

ECN-C--04-094



## **ENERGY TRENDS FOR EUROPE IN A GLOBAL PERSPECTIVE**

Baseline projections by twelve E3-models  
in the CASCADE MINTS project

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**The CASCADE MINTS project is funded by the EU  
under the Scientific Support to Policies priority  
of the Sixth RTD Framework Programme**

DECEMBER 2004

## Preface

The CASCADE MINTS project on ‘Case Study Comparisons And Development of Energy Models for INtegrated Technology Systems’ is partially funded by the EU under the Scientific Support to Policies priority of the Sixth RTD Framework Programme. More information on the project can be found on [www.e3mlab.ntua.gr/cascade.html](http://www.e3mlab.ntua.gr/cascade.html).

The following partners are involved in Part 2 of the Cascade Mints project:

- Energy research Centre of the Netherlands (ECN) (The Netherlands); coordination/MARKAL model.
- ICSS/NTUA - E3MLAB (Greece); PRIMES and PROMETHEUS models.
- The International Institute for Applied Systems Analysis (IIASA) (Austria); MESSAGE model
- IPTS (Institute for Prospective Technological Studies), Joint Research Centre, EC (Spain); POLES model.
- Paul Scherrer Institute (PSI) (Switzerland); GMM model.
- The Centre for European Economic Research GmbH (ZEW) (Germany); PACE model.
- The Institute for Energy Economics and the Rational Use of Energy (IER) (Germany); TIMES-EE and NEWAGE-W models.
- ERASME-Équipe de Recherche en Analyse des Systèmes et Modélisation Économiques, University of Paris (France); NEMESIS model.
- International Energy Agency (France); ETP model.
- U.S. DOE/EIA Energy Information Administration of the U.S. Department of Energy (USA); NEMS model.
- Research Institute of Innovative Technology for the Earth (Japan); DNE21+ model.
- National Institute for Environmental Studies (Japan); AIM model.
- Natural Resources Canada (Canada); MAPLE model.

The authors wish to thank Ian Hayhow (Natural Resources Canada) for providing constructive comments, and Cees Volkers (ECN) for developing the analysis tool.

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## Abstract

In the coming decades, Europe’s energy system is facing a number of challenges. Some of these, such as the enhanced greenhouse effect and depletion of fossil fuel resources have a worldwide dimension. Consequently, the strategies for tackling these issues must be designed taking worldwide developments into account. Alternative energy sources and new technologies will have to play a key role. In the analysis of the potential impact of new technologies and the evaluation of possible policy options, energy - economy - environment (E3) models can provide useful insights. In the CASCADE MINTS project, these E3 models have been used to evaluate possible developments of the world energy system and the implications for Europe.

The objectives of this report are first to document the baseline assumptions and results in the project as a basis for analysis of policy cases. Secondly the report aims at providing information to policy makers, based on a scientific consensus among modellers, on possible developments in a world with moderate GDP and population growth, with no additional policies in place. The variety of technological and other assumptions in the different models causes a range in the results that reflects the uncertainty inherent to any projection of future developments.

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## POLICY BRIEF

In the coming decades, Europe's energy system is facing a number of challenges. Some of these, such as the enhanced greenhouse effect and depletion of fossil fuel resources have a worldwide dimension. Consequently, the strategies for tackling these issues must be designed taking worldwide developments into account. Alternative energy sources and new technologies will have to play a key role. In the analysis of the potential impact of new technologies and the evaluation of possible policy options, energy - economy - environment (E3) models can provide useful insights. In the CASCADE MINTS project, twelve of these E3 models have been used to evaluate possible developments of the world energy system and the implications for Europe.

This policy research comes right at a time when the EU has started a reflection on the actions on climate change for the post-2012 period<sup>1</sup>, especially considering the benefits and costs and taking into account both environmental and competitiveness concerns.

The policy brief provides an outlook on global and European energy developments towards 2050, summarising the main results generated by these models. It reflects the scientific consensus among modellers concerning the baseline presented and the main policy messages included in this brief. Although all models confirm the major trends, there are sometimes significant differences among individual model results, reflecting the different dynamics and assumptions and indicating the impact of uncertainties in the future energy system. The graphs, presented in this policy brief, show projections from different models, and should be regarded as illustrative of the discussed trends, by no means the only possible paths. The models used in the baseline projections are: PRIMES, PROMETHEUS, MARKAL, MESSAGE, POLES, GMM, PACE, TIMES-EE, NEWAGE-W, NEMESIS, NEMS and DNE21+.

### *Developments against a background of moderate economic growth*

The outlook is based on a common, harmonised baseline scenario. The baseline will serve as a benchmark against which policy scenarios will be compared in later stages of the project. It is based on the B2 scenario from the IPCC Special Report on Emissions Scenarios, because this scenario is characterised by a moderate economic and demographic growth. Some assumptions of major importance in this scenario are listed below.

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<sup>1</sup> See [http://europa.eu.int/comm/environment/climat/future\\_action.htm](http://europa.eu.int/comm/environment/climat/future_action.htm).



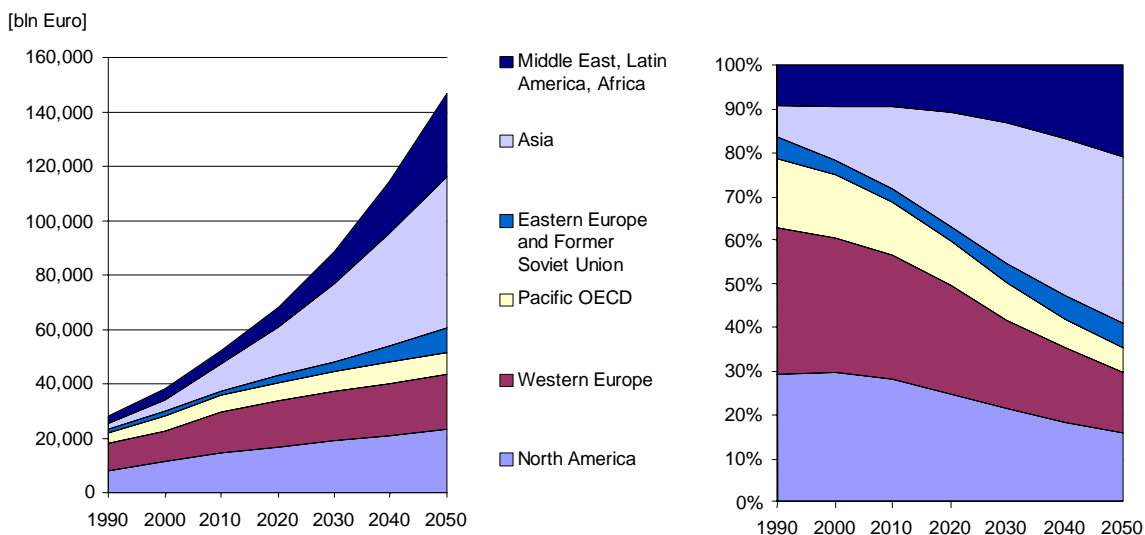


Figure P.1 *Development of GDP per region and share of these regions in world GDP*

In all regions of the world, the average GDP growth in the period 1990-2050 is lower than in 1950-1990. Asia shows by far the highest growth, while the economies in Western Europe, North America, Japan and Australia grow at a lower pace than the other world regions. This increasing dominance of the developing countries has a direct impact on energy consumption and greenhouse gas emissions. Despite the economic ‘catch up’, income differences between industrialised and developing countries remain significant.

