,940	32,920	31,100	29,180	25,050
Greece	15,580	12,410	8,550	4,970	4,270
Hungary	3,680	4,010	4,090	3,300	2,300
Ireland	3,650	3,400	2,710	1,880	1,830
Italy	43,290	40,520	35,090	29,760	24,290
Malta/Cyprus	2,470	2,440	2,250	1,990	1,910
Netherlands	3,180	3,300	3,210	3,100	2,730
Norway	1,800	1,880	1,880	1,860	1,730
Poland	11,610	12,100	11,890	11,370	8,890
Portugal	9,100	8,100	6,490	4,890	4,260
Romania	6,640	6,710	6,430	6,050	4,660
Slovakia	3,240	3,050	2,700	2,320	1,840
Slovenia	1,380	1,270	1,090	910	710
Spain	40,730	37,950	30,800	23,650	20,300
Sweden	2,670	2,980	3,170	3,330	3,040
Switzerland	3,940	3,870	3,600	3,310	2,880
United Kingdom	12,910	14,450	15,350	16,210	14,950
EU27 + 2	**242,540**	**236,870**	**215,000**	**190,330**	**161,640**
Turkey	34,120	37,290	37,720	36,970	32,180
Total Europe	**276,650**	**274,160**	**252,720**	**227,300**	**193,830**

Source: BSR Sustainability GmbH

Table 5-37: **Differences in cement production between the Reference Scenario and the 2°C Scenario in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2000 – 2050**

Country or country group	2000	2010	2020	2030	2050
Austria	0	20	220	420	800
Baltic States	0	10	110	220	390
Belgium/Luxembourg	0	50	400	710	1,350
Bulgaria	0	20	140	240	400
Czech Republic	0	20	250	400	610
Denmark	0	10	120	230	450
Finland	0	10	90	200	380
France	0	110	1,270	2,540	4,910
Germany	0	160	1,810	3,430	6,460
Greece	0	60	500	590	1,100
Hungary	0	20	240	390	590
Ireland	0	20	160	220	470
Italy	0	200	2,050	3,490	6,260
Malta/Cyprus	0	10	130	240	490
Netherlands	0	20	190	360	700
Norway	0	10	100	220	440
Poland	0	60	690	1,330	2,290
Portugal	0	40	380	580	1,100
Romania	0	40	380	710	1,210
Slovakia	0	10	160	280	470
Slovenia	0	0	60	100	190
Spain	0	190	1,790	2,770	5,240
Sweden	0	20	190	390	780
Switzerland	0	20	200	390	740
United Kingdom	0	70	900	1,900	3,850
EU27 + 2	**0**	**1,190**	**12,510**	**22,330**	**41,680**
Turkey	0	190	2,200	4,340	8,300
Total Europe	0	1,380	14,710	26,660	49,980

Source: BSR Sustainability GmbH

Results for paper production in European countries – 2000 to 2050

While in the Reference Scenario, paper production increased steadily over the whole period, European paper policies are inducing a lower growth in paper demand savong 10 Mt in 2020 and up to 90 Mt in 2050 (see Table 5-39). This reduction is assumed to be achieved by lighter papers, new papers in particular, by paper substitution (including modern communication systems), and a more efficient paper use in packaging and copying on office uses (both sides).

In total, this leads to a stagnation of paper production at around 118 Mt in Europe after 2035, which substantially would reduce the energy demand for this energy-intensive prodct (see Table 5-38). .

Table 5-38: Production of paper in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	4,390	5,350	5,690	5,920	6,220
Baltic States	120	220	210	210	280
Belgium/Luxembourg	1,730	1,890	2,120	2,320	2,360
Bulgaria	140	360	410	470	490
Czech Republic	540	790	800	760	890
Denmark	260	410	470	470	470
Finland	13,510	12,940	14,010	13,890	13,260
France	10,010	10,380	10,920	10,420	10,380
Germany	18,180	23,250	21,870	22,400	21,000
Greece	500	550	560	590	600
Hungary	510	590	580	620	780
Ireland	40	50	50	50	40
Italy	9,130	11,330	13,380	15,510	15,410
Malta/Cyprus	–	10	10	4	10
Netherlands	3,330	3,610	3,660	3,660	3,300
Norway	2,300	2,170	2,210	2,220	2,090
Poland	1,930	2,810	2,870	2,670	3,200
Portugal	1,290	1,820	2,430	2,970	3,260
Romania	340	390	600	780	910
Slovakia	930	890	860	760	1,280
Slovenia	410	650	610	570	590
Spain	4,770	5,840	7,630	7,620	8,100
Sweden	10,790	13,150	15,630	15,990	14,810
Switzerland	1,620	1,720	1,730	1,610	1,840
United Kingdom	6,610	6,630	6,230	5,980	6,170
EU27 + 2	**93,350**	**107,790**	**115,540**	**118,420**	**117,720**

Source: BSR Sustainability GmbH

Table 5-39: Differences in paper production between the Reference Scenario and the 2°C Scenario in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	0	20	340	780	2,160
Baltic States	0	0	10	20	90
Belgium/Luxembourg	0	10	130	300	810
Bulgaria	0	0	30	70	160
Czech Republic	0	10	50	100	300
Denmark	0	0	30	70	160
Finland	0	70	830	1,840	4,590
France	0	50	640	1,380	3,590
Germany	0	120	1,300	2,960	7,260
Greece	0	0	30	80	210
Hungary	0	10	40	80	260
Ireland	0	0	0	0	20
Italy	0	60	800	2,050	5,330
Malta/Cyprus	-	0	0	6	0
Netherlands	0	20	210	480	1,150
Norway	0	10	130	300	730
Poland	0	20	170	350	1,100
Portugal	0	10	140	400	1,120
Romania	0	10	40	100	310
Slovakia	0	0	50	100	440
Slovenia	0	0	40	70	210
Spain	0	30	460	1,010	2,810
Sweden	0	60	920	2,120	5,120
Switzerland	0	10	110	210	630
United Kingdom	0	40	370	790	2,140
EU27 + 2	**0**	**550**	**6,850**	**15,690**	**40,710**
Turkey	0	20	340	780	2,160
Total Europe	**0**	**0**	**10**	**20**	**90**

Source: BSR Sustainability GmbH

Results for total glass production in European countries – 2000 to 2050

The demand and related doestic production of glass is quite complex, because two complentary developments had to be taken into account: on the one hand additional efficiencies of glass use and glass substitution (e.g. by plastics) had to be taken into account. On the other hand, increasing production of double and triple glazing of low energy and passive buildings had to be considered in the 2°C scenario leading to quite substantial differences among countries between the Reference and the 2°C Scenario. This is why total glass production in Europe stagnates at around 2030 after an increase of 15% relative to 2005 (Table 5-40). However, there are important structural changes among European countries (Table 5-41): the new member countries and some westenr Euorpean countries with low building standards in the past have small reductions in glass production, while southern European countries experience reductions in total glass production between 20 and 25%.

Table 5-40: Production of total glass in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	Glass category	2000	2010	2020	2030	2050
Austria	Total Glass	480	500	520	510	480
Baltic States	Total Glass	70	80	80	80	80
Belgium/Luxembourg	Total Glass	1,760	1,890	2,070	2,220	2,460
Bulgaria	Total Glass	240	760	850	950	960
Czech Republic	Total Glass	1,200	1,750	1,880	1,970	2,220
Denmark	Total Glass	190	190	200	210	200
Finland	Total Glass	140	150	150	150	150
France	Total Glass	5,530	5,760	5,960	5,950	5,580
Germany	Total Glass	7,680	6,980	7,230	7,330	7,060
Greece	Total Glass	290	330	340	350	340
Hungary	Total Glass	960	1,060	1,100	1,120	1,210
Ireland	Total Glass	190	240	260	270	260
Italy	Total Glass	4,910	5,530	5,810	5,850	5,530
Malta/Cyprus	Total Glass	–	0	0	0	0
Netherlands	Total Glass	1,360	840	880	890	840
Norway	Total Glass	90	80	80	70	60
Poland	Total Glass	1,580	2,030	2,080	2,050	2,100
Portugal	Total Glass	1,140	1,490	1,650	1,730	1,530
Romania	Total Glass	280	390	420	430	430
Slovakia	Total Glass	170	190	200	200	200
Slovenia	Total Glass	120	130	130	130	130
Spain	Total Glass	2,940	3,340	3,660	3,840	3,780
Sweden	Total Glass	350	380	420	440	480
Switzerland	Total Glass	410	320	330	330	350
United Kingdom	Total Glass	2,960	3,560	3,700	3,800	3,750
EU27 + 2	**Total Glass**	**35,020**	**37,980**	**40,000**	**40,880**	**40,190**
Turkey	Total Glass	1,600	2,220	2,720	3,310	4,220
Total Europe	**Total Glass**	**36,620**	**40,200**	**42,720**	**44,180**	**44,410**

Source: BSR Sustainability GmbH

Table 5-41: Differences in total glass production between the Reference Scenario and the 2°C Scenario in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2000 – 2050

Country or Country group	Glass category	2000	2010	2020	2030	2050
Austria	Total Glass	0	0	10	50	140
Baltic States	Total Glass	0	0	0	0	10
Belgium/Luxembourg	Total Glass	0	0	-20	-50	-150
Bulgaria	Total Glass	0	10	50	140	320
Czech Republic	Total Glass	0	0	-30	-70	30
Denmark	Total Glass	0	0	10	10	40
Finland	Total Glass	0	0	10	10	20
France	Total Glass	0	20	170	440	1,180
Germany	Total Glass	0	20	120	370	1,010
Greece	Total Glass	0	0	0	20	60
Hungary	Total Glass	0	0	-40	-40	50
Ireland	Total Glass	0	0	10	20	60
Italy	Total Glass	0	20	200	500	1,330
Malta/Cyprus	Total Glass	-	-	-	-	-
Netherlands	Total Glass	0	140	180	250	430
Norway	Total Glass	0	0	0	10	20
Poland	Total Glass	0	-120	-140	-120	60
Portugal	Total Glass	0	-10	70	210	510
Romania	Total Glass	0	-50	-60	-40	-20
Slovakia	Total Glass	0	0	0	0	20
Slovenia	Total Glass	0	10	0	0	20
Spain	Total Glass	0	40	190	450	1,080
Sweden	Total Glass	0	0	10	0	-10
Switzerland	Total Glass	0	0	-10	-10	40
United Kingdom	Total Glass	0	0	50	230	650
EU27 + 2	**Total Glass**	**0**	**80**	**790**	**2,350**	**6,890**
Turkey	Total Glass	0	20	290	740	1,790
Total Europe	**Total Glass**	**0**	**100**	**1,080**	**3,100**	**8,690**

Source: BSR Sustainability GmbH

5.2.3 Remarks on data availability

There are marked differences in the availability of production output data in the various industry sectors.

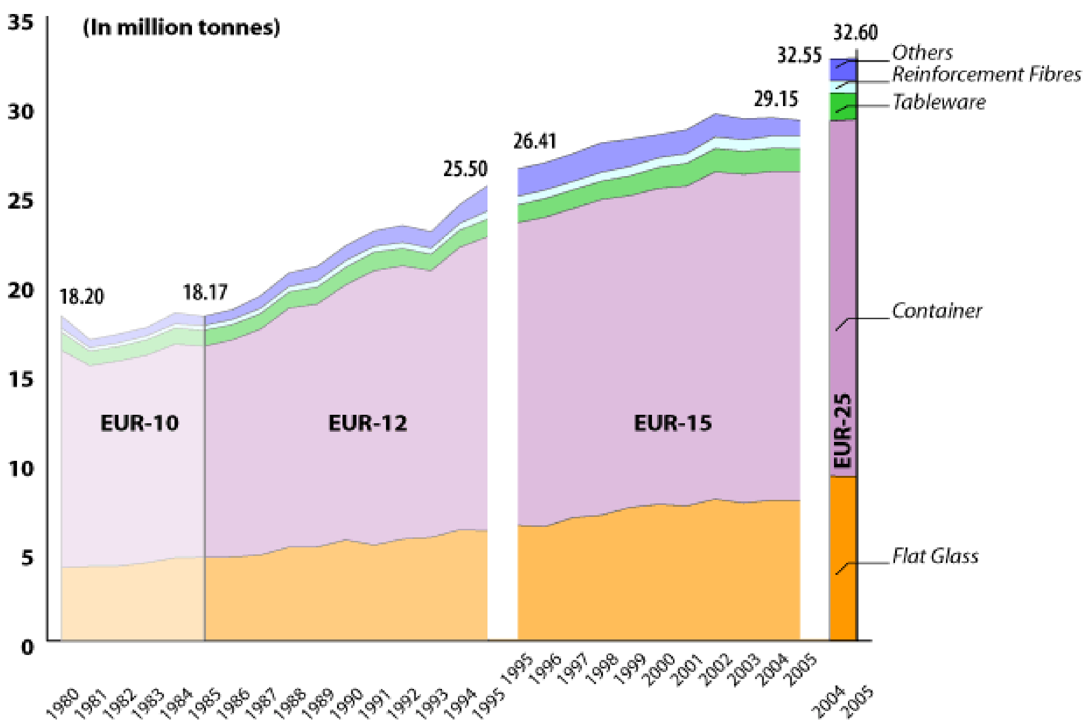
The available database of the cement industry is relatively widespread. Historical data (including export and import data) for the countries are present in different databases. The oldest accessible data for cement production are from the year 1913 (World statistical review N°18, Cembureau). Current key factors of the cement industry sector are also available (Word Statistical Review (Annual), Cembureau). Useful sources for cement data were: The European Cement Association (CEMBUREAU), national federations (e.g. Verein Deutscher Zementwerke e.V. [VDZ], Bundesverband der deutschen Zementindustrie e.V. (BDZ), FEBELCEM, etc.) and national/international statistical offices (Eurostat, Destatis, etc.).

The availability of production data for the aluminium industry, the steel industry and the paper industry is also satisfactory. The Statistical Yearbooks of the Steel Industry and the Metallstatistik/Metal Statistics (World Bureau of Metal Statistics) are common benchmarks for metals, which contain data for most western and eastern European countries. These sources can be used as annual reports or taken from the Internet (e.g. US Geological Survey, USGS).

For the paper sector, the Verband Deutscher Papierfabriken e.V. (VDP), the Confederation of European paper industries (CEPI), Eurostat and the statistical database FAOSTAT of the food and agriculture organisation of the United Nations provide the best data.

In contrast to the sectors mentioned above, the glass sector and the wood sector have the poorest data availability. The glass production data are compiled from national sources (statistical offices, associations of the glass industry), annual reviews of companies, press releases, the Internet, glass market studies (e.g. Overview of Glass Container Production in the EU: 2006, British Glass), the Standing Committee of the European Glass Industries (CPIV) and the European Federation of Glass Packaging.

As already stated in the section "Assumptions on the drivers of glass production in Europe", the glass industry is very heterogeneous with a wide variety of products and applications (food industry, building industry, beverage industry, automotive industry, etc.). In addition there are problems with data confidentiality. Therefore the available statistics on glass production in Europe are very sparse. Production figures by glass types are only available at EU level (see Figure 5-2). Production data for most eastern European countries are very difficult to find.



Source: The Standing Committee of the European Glass Industries

Figure 5-2: EU glass production 1980 to 2005

The wood sector covers wood production for material utilisation (industrial wood) as well as wood production for energy use. But a large proportion of the wood produced is used privately by forest owners without any records. Therefore official statistics of “wood cuttings” do not feature the real amount of wood used. Furthermore the wood sector, which is not well organised, is subdivided into different industrial sectors and various categories of wood utilisations. In particular, there are not many subdivided statistics available for fuelwood (firewood, woodchips and wood pellets; see also section 5.3).

5.2.4 References

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5.3 Wood fuel demand in Europe in the Reference and 2°C Scenarios, 2000 to 2050

5.3.1 The Reference Scenario

As the results of the Efiscen model (see Chapter 5.1.2.1) show, there is slightly more roundwood available (including forest residues such as topwood or branches) in Europe in the Reference Scenario (+9.4 %) than in the Base Case Scenario. this is due to higher average temperatures and more precipitation north of the Alps. However, these changes are not uniform for total Europe, as the vegetation of forests is favoured north of the Alpes, but dampended south of the Alps due to diminished precipitation.

5.3.1.1 Assumptions on the Reference Case (4° C Scenario)

There are considerable differences regarding roundwood availability (including forest residues) between countries north of the Alps and countries south of the Alps. In the Reference Case, the South-Alps region has less biomass available than the North-Alps region, because drier periods on the one hand and more irregular rainfall on the other hand are expected in this area. No changes are assumed for waste wood availability and wood-based products. There are also no different assumptions for fuel wood for cogeneration and district heating plants in the Reference Case. From 2000-2010, the data for the Reference Scenario in all sectors are taken from the Base Case Scenario. The general trend of the South-Alps region compared with the North-Alps region shows less biomass development (see Table 5-42).

Table 5-42: Roundwood availability in EU-27 (including forest residues) (Reference Scenario)

Country group	Roundwood availability in PJ								Difference to Base Case in %		
	Base	**Ref.**	**Base**	**Ref.**	**Base**	**Ref.**	**Base**	**Ref.**			
	2005		2020		2030		2050		2020	2030	2050
N. Alps	3,374	3,374	4,396	4,409	5,131	5,188	5,333	6,023	+0.3	+1.1	+13.0
S. Alps	1,106	1,106	1,287	1,279	1,510	1,503	1,960	1,954	-0.6	-0.4	-0.3
EU27+2	**4,479**	**4,479**	**5,683**	**5,688**	**6,641**	**6,691**	**7,293**	**7,977**	**+0.1**	**+0.8**	**+9.4**

Note: South Alps countries: Bulgaria, France, Greece, Hungary, Italy, Portugal, Romania, Slovenia, Malta, Cyprus and Spain

Source: Efiscen, FAO 2008, own calculations

Based on these assumptions, the Mateff model distinguishes between two regions for the calculations of fuelwood in Europe: South of the Alps and North of the Alps. Calculations and projections were made for both regions which are described below

Countries south of the Alps

In the Reference Case (4°C Scenario – climate change without additional mitigation policies), the countries further south of the Alps (Bulgaria, France, Greece, Hungary, Italy, Portugal, Romania, Slovenia, Malta, Cyprus and Spain) are forecasted to have a little less less biomass than in the Base Case Scenario (-1.3% until 2050), because they are likely to be drier and experience more heavy rainfalls, but with less water available due to dried out soils. Based on these assumptions, the availability for woodchips directly from the forest (70 % of the woodchips) and firewood directly from the forests (80 % of the firewood) is assumed to decrease by 4% per year and country from 2011 onwards in private households, services, agriculture, district heating, co-generation and industry sectors as the demand of wood for construction and paper does not change in the Reference Scenario. However, this declining availability of fuel wood coincides with warmer temperatures and less heating demand (see Chapter 6.3 and 6.5).

Countries north of the Alps

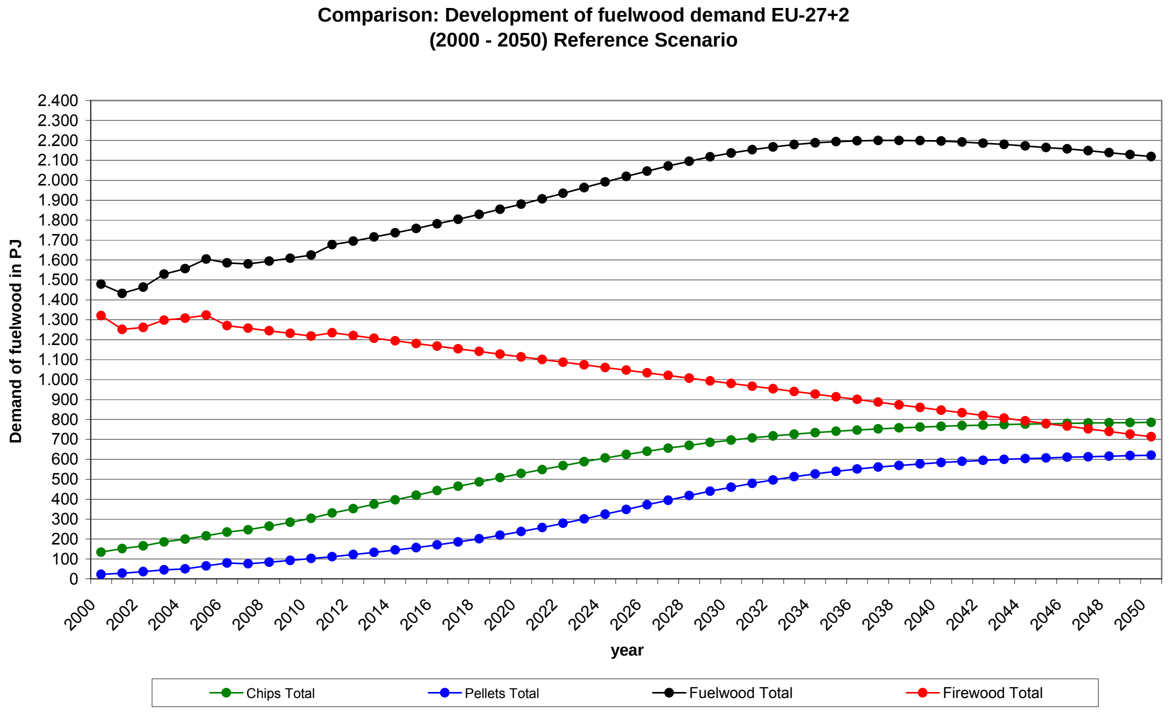
The situation in the countries further north of the Alps (Austria, the Baltics, Belgium, Luxemburg, Czech Republic, Denmark, Finland, Germany, Ireland, Netherlands, Norway, Poland, Slovakia, Sweden, United Kingdom and Switzerland) is predicted to develop contrary to the development in the South, i.e. an increase in biomass. More wood is available than in the Base Case Scenario (+13%), because more biomass can grow in these countries due to warmer temperatures and advantageous growing conditions. The availability for woodchips and firewood is predicted to increase by almost of 4% per year and country from 2011 onwards in private households, services, agriculture, district heating, co-generation and industry.

5.3.1.2 Results of the Reference Scenario

Comparison firewood, pellets and chips demand (Reference Scenario)

Contrary to the differences between the regions north and south of the Alps the EFISCEN model calculated for the total roundwood availability in EU 27+ Norway and Switzerland (+9% in 2050 relative to the Base Case Scenario), total wood supply of the Reference Scenario (includig wood wastes and and landscape wood) available for fuelwood use in non-grid connected firing plants appears quite similar to the Base Case Scenario. The overall picture shows an increase in total fuelwood to a maximum of 2200 PJ in 2038 (see Figure 5-3).

There may be a small unused potential due to some not implemented measures of sustainable forestmanagment in some European countries. In 2050, total fuelwood amounts to about 2120 PJ in EU27+2. Looking at the Reference Scenario in more detail, it becomes obvious that woodchips substituting the firewood use pass the break even point in Europe around 2045 onwards. Woodchips from short rotation crops, such as already exist in Portugal, Sweden or Spain, can also displace conventional firewood (see Figure 5-3).



Source: BSR-Sustainability 2008

Figure 5-3: Share of firewood and new forms of fuelwood, Reference Scenario, 2000 to 2050

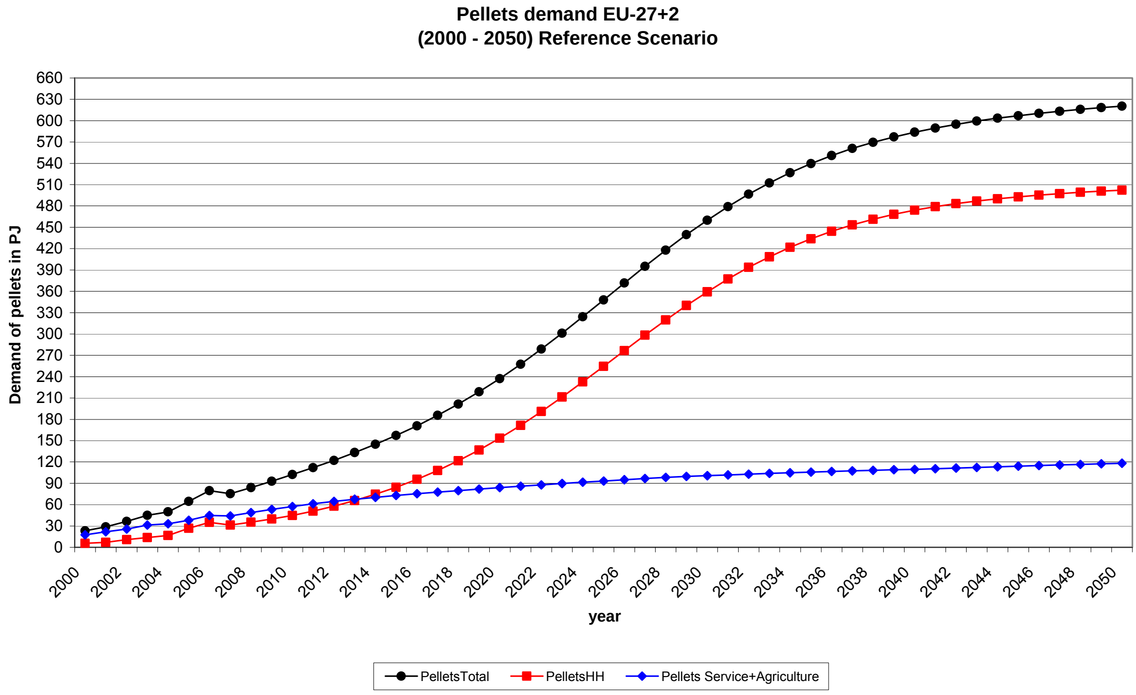
Table 5-43: Fuelwood demand in EU-27+2 in the Reference Scenario

Country group	Fuelwood demand in PJ								Difference to Base Case in %		
	Base Case	Reference Scenario	Base Case	Reference Case	Base Case	Reference Case	Base Case	Reference Case			
	2005		2020		2030		2050		2020	2030	2050
North-Alps	1,189	1,189	1,409	1,447	1,582	1,621	1,548	1,582	+2.7	+2.4	+2.2
South-Alps	416	416	433	432	517	515	537	535	-0.2	-0.2	-0.3
EU-27+2	**1,605**	**1,605**	**1,842**	**1,879**	**2,098**	**2,136**	**2,085**	**2,118**	**+2.0**	**+1.8**	**+1.6**

Source: BSR-Sustainability 2008

The different kinds of fuelwood in detail

The detailed calculations of the different kinds of fuelwood - pellets, chips and firewood - are similar to the data in the Base Case Scenario. The Reference Scenario does not consider policy changes, so there are no differences in pellet demand to the Base Case Scenario, because pellets are mainly produced from sawdust and it is quite inefficient to produce pellets from fresh roundwood. Similar to the Base Case, pellet demand in 2050 is considered to increase up to 620 PJ in total (see Figure 5-4).

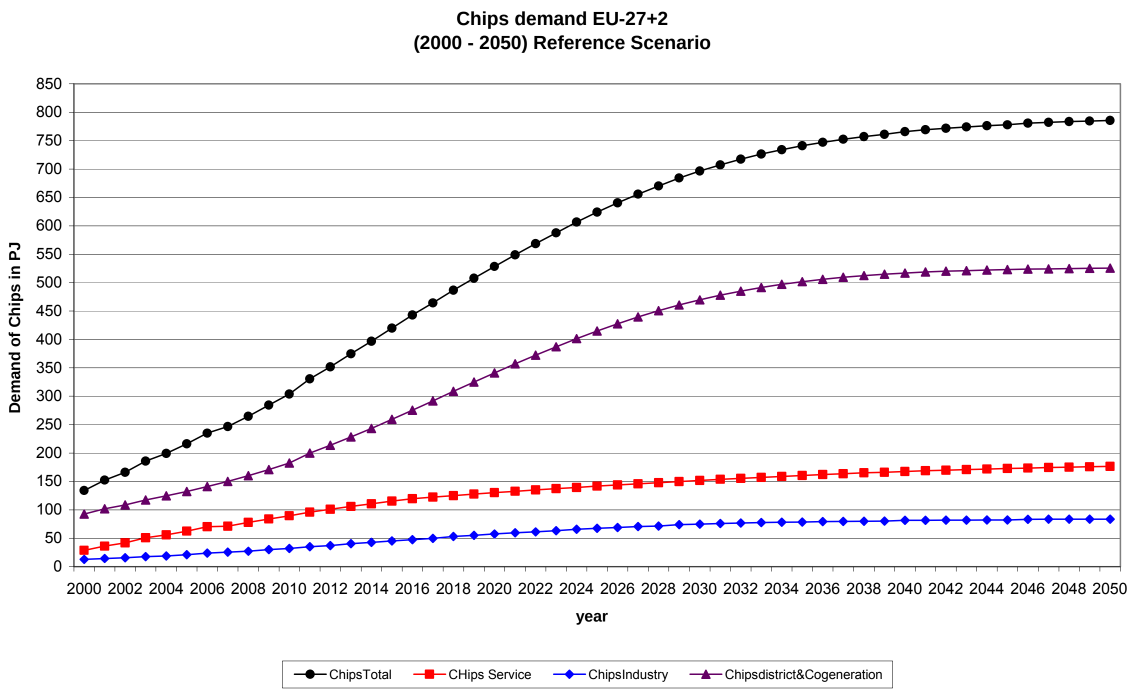


Source: BSR-Sustainability 2008

Figure 5-4: Pellet demand (EU 27+2) in different sectors, 4° C Scenario, 2000-2050

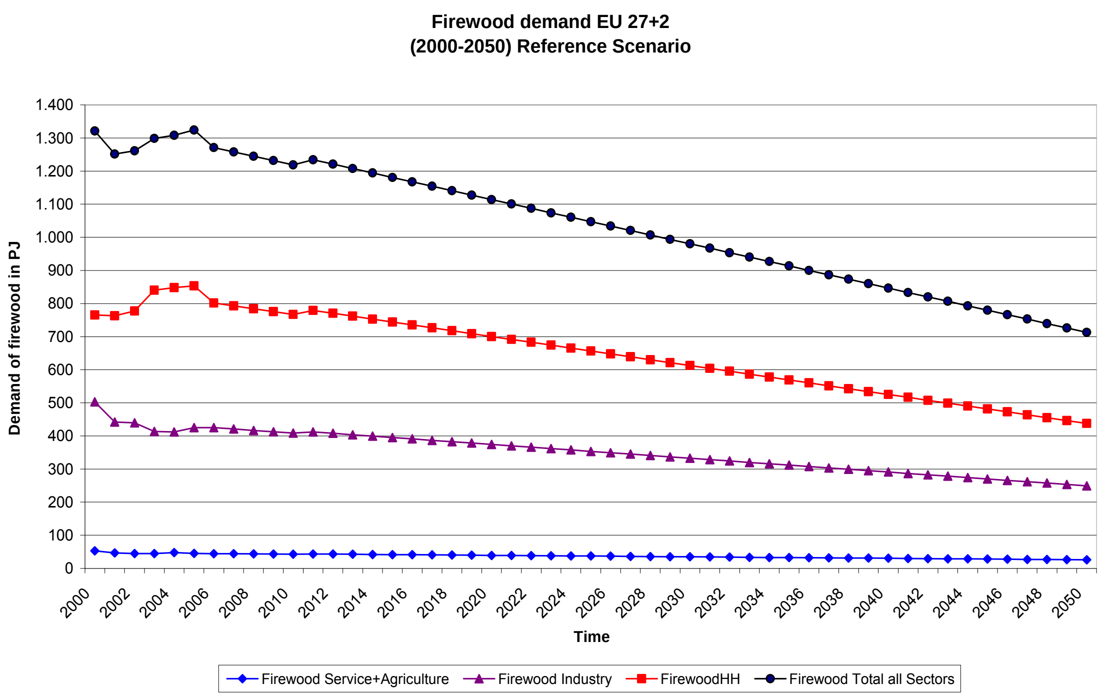
Contrary to pellets, there is a higher increase in woodchip demand in EU27+2 in the Reference Scenario than in the Base Case Scenario, because more wood biomass is available and more wood can be used efficiently as chips either directly from the forest or from short rotation crops. There is an almost continuous increase in woodchip demand in the Reference Scenario in Europe (EU27+2). Woodchips are mainly used in district heating plants, co-generation and industry. Total woodchip demand in 2050 is predicted to rise to 785 PJ (see Figure 5-5).

In the Reference Scenario, the firewood demand in Europe decreases by 46 % between 2000 and 2050 from around 1,320°PJ in 2000 to 710°PJ in 2050 (see Figure 5-6) which is essentially the same as in the Base Case Scenario. This means that the slightly higher biomass availability has no influence on firewood demand (see Table 5-42). The main share of this firewood is used in boilers, particularly in private households and farms outside of the cities, and also in boilers and wood gasification plants, particularly in industry and district heat plants.



Source: BSR-Sustainability 2008

Figure 5-5: Woodchip demand (EU27+2) by sectors, Reference Scenario, 2000 to 2050



Source: BSR-Sustainability 2008

Figure 5-6: Firewood demand of EU27+2 by sectors, Reference Scenario, 2000-2050

5.3.2 The 2°C Scenario

In the 2°C Scenario, the same distinction is made as in the Reference Scenario between the regions North-Alps and South-Alps for the projections of fuelwood. In addition to the relatively small changes in wood supply due to lower temperatures, the 2°C Scenario also assumes major policy changes and technical improvements; this leads to greater use of pellets and woodchips in all sectors, industry, co-generation and heating plants. For the first decade (2000-2010), however, the data for the 2°C Scenario remain the same as projected for the Base Case Scenario for all sectors because the changed policies do not have an effect before the second decade.

5.3.2.1 Assumptions of the 2° C Scenario

Based on the 2°C Scenario, the projections made by the MATEFF model include (small) changes in the growth of European forests and (major) policy changes as two factors of influence on the future use of fuelwood in Europe.

Natural changes in European forests

In the 2° Scenario, the countries south of the Alps (Bulgaria, Greece, Hungary, Italy, Portugal, Romania, Slovenia, Malta, Cyprus and Spain) are forecasted to have slightly less biomass than in the Base Case Scenario, because they are likely to have a drier climate with drier soils than in the Base Case Scenario. Fewer fellings are expected from forests in these countries compared to the Base Case Scenario. This is reflected in a slightly smaller production of woodchips and firewood directly from forests by some 1 % per year starting in 2011. This slight decline affects every sector: private households and services, the agricultural sector, district heating and co-generation plants as well as industry in the countries south of the Alps.

As the forests north of the Alps benefit from climate change in the 2°C Scenario, the projections for this part of Europe assume slightly higher biomass production compared to the Base Case Scenario. The production potential of woodchips and firewood stemming directly from the forest is predicted to increase by about 1 % yearly in all the sectors mentioned above.

Policy changes and technical improvements

In the 2° Scenario, changing polices will lead to greater use of renewable energies – therefore, there will be an increase in overall fuelwood demand in Europe. A substantial increase in the use of pellets and chips is expected in all European countries except Greece, Malta and Cyprus due to the reduced wood availabilty here in the 2°C Scenario. Almost stagnating demand is assumed in the Mediterranean countries, because these countries have low amounts of wood available from their forests, but high potentials for solar energy using solar thermal collector systems. Pellet use in private households and the service sector will almost stagnate relative to the Base Case Scenario as less wood availability from forests is compensated by more use of demolition wood and industrials waste wood.

In countries north of the Alps, changing policies will lead to increased pellet use due to increased mobilisation of demolition wood and short rotation crops; this will also increase the use of fuel wood in co-generation, industry and district heating. The pellet demand in industry, district heating and co-generation is calculated based on the woodchip development in the service sector in the Base Case Scenario. Starting in 2011, the chips data of the Base Case Scenario are increased annually by 1% in the service sector of each country. The service sector is used because its chip use in the Base Case Scenario is expected to develop in a similar way to industrial pellet demand and the use of pellets in co-generation.

In addition, technical improvements in industrial wood use lead to more wood being available as wood fuel. For instance, more wood fuel is available because of the drop in the demand for wood due to highly efficient paper production technologies (see Table 5-38). Moreoever, the resulting fresh wood available can be efficiently turned into woodchips. This is assumed to trigger a 3% annual increase in the demand for woodchips in industry, district heat and cogeneration in each country north of the Alps in the 2°C Scenario.

5.3.2.2 Results 2°C Scenario: firewood, pellet and chip demand

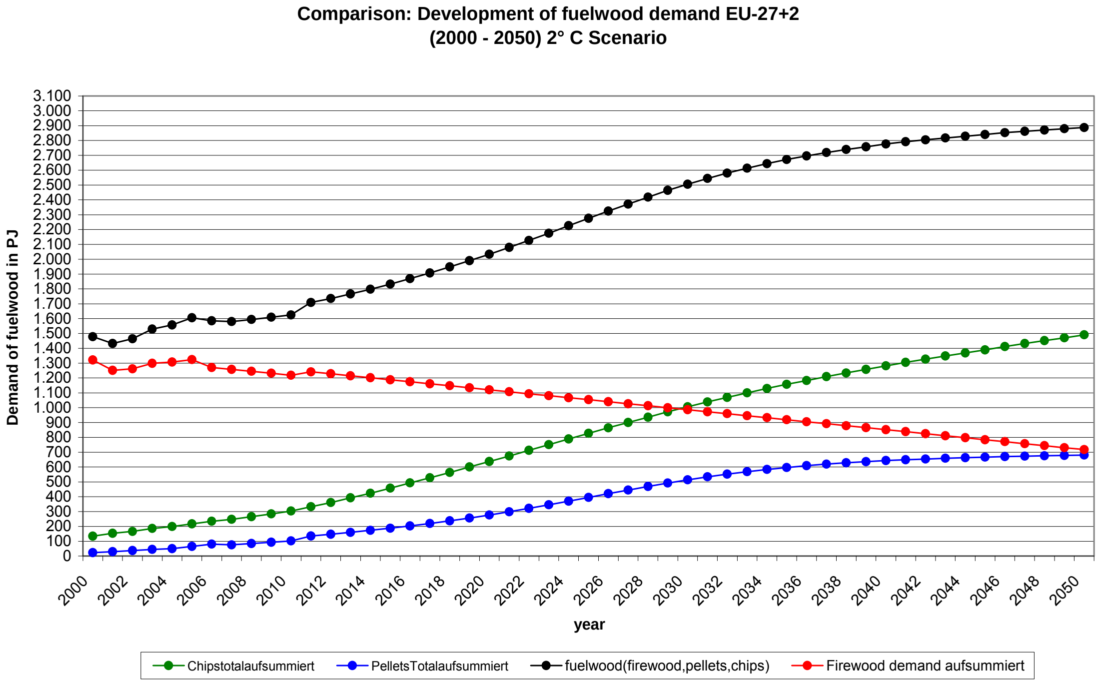
In the 2°C Scenario, there is a sharp drop in the use of conventional firewood. In contrast, woodchips and pellets show increasing market shares, because the changes in policies support new forms of fuelwood and because modern automatic fuelwood plants and improved efficiencies in industrial wood use increase the amount of wood available for energy use. Pellets and chips can easily be delivered by van (similar to oil) and their energy density is higher than firewood, which has different economic advantages, (see Table 5-44).

Table 5-44: Gross calorific value of different kinds of wood (in kWh/kg)

Firewood		Pellets	Wood briquettes	Woodchips	
Conifer	Deciduous			dry G30 (water content < 20%)	damp G50 (water content ~ 50%)
4.3	4.2	4.7-5	5	4	2

Source: BSR-Sustainability 2008

Compared to the Base Case Scenario, wood fuel demand in the 2°C Scenario is high (see Table 5-45). By the year 2005, the use of fuelwood peaks at a maximum of around 2,890 PJ. By 2030, the demand for firewood drops to 990 PJ which is lower than the demand for woodchips (around 1,000 PJ). In 2050, the pellets demand almost reaches with around 680 PJ the traditional firewood use with around 710 PJ (see Figure 5-7).



Source: BSR-Sustainability 2008

Figure 5-7: Share of firewood and new forms of fuelwood, 2°C Scenario, 2000 to 2050

Table 5-45: Total fuelwood demand (firewood, wood pellets, woodchips), all sectors in EU-27 + 2 in PJ – Comparison of the Base Case Scenario and the 2 °C Scenario, 2015 – 2050

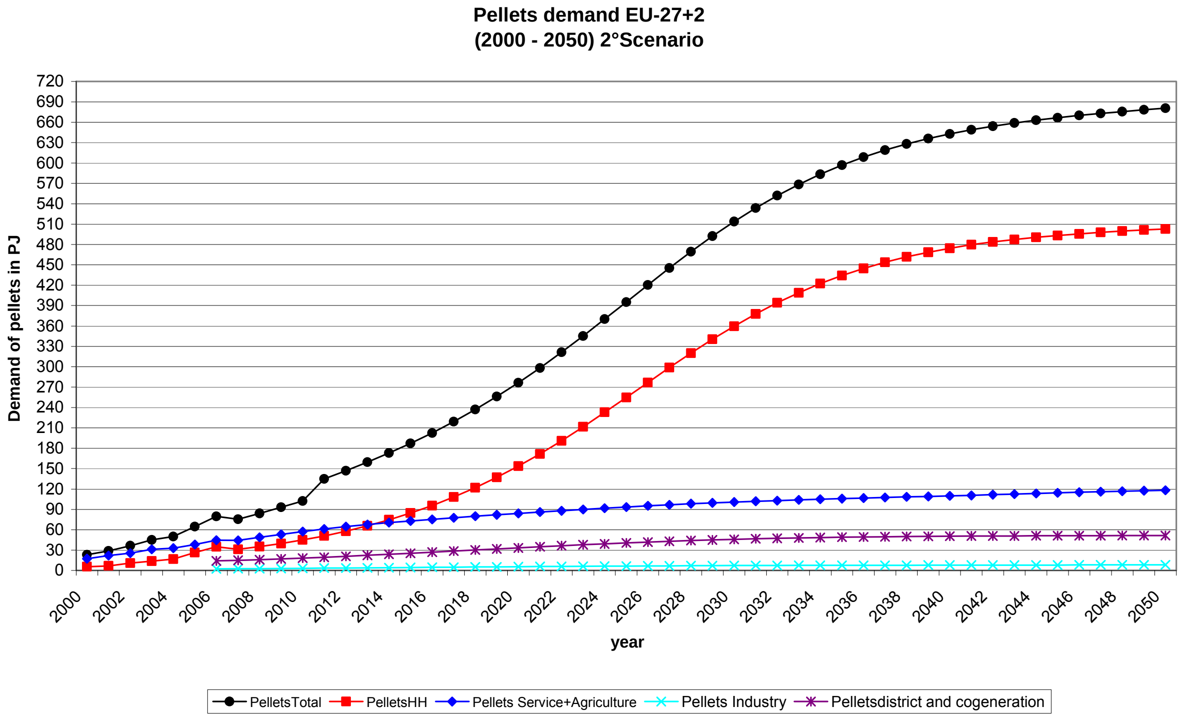
Country or country group	2015		2020		2030		2050	
	Base Case	2 °C Scenario	Base Case	2 °C Scenario	Base Case	2 °C Scenario	Base Case	2 °C Scenario
Austria	113	115	123	129	141	160	137	178
Baltic States	94	99	95	103	96	111	89	117
Belgium/Luxembourg	24	25	27	29	32	40	34	52
Bulgaria	27	27	26	26	27	29	25	31
Czech Republic	48	49	50	53	55	62	52	68
Denmark	20	21	21	22	21	24	22	26
Finland	218	229	219	238	209	244	171	237
France	72	73	85	88	142	149	161	175
Germany	263	284	311	358	375	480	350	550
Greece	9	9	10	9	13	13	17	18
Hungary	22	22	22	23	27	30	32	40
Ireland	9	9	11	12	17	21	22	32
Italy	72	79	79	89	87	103	86	114
Malta/Cyprus	0	0	0.0	0	0.0	0	0.1	0
Netherlands	7	7	8,3	9	10	10	10	11
Norway	54	56	58	61	62	68	63	74
Poland	143	145	143	147	156	178	150	212
Portugal	9	9	10	10	16	16	20	20
Romania	72	79	70	78	72	83	69	88
Slovakia	13	13	14	14	18	22	22	34
Slovenia	17	17	18	18	22	25	21	30
Spain	115	115	112	112	111	112	106	110
Sweden	223	247	235	272	251	316	274	396
Switzerland	48	51	68	80	106	147	117	206
United Kingdom	26	30	28	34	32	44	35	57
EU-27 + Norway and Switzerland	**1,721**	**1,833**	**1,842**	**2,034**	**2,098**	**2,505**	**2,085**	**2,888**

Source: BSR-Sustainability 2008

The different kinds of fuelwood in detail

As a consequence of policies encouraging energy-efficiency and renewables, and technology improvements, the use of pellets will increase in private households and the service sector and they will also be used in district heating, industry and co-generation (in total almost 690 PJ by the year 2050; see Figure 5-8). It becomes clear that by the year 2050 the use of pellets and woodbriquettes occurs with around 503 PJ mainly in private households, but the service sector also has a relevant share (approx. 120 PJ) (see Figure 5-8).