Population growth is in line with current population trends and based on the UN median population projections from 1998. Global population increases to about 9.4 billion people by 2050. Population growth is highest in the developing countries in Africa, Latin America, and the Middle East. It is significantly lower in Asia and North America, whereas the population of both Europe and the Former Soviet Union remains almost constant until 2050.

Oil prices reflect assumptions of low to moderate resource availability. In the period 2000-2050, the world oil price is projected to increase from 4.2 to 6.2 Euro<sub>2000</sub>/GJ, which is equivalent to a range of ca. 26 to 38 US\$<sub>95</sub>/barrel. Obviously there is a great deal of uncertainty to this assumption.

Only instrumented policies in force or approved on December 31<sup>st</sup> 2003 have been included in the baseline scenario. Moreover, some representation of climate policy or emission trading for the region of Europe has been included. This is reflected in a generic carbon tax of 10 Euro<sub>2000</sub>/tonne CO<sub>2</sub> as from the year 2012.

#### *A continuing worldwide reliance on fossil fuels*

World primary energy consumption is expected to more than double in 2000-2050. This is a consequence of the assumptions regarding moderate economic and population growth, implying that a larger growth would also be possible. In line with the assumptions, Asia grows fastest, and quadruples its energy consumption by 2050.

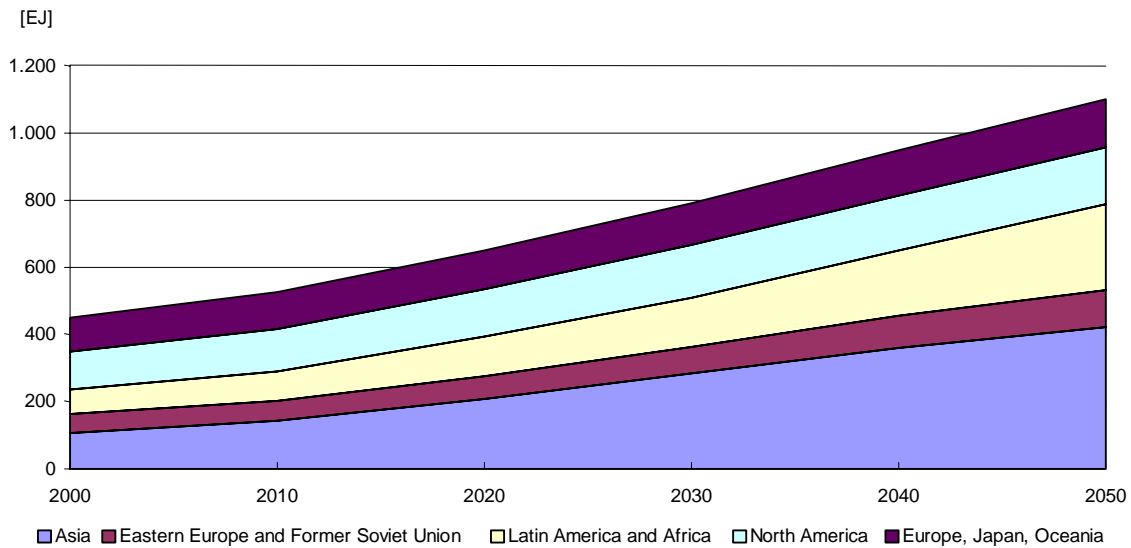


Figure P.2 *Development of primary energy consumption by regions*

All models indicate that fossil fuels are expected to remain dominant in the world fuel mix by supplying 65-80% of primary energy use (Figure P.3). Combined with the growth in primary energy consumption, this will result in an even faster depletion of the global natural resources than today. Although Europe's primary energy consumption shows a much slower growth than the world average - some 20% until 2030 - its reliance on fossil fuels (70-75% of the primary energy mix, depending on the model), is comparable to the rest of the world.

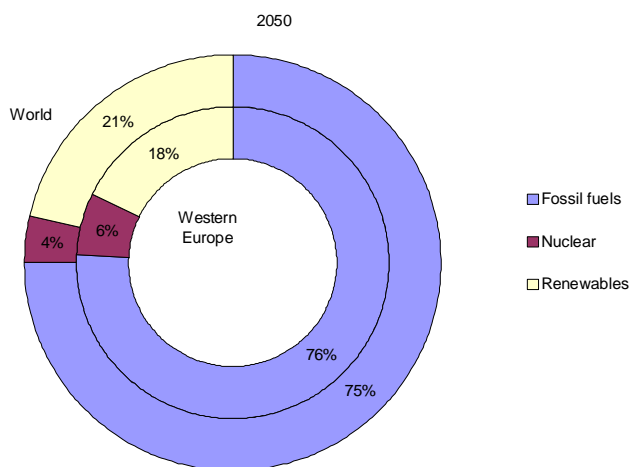


Figure P.3 *Fuel mix of primary energy consumption in the world and Western Europe, 2050*

Although the models show a consistent picture of the share of fossil and non-fossil fuels in future primary energy mix, they deviate on the contributions of individual fuels. In Europe, particularly the prospects of solid fuels and nuclear energy differ, due to different assumptions on technological development and costs. The power generation sector plays a key role in these fuel and technology choices. Coal consumption is expected to stabilise or grow. Some models expect nuclear energy to be phased out, due to high costs. There is a certain consensus on Europe's consumption of natural gas for power production, which is expected to increase significantly, and on the moderately increasing consumption of oil, mainly in the transport sector. Developments of energy prices may play a key role here.

On world level, a similar variation in projections exists. One of the models includes constraints on sulphur emissions, which induce a smaller share of particularly solids, and a substitution with nuclear and renewables.

These observations have the following implications for Europe.

- Europe will encounter more competition on increasingly scarce fossil resources. Given the limited domestic resource base, the growing dependency on imported fuels, particularly oil and natural gas, will bring about more risks of high prices and supply disruptions.
- The differences in projections of the primary energy mix indicate that there is room for fuel switch, particularly in the power sector. The results indicate that the future development of use of energy sources may substantially be influenced by policies, such as emissions regulations and stimulating non-fossil fuels. Moreover, high oil and gas prices might accelerate changes in Europe's energy mix.

*Energy savings increasingly important*

Europe's energy intensity is among the lowest in the world. In the current baseline projections, Europe is expected to maintain this leading role. However, as illustrated in Figure P.4, the scope for further efficiency improvements is more limited than in other world regions. On the other hand, Europe's energy consumption per capita is more than twice the world average, and keeps increasing. The increasing trend is in line with developments in other world regions.

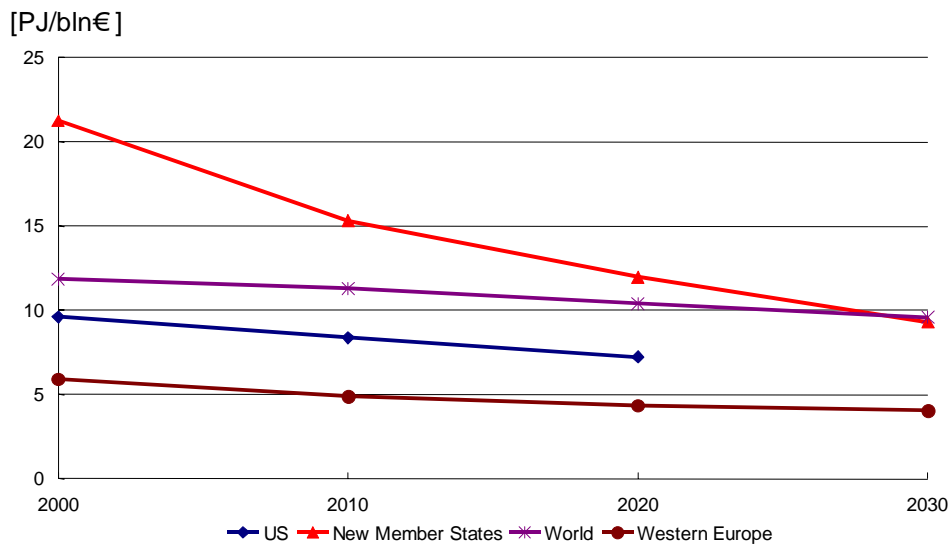


Figure P.4 *Europe's energy intensity of GDP compared to other world regions*

- Recognising that Europe's energy consumption is substantial but relatively efficient, policy measures should focus on stimulating energy savings in order to slow down the steady growth in energy consumption of the average European citizen.

*Security of supply becomes a key issue*

Given the continuing global reliance on fossil fuels, an important issue in the years to come will be the increasing dependence on oil from the Middle East. Although the models show different projections of the evolvement of oil production, they agree that the contribution from the Middle East region grows, and becomes substantially larger. Given the large uncertainty on future oil price developments, confirmed by one of the models indicating that there is a substantial

probability of sudden increases in the oil price, this may lead to increased concerns about the security of oil supply on the longer term, particularly in view of the present uncertain political situation in the Middle East.

For Europe, trends are in line with the global developments. Europe’s oil consumption is expected to stabilise at about a third of its primary energy consumption in 2030. Domestic production however is expected to decrease due to limited reserves and high production costs, thereby introducing a greater reliance on imports up to 85% (Figure P.5).

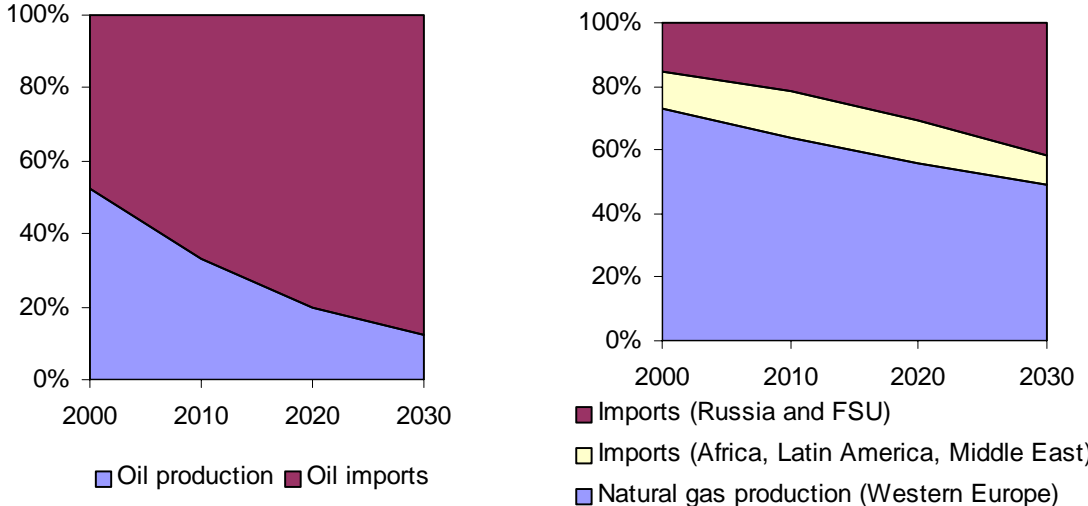


Figure P.5 Shares of production and imports of oil and natural gas (Western Europe)

For natural gas, Europe’s external dependency will also grow in the next decades. A continuing growth in gas consumption combined with a decrease of gas production in the UK, the Netherlands and Norway, will lead to a higher share of imports from the two main suppliers Russia and Algeria. Additionally, the accession of the new Member States and their heavy reliance on supplies from Russia increases the risks related to gas supply security.

There is another dimension to security of supply than dependency on imported fuels. The level of diversification is inversely related to the dependence on a few primary fuels, and is related to the correlation between the fuels in terms of costs and availability. The level of diversification may further influence the sensitivity of Europe to fuel supply disruptions.

- Europe’s dependence on oil from the Middle East is expected to increase significantly in the next decades. Given the prospect that other world regions will also increasingly rely on oil from this region, this may indeed lead to further oil price increases, which will affect all economic sectors.
- An increase in diversification – for instance a growing contribution from renewables – may to a certain extent alleviate the increase in external dependence for oil and gas. In the current analysis, the models show large differences in their projections of Europe’s future fuel mix, and thus in the expected level of diversification. This suggests that new policies may be required to stimulate an increased uptake of renewables or other sources.

### *The challenge of climate change remains*

It is highly likely that global warming is attributable to human activities, in particular to emissions of greenhouse gases. All models project a continuing growth of these emissions, of which CO<sub>2</sub> is the most important one. Overall, the CO<sub>2</sub> emissions in 2030 are expected to be approximately twice the level of 1990, the base year of the Kyoto protocol. The largest growth is expected to occur in the developing world, in particular in Asia. There is a large variation in emissions projections between models, related to the differences in the primary energy mix, particularly the share of fossil fuels. These differences are due to different assumptions on technological development and the associated technology costs.