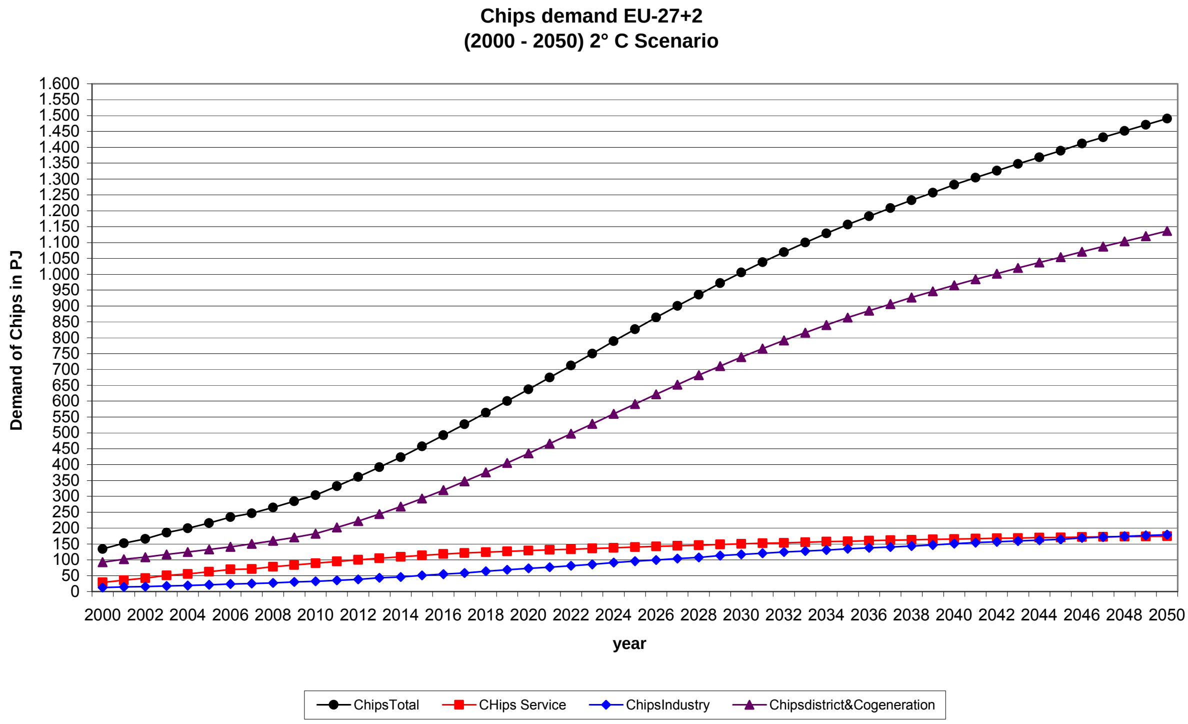
The 2°C Scenario indicates an almost continuous increase in woodchip demand from around 135 PJ in 2000 up to roughly 1,500 PJ in 2050 (+1010%). Woodchips are mainly used in district heating plants, cogeneration and industry (almost 1,320 PJ in 2050). Utilisation of woodchips in the service sector amounts to 140 PJ in 2050 (see Figure 5-9). Woodchip use in the service and agricultural sector is especially frequent in rural areas, which have easily available wood and sufficient storage space for woodchips.



Source: BSR-Sustainability 2008

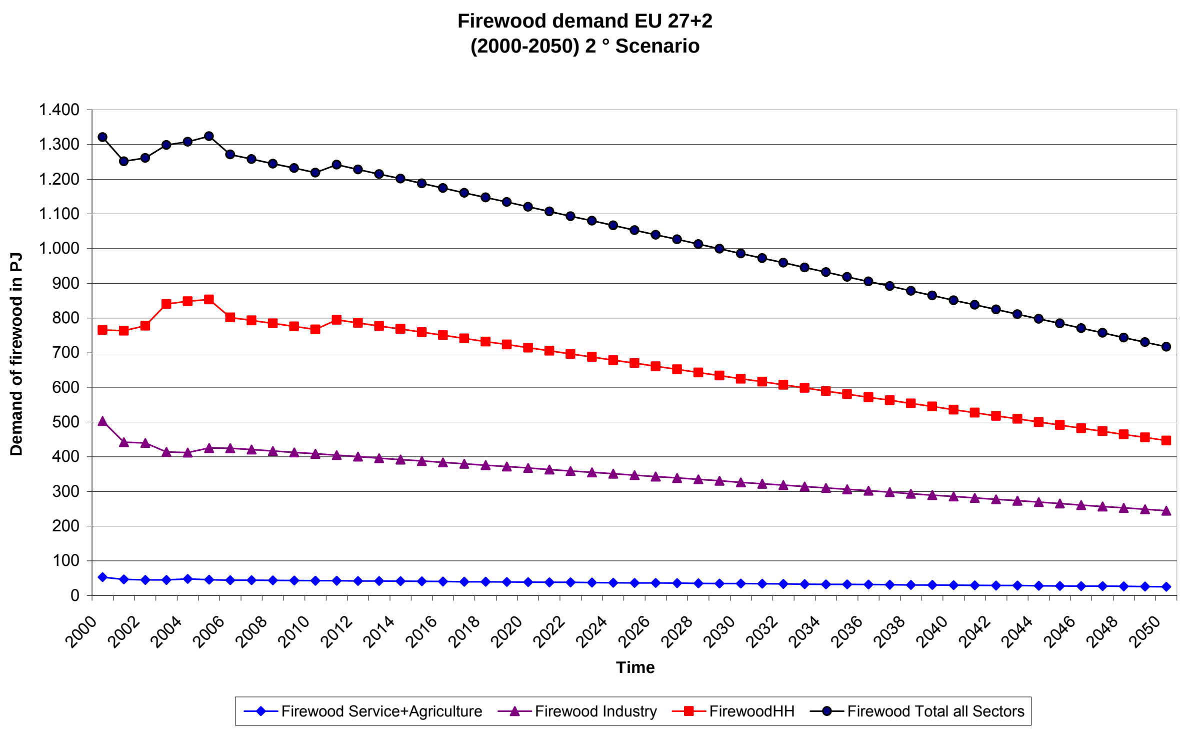
Figure 5-8: Pellet demand (EU27+2) in different sectors, 2°C Scenario, 2000 - 2050

From around 1320°PJ in 2000, firewood decreases to 717°PJ in 2050. In 2050 firewood is mainly used in private households (almost 450 PJ), predominantly in efficient and modern firing plants and no longer in conventional stoves. The majority of firewood is used in the wood gasification plants of family houses (see Figure 5-10).



Source: BSR-Sustainability 2008

Figure 5-9: Chips demand (EU27+2) by sectors, 2° C Scenario, 2000 to 2050



Source: BSR-Sustainability 2008

Figure 5-10: Firewood demand (EU27+2) by sectors, 2°C Scenario, 2000 – 2050

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6 Assumptions and results of the final energy models – Reference Scenario

This Chapter (and the following Chapter 7) describes the assumptions and results of the Reference Scenario, where the impacts of climate change - 4°C global surface temperature increase - are modelled by sectoral bottom-up models for the period 2000 to 2050. The models are more detailed than the POLES model which makes it possible to compare the results of the two types of models; this will be done in the final deliverable of this work package in April 2009.

Comparing the results of this Reference Scenario with those of the Base Case Scenario allows the adaptation costs of the energy system to be quantified in principle. These are calculated for all sectors and include the identification of the related economic impacts at the macroeconomic level (see Chapter 8). However, it has to be stressed that the knowledge about changes in extreme events is extremely limited, so that only changing temperatures could be taken into account in this analysis, but not changing precipitation, storms, heat waves, or droughts. This means that the adaptation costs calculated here are smaller than those to be expected from an actual 4°C increase in the global average surface temperature.

6.1 Methodology used to reflect the impacts of climate change on energy demand

It is assumed that a warmer climate in the future will affect energy demand in two ways: First, the share of cooled floor area is assumed to increase and, secondly, the specific energy demand of cooled floor area is assumed to increase. To estimate this impact for the tertiary (service) and the residential sector at European level, their energy demand is modelled for 29 European (EU27+2) countries for two different scenarios: namely, a Base Case Scenario assuming past climate conditions and a Reference Scenario assuming a warmer climate. The latter is characterised with an average surface temperature increase of about 4°C at the end of this century relative to pre-industrial temperatures, depending on country and month, as estimated by the IMAGE model within the ADAM project (Isaac, M. et al., 2008). A two stage bottom-up modelling approach is followed where each of the two stages is performed both with Base Case climate data (1982 to 1999) and with Reference data (i.e. + 4°C above pre-industrial temperatures).

- Firstly, building physics models were run to estimate the specific energy demand for various building types.
- Secondly, an energy bottom-up model was used to project the energy demand of the sector as a whole. The results of the first stage regarding specific energy demand data (per m^2) are used as input here. Changes in the conditioned floor area are also modelled.

For both the tertiary and the residential sector, the modelling of climate change impacts is based on the following assumptions that differentiate between the cases of heating and cooling:

- In Europe, the **heated** floor area will **not** decrease due to the warmer climate (but the specific energy demand of heated floor area will decrease).

- In contrast, the share of **cooled** floor area **will increase** due to the warmer climate (moreover, the specific energy demand of cooled floor area will increase).
- It is assumed that the relative shares of heating systems (oil, gas, wood etc.) are not affected by climate change.

To facilitate data transfer between stage 1 and stage 2, results regarding specific energy demand values and shares of cooled floor area are related to heating degree days (HDD) and cooling degree days (CDD). Heating and cooling degree days are based on the difference between a reference temperature of 18°C and the average outside temperature (approximated as mean between minimum and maximum daily temperature) if the latter exceeds or falls below a defined temperature threshold T (HDD: 15°C, CDD: 18°C).

6.1.1 Impact of a warmer climate at the level of individual buildings

In the first stage, the specific energy demand for lighting, ventilation, cooling, appliances, heating and other thermal applications is modelled for different building types and locations in Europe. 14 locations (see Table 6-1) are chosen to cover both the relevant regions in terms of the energy demand of the residential and tertiary sector and the range of climate conditions in Europe.

Energy demands (and indoor climate conditions) are estimated with a dynamic building simulation model (IDA-ICE). Simulation results differentiate between the main types of energy services, namely lighting, ventilation, cooling, heating and other thermal applications, and will reveal the impact of climate change on the specific energy demand and the need for adaptation measures in buildings to ensure an acceptable level of comfort for their occupants. The impact estimated by our own building model simulation is backed up by evidence from the literature, particularly from Rivière, Adnot et al. (2008), Cartalsi, Synodinou et al. (2001), Frank (2005) and Aebischer et al. (2007).

6.1.1.1 Impact of a warmer climate at the sectoral level

In the second stage, the energy demand of the residential and tertiary sector was modelled for the two scenarios (Base Case and Reference) up to 2050. In the case of the service sector, the bottom-up model differentiates between five main sectors, namely finance, retail, education, health/hotels/restaurants and a residual sector. Likewise, the residential sector model differentiates between different building types and different construction periods (see Jochem et al. 2007a, b for more details). The main drivers are the conditioned (heated and possibly cooled) floor area and the specific energy demand for different types of energy services. The basic structure of the bottom-up modelling approach of the service sector can be described as follows:

$$Energy\ demand = \sum_{i,k,e} FA_{i,k,e} \cdot specific\ energ\ demand_{i,k,e} \qquad \text{(equ. 6-1)}$$

where *FA* denotes the conditioned floor area, *i* the economic sector or sub-sector, *k* the energy type and *e* the type of energy service (e.g. heating, cooling), respectively. Both floor area and specific energy demand change over time. The floor area, i.e. the building stock of the service sector, is further differentiated into buildings with different levels of energy services (e.g. with or without central or room air conditioning). Specific energy demand input data are derived from both historical data and from the results of the first stage as described above.

The relationship between climate and share of cooled floor area is based on market data and projections of the cooling market in Europe, on findings of a study for the DGTREN of the EC (Adnot et al., 2003) and on preparatory studies of the ECODESIGN Lot 10 (Rivière, Adnot et al. 2008), particularly on Draft report of Task 2-V5 October 2007: Economic and Market analysis.

As the specific approach differs slightly between the residential and the tertiary sector, more details are given in the subsequent sections.

6.1.1.2 Temperature and degree days of the two underlying climate scenarios

Two climate scenarios are defined: a Base Case Scenario (BC, assuming no climate change at all) and the Reference Scenario (warmer climate: WC scenario). HDD and CDD of the Base Case Scenario were calculated for 39 locations[8] in 23 different countries using typical meteorological year (TMY)[9] hourly data from IWEC weather stations (as published on the website http://www.equaonline.com/iceuser/). Each of the EU27+2 countries is represented by one or a weighted average of several IWEC weather stations.

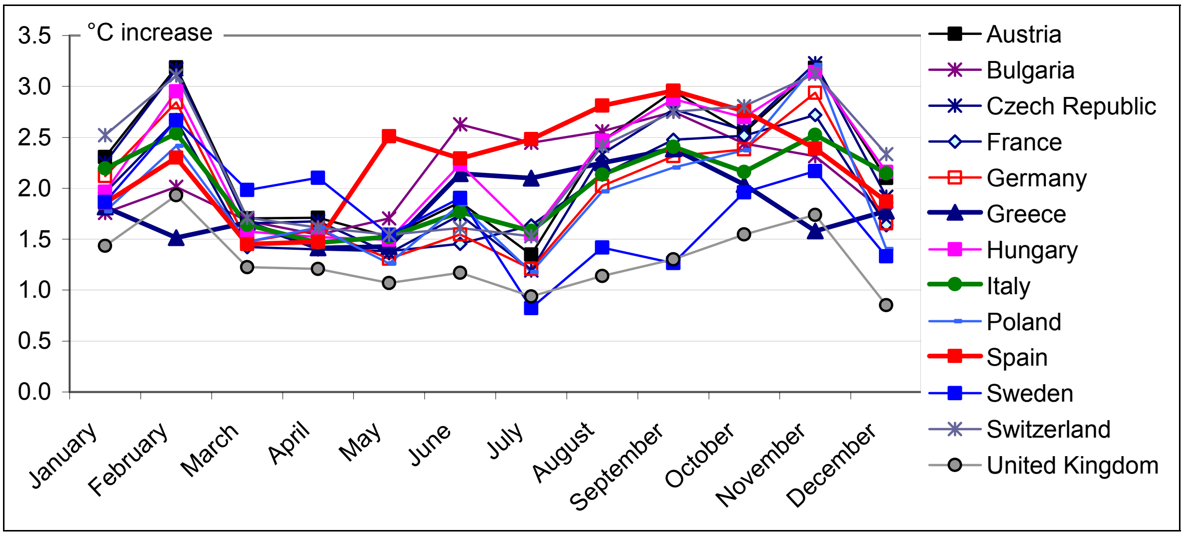
HDD and CDD of the Reference Scenario are calculated using hourly T data of the Base Case Scenario to which monthly average T differences between the considered modelling year (2005 to 2050) and the average of 1980 to 2000 were added for each country individually. These monthly T differences stem from simulation results of the climate model IMAGE. The underlying simulation runs were performed by Isaac et al. (2008) within the ADAM project. All of these monthly differences are positive for all countries and all months and vary mostly between 1.5°C and 3°C for 2050. For almost all European countries, the increase is lowest in spring (see Figure 6-1). In southern Europe, the largest increase is in late summer whereas in central Europe the largest increase tends to be in winter.

The assumptions of the Reference Scenario are summarised below:

- Building physics simulations are based on hourly T data.
- Over the average of all hours within a month, T increase is uniform within each month, but different between different months and for each country (see Figure 6-1).
- Monthly increases are superposed by an additional daily variation of the temperature, assuming a sin function of the form $0.5 * \sin\left\{\left(\frac{t+6}{24}\right)2\pi\right\}$ °C (equ. 6-2)
- No change in direct and global radiation (it is unclear in climate models whether radiation would decrease due to more clouds or increase) and relative humidity.

8 Vienna (AT), Brussels (BE), Copenhagen (DK), Helsinki (FI), Paris, Marseille (FR), Berlin, Bremen, Frankfurt, Munich, Koeln, Stuttgart (DE) Athens, Thessaloniki (GR), Dublin, Kilkenny (IE), Milan, Rome, Naples (IT), Nancy (FR, also used for LU), Amsterdam (NL), Coimbra (PT), Madrid, Sevilla (ES), Stockholm (SE), Birmingham, London (UK), Larnaca (CY), Prague (CZ), Debrecen (HU), Kaunas (LI), Warsaw (PL), Bratislava (SK), Ljubljana (SL), Bergen, Oslo (NO), Geneva (CH), Bucharest (RO), Sofia (BG).

9 Up to 18 years of weather data of the period 1982–1999 were processed by ASHARE using Hall's method, see ASHRAE (2002).



Source: own representation (based on Isaac et al., 2008: increase between 2050 and average 1980-2000)

Figure 6-1 Assumed increase of monthly T in the Reference Scenario for 2050 (selected European countries)

First it is interesting to note that the impact of the above temperature change assumptions do not have a linear impact on either heating or cooling degree days, neither in relative nor in absolute terms. In relative terms, HDD and CDD change increasingly with lower initial values following a concave course. HDD decrease by about 25 % to 30 % in southern Europe, and by about 15 % to 20 % in the rest of Europe (see Table 6-1). In relative terms, CDD are affected most strongly in Scandinavian and northern climates (up to +100% and even more), but much less so in southern Europe (+35% to 62%).

Heating and cooling degree data can be categorised into different regions within Europe. Five regions can be discerned for CDD (see Table 6-1). Regarding HDD, the regions south-east and mid-west could be summarised, but north (Scandinavian) and north-west (Ireland and U.K.) should still need to be distinguished. These results will be used to calculate the changes in heating and cooling demand in all final energy sectors (see Chapter 6) and also their impact on the conversion efficiencies of energy converting technologies (see Chapter 7).

Econometric analyses for several European countries and different climatic conditions conclude that rising incomes bring about a higher demand for heating and cooling. This effect is also taken into account (see Chapters 6.2 and 6.3).

Table 6-1: Heating degree days (HDD) and cooling degree days (CDD), Reference Scenario, in Centigrade, 2005 - 2050

Country or country group	HDD 2005	HDD 2020	HDD 2035	HDD 2050	HDD 2005-2050	CDD 2005	CDD 2020	CDD 2035	CDD 2050	CDD 2005-2050
Austria	3025	2874	2676	2495	-18%	248	287	343	408	65%
Baltic States	4018	3886	3698	3505	-13%	69	79	95	115	67%
Belgium/Luxembourg	2823	2666	2480	2287	-19%	108	127	155	190	76%
Bulgaria	2890	2762	2609	2467	-15%	278	336	417	506	82%
Czech Republic	3545	3370	3143	2936	-17%	90	109	137	169	88%
Denmark	3492	3380	3219	3044	-13%	26	31	39	49	90%
Finland	4691	4499	4259	4031	-14%	30	36	47	58	94%
France	2220	2092	1936	1776	-20%	298	338	397	464	56%
Germany	3155	3002	2798	2606	-17%	120	139	169	204	70%
Greece	1306	1229	1127	1032	-21%	993	1078	1189	1304	31%
Hungary	2993	2854	2669	2489	-17%	314	363	430	504	60%
Ireland	2940	2834	2695	2549	-13%	4	6	9	14	221%
Italy	1882	1766	1624	1476	-22%	564	628	714	805	43%
Malta/Cyprus	642	601	533	425	-34%	1270	1350	1461	1576	24%
Netherlands	2861	2730	2540	2363	-17%	62	70	83	100	61%
Norway	4040	3902	3710	3512	-13%	27	32	41	52	95%
Poland	3484	3342	3149	2958	-15%	98	114	140	172	74%
Portugal	1067	967	846	717	-33%	510	599	721	849	66%
Romania	2883	2764	2611	2442	-15%	425	489	577	668	57%
Slovakia	2887	2741	2577	2408	-17%	278	322	384	455	63%
Slovenia	3166	3010	2804	2603	-18%	187	226	282	346	85%
Spain	1553	1459	1327	1203	-23%	766	851	971	1099	43%
Sweden	4177	4017	3837	3647	-13%	33	39	51	68	107%
Switzerland	2783	2619	2429	2241	-19%	225	257	304	360	60%
United Kingdom	2890	2777	2634	2480	-14%	25	30	41	55	125%

Source: own categorisation and calculations using data from http://www.equaonline.com/iceuser/ (based on ASHRAE 2002) and from Isaac et al. (2008).

6.2 Residential buildings - projected by RESIDENT

This section includes building-related energy demand, particularly heating. Cooling is provided mostly by appliances in the residential sector and is handled in section 6.3.

6.2.1 Assumptions for residential buildings - Reference Scenario 2000 to 2050

Due to the warmer climate, the specific energy demand for heating is reduced. As the specific heating energy demand (SED) increases more or less linearly with increasing HDD, linear functions of the type shown in equations 6-3 und 6-4 may be used to estimate the impact of a warmer climate. The impact of a warmer climate on the specific energy demand is greater in less energy-efficient buildings. In other words, the slope m_{EE} of the linear fits depends on the energy efficiency of the assessed buildings.

$$SED_{EE} = b_{EE} + m_{EE} * HDD \quad \text{(equ. 6-3)}$$

$$SED_{WC} = SED_{PC} + m_{EE} * (HDD_{WC} - HDD_{PC}) \quad \text{(equ. 6-4)}$$

m_{EE} is obtained from calculations according to the norms SN EN 832 or the Swiss standard SIA 380/1. Values range between 0.17 and 0.22 in the case of a non-insulated multi-family house to about 0.1 in the case of new buildings with adjusted ventilation rates (SED expressed in MJ/m^{2}a and HDD in Kd). In the case of very energy-efficient buildings that satisfy the criteria of the German Passive house or the Swiss Minergie-P standard, m_{EE} may be even lower than 0.037.

Equations (6-3) and (6-4) and the respective coefficients (see Table 6-2) describe the model used to relate the SED for heating purposes to HDD. In accordance with the results of the building physics simulation model, it is assumed that the slope m_{EE} is maximal in the case of non-retrofitted existing buildings and minimal in the case of buildings that comply with the German Passive house or the Swiss Minergie-P standard. The coefficients of different building cohorts (old, medium old, recent, new) of countries with intermediate energy-efficiency (EE) are interpolated within these two boundary cases.[10] Moreover, as the average building stock will be retrofitted between 2005 and 2050, the impact of warmer climate will steadily decrease over time and accordingly m_{EE} will also decrease.

Table 6-2: Coefficients of equations 6-3 and 6-4

	b_{EE}	m_{EE}
EE = existing building stock without retrofit	1.3	0.167
EE = best practice (equivalent to the German Passive house or the Swiss Minergie-P standard)	-35.0	0.027

Source: Assumptions of the authors [last updated September 2008]

6.2.2 Results for residential buildings – Reference Scenario 2000 to 2050

6.2.2.1 Final energy demand for space heating

For Europe as a whole, the final energy demand for space heating will decrease continuously throughout the period. In 2050, the impact of the warmer climate (+4°C at the end of this century) amounts to a decrease in space heating by some 1,400 PJ or -16 % for EU27+2 (see Table 6-3). The changes vary in the different European countries.

The heating demand decline in buildings in the Nordic and Baltic countries is small in relative terms (changes of 13 to 15 %), but large in absolute terms; In contrast, the decrease in Mediterranean countries by the year 2050 is large in relative terms (16 to 33 %) but comparatively small in absolute energy terms relative to a Base Case Scenario. The reductions here are higher in relative terms due to the larger changes in HDD. However, specific heating demand in absolute terms is currently much higher in the Nordic countries, so in absolute terms, the reduction in energy demand (and the economic benefits associated with this) is much higher in countries north of the Alps (see Table 6-3).

[10] For old buildings, mEE of almost all countries is found to be at the upper boundary with the exception of some Nordic countries that are more efficient than could be expected from equation 6-3. In the case of well insulated or new buildings, m_{EE} typically varies between 0.08 and 0.12 (depending on the building type).

Table 6-3: Energy demand for space heating in PJ per year, Europe, Reference Scenario and the impact of warmer climate relative to Base Case Scenario, 2005 – 2050

Country or country group	Space heating demand					Impact of warmer climate		
	2005	2020	2035	2050	2005-2050	2020	2035	2050
Austria	208	200	201	180	-14%	-6%	-10%	-15%
Baltic States	128	118	106	93	-28%	-5%	-9%	-13%
Belgium	324	297	304	277	-15%	-5%	-9%	-14%
Bulgaria	60	54	48	41	-31%	-5%	-9%	-13%
Czech Republic	176	169	155	140	-21%	-7%	-13%	-18%
Denmark	118	108	108	99	-16%	-4%	-9%	-14%
Finland	116	106	106	98	-15%	-5%	-10%	-14%
France	1250	1243	1272	1187	-5%	-6%	-11%	-18%
Germany	1998	1801	1779	1562	-22%	-5%	-10%	-15%
Greece	157	144	145	139	-12%	-4%	-8%	-13%
Hungary	173	161	146	130	-25%	-6%	-12%	-17%
Ireland	72	84	97	100	39%	-5%	-9%	-14%
Italy	805	754	754	660	-18%	-7%	-12%	-18%
Malta/Cyprus	9	10	10	9	-3%	-9%	-18%	-33%
Netherlands	256	238	234	208	-19%	-6%	-13%	-19%
Norway	87	82	86	82	-5%	-6%	-10%	-15%
Poland	510	514	493	458	-10%	-5%	-10%	-15%
Portugal	52	49	47	39	-25%	-14%	-25%	-37%
Romania	257	249	232	210	-18%	-5%	-9%	-13%
Slovakia	87	82	76	71	-18%	-6%	-11%	-16%
Slovenia	33	35	36	34	3%	-6%	-11%	-17%
Spain	278	269	270	239	-14%	-9%	-16%	-24%
Sweden	195	174	174	165	-15%	-5%	-9%	-13%
Switzerland	164	150	147	121	-27%	-8%	-13%	-19%
United Kingdom	1071	1029	1114	1124	5%	-5%	-9%	-14%
North Europe	515	470	474	444	-14%	-5%	-9%	-14%
West Europe	5343	5042	5148	4758	-11%	-5%	-10%	-16%
Central-east	1107	1079	1012	926	-16%	-6%	-11%	-16%
South Europe	1618	1529	1506	1337	-17%	-7%	-12%	-19%
Total Europe	**8584**	**8121**	**8140**	**7465**	**-13%**	**-6%**	**-11%**	**-16%**

Source: CEPE, ETH Zurich

6.2.2.2 Adaptation costs

Regarding heating, there are no (direct) adaptation costs in terms of investments due to a warmer climate. Instead the residential sector stands to gain somewhat because of reduced energy costs (see Chapter 6.4). The model does not assume reduced investments due to heating degree days, e.g. reduced insulation because the insulation levels are assumed to be still profitable given the expected energy prices of the residential sector for heating purposes.

6.3 Residential electrical appliances – projected by RESAPPLIANCE

6.3.1 Assumptions for electrical appliances – Reference Scenario 2000 to 2050

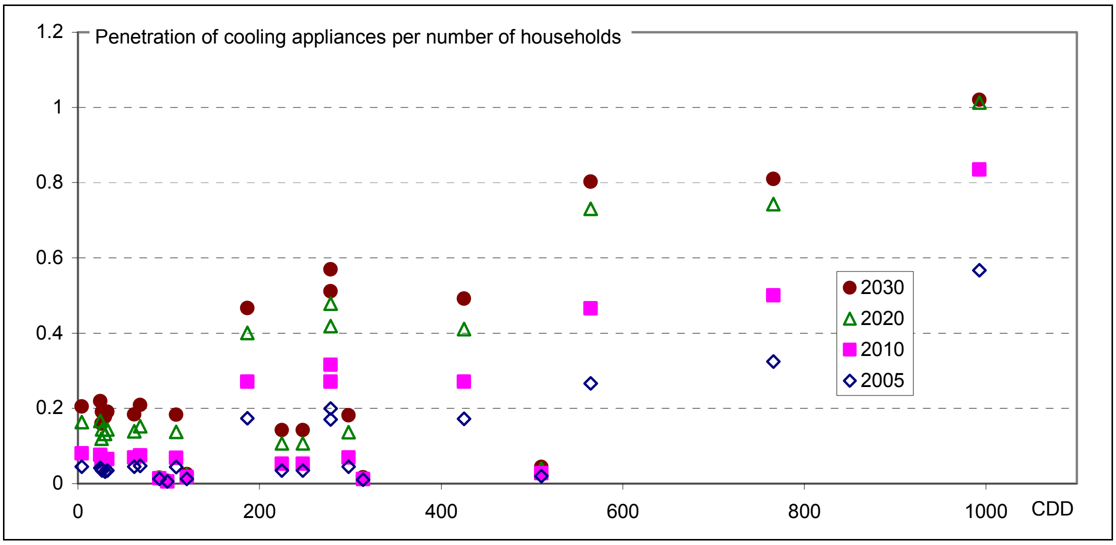
Compared to the Base Case, all the assumptions regarding the number of appliances and specific energy demand are the same with the following exceptions due to the impact of warmer climate conditions:

- increased number of cooling appliances
- increased electricity demand per cooling appliance.

6.3.1.1 Increased number of cooling appliances

The quantitative driver of cooling energy demand of the household sector is the number of cooling appliances rather than the cooled floor area as in the tertiary sector.

In order to model the impact of warmer climate on the diffusion of cooling systems ([movable] room air conditioners or split systems), the penetration of cooling appliances (which is defined as the ratio of cooling appliances by the number of households) is plotted against the cooling degree days per country (see Figure 6-2) and a function of the type (6-5) is fitted for each five year period (or ten year period after 2030). The future development of the penetration of cooling appliances is based on results adopted from Rivière, Adnot et al. (2008) who estimated the diffusion of appliances using a Bass diffusion model for several European countries.



Source: own representation (CDD based on hourly data from IWEC weather stations and on Isaac et al., 2008, number of cooling appliances based on Rivière, Adnot et al. (2008), number of households based on Jochem et al. 2007)

Figure 6-2: Average number of cooling appliances per household as a function of historical CDD (in Kelvin days, Kd), 2005 to 2030

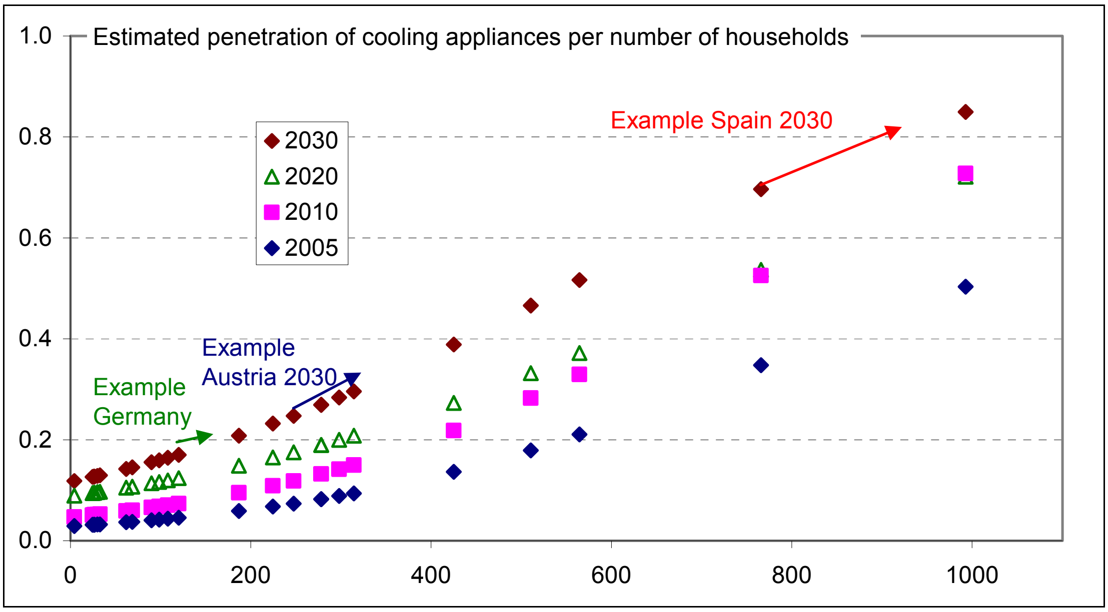
Currently, the average share of cooling appliances per household is quite low for most European countries (less than ten percent for countries with CDD below 200 and up to 20% for countries with CDD below 400 (see Figure 6-2). Note that the CDD of most countries in Europe is below 300 with only the Mediterranean countries and Romania above this threshold. Based on the estimations of Rivière, Adnot et al. (2008), the penetration of cooling appliances into countries with CDD of less than 200 will not exceed 20%

$$PentrationCoolingAppliances(CDD) = \frac{1}{(c0 + A \cdot Exp(-b \cdot [CDD - x_0]))} \qquad \text{equ. 6-5}$$

For each point in time T, the penetration of cooling appliances (PCA) of a given country for the case of a future warmer climate is estimated by its share in the case of present climate and by an increment which amounts to the difference of the equation 6-5 estimated at the CDD of the present climate (PC) and the warmer climate (WC) respectively (equation 6-6).

$$PCA_{Country,WC,T} = PCA_{Country,PC,T} + PCA(CDD_{WC,T}) - PCA(CDD_{PC,T}) \qquad \text{equ. 6-6}$$

Up to CDD of about 200, the slope of the penetration curve is quite flat, i.e. increase of the estimated penetration as a function of CDD of cooling appliances is quite low (see Figure 6-3). Note that the CDD of most of the countries in Europe is below 300 with only the Mediterranean countries and Romania above this threshold. As a matter of fact, the increase of the penetration of cooling appliances as a function of time assuming constant climate largely exceeds the impact of warmer climate, particularly in the case of most non-Mediterranean countries, as the example of Austria shows (see Figure 6-3). Indeed, with constant climate, the penetration would increase from 3.5% to 14% between 2005 and 2030 in the case of Austria (based on the number of appliances of Rivière, Adnot et al. 2008 and on the number of households as used within the ADAM project).



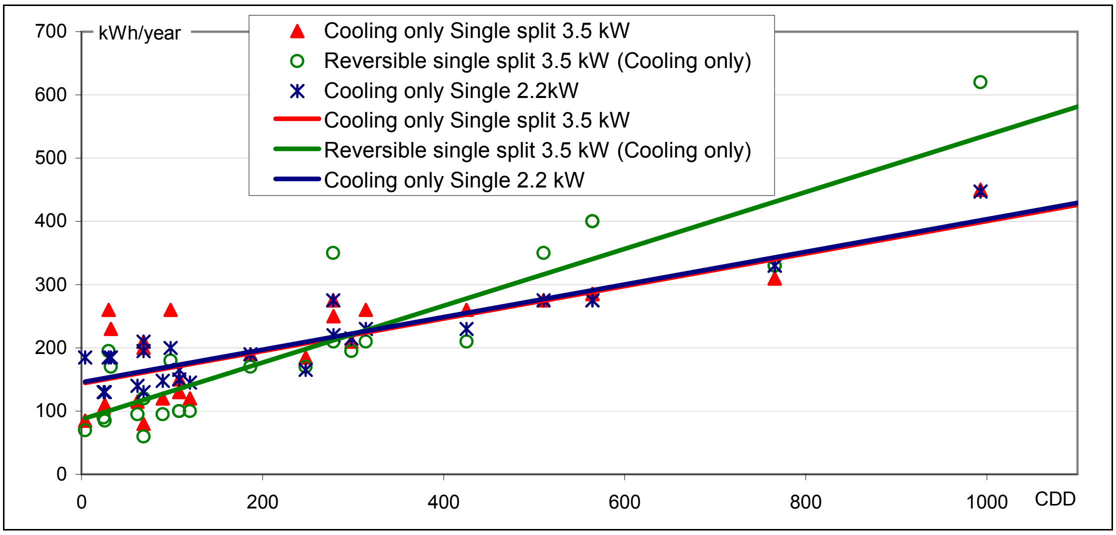
Source: own estimations based on equation 6-5 using data as depicted in Figure 6-2

Figure 6-3: Penetration of cooling appliances per household as a function of historical CDD, selected European countries, 2005 to 2030

With warmer climate, i.e. with CDD that increase from 248 to 323, Austria's penetration would be 6 %-points higher, i.e. it would reach 20 % instead of 14 % in 2030. In the case of most other European countries, the impact of warmer climate in the Reference Scenario as compared to the development in the Base Case Scenario is even lower: the penetration curve as a function of CDD below 200 Kd is less steep, but there is nevertheless a quite noticeable increase of the penetration between 2005 and 2030.

6.3.1.2 Increased electricity demand per cooling appliance

The specific energy demand of cooling appliances depends both on the quality of products (energy efficiency, controls) and their use, the building and its operation and ultimately on the climate. As can be concluded from Rivière, Adnot et al. (2008), there are large differences between the countries, not only due to differences in climate, but also due to the building stock and due to cultural factors that influence the use of cooling appliances (Figure 6-4). Note that cooling appliances are characterised by a certain "base load" consumption which is constant and varies only slightly with CDD: the specific energy demand (SED), i.e. the yearly energy consumption, amounts to between 100 and 200 kWh/year at the least, even in countries with CDD of 100 or less.



Source: *own representation based on Rivière, Adnot et al (2008) (yearly energy demand per appliance per country) and on CDD as described in section 6.1*

Figure 6-4: Penetration of cooling appliances per household as a function of historical CDD

In order to model the impact of climate change on the specific energy demand of cooling appliances, the specific energy demand per country as indicated by Rivière, Adnot et al. (2008) is used as a starting basis. The impact of the warmer climate is added to it (see equation 6.3-3). ??

$$SED_{Country,WC(T),T} = SED_{Country,PC,T=2005} + h_T \cdot (CDD_{Country,WC(T)} - CDD_{Country,PC,T=2005}) \quad \text{equ.6-6}$$

To do so, the yearly energy (electricity) demand values of the different type of cooling appliance are aggregated to a weighted average per country, using their relative proportions in the appliance stock of each five year period (based on Rivière, Adnot et al. 2008). These country-specific values are linearly fitted against the CDD. As the relative proportions of the different cooling systems vary over time, the estimated slope also varies over time, however only slightly: between 0.36 in 2005 and 0.4 in 2030 (SED is measured in kWh/year and disregarding technical efficiency progress with is modelled separately). The estimated coefficient is used as coefficient h_T in equation 6-6 to estimate the impact of warmer climate.

6.3.2 Results of electric appliances - Reference Scenario 2000 to 2050

6.3.2.1 Electricity demand

The demand for air conditioning is greatly increasing in Europe, both in Base Case Scenario and in Reference Scenario (see Table 6-4). As discussed in the previous section, there are two drivers: more diffusion and more energy for cooling because of warmer climate (in old and new cooled area). In absolute terms, the major impacts are in the southern countries, because of the much bigger air cooled area. In these countries the saturation level is approaching, so there is a slightly noticeable smaller growth in floor area (which would be seen in a longer period). In relative terms, the area most affected is central Europe, because of the lower initial level, but with greater need for cooling (compared to the northern countries).

Table 6-4: Electricity demand for cooling, in PJ, Reference Scenario and impact of warmer climate, EU27+2 and foru European regions, 2005– 2050

	Cooling demand					Impact of warmer climate		
	2005	2020	2035	2050	Δ% 2005 -2050	2020	2035	2050
Austria	0.1	0.3	0.7	0.8	1007%	43%	113%	175%
Baltic States	0.1	0.3	0.4	0.4	332%	7%	18%	26%
Belgium/Luxembourg	0.1	0.4	0.6	0.7	562%	14%	42%	63%
Bulgaria	0.6	1.6	2.2	2.2	298%	23%	62%	88%
Czech Republic	0.0	0.1	0.1	0.1	372%	67%	219%	373%
Denmark	0.0	0.1	0.2	0.2	376%	4%	12%	17%
Finland	0.1	0.2	0.3	0.3	465%	4%	11%	15%
France	0.9	3.8	7.2	9.0	896%	36%	92%	140%
Germany	0.2	0.7	1.2	1.6	589%	50%	165%	286%
Greece	4.5	9.3	10.9	11.6	156%	14%	34%	44%
Hungary	0.0	0.2	0.4	0.6	1743%	302%	832%	1391%
Ireland	0.0	0.2	0.3	0.3	653%	1%	3%	5%
Italy	7.8	27.1	35.9	37.5	378%	20%	51%	68%
Malta/Cyprus	0.5	1.1	1.4	1.6	221%	10%	27%	34%
Netherlands	0.1	0.5	0.7	0.8	430%	6%	19%	27%
Norway	0.0	0.2	0.3	0.4	677%	3%	9%	13%
Poland	0.0	0.1	0.3	0.5	819%	114%	367%	668%
Portugal	0.1	0.8	1.8	2.7	2679%	274%	658%	1015%
Romania	1.2	3.4	5.6	6.0	420%	37%	93%	128%
Slovakia	0.3	0.7	1.1	1.2	340%	20%	57%	79%
Slovenia	0.1	0.2	0.4	0.4	400%	19%	58%	81%
Spain	5.9	18.8	28.7	32.5	450%	31%	75%	99%
Sweden	0.1	0.4	0.6	0.6	538%	4%	13%	19%
Switzerland	0.1	0.3	0.5	0.6	746%	35%	90%	140%
United Kingdom	0.5	1.9	2.9	3.1	580%	3%	13%	19%
North	0.2	1.0	1.4	1.5	519%	4%	12%	17%
West	2.0	8.0	14.1	16.9	733%	24%	63%	96%
Central-East	0.6	1.6	2.7	3.2	474%	33%	89%	139%
South	20.6	62.2	86.5	94.2	357%	24%	60%	81%
Total Europe	23.4	72.9	104.7	115.8	394%	24%	60%	83%

Source: CEPE, ETH Zurich.

The demand for air conditioning in 2050 is very or relatively small, compared with the other appliances (see Table 6-5), ranging from 0.8 % in northern countries to 11 % in southern Europe (with an average of 4 % overall Europe, however tripling between 2005 and 2050).

Table 6-5: Cooling demand share of the electric appliances (without cooking and lighting), in %, European regions, Reference Scenario, 2005– 2050

	2005	2020	2035	2050
North	0.2%	0.6%	0.8%	0.8%
West	0.2%	0.7%	1.0%	1.1%
Central-east	0.4%	0.8%	1.1%	1.1%
South	4.1%	9.8%	11.4%	11.0%
Total Europe	**1.3%**	**3.4%**	**4.1%**	**4.0%**

Source: CEPE, ETH Zurich.

6.3.2.2 Adaptation costs

Adnot (2007) estimated costs of room air conditioning for several European countries: the values are in the range between 335 € and 695 € per movable air conditioner, and between 449 € and 1216 € for split air conditioners. This means a cost between 127 € and 242 € per installed thermal Watt.

To calculate the investment costs of additional air conditioning, a re-investment cycle of 15 years is assumed. Of the re-invested air conditioners, only 1/3 is included in the additional investment costs: nearly 2/3 of air conditioners will be installed anyway in the Base Case Scenario, but with an anticipation of some years/decade in the Reference Scenario.

The total investment costs in the new appliances are in the region of170 € to 510 million € per year (i.e. up to few euros per person), but with a perceptibly higher impact in southern countries (higher investment per person) and in western Europe (most populous region).

Table 6-6: Adaptation investment costs because of warmer climate (due to more cooling appliances) in the residential sector in Euopean regions , in million € per year, 2010– 2050

	Investment costs cooling appliances			
Country group	**2010**	**2020**	**2035**	**2050**
North	0	2	3	5
West	31	103	156	201
Central-east	6	20	27	33
South	132	208	253	277
EU27+2	**169**	**333**	**440**	**516**

Source: CEPE, Zurich

6.4 Overall results regarding energy demand in the residential sector

Fuel demand in the residential sector is derived from three areas: heating demand (82 to 84 %), hot water demand (12 to 14 %), and cooking (4 %). For the two last items, there is no climate impact (by model assumption), and their share is less than 20 % of total fuel demand.

For these reasons, we refer back to Section 6.2.2 for the results discussion, and the Table below for the aggregate data.

For Europe as a whole, the fuel and district heat demand will decrease continuously throughout the period. In 2050, the impact of the warmer climate (+4°C at the end of this century) amounts to a decrease due to reduced space heating by some 1,400 PJ or -14 % for EU27+2 (see Table 6-7). The changes vary in the different European countries as explained in chapter 6.2.2.