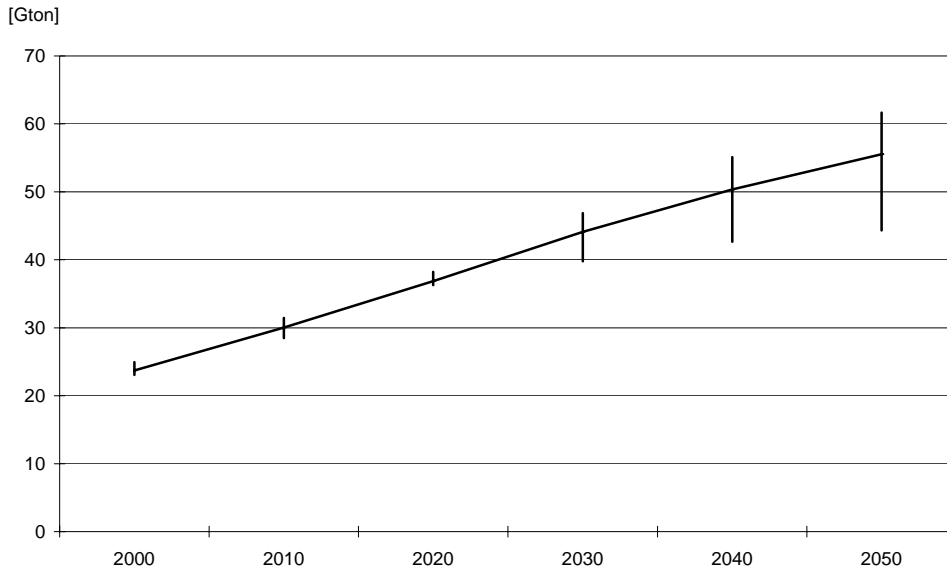


Figure P.6 *Range among models in average energy related CO<sub>2</sub> emissions projections*

In Europe, CO<sub>2</sub> emissions grow moderately, when compared to trends at world level (Figure P.7). Still, Western Europe is not on track towards the targets agreed under the Kyoto Protocol. Western Europe is committed to achieving an 8% reduction of CO<sub>2</sub> emissions by 2008-2012, as compared to the level in 1990. This means that in this period, the level of total CO<sub>2</sub> emissions (including non-energy uses) should not exceed approximately 3100 Mton per year. However, all models indicate that the energy-related CO<sub>2</sub> emissions alone are already expected to exceed this level. The carbon tax of 10 euro/(ton CO<sub>2</sub>), included from 2012 onwards to reflect the assumption that some type of climate policies will be implemented, does not suffice to curb the growing trend in greenhouse gas emissions.

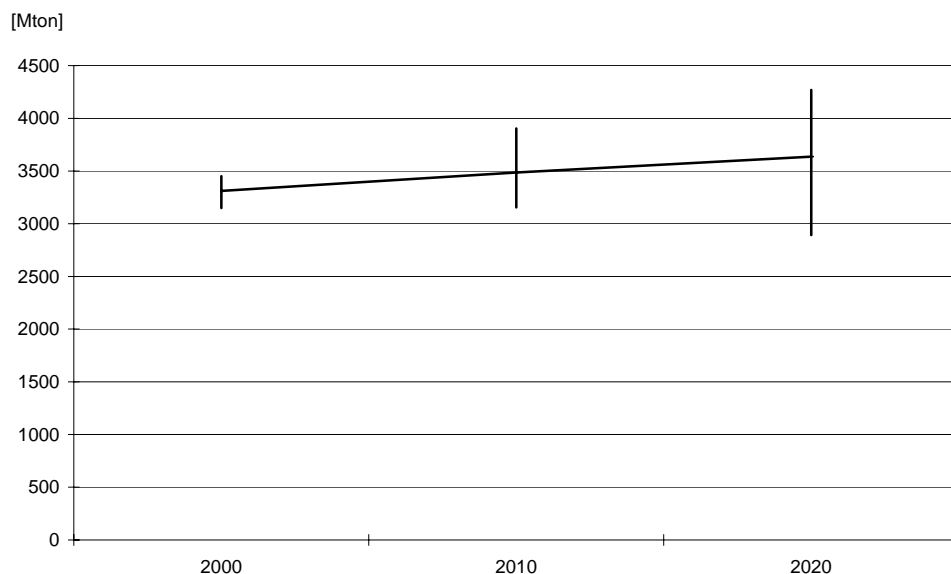


Figure P.7 *Range among models in average energy related CO<sub>2</sub> emissions projections in Western Europe*

- The results clearly indicate that under current policies, Europe will have severe difficulties achieving its Kyoto target. Therefore, additional instruments, such as emissions trading with countries outside Europe (Annex A), based on the JI and CDM instruments, may have to play a key role in meeting Kyoto commitments.
- Beyond 2012, a moderate carbon tax appears to be insufficient for curbing the trends in Europe, as emissions are expected to continue their growth with some 0.4% annually. In the rest of the world - in the absence of international incentives or regulation for mitigation - carbon emissions are expected to increase at a much higher pace, particularly in the developing countries. Therefore post-Kyoto policies will need to be developed. Given the large inertia in the energy system, short-term action is needed to foster the introduction of advanced and cleaner technologies, in order to enable these technologies to play a significant role in the long term.

#### *Outlook: strategies and directions*

The analysis presented in this report has identified some major challenges that the world is facing today. The findings are in line with the Commission WETO report<sup>2</sup> and the IEA World Energy Outlook 2004 (IEA, 2004). In the next phases of the CASCADE MINTS project, several strategies will be explored that may help to counter these developments.

*Renewables* are indigenous and CO<sub>2</sub> neutral, and therefore may improve diversification, and avoid greenhouse gas emissions. However these technologies still face financial and other barriers, and will have to be stimulated 'down the learning curve'. Questions to be explored include the amount of support necessary and the potential of these sources.

Similarly, *nuclear power* is an energy supply option that may help mitigating the greenhouse effect, but comes with other problems, such as the waste issue and the lack of political consensus.

<sup>2</sup> See [http://europa.eu.int/comm/research/energy/gp/gp\\_pu/article\\_1257\\_en.htm](http://europa.eu.int/comm/research/energy/gp/gp_pu/article_1257_en.htm).

*CO<sub>2</sub> capture and storage* is an alternative way to combat climate change while continuing the use of fossil fuels, but many technical and institutional issues still need to be solved. The project will evaluate the conditions and policy instruments that are required to make CO<sub>2</sub> capture and sequestration in old gas and oil fields or in aquifers become environmentally and economically feasible.

Finally, the project will explore the prospect of a *hydrogen* economy, which may potentially transform the complete energy system. The project will evaluate the costs, required R&D efforts, and policy measures in an integrated analysis.