Table 6-7: Demand for fuels, in PJ, and relative impact of climate change in %, EU27+2 and European regions, Reference Scenario, 2005– 2050

Country or Country group	Fuels					Impact of warmer climate		
	2005	2020	2035	2050	2005-2050	2020	2035	2050
Austria	231	225	224	201	-13%	-5%	-9%	-14%
Baltic States	144	130	113	97	-32%	-4%	-8%	-12%
Belgium	384	348	351	319	-17%	-4%	-8%	-12%
Bulgaria	58	53	46	40	-31%	-5%	-9%	-12%
Czech Republic	192	182	168	152	-21%	-6%	-10%	-15%
Denmark	143	134	132	121	-16%	-4%	-7%	-11%
Finland	134	125	122	110	-18%	-4%	-8%	-11%
France	1279	1262	1277	1184	-7%	-5%	-10%	-16%
Germany	2211	2019	1984	1750	-21%	-5%	-9%	-13%
Greece	165	143	150	146	-11%	-3%	-7%	-11%
Hungary	203	185	166	147	-27%	-5%	-10%	-15%
Ireland	84	94	107	110	31%	-4%	-9%	-13%
Italy	941	878	863	754	-20%	-6%	-10%	-16%
Malta/Cyprus	10	11	12	11	5%	-6%	-13%	-25%
Netherlands	352	327	315	280	-20%	-5%	-10%	-15%
Norway	38	41	48	45	21%	-5%	-10%	-15%
Poland	639	632	597	545	-15%	-4%	-8%	-13%
Portugal	82	77	72	61	-26%	-10%	-18%	-28%
Romania	282	268	248	222	-21%	-5%	-8%	-12%
Slovakia	96	89	83	76	-22%	-5%	-9%	-14%
Slovenia	35	38	38	36	4%	-5%	-11%	-16%
Spain	475	474	456	404	-15%	-5%	-10%	-15%
Sweden	181	194	198	189	4%	-4%	-7%	-11%
Switzerland	166	150	145	119	-28%	-7%	-12%	-18%
United Kingdom	1394	1295	1345	1326	-5%	-4%	-7%	-11%
North	496	494	500	465	-6%	-4%	-8%	-12%
West	6100	5720	5749	5288	-13%	-5%	-9%	-14%
Central-east	1309	1256	1165	1053	-20%	-5%	-9%	-14%
South	2013	1904	1848	1637	-19%	-5%	-10%	-15%
Total Europe	**9917**	**9374**	**9262**	**8443**	**-15%**	**-5%**	**-9%**	**-14%**

Source: CEPE, Zurich.

The overall demand for electricity in the residential sector is dominated by electric appliances (up to 70 % in 2005 and to 83 % in 2050), but only two "minor" parts have climate impacts: heating and cooling. Furthermore, these two impacts compensate each other due to increasing average temperatures as explained in the previous chapters. For these reasons the electricity demand in the residential sector has a low impact on warmer climate (see the Table 6-8). Due to very different heating structures at the country level (e.g. electric resistance heating and heat pumps) and differing climate changes, the impact could be positive (on countries with high shares of electric heating, or on northern European countries where the air conditioning impact is smaller), or negative (on the other countries, in particular southern countries where air conditioning is an important factor and heating demand is lower).

Table 6-8: Electricity demand in residential sector in PJ and impact of warmer climate, in %, EU27+2 and European regions, Reference Scenario 2005– 2050

Country or Country group	Electricity in residential sector					Impact of warmer climate		
	2005	2020	2035	2050	2005-2050	2020	2035	2050
Austria	46	47	51	54	17%	-0.3%	0.1%	0.4%
Baltic States	23	27	31	36	57%	-0.8%	-1.1%	-1.3%
Belgium/Lux.	53	64	70	75	41%	0.1%	0.3%	0.4%
Bulgaria	31	34	37	39	26%	-0.1%	1.3%	1.8%
Czech Republic	56	59	59	61	8%	-2.7%	-4.1%	-4.6%
Denmark	37	38	40	42	13%	-0.3%	-0.3%	-0.3%
Finland	75	72	72	70	-6%	-1.5%	-2.3%	-3.2%
France	488	537	586	615	26%	-1.2%	-1.8%	-2.6%
Germany	464	470	490	505	9%	-0.3%	-0.3%	-0.2%
Greece	72	86	85	88	21%	-0.7%	0.6%	0.9%
Hungary	46	48	51	56	22%	-0.2%	-0.1%	0.0%
Ireland	19	28	36	43	121%	0.0%	0.0%	0.0%
Italy	243	295	333	353	46%	1.4%	3.5%	4.1%
Malta/Cyprus	8	11	13	15	76%	-0.6%	-0.5%	-1.6%
Netherlands	71	80	90	99	40%	0.0%	0.1%	0.2%
Norway	110	106	107	113	3%	-2.4%	-3.9%	-5.3%
Poland	104	120	140	168	61%	-0.3%	-0.4%	-0.4%
Portugal	51	61	71	79	56%	1.0%	2.3%	3.2%
Romania	44	64	85	106	139%	1.5%	3.3%	3.3%
Slovakia	19	21	24	28	47%	-1.5%	-1.8%	-2.4%
Slovenia	9	10	11	13	36%	-0.1%	0.3%	0.4%
Spain	249	293	340	368	48%	1.2%	3.2%	3.9%
Sweden	138	105	103	103	-26%	-1.2%	-1.5%	-1.8%
Switzerland	54	58	62	59	9%	-1.4%	-2.3%	-3.1%
United Kingdom	404	474	535	583	44%	-1.0%	-1.9%	-2.9%
North	360	321	321	328	-9%	-1.6%	-2.3%	-3.2%
West	1600	1759	1922	2032	27%	-0.8%	-1.2%	-1.7%
Central-east	258	286	316	361	40%	-0.9%	-1.2%	-1.3%
South	698	845	963	1047	50%	1.0%	2.9%	3.4%
Total Europe	2916	3211	3522	3769	29%	-0.4%	-0.2%	-0.4%

Source: CEPE, Zurich.

In the residential sector, adaptation reduces the energy demand and the energy costs: all buildings are affected more or less by reduced heating demand, but in some southern parts of Europe, electricity demand is increasing. Contrary to the service sector, air conditioning will only be additionally installed in relatively few buildings, thus reducing the negative effects of adaptation.

In 2050, the heating costs are reduced by 30 € to 51 € per inhabitant per year, assuming the penergy prices from the POLES model results, i.e. on the average of 43 € per inhabitant in Europe. The region most affected is western Europe (51 € per inhabitant per year) because of higher climate impact, together with higher heating demand. In terms of electricity costs, the average European saving is about 3 € per inhabitant per year, but with increment from 3 € per inhabitant per year in central Europe to reducing 13 € per inhabitant per year in northern Europe. In this case, the two effects of reduced heating demand with the additional cooling demand are added (see Table 6-9). The variability between countries (and regions) is due to the varying share of electricity demand for heating (resistance heating and heat pumps) in the different countries.

Table 6-9: Change in energy costs (fuels and electricity) between Base Case and Reference Scenario, in Mill. € per year, EU27+2 and European regions, 2005– 2050.

Country group	Fuels				Electricity			
	2010	2020	2035	2050	2010	2020	2035	2050
Austria	-76	-153	-290	-414	-4	-5	-3	0
Baltic States	-36	-55	-86	-117	-3	-7	-12	-16
Belgium/Luxembourg	-70	-168	-393	-705	0	1	3	5
Bulgaria	-9	-18	-30	-40	-3	-3	1	4
Czech Republic	-43	-88	-178	-274	-17	-30	-45	-52
Denmark	-50	-96	-219	-345	-5	-6	-8	-8
Finland	-28	-55	-104	-158	-15	-23	-36	-49
France	-394	-865	-1920	-3289	-93	-175	-318	-497
Germany	-634	-1319	-2857	-4647	-46	-64	-71	-54
Greece	-42	-75	-166	-290	-18	-22	-19	-20
Hungary	-26	-50	-114	-198	-2	-2	-3	-3
Ireland	-16	-48	-132	-248	0	0	0	0
Italy	-462	-933	-1824	-2802	17	91	216	275
Malta/Cyprus	-4	-10	-28	-66	-2	-3	-5	-10
Netherlands	-115	-231	-545	-854	0	1	2	4
Norway	-17	-35	-80	-125	-48	-90	-159	-233
Poland	-100	-223	-530	-1011	-3	-7	-11	-16
Portugal	-59	-119	-237	-367	3	15	32	46
Romania	-57	-91	-161	-244	2	10	25	33
Slovakia	-18	-37	-75	-123	-5	-11	-17	-25
Slovenia	-12	-27	-64	-110	-1	-1	-1	-1
Spain	-127	-252	-561	-908	-3	29	92	124
Sweden	-50	-116	-224	-336	-38	-46	-59	-72
Switzerland	-72	-140	-297	-440	-17	-32	-59	-75
United Kingdom	-247	-566	-1455	-2814	-78	-181	-416	-707
North	-144	-301	-627	-964	-106	-165	-261	-361
West	-1625	-3489	-7890	-13411	-238	-455	-861	-1324
Central-east	-235	-481	-1047	-1833	-31	-58	-89	-113
South	-761	-1498	-3007	-4717	-4	117	343	451
Total Europe	**-2766**	**-5770**	**-12572**	**-20926**	**-379**	**-561**	**-868**	**-1346**

Source: CEPE, Zurich.

6.5 The service sectors and agriculture – projected by SERVE-E

In this section, the impact of climate change on the energy demand of the tertiary sector of Europe (EU27+2) is estimated, based on the methodology described in section 6.1.[11]

As pointed out by Varga and Pagliano (2006), and referring to forecasts by the IEA Future Building Forum and Adnot (e.g. Adnot, 2003), one of the fastest growing sources of new energy demand is cooling. This increase is related to bad building design (e.g. missing solar protection), increasing internal heat loads of electric office equipment, lighting and comfort needs that are translated into inappropriate thermal requirements (Varga and Pagliano, 2006). An increasingly warmer climate will amplify this trend and thus will impact significantly on the energy demand of the building sector in Europe. This impact can be structured into two main components, namely, a direct physical impact and a socio-economic impact. The first mentioned impact refers to the increased specific energy demand in buildings with installed cooling systems, which lead to an additional heat load and to a decrease in heating energy demand (Frank, 2005, Christenson Manz et al., 2006). The second mentioned impact refers to the changed behaviour of investors and building users, which leads to a wider diffusion of cooling systems and devices in the building stock.

For three reasons, the tertiary sector is particularly relevant with regard to the impact of climate change. First, it has one of the fast growing energy and especially electricity demand and thus makes an increasing contribution to the problem. Second, efficiency potentials and hence CO_2 mitigation potentials are particularly large in this sector. Third, the buildings of the tertiary sector are much more vulnerable to a changed (warmer) climate and hence adaptation measures are particularly relevant, both for physical reasons (e.g. high internal loads, less air exchange through windows compared to residential buildings, especially at night) and due to impacts on indoor comfort conditions and ultimately on productivity (Aebischer et al., 2007).

6.5.1 Assumptions for services and agriculture – Reference scenario 2000 to 2050

6.5.1.1 Impact on cooling energy

Choosing a new office building with high internal loads and a rather large proportion of glazing as an illustrative example, it can be stated that the electricity demand for cooling increases with increasing CDD, not linearly, but with a decreasing gradient (see Figure 6-5), Note however that growth rates are increasing: a doubling of the CDD from 20 to 40 increases cooling energy demand by 4%, from 40 to 80 by 7%, and from 640 to 1,280 by 37%. Since relative changes in CDD follow an opposite pattern (see Table 6-1), the impact of warmer climate on specific cooling electricity is quite similar across regions: between 13% (Warsaw) and about 20% for locations as different as Birmingham, Stockholm, Zurich, Berlin, Warsaw, Prague, Sofia, Debrecen (Hungary), Madrid, Marseille, Rome, and Paris. It is also worth noting that in this type of building there is a non-negligible cooling demand even in locations with very low or zero CDD. Its value amounts to about 60 MJ_e/m^2a, which is

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equivalent to a thermal load of about 110 MJ_{th}/m^2a. In absolute terms, total specific electricity demand of southern regions is clearly above the average of all locations. High cooling energy demand is partially, but not fully, compensated by low lighting energy demand due to more daylight availability. Except for the southern regions, most of Europe has a similar specific electricity demand: 280 to 310 MJ/m^2a in the Base Case and 300 to 330 MJ/m^2a with a warmer climate.

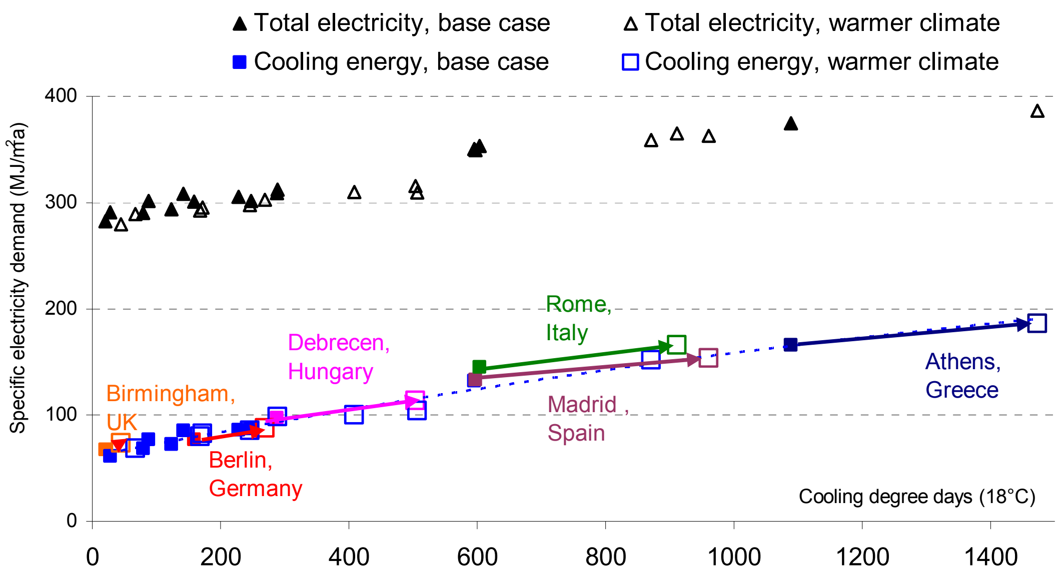


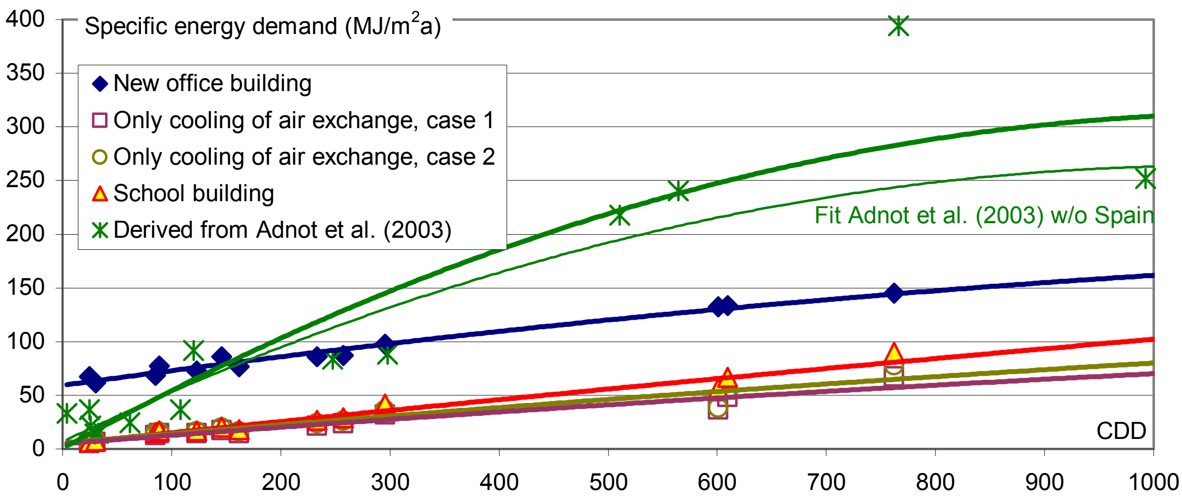
Figure 6-5: Cooling and total electricity demand of new office buildings as a function of cooling degree days (CDD) for different locations in Europe.

Depending on the building type, its cooling concept and mode of operation, specific energy demand for cooling varies considerably, as also pointed out by Adnot et al. (2003), Volume 1, p. 16. Indeed, specific cooling energy demand of certain buildings in locations such as London with almost zero CDD might be higher than the cooling energy demand of other building types in locations such as Milan with about 350 CDD (note that the impact of warmer climate on CDD is much smaller for most European regions, see Table 6-1).

Similarly, the impact of warmer climate for a given location (e.g. Switzerland) can be quite different depending on the building type considered. The climate impact on the cooling energy demand (in absolute values) is much smaller (10 to 25 MJ/m^2a) than the impact of the building type, which ranges from 5 to more than 100 MJ/m^2a of electricity for cooling, see Aebischer, Jakob et al. (2007). This means that even with a warmer climate, cooling energy demand can be reduced substantially if building and cooling concepts are adjusted accordingly. Particularly, it can be reduced below the demand in many cases with today's climate. In other words: the impacts of targeted energy efficiency measures may be of larger magnitude than climate change impacts.

Another parameter that determines the electricity demand for cooling and that could be affected by changed outdoor conditions is the yearly averaged coefficient of performance (COP). It could be both de- or increased. An argument for an increase would be the economics of energy efficiency (the higher the electricity demand, the more economical energy-efficiency improvements become). Arguments for a decrease would be sub-optimal design of heat exchangers, less operating hours with moderate outdoor temperature. Since it is unclear which of the arguments would dominate, it is assumed that the annual COP of cooling systems is constant between the two climate scenarios (an average value of 2.5 was assumed). This approach allows for a ceteris paribus study of the impact of changed outdoor temperature, i.e. regardless any change in HVAC efficiency. Also it is assumed that indoor set point T would not change with warmer climate: a set point temperature of 26°C was assumed in both cases. Moreover, control strategies, for instance of solar protection elements, are assumed to be constant.

Figure 6-6 displays results obtained from IDA-ICE simulations of three different types of office buildings and one type of school building. Each building case was simulated for fourteen different locations in Europe for the two climate scenarios. For the sake of readability, only the results of the base case are displayed in Figure 6-6, as the results of the WC scenario follow the same pattern. For comparison, the results of Adnot et al. (2003) are also included in the graph. Similar to the case of heating, the slope of fitted (quadratic) functions is lower, the more energy-efficient the considered building types and cooling systems and concepts are. In the case of our own simulations, assumptions are valid for rather efficient concepts (adjusted air exchange rate, room-set-point T of 26°C) which might not be fully achieved in practice, especially not in the case of old buildings and cooling systems. This also explains the difference to the results of Adnot et al. (2003) which are presumably representing not only new buildings and optimised practice (note for instance, that set-point T lower than 26°C, e.g. 23°C, would increase cooling energy demand by several tens of percentage-points), but the building stock as a whole.



Source: Adnot et al. (2003), own calculations (simulation model IDA), CDD derived from ASHRAE (2002) and Isaac et al. (2008).

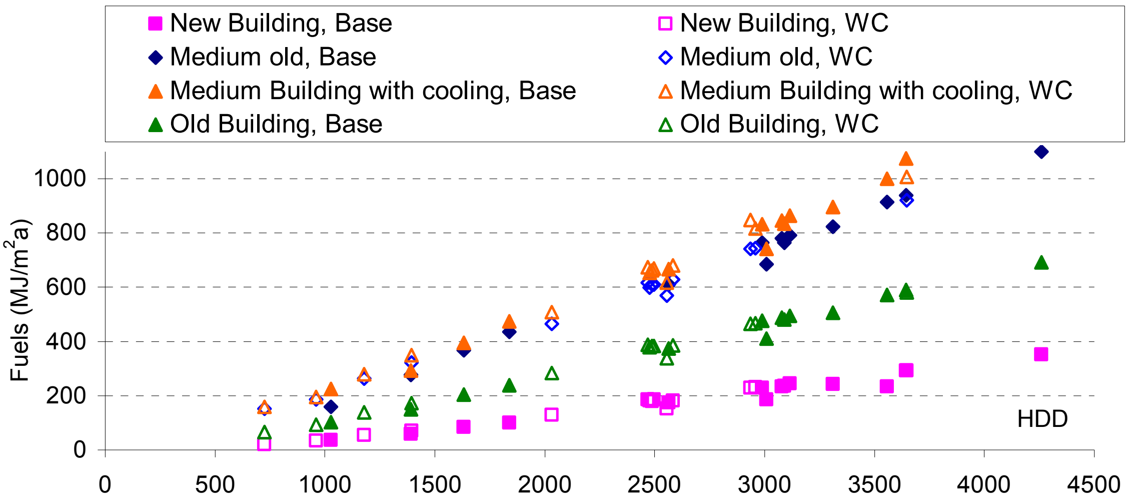
Figure 6-6: Specific electricity demand for cooling of various buildings as a function of cooling degree days (CDD) for different locations in Europe (base case climate scenario).

6.5.1.2 *Impact on specific heating energy demand*

Specific heating energy demand (SED) is increasing more or less linearly with increasing HDD (see Figure 6-7) which allows for fitting linear functions of the type of equation (3). Note that heating is only needed in situations with HDD of more than about 500 °Cd. ??? Indeed, due to solar and internal heat gains, heating is not necessary even if daily average outdoor temperature is – to a certain extent – distinctly lower than desired indoor temperature,[12] which implies negative b_{EE}. The slope m_{EE} of the linear fits depends on the energy efficiency of the assessed buildings.

$$SED_{EE} = b_{EE} + m_{EE} * HDD \qquad (3)$$

m_{EE} obtained from fits to results of building simulation runs with IDA-ICE and calculations according to the norms SN EN 832 or SIA 380/1 range between 0.17 and 0.2 in the case of non-insulated multi-family house type buildings (depicted as "old buildings" in Figure 6-7), between 0.25 to 0.28 in the case of medium-old buildings with ventilation systems, and about 0.1 in the case of new office buildings with adjusted ventilation rates (SED expressed in MJ/m^2a and HDD in Kd). In the case of very energy-efficient buildings that follow the German Passive house or the Swiss Minergie-P standard, m_{EE} can be even lower than 0.025.



Source: own calculation, using simulation model IDA, HDD according to Table 6-1.

Figure 6-7: Impact of warmer climate on fuel energy demand of office buildings as a function of HDD for the base case (base) and warmer climate (WC) scenario.

6.5.1.3 *Impact of warmer climate on the level of the tertiary sectors of Europe*

Main driver of the bottom-up model in terms of quantity is the energy floor area, which is determined by the number of employees (derived from value added per sector and productivity progress, adopted from the economic model E3ME) and their projected specific floor area. The current state of the floor area is derived from the ODYSSEE database and from statistical data of the number of employees per sector and per country. For each sector, a

[12] This is also the reason why other HDD definitions with lower thresholds would be more appropriate (e.g. HDD are 0 for all days with average T above 12°C).

long-term saturation level is assumed (see Jochem et al. 2007 for details). In some sectors, the floor area per employee rather decreases (e.g. office space) whereas in others it increases (e.g. commerce where less and less personal per square meter of sales area is needed) which entails a structural change between the sub-sectors.

Specific energy demand per unit of floor area (SED) of the model base year is derived from the ODYSSEE database. To project the specific energy demand in 2050, assumptions on the technical progress and on the “income” elasticity of the specific energy demand (dSED/SED / dVA/VA) where “income” is expressed in value added (VA) are made (see Jochem et al. 2007 for details). These assumptions are made on the level of the previously mentioned six sub-sectors.

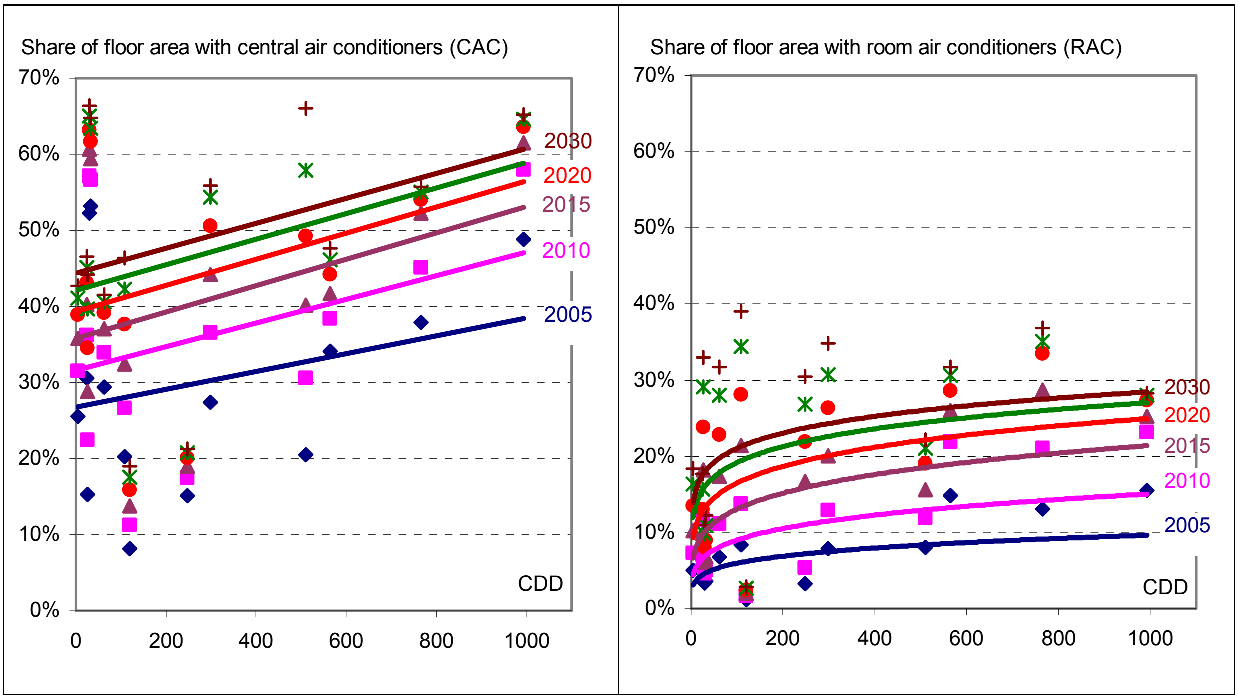
In order to model the impact of warmer climate, specific electricity and non-electricity (fuels) demand are disaggregated into space-cooling and other electricity services and into space-heating and “process” heat energy respectively. It is assumed that space-cooling and space-heating varies with climate, whereas process-cooling (for instance to cool products), other electricity services and process heat is assumed to be invariant to climate change. Process heat as defined in this paper includes all thermal heating energy services such as hot water, laundry and other washing services, cooking, etc. but excludes space heating. The share of process heat varies between the sub-sectors and ranges from roughly 10 % (trade, finance, administration, education), 25 % (health) to about 50 % (hotels, restaurants).

6.5.1.4 Assumptions and results regarding the impact of WC on the share of cooled floor area

As opposed to the case of heating, where 100% of the occupied floor area (FA) is heated, significantly less than 100% of the FA is cooled and/or ventilated. Empirical evidence regarding the quantitative relevance of central air conditioning (CAC) or room air conditioners (RAC) can be found in two studies DGTREN of the EC, namely in Adnot et al. (2003) in Rivière, Adnot et al. (2007). The amount of cooled FA was obtained by dividing their results regarding installed power by specific values of installed capacity per square meter (W/m^2). These values, which are country- and building-type-specific, were adopted from Rivière, Adnot et al. (2007), Task 4. If ideally dimensioned or chosen, these values range typically between 70 and 130 W/m^2 (in the case of cooling, only air conditioners). However, in practice, cooling systems and devices are often over-dimensioned. For CAC, a factor of over-dimensioning of 1.5 and for RAC a factor of 2 is assumed. These factors may seem high; note however that shares of cooled FA of more than 100% would be obtained with lower factors.

The country-specific shares of cooled floor area are obtained by dividing the obtained cooled floor area by the countries’ total modelled floor area. For the model base year (2005), these shares range between about 20% to about 35% for most of the countries north of the Alps (a noticeable exception is Germany with only 9%) and between 50% and 65% for the Mediterranean countries. Hence, even with CDD close to 0, a noticeable share of office and other space of the tertiary sector is either centrally air conditioned or equipped with RAC.

Next to empirical evidence regarding the to-date levels of cooling devices, both mentioned DGTREN studies performed projections up to 2020 and up to 2035 respectively. These projections are based on a cohort approach and a Bass diffusion model which is adjusted to past sales data (see Rivière, Adnot et al. 2008). The thereby derived cooled floor area was related to the total floor area of the model base year 2005. The thus obtained shares of cooled floor of the different European countries and years are then related to country-specific CDD data. In the case of CAC, linear models of the form $Share_{CAC}=m_Y*CDD_{Base}+b_Y$ are suitable for each model year *Y* and in the case of RAC a power model of the form $Share_{RAC} = m_Y*CDD^{by}$, see Figure 6-8.



Source: Adnot et al. (2003), Isaac (2007), Jochem et al. (2007), own calculations

Figure 6-8: Shares of central air conditioning (CAC, left graph) and of room air conditioners (RAC, right graph) as a function of cooling degree days (CDD)

The impact of warmer climate was modelled separately for CAC and for RAC. In the case of CAC, $S^C_{CAC,WC}$, which denotes the share of FA cooled with CAC of country C in the case of warmer climate (WC) of a given model year Y, is obtained by equation (5), where m_Y is the slope of a given model year Y which was obtained from the linear regression. In the case of RAC, the share of cooled FA was obtained by equation (6). Hence, in both cases, the individual share of each country was taken as a starting base to which was added the mean impact of WC obtained by the regression models.

$$S^C{}_{CAC,WC} = S^C{}_{CAC,PC} + m_Y * (CDD^C{}_{WC} - CDD^C{}_{Base}) \quad (5)$$

$$S^C{}_{RAC,WC} = S^C{}_{RAC,PC} + m_Y * (CDD^C{}_{WC})^{bY} - m_y * (CDD^C{}_{Base})^{bY} \quad (6)$$

From the slopes and the course of the power functions (Figure 6-8) and the change of CCD due to warmer climate in Table 6-1, on the one hand, and from the differences between the different model years on the other hand, it can be concluded that current trends as projected by Adnot et al. (2003) and Rivière, Adnot et al. (2008) have a stronger impact than the assumed climate change. Indeed, total shares of CAC and RAC increase by typically 25% to 40%-points between 2005 and 2030, whereas the additional increase due to warmer climate typically amounts to 1% to 3% in the case of the countries north of the Alps and to 3% to 5%

in the case of the Mediterranean and south-eastern European countries. Further increases are expected up to 2050 (see Table 6-10).

Table 6-10: Resulting cooled floor area of the service sectors of Europe (EU27+2) for 2005, 2020, 2035, and 2050 (billion m²) and relative changes

		Base Case						Warmer Climate (WC)						WC/Base		
	2005	2020	2035	2050	2020/ 2005	2035/ 2005	2050/ 2005	2020	2035	2050	2020/ 2005	2035/ 2005	2050/ 2005	2020	2035	2050
Mediterr., SE EU*	0.70	1.48	1.93	2.12	2.1	2.7	3.0	1.55	2.04	2.32	2.2	2.9	3.3	1.04	1.06	1.09
Rest of EU27+2	1.27	2.75	3.71	4.15	2.2	2.9	3.2	2.83	3.86	4.44	2.2	3.0	3.5	1.03	1.04	1.07
Total EU27+2	1.97	4.23	5.64	6.27	2.1	2.8	3.2	4.38	5.90	6.75	2.2	3.0	3.4	1.03	1.05	1.08

Source: Calculations by the authors, based on data from Adnot et al. (2003), Rivière, Adnot et al (2008), Isaac et al. (2007), ASHRAE (2002) and Jochem et al.(2007), [last updated 17 September 2008] * South-east Europe including Romania and Bulgaria.

For Europe as a whole (EU27+2), the amount of cooled floor area in absolute terms roughly triples up to 2035 (Table 6-10), whereas in relative terms it roughly doubles (from 31% to 63% in the base case and to 65% in the case of warmer climate), as can be derived from Table 6-11. Note that the relative increase between 2005 and 2035 is higher in the case of the more northerly countries as these countries start from quite a low level (in 2005, only about 25% of the floor area are cooled, which is about half of the respective share in the southern countries). Up to 2050, almost one hundred percent of the floor area of the service sector in the Mediterranean and south-east European countries is assumed to be cooled and also in the rest of Europe, the share of cooled floor area reaches about 70%.

Table 6-11: Resulting cooled floor area as share of total floor area of the service sectors of Europe (EU27+2) for 2005, 2020, 2035, and 2050

		Base Case			Warmer Climate (WC)		
	2005	2020	2035	2050	2020	2035	2050
Mediterr., SE EU *	0.41	0.66	0.71	0.74	0.68	0.75	0.81
Rest of EU27+2	0.23	0.39	0.45	0.49	0.40	0.47	0.52
Total EU27+2	0.27	0.45	0.51	0.55	0.47	0.54	0.59

Source: calculations by the authors, based on Table 6-10 and Jochem et al. 2007), [last updated 17 September 2008] * South-east Europe including Romania and Bulgaria.

6.5.1.5 Assumptions regarding the impact of WC on the specific energy demand for cooling

Resuming the findings of the respective previous section (Figure 6-6), it is assumed that the specific energy demand (SED^C_Y) for cooling of country *C* of a given year *Y* is the sum of the country's base SED and the difference of a function which is quadratic in CDD and which is evaluated at the year Y and the base period, see equation (7). Due to technical progress, it is assumed that the coefficients of the mentioned quadratic function will change over time. Indeed, due to structural changes (increasing share of new buildings) and retrofitting of existing cooling systems, one can assume that the impact of warmer climate becomes weaker and weaker (as in Figure 6-6, the slopes of new buildings are less steep than today's average). In Table 6-12 the assumed coefficients for the years 2005 and 2050 are displayed. For interim model years, the outcome of equation (7) is interpolated between 2005 and 2050.

$$SED^{C}{}_{Y,WC} = SED^{C}{}_{Base} + \left[a_i * (CDD^{C}{}_{Y,WC})^2 + b_i * (CDD^{C}{}_{Y,WC})\right] \\ -\left[a_i * (CDD^{C}{}_{Y0,Base})^2 + b_i * (CDD^{C}{}_{Y0,Base})\right] \quad (7)$$

Table 6-12: Coefficients of equation (7)

	ai	bi
Model base period (i=1)	-0.000230	0.5
Time horizon of model 2050 (i=2)	-0.000015	0.2

Source: assumptions of the authors [last updated 22 July 2008].

Note that in both cases, a techno-economic progress that increases the energy efficiency of providing cooling services by 0.5%/year was assumed which results in an EE improvement of 20% up to 2050.

6.5.1.6 Assumptions regarding the impact of WC on the specific heating energy demand

Equations (3) and (4) and respective coefficients (Table 6-13) describe the adopted model that relates specific energy demand for heating purposes to HDD. As in the case of residential buildings, the coefficients of buildings of sectors and countries with intermediate energy efficiency (EE) are interpolated within these two boundary cases. Similar to the case of residential buildings, the impact of warmer climate is steadily decreased as m_{EE} decreases due to EE improvements of the building stock.

$$SED_{WC} = SED_{PC} + m_{EE} * (HDD_{WC} - HDD_{PC}) \quad (4)$$

Table 6-13: Coefficients of equation (3)

	b_{EE}	m_{EE}
EE = existing building stock without retrofit	-70	0.20
EE = well insulated buildings	-30	0.05
EE = best practice (equivalent to the German Passive house or the Swiss Minergie-P standard)	-25.0	0.023

Source: assumptions of the authors [last updated 22 July 2008].

In the case of no climate change (base case, present climate), non-electricity SED decrease from the current levels in all sectors, with the exception of the commerce/trade sector where a decrease is detected only after a period of growth (by 15% up to 2020, see Table 6-14). As a result of technical progress, non-electricity SED in 2050 is expected to be 20% to almost 30% below the level of 2005 (except commerce/trade: only 8% lower). In the case of warmer climate, non-electricity SED decreases significantly more, namely by about 25% to more than 40% (commerce/trade only by 21%). Hence, in 2050 non-electricity SED of the WC scenario is between 10% and 20% below the scenario for which no climate change was assumed. Note that the impact of warmer climate differs between sectors as there are structural differences between northern and southern European countries.

Table 6-14: Resulting non-electricity specific energy demand (in MJ/m²a) of the service sectors of Europe (EU27+2), weighted average of EU27+2) for 2005, 2035, and 2050 and relative change

		Base Case						Warmer Climate (WC)						WC/Base		
	2005	2020	2035	2050	2020/ 2005	2035/ 2005	2050/ 2005	2020	2035	2050	2020/ 2005	2035/ 2005	2050/ 2005	2020	2035	2050
Commerce, trade	530	610	569	486	1.15	1.07	0.92	577	510	408	1.11	0.98	0.79	0.95	0.90	0.84
Finance	643	556	505	467	0.87	0.79	0.73	523	448	388	0.83	0.71	0.62	0.94	0.89	0.83
Hotels, restaurants	761	700	654	608	0.92	0.86	0.80	674	609	548	0.90	0.81	0.73	0.96	0.93	0.90
Education	308	262	232	217	0.85	0.76	0.71	241	198	171	0.80	0.66	0.57	0.92	0.85	0.79
Health	678	596	553	520	0.88	0.82	0.77	565	500	446	0.85	0.75	0.67	0.95	0.90	0.86
Other	458	415	386	359	0.91	0.84	0.78	387	337	292	0.86	0.75	0.65	0.93	0.87	0.81

Source: Jochem et al. (2007), complemented and calculated by the authors [last updated 28 July 2008]

6.5.2 Results for services and agriculture – Reference scenario 2000 to 2050

6.5.2.1 Energy demand

The aggregate energy demand of the service sector as a whole is obtained from the sum product of the floor area per sector and the specific energy demand inputs. In the base case, non-electricity fuel energy demand is increasing by 36% up to 2035, but only by 24% in the warmer climate scenario. Due to technical progress, a decrease up to 2050 is then expected in both cases. In relative terms, the impact of warmer climate is slightly larger in the case of the Mediterranean and south-eastern (SE) European countries as compared to the rest of Europe. This is due to a larger relative change of HDD. As can be expected, the total of the EU27+2 countries is dominated by the non-Mediterranean and non-south-eastern (SE) countries. Due to the warmer climate, total non-electricity fuel energy demand which is dominated by space-heating in most sub-sectors is reduced by 16% in 2050 as compared to the base case and by about 14% as compared to 2005.

Table 6-15: Fuel demand (w/o electricity) Service sector, in PJ per year, EU27+2 and European regions, Reference Scenario, 2005 – 2050.

Country or Country group	Fuels in service sector					Impact of warmer climate		
	2005	2020	2035	2050	2005-2050	2020	2035	2050
Austria	70	78	79	68	-3%	-7%	-13%	-18%
Baltic States	43	58	62	57	31%	-5%	-9%	-14%
Belgium/Luxembourg	133	147	147	125	-6%	-6%	-12%	-18%
Bulgaria	8	9	9	7	-16%	-11%	-20%	-30%
Czech Republic	92	118	119	113	23%	-6%	-10%	-16%
Denmark	46	57	63	57	22%	-4%	-8%	-12%
Finland	59	61	61	54	-9%	-6%	-10%	-15%
France	417	450	446	376	-10%	-7%	-14%	-21%
Germany	818	975	964	826	1%	-7%	-12%	-17%
Greece	14	17	19	18	22%	-8%	-13%	-18%
Hungary	114	149	160	138	22%	-4%	-7%	-12%
Ireland	49	60	62	55	11%	-4%	-8%	-12%
Italy	344	368	354	295	-14%	-8%	-16%	-23%
Malta/Cyprus	3	4	5	4	9%	-7%	-14%	-26%
Netherlands	280	300	295	252	-10%	-4%	-9%	-14%
Norway	18	18	18	15	-15%	-8%	-14%	-21%
Poland	171	251	272	229	34%	-5%	-10%	-16%
Portugal	62	105	157	157	154%	-3%	-5%	-8%
Romania	14	17	20	19	38%	-9%	-16%	-25%
Slovakia	87	137	154	132	52%	-2%	-4%	-6%
Slovenia	19	25	24	21	9%	-5%	-10%	-15%
Spain	138	189	200	180	31%	-7%	-14%	-21%
Sweden	72	88	94	81	13%	-5%	-8%	-13%
Switzerland	61	63	62	53	-13%	-9%	-15%	-20%
United Kingdom	449	523	579	537	19%	-5%	-9%	-13%
North	195	224	236	207	6%	-5%	-9%	-14%
West	2277	2597	2635	2291	1%	-6%	-11%	-17%
Central-east	526	737	791	690	31%	-4%	-8%	-13%
South	584	710	764	679	16%	-7%	-13%	-19%
Total Europe	**3581**	**4268**	**4426**	**3868**	**8%**	**-6%**	**-11%**	**-16%**

Source: CEPE, ETH Zurich.

In the Base Case Scenario with present climate, electricity demand is expected to increase by about 56 % up to 2050. In the Reference Scenario, the increase is slightly higher, namely by about 8 %-points. In 2050, electricity demand is 6 % higher in the Reference Scenario than in the Base Case Scenario (about 1 % already occurred between the Base Case Senario and the year 2005). A noticeable difference can be discerned between the Mediterranean and south-eastern European countries on the one hand and the rest of the European countries on the other hand. For the former, the difference between the Base Case Scenario and the Reference Scnario is 10 %, whereas for the rest of the EU27+2 countries it is only 3 % in 2050.

The difference between the two scenarios is caused by the different development of electricity demand for cooling and reduced electricity demand for heating. Whereas in the base case, cooling electricity increases from 271 PJ to about 681 PJ, which represents an increase of +150%, it increases from 288 PJ in 2005 to 931 PJ which represents an increase of +220%.

Table 6-16: Electricity demand service sector, EU27+2 and European regions, Reference Scenario, 2005 – 2050.

Country or Country group	Electricity in service sector in PJ					Impact of warmer climate		
	2005	2020	2035	2050	2005-2050	2020	2035	2050
Austria	56	68	78	77	37%	2%	3%	3%
Baltic States	24	37	47	52	118%	1%	1%	2%
Belgium/Luxembourg	45	56	65	64	42%	2%	4%	5%
Bulgaria	22	27	33	35	58%	8%	12%	14%
Czech Republic	46	69	77	89	92%	2%	3%	3%
Denmark	38	49	59	59	56%	0%	1%	1%
Finland	55	63	72	70	28%	0%	1%	1%
France	494	648	795	791	60%	3%	4%	5%
Germany	447	582	654	645	44%	1%	2%	3%
Greece	52	72	94	101	94%	4%	7%	12%
Hungary	34	50	63	63	85%	3%	5%	6%
Ireland	33	43	50	49	49%	0%	0%	0%
Italy	279	356	428	432	55%	6%	11%	14%
Malta/Cyprus	9	14	16	17	94%	1%	4%	9%
Netherlands	137	158	181	178	30%	1%	1%	1%
Norway	81	94	105	103	27%	0%	0%	0%
Poland	104	168	219	221	113%	1%	2%	2%
Portugal	53	90	141	156	194%	7%	11%	13%
Romania	36	50	74	91	151%	9%	13%	15%
Slovakia	65	104	130	130	100%	1%	2%	2%
Slovenia	11	15	18	16	52%	2%	4%	5%
Spain	219	343	432	470	114%	7%	11%	15%
Sweden	100	121	145	145	45%	1%	1%	1%
Switzerland	53	62	71	71	34%	2%	2%	3%
United Kingdom	377	456	546	568	51%	0%	1%	1%
North	274	327	381	378	38%	0%	1%	1%
West	1642	2072	2439	2443	49%	1%	3%	3%
Central-east	284	444	553	572	101%	2%	2%	3%
South	670	952	1218	1301	94%	6%	11%	14%
Total Europe	**2870**	**3795**	**4590**	**4694**	**64%**	**3%**	**4%**	**6%**

Source: CEPE, ETH Zurich.

As already stated above, there is a noticeable difference between the southern countries and the rest of the EU27+2 countries. First of all, the share of electricity demand for cooling as compared to total electricity demand is larger already today: it is 30% in the southern countries, but only 4% in western Europe and only 9% on the European average. Moreover, the share of the southern countries increases much more distinctly, namely by 7%-points whereas in the other countries it increases only by 1% to 3%-points.

Finally, it can be stated that the share of electricity demand for cooling first increases, but then decreases again, particularly in the base case, but to a minor extent also in the WC scenario. First, this is due to stronger saturation phenomena in the case of cooling (particularly regarding the share of cooled floor area, see Table 6-11 in the previous section) compared to other types of electricity demand. Second, stronger techno-economic progress was assumed in the case of cooling (0.5%/year) as compared to other electricity services (0.2% to 0.5%, see Jochem et al. 2007).

Due to the warmer climate, non-electricity fuel energy demand which is dominated by space heating in most sub-sectors, is reduced by 16% in 2050 (i.e. by 760 PJ), and electricity demand is increased by 6% (by about 250 PJ). As such, the impact of warmer climate is lower than the "regular" electricity demand increase between 2005 and 2050 due to cooling, which is estimated at about 410 PJ in the base case (from 270 to 680 PJ).

Electricity and other energy demand of the tertiary sectors of the European countries are expected to increase considerably up to 2050 in both the base case and warmer climate scenario, namely by 27% (base case) and by about 8% (warmer climate) in the case of non-electricity fuels and by more than 50% in the case of electricity. Depending on the future primary energy intensity of electricity generation, these results imply either a slight improvement or a slight worsening in the level of primary energy.

Note that in the case of electricity, the impact of WC in 2050 is lower than the "regular" demand increase between 2005 and 2050 due to cooling which is estimated at about 410 PJ in the base case (from 270 to 680 PJ). However, it should be noted that electricity demand due to cooling might increase considerably more, if the share of cooled floor area approached saturation not only in the case of Mediterranean and south-eastern EU countries, but also in the case of other countries which are of higher relevance in terms of energy demand. Particularly, heat waves could accelerate the purchase of room air conditioners. Moreover, electricity could be increased due to the use of reversible appliances which are installed for cooling purposes, but would be utilised also in their heat mode.

6.5.2.2 Adaptation cost

The reduced heating demand over-compensates the increase of electricity demand due to air conditioning, in particular in the long term. Until 2020 the adaptation effect is stronger, thus the additional costs of air conditioning are in the same order as the reduced energy cost of heating, but in the longer term (period 2030-2050), the existing trend of air conditioning more area (also in the Base Case Scenario) will diminish the additional cost of electricity for air conditioning.

In addition to energy costs differences (reduced for heating, increased for air conditioning), there are also additional investments to increase the air conditioned area, to maintain comfort, which are in the order of 90 € to 230 € per inhabitant per year, with an European average of 192 € per inhabitant per year.

The additional investments, as a result of a warmer climate, are based on specific costs found in Adnot (2007) for room air conditioning, and in Jakob (2006) for central air conditioning and ventilation installations. The re-investment cycles range from 15 years for room air conditioning to 20 years for central air conditioning. After a re-investment cycle, only 1/3 of the floor area is considered in the additional investment. The other 2/3 are no longer considered, because they are already included in the baseline scenario, i.e. the Reference Scenario anticipates the investment by a few years only. The costs are up to 1.5 bimillionard € per year, thus few euros per inhabitant per year.

Table 6-17: Change in energy costs (fuels and electricity) between Base Case and Reference Scenario, in Mill. € per year, EU27+2 and European regions, 2005– 2050.

Country group	Fuels				Electricity			
	2010	2020	2035	2050	2010	2020	2035	2050
Austria	-36	-77	-153	-206	14	33	56	61
Baltic States	-13	-24	-48	-72	2	9	19	23
Belgium/Luxembourg	-42	-111	-274	-450	11	41	100	111
Bulgaria	-4	-9	-17	-23	15	34	64	76
Czech Republic	-23	-55	-124	-215	8	21	37	45
Denmark	-19	-42	-104	-160	2	10	26	30
Finland	-17	-37	-71	-98	3	6	11	11
France	-203	-443	-986	-1507	144	428	859	1031
Germany	-400	-923	-2056	-3033	97	288	602	746
Greece	-11	-20	-46	-69	21	53	117	193
Hungary	-12	-28	-79	-140	13	34	63	73
Ireland	-11	-34	-89	-149	0	1	4	5
Italy	-245	-544	-1189	-1728	346	907	1764	2200
Malta/Cyprus	-2	-4	-10	-22	2	4	14	31
Netherlands	-84	-185	-463	-727	18	42	84	94
Norway	-14	-26	-51	-72	2	6	15	18
Poland	-47	-125	-354	-619	11	41	91	113
Portugal	-20	-51	-155	-294	60	167	375	471
Romania	-7	-14	-31	-52	32	78	172	233
Slovakia	-10	-24	-53	-84	12	37	70	80
Slovenia	-6	-16	-39	-63	4	8	15	17
Spain	-81	-193	-507	-890	247	570	1075	1509
Sweden	-25	-62	-128	-192	9	21	43	49
Switzerland	-34	-71	-145	-214	15	36	64	77
United Kingdom	-120	-308	-800	-1391	17	70	187	247
North	-75	-168	-354	-522	16	43	96	109
West	-930	-2151	-4965	-7678	316	939	1957	2372
Central-east	-112	-272	-696	-1194	50	150	296	352
South	-370	-834	-1955	-3078	723	1813	3581	4713
Total Europe	**-1487**	**-3425**	**-7970**	**-12471**	**1104**	**2945**	**5929**	**7546**

Source: CEPE, ETH Zurich

Table 6-18:: Adaptation investment costs due to warmer climate (due to more space cooling) in the service sector, in million € per year, 2010– 2050.

Country group	Investment costs cooling systems			
	2010	2020	2035	2050
North	17	39	52	60
West	294	535	707	796
Central-east	42	72	91	101
South	269	391	538	540
Total Europe	621	1037	1387	1497

Source: CEPE, ETH Zurich.

6.6 Industry – projected by ISINDUSTRY

6.6.1 Assumptions for industry - ReferenceScenario 2000 to 2050

6.6.2 Results for the industrial sector - Refeence Scenario 2000 to 2050

6.6.2.1 Final energy demand

While the industrial fuel demand of Europe as a whole increases slightly up to the year 2050, there are larger variations on the level of regions and even more on the country level. Fuel consumption in Western Europe with the most saturated industrial structue falls by about 19 % until 2050 whereas the northern countries show a 39 % growth in the same time frame. The increase in the Nordic countries is mainly driven by a significant growth in energy intensive industries like the pulp and paper production. On the other hand, fuel demand in countries within the most saturated Western European industries (Germany, France, UK) falls considerably, which is to a large share related to the stagnation in the production of energy intensive bulk products like steel or cement in these countries.

Table 6-19: Fuels demand of industry, in PJ per year, EU27+2 and European regions, Reference Scenario, 2005 – 2050

Country or Country group	Fuels industry					Impact of warmer climate		
	2005	2020	2035	2050	2005-2050	2020	2035	2050
Austria	194	232	297	402	107%	-0.7%	-1.4%	-1.9%
Baltic States	76	59	57	68	-11%	-0.5%	-0.9%	-1.3%
Belgium/Luxembourg	424	479	489	489	15%	-0.6%	-1.1%	-1.6%
Bulgaria	136	151	182	289	113%	-0.6%	-1.0%	-1.4%
Czech Republic	375	367	334	414	10%	-0.6%	-1.2%	-1.8%
Denmark	78	93	92	91	16%	-0.4%	-0.9%	-1.3%
Finland	419	442	452	459	10%	-0.6%	-1.0%	-1.4%
France	1086	1055	937	810	-25%	-0.8%	-1.4%	-2.2%
Germany	1836	1644	1384	1133	-38%	-0.8%	-1.4%	-2.0%
Greece	115	90	102	116	1%	-1.2%	-2.1%	-3.1%
Hungary	127	93	98	124	-2%	-0.4%	-0.8%	-1.3%
Ireland	54	50	45	46	-14%	-0.4%	-1.1%	-1.7%
Italy	1306	1446	1407	1397	7%	-0.9%	-1.7%	-2.5%
Malta/Cyprus	14	7	5	4	-70%	-1.2%	-2.1%	-3.1%
Netherlands	635	687	723	709	12%	-0.4%	-0.9%	-1.3%
Norway	113	135	202	297	161%	-0.5%	-1.0%	-1.6%
Poland	588	651	700	751	28%	-0.6%	-1.2%	-1.8%
Portugal	205	268	292	268	31%	-0.3%	-0.6%	-0.9%
Romania	527	604	757	1025	95%	-0.2%	-0.4%	-0.6%
Slovakia	166	123	112	123	-26%	-0.3%	-0.5%	-0.8%
Slovenia	47	39	34	41	-13%	-0.6%	-1.1%	-1.6%
Spain	949	1153	1213	1210	28%	-0.7%	-1.3%	-1.9%
Sweden	391	585	586	541	38%	-0.4%	-0.8%	-1.2%
Switzerland	91	91	87	84	-8%	-0.7%	-1.4%	-1.9%
United Kingdom	853	712	649	530	-38%	-0.6%	-1.2%	-1.8%
North	1002	1255	1332	1388	39%	-0.5%	-0.9%	-1.4%
West	5173	4950	4612	4202	-19%	-0.7%	-1.3%	-1.8%
Central-east	1380	1333	1336	1521	10%	-0.6%	-1.1%	-1.6%
South	3252	3719	3957	4310	33%	-0.6%	-1.2%	-1.7%
Total Europe	**10807**	**11256**	**11237**	**11422**	**6%**	**-0.6%**	**-1.2%**	**-1.7%**

Source: ISIndustry.

Electricity demand – in contrast to fuels demand – shows a significant growth and increases by 55 % up to the year 2050. However, compared to the past 50 years, this growth seems rather on a lower level.

Looking at the regions, it is mainly in the central-east countries where electricity demand grows rapidly and more than doubles up to 2050.

On a country level, Poland, Romania, Bulgaria and Czech Republic show the highest growth rates in Europe, while countries like Switzerland, Germany or France show the lowest growth of about 13 to 33 % (the values for Malta and Cyprus seem rather exceptional here, with only 19 % growth).

Table 6-20: Electricity demand industry sector, in PJ per year, reference scenario, 2005 – 2050.

Country or Country group	Electricity in industrial sector					Impact of warmer climate		
	2005	2020	2035	2050	2005-2050	2020	2035	2050
Austria	80	92	111	140	75%	0.1%	0.1%	0.2%
Baltic States	24	23	25	32	34%	0.0%	0.1%	0.1%
Belgium/Luxembourg	164	212	256	308	88%	0.1%	0.1%	0.2%
Bulgaria	36	42	52	84	134%	0.1%	0.3%	0.4%
Czech Republic	82	115	127	185	124%	0.0%	0.1%	0.1%
Denmark	35	39	45	54	53%	0.0%	0.0%	0.0%
Finland	163	195	223	257	58%	0.0%	0.0%	0.0%
France	501	554	606	668	33%	0.1%	0.1%	0.2%
Germany	849	930	1002	1060	25%	0.0%	0.1%	0.1%
Greece	54	59	75	94	75%	0.2%	0.3%	0.5%
Hungary	36	43	39	46	31%	0.1%	0.2%	0.3%
Ireland	24	26	29	35	43%	0.0%	0.0%	0.0%
Italy	588	800	875	967	64%	0.2%	0.4%	0.6%
Malta/Cyprus	4	4	4	5	19%	0.2%	0.3%	0.4%
Netherlands	154	190	233	272	77%	0.0%	0.0%	0.0%
Norway	183	215	262	319	74%	0.0%	0.0%	0.0%
Poland	159	261	319	381	140%	0.0%	0.1%	0.1%
Portugal	59	80	95	104	75%	0.2%	0.4%	0.5%
Romania	124	165	207	292	136%	0.2%	0.4%	0.6%
Slovakia	40	49	51	63	58%	0.0%	0.1%	0.1%
Slovenia	26	30	32	43	68%	0.1%	0.1%	0.2%
Spain	374	436	480	535	43%	0.3%	0.5%	0.7%
Sweden	195	243	255	258	32%	0.0%	0.0%	0.0%
Switzerland	67	74	75	76	13%	0.0%	0.1%	0.1%
United Kingdom	466	482	579	661	42%	0.0%	0.0%	0.0%
North	576	692	786	888	54%	0.0%	0.0%	0.0%
West	2304	2560	2890	3219	40%	0.0%	0.1%	0.1%
Central-east	366	520	593	750	105%	0.0%	0.1%	0.1%
South	1240	1587	1790	2082	68%	0.2%	0.4%	0.6%
Total Europe	4486	5359	6059	6939	55%	0.1%	0.2%	0.3%

Source: ISIndustry.

The impact of warmer climate, as compared to the baseline scenario, is rather minor on industry showing only 1.7 % decrease for the fuels consumption and 0.3 % increase for the electricity demand until 2050. The differences mainly arise from changed heating and air conditioning needs. But due to the low share of building related energy demand in industry, the resulting differences are rather minor. E.g. in Germany the share of fuel consumption for space heating is only 8 % whereas in the residential or service sector it accounts for the largest part of fuel consumption. The remaining fuels in industry are used in process technologies where the temperature level is so high that the influence of some degree warmer climate is insignificant.

In general, the southern countries show a higher impact from the warmer climate. In particular air-conditioning drives electricity demand considerably stronger than in the northern countries.

However, shifts in the production of industrial godds or other indirect effects that might also impact on the energy demand were not taken into account here.

6.6.2.2 Adaptation cost

In line with the relatively low impact of warmer climate on the industrial energy demand, also the adaptation costs remain on a low level. In general, the increase in electricity and investment costs is more than outbalanced by the decrease in fuel costs.

Table 6-21: Change in energy costs (fuels and electricity) between Base Case and Reference Scenario, in Mill. € per year, 2005– 2050.

Country or Country group	Fuels				Electricity			
	2010	2020	2035	2050	2010	2020	2035	2050
Austria	-4.7	-10.9	-32.0	-73.6	0.3	1.0	2.7	5.1
Baltic States	-0.6	-1.0	-2.2	-4.5	0.0	0.1	0.2	0.3
Belgiem/Luxemburg	-4.9	-11.7	-29.6	-56.0	0.5	2.1	7.5	14.7
Bulgaria	-1.5	-3.5	-9.0	-24.0	0.1	0.5	1.3	2.8
Czech Republic	-4.0	-7.1	-15.4	-33.9	0.2	0.6	1.4	3.0
Denmark	-1.2	-2.7	-7.0	-12.3	0.0	0.0	0.2	0.3
Finland	-7.0	-15.5	-28.8	-46.8	0.1	0.2	0.6	1.1
France	-22.1	-46.0	-84.7	-123.4	1.2	3.8	8.9	16.3
Germany	-46.2	-86.9	-157.2	-207.6	2.0	5.7	13.5	22.6
Greece	-3.9	-6.3	-15.0	-31.0	0.7	1.5	3.4	6.0
Hungary	-1.2	-2.0	-5.3	-12.5	0.2	0.6	1.0	1.8
Ireland	-0.6	-1.4	-3.9	-7.5	0.0	0.0	0.0	0.1
Italy	-37.7	-80.8	-187.7	-320.7	25.2	63.8	134.6	210.6
Malta/Cyprus	-0.6	-0.6	-1.0	-1.4	0.1	0.1	0.2	0.3
Netherlands	-6.7	-16.2	-42.4	-72.3	0.2	0.6	1.7	3.3
Norway	-3.3	-7.0	-18.5	-42.3	0.0	0.1	0.5	1.1
Poland	-5.3	-14.1	-37.1	-68.9	0.2	1.1	3.0	5.8
Portugal	-3.4	-6.4	-14.6	-22.5	1.2	2.9	5.8	8.3
Romania	-1.3	-3.2	-9.8	-26.2	2.7	6.3	13.0	24.8
Slovakia	-0.7	-1.1	-2.5	-5.3	0.1	0.2	0.4	0.8
Slovenia	-1.0	-1.7	-3.2	-6.5	0.1	0.3	0.6	1.2
Spain	-18.3	-43.5	-111.7	-198.1	8.8	18.1	33.3	50.4
Sweden	-8.0	-21.0	-41.5	-63.2	0.1	0.3	0.8	1.3
Switzerland	-1.7	-3.6	-8.1	-13.9	0.2	0.5	1.1	1.7
United Kingdom	-14.1	-28.0	-72.6	-109.9	0.2	1.1	3.9	8.1
NE	-19.5	-46.2	-95.7	-164.6	0.2	0.7	2.0	3.7
WE	-101.2	-204.7	-430.5	-664.2	4.5	14.8	39.3	72.0
CE	-12.7	-27.0	-65.7	-131.6	0.9	2.8	6.6	12.9
SE	-66.7	-144.2	-348.8	-624.1	38.8	93.2	191.6	303.2
Total Europe	**-200.0**	**-422.2**	**-940.6**	**-1584.4**	**44.4**	**111.5**	**239.6**	**391.7**

Source: ISIndustry and CEPE, Zurich.

When being compared to the service and the residential sector, investments in adaptation measures seems about a factor of 10 lower in industry, which, as mentioned above, can be mainly traced back to the low importance of space heating and cooling in industry.

Table 6-22: Adaptation investment costs because of warmer climate (due to more air conditioning) in industry in European regions, 2010– 2050

Country or country group	Investment costs in Mill. €			
	2010	2020	2035	2050
North	1	1	2	5
West	10	20	31	52
Central-east	1	2	4	6
South	18	25	33	41
Total Europe	**30**	**48**	**70**	**104**

Source: CEPE, ETH Zurich.

6.7 Transportation – projected by ASTRA

6.7.1 Assumptions for the transportation sector - Reference Scenario 2000 to 2050

Climate change is expected to have both positive and negative effects on the transport system. No literature sources could be identified which explicitly tried to quantify the expected effects. Therefore, we developed a systematic approach for quantification. First, we compiled a list of all possible effects found during a comprehensive literature search. This search confirmed that only qualitative assessments exist as yet. We then identified the geographical structure and climate zone for each European country. This information was combined in order to assemble impacts of climate change on both the average transport times as well as the yearly necessary repair investments caused by damage due to climate change.

Qualitative analysis of effects of climate change on the transport system

Heat waves have an impact on every kind of transport system because less roads, rails, bridges etc. can be constructed due to worries about safety and security as described by the Transportation Research Board 2008. Also, forest fires can block the entire infrastructure as stated by the COMMISSION OF THE EUROPEAN COMMUNITIES 2007. Furthermore, longer periods of extreme heat will cause deformation of rail lines which could eventually lead to derailments as reported by Michael D.Meyer 2008. Trains would have to run more slowly and with more distance between each other to avoid rails heating up due to braking. Regarding highways, there will be problems like increased rutting and softening of asphalt; these troubles also affect runways (IPCC 2007 and Atkins 2008). In addition, Marc Zebisch et al. 2005a declare that there could be more accidents on roads because of lack of concentration as a result of heat inside cars. In big cities, people may use other transport options instead of underground railways because of the unbearable suffocating heat as reported by Geoff Darch 2006. Lower air pressure as a result of the heat leads to reduced carrying capacity, cancellation of flights and as indicated by CCSP 2008, more airport runway length and fuel is needed.

Higher temperatures in the Arctic will result in warming and thawing of permafrost, which results in instability of subsurface or even land subsidence. Roads, airstrips and rails have to be stabilised or dislocated. The Transportation Research Board 2008 also indicates that "warming winter temperatures have also shortened the season for ice roads that provide vital access to communities and industrial activities in remote areas." Thawing of permafrost will also enhance the risk of rock slides and avalanches in Alpine regions, leading to interruptions in road traffic as shown by Arbeitsgemeinschaft Ecoplan/Sigmaplan 2007. Otherwise, warming temperatures will reduce Arctic ice sheet and northern harbours would be ice-free for longer periods, providing the opportunity for new, rather longer use of navigation routes as described by US Arctic Research 2002.

Then again, in other regions one could also benefit from increases in mean temperature: rails would freeze more rarely and streets would be safer owing to less snowfall as stated by IPCC 2007 and World Meteorological Organization 2007. On the one hand, in warmer regions there would be less damage due to freezing in pavements, but on the other hand, numerous freeze-thaw cycles harm the streets as stated in Fiona J.Warren 2004. In summer warm weather also affects people's behaviour: risky and drunk driving is more likely. Furthermore, using air conditioning appliances results in more energy expenditures.

Rising sea levels will cause interruption or even loss of low-lying infrastructure in coastal areas and little islands as constituted by World Meteorological Organisation 2008. In addition, coastal flooding (also as a consequence of surges) will result in great damage. In reference to the UNEP 1999, migration to the interior will overstrain the infrastructure there. Moreover, as shown by Fiona J.Warren 2004 "erosion and subsidence of road bases and rail beds, as well as erosion and scouring of bridge supports" will pose problems in future years. But pursuant to CCSP 2008, deeper water would "permit greater ship drafts" as well.

Higher frequency of extreme weather incidences such as snowfall in spring or autumn (causing longer use of winter tires), tempests and rainstorms will impede infrastructure in many respects. Concerning aviation, storms can lead to delays, cancellation of flights and cases of emergency. Severe storms will impair ports, while containers could get lost at sea by falling overboard. As illustrated by Münchener Rück 2007, streets are also affected in several aspects such as broken down cars, closed and damaged roads because of fallen trees. Railroad companies will have to face the same problems (Bruno Merz, Heiko Apel 2004).

Periods of low rainfall inhibit inland waterway transportation, especially in non-regulated rivers (the Rhine in particular) because low tide forces the ships to reduce cargo weight as demonstrated by Marc Zebisch et al. 2005b and Arbeitsgemeinschaft Ecoplan/Sigmaplan 2007. Actually, the Bundesanstalt für Gewässerkunde 2006 even expects navigation will have to be stopped temporarily.

Periods of heavy rainfall produce flood water, inundation and mudslides which affects all different sectors of the transport system (railway, aviation, navigation, roads) and S.Saarelainen 2006 demonstrates that infrastructure is likely to be obstructed or destroyed due to rainfall. Furthermore, the Red Cross / Red Crescent 2007 gave an idea of the problem of soil erosion which can lead to subsidence of streets. Jörg Uwe Belz, Silke Rademacher 2007 state that closing down navigation may be necessary because of high water in rivers.

Quantification of effects based on country characteristics.

In order to quantify the effects of climate change on a country’s transportation system, both the geographical structure and the climate zone were evaluated to compile a matrix indicating the effects on both the transport times and the expected investments. We identified four main characteristics:

1. Mountains lead to higher vulnerability of the infrastructure due to mudslides and heavy snowfall. Therefore, many mountains in a country imply a rise in average transport times as well as a rise in investments for repairing damaged infrastructure.
2. Rivers: countries with large rivers and much industrial infrastructure in regions threatened by flood are also more vulnerable.
3. Heat: countries in regions with rising probability of heat waves are exposed to blocked infrastructure due to melting asphalt as well as a higher likelihood of accidents.
4. Snowfall: countries in colder regions are more likely to experience blocked infrastructure due to heavy snowfall. This effect does not destroy the infrastructure and therefore has no influence on investments.

This analysis was carried out for each European country, resulting in Table 6-23.

Table 6-23: Impacts of geographical structure and climate zone on the transport system

Impacts on	Transport Times				Investments			
Because of	Mountains	Rivers	Heat	Snowfall	Mountains	Rivers	Heat	Snowfall
Austria	1	1	0	-1	1	1	0	0
Belgium/Luxembourg	0	1	0	0	0	1	0	0
Denmark	0	1	0	0	0	1	0	0
Spain	1	1	1	0	1	1	1	0
Finland	0	1	0	-1	0	1	0	0
France	1	1	1	-1	1	1	1	0
United Kingdom	0	1	0	0	0	1	0	0
Germany	1	1	1	-1	1	1	1	0
Greece	0	0	1	0	0	0	1	0
Ireland	0	1	0	0	0	1	0	0
Italy	1	1	1	0	1	1	1	0
Netherlands	0	1	0	0	0	1	0	0
Portugal	1	1	1	0	1	1	1	0
Sweden	0	1	0	-1	0	1	0	0
Bulgaria	0	1	1	0	0	1	1	0
Switzerland	1	1	0	-1	1	1	0	0
Cyprus	0	0	1	0	0	0	1	0
Czech Republic	1	1	0	-1	1	1	0	0
Estonia	0	1	0	-1	0	1	0	0
Hungary	0	1	1	-1	0	1	1	0
Latvia	0	1	0	-1	0	1	0	0
Lithuania	0	1	0	-1	0	1	0	0
Malta	0	0	1	0	0	0	1	0
Norway	1	1	0	-1	1	1	0	0
Poland	1	1	0	-1	1	1	0	0
Romania	1	1	1	-1	1	1	1	0
Slovenia	1	1	0	-1	1	1	0	0
Slovakia	0	1	0	-1	0	1	0	0

Source: Fraunhofer-ISI

Differing weights of influence on investments and transport times were assigned to each of the four characteristics as shown in Table 6-24. Also, the impacts were assumed to intensify over time, from no impact in 2010, to factor 1 for 2025, factor 3 for 2040 and factor 5 for 2050.

Table 6-24: Weights of influences of country characteristics on the transport system

Weights of influences	Mountains	Rivers	Heat	Snowfall
Transportation times	0.010	0.010	0.015	0.005
Investments	0.020	0.040	0.010	0.005

Source: Fraunhofer-ISI

These steps lead to country-specific assumptions on factors quantifying the expected rise of transport times and investments due to climate change for all European countries. In 2010, no changes compared to the base case were assumed. The transport times were thereby estimated to rise between 0.05 % and 0.3 % around 2025, between 0.15 % and 1.05 % in 2025, as well as between 0.25 % and 1.75 % in 2050. The investments were estimated to rise between 0.1 % and 0.7 % around 2025, between 0.3 % and 2.1 % in 2040, and between 0.5 % and 3.5 % in 2050.

6.7.2 Results for the transportation sector - Reference Scenario 2000 to 2050

Three main items reacting in response to climate change have been identified in the transport sector:

- increased usage of air conditioning in cars,
- impact on travel times due to blocked infrastructure because of flooding or damages or changes in ice and snow impacts, and
- increased investment in repairs for transport infrastructure.

The changes in journey times are the most relevant for the transport sector itself, while the use of air conditioning is more relevant for the energy estimates. Since journey time changes are of minor importance for the economic assessment, investments in repairs remain the most important issue.

6.7.2.1 Final energy demand

In the total balance of changes in the transport system we observe an increase in energy use. This is more pronounced for freight transport, which is mostly driven by the higher travel times of the Reference Scenario, increasing fuel demand by some 10 Mtoe or 400 PJ in 2050 (see Figure 6-9) .

There are two counteracting drivers for passenger transport in the Reference Scenario: first, the higher use of air conditioning increases energy demand by roughly 5 – 7 %. But the increase in travel times, in particular for road and rail transport as a consequence of extreme events (e.g. storms and floods damaging network infrastructure) leads to a modal shift reducing the use of cars and increasing the use of bus, rail and slow modes, all of which are more efficient than car transport. This leads to a decline in passenger car mileage of some 250 Billion passenger-km in 2050 for car transport and almost 50 Billion passenger-km for planes (see Figure 6-10). This decline is only partially compensated for by bus, train, and slow transport.

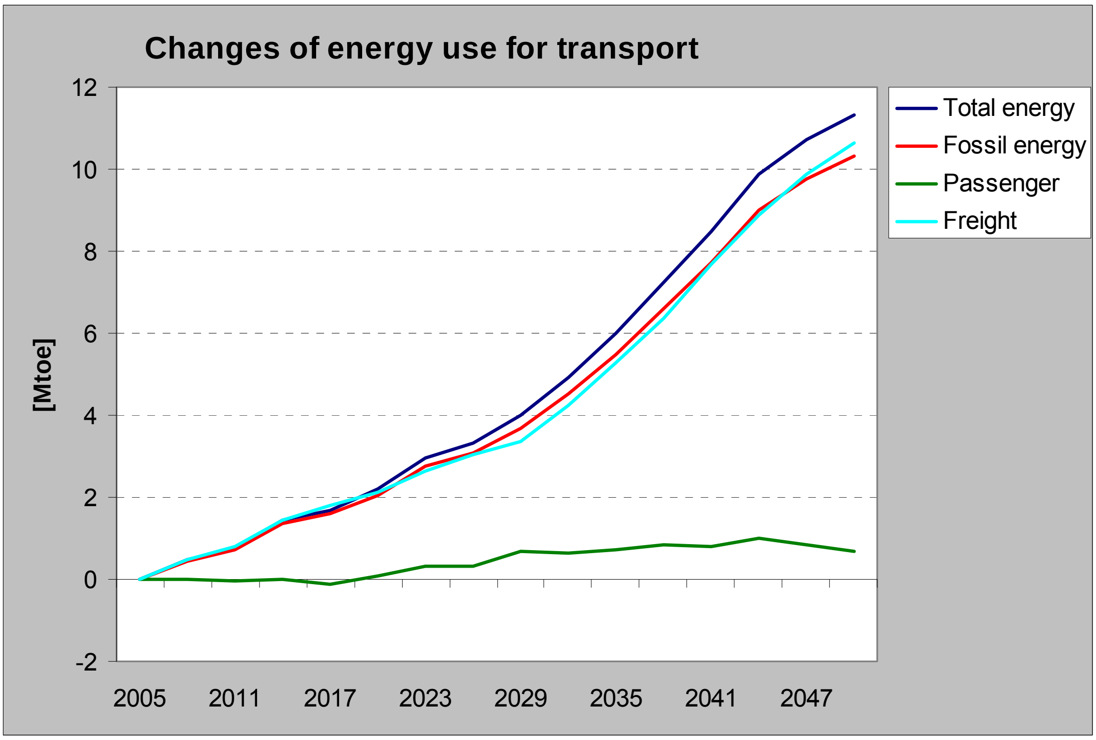
However, final energy demand for the transportation sector does not decrease relative to the Base Case Scenario, but rather increases at the European level by 1.9 % due to the factors mentioned above (more air conditioning, longer travel times and blocked infrastructure due to more extreme events (see Table 6-25)). .Although there are differences among European countries or regions, the impact is somewhat smaller in northern and western Europe compared to central-east and southern Europe (see Table 6-25).

Table 6-25: Energy demand in transportation sector, EU27+2 and European regions, Reference Scenario, 2005 – 2050

Country or Country group	Transportation sector in PJ per year					Impact of warmer climate		
	2005	2020	2035	2050	2005-2050	2020	2035	2050
Austria	197	202	179	168	-14%	0.3%	0.4%	0.9%
Baltic States	245	266	251	265	8%	0.5%	1.3%	2.2%
Belgium/Luxembourg	541	597	548	543	0%	0.2%	-0.9%	-0.4%
Bulgaria	124	130	132	133	7%	0.3%	0.6%	1.1%
Czech Republic	166	168	158	161	-3%	0.8%	0.5%	2.9%
Denmark	135	148	145	148	10%	0.4%	1.1%	2.2%
Finland	225	226	237	279	24%	0.3%	0.8%	1.5%
France	3004	3133	3092	2977	-1%	0.5%	1.2%	2.2%
Germany	2380	2198	1913	1783	-25%	0.4%	0.9%	1.6%
Greece	162	172	161	156	-4%	0.3%	0.9%	1.5%
Hungary	199	193	168	159	-20%	0.5%	2.0%	3.1%
Ireland	88	104	110	109	25%	0.5%	1.6%	3.7%
Italy	1320	1322	1220	1227	-7%	0.2%	1.5%	2.8%
Malta/Cyprus	97	80	69	72	-25%	0.3%	0.1%	1.6%
Netherlands	310	313	308	306	-1%	0.4%	1.0%	1.6%
Norway	327	371	378	417	28%	0.4%	1.1%	2.2%
Poland	364	517	543	532	46%	0.4%	1.5%	3.1%
Portugal	333	398	376	376	13%	0.5%	1.4%	2.2%
Romania	515	440	384	384	-25%	0.3%	1.0%	2.6%
Slovakia	73	78	77	82	11%	0.6%	1.7%	3.5%
Slovenia	129	180	183	212	64%	0.2%	0.4%	0.2%
Spain	1029	1163	1080	1049	2%	0.6%	1.9%	2.7%
Sweden	389	402	395	406	4%	0.3%	0.7%	1.5%
Switzerland	325	316	284	268	-18%	0.6%	1.6%	2.6%
United Kingdom	1644	1675	1626	1627	-1%	0.3%	0.7%	0.8%
North	1076	1147	1156	1251	16%	0.3%	0.9%	1.8%
West	8489	8538	8059	7781	-8%	0.4%	0.9%	1.5%
Central-east	1176	1402	1380	1410	20%	0.5%	1.3%	2.5%
South	3581	3705	3424	3398	-5%	0.4%	1.4%	2.5%
Total Europe	14322	14793	14018	13840	-3%	0.4%	1.1%	1.9%

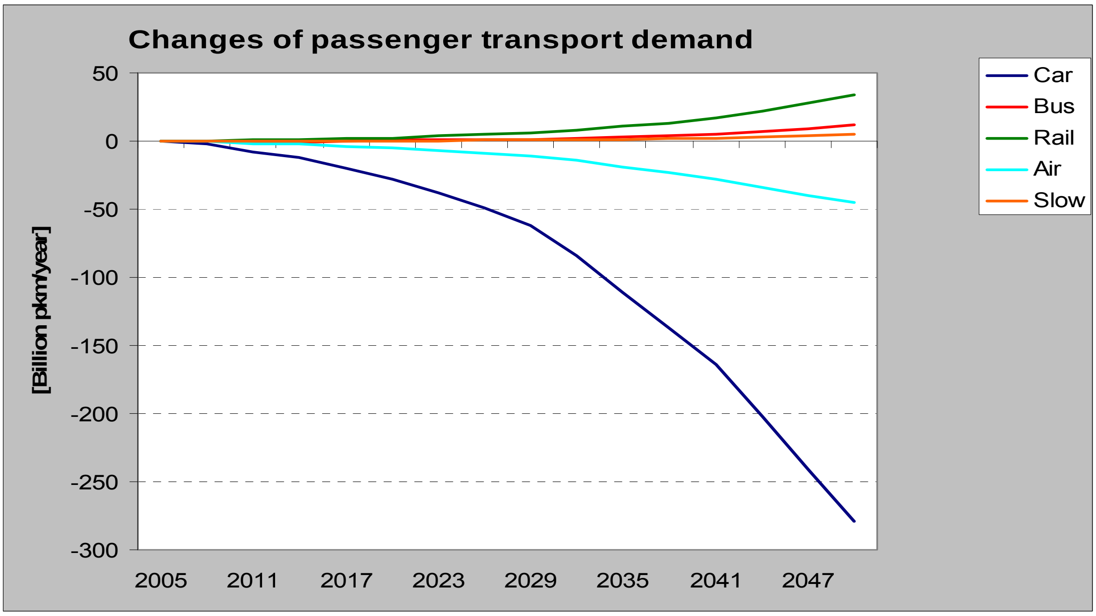
Source: ASTRA.

To conclude, the impact of warmer climate on energy demand in a 4°C Scenario such as the Reference Scenario is rather small compared to the impact on the residential and service sectors and similar to the industrial sector. This also implies that the changes in fuel and energy cost for the transport sector are rather small (see Chapter 6.7.2.2).



Source: ASTRA.

Figure 6-9: **Increase of energy demand from transport, EU27+2, Reference Scenario compared with the Base Case Scenario, 2005 to 2050**



Source: ASTRA.

Figure 6-10: Reaction of passenger transport demand by mode due to adaptation impacts in Europe (EU27+2), Reference Scenario, 2005 to 2050

6.7.2.2 Adaptation cost

The travel time losses due to adaptation amount to from 0.5 % up to 1.5 % in 2050 for the different European countries.

Investments of the countries depend on their vulnerability e.g. mountainous countries or countries with coastal areas and many rivers are more vulnerable than others. In total, the investments for repairs to transport infrastructure are estimated to be 3 to 6 billion € annually in 2050.

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6.8 Final energy demand of all sectors, direct CO_2 emissions, and adaptation cost of the Reference Scenario

This chapter summarises the findings of all final energy sectors derived from the various bottom up models regarding final energy demand, direct CO_2 emissione and adaptation cost.

6.8.1 Final energy demand

As fuel demand is quite dependent on heating demand in Europe, the impact of warmer climate assumed in the Refererence Scenario on energy demand is a decline of almost 9 % in 2050 (see Table 6-26). Of course, there are substantial differences among the Erurpean countries, depending on their climate (maritime or continental, Nordic or Mediterrainean) and on their economic structure and income per capita. West Europe benefits most from the warmer climate (-10 %), while the Scandinavian countries reduce their fuel demand by only 5 % during the same period until 2050 (see Table 6-26). In those countries, where industrial production is relatively small, the climate impact ism more pronounced (see Malta/Cyprus, Switzerland, Slovenia).

Electricity demand of the Reference Scenario is slightly increased by 1.7 % due to increasing air conditioning and cooling (see Table 6-27). South Europe has the highest increase (almost 5 %) not ony due to higher temperatures but also because industrial production does not play the same role as in countries north of the Alps.

Total electricity demand of Europe increases by 50 % between 2005 and 2050 reaching more than 15,400 PJ in 2050 (or 4,280 TWh). Ihe increase is highest in the central-east European countries (Baltic States. Poland, Czech Rebublic, Slovakia, slovenia, Romania, and Bulgaria, due to their expected economic growth adding 86 % to the present electricity demand (+775 PJ or 215 TWh) until 2050.

Table 6-26: Final energy demand and its change for heating and process heat between Base Case and Reference Scenario, EU27+2 and European regions, 2005–2050

Country or Country group	Fuels PJ					Impact of warmer climate		
	2005	2020	2035	2050	2005-2050	2020	2035	2050
Austria	495	535	601	670	35%	-3.5%	-6.0%	-7.6%
Baltic States	263	247	232	222	-16%	-3.6%	-6.8%	-9.6%
Belgium/Luxembourg	940	975	988	932	-1%	-2.7%	-5.2%	-8.0%
Bulgaria	202	213	237	336	66%	-2.2%	-3.4%	-3.6%
Czech Republic	658	667	621	679	3%	-2.9%	-5.7%	-7.6%
Denmark	268	283	286	269	0%	-2.6%	-5.4%	-8.5%
Finland	611	628	636	622	2%	-1.8%	-3.3%	-4.6%
France	2782	2767	2661	2370	-15%	-4.0%	-8.0%	-12.8%
Germany	4865	4639	4332	3709	-24%	-3.8%	-7.3%	-11.2%
Greece	294	250	271	279	-5%	-2.9%	-5.5%	-8.1%
Hungary	444	427	424	410	-8%	-3.7%	-7.2%	-10.3%
Ireland	187	204	215	211	13%	-3.2%	-6.8%	-10.6%
Italy	2591	2692	2624	2446	-6%	-3.5%	-6.7%	-9.8%
Malta/Cyprus	28	23	22	19	-33%	-4.8%	-10.8%	-21.3%
Netherlands	1266	1314	1333	1240	-2%	-2.4%	-5.0%	-7.5%
Norway	169	195	269	357	111%	-2.4%	-3.7%	-4.4%
Poland	1399	1534	1569	1525	9%	-2.9%	-5.6%	-8.2%
Portugal	348	450	521	485	39%	-2.7%	-4.7%	-7.4%
Romania	823	889	1025	1267	54%	-1.8%	-2.7%	-3.3%
Slovakia	349	350	349	330	-5%	-2.2%	-4.1%	-6.2%
Slovenia	102	101	97	98	-3%	-3.4%	-7.1%	-10.3%
Spain	1562	1816	1869	1795	15%	-2.6%	-5.0%	-7.4%
Sweden	644	866	878	812	26%	-1.7%	-3.2%	-4.8%
Switzerland	318	304	294	256	-19%	-5.6%	-9.9%	-13.8%
United Kingdom	2696	2530	2573	2393	-11%	-3.0%	-6.1%	-9.9%
North	1693	1973	2068	2060	22%	-1.9%	-3.6%	-5.2%
West	13550	13267	12996	11782	-13%	-3.5%	-6.8%	-10.5%
Central-east	3215	3326	3292	3264	2%	-3.0%	-5.8%	-8.3%
South	5848	6332	6569	6627	13%	-2.9%	-5.3%	-7.5%
Total Europe	**24,305**	**24,899**	**24,925**	**23,732**	**-2%**	**-3.1%**	**-6.0%**	**-8.9%**

Source: CEPE, ETH Zurich.

Table 6-27: Electricity demand and its change between Base Case and Reference Scenario, EU27+2 and European regions, 2005– 2050.

Country or Country group	Electricity demand in PJ					Impact of warmer climate		
	2005	2020	2035	2050	2005-2050	2020	2035	2050
Austria	182	207	240	271	49%	0.5%	0.9%	1.1%
Baltic States	70	87	103	120	70%	0.1%	0.3%	0.3%
Belgium/Luxembourg	262	331	391	447	70%	0.4%	0.8%	0.9%
Bulgaria	89	104	122	158	78%	1.9%	3.6%	3.4%
Czech Republic	185	243	263	335	81%	-0.2%	-0.1%	0.0%
Denmark	110	126	145	155	41%	0.1%	0.2%	0.3%
Finland	293	330	367	397	36%	-0.2%	-0.3%	-0.4%
France	1483	1739	1987	2073	40%	0.6%	1.2%	1.1%
Germany	1759	1982	2147	2210	26%	0.3%	0.6%	0.8%
Greece	178	217	254	283	59%	1.0%	2.9%	4.3%
Hungary	116	141	153	166	43%	1.1%	2.0%	2.2%
Ireland	76	97	115	126	65%	0.0%	0.1%	0.1%
Italy	1110	1452	1636	1753	58%	1.9%	3.6%	4.4%
Malta/Cyprus	21	28	33	37	72%	0.5%	1.9%	3.4%
Netherlands	362	428	504	549	52%	0.2%	0.4%	0.4%
Norway	374	415	473	535	43%	-0.6%	-0.8%	-1.1%
Poland	367	549	678	770	110%	0.3%	0.6%	0.6%
Portugal	163	230	306	338	108%	2.8%	5.3%	6.4%
Romania	204	280	366	489	139%	1.9%	3.5%	3.6%
Slovakia	124	174	205	222	78%	0.6%	1.1%	1.1%
Slovenia	46	55	60	72	58%	0.7%	1.3%	1.3%
Spain	842	1073	1252	1373	63%	2.5%	4.5%	5.9%
Sweden	433	470	503	506	17%	-0.1%	-0.1%	-0.1%
Switzerland	175	195	208	206	18%	0.1%	0.1%	0.1%
United Kingdom	1247	1412	1660	1812	45%	-0.2%	-0.3%	-0.6%
North	1210	1341	1488	1593	32%	-0.3%	-0.3%	-0.5%
West	5547	6391	7251	7694	39%	0.3%	0.5%	0.5%
Central-east	908	1249	1462	1683	85%	0.3%	0.7%	0.7%
South	2608	3384	3970	4431	70%	2.1%	4.0%	4.9%
Total Europe	**10,272**	**12,365**	**14,172**	**15,402**	**50%**	**0.7%**	**1.4%**	**1.7%**

Source: CEPE, ETH Zurich.

Total final energy demand of EU27+2 increases slightly from 2005 to 2050 by 8 % (or 4,080 PJ) to almost 53,000 PJ passing a maximum demand between 2030 and 2040 (see Table 6-28). This pattern of maximum final energy demand is determined by the West European countries, while the final energy demand of the other European countries steadily grow at small rates until 2050. Compared to the Base Case Scenario (no climate change), total final energy demand of Europe is 3.3 % less in 2050 with the most pronounced impact in West European countries (-4.3 %) and the least impact in southern European countries (1.7 %) in 2050. In some countries, energy demand grows more strongly in the perioda until 2035, but surprisingly, in some other relative growth is more pronounced in the last period (2035 to 2050), due to different patterns of population and economic growth and the additional influence of the changing climate.

In total, the changes due to the changing climate do not seem to be very important; however, they do have some impact on energy cost savings and additional investments in air-conditioners, cooling systems, road infrastructure etc. which are unevenly distributed among European countries and regions (see Chapter 3.8.3).