# 1. INTRODUCTION

## 1.1 The CASCADE MINTS project

The current report presents results of Part 2 of the CASCADE MINTS project (CMP2). This project involves the development and use of energy and energy/economy models with special emphasis on analysing technological developments. The CASCADE MINTS project is split into two distinct parts:

- Part 1 focuses on modelling, scenario evaluation and detailed analysis of the prospects of the hydrogen economy. It involves extensive development and use of detailed energy models that have received assistance from previous framework Programmes of DG Research. The ultimate aim of this part of the project is to enable perspective analysis of the conditions under which a transition to an energy system dominated by hydrogen is possible.
- Part 2 does not involve significant model development. Its main aim instead is to use a wide range of existing operational energy and energy/economy models in order to build analytical consensus (to the extent that this is possible) concerning the impacts of policies aimed at sustainable energy systems. This part builds on the experience obtained in the ACROPOLIS project (Das et al, 2003), funded by DG Research within the 5th Framework Programme and involves common exercises carried out using a wide variety of models. This part involves modelling teams from both inside and outside the EU. The emphasis is placed on evaluating the effects of policies influencing technological developments.

This policy research comes right at a time when the EU has started a reflection on the actions on climate change for the post-2012 period, especially considering the benefits and costs and taking into account both environmental and competitiveness concerns.

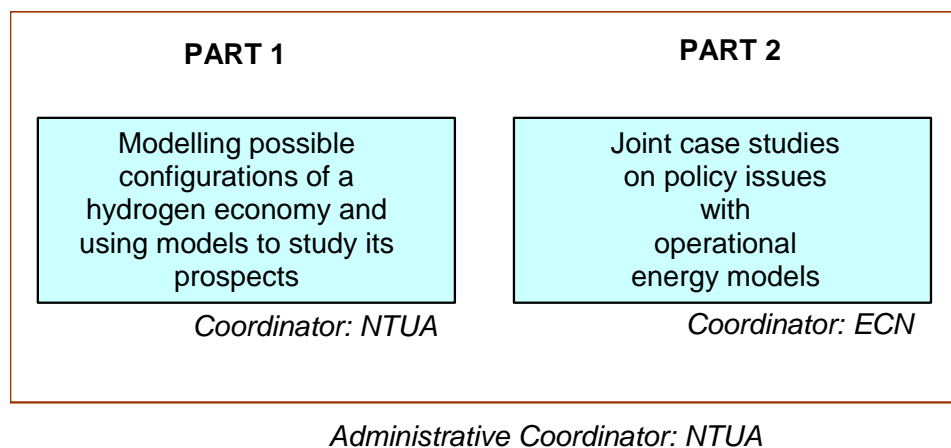


Figure 1.1 Overview of the CASCADE MINTS project

Part 2 of the project consists of six work packages. Five of these involve modelling work, and one work package is devoted to reporting and dissemination. This report presents results of the first work package on harmonisation of initial assumptions and evaluating a common baseline projection. In each of the next four work packages a set of common case studies will be analysed with the participating modelling teams. These work packages are briefly summarised below.



### *Renewable energy (WP 2.2)*

Renewable energy sources have the potential to play a much larger role than they presently do. However, targets for steadily increasing the share of renewables prove difficult to achieve. What are the consequences of different targets in 2020? What is an optimal share for renewables under different CO<sub>2</sub> mitigation and import dependency constraints? Under what conditions and by means of which policy instruments can the 2020 target of a 20% renewable energy share (of primary resources) be reached? What is the related impact on GHG emission reduction and import dependency in 2020 and 2050? What mix of renewable technologies (solar, wind, biomass, geothermal) will be applied in which sectors?

### *Nuclear energy (WP 2.3)*

Nuclear power currently accounts for approximately one-third of the electricity generating capacity in the EU and is therefore a main topic in the current debate concerning security of energy supplies in the EU and the reduction of GHG emissions. Replacement of existing nuclear power plants puts even more stress on both policy issues. Important issues which will shape the future trends in the nuclear sector, are the problems of managing nuclear waste, the economic viability of the new generation of nuclear power plants, the safety of reactors in eastern Europe, in particular Candidate Countries and the policies to combat climate change and improve the security of supply. The main research question that will be addressed is under what conditions and by means of which policy instruments will new nuclear power plants become environmentally and economically feasible? What will be the potential impact of nuclear energy in terms of GHG emission reduction and improving of supply security in 2020 and 2050?

### *CO<sub>2</sub> capture/storage (WP 2.4)*

CO<sub>2</sub> capture and sequestration will always come with an additional cost to any power generation plant. This is true both for the conversion to electricity and the conversion to hydrogen, if hydrogen is used as an energy carrier. CO<sub>2</sub> capture and sequestration will therefore only be applied if future specific or general policies provide the necessary financial incentive. Under what conditions and by means of which policy instruments will CO<sub>2</sub> capture and storage in old gas and oil fields as well as aquifers become environmentally and economically feasible? Considering different possible policy strategies to intervene and to stimulate CO<sub>2</sub> capture and storage becoming a mature technology, what is the potential impact of CO<sub>2</sub> capture and storage in terms of GHG emission reduction in 2020 and 2050?

### *Trade offs and synergies (WP 2.5)*

The final work package forms the link between Part 1 and Part 2 of the project. It integrates WP 2.2 (renewable energy), WP 2.3 (nuclear energy), WP 2.4 (CO<sub>2</sub> capture/storage) and WP 1.2 (hydrogen).

## 1.2 Report overview

The objectives of this report are first to document the baseline assumptions and results in the project as a basis for analysis of policy cases. Secondly the report aims at providing information to policy makers on possible developments in a world with moderate GDP and population growth, with no additional policies in place. The variety of technological and other assumptions in the different models causes a range in the results that reflects the uncertainty inherent to any projection of future developments.

The report is structured as follows. Chapter 2 introduces all models involved in the project and classifies and clusters these in order to provide a framework for interpreting their results. Chapter 3 documents the assumptions, which the modelling teams agreed to harmonise. Next, Chapters 4 and 5 provide the main results of the baseline projections for the world and Europe, respectively. Finally, Chapter 6 presents the key messages formulated on the basis of previous chapters.

## 2. ENERGY MODELS IN CASCADE MINTS PART 2

### 2.1 Classifying different types of energy models

In the CASCADE MINTS Part 2 (CMP2) project, 15 different models will be used to help understand the policy questions related to climate change and security of supply. The models are representative of the variety of analytical approaches used in current energy and climate policy analysis. Generally, different studies use different models, or only a limited set of models, which may cause difficulty in interpreting the differences in outcomes. Hence, the project aims at starting off with a comparison of various models, providing a background for understanding possible different outcomes when using different models. Building on this comparison, the CMP2 project will provide the specific outcomes from each of the 15 models and synthesise the results. Each model will provide different insights to energy policy issues because of its design; therefore a range of policy effectiveness may be determined. This chapter will provide an overview of the different models participating in the CMP2 project, and classify and cluster these in order to provide a framework for analysing their results. Table 2.1 lists all models by coverage and affiliation.