Table 6-28: Total final energy demand (fuels for heating and transportation, and electricity) and its change compared to Base Case Scenario, EU27+2, Reference Scenario, 2005 – 2050

Country or country group	Final energy demand in PJ					Impact of warmer climate		
	2005	2020	2035	2050	2005-2050	2020	2035	2050
Austria	874	944	1019	1109	27%	-1.9%	-3.3%	-4.3%
Baltic States	579	600	587	606	5%	-1.3%	-2.2%	-2.8%
Belgium/Luxembourg	1744	1903	1927	1922	10%	-1.3%	-2.8%	-3.9%
Bulgaria	416	447	491	627	51%	-0.5%	-0.7%	-0.9%
Czech Republic	1009	1079	1042	1174	16%	-1.7%	-3.4%	-4.2%
Denmark	513	557	577	571	11%	-1.3%	-2.5%	-3.6%
Finland	1129	1185	1240	1298	15%	-1.0%	-1.7%	-2.1%
France	7269	7639	7739	7421	2%	-1.2%	-2.2%	-3.4%
Germany	9005	8819	8392	7701	-14%	-1.9%	-3.6%	-5.2%
Greece	634	639	685	719	13%	-0.7%	-1.0%	-1.5%
Hungary	758	761	745	735	-3%	-1.8%	-3.4%	-5.0%
Ireland	351	405	440	447	27%	-1.5%	-3.1%	-4.5%
Italy	5022	5465	5481	5426	8%	-1.3%	-2.0%	-2.9%
Malta/Cyprus	146	132	124	128	-13%	-0.6%	-1.5%	-2.0%
Netherlands	1937	2055	2144	2095	8%	-1.4%	-2.9%	-4.3%
Norway	870	981	1120	1310	51%	-0.6%	-0.9%	-1.0%
Poland	2130	2600	2789	2826	33%	-1.6%	-2.8%	-3.9%
Portugal	844	1078	1204	1199	42%	-0.4%	-0.5%	-0.9%
Romania	1542	1609	1776	2139	39%	-0.6%	-0.7%	-0.8%
Slovakia	547	602	631	634	16%	-1.1%	-1.8%	-2.6%
Slovenia	276	336	340	382	38%	-0.8%	-1.7%	-2.5%
Spain	3434	4052	4201	4217	23%	-0.4%	-0.6%	-0.9%
Sweden	1466	1738	1775	1724	18%	-0.8%	-1.4%	-2.0%
Switzerland	818	815	786	731	-11%	-2.0%	-3.4%	-4.4%
United Kingdom	5587	5617	5859	5832	4%	-1.3%	-2.7%	-4.3%
North	3978	4461	4712	4904	23%	-0.9%	-1.5%	-2.0%
West	27585	28197	28306	27257	-1%	-1.5%	-2.9%	-4.3%
Central-east	5299	5978	6134	6358	20%	-1.5%	-2.8%	-3.8%
South	12037	13421	13963	14455	20%	-0.8%	-1.2%	-1.7%
Total Europe	**48,899**	**52,056**	**53,114**	**52,974**	**8%**	**-1.3%**	**-2.3%**	**-3.3%**

Source: ADAM

6.8.2 Direct CO_2 emissions of final energy demand sectors

Direct CO_2 emissions of the final energy demand sectors residential, services, industry, and transportation are calculated based on the results of the previous section using specific emission factors (Table 6-29).

Table 6-29: **CO_2 intensity (CO_2 emission factors) in [kg CO_2/GJ] or [tCO_2/TJ].**

Natural gas	Oil	Coal	Propane	Diesel	Gasoline	Kerosene	Naptha	Other oil products
56.1	73.7	94.6	70.0	73.6	73.9	72.1	73.3	65.5
Note: No direct CO_2-Emissions for Electricity, Wood, Biogas, Solar, District Heat, Hydrogen, Environmental Heat (e.g. from ground coupled heat pumps), Bio diesel, Bio ethanol								

Source: BFE (2002); DIW (2002); ETC/ACC Technical Paper 2003/10, http://air-climate.eionet.europa.eu/docs/ETCACC_TechnPaper_2003_10_CO2_EF_fuels.pdf

Table 6-30: **Direct CO_2 emissions in million t CO_2 per year, EU27+2 and European regions, Reference Scenario, 2005 – 2050**

Country or country group	CO_2 Mill. t					Impact of warmer climate		
	2005	2020	2035	2050	2005-2050	2020	2035	2050
Austria	37	34	34	37	0%	-1.5%	-2.6%	-3.2%
Baltic States	25	25	23	25	-2%	-0.2%	-0.2%	-0.1%
Belgium/Luxembourg	104	106	101	96	-8%	-1.4%	-3.4%	-4.9%
Bulgaria	20	20	21	28	40%	-0.4%	-0.6%	-0.9%
Czech Republic	50	48	44	49	-2%	-1.4%	-3.0%	-3.7%
Denmark	21	20	19	18	-11%	-0.8%	-1.5%	-2.0%
Finland	34	28	25	26	-22%	-0.5%	-0.5%	-0.1%
France	381	376	355	328	-14%	-1.5%	-2.7%	-3.9%
Germany	463	413	359	312	-33%	-2.1%	-4.2%	-6.2%
Greece	33	29	28	27	-16%	-1.4%	-2.6%	-3.7%
Hungary	36	33	31	30	-16%	-1.9%	-3.9%	-5.7%
Ireland	17	19	19	18	6%	-1.4%	-2.8%	-3.7%
Italy	260	253	236	223	-14%	-2.1%	-3.7%	-5.1%
Malta/Cyprus	9	7	6	6	-30%	-0.8%	-2.4%	-3.3%
Netherlands	96	95	92	85	-12%	-1.6%	-3.4%	-5.2%
Norway	33	37	42	52	56%	0.1%	0.2%	0.4%
Poland	112	125	126	124	10%	-1.5%	-3.0%	-4.4%
Portugal	46	54	56	54	16%	-1.1%	-1.7%	-2.3%
Romania	82	79	84	99	21%	-0.4%	-0.6%	-0.5%
Slovakia	26	23	22	21	-16%	-1.3%	-2.3%	-3.2%
Slovenia	15	18	18	20	33%	-0.8%	-1.7%	-2.5%
Spain	179	194	187	177	-1%	-1.1%	-2.0%	-3.0%
Sweden	47	46	43	41	-12%	-0.1%	0.0%	0.3%
Switzerland	43	40	36	33	-23%	-2.3%	-3.9%	-5.0%
United Kingdom	285	266	260	248	-13%	-1.5%	-3.3%	-5.4%
North	135	131	130	138	2%	-0.2%	-0.3%	-0.1%
West	1426	1349	1257	1156	-19%	-1.7%	-3.4%	-5.0%
Central-east	263	272	264	268	2%	-1.4%	-2.7%	-3.8%
South	628	637	619	613	-2%	-1.4%	-2.4%	-3.3%
Total Europe	**2452**	**2389**	**2270**	**2176**	**-11%**	**-1.5%**	**-2.9%**	**-4.1%**

Source: CEPE, ADAM

Since in this section, only direct CO_2 emissions are reported, emission factors of electricity, wood fuel, biogas, solar, district heat, hydrogen, environmental heat (e.g. from ground coupled heat pumps), bio-diesel, bio-ethanol are set to 0. Some of these energies are renewables, others are converted by fossil energies. Accordingly, these emissions are calculated and reported in the section of the conversion sector (see Chapter 7.2.8).

The development of the direct CO_2 emissions is determined by the development of final energy demand (as reported in the previous section) and substitution effects between fossil energies of different CO_2 intensity[13] (e.g. from coal to oil or from oil to gas) and between fossil energies and renewable energies.

Overall, direct CO_2 emissions are steadily reduced in the EU27+2 by 11 % up to 2050, whereas the emissions of the north and central-east European regions are increased by 2 % and those of south Europe decreased by 2 % reaching a maximum level in 2020 (see Table 6-30). Emission reductions are most pronounced in West Europe with 270 Mill. tonnes CO_2 (-19 %) until 2050. Emissions of the European service sector are slightly increasing and stagnating in industry during the period.

The impact of warmer climate reduces the direct CO_2 emissions by 4.1 % until 2050, most pronounced in the west European region and least in Scandinavia (see Table 6-31). The impact is around 3 to 4 % in central-east and south European countries respectively. However, it has to be stressed that the emissions from electricity demand changes are not included in this analysis of the final energy sectors as these changes of CO_2 emissions depend on the mix of electricity generation which also delelops quite substantially during the next few decades by increasing shares in renewable energies and high efficient thermal power plants using fossil fuels (see chapter 7).

6.8.3 Changed costs due to the impact of warmer climate

The changing demand for energy used in all final energy sectors was multiplied by the prices of final energies that had been calculated by the POLES model for each European country, the four final energy sectors and the various energy carriers (see Chapter 4). As the fuels for heating for all countries diminished during the period 2005 to 2050 due to warmer temperatures, the saved energy cost increases from some 4.4. Billion in 20010 to almost 35 Billion € in 2050; more than 60 % of these savings stem from west European countries (see Table 6-31).

On the other hand, additional electricity cost have to be considered due to additional demand for air conditioning and cooling services. These additional cost increase from .0.82 Bill. € in 2010 to 7,3 Bill. € in 2050, but not in all regions with comparable trends. As a substantial share of the heating demand is generated by electricity in some Scandinavian countries and the U.K., and as the additional electricity dmand for cooling is small, the electricity cost of the north European countries are declining (seeTable 6-31).

The net energy cost savings of the final energy sector, therefore, are about 27.5 Bill. € in 2050 compared to the case that no climate change occurs during the next decades. On the other hand, Spain, Italy, and southern France can expect substantial increases in their electricity bills. While the total energy bill per capita for total Europe is reduced by some 60 € per capita in 2050, the benefit of the Scandinavian countries is almost 140 € per capita in 2050 and practically zero in most southern European countries like Spain, Greece, Romania, or Bilgaria (see Table 6-31).

[13] The CO_2 intensity of final energy demand is defined as the ratio of direct CO2 emissions per unit of energy demand. As such, it reflects the carbon content of the fuels consumed.

Table 6-31: Change in energy costs (fuels and electricity) between Base Case and Reference Scenario, in Mill. €, EU27+2 and European regions, 2005– 2050

Country or Country group	Fuels 2010	Fuels 2020	Fuels 2035	Fuels 2050	Electricity 2010	Electricity 2020	Electricity 2035	Electricity 2050
Austria	-117	-240	-474	-694	10	30	60	71
Baltic States	-49	-81	-136	-194	-1	1	8	9
Belgium/Luxemburg	-117	-290	-696	-1211	12	45	114	136
Bulgaria	-15	-30	-56	-88	12	34	74	91
Czech Republic	-70	-150	-318	-523	-9	-9	-6	-3
Denmark	-70	-140	-329	-517	-3	3	19	23
Finland	-52	-108	-204	-303	-13	-17	-23	-36
France	-620	-1354	-2991	-4920	54	264	586	604
Germany	-1079	-2329	-5070	-7887	54	232	552	726
Greece	-57	-101	-227	-389	8	43	129	213
Hungary	-39	-80	-198	-351	11	33	64	75
Ireland	-28	-83	-225	-405	0	2	4	6
Italy	-745	-1558	-3201	-4851	410	1141	2362	2978
Malta/Cyprus	-7	-14	-39	-89	0	3	13	26
Netherlands	-205	-432	-1051	-1654	18	44	90	105
Norway	-34	-68	-150	-239	-46	-83	-143	-213
Poland	-153	-362	-921	-1699	9	35	84	104
Portugal	-82	-177	-407	-684	65	187	425	544
Romania	-65	-108	-202	-322	40	103	238	325
Slovakia	-29	-62	-131	-212	8	28	59	63
Slovenia	-19	-45	-106	-179	3	8	17	19
Spain	-227	-488	-1179	-1997	272	676	1377	1905
Sweden	-83	-199	-394	-591	-29	-24	-14	-19
Switzerland	-108	-215	-450	-667	-1	5	10	8
United Kingdom	-381	-902	-2327	-4315	-61	-108	-218	-442
North	-238	-515	-1077	-1651	-90	-121	-161	-245
West	-2657	-5845	-13285	-21753	85	513	1200	1214
Central-east	-359	-780	-1809	-3159	20	97	224	268
South	-1198	-2477	-5311	-8419	806	2187	4618	6082
Total Europe	**-4,453**	**-9,617**	**-21,483**	**-34,981**	**822**	**2676**	**5881**	**7318**

Source: CEPE, ETH Zurich.

Regarding investments, it has been argued that there are no reduced investments in heating systems because extreme low temperatures in winter can still occur. However, warmer temperatures in summer lead to additional investments in air conditioning and cooling (seeTable 6-32) as well as in additional road repairs and truck capacity due to heat waves and more traffic jams stemming from extreme weather events. Total additional investment is around 10 Billion € in 2050 mainly stemming from countries south of the Alps.

Table 6-32: Adaptation in terms of investment costs due to more air conditioning and cooling in the final energy sectors, EU-27+2 and European regions, Reference Scenario , 2010– 2050

Country or country group	Yearly investment in Bill. €			
	2010	2020	2035	2050
Austria	0.1	0.1	0.2	0.3
Baltic States	0.0	0.0	0.0	0.0
Belgium/Luxemburg	0.1	0.2	0.3	0.6
Bulgaria	0.0	0.0	0.0	0.1
Czech Republic	0.0	0.0	0.0	0.1
Denmark	0.0	0.0	0.0	0.1
Finland	0.0	0.0	0.0	0.1
France	0.2	0.4	0.6	0.9
Germany	0.5	0.9	1.3	1.8
Greece	0.1	0.1	0.1	0.1
Hungary	0.0	0.1	0.1	0.1
Ireland	0.0	0.0	0.0	0.0
Italy	0.7	1.0	1.3	1.7
Malta/Cyprus	0.0	0.0	0.0	0.0
Netherlands	0.0	0.1	0.1	0.2
Norway	0.0	0.0	0.0	0.1
Poland	0.1	0.1	0.2	0.2
Portugal	0.1	0.2	0.3	0.2
Romania	0.0	0.1	0.1	0.1
Slovakia	0.0	0.0	0.0	0.0
Slovenia	0.0	0.0	0.0	0.0
Spain	0.6	0.7	0.9	0.9
Sweden	0.0	0.1	0.1	0.1
Switzerland	0.0	0.1	0.1	0.1
United Kingdom	0.0	0.1	0.3	0.5
North	0.1	0.1	0.2	0.4
West	1.0	1.9	2.9	4.4
Central-east	0.1	0.2	0.3	0.5
South	1.5	2.0	2.7	3.2
Total Europe	2.7	4.3	6.2	8.4

Source: CEPE, ETH Zurich [last updated 3 February 2009].

Finally, the investments in air conditioners and cooling systems had to be structured according to the delivering industrial branches and related service sectors. The air-conditioning systems and cooling systems have different sizes, technologies, and planning efforts which had to be reflected for the different final energy sectors (see Table 6-34). For instance, the traded small air conditioning units for private households result in costs for trade and installation by craftsmen, while the large cooling plants for industrial purposes have major inputs from electrical goods and metal products. These investment shares are used in the IMPULSE model to reflect the additional investments of the Reference Scenario in the macroeconomic models (see Chapter 8).

Table 6-33: Split of the investment cost in air conditioners and cooling systems according to major delivering economic sectors

	House-holds	Services	Industry	All Sectors
Non-metallic mineral products	0%	0%	0%	0%
Chemical products	0%	1%	1%	1%
Metal products except machinery	0%	22%	22%	21%
Industrial (and agricultural) machinery	0%	9%	9%	9%
Office and data processing machines, computer	0%	1%	1%	1%
Electrical goods	62%	50%	50%	51%
Building and construction	10%	5%	5%	5%
Inland transport services	2%	3%	3%	3%
Services of credit and insurance institutions	1%	2%	2%	2%
Other market services (engineering, consulting etc)	25%	6%	6%	7%
Non-market services (public administration, etc.)	0%	1%	1%	1%
Total	100%	100%	100%	100%

Source: CEPE, ETH Zurich.

6.9 References Chapter 6

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7 Assumptions and results of the models on primary energy conversion, non-energy use, and distribution losses – Reference Scenario

The results of the final energy demand from Chapter 6 have to be projected into the relevant demand of primary energy. This chapter summarises the results of the two conversion models PowerAce which covers most of the renewable energies and draws together the results on renewables of the final energy sectors (see Chapter 7.1) and EuroMM which projects the primary energy demand of the traditional conversion sector including transmission and distribution losses and total CO_2 emissions (see Chapter 7.2).

7.1 Use of renewable energies - projected by the bottom up models

The use of primary energy conversion based on renewable energy sources (RES) up to the year 2050 is projected by different models. The agent-based simulation model PowerACE covers the projection of grid-connected energy conversion plants using RES (pure electricity generation, CHP and biomass district heating plants; see Chapter 7.1.1). The development of non-grid connected heat production (geothermal heat pumps and solar thermal collectors) is projected by the demand-driven final energy models SERVE, RESIDENT, ASTRA, and ISIINDUSTRY for the corresponding final energy sectors (see Chapter 6). Non-grid based heat production using wood fuel is treated by MATEFF (see Chapter 5.3). Finally in Chapter 7.1.2, wood fuel in district heating plants is covered.

7.1.1 Electricity generation by renewable energies in Europe

Electricity generation by renewables is increasing even without additional policies as described in the Base Case scenario due to existing legal boundary conditions (e.g. feedin tariffs, financial incentives). This chapter describes the impact of climate change for the Reference Scenario which is mostly related to increasing temperatures. As changes in extreme events are still not quantified to a large degree for the different European regions and countries, the impact desbribed covers only a part of the climate change effects which the renewable energy technologies will face in the coming decades.

7.1.1.1 The effect of climate change on the use of renewable energies

While the use of renewable energy sources (RES) might contribute significantly to mitigating climate change, some RES are also vulnerable to changes in global climate. The increase in CO2 concentration involves changes in temperature, precipitation patterns, evaporation, wind speeds and cloudiness, which again may have an impact on the use of renewable energies. Temperature changes may have a direct influence on the available RES, such as solar irradiation, wind speed or changes in river discharge volumes. As a result the capacity factor of a RES-E plant is affected, implying a modified power output. As RES electricity is characterised by a high share of investment in total electricity generation costs, the related impacts on average electricity generation costs can be substantial and can greatly influence the competitiveness of RES in the conventional electricity market. Besides the total amount of electricity produced, climate change may have an impact on the variability of the power output, in particular regarding hydro power plants or wind turbines. Growth characteristics of woody and agricultural biomass plants may be affected by changing temperature, as well as by an increased CO_2 concentration in the atmosphere. Temperature increases may also affect characteristics of the applied conversion technologies, for instance, regarding the solar cell efficiency of PV plants. A higher module temperature is generally accompanied by a reduction of solar cell efficiency.

Regarding the representation of the future RES development in Europe within the model PowerACE-ResInvest-ResInvest, quantification of climate change impacts on RES is required. However, the quantification of climate change impacts on RES presents a challenging task. Impacts have to be quantified using input from climate data predicted commonly by general circulation models (GCM). However, uncertainties related to the GCM-predicted changes in global climate imply that derived results are only of an exploratory character. Furthermore, the resolution of climate models is often too coarse to model their impact on the availability of RES, for instance, regarding the prediction of wind speeds. The refinement or local downscaling of GCM output represents one approach towards improving geographical resolution. Detailed consequences of climate change on the use of RES will be discussed subsequently.

Wind energy

The productivity of wind electricity generation is predominantly characterised by a high dependency on local wind regimes. More precisely, the power output of a wind turbine is proportional to the cube of the wind speed. For this reason, even small changes in wind speed, possibly caused by climate change, may have a considerable impact on the power output of a wind turbine, thus leading to a modification of the total available wind energy potential.

Wind power is further characterised by fluctuations and a certain unpredictability of the power output. To a certain extent, the impact of climate change may represent an additional risk for wind power investments, reinforcing existing uncertainties regarding the total amount of electricity generated by a wind turbine.

Climate change is expected to induce an increase in extreme wind speeds and calms, on the one hand, and induce changes in mean wind speeds on the other hand. At this point we shall focus on the discussion of the climate change impact on mean wind speeds, as their development is crucial for the potential future magnitude of the electricity output generated with wind turbines.

In particular, the quantitative analysis of the impact of climate change on wind power represents a rather challenging task. Existing General Circulation Models (GCM) used to project climate change effects provide data about changes in wind speeds, but the coarse geographical resolution of the models is not sufficient to map a realistic picture of the possibly strongly varying wind conditions at a regional level. This fact can be explained by the strong regional dependence of wind power regimes and thereby a strong regional dependence of the climate change impacts on wind power. In addition, wind speed accuracy with an error of ±1m/s which is regarded as quite accurate may lead to considerable differences in the resulting power output.

After the majority of the existing climate change studies focussed on the description of precipitation and temperature effects, an increasing number of studies has been carried out to investigate the potential effect of climate change on wind power in recent years. To the authors' knowledge, there is no study available covering Europe as whole at a national level at present. The first studies in this field focussed regionally on the USA, Scandinavia and the United Kingdom. Recently, further work has been carried out to analyse the impact of climate change on German wind speeds. However, most of the scientists still point out the explanatory character and the high degree of uncertainty of the obtained results.

In most of the cases, data output from GCM models is employed within this analysis in order to represent changing climate conditions. As the comparatively coarse geographical resolution of the GCM models tends to be insufficient for the analysis of wind power potential, refinement methodologies are used in order to downscale the global climate data and convert it to a higher disaggregated regional level. Common methodologies represent empirical or statistical geographic downscaling. Indeed, downscaling in principle does not allow for dealing with small-scale effects.

Some of the first studies carried out in the field dealt with climate change and wind energy in the USA. In order to estimate the impact of climate change on wind power potential, (Segal et al. 2001) used a refined regional climate model based on HADCM2 outputs. The explanatory results of this study indicate a seasonal reduction of wind power potential by 0 % to 30 % and an annual change of about ±10 %, assuming a hub height of 40 m. At the same time, the authors found that the southern and north-western USA seem to experience an increase in wind power potential of up to 30 %. Furthermore, the wind power potential appears to remain unaffected by climate change in regions with favourable wind conditions. (Breslow, Sailor 2002) estimated the potential impacts of climate change on wind regimes in the USA, using the general circulation models from the Canadian Climate Center and the Hadley Center (HADCM2). The authors predict a decrease in wind speed of 1.0 % to 3.2 % by 2050 and 1.4 % to 4.5 % by 2100 at an altitude of 10 m. In this study, climate output data is used without applying any downscaling technique. The authors highlight the uncertainty of predictions, in particular for the time horizon after 2050. However, the authors do not make any statement about the evolution of the wind speed at turbine height of about 60 m to 100 m. As wind speed rises with increasing distance from the surface, depending on the roughness of the ground wind speed, information on changes at hub height would be necessary in order to evaluate the concrete impact on power output. In a more recent article (Sailor et al. 2008) focus is placed on the estimation of the climate change implications on wind power in five concrete sites within the northwest United States. In order to improve regional data quality of the GCM data from the IPCC, statistical downscaling was applied, a technique used to simulate large circulation features from GCM models at a higher disaggregated regional level. The resulting validation of statistically downscaled climate output data against real data from selected sites showed a significantly improved data consistency as compared to the original data output. In a next step, the authors scaled up wind speeds to a hypothetical hub height of 50 m and derived the changes in monthly power densities . The results show a decrease in wind power potential of up to 40 % in spring and summer, whereas results for winter seem to be less consistent, indicating, however an increase in future wind power potential.

Another piece of research was carried out by (Venäläinen et al. 2004) who analysed climate change impacts on the Finnish energy system. Results based on the hub-height corrected offshore wind speed data from the GCM HADCM3 model indicate an average increase of offshore wind power potential by 2 % to 10 %, representing a rise of 20 % to 30 % in winter and 10 % to 15 % in summer time.

The British authors (Harrison, Wallace 2005) intended to approximate a range of potential climate change vulnerability of wind and wave power potential using sensitivity analysis without considering country-specific GCM-derived future climate data. In a very recent study (Harrison et al. 2008) went one step further and applied UK climate data in order to investigate changes in wind speed induced by climate change. The authors built their analysis on HADRM3-ouput, representing a regionally refined equivalent of HADCM3. Results indicate slight averaged changes on an annual basis, and seasonal and geographical differences. The annual mean wind speed increased by 0.5 % up to 2080. Seasonal wind speeds augmented by 5 % to 10 % in the south and east of the UK, while slight reductions were projected for the north of Scotland and Northern Ireland. At the same time, summer wind speeds were predicted to decline by 5 % to 10 %. The Scottish Road Network Climate Change Study carried out by (Galbraith et al. 2005) reports on expected changes in two-year daily mean wind speed amounting to a magnitude of ± 5 % for Scotland.

Results from an investigation carried out by (Pryor et al. 2006) for Scandinavia and the Baltic States based on climate data from HADCM3 indicate that there appears to be no considerable change either in the evolution of annual wind indices or in the seasonal differences.

Recently published results of a project investigating climate change in Germany indicate that there will not be an increase in frequency of extreme wind events including days with a mean wind speed exceeding 10 m/s (Jacob et al. 2008). Regarding average wind speeds, the authors expect no change in the annual means and only moderate changes at a seasonal level. Wind speeds are estimated to increase slightly in some months by up to 0.4 m/s up to 2050. Looking at the time frame up to the end of the 21st century, wind speeds in Germany seem to rise slightly in winter, whilst a low decrease is foreseen for the summer months.

To the authors' knowledge, there are no studies providing detailed results on climate change impacts for Europe as a whole. In an analysis carried out by (Watson et al. 2002), trends of offshore wind speeds over the past 40 to 100 years for the European Atlantic, the Baltic Sea and the Mediterranean were observed, without predicting any changes for the future. In another study the impact of climate change on wind power is estimated for Europe with a focus on German wind speeds, again without providing detailed geographical results. The research consortium made projections of mean changes in wind speeds by the end of this century, based on three regional climate models (Walter et al. 2006). The authors observe an increase in annual mean wind speeds at 10 m height during winter over Europe, with a strong increase in the Baltic and North Sea, a decrease in the Mediterranean area and a decrease in summer. Annual means seem to increase by up to 1 m/s in the Baltic Sea and decrease by about 1 m/s in the Mediterranean area on average.

Given the incomplete data availability, on the one hand, and the insufficient data accuracy of the existing outputs on the other, we decided not to consider the quantitative effects of climate change on wind power into the renewable capacity expansion modelling. Indeed, one should still consider that changes in wind speeds may have considerable impacts on the utilisation of wind turbines and therefore on the power output, as the power output varies with the cube of the wind speed. As we have seen in the literature review, wind speeds strongly depend on regional characteristics and on the seasons, implying that possibly a part of the expected changes may be levelled out.

Photovoltaics

Photovoltaic electricity generation may be affected in two ways. First, a possible change in solar irradiation affects the utilisation of a PV power plant, leading to a modified electricity output. The change in solar irradiation may occur as a consequence of changed clouding possibly induced by climate change. Given the difficulty to model and predict long-term changes in clouding, the estimation of this effect represents a very challenging task and cannot be provided within this study. The other effect is related to efficiency losses caused by a temperature increase in the PV module as described by (Nordmann, Clavadetscher 2003). Given the comparatively low overall impact of climate change on PV electricity generation and the challenging quantification of the impacts, we do not consider climate change for this technology within the renewables modelling exercise.

Biomass

Climate change influences the availability of biomass in different ways. While an increased CO_2 concentration tends to influence positively most of the existing crops, changes in precipitation patterns or temperatures may favour or prejudice crop productivity (Tubiello, Ewert 2002). Results from a modelling exercise carried out by (Olesen et al. 2007) indicate a rise in crop productivity in northern European countries as a consequence of longer growing cycles and higher CO_2 concentrations. Compared to that, crop productivity may decline or increase only slightly in southern European countries due to changing precipitation patterns. In this way, the biomass potential in Finland is estimated to increase by about 10 % to 15 % (Venäläinen et al. 2004).

Regarding the modelling of RES-development, we consider the modified potential of biomass resources from forest residues provided by EFISCEN (see Chapter 5.1). Changes in agricultural biomass potential are not considered due to lack of data availability.

Hydro power

The driving force for the hydro power potential affected by climate change represents the discharge volume of rivers, which is mainly induced by changing precipitation patterns and evaporation. While precipitation changes may show increasing as well as decreasing trends, depending on the geographical area and the season, evaporation is expected to rise due to ascending temperatures. Hence, considerable changes in discharge regimes are expected for the future as a consequence of climate change. Taking into account the significant share of hydro power in RES-E generation, altered discharge regimes may have severe impacts on the amount of electricity produced. Therefore, we consider the impacts of climate change on hydro power production in modelling the capacity development of RES in the Reference Case.

Since the changing discharge volumes of rivers were not investigated within the ADAM project, we had to rely on information about changing hydro power potential available in the literature. Thus, we resorted to a study that estimated the impact of climate change on hydro power potential for Europe on a national scale carried out by (Lehner et al. 2005). The authors calculated the influence of climate change on the gross hydro power potential as well as its impact on the already developed hydro power capacity. Results obtained in the analysis mentioned indicate discharge volumes for southern and east-central Europe decreasing in parts by more than 25 %, whilst foreseen rises in discharge volumes for northern European countries may in part exceed 25 %. In addition, one should consider that hydro power production is characterised by a high annual variability which may even provoke higher changes on an annual basis.

In the study mentioned, percentage discharge changes with respect to historical weather conditions including average values between 1961 and 1990 were calculated, using the integrated global water model WaterGAP. In order to integrate the results into the PowerACE-ResInvest-ResInvest model, the given changes in hydropower potential are transferred into percentage changes of utilisation and broken down for each time increment of one year, assuming that existing energy conversion efficiencies remain unaffected by the modified utilisation. Since only a limited growth of hydro power capacity is expected in European countries, we base our calculations on the impact on the hydro power capacity already developed. Possible efficiency changes induced by refurbishment of old plants are not considered.

The underlying assumptions of the study used regarding climate change input data are slightly below those of the ADAM reference case, assuming an average annual increase in CO_2 emissions of 1 %. This amount corresponds to the no-climate-policy of the IPCC-IS92a scenario and slightly exceeds the intermediate "A1B-Scenario" of the IPCC-SRES scenarios updated in 2000.

Table 7-1: Comparison of climate change assumptions in the ADAM Reference Case and the applied data for the derivation of the change in hydro power potential

	(Lehner et al. 2005) based on the A1B-Scenario	ADAM Reference Case
CO_2 concentration in 2070	600 ppm	620 ppm
Increase in temperature (since the pre-industrial age)	+ 2.3°C	+ 2.8°C

Looking at the influence of climate change on hydro power generation, one should consider that results are estimated based on various assumptions, including uncertainties regarding for instance the input from the GCM models.

In accordance with the described results, (Venäläinen et al. 2004) estimate an increase in hydropower production in Finland amounting to between 7 % and 11 %. Results are based on hydrological modelling for three hydro power plants which represent 70 % of Finnish hydropower production.

Another article describes the impact of climate change on hydro power plants in Switzerland. (Hauenstein 2005) discusses, in a mainly qualitative manner, the impact of climate change on hydro power plants in Switzerland, focussing on the impact on Alpine hydro power plants. As compared to the impact on the productivity of common hydro power plants, Alpine hydro power plants are affected differently by climate change. First, an increased hydro power production in summer provoked by melting glaciers is foreseen, until several glaciers may have disappeared. On the other hand, stronger precipitation in form of snow expected during wintertime might increase river flow in spring and early summer. Then, an increasing share of rainfall in precipitation in wintertime will be directly available for hydro power production, while less hydro power is expected for summer, due to decreased precipitation in summer and diminishing snow reserves.

7.1.1.2 Assumptions for electricity generation by renewables – Reference 2000 to 2050

The basic assumptions for electricity generation by renewables in the Reference Scenario are similar to those undertaken within the Base Case Scenario. Techno-economic data of the technologies (see Table 7-2), the status quo of RES-E in 2005 as well as support conditions and political and legal boundary conditions for the diffusion of renewable energies remain completely the same (see Jochem et al. 2007).

Impacts of climate change on the future development of renewable energies have been considered in the technical potentials (see Table 7-3). First, climate-change-induced modifications in the capacity factor for hydro power affect the total available hydro power potential in terms of electricity generation. Second, the overall available potential of wood affected by climate change was modelled in the forest model EFISCEN (see Chapter 5.1), then recalculated considering paper production and other industrial wood demand (see chapter 5.2 and 5.3), and finally used as input data for the PowerACE-ResInvest model runs.

The hydro-electricity generation potential decreases by about 11 % or down to 1,270 PJ of electricity at the EU level including even larger deviations in some of the Member States. However, the impact of the modified hydro power potential on total electricity generation potential from all RES (excluding biomass) at more than 17,300 PJ is comparatively small (see Table 7-3). The technical potentials of the other renewables such as wind (almost 10,000 PJ), solar (5,600 PJ), geothermal energy (1,400 PJ), and wave and tide power (450 PJ) are considered not to change in the Reference Scenario compared to the Base Case Scenario. When taking the climate change impacts on additional wood fuel potentials into consideration, the overall biomass primary potential increases by roughly 1 % to a level of more than 11,000 PJ primary energy.

Consistent with the overall definition of the ADAM Reference Scenario, the particular assumptions for renewable energy sources do not consider any additional climate policies to be active. There are, however, a number of policies presently existing at the EU Member State level which actively promote renewable energies for energy policy reasons (i.e. security of supply, environmentally benign) and which were also partially motivated by climate policy when introduced beginning in the mid-1990s. Therefore the key assumption here was to continue innovations that have been initiated by these policy measures in the past, but not to initiate strengthened new policies motivated by climate policy objectives. In this way, it is assumed that the financial support currently available is reduced on a yearly basis according to the technological progress of the renewable technologies. If no financial support is available for a certain technology in a country, the wholesale electricity price (excl. taxes) represents the possible turnover per unit of electricity generated.

Table 7-2: Technical and economic characteristics of RES technologies in 2005

Technology	Plant specification	Investment	O&M costs	Electric efficiency	Heat efficiency	Life-time	Typical plant size
		[€/kWel]	[€/ (kWel*yr.)]			[years]	[MWel]
Biogas	Agricultural biogas plant	2550 - 4290	115 – 140	0.28 - 0.34	-	25	0.1 - 0.5
	Agricultural biogas plant – CHP	2760 - 4500	120 – 145	0.27 - 0.33	0.55 - 0.59	25	0.1 - 0.5
	Landfill gas plant	1280 - 1840	50 – 80	0.32 - 0.36	-	25	0.75 – 8
	Landfill gas plant – CHP	1430 - 1990	55 – 85	0.31 - 0.35	0.5 - 0.54	25	0.75 – 8
	Sewage gas plant	2300 - 3400	115 – 165	0.28 - 0.32	-	25	0.1 - 0.6
	Sewage gas plant – CHP	2400 - 3550	125 – 175	0.26 - 0.3	0.54 - 0.58	25	0.1 - 0.6
Biomass	Biomass plant	2225 - 2530	75 – 135	0.26 - 0.3	-	30	1 – 25
	Co-firing	550	60	0.37	-	30	-
	Biomass plant – CHP	2600 - 4230	80 – 165	0.22 - 0.27	0.63 - 0.66	30	1 – 25
	Co-firing – CHP	550	60	0.2	0.6	30	-
Biowaste	Incineration plant	4300 - 5820	90 – 165	0.18 - 0.22	-	30	2 – 50
	Incineration plant – CHP	4600 - 6130	100 – 185	0.14 - 0.16	0.64 - 0.66	30	2 – 50
Geothermal electricity		2000 - 3500	100 – 170	0.11 - 0.14	-	30	2 – 50
Hydro large-scale		850 - 5950	35	-	-	50	20 – 250
Hydro small-scale		800 - 6050	40	-	-	50	0.25 – 10
Photovoltaics		4000 - 6100	38 – 47	-	-	25	0.005 - 0.05
Solar thermal electricity		2880 - 4465	163 – 228	0.33 - 0.38	-	30	2 – 50
Tidal energy		2670 - 3025	44 – 53	-	-	25	0.5 – 2
Wave energy		2135 - 2850	44 – 53	-	-	25	0.5 – 2
Wind onshore		890 - 1100	33 – 40	-	-	25	2
Wind offshore		1590 - 2070	55 – 68	-	-	25	5

Source: Ragwitz, M., Resch, G. (2006). In case of PV: Staiß (2007)

The assumptions on the overall energy system such as wholesale or end use electricity prices are based on the results of the POLES model (see Chapter 4). Furthermore, electricity demand data influenced by increasing temperatures and forecasted by the different bottom-up models calculating sectoral electricity demand (see Chapter 6) have been used by the PowerAce model in this chapter.

Table 7-3: Technical potentials for renewable energies generating electricity, EU27, Reference Scenario, 2050

	Electricity Generation Potential [PJ]						Primary Energy Potentials[14] [PJ]
	Wind	Solar	Geothermal (only hydrothermal)	Hydro	Wave &Tide	**Total (excl. BM)**	**Biomass**
Austria	35	94	0	137	0	**266**	**307**
Belgium	107	56	0	1	1	**164**	**105**
Luxembourg	4	6	0	0	0	**11**	**5**
Bulgaria	26	122	5	33	3	**189**	**244**
Cyprus	7	12	0	0	1	**20**	**12**
Malta	1	7	0	0	0	**8**	**1**
Slovenia	2	20	0	27	0	**49**	**110**
Czech Republic	196	105	0	10	0	**311**	**190**
Germany	746	544	0	89	28	**1,406**	**1,654**
Denmark	661	60	0	0	9	**730**	**166**
Estonia	132	23	0	0	4	**160**	**99**
Latvia	98	50	0	17	2	**167**	**157**
Lithuania	31	69	0	3	1	**104**	**279**
Spain	893	954	0	90	48	**1,985**	**889**
Finland	229	48	0	66	6	**349**	**484**
France	1,420	795	1	173	47	**2,437**	**1,576**
Greece	89	149	1	10	14	**263**	**188**
Hungary	11	158	0	5	0	**174**	**216**
Ireland	674	77	0	3	14	**769**	**53**
Italy	209	650	6	132	12	**1,009**	**765**
Netherlands	254	83	0	0	4	**341**	**127**
Poland	385	415	0	10	4	**813**	**1,267**
Portugal	309	169	1	26	27	**531**	**206**
Romania	49	395	0	72	2	**518**	**313**
Sweden	1,253	73	0	329	11	**1,666**	**670**
Slovakia	21	63	0	17	0	**101**	**152**
United Kingdom	2,144	418	0	20	212	**2,793**	**875**
EU27	**9,987**	**5,616**	**14**	**1,272**	**448**	**17,337**	**11,111**

Source: own calculations and estimations, partially based on European Environment Agency (2006); Ragwitz et al. (2006).

7.1.1.3 Results for electricity generation by renewables in Europe – Reference Scenario 2000 to 2050

Given the continuity of support policies currently in place without improving efforts and assuming that temperature will increase by 4° C up to 2100, we expect an increase in RES-E generation from 488 TWh to 1,358 TWh by 2050. Most of the contribution to electricity generation using renewable energies will come from the United Kingdom, France, Spain, Germany and Sweden followed by Italy and Austria (see Table 7-5). Hydro power was the dominating renewable energy source in 2005 amounting to 69 %, but according to projections

[14] The biomass primary energy potential includes the potential for grid-connected energy conversion plants (pure electricity generation plants, CHP plants and district heating plants). The potential for non-grid connected heat production based on biomass is excluded in this table, but has been considered separately in Chapter 6 in the final energy sectors.

dynamic wind development will make wind the leading renewable source (at 47 %) by the middle of this century. Since the potential for hydropower has nearly been fully exploited, this technology only shows moderate growth of some 8 % until 2050. The share of biomass technologies including solid biomass, biowaste and biogas in total renewables will increase from 15 % in 2005 to 17 % in 2050 allowing a growth of some 160 TWh, or more than tripling between 2005 and 2050 (see Table 7-4).

Table 7-4: Overview on electricity generation based on renewable energies, in TWh, EU27 total, Reference Scenario, 2005 – 2050

Electricity generation [TWh]	2005	2010	2020	2030	2040	2050
Wind	71	108	202	327	466	638
Solar	1	6	25	51	69	78
Geothermal	5	6	8	8	8	8
Hydro	336	360	367	366	365	363
Biomass	49	72	94	98	102	104
Biowaste	10	20	24	25	26	28
Biogas	15	22	46	70	87	103
Wave & Tide	0	0	3	10	22	35
RES-E total	**488**	**593**	**767**	**955**	**1,145**	**1,358**

Source: PowerACE-ResInvest, own calculations

The following sections comment briefly on the development of each renewable energy generating electricity in terms of its development for each Member Country and the EU27.

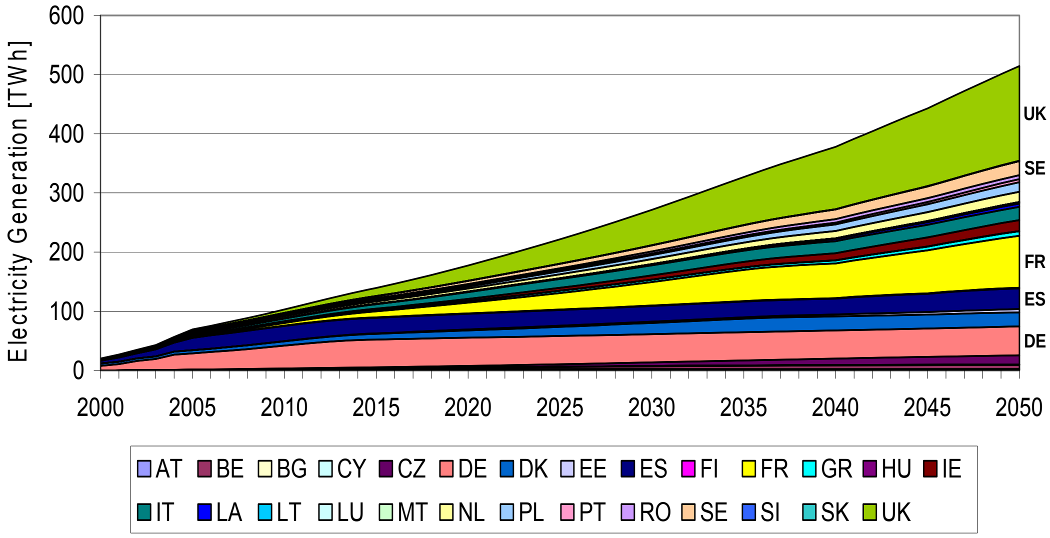
Table 7-5: **Electricity generation based on renewable energies, in TWh, EU27, Reference Scenario, 2005 to 2050**

Electricity generation	2005	2010	2020	2030	2040	2050
Austria	40	43	46	48	48	49
Belgium	2	4	8	13	17	19
Bulgaria	4	6	7	6	5	5
Cyprus	0	0	0	0	0	1
Czech Republic	3	5	9	13	18	23
Germany	62	85	112	125	133	141
Denmark	10	13	21	33	41	41
Estonia	0	1	2	3	4	6
Spain	58	73	87	96	104	122
Finland	23	27	28	29	30	33
France	69	77	98	127	160	200
Greece	7	9	15	21	23	26
Hungary	2	3	4	6	7	7
Ireland	2	3	8	15	23	33
Italy	48	58	78	97	110	114
Latvia	3	4	4	5	8	10
Lithuania	0	1	1	1	2	4
Luxembourg	0	0	0	0	1	1
Malta	0	0	0	0	0	0
Netherlands	8	9	12	17	25	36
Poland	4	8	14	21	28	36
Portugal	15	20	26	30	32	35
Romania	20	22	23	25	28	29
Sweden	82	85	87	97	110	128
Slovenia	4	6	8	8	8	8
Slovakia	5	5	6	7	7	7
United Kingdom	17	26	61	112	173	244
EU 27	**488**	**593**	**767**	**955**	**1,145**	**1,358**

Source: PowerAce-ResInvest, own calculations

Wind onshore

As can be seen under the assumptions of the reference Scenario, a continuous increase in wind electricity generation is expected at the EU level (see Table 7-1). Whereas penetration is expected to saturate or only moderately increase in countries like Germany and Spain with already high shares of wind generation in the overall portfolio, other countries like France and the UK will catch up and will become similarly important by the year 2030. About 515 TWh will be generated by wind electricity in 2050 under the assumptions made for this projection.



Source: PowerACE-ResInvest, own calculations

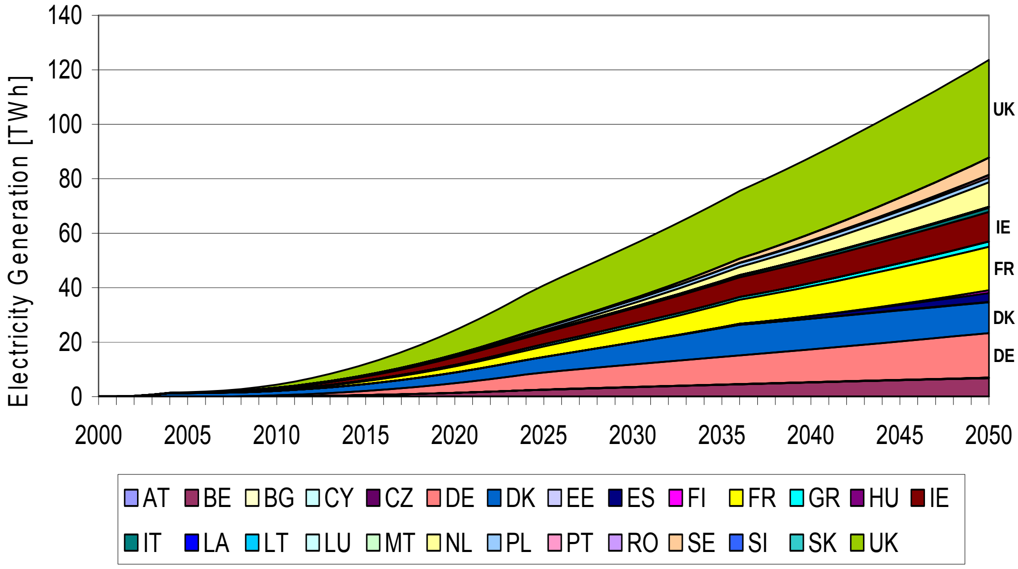
Figure 7-1: Electricity generation based on wind onshore, EU27, Reference Scenario, 2000 to 2050

Wind offshore

At present wind offshore development lags somewhat behind expectations, due to existing problems in this sector (i.e. technical problems concerning foundation, grid integration, problems with obtaining permissions). Thus, the future evolution of the use of wind energy at sea depends on whether and when the currently existing technical and administrative barriers can or may be overcome. Taking this fact into account, wind offshore diffusion starts with a smooth development until 2020 and continues with stronger growth (see Figure 7-2). Given the existing technical potentials and the policy support offered in particular countries, the United Kingdom, Denmark and Germany generate electricity using wind offshore amounting to 36 TWh (UK), 16 TWh (DE) and 11 TWh (DK). Electricity generation using wind at sea already possesses a huge potential that is not exploited in the ADAM Reference Scenario.