Table 2.1 *General overview of the models used in CASCADE MINTS Part 2*

Model	Geographical coverage	No. of Regions	Affiliation	Participating in work packages
<i>Global, US, Canada</i>				
AIM	World	21	NIES, Japan	Baseline, renewables
DNE 21+	World	77	RITE, Japan	All
ETP	World	15	IEA, France	From fall 2004 ready to participate
GMM	World	5	PSI, Switzerland	All
MESSAGE	World	5	IIASA, Austria	All except Nuclear
NEWAGE	World	13	IER, Germany	All
POLES	World	38	IPTS, Spain	All
PROMETHEUS	World	3	NTUA, Greece	All except CCS
NEMS	USA	5-32	EIA, USA	All
MAPLE	Canada		NRCan, Canada	All
<i>Europe</i>				
MARKAL	Western Europe	1	ECN, Netherlands	All
NEMESIS	Europe	16	ERASME, France	All
PACE	World	9	ZEW, Germany	All except CCS
PRIMES	EU-25 countries	25	NTUA, Greece	All except CCS
TIMES-EE	Europe	19	IER, Germany	All

Three of these models have not participated in the current phase, for various reasons. The ETL model of the IEA, and the MAPLE model of Natural Resources Canada are still under development. The AIM/CGE model of NIES in Japan is currently being upgraded and was for this reason not available. These three institutes participate in the CASCADE MINTS project without EU funding.

Annex A provides a summary overview of model characteristics as provided by the respective institutes, used for the classification. Generally, a distinction is made between ‘bottom-up engineering models’ which provide a detailed representation of the energy system and satisfy a given energy demand with least cost supply, and ‘top-down energy economy models’ which de-

scribe the interaction between the economy as a whole and the energy sector but lack technological detail. Presently, most energy models are hybrids that attempt to compensate the drawbacks of the two approaches. The classification draws on the taxonomy of energy models provided by (IPPC-TAR, 2001).

### 2.1.1 Top-down models

Top-down models usually describe the entire economy in aggregate terms, drawing on analysis of historical trends and relationships to predict large-scale interactions between the energy sector and the rest of the economy. They incorporate relatively little detail on energy use and technological development. Top-down modelling approaches are further classified into two groups.

- *Macro-economic models.* These models are usually simulation models, describing investment and consumption patterns in various sectors. They implicitly reflect past behaviour in that the driving equations are estimated using econometric techniques on time-series data. In the CMP2 project, only the NEMESIS model, a Neo-Keynesian macro econometric model with detailed energy/environment module for Western Europe, falls into this category.
- *Computable General Equilibrium Models.* CGE models construct the behaviour of economic agents based on microeconomic principles. The models typically simulate markets for factors of production (e.g., labour, capital, energy), products, and foreign exchange, with equations that specify supply and demand behaviour. The models are solved for a set of wages, prices, and exchange rates to bring all of the markets into equilibrium. CGE models examine the economy in different states of equilibrium and so are not able to provide insight into the adjustment process. The parameters in CGE models are partly calibrated and partly statistically or econometrically determined. In the CMP2 project, three CGE models will be used. AIM/CGE, PACE and NEWAGE are global models. PACE provides a detailed representation of the power sector.

### 2.1.2 Bottom-up models

Typically, a bottom-up engineering model incorporates detailed data on costs and efficiencies of a wide range of available and new technologies, and describes energy use in great detail. Based on these data, the model determines a (least cost) strategy for satisfying exogenously determined final or useful demand for energy services. These models incorporate relatively little detail on non-energy consumer behaviour and interactions with other sectors of the economy. They tend to provide results in which technological progress plays a key role, because they disregard market thresholds and non-technical barriers. Bottom-up approaches can be further classified into two categories.

- *Dynamic Energy System Optimisation Models.* These technology-oriented models minimize the total costs of the energy system, including all end-use sectors, over a time horizon of several decades and thus compute a partial equilibrium for the energy markets. Recent versions allow demand to respond to prices. Some models link aggregate macroeconomic demand and energy demand. Technology learning is endogenous in some models. This class of models is well represented in the CMP2 project. DNE21+, GMM, ETP and MESSAGE are global models. The models differ in their regional and technological coverage and their incorporation of technology learning. For Europe, MARKAL describes the Western European energy system as a whole, while TIMES-EE describes the electricity production sector in the EU-15 plus Norway, Switzerland, Poland and Czech Republic.
- *Integrated Energy-System Simulation Models.* Integrated energy-system simulation models are bottom-up models that include a detailed representation of energy demand and supply technologies, which include end-use, conversion, and production technologies. Demand and technology development are driven by exogenous scenario assumptions often linked to technology vintage models and econometric forecasts. The demand sectors are generally disaggregated for industrial sub-sectors and processes, residential and service categories, transport modes, etc. In this category, the largest variation of methodologies can be found.

POLES is characterised as a recursive simulation model of the world energy market, while PRIMES, NEMS and MAPLE have in common a ‘generalised equilibrium’ structure, meaning that they formulate the behavioural conditions for economic agents in a variety of formulations for separate sub models, which are solved by a market clearing algorithm.

Finally, one model remains to be classified. The PROMETHEUS model is a stochastic model of the world energy system. It could be regarded a bottom-up model without fitting in one of the categories listed above.

### 2.1.3 Classification summary

Summarising, the models participating in CMP2 provide a variety of methodologies giving complementary information. Not surprisingly, more energy sector models are involved in the CMP2 analysis than macro economic ones. Still, it should be stressed that no classification does justice to the richness of approaches. Many of the models have ‘hybrid’ characteristics reflecting the attempts that modellers have made to adjust for specific drawbacks of a given approach.

Geographical coverage	<i>Top-down</i>		<i>Bottom-up</i>	
	Macro-economic	CGE	Energy System Optimisation	Integrated Energy System simulation
Global		AIM NEWAGE PACE	DNE21+ ETP GMM MESSAGE  PROMETHEUS	POLES
US, Canada				NEMS MAPLE
Europe	NEMESIS		MARKAL Europe TIMES-EE	PRIMES

Figure 2.1 *Classification summary*

#### *World*

As illustrated in Figure 2.1, eight different models will provide projections of global energy sector developments. Three of these are top-down (CGE) models, which will study macro-economic feedbacks on energy policies. Four of the others are energy system optimisation models that will provide the bottom-up technology rich perspective. Furthermore, one stochastic model will shed more light on the role of uncertainties and one integrated energy system simulation model is available. Moreover, two integrated energy system simulation models describe the US and Canada energy systems.