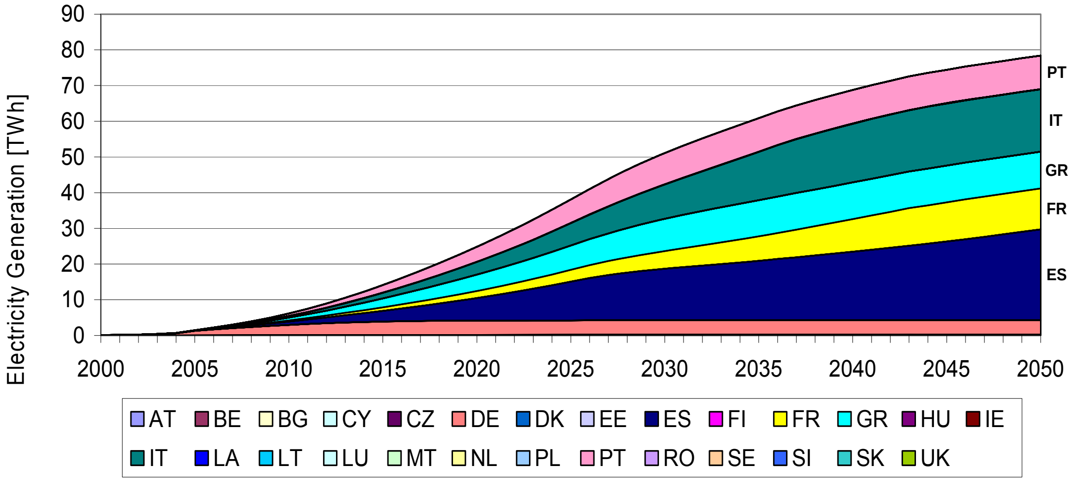
Solar energy

While PV electricity may theoretically be produced in all European countries, solar thermal electricity generation needs direct solar irradiation (without clouds) and electricity generation only makes sense in southern European countries. If there is sufficient direct solar irradiation to generate electricity using solar thermal conversion technologies, generation costs are significantly below those of PV, at least for the next two decades. Even so, grid-connected PV technology already shows higher market diffusion rates than solar thermal electricity within Europe at present and accounted for 3.3 GW of installed capacity (EurObserv'ER 2007). Germany is the country with most installed solar energy capacity in terms of photovoltaics, delivering more than 85 % of the total PV electricity generated within Europe. Nevertheless, the development of PV in Germany will slow down compared to southern European countries such as Spain, Italy, Greece, France and Portugal, since they have better climate conditions for the use of solar energy. As a result of the currently implemented favourable support conditions for PV and solar thermal electricity, Spain will deliver most of the solar electricity in the year 2050 (Figure 7-3).



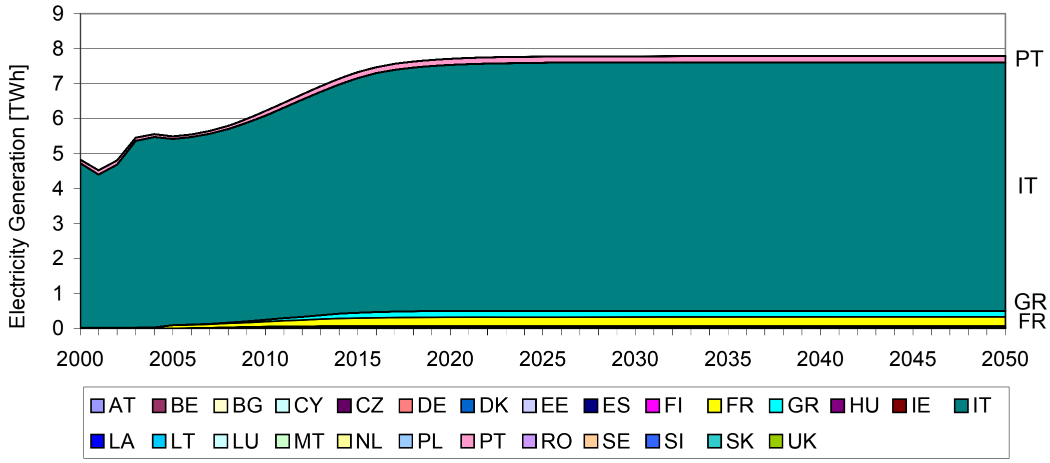
Source: PowerACE-ResInvest, own calculations

Figure 7-2: Electricity Generation based on wind offshore, EU27, Reference Scenario, 2000 to 2050



Source: PowerACE-ResInvest, own calculations

Figure 7-3: Electricity generation based on solar energy, EU27, Reference Scenario, 2000 to 2050

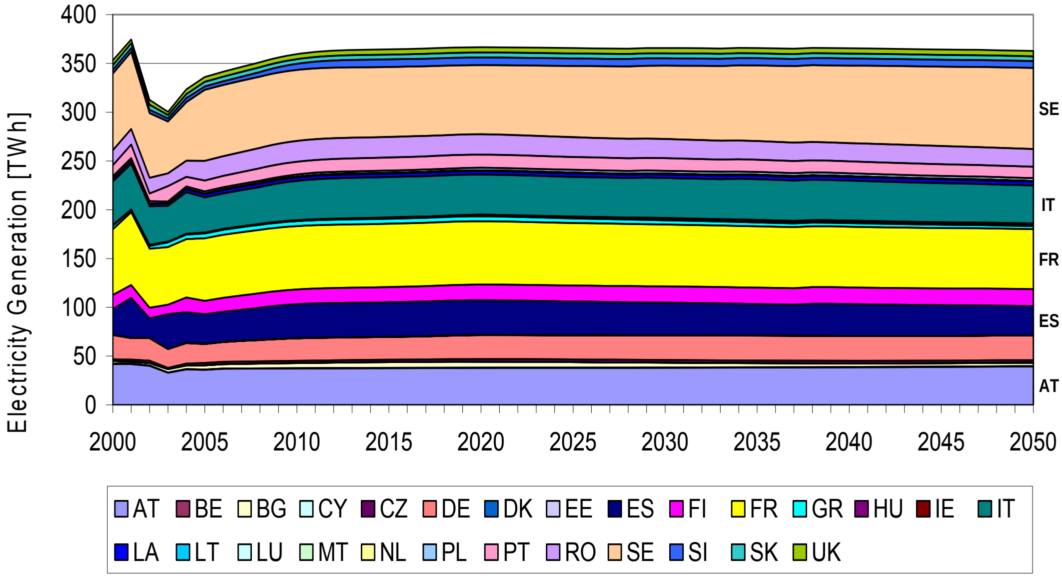


Source: PowerACE-ResInvest, own calculations

Figure 7-4: Electricity generation based on geothermal energy, EU27, Reference Scenario, 2000 to 2050

Hydro energy

Hydro energy is the RES most vulnerable to climate change, depending substantially on altered rainfall conditions. At the EU level, hydro power capacity increases slightly up to 2050, in particular including small hydro power plants with a capacity size of up to 10 MW. At the same time, the electricity output from hydro power plants shows a slight increase up to 2020, followed by a minor decrease up to 2050 as a consequence of climate change (see Figure 7-5).



Source: PowerACE-ResInvest, own calculations

Figure 7-5: Electricity Generation based on hydro energy, EU27, Reference Scenario, 2000 to 2050

As compared to a scenario not considering climate change impacts, hydro power production decreases by about 8 % at the EU level. However, observing development at the national level, one can see that some countries experience considerable changes in hydro electricity production. Whilst hydro power production in northern European countries seems to augment, decreasing rainfall leads to reduced hydro electricity output in southern European countries.

The strongest decrease is expected for Bulgaria producing 53 % less hydro electricity in a climate change scenario as compared to the Base Case Scenario without considering climate change (see Figure 7-6). The fact that the decreasing trend stops temporarily after 2044 is due to an increase in installed hydro capacity taking place in the Reference Scenario, but not in the Base Case Scenario. Modelling runs predict a decrease in hydro power generation of up to 40 % by 2050. According to the scenario runs, western Mediterranean countries such as Spain, Portugal and Italy produce between 13 % (PT) and 22 % (ES) less hydro electricity than in the Base Case Scenario. Countries benefiting from climate change in terms of hydro power production are the Baltic States (Estonia with an increase of 18 % and Latvia with an increase of 10 %) and Scandinavian countries, where Finland shows a hydro electricity production increase of 12 % and Sweden 9 %. Austria and France, two of the three countries with the highest contribution to total EU hydro electricity production, show decreasing hydro power output, whereas the third major hydro power country Sweden expects an increased electricity output under climate change conditions. In general, one should take into account the uncertainty of the presented results given still little understanding of projecting extreme events and changed wind patrerns or river flows.

Results regarding the modified electricity output of hydro power plants in the Reference Scenario should be considered carefully due to the uncertainty associated with the hydro power potential data derived from climate models.

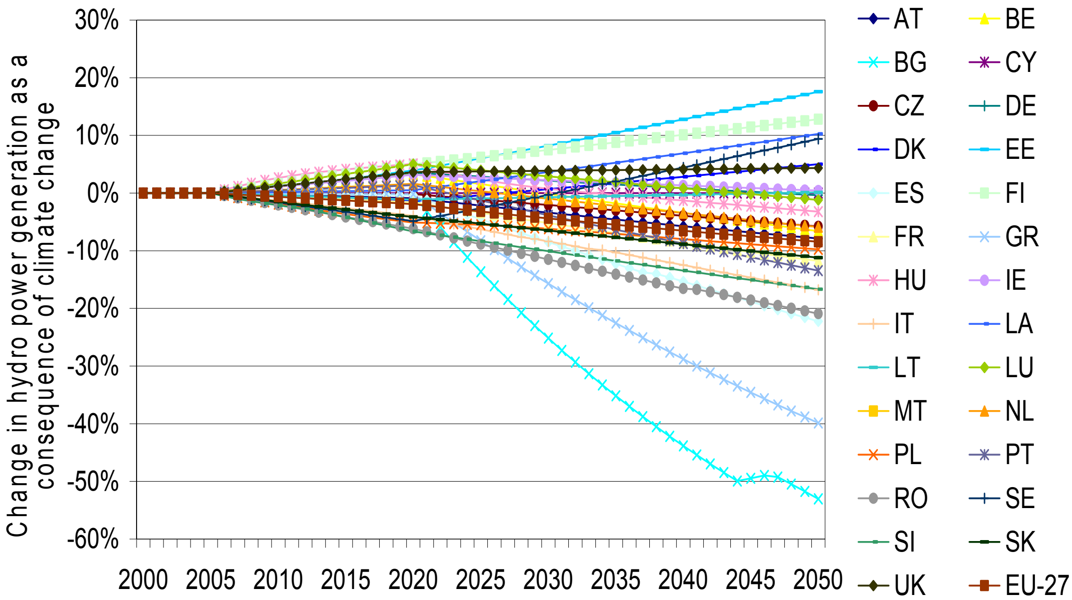
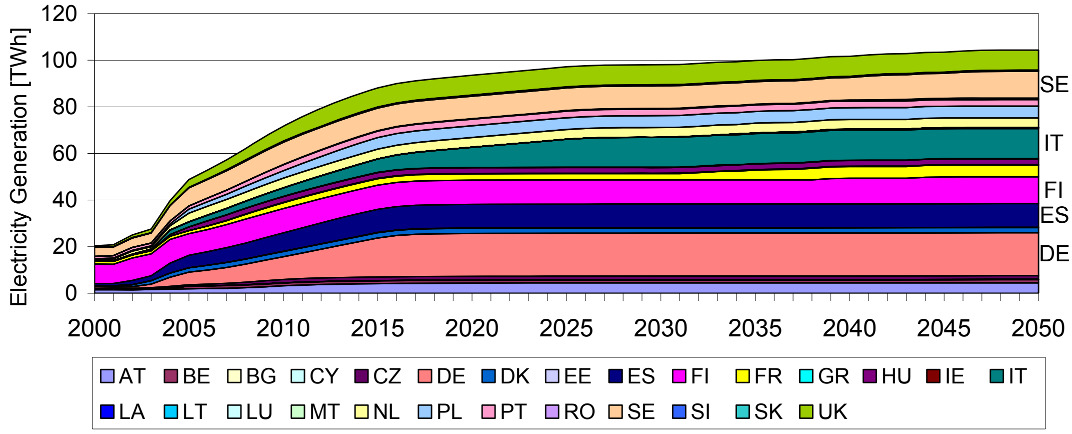


Figure 7-6 **Change in hydro power generation in the Reference Case as compared to the Base Case Scenario of EU Member States, 2005 to 2050**

Solid biomass

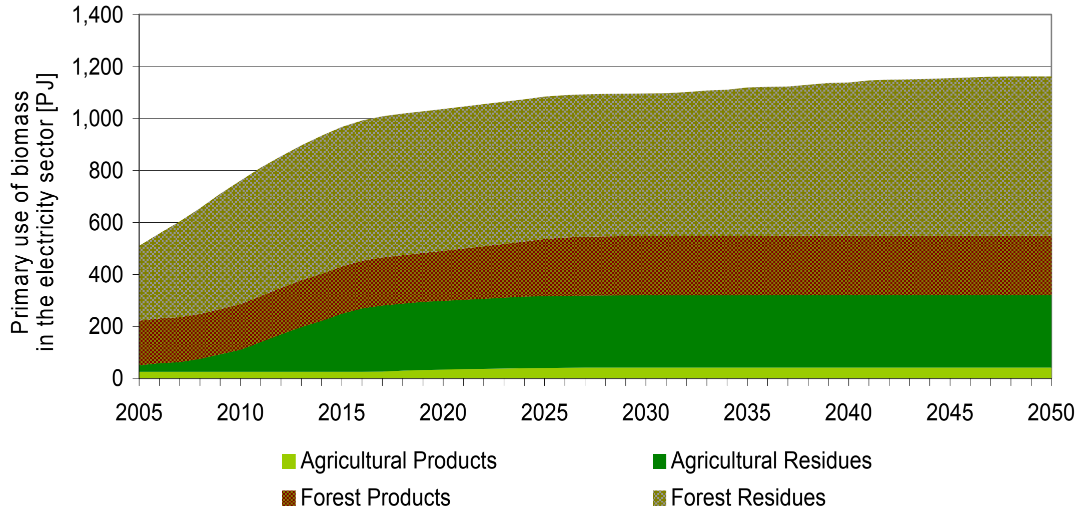
According to modelling results, the influence of climate change on the use of biomass for electricity generation seem to be rather small. Therefore, total electricity generation from biomass by 2050 increases by only 1 % as compared to the Base Case Scenario reaching an annual electricity production of 104 TWh (see Figure 7-7). The modelling output shows that assuming the Base Case Scenario this growth slows down slightly starting in 2005 and declines even more rapidly around 2015 due to an exploitation of low-cost biomass potentials. In particular northern European countries with a large wood and paper industry (SE, FI) are expected to produce electricity amounting to about 12 TWh each in 2050. About 61 % of the electricity generated in 2050 is expected to be produced in CHP plants.



Source: PowerACE-ResInvest, Own calculations

Figure 7-7: Electricity generation based on biomass, EU27, Reference Scenario, 2000 to 2050

Looking at the type of biomass resources used, one can see that biomass electricity generation is mainly based on the use of forest residues at present as well as by 2050. Due to comparatively high feedstock prices, the use of wood products (particularly of chips) does not show a significant increase up to 2050 and remains almost at a constant level (see Figure 7-8). A similar statement applies for the use of agricultural products starting at a very low level and remaining almost constant up to 2050. As compared to that, the use of agricultural residues increases from a very low level in 2005 to 280 PJ, thus exceeding the use of forest products. Given the economic disadvantages of the use of biomass products and their potential application for non-energy uses (e.g. food production, material use) the use of biomass residues is preferable.

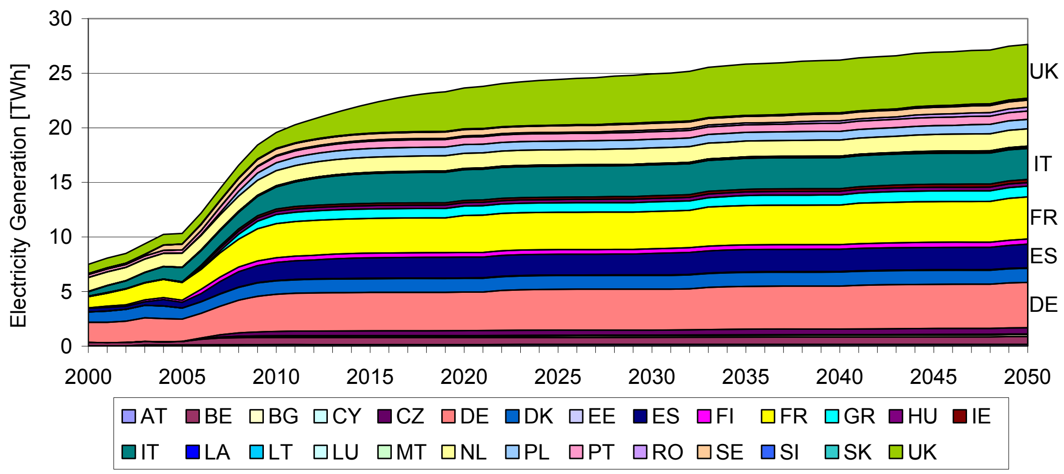


Source: PowerACE-ResInvest, own calculations

Figure 7-8: Primary use of biomass in the electricity sector according to the corresponding biomass input[15]

Biowaste

The evolution of biowaste according the PowerACE Reference Scenario is characterised by considerable growth until 2010 and then slows down, since exploitation already approaches the potential limits (see Figure 7-9).



Source: PowerACE-ResInvest, own calculations

Figure 7-9: Electricity generation based on biowaste, EU27, Reference Scenario, 2000 to 2050

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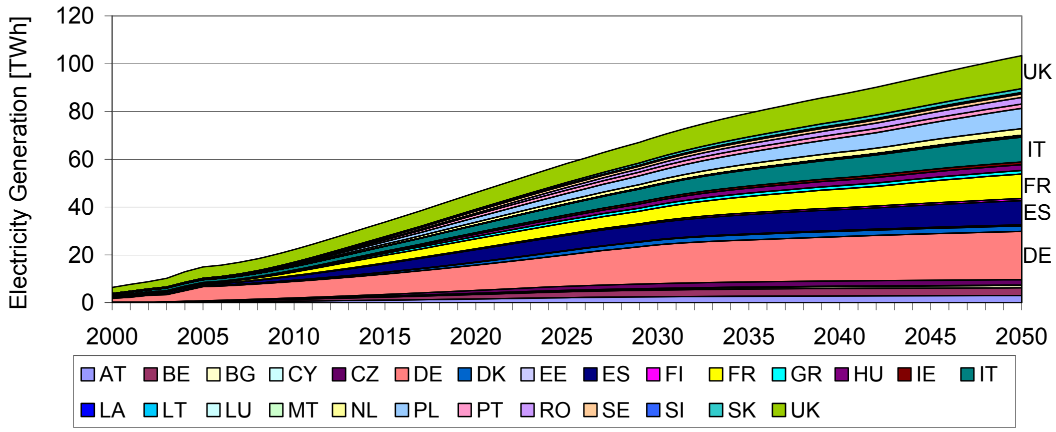
15 As data regarding the historical use of biomass for electricity generation, figures were estimated using known shares of biomass primary composition as described in (EurObserver, 2007).

Biogas

About 65 % of the electricity produced using biogas in 2050 corresponds to the use of agricultural biogas resulting from agricultural products (cereals, oil crops, grass, maize, perennial grasses, etc.) and agricultural residues (manure and crop residues). 28 % of the electricity production from biogas in 2050 is based on the use of landfill, with the rest attributed to sewage gas (see Figure 7-10).

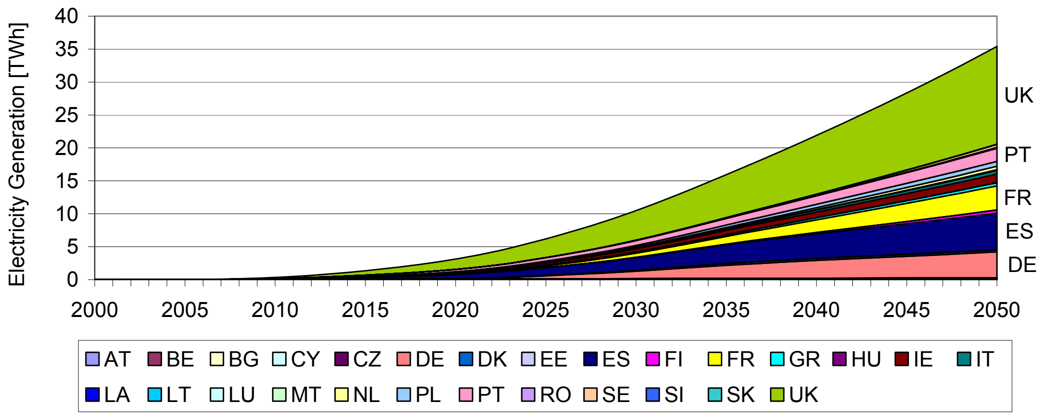


Source: PowerACE-ResInvest, own calculations

Figure 7-10: Electricity generation based on biogas (agricultural biogas, landfill gas and sewage gas), Reference Case Scenario, 2000 to 2050

Ocean energy

Wave and tidal energy development is characterised by slow growth until 2030, since there is only little practical experience with both technologies at present (see Figure 7-11). The first commercial wave power plant with a size of 2.25 MW has recently been implemented in Portugal near the city of Porto (September 2008).



Source: PowerACE-ResInvest, own calculations

Figure 7-11: Electricity generation based on wave and tidal energy, EU27, Reference Scenario, 2000 to 2050

7.1.1.4 Adaptation cost

Since climate change does not induce a change in renewable capacity, but rather only in generation, emerging adaptation investments occur within the conventional power sector. The missing generation from RES is replaced by conventional electricity generation capacity. Thus adaptation investments induced by renewables show up in terms of adaptation investments within the electricity sector model EuroMM. Average electricity generation costs for hydro power plants are affected by climate change, since the investments remain equal compared to the Base Case and the produced electricity changes at the same time. Here increasing electricity generation is characterised by decreasing average electricity generation costs. Conversely, decreasing electricity generation implies a rise in the average electricity generation costs.

7.1.2 Use of wood fuels for heat generation in the conversion sectors

Since the 1990s, there has been a tendency to use wood fuel in some European countries with large forest areas in heating plants and cogeneration plants. Most of the fuel wood is used in the form of chips, but pellets and wood briquettes are also more frequently used in those plants. This trend is likely to prevail in the future, given rising prices for fossil fuels and improved harvest machines in forestry.

The development of grid connected biomass-based district heat generation is modelled with PowerACE-ResInvest and follows the same logic as in the case of electricity generated by renewable energies.

7.1.2.1 Assumptions for renewable energy use for stationary applications - Reference Scenario 2000 to 2050

Under the climate conditions of the Reference Scenario, the countries south of the Alps (Bulgaria, France, Greece, Hungary, Italy, Portugal, Romania, Slovenia, Malta, Cyprus and Spain) are forecasted to have less biomass growing in forests than in the Base Case Scenario, because they are more likely drier and will have more heavy rainfalls, with less water availability caused by dried out soils.

Less wood is allocatable than in the Base Case Scenario. The demand for woodchips directly from the forest ([EFISCEN] ~70%) and firewood directly from the forests ([EFISCEN] ~80%) is predicted to decrease 4% in the private households, the service sector, and industry (see Chapter 5.3) and also in district heating and co-generation

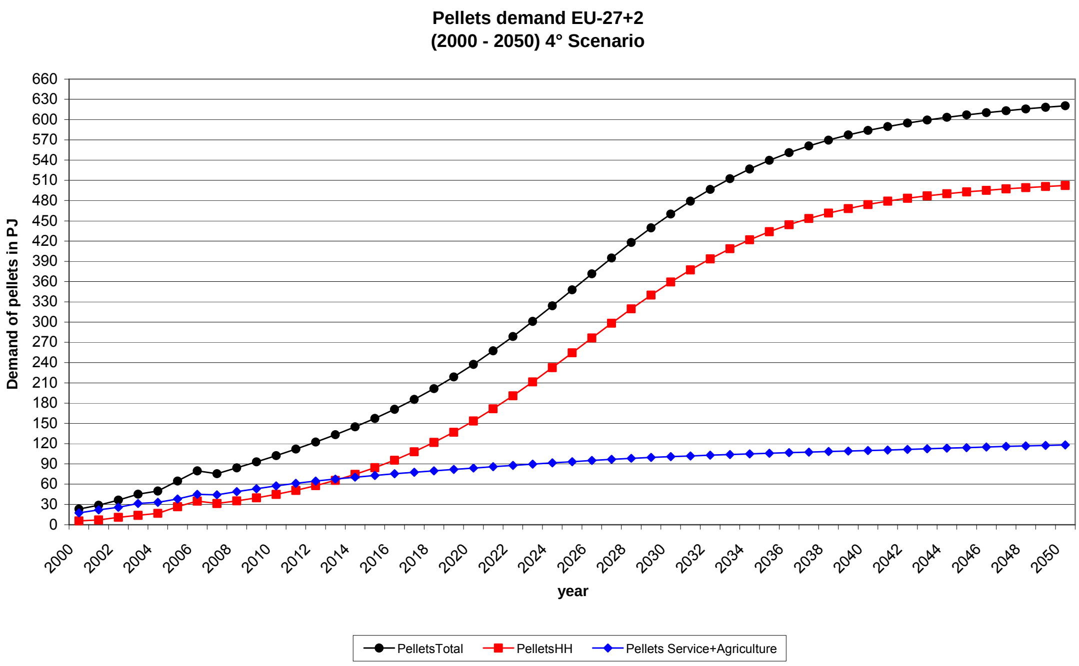
The situation in the countries north of the Alps (Austria, the Baltic states, Belgium, Luxembourg, Czech Republic, Denmark, Finland, Germany, Ireland, the Netherlands, Norway, Poland, Slovakia, Sweden, United Kingdom and Switzerland) is predicted developing contrary to the development in the South: Higher biomass growth is estimated. More wood is allocatable than in the Base Case Scenario, because more biomass can grow in these countries because of warmer temperatures and advantageous vegetation climate, i.e. higher atmospheric CO_2 concentrations in combination with more precipitation. The demand for woodchips (directly from the forest [EFISCEN] ~70%) and firewood (from the forests [EFISCEN] ~80%) is predicted to increase equally 4 % in private households, the service sector, and industry, in district heating and co-generation.

From 2000 to 2005, the data of wood fuel use in all sectors are adopted from the Base Case Scenario.

7.1.2.2 Results for renewable energy use for stationary applications – Reference Scenario 2000 to 2050

Wood pellets & wood briquettes

Figure 7-12 shows the outlook of the demand for pellets in Europe (EU 27+2) in total, in the private household and service sectors for the Reference Scenario. The results are the same as in the Base Case Scenario - pellet demand in 2050 is expected to increase up to 620 PJ in total, because pellets are more dependent on policy decisions and industrial wood waste (which do not change in the Reference Scenario) than on forest residues.

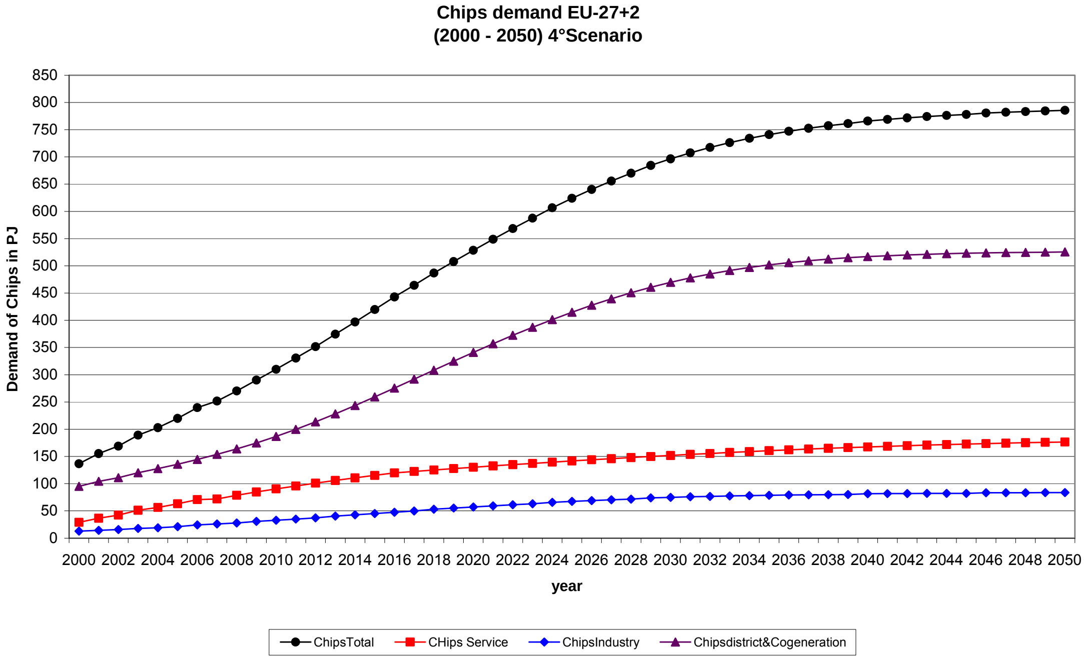


Source: MATEFF, BSR-Sustainability 2008

Figure 7-12: Pellets demand, total and in different sectors, (EU 27+2) Reference Scenario, 2000-2050

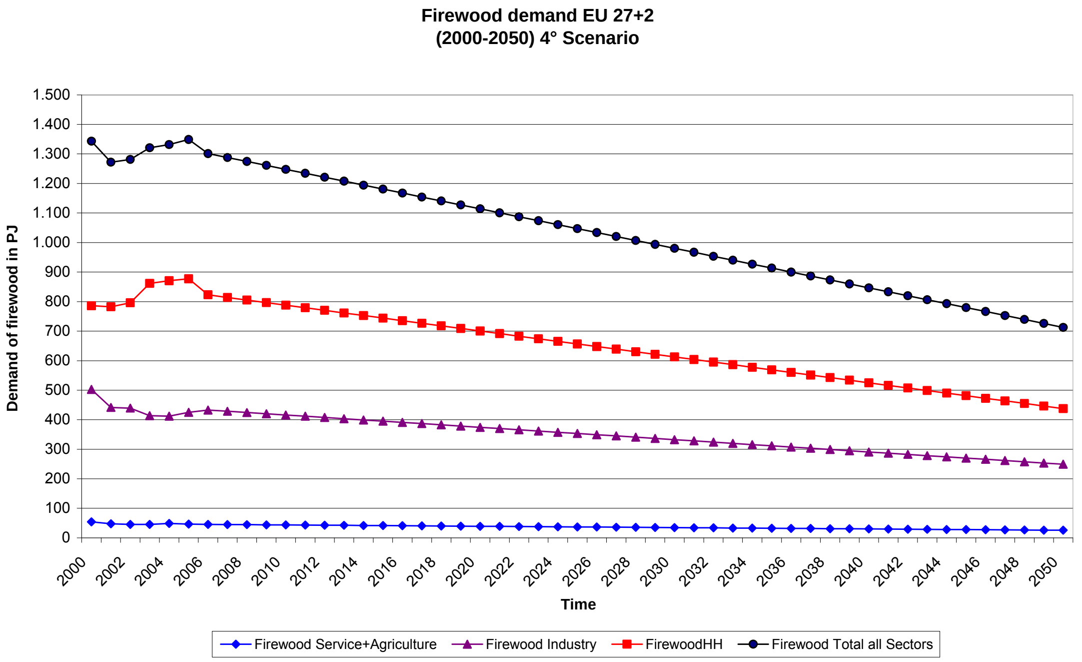
Woodchips

Contrary to pellet, the woodchip demand is expected to change in the Reference Scenario, because in countries north of the Alps there will be more available biomass – and south of the Alps less biomass is expected. The outlook for woodchip demand in Europe (EU27+2) in total (see Figure 7-13) indicates an almost continuous increase in the demand for woodchips. Woodchips are used mainly in district heating plants, co-generation and industry. In rural areas with the possibility of easily accessible forests and inexpensive storage space for woodchips, the tendency towards using woodchips in the service sector – especially in the agricultural sector - is quite high (up to almost 180 PJ in 2050). The total chip demand is expected to reach almost 790 PJ in 2050.



Source: MATEFF, BSR-Sustainability 2008

Figure 7-13: Chips demand total and in several sectorss, (EU 27+2), Reference Scenario, 2000 to 2050



Source: MATEFF, BSR-Sustainability 2008

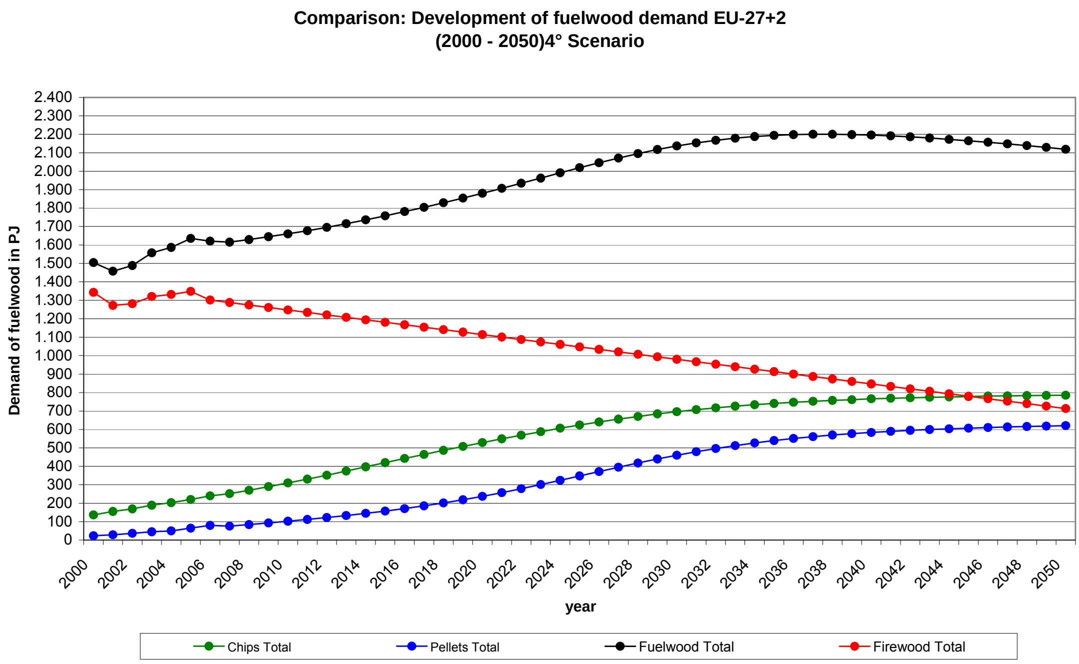
Figure 7-14: Firewood demand total and by sectors, EU27+2, Reference Scenario, 2000-2050

Firewood

Firewood demand in Europe (EU27+2) decreases in all sectors, i.e. in the private household, service and industry sectors for the Reference Scenario due to its inconvenience relative to other energy carriers or modern forms of wood fuel (see Figure 7-14). From around 1,320°PJ of total firewood use in EU27+2 in the year 2000, the projection for 2050 is a decreased firewood demand of only 713°PJ.

Comparison of firewood, pellet and chips demand

The results of the Reference Scenario for the different kinds of wood fuels in Europe show that “old forms" of wood fuel such as firewood are going to decrease and “new forms" of wood fuel such as and woodchips and pellets are increasing in the market because the new forms are convenient to use in modern automatic wood fuel plants (see Figure 7-15). They can be delivered easily by van (similar to oil) and have a higher energy density than firewood, which leads to various economic advantages (gross calorific value of 1kg wood pellets ~ 4.9 kWh; gross calorific value of 1kg firewood ~ 4.1 kWh). The overall view shows an increase of total fuel wood to a maximum of 2,200 PJ shortly before the year 2040. In 2050 the total fuel wood is going to be used at a level of around 2,120 PJ in EU 27+2.



Source: MATEFF, BSR-Sustainability 2008

Figure 7-15: Share of firewood and new forms of wood fuels, 2°C Scenario, 2000 to 2050

7.1.2.3 Adaptation cost

There are no specific adaptation costs in the Reference Scenario for fuel wood, neither in countries south of the Alps nor north of the Alps. The four percentage points in both directions only slightly change the productivity of harvesters in the forests, although slight price changes may occur, i.e. slightly higher in the countries south of the Alps and slightly lower in the countries north of the Alps.

7.1.3 References

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7.2 Use of primary energy by large scale conversion technologies - projected by EuroMM

7.2.1 Electricity transmission and distribution losses and district heat generation

7.2.1.1 Assumptions and results for electricity transmission and distribution losses – Reference Scenario 2000 to 2050

For the Reference Scenario, the effects of climate change on the electricity transmission and distribution grid are investigated and when possible integrated in the model EuroMM. Under climate change, it is expected that the number of occurrences of extreme weather events (e.g. icy storms) will change and that average air temperatures will increase (IPCC report). Since we do not have reliable information about changing weather conditions, we focused on the change in air temperature. Higher ambient temperatures will increase electrical resistance in transmission and distribution lines leading to higher losses in electricity transmission. Using estimates according to Zhelezko (Zhelezko et al, 2005) to calculate the resistance change in relation to air temperatures, we found that electricity losses will increase up to 0.7 % until 2050 compared to the base line and depending on the average air temperature of the European region investigated (see Table 7-6).

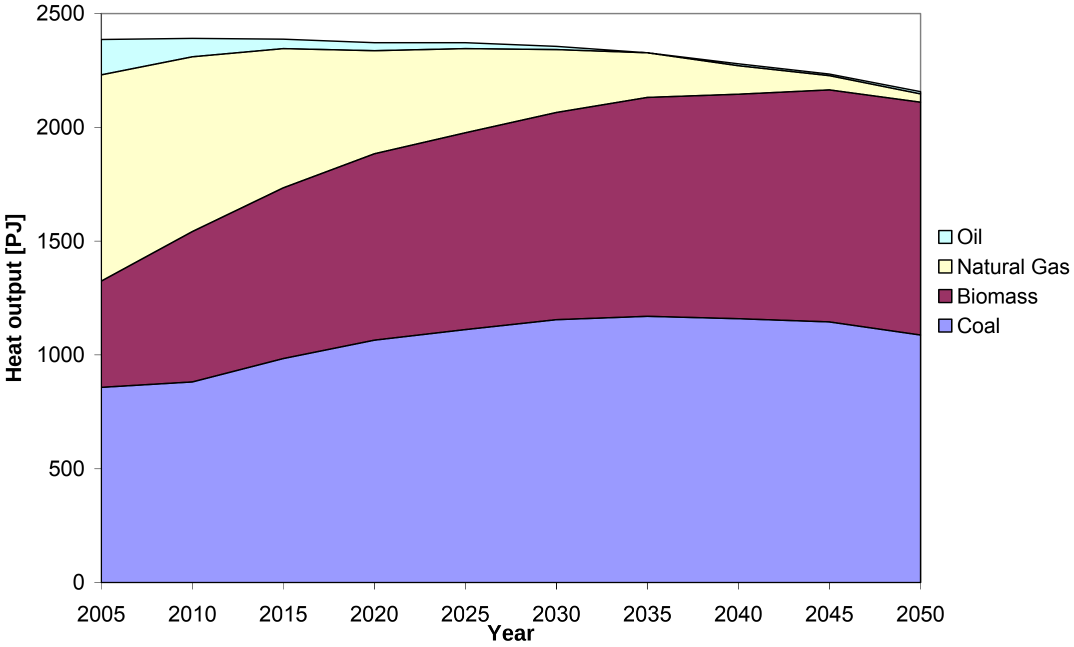
Table 7-6: Additional electricity losses, depending on the increase in ambient air temperature (for selected years and European regions).

	Year	**2005**	**2010**	**2020**	**2030**	**2040**	**2050**
	Temp increase	0.000	0.222	0.667	1.111	1.556	2.000
Region	Average temp	Additional electricity losses [%]					
North	5	1	0.08	0.24	0.39	0.55	0.71
Central	10	1	0.08	0.23	0.39	0.54	0.69
South	17	1	0.08	0.23	0.38	0.53	0.68

Source: EuroMM

7.2.1.2 Overview low temperature heat generation

The demand for low temperature heat (district heat) was calculated from the other bottom-up models (SERVE/RESIDENT/ISINDUSTRY) (see Chapter 6.8) and used as direct demand input into EuroMM. In the Reference Scenario, the low temperature heat demand will be supplied mainly by inexpensive coal and easily available biomass, particularly municipal wastes and increasing shares of wood fuel, for combined heat and power plants. By 2050, gas-based district heat production will be replaced as heating oil-based plants are phased out earlier between 2020 and 2030 (see Figure 7-16). The production of low temperature heat only represents a minor market activity below 2,400 PJ with declining trend down to 2,100 PJ due to decreasing demand for heating buildings in the coming decades (see Chapter 6.8).



Source: EuroMM

Figure 7-16: Fuel share for district heat generation, EU-27+2, Reference Scenario, 2005 to 2050

7.2.2 Electricity generation by thermal power plants in Europe

The largest share in electricity production is due to thermal power plants fuelled by coal, gas, lignite, and nuclear energy. This share is dependent on long term reinvestment cycles and strategic considerations such as long term price perspectives for fossil fuels, security of supply of primary energies and their capacities for adaptation to climate change policies during their life times.

EuroMM, the model used in this analysis, produces the electricity needed after the electricity produced by the renewables (see Chapter 7.1) has supplied some part of the electricity demand of all final energy sectors (see Chapter 6.8) and of the conversion sector itself. The model selects the new investments in the electricity generation system with a least-cost algorithm and on a country level, not taking into consideration substantial changes in electricity trade between the EU27+2 countries.

7.2.2.1 *Assumptions for electricity generation by thermal power plants - Reference Scenario 2000 to 2050*

Two temperature effects due to climate change are influencing the output of thermal power plants and are considered in the model calculations for the described Reference Scenario. On the one hand, higher temperatures of power plant cooling media influence the efficiencies of the plants. The efficiency decrease was derived and implemented in EuroMM for all types of thermal power plants using the input of the ADAM work package Scenarios (temperature values for the Reference Scenario) together with assumptions for efficiency calculations based on Durmayaz (Durmayaz et al, 2006).

On the other hand, the power plant output is highly dependent on the availability of cooling water and the cooling medium temperature. With climate change and increasing temperatures, water availability for cooling purposes decreases due to changing runoff patterns, mainly in southern European regions. However, environmental regulations regarding the use of water for cooling purposes are also likely to reduce the availability for power plants. Specifically, if the regulatory threshold temperature of 25°C is reached in rivers used for cooling, utilities will be unable to release cooling water and hence will have to decrease power output. In southern countries and under extreme weather conditions, some power plants may have to shut down completely.

Avoiding such instances will require additional investment to install advanced cooling systems such as dry cooling towers. However, these technologies usually consume more electricity then conventional cooling systems such as once-through cooling systems. In EuroMM efficiency losses in power plants were integrated for all types of power plants, availability factors are estimated using a sub-model of seasonal river temperatures. Accordingly the model has options to install additional cooling capacities using either wet or dry cooling systems to respond to climate change aspects.

7.2.2.2 *Results for electricity generation by thermal power plants in Europe - Reference Scenario 2000 to 2050*

Coal:

In the Reference Scenario, coal will continue to play a major role in electricity production in Europe. European Countries with abundant coal resources (e.g. Poland, Czech Republic and Germany) will see continuous growth in coal fired power production to cover own demand as well as exporting electricity to regions with lower resource availability (see Figure 7-17).