#### *Europe*

When it comes to modelling policy cases within Europe, four different models are available, whereas most of the global models distinguish enough regions to be able to focus on Europe as well. One of the ‘European’ models (NEMESIS) provides the macro economic point of view, two energy systems optimisation models (MARKAL and TIMES-EE) provide the bottom-up perspective using different regional classifications, while one integrated energy-system simulation model (PRIMES) also pays attention to behavioural aspects.

### 3. KEY ASSUMPTIONS FOR HARMONISATION

#### 3.1 Introduction

In modelling, the effects of policies are analysed by comparing a situation in which the policy is implemented to a situation in which no action is taken. Thus, when considering the impact of policies, an image of the world has to be constructed in which none of the policies that are under scrutiny are included. As such an image serves as the baseline against which scenarios will be compared, it is generally called the baseline scenario.

The models used in the CASCADE MINTS project are too diverse to define a truly common baseline scenario. Therefore, instead of attempting to define a common baseline scenario, an approach is followed where a set of basic assumptions are harmonised. Thus, a baseline scenario is defined for each model separately, subject to the requirement that some of the initial conditions have to be harmonised. The objective of this harmonisation is to allow for a common basis for comparing baseline results and policy cases. This provides more insight in the range of results supplied by the different models. Moreover, it enables a better identification of the sources of discrepancies among the results.

Different levels of harmonisation may be chosen for the baseline, depending on the desirability and feasibility of these levels. Factors that must be taken into account are, for example, the desired ‘richness’ of the baseline results provided by the models, the variety of types of models (bottom-up or top-down approach), the type of baseline variables (exogenous or endogenous), and the available amount of time and budget. Figure 3.1 shows various possible levels of harmonisation. The lowest level of harmonisation concerns the harmonisation of qualitative assumptions based on a scenario storyline. The highest level of harmonisation refers to the harmonisation of quantitative assumptions on variables such as GDP, population, international energy prices, etc. combined with harmonisation of input data on technologies. For CASCADE MINTS a moderate level of harmonisation is chosen. This means that only a small number of quantitative assumptions (key economic parameters) will be harmonised, whereas technology-specific assumptions will not be harmonised. This level of harmonisation brings the baseline results of the various models more into line, while preserving the ‘richness’ of the baseline results due to the different modelling approaches and model structures. Before discussing the initial conditions that are to be harmonised in the CASCADE MINTS project, the choice of baseline scenario will be outlined first in the next section.

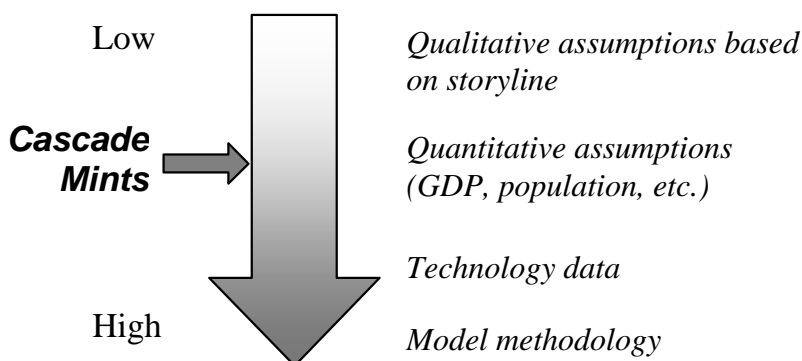


Figure 3.1 *Level of harmonisation of initial conditions in CASCADE MINTS*

### 3.2 Choice of baseline scenario

As a starting point for the development of a baseline scenario, the IPCC/SRES ‘B2 marker scenario’ has been chosen, which is derived from the Special Report on Emission Scenarios by the Intergovernmental Panel on Climate Change (IPCC, 2000). This B2 marker scenario represents a group of scenarios that have similar characteristics and fit within the same qualitative storyline (B2). This scenario is used in CASCADE MINTS to provide a common and consistent basis for harmonisation of initial conditions in the baseline scenario. The objective of this project is *not* to reproduce the outputs provided by the models for the B2 scenario in IPCC (2000) by a different set of models. Because the harmonisation is only done for a minimum set of initial conditions and not for all assumptions used by the models, each model defines and uses its own baseline scenario. Therefore, the set of baselines used in CASCADE MINTS is probably broader than the B2 group of scenarios but the added value of these variations is that they reflect uncertainty about future developments. Moreover, the diversity of the models will provide different views on the effectiveness of the policy approaches.

Regarding the timescale (up to 2100) and geographical scale (global), the four IPCC/SRES scenarios are suitable as a baseline for CASCADE MINTS. All four storylines, i.e. A1, A2, B1 and B2, represent different directions of future developments and are considered equally plausible. They only cover gradual changes in these different directions and do not include ‘catastrophic futures’ or ‘surprises’. Although none of them can be treated as a ‘business as usual’ scenario, they can be considered relatively ‘neutral’ in terms of policy assumptions. They do not include explicit climate change or renewable energy policies. The storylines of these scenarios can be used to develop and evaluate policies by assuming additional policies and measures, which also makes them suitable as baseline scenarios for CASCADE MINTS.

From these four scenarios, the B2 scenario is chosen as a baseline scenario for CASCADE MINTS because this scenario shows more gradual changes and less extreme developments than the other three scenarios in all respects, including geopolitics, demographics, productivity growth, and technological dynamics. The other three scenarios may show moderate developments as well for some of the characteristics mentioned above, but in general they are more ‘extreme’ than B2, assuming, for example, ‘low’ or ‘(very) high’ economic and population growth rates, or technological improvement rates. In this respect, the B2 scenario can be considered the closest approximation to a ‘dynamics as usual’ scenario.

Figure 3.2 shows the four scenario families and their general characteristics, categorised according to two dimensions, i.e. a global-regional and an economic-environmental orientation. More details on the storylines and quantitative characteristics of the scenarios can be found in IPCC (2000).