For southern European regions it is highly relevant that additional cooling capacity is necessary to deal with the impacts of climate change. Almost 20 % of coal fired power production in Europe will need additional cooling capacity, mainly in Italy, Spain, Portugal and Greece (see Figure 7-18).

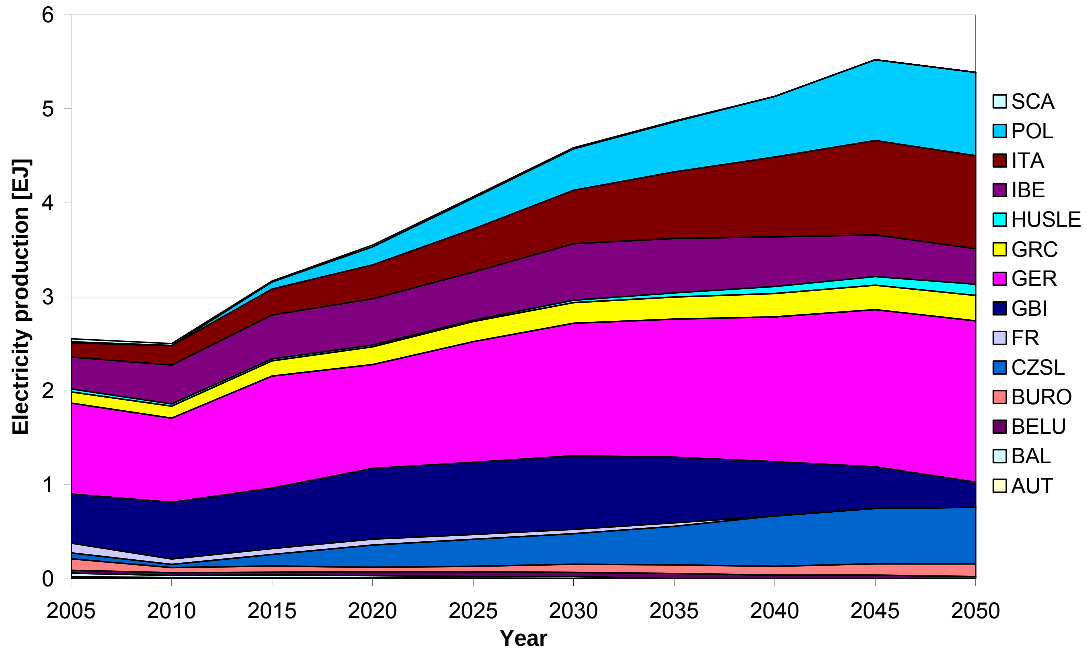
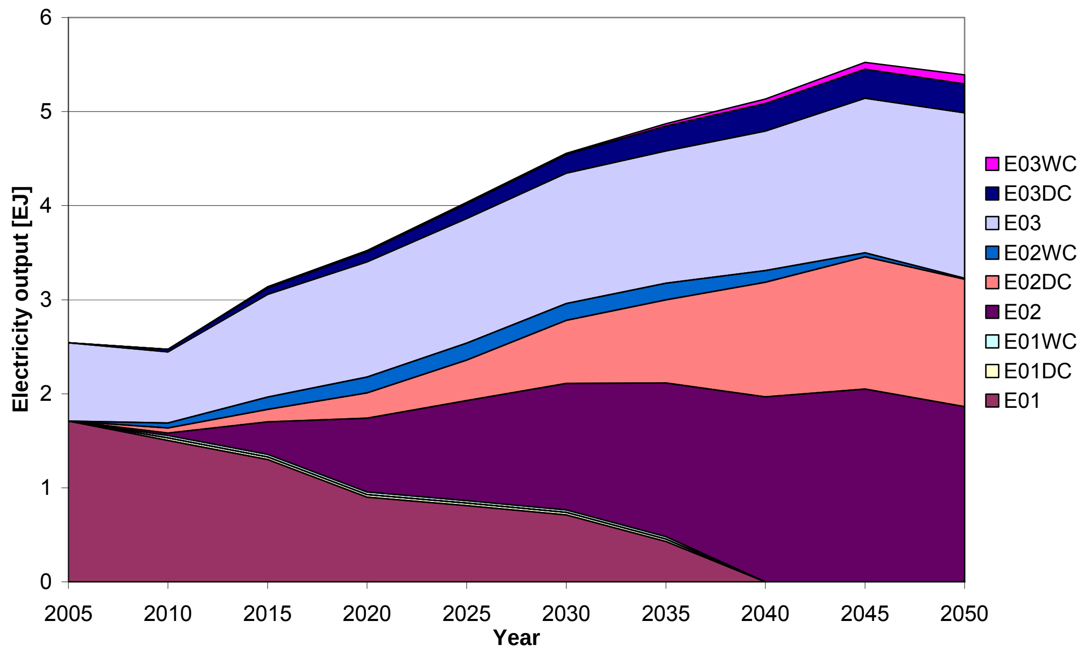


Figure 7-17: Electricity generation using coal in thermal power plants, EU27+2, Reference Scenario, 2005 to 2050



Notes: DC stands for dry cooling, WC stands for wet cooling. E01 is coal conventional, E02 is pressurised coal supercritical and E03 is lignite powered conventional thermal electricity generation.

Figure 7-18: Coal fired power plants and the change in cooling systems, EU27+2, Reference Scenario, 2005 to 2050

Gas

Due to high gas prices (which are unchanged compared to the Base Case Scenario) and declining European natural gas reserves, natural gas-based power production plays a decreasing role in the Reference Scenario (see Figure 7-19). Total European electricity production on the basis of natural gas declines from 1,550 PJ to about 500 PJ in 2050. Only Norway shows an increase in gas-based power generation until the end of the model horizon, which describes the use of own resources for growing electricity demand.

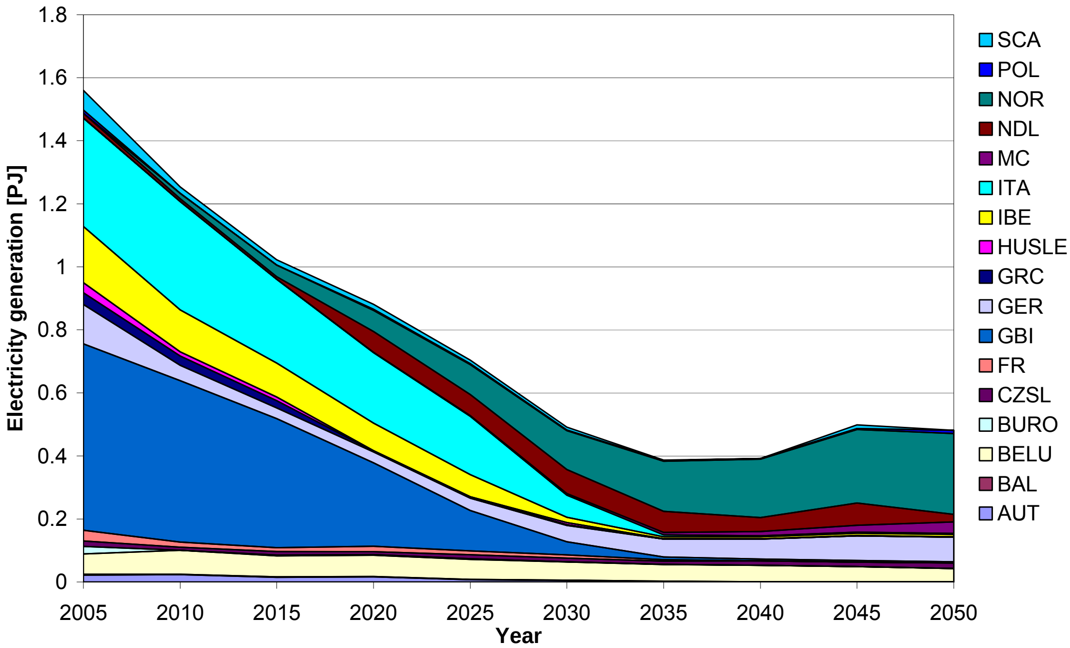


Figure 7-19: Output of thermal power plants based on natural gas, EU27+2, Reference Scenario, 2005 to 2050

Nuclear:

The share of nuclear power compared with total power production remains constant in the Reference Scenario. After a declining period in which less nuclear-based power is produced because of phase out policies in some countries (e.g. Germany, Hungaria, Slovakia, and the Baltic States), high investments are needed to replace existing capacity and to install additional power plants (see Figure 7-20). Countries with high acceptance for nuclear power will continue to exploit this technology for power production (e.g. France, Belgium, U.K., and Spain).

In total, electricity produced by nuclear energy increases from some 3,700 PJ in 2005 to almost 5,000 PJ in 2050 (see Figure 7-20).

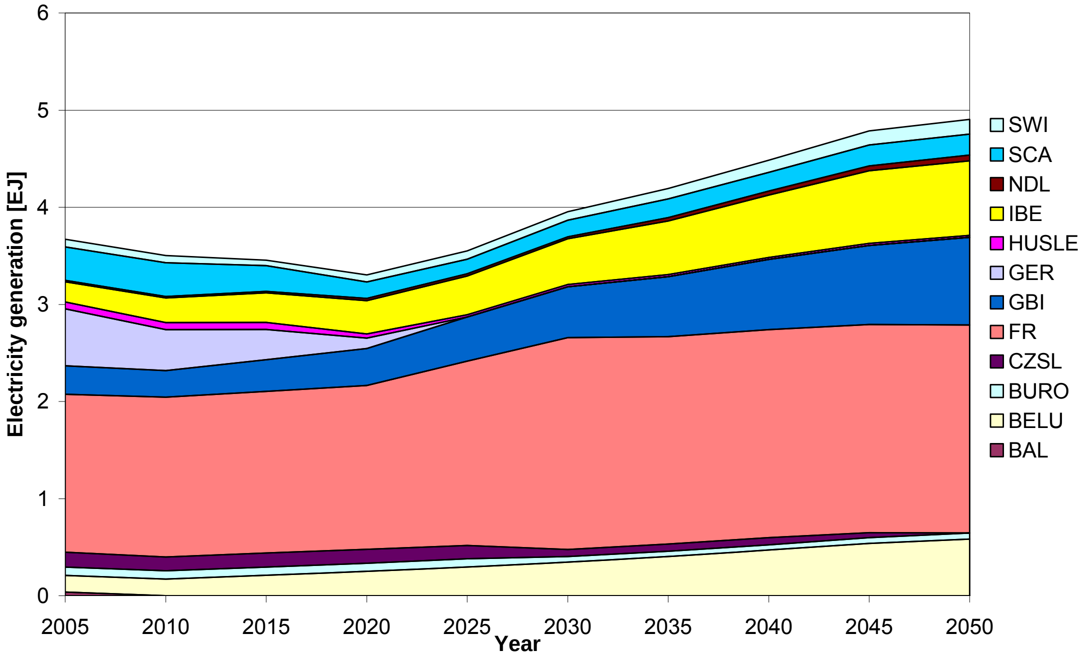


Figure 7-20: Electricity production based on nuclear energy, EU27+2, Reference Scenario, 2005 to 2050

Biomass

Results for biomass-based power generation are adapted from the PowerAce model and described in detail in section 7.1. However, all biomass-based technologies are included in the analysis of the additional adaptation cost for electricity generation, described in the following section 7.2.2.3.

7.2.2.3 Adaptation cost

Adaptation cost measured in terms of investment for conventional thermal generation is approximately 12 % (or almost 1 Billion € per year) higher in 2050 compared to the Base Case Scenario (see Figure 7-21). This additional cost is based on investments in advanced cooling technologies to cope with the reduced cooling capacities of rivers and oceans and on investments in new capacity to offset efficiency losses on the one hand and increased electricity demands on the other.

It is expected that even more investment will be necessary under climate change conditions if seasonal electricity demands are implemented in the simulation runs of EuroMM. In this case, the additional electricity demand will take place mainly in summer due to higher demands for air conditioning and cooling. It is estimated that the total electricity demand will increase by approx. 6 % in the Reference Scenario compared to the Base Case Scenario. This increase in demand will be covered mainly by coal and nuclear-based electricity generation. The higher demands in summer coincide with reduced efficiencies of power plants as described above. This will require additional investment for retrofitting of existing power plants and new investment in advanced cooling systems. Southern European regions will suffer more under these changed conditions than northern European regions.

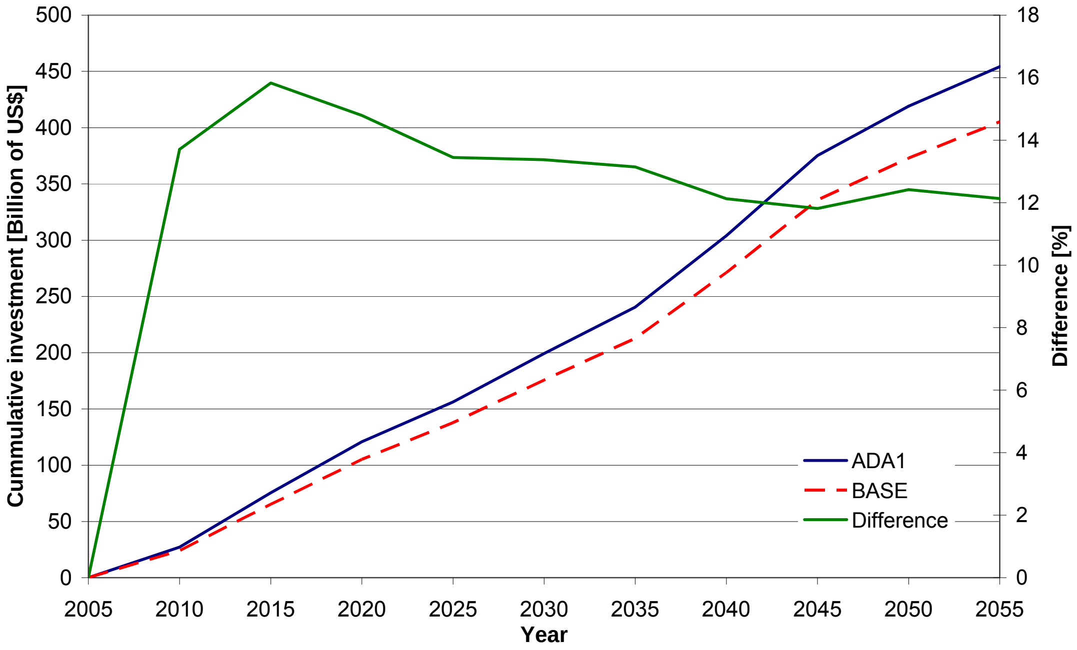


Figure 7-21: Comparison of investment in thermal power plants between the Base Case Scenario and the Reference Scenario (ADA1), EU27+2, 2005 to 2050

7.2.3 Electricity generation by hydro power plants in Europe

7.2.3.1 Assumptions for electricity generation by hydro power plants - Reference Scenario 2000 to 2050

The total output of electricity from hydro power plants is defined by the PowerAce model as described in Chapter 7.1. The seasonal reservoir availability defining the output of hydro power is calculated from statistics (NORDEL, UCTE), independent of the PowerAce model. For the Reference Scenario, first assumptions are integrated in EuroMM using a changed reservoir availability pattern due to climate change. However, we will implement better assumptions for reservoir availability under changed climate conditions to improve model results. It is expected that for this case, the annual hydro power potential will remain unchanged, but seasonal output will vary and investments, mainly in southern European countries, are most likely to increase in order to balance decreased hydro power output in summers.

7.2.3.2 Results for electricity generation by hydro power plants in Europe - Reference Scenario 2000 to 2050

Results for the annual hydro power output are given in Figure 7-22. In comparison with the Base Case Scenario, lower output of hydro power is achieved in southern European regions whereas higher outputs are expected in northern European regions due to the changing precipitation patterns in Europe. In total, the increase of hydro electricity from 1,750 PJ to slightly more than 1,800 PJ is small.

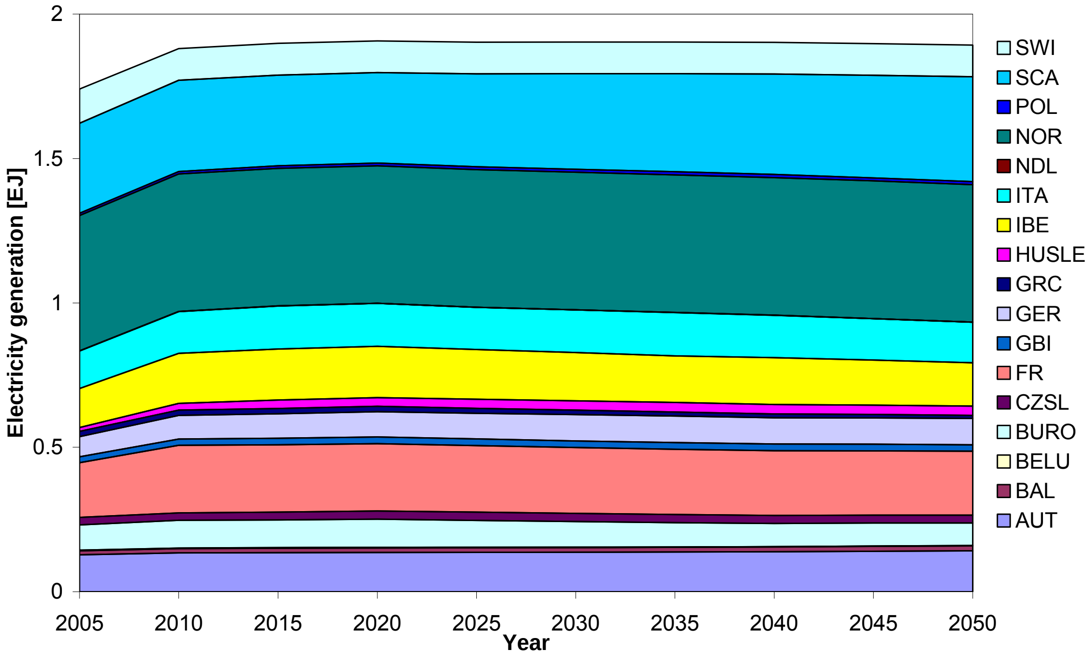


Figure 7-22: Hydro power output according to the PowerAce model, EU27+2, Reference Scenario, 2005 to 2050

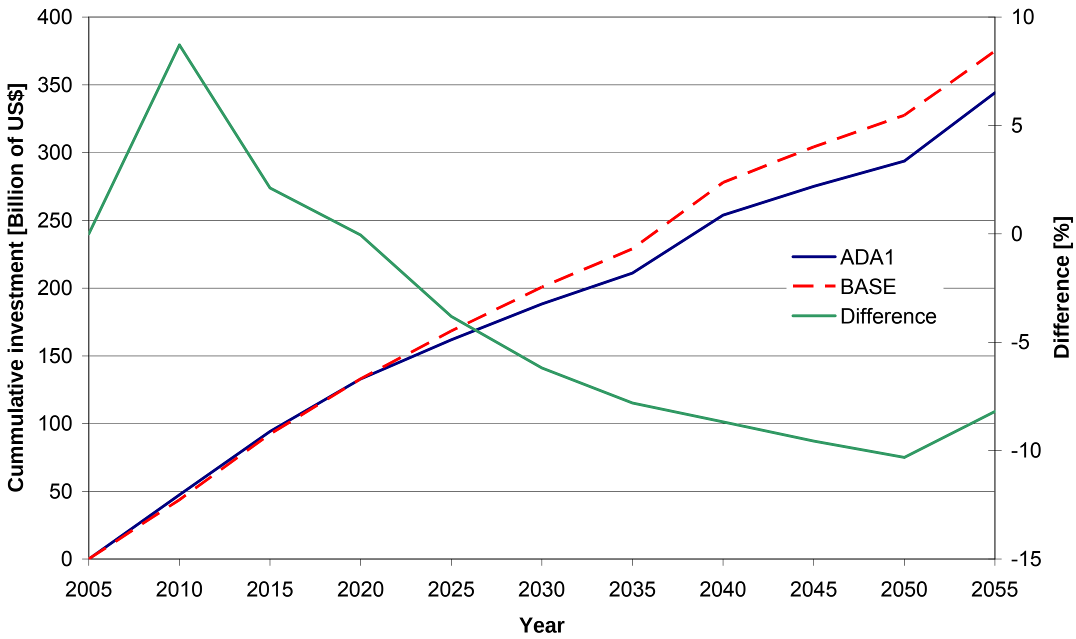


Figure 7-23: Differences in the investment in hydro power in the Base Case Scenario and Reference Scenario (ADA1), EU27+2, 2005 to 2050

7.2.3.3 Adaptation cost

In southern European countries in particular, the output of hydro power plants will decrease under climate change. Lower investments are necessary in this case since not all existing plants will be replaced at the end of their lifetime (see Figure 7-23). However, in northern European regions (e.g. Sweden, Finland and Norway) an increase of hydro power output is possible if the growing hydro power potentials due to climate change can be exploited by building new dams and re-inforcing existing hydro power plants.

The difference of the adaptation investments peaks within the next few years at about 9 % of the yearly investments in hydro power plants and then declines below zero % around 2020, before investments decline due to less reinvestment in southern Europe and higher productivity of northern hydro power plants.

7.2.4 Electricity and heat generation by co-generation and heat production plants in Europe

7.2.4.1 Assumptions for electricity and heat generation by co-generation and heat production plants - Reference Scenario 2000 to 2050

As for the electricity-only plants, the CHP plants are modelled in the Reference Scenario with lower efficiencies and the possibility to install additional cooling systems. No changes regarding district heating plants are introduced in the model.

7.2.4.2 Results for electricity and heat generation by co-generation and heat production plants in Europe - Reference Scenario 2000 to 2050

In the first periods of the model horizon we see an increase in electricity and heat production from CHP plants across Europe where the model is optimising the use of existing CHP plants to cover increased heat and electricity demands (see Figure 7-24 and Figure 7-25). From 2020 on, the overall electricity to heat ratio of CHP plants changes and relatively more heat is produced. The different trends in electricity and heat output shown in these two figures reflect the relative heat/electricity ratios at which the plants can be operated (which vary from region to region, and also across time). This implies that investments in new capacities are made in CHP plants with higher heat output together with investments in electricity-only plants, replacing existing CHP plants with a higher electricity to heat ratio. From 2035 on, the declining district heat demand due to higher temperatures in winter will decrease the use of cogeneration plants which seem to be rather sensitive given the sharp decline in electricity generation between 2020 and 2050 (see Figure 7-24).

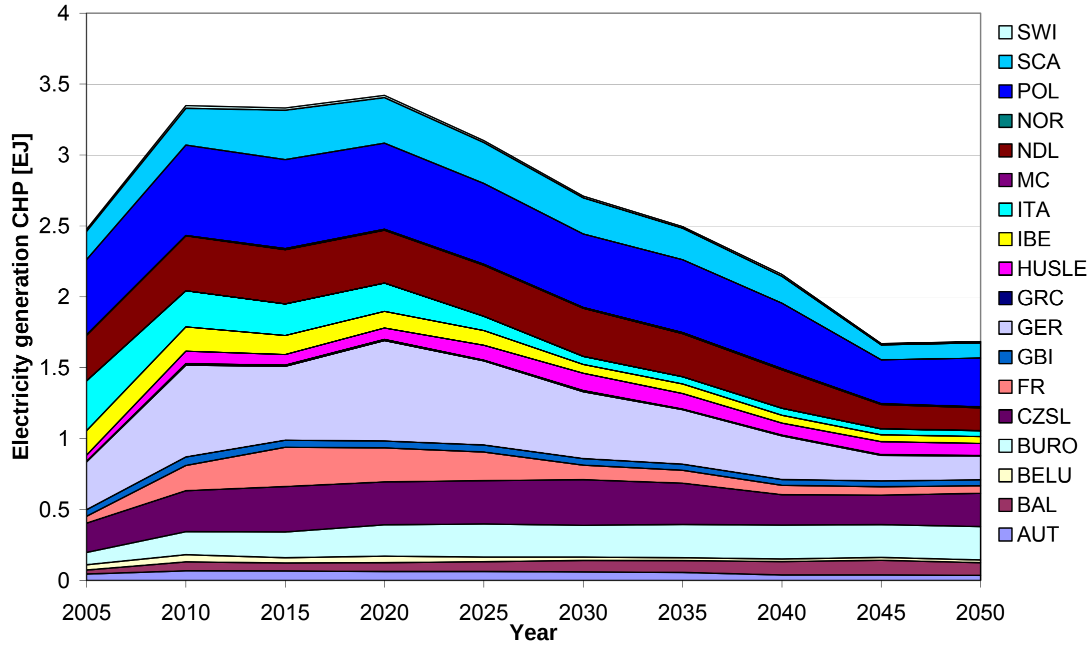


Figure 7-24: Electricity generation by CHP plants, EU27+2, Reference Scenario, 2005 to 2050

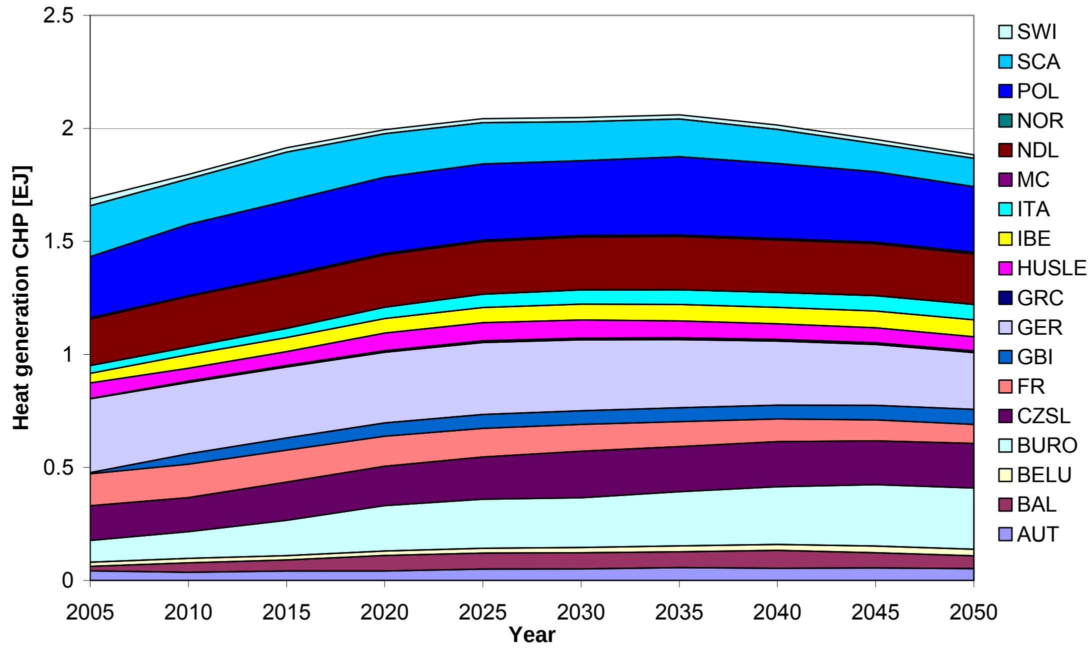


Figure 7-25: Total heat output of CHP plants, EU27+2, Reference Scenario, 2005 to 2050

7.2.4.3 Adaptation cost

The lower demand for district heat in the Reference Scenario allows for a shift from CHP plants to electricity-only plants. Therefore lower investments in CHP technologies are necessary. Until the end of the modelled period approx. 2-3% less investment in CHP technologies is needed compared to the Base Case Scenario (see Figure 7-26).

Figure 7-26: **Adaptation cost for CHP plants in the Reference (ADA1) and Base Scenario, EU27+2, 2005 to 2050**

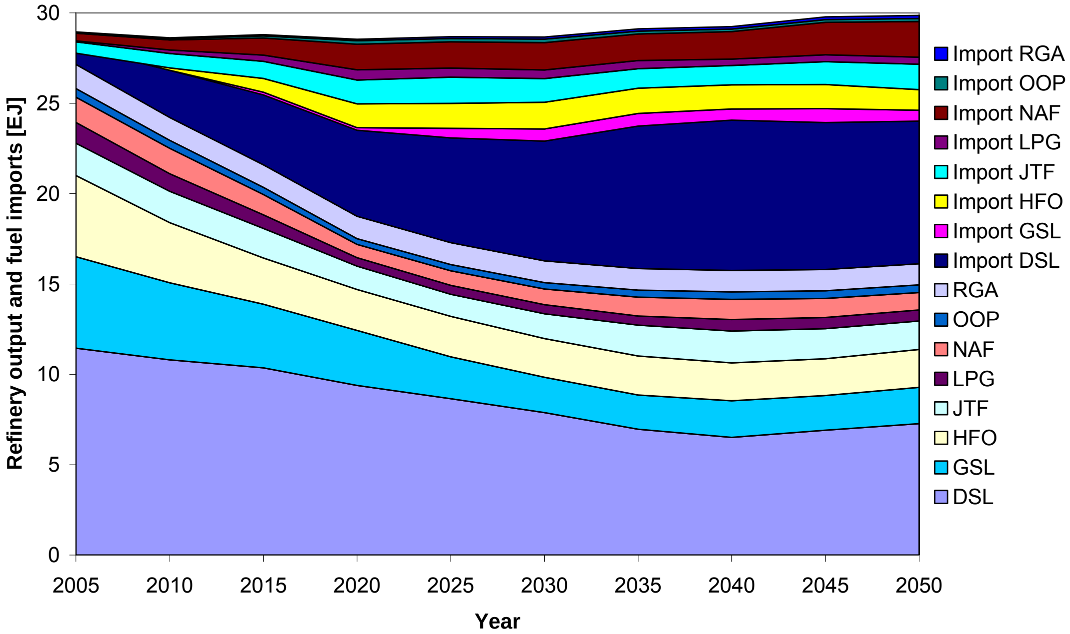
7.2.5 Refineries in Europe

7.2.5.1 Assumptions for refineries - Reference Scenario 2000 to 2050

Since the demand for heating oil in the buldings and industry and fuels in the transportation sector is slightly smaller in the Reference Scenario compared with the Base Case Scenario (see Chapter 6.8), no additional assumptions are included in the model.

7.2.5.2 Results for refineries in Europe - Reference Scenario 2000 to 2050

Total refinery output follows a declining path until the end of the model horizon (see Figure 7-27). This is in contrast to the first set of results of the Base Case Scenario, presented in the first ADAM-M1 deliverable. This is because the representation of the refineries has subsequently been changed in the model to reflect limited flexibility of refineries to vary the proportion of different petroleum product outputs. Due to this limited flexibility in terms of the mix of outputs, the model imports additional fuels instead of installing additional refinery capacity that can not be utilized differently (see Figure 7-27). Excess production of gasoline is exported to other world regions in the inintal periods only.



note: diesel (DSL), gasoline (GSL), heavy fuel oil (HFO), jet fuel (JTF), LPG (liquefied petrol gas), naphtha (NAF), refinery gas (RGA) and other oil products (OOP).

Figure 7-27: Refinery output and additional net fuel imports into EU27+2, Reference Scenario, 2005 to 2050

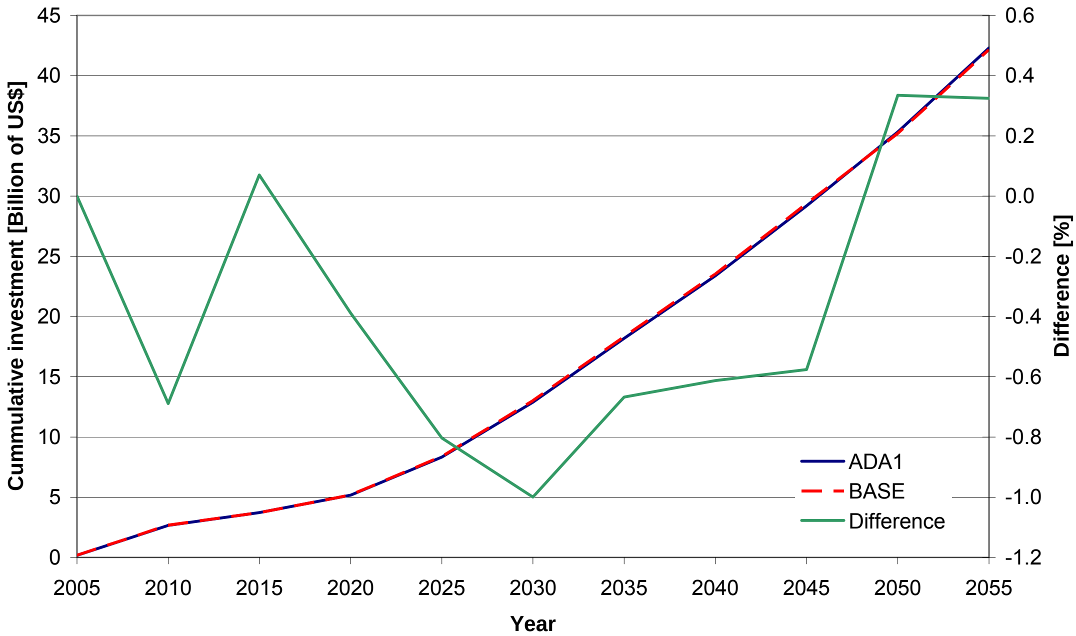


Figure 7-28: Changes in investment for refineries between Base Case Scenario and Reference Scenario, EU27+2, 2005 to 2050

7.2.5.3 Adaptation cost

The adaptation cost for refineries is small, comparing the Reference and the Base Case Scenario (which has been updated with the new representation of refineries described above). Since the demands change only slightly, no effects on refinery output can be observed (see Figure 7-28). The difference between the Base Case Scenario and the Reference Scenario (ADA1) only vary less then 1% per period.

7.2.6 Gas transmission and distribution losses in Europe

7.2.6.1 Assumptions for gas transmission and distribution losses - 2000 to 2050

Compared to the base scenario, no adaptation measures were introduced into EuroMM. No data was available about changes in evaporation losses or higher energy needs for transportation. The percentage losses for each region can be found in the 1st deliverable of the ADAM-M1 group.

7.2.7 Primary energy demand in Europe – Reference Scenario 2000 to 2050

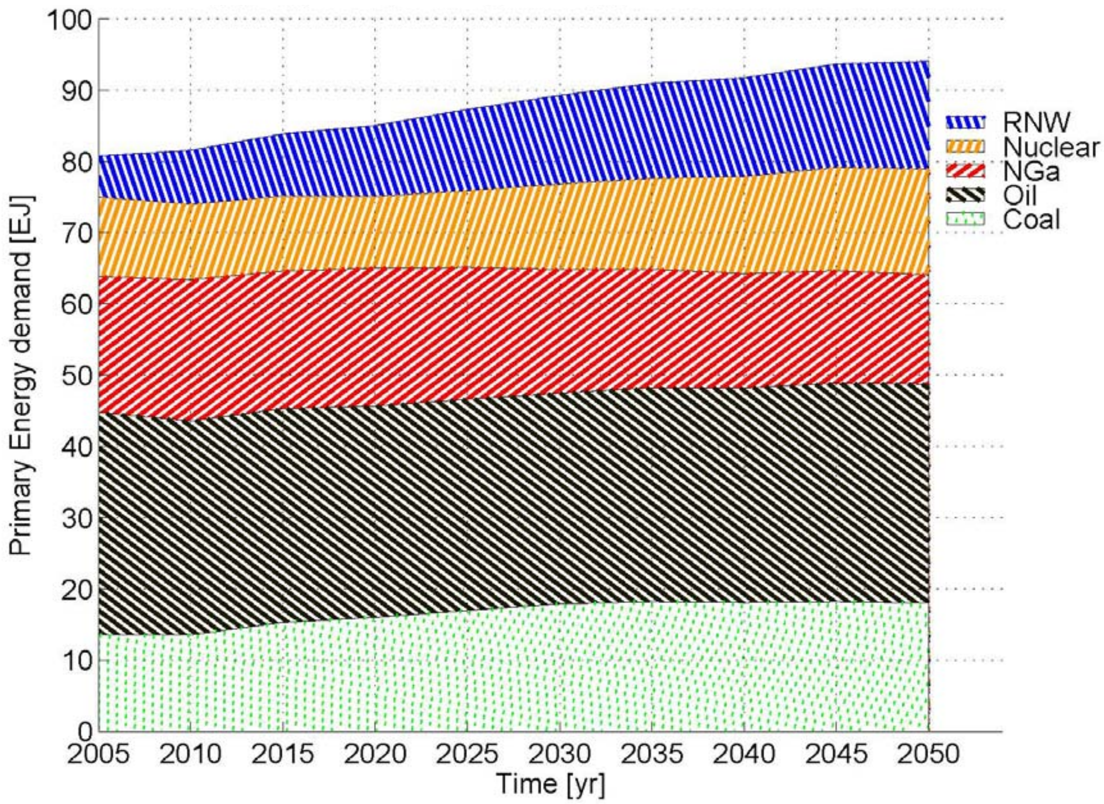


Figure 7-29: Annual primary energy demand for EU-27+2, Reference Scenario, 2005 to 2050

The primary energy demand in the Reference Scenario does not change considerably compared to the Base Case Scenario in aggregated terms (see Figure 7-29). The lower demand for low temperature heat in winter is offset by the higher need for electricity in summer and the higher inputs to conversion plants due to efficiency losses. As described above, the increased demand for electricity will be covered by coal and nuclear-based electricity which increase by approx. 10 % by 2050 in the Reference Scenario compared to the Base Case Scenario.

The shares and quantities of coal, oil, natural gas (NGa), nuclear and renewable energy remain almost unchanged in the Reference Scenario compared to the Base Case Scenario.

7.2.8 Carbon dioxide emissions from the conversion sector in Europe

CO_2-emissions of the energy use in EU27+2 remain at a high level of approx. 4,500 Mill. t/yr. They slightly increase until 2030 due to more intensive coal use in electricity production and decline slightly thereafter due to more growth in absolute terms of the renewable energies in the last two decades of the Reference Scenario. Since no shift in aggregated fuel demand in the total of the final energy sectors and the energy conversion sector is observed, CO_2 emissions remain at a relatively high level of approx. 4,500 Mt/yr (see Figure 7-30).

Compared to the results presented in Deliverable 1 of Working Package M1, coal conversions such as coke and briquette production together with derived gas output are now included in EuroMM bringing the total CO_2 emissions closer to the official data of the European statistics for 2005.

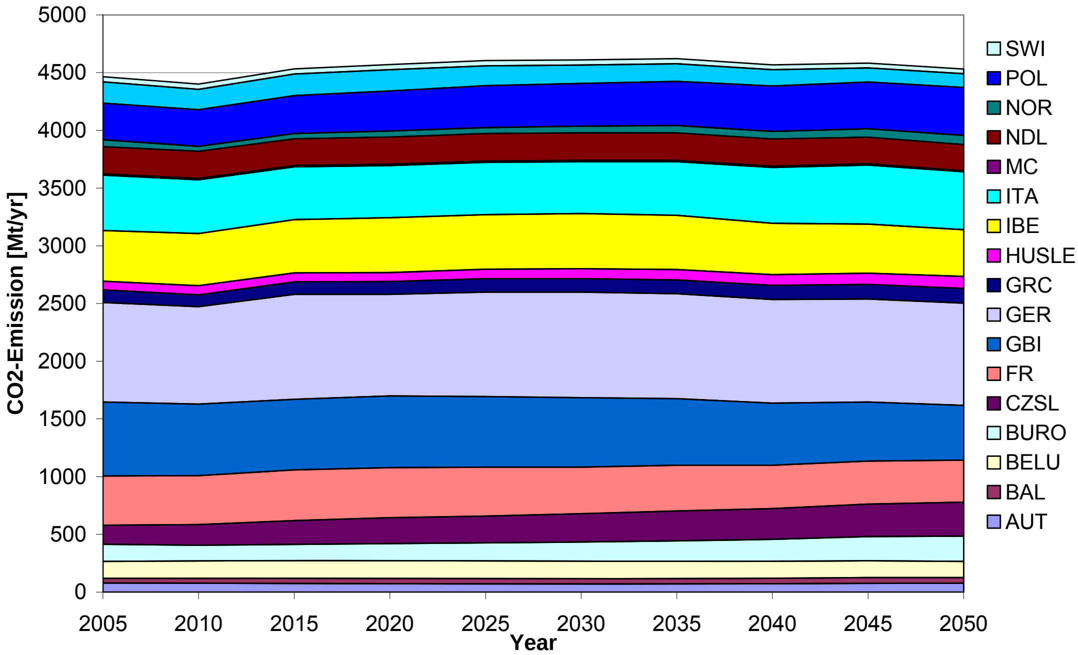


Figure 7-30: Total CO_2-emissions stemming from energy use, EU27+2 in Mill. t/yr, Reference Scenario, 2005 to 2050

7.2.9 References

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8 Linking the results of the Reference Scenario back to the macro-models

One of the essential questions of climate change policy is the impact of adaptation and mitigation on the macroeconomy. The analysis started with the macroeconomic drivers calculated by the two macroeconomic models E3ME and ASTRA (see Figure 2-1 and Chapter 2.2). These economic drivers had been used to convert them into drivers for the POLES model (see Chapters 3 and 4) and for the bottom up models (see Chapter 6) to calculate the energy demand in all final energy sectors in Europe as well as the appropriate energy supply (see Chapter 7). Finally, the comparison between the Base Case Scenario and the Reference Scenario identified the adaptation cost in terms of changed investments and changed energy cost. These changes in investments and energy cost had to be collected for all sectors in the IMPULSE model (see Chapter 8.1and 8.2) and fed into the ASTRA model in order to calculate the impacts on economic growth and employment. An overview description of the ASTRA model is provided in our deliverable M1.1 (Jochem et al. 2007), details are given in Schade (2005). Results from the E3ME model, the second macroeconomic model, were not available, but will be included in the final deliverable.

8.1 Methodological approach – the IMPULSE model

The linkage between the bottom-up world and the macroeconomic world is implemented via six impulses estimated by the bottom up models and integrated as economic stimulus in the macroeconomic models. The impulses are:

- Investments due to climate change (adaptation) or climate change policy (mitigation),
- Avoided investment, e.g. less insulation of houses needed because of warmer climate,
- Changes in energy cost due to changes on supply or demand side of energy,
- Changes in prices of other goods due to adaptation investments of the producers (industry and services),
- Changes of energy imports, and
- Changes of government expenditures, e.g. in cases when government pursues adaptation policies (e.g. repair of damaged infrastructure) or mitigation policies (e.g. subsidies of efficient appliances or vehicles).

The way these impulses are linked to the ASTRA model is shown in Figure 8-1. In the case of the Reference Scenario, primarily adaptation investments (e.g. more air conditioning, more electricity plants) and energy cost changes (e.g. more electricity for air conditioning, less fuel for heating) play a role.

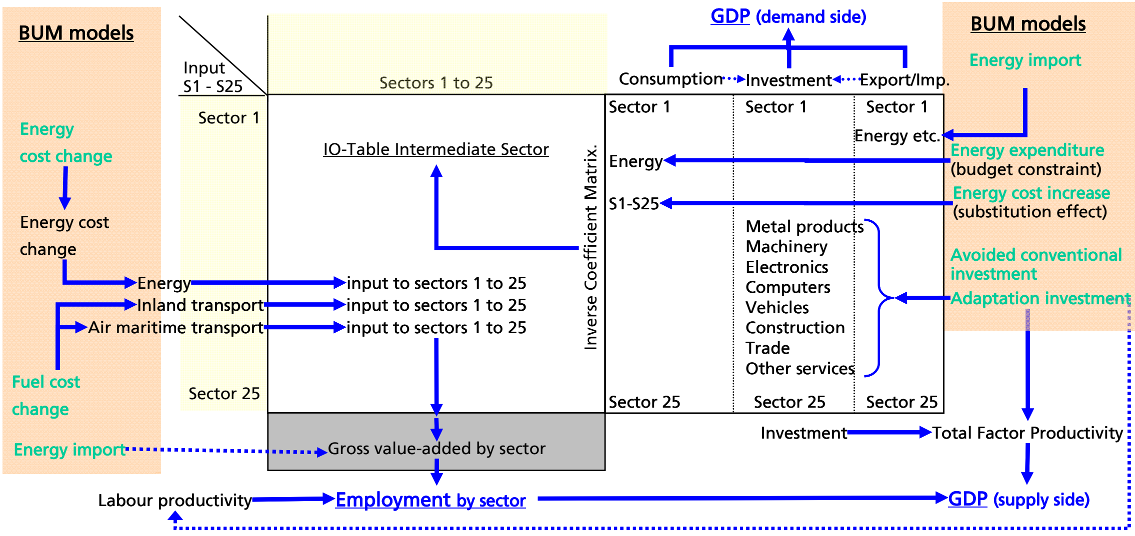


Figure 8-1: **Linking the bottom up models (BUM) with the macroeconomic models and their sectoral level- the hybride approach: the example ASTRA**

8.2 Bottom-up impulses – Changed investments and operational cost

8.2.1 Net investments due to adaptation of the energy system

The change of net investment between the Reference Scenario and the Base Scenario comprises two elements: first the direct adaptation investments estimated by the BUM models (bottom-up models), and second, the second round changes of investments in response to the change of growth and the structural change stimulated by direct investments as well as the cost changes.

The following Figure 8-2 presents the adaptation investments of the main sectors differentiated in terms of their adaptation activities. These investments comprise first the adaptation of the energy sector in response to higher temperatures changing the cooling capacities of power plants e.g. at rivers and the demand patterns, and second the increased installation and use of air conditioning in households, industry and services. In the first years, in particular the adaptation of the energy sector, presented as the net investment change of additional and avoided investment, requires investment, while over the medium to long-term the increase of air conditioning in all final energy sectors is the most investment-intensive. Service sectors will spend up to 1.7 billion € and households up to 600 million € annually to adapt to the higher temperatures.

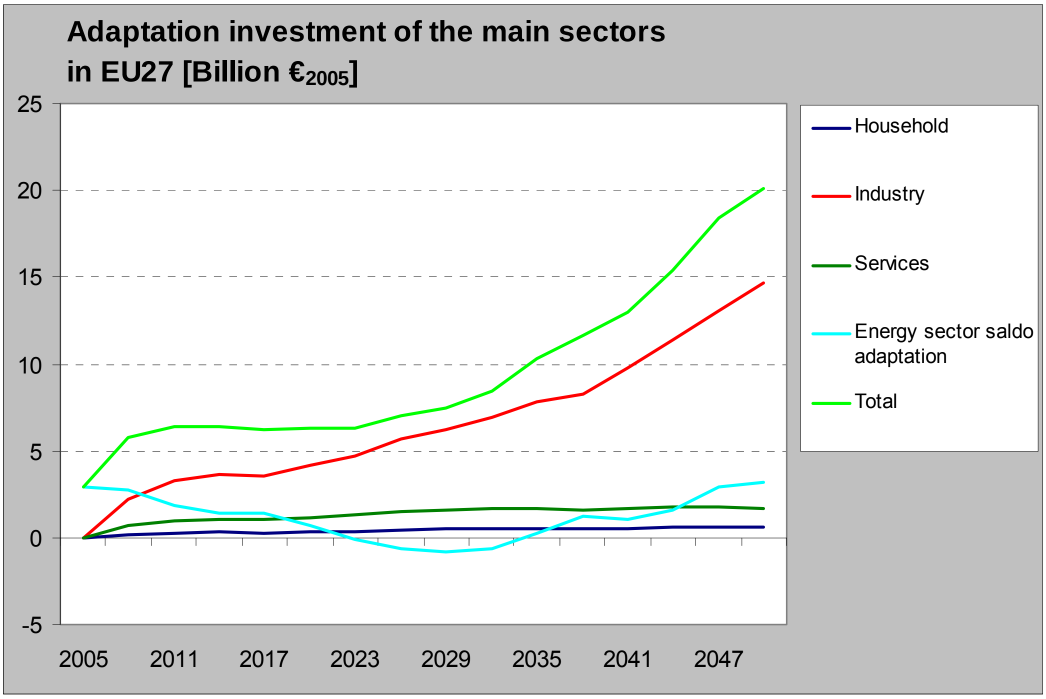
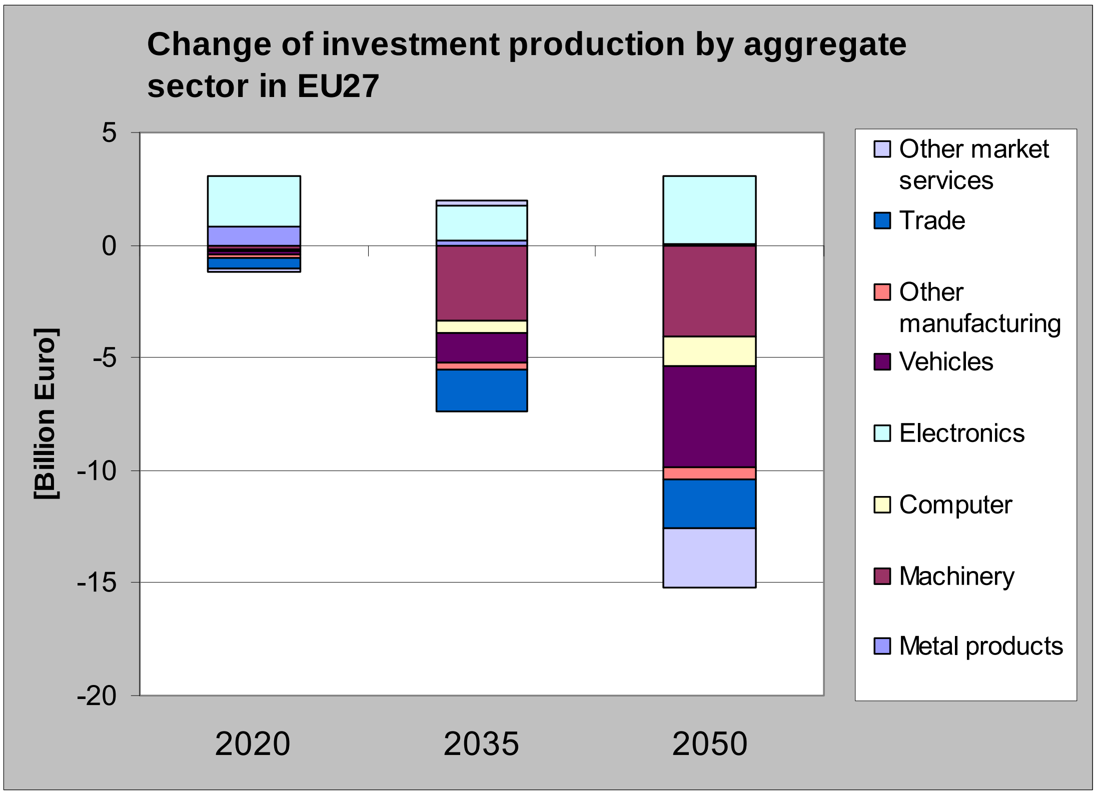


Figure 8-2: Investment impulse of the Reference Scenario broken down into the major aggregate sectors in the ASTRA model

The investments of the energy sector are estimated by the EuroMM model, which also provides the corresponding changes in energy costs to ASTRA so that the investments are financed by adapting energy prices and thus revenues of the energy sector. Household investments are estimated by the RESIDENT model and are funded in ASTRA from the household budget, thus reducing the available budget for other purposes. The investments of industry and service sectors other than energy are estimated by SERVE and ISI-Industry models and the resulting changes in product prices are calculated in ASTRA. In all cases, not only the investment impulse, but also at least impulses that change product prices enter the macroeconomic models in ASTRA.

Figure 8-3 presents the net investment impulse of the major sectors that produce investment goods. The net investment impulse constitutes the resultant of the direct adaptation impulse and the second round effects occurring in the economic models. The net investment effect is negative because GDP is reduced in particular due to damages to capital stock as a consequence of lower efficiencies and lower yearly operating hours in case of extreme events and higher temperatures. Primarily electronics and a very limited range of metal products increase their production of investment goods because they benefit most from the investments in air conditioning and adaptation of the energy system. The other sectors loose about 15 billion € in demand for investment goods in 2050.



Source: ASTRA model

Figure 8-3: Annual net investment impulse of the Reference Scenario presented for the major sectors that deliver investment goods and services, EU27+2, 2010 to 2050

8.2.2 Changed operational cost due to adaptation of the energy system

In ASTRA, energy expenditures such as the money spent for electricity, heating and fuels enter the economic equations. The energy expenditures depend both on the prices paid and the quantities of energy used. In ADAM the change in energy prices is estimated by the EuroMM model and the change of energy demand for households, industry and service sectors is estimated by the RESIDENT, SERVE and ISINDUSTRY models. In ASTRA the two impulses are combined and influence the economic models. This can be summarized as:

Energy expenditure EE = price of energy P x quantity of energy Q

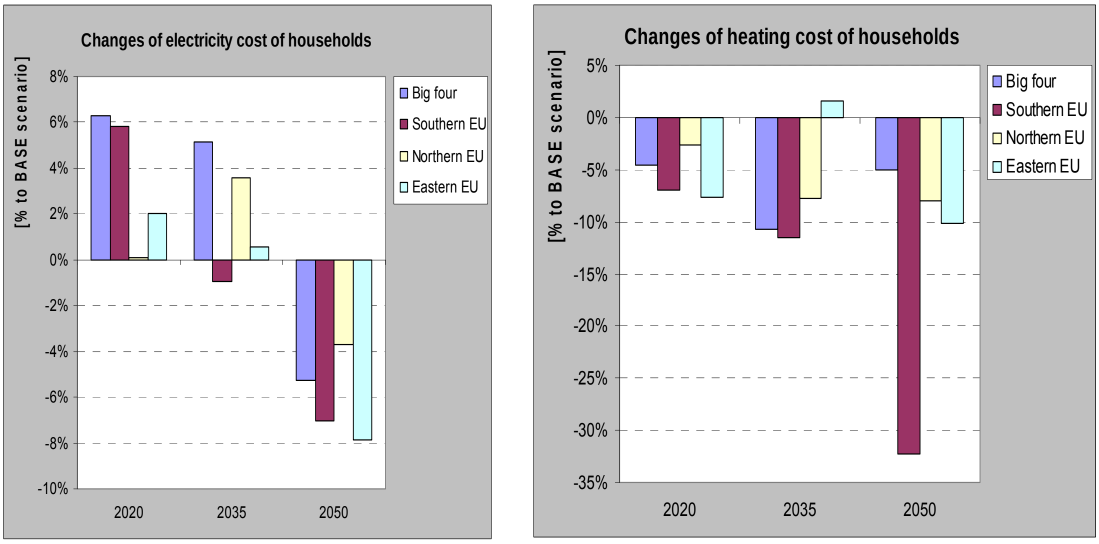
EE = P x Q and as the changes to the Base Scenario enter the ASTRA model

$\Delta EE = \Delta P \times \Delta Q$

In general it can be observed that the energy prices increase in the first decade but at least in some countries drop in the long run. The picture differs for energy demand: In the first decade it changes only marginally, but in the long run it increases for electricity in particular in the Southern countries that face significant temperature increases, while demand for heating is reduced. This results in the energy expenditure changes presented in Figure 8-4 for households and in Figure 8-5 for the industry sectors. The country groupings represent:

- Big four: France, Germany, Italy, United Kingdom,
- Southern EU: Cyprus, Greece, Malta, Portugal, Spain,

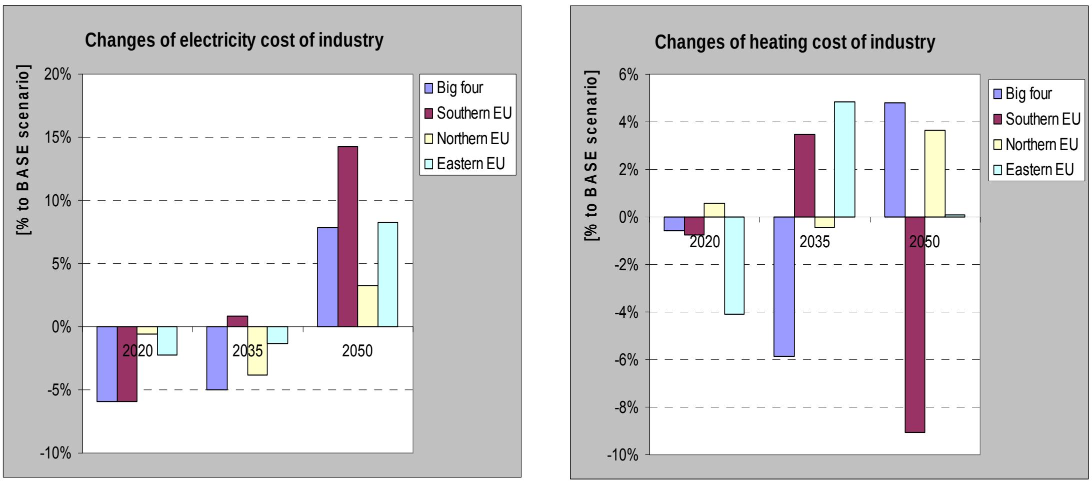
- Northern EU: Austria, Belgium, Denmark, Finland, Ireland, Luxemburg, Netherlands, Sweden,
- Eastern EU: Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovenia, Slovakia.



Source: ASTRA model

Figure 8-4: Changes of energy expenditures of households in Reference Scenario compared with Base Case Scenario, EU27+2, 2010 2050

The cost increase of electricity for industry corresponds to the high investment in air conditioning and cooling systems as well as in longer operating hours of existing plants (see Figure 8-2).



Source: ASTRA model

Figure 8-5: Changes in energy expenditures for industry in Reference Scenario compared with Base Case Scenario, EU27+2, 2010 to 2050

8.2.3 Price impact of adaptation investment for non-energy sectors

While the cost changes for the adaptation of the energy sector are estimated in the EuroMM bottom-up model, the changes in product prices due to adaptation investments have to be calculated in the ASTRA model. To calculate the change of product prices again, both changes of energy demand and changes in production cost have to be considered. The changes of energy demand can be taken directly from the BUM models. The product cost changes are derived in ASTRA by calculating the ratio between adaptation investment and production value by sector and interpreting this ratio as the required change of product price to fund the adaptation investment (see Figure 8-6). Averaged by country the sectoral cost increase remains below 0.1% except in Bulgaria and Romania, where it reaches up to 0.3% and 0.5% respectively.

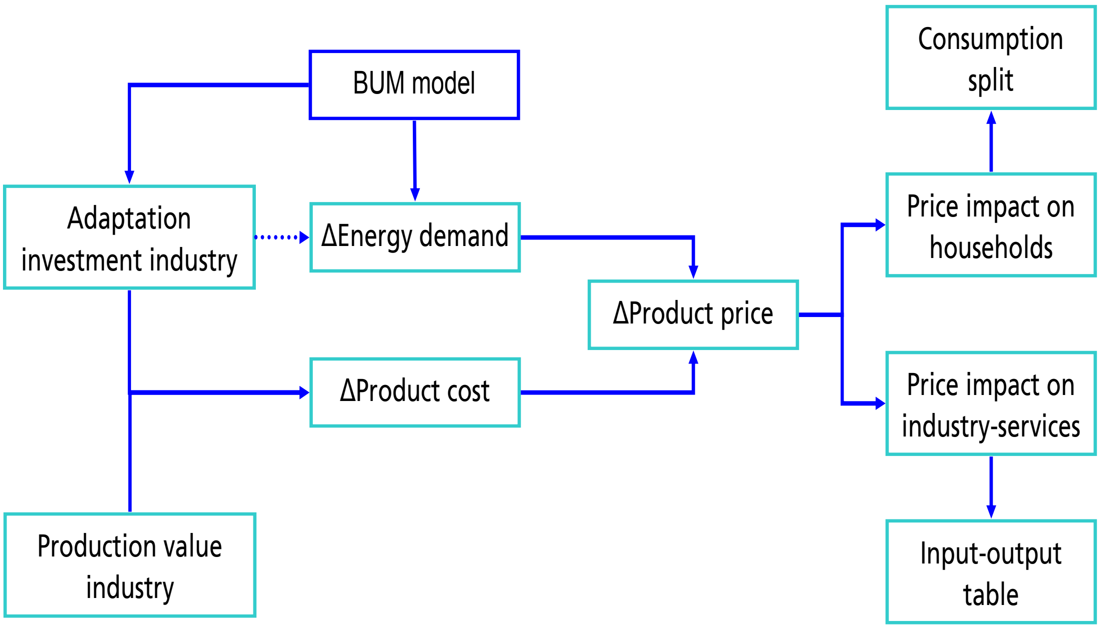
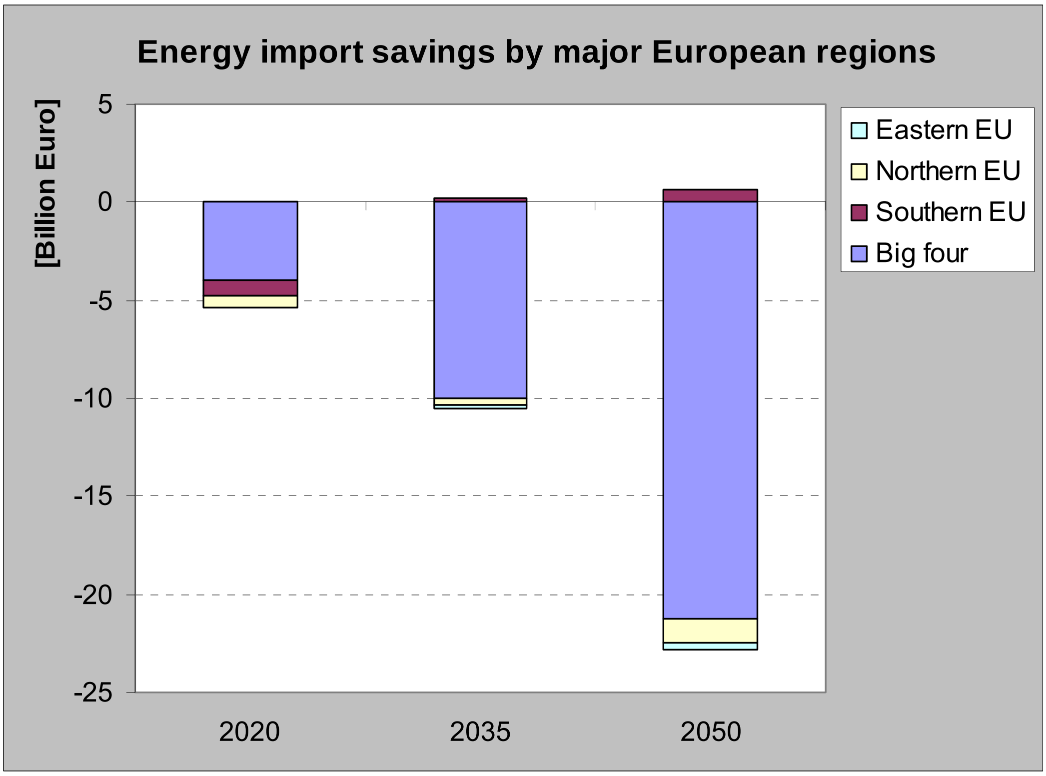


Figure 8-6: Price impact of adaptation investments in all sectors except the energy and transport sector – impulse estimated by the ASTRA model

The sectoral product price changes then affect the consumption decisions of households using sectoral price elasticities of demand and thus altering the consumption split across sectors. Similarly, the product price changes alter the exchange of intermediate inputs between sectors and thus finally leads to sectoral changes of value added and then changes in employment for the different sectors.

8.2.4 Change of energy imports due to adapted energy demand

The changes in energy demand, in particular the reduction of heating demand, will reduce energy imports of the EU27+2. Until 2035 the energy import bill of the EU27+2 can be reduced by 10 billion € and until 2050 by about 22 billion € , a positive economic stimulus (see Figure 8-7).



Source: ASTRA model

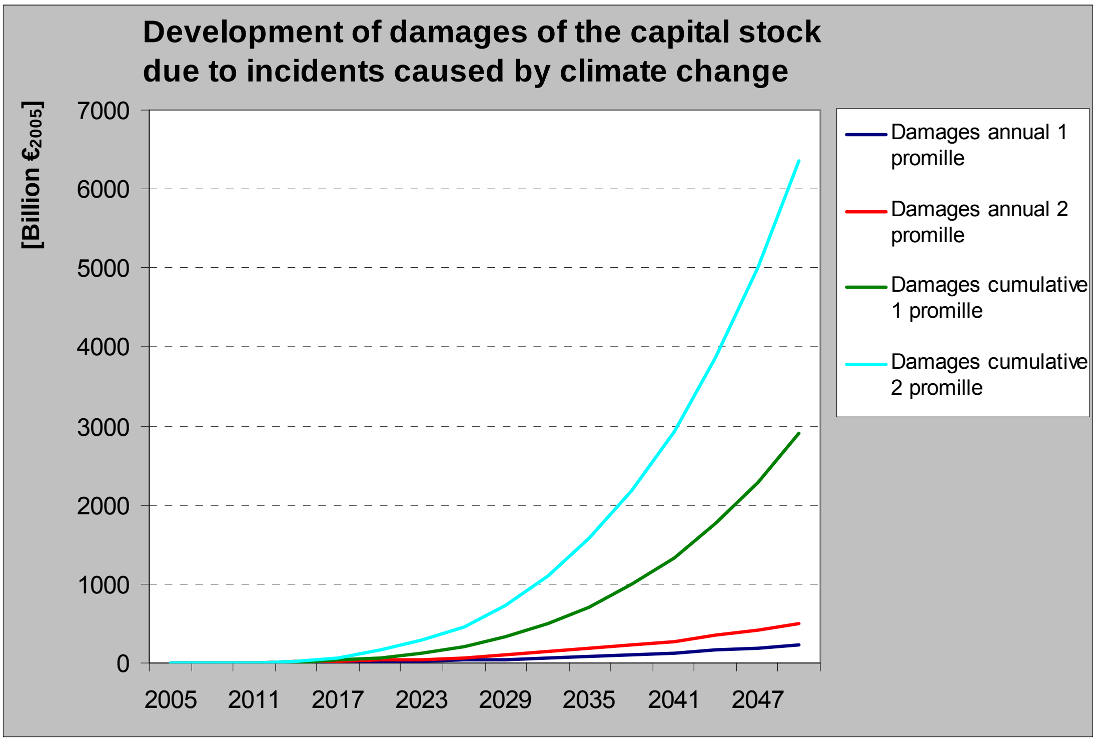
Figure 8-7: Reduced energy import due to lower heating demand, EU-27+2, Reference Scenario, 2020 to 2050

8.2.5 Damages to capital stock

Besides adaptation effects like the adaptation of energy supply (e.g. higher cost due to more cooling) and energy demand (e.g. more energy expenditures due to more air conditioning), climate change will also increase the number of extreme events in which parts of the infrastructure are destroyed. In Europe such extreme events could be in particular heavy winter storms, single weather events like tornadoes or hail and flooding both along rivers and lakes but also along the coast (Munich RE, 2008). Such events will cause damage to so-called capital stock, which in macroeconomic terms includes any kind of infrastructure such as buildings, bridges and railway lines, electricity and telecommunication networks or production facilities. The capital stock constitutes one of the central building blocks of economic production potential. A lower capital stock e.g. due to damage caused by climate-induced incidents will reduce the production potential of the European economies, and will thus lead to a reduction of gross domestic product (GDP). Since great uncertainty exists regarding how the effects on capital stock will be – besides the general expectation that it will grow stronger in the second half of this century while in the next two decades the effects should be low, suggesting the application of an exponential curve to the damages – the effect of damage to capital stock was considered by a sensitivity analysis. It was then decided to apply the more conservative approach. Two analysed variants were:

- an annual loss of about 1 $^{\circ}/_{oo}$ of the capital stock in 2050, and
- an annual loss of about 2 $^{\circ}/_{oo}$ of the capital stock in 2050.

Figure 8-8 presents the resulting losses in man-made capital stock in monetary terms. Losses start after 2010. With the 1 $^{o}/_{oo}$ case about 16 billion € (1 billion = 1x10^9) annually would be damaged in 2020, which is about twice the damage caused by the winter storm Kyrill in Europe in 2007. This value grows to about 230 billion € annually. Though this number is significant (e.g. when comparing it with EU27 GDP in 2050 it amounts to about 1 % of GDP), we understand the value of 1 $^{o}/_{oo}$ loss of the capital stock in 2050 due to climate change incidents as a conservative assumption.



Source: ASTRA model

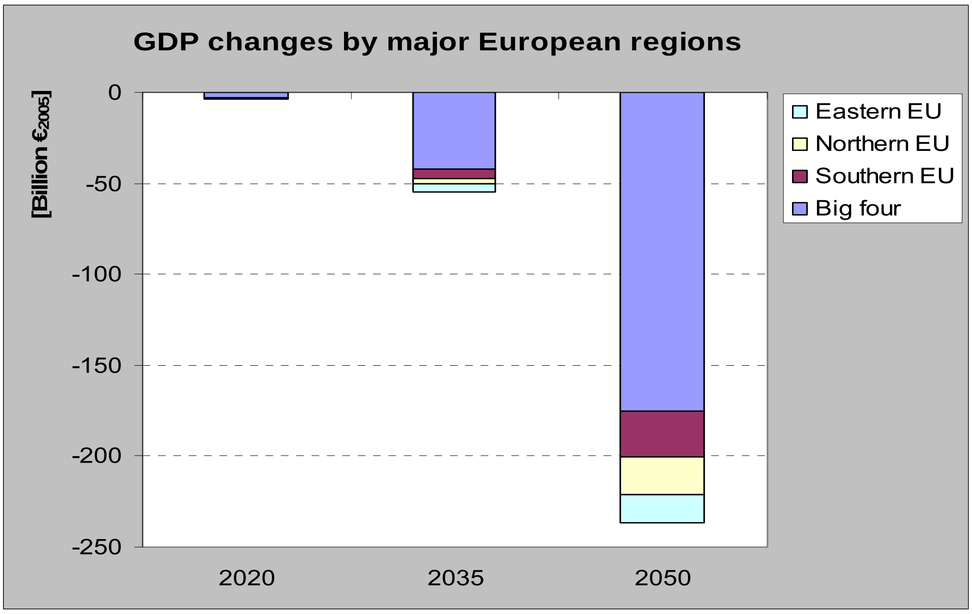
Figure 8-8: Development of damage cost of EU27 in the sensitivity analysis for extreme events, Reference Scenario, 2010 to 2050

These damages represent monetary values of capital stock and do not include any external cost, i.e. they do not include values for injuries or human life lost, nor for damages to nature and landscape, nor for illness due to climate change (e.g. Malaria coming back to southern Europe, health impact of heat waves).

8.3 Macro-economic impacts of the adapting energy system – ASTRA results

In general, in the first decade until 2020 the economic impact of climate change seems to be negligible. In particular GDP reveals the same development as in the Base Case Scenario, while for employment the moderate structural change leads to still very moderate reductions of employment on the European scale. This picture changes in the following decades and the shape of changes seems to follow an exponential curve, which is expected to unfold its full destructive strength only after 2050, i.e. beyond the scope of this modelling exercise. The exponential tendency due to the adaptation measures and the assumed exponential damage of extreme events (see Chapter 8.2.5) can be seen in the following Figure 8-9 to Figure 8-12.

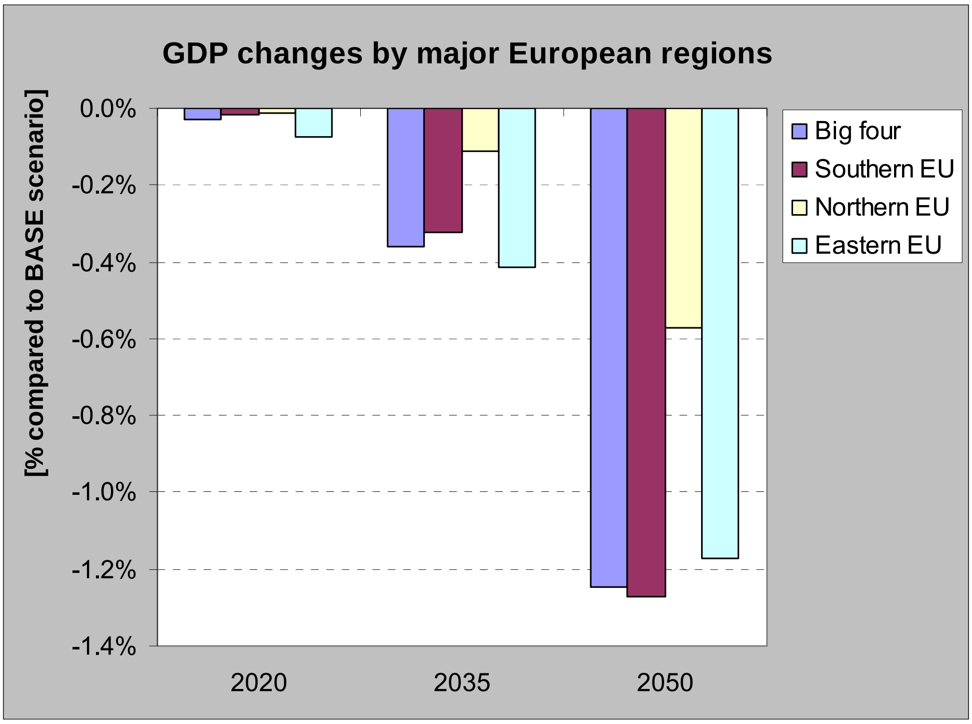
Obviously the largest country grouping, comprising the four biggest European countries, experiences the largest loss of GDP amounting to some 40 billion € in 2020 (see Figure 8-9). For EU27 the annual loss amounts to about 50 billion € in 2035 and about 240 billion € in 2050,i.e. in the fifteen years between 2020 and 2035 the loss increases by 50 billion €, while in the fifteen years period from 2035 to 2050 the loss increases by 190 billion € or four times more than in the first 15-year period, thus reflecting the exponential development of economic impact (see Figure 8-9).



Source: ASTRA model

Figure 8-9: Annual loss of GDP in the different European regions and the EU27, Reference Scenario, 2020 to 2050

The picture differs in terms of percentage loss of annual GDP. The largest loss is observed for the Southern countries in 2050, though the Big Four and the Eastern Countries also lose about 1.2% of GDP compared with the Base Case Scenario, i.e. with a scenario without climate change and adaptations. Only the Northern countries reveal a significantly smaller impact with a loss of about -0.6% which could have been expected already from the energy analysis in Chapters 6 and 7 (see Figure 8-10).

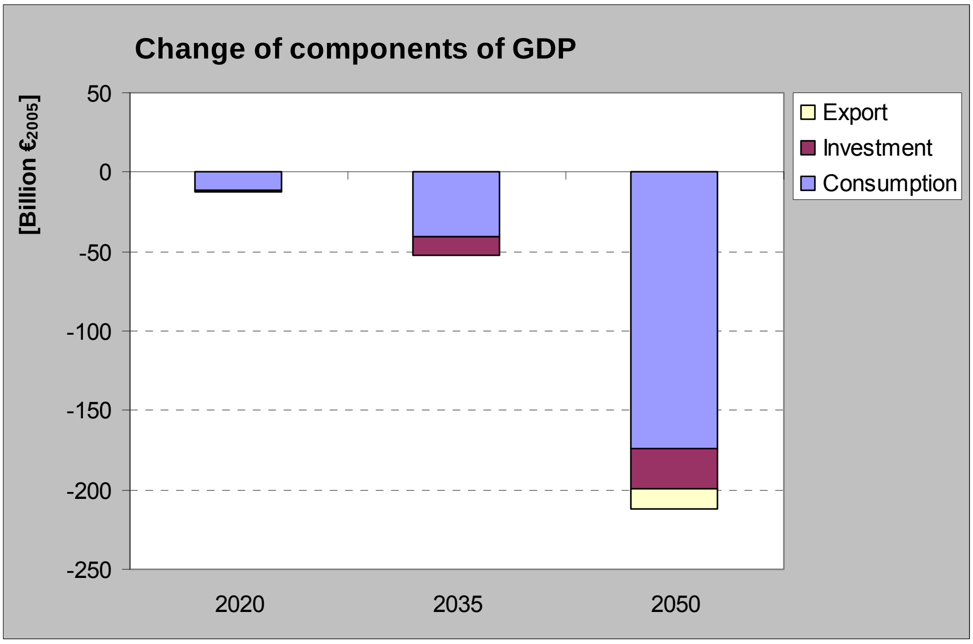


Source: ASTRA model

Figure 8-10: Percentage loss of GDP in the different European regions, EU27, Reference Scenario, 2020 to 2050

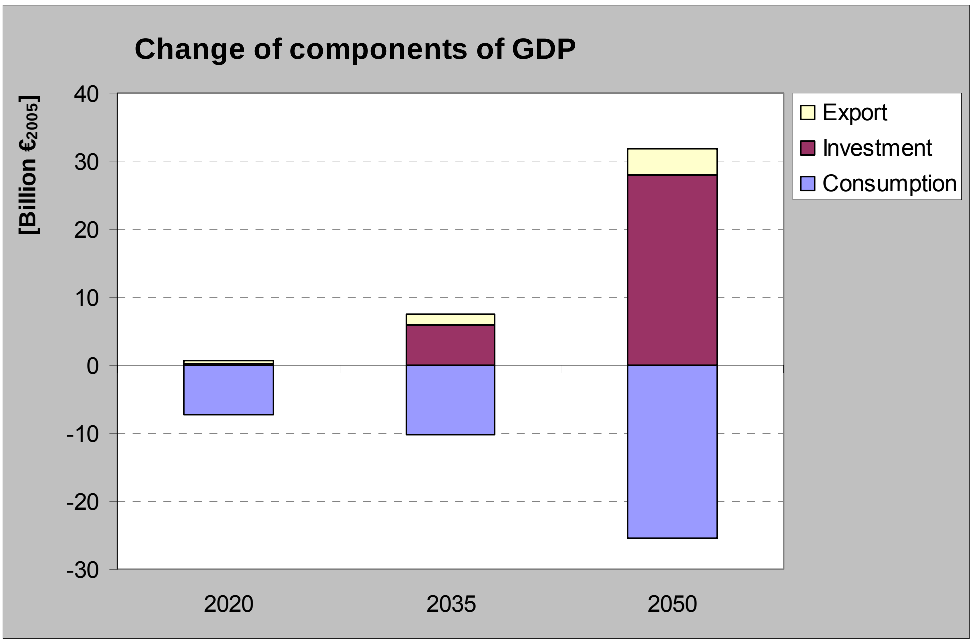
Looking at the change of major components of GDP it can be observed that the reduction of consumption is the main driver of this GDP loss (see Figure 8-11). This has two reasons: first, in the first two decades the adaptation of the energy system and the adaptation to higher temperatures leads to shifted consumption patterns that reduce GDP and thus income and consumption (see also Figure 8-12 for the analysis without damages to the capital stock). Second, in the longer run the damaged and thus reduced capital stock reduces GDP, leading to lower disposable income and consumption. In the medium term, the reduction of investments as a second-round effect of reduced GDP and consumption also becomes visible (2035 in Figure 8-11),

Considering mainly the direct effect of adaptation of the energy system and the changed air conditioning, cooling, and heating patterns and not the damages to the capital stock, the investment would contribute a positive stimulus to GDP, as can be seen in Figure 8-12. This analysis reveals that only these adaptations would be about neutral for economic development in Europe and that the negative economic impact comes from the damages to the capital stock due to extreme events. As this effect has been a mere assumption (see Chapter 8.2.5), this issue will need more attention in the future.



Source: ASTRA model

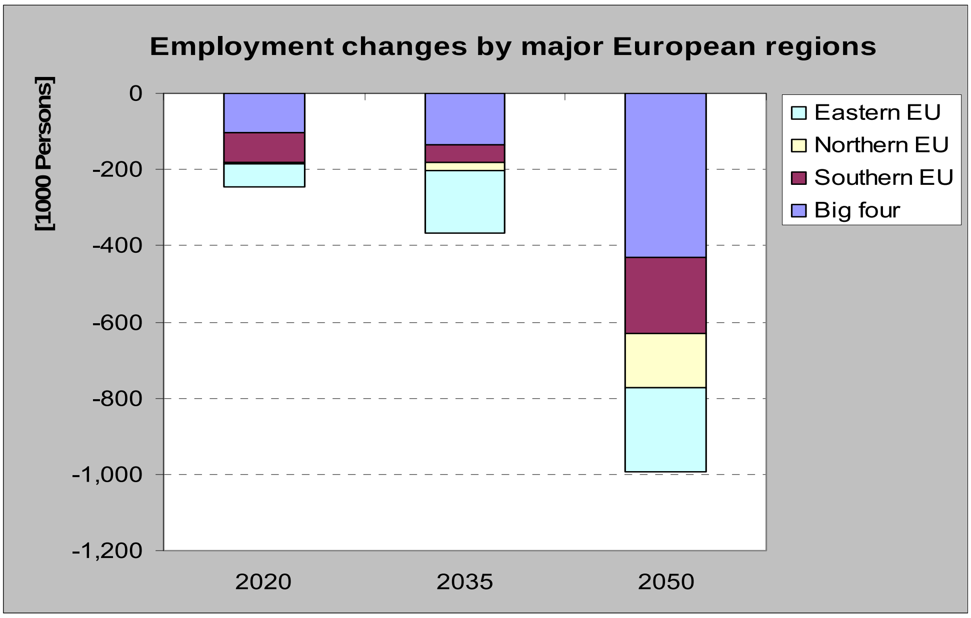
Figure 8-11: Importance of the different impulses to stimulate GDP, EU27, 2020 to 2050



Source: ASTRA model

Figure 8-12: Importance of the different impulses to stimulate GDP when no damages to the capital stock are considered in the ASTRA model.

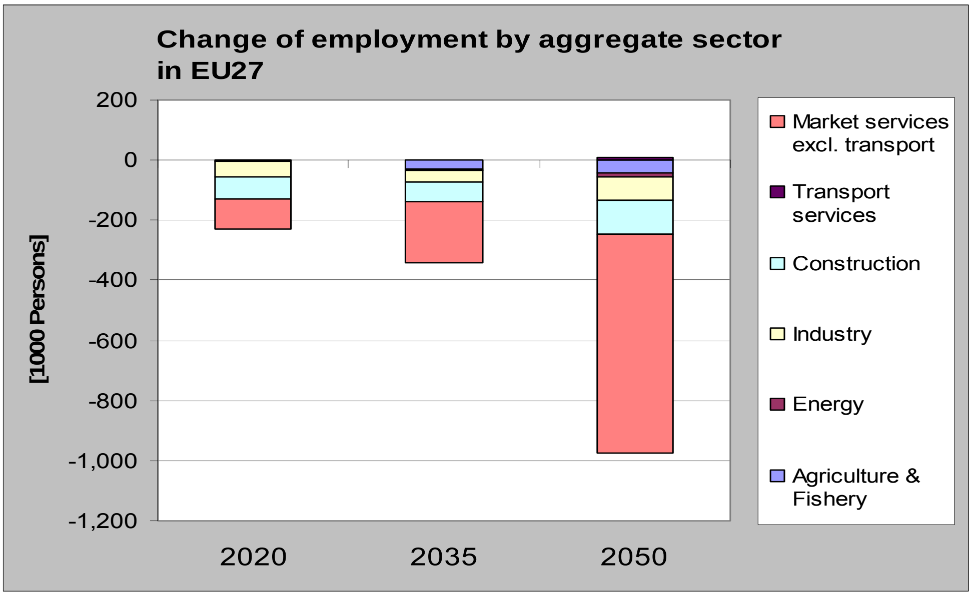
The following two figures describe the impact on employment in the EU27. Figure 8-13 shows the loss of employment by region. In absolute terms again the Big Four grouping loses most, though in percentage changes compared to the Base Case Scenario the loss is highest in the Eastern countries with more than -0.3% in 2035 and in 2050 it is highest in the Southern countries with more than -0.9% of employment. In 2050 about 1 million persons will have lost their job due to the lower GDP as a consequence of the described climate change impacts.



Source: ASTRA model

Figure 8-13: Impact of climate change on European regional employment, Reference Scenario, 2020 to 2050

Figure 8-14 presents the sectoral distribution of employment losses. While in 2020 the loss rather evenly affects industry sectors, construction and market-services, until 2050 the losses shift more and more towards the market-service sectors, which are much more dependent on consumption expenditures than the other sectors, and as shown above the private consumption is the GDP component that is affected most negatively until 2050.



Source: ASTRA model

Figure 8-14: Impact of climate change on sectoral employment in the ASTRA model.

Two disclaimers should accompany these results: first, the considered impacts definitely do not constitute the full impacts of climate change; and second together with the fact that we have chosen a conservative estimate for the damages to the capital stock we would thus expect that the economic impact of climate change until 2050 is larger than our estimates, making these estimates a lower boundary of impacts of adaptation to be expected.

8.4 References

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Munich Re (2008) Highs and lows - Weather risks in central Europe. Published in the Knowledge Series of Munich Re, Munich.

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9 Conclusions –The Reference Scenario

This report still reflects the results of an ongoing analysis of the cost of mitigation and adaptation of the European energy system until 2050 (and 2100). However, first conclusions can be drawn from the perspective of energy and climate policy (see Chapter 9.1) and from a methodological view point (see Chapter 9.2), as the hybrid model system of work package M1 has been fully applied for the first time.

9.1 Policy-relevant conclusions

Adaptation of the European energy system is likely to take place in incremental steps during the next decades: while there will be reduced heating energy demand in all countries in winter and additional electricity demand for air-conditioning and cooling, the net effects will vary with location and future climate change.

The *efforts of adaptation are not equally distributed over Europe*. Countries or regions with maritime climates will experience less change in heating and air-conditioning, while the net effect of a warmer climate is likely to hit the Mediterranean countries most:

- Higher temperatures and less precipitation will reduce the growth of forests and hence induce additional investments and energy cost in irrigation and water transmission.
- The changing climate of the Reference Scenario will also increase the investment and energy cost for air conditioning and cooling much more compared to countries north of the Alps. However, sectors are differently affected and the impact is still relatively small in terms of total energy demand. For instance, the demand for air conditioning in the residential sector in 2050 is relatively small compared to the other appliances (see Table 6-5), ranging from 0.8 % in northern countries to 11 % in southern Europe (with an average of 4 % for overall Europe, tripling however between 2005 and 2050).
- Finally, higher average temperatures will induce less efficient power generation and transmission and, herewith, additional investment in power generation capacity.

This means that there are distributional issues regarding adaptation or mitigation policies between northern and southern European countries. It may also lead to a greater need to balance summer electricity flows via the trans-European electricity grid, particularly during extreme heat waves or during cold winter storms.

Considering mainly the direct effect of adaptation of the energy system and the changed air conditioning, cooling, and heating patterns and not damage to capital stock, the investment would contribute a positive stimulus to GDP, as can be seen inFigure 8-12. This analysis reveals that only these adaptations of the European energy system would be about neutral for economic development for total Europe and that the negative economic impact reducing GDP of EU27 by about 240 billion € comes from the damage to capital stock due to extreme events. However, this damage effect has been considered by a mere assumption (see Chapter 8.2.5), such that this issue will need more attention in the future.

The preliminary discussion of the European transport system in case of extreme events clearly indicates that presently unexpected impacts on parts of the energy system and other infrastructures may be more important than adaptation measures.

There is also an issue regarding long-term energy infrastructure investments and the risk of extremes and adaptation responses, though the lack of knowledge and the uncertainty in prediction of such events presently makes exploration of these issues challenging. The issue is urgent given the long lifetimes of energy infrastructures such as hydro or thermal power plants and high voltage transmission lines, as well as forests (as fuel wood sources), buildings, and transport systems.

Less heating demand and increasing air-conditioning, better long distance transmission connectivity, smart grids, flexible electricity demand in all sectors, and electricity storage facilities have important linkages to mitigation options – thus there is a need for linked and synergistic adaptation-mitigation policy responses (e.g. smart grids, intensive use of renewable energies) and related analyses. However, the linkage and implications between adaptation and mitigation are still scarcely studied. There may also be unintended co-effects that increase or decrease vulnerability to climate change (e.g. the intermittency of renewables and peak summer day electricity demand, decentralised electricity generation and disruption risks).

The extent to which adaptation will be implemented in the European energy system will also depend on the present and *near future global policy efforts and successes in mitigation*. The more governments of industrialised and emerging countries postpone mitigation policies and the more likely global greenhouse gas emissions will not be curbed by 2030, the greater the tendency of European policy makers and investors to invest more to adaptation. There is a risk that the adaptation strategy will gain attention as it can be easily implemented at the national level, particularly in industrialised regions such as Europe.

9.2 Methodological conclusions

The concept of the ADAM hybrid model system (HMS) certainly has the advantage of simulating quite differentiated and transparent adaptation by the bottom up models and to some extent also by the more aggregated POLES model. On the other hand, using the same macroeconomic models to set the economic drivers and calculate the impact of adaptation in the Reference Scenario, the impacts on the economy in terms of economic growth, structural impact and employment or energy imports is quite convincing, because the difference induced by the concisely identified adaptation measures can be traced by the same macroeconomic model. If necessary, several iterations can be made, which may be the case in very ambitious mitigation scenarios. These are underway and will be reported on in the final deliverable of our work package M1 in July 2009.

The data transfer between the various models is still not satisfactory and a source of misinterpretation and errors. However, the authors are optimistic that by the end of the project in July 2009 there will be comfortable computer based data-handling that avoids those sources of errors, speeds up data exchange among the models and allows for a sufficient number of iterations to arrive at consistent model responses.

Some of the effects that are likely to occur such as more intensive electricity transmission during different seasons or extreme events are not yet modelled by the model system and will not be until the end of the ADAM project.