<b>Economic</b>	
<b>A1</b>	<b>A2</b>
<ul style="list-style-type: none"> <li>• Very rapid economic growth</li> <li>• Low population growth</li> <li>• Rapid introduction of new and more efficient technologies</li> <li>• Convergence among regions</li> <li>• Capacity building</li> <li>• Increased cultural and social interactions</li> <li>• Reduced regional differences in per capita income</li> </ul>	<ul style="list-style-type: none"> <li>• Very heterogeneous world</li> <li>• Economic development primarily regionally oriented</li> <li>• High population growth</li> <li>• Self-reliance and preservation of local identities</li> <li>• Per capita economic growth and technological change more fragmented and slower than in other storylines</li> </ul>
<b>Global</b>	<b>Regional</b>
<b>B1</b>	<b>B2</b>
<ul style="list-style-type: none"> <li>• Convergent world</li> <li>• Low population growth</li> <li>• Changes in economic structures toward a service &amp; information economy</li> <li>• Reductions in material intensity</li> <li>• Introduction of clean and resource-efficient technologies</li> <li>• Global solutions to economic, social environmental sustainability</li> <li>• Improved equity</li> </ul>	<ul style="list-style-type: none"> <li>• Intermediate levels of economic development</li> <li>• Moderate population growth</li> <li>• Emphasis on local solutions to economic, social, and environmental sustainability</li> <li>• Less rapid and more diverse technological change (compared to B1 and A1)</li> <li>• Environmental protection and social equity, focusing on local and regional levels.</li> </ul>
<b>Environmental</b>	

Figure 3.2 *Four IPCC/SRES scenario families and their general characteristics (IPCC, 2000)*

Two important features of the B2 storyline are the high priority given to environmental issues and the trend toward local self-reliance and stronger communities. These characteristics are not explicitly harmonised in the models used for CASCADE MINTS. The reason for this is that the B2 scenario is only used as a common and consistent basis for harmonisation of initial conditions and not to achieve complete reproduction of the outputs for the B2 scenario as described in IPCC (2000). However, some of the models may have incorporated storyline characteristics of the B2 scenario in other assumptions apart from the minimum set of assumptions to be harmonised within CASCADE MINTS, which will be discussed in the next section.

### 3.3 Initial conditions to be harmonised

The harmonisation of initial conditions is restricted to a number of key parameters, assuming differences in other input variables reflect the uncertainties present or specific local conditions. The variables to be harmonised may be either endogenous or exogenous, depending on the type of model. Only those parameters that are exogenous in the models have to be harmonised.

The minimum set of initial conditions that must be harmonised, if exogenous, consists of the following variables<sup>3</sup>:

- GDP
- Population
- Energy prices (oil and optionally coal)
- Overall discount rate
- Policy.

For GDP and population, the harmonisation is based on quantitative information from the IPCC/SRES B2 marker scenario. More details on the assumptions for GDP and population will be presented in Section 3.4.

Assumptions for energy prices of oil and, in some models, coal only concern the international oil and coal prices. The prices of natural gas are not to be harmonised since they are regional, they may be determined endogenously and/or they may be coupled to the oil prices. The oil and coal prices that are used for harmonisation are based on results of the POLES model since the B2 marker scenario did not provide information on international market prices (only on marginal costs). The assumptions on international oil and coal prices will be presented in Section 3.5.

The overall discount rate denotes the rate used for discounting future investments and prices to the reference year 2000. The overall discount rate has been derived from the discount rates that are currently used in the participating models. Based on this information, a value of 5% has been chosen for the overall discount rate.

The harmonisation of policy assumptions is one of the most difficult tasks, since policy schemes may be very complex and they may vary substantially among countries and regions included in the models. The general guidelines for harmonisation of policy assumptions in the baseline scenario are described in Section 3.6. This section also presents the assumptions for specific policy fields that are to be harmonised.

### 3.4 GDP and population

For the harmonisation of GDP and population quantitative information from the IPCC/SRES B2 marker scenario is used. IPCC (2000) provides information about the development of GDP and population on global level as well as for different regions. Modelling teams use the assumptions on GDP and population for the regions that are included in their models and, if necessary, they make their own assumptions for sub-regions in accordance with the assumptions on regional level. Here, only the assumptions for world region (based on GMM) and Europe (based on MARKAL) are presented since CASCADE MINTS focuses on these regions. Figure 3.3 shows the assumptions for the world and European population for the period 2000-2050. The average annual growth rate of the world population is ca. 0.9%, whereas the population of Europe remains almost constant until 2050.

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<sup>3</sup> Given the differences in sectoral and/or regional aggregation and different nesting assumptions in the models, harmonisation of substitution elasticities in CGE models is not feasible. A similar remark applies to the harmonisation of final energy demand in bottom-up models.



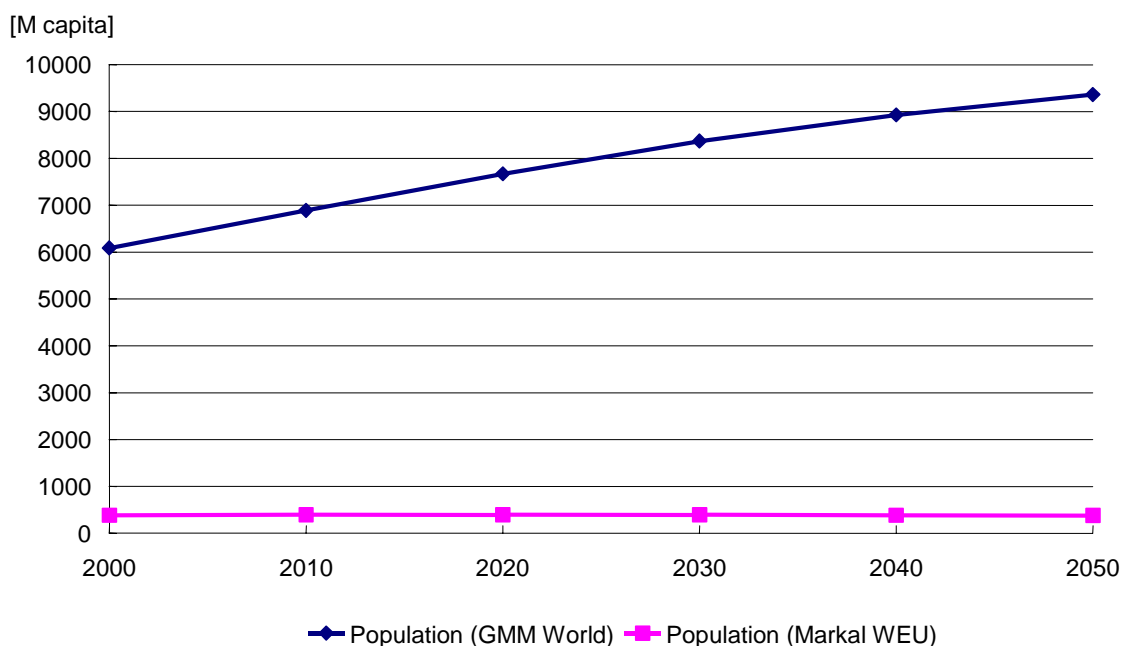


Figure 3.3 *Harmonisation of population for world (GMM) and Europe (MARKAL) for 2000-2050*

Figure 3.4 presents the assumptions on world and European GDP in the period 2000-2050. The GDP of the European region is expected to grow by ca. 70% in the period 2000-2050 (ca. 1.1% per year), whereas the world GDP is projected to almost quadruple in this period, which corresponds to an average annual growth rate of ca. 2.7%. This large difference is mainly due to the strong economic growth that is expected in Asia, Latin America, and, to a lesser extent, in Eastern Europe and the states of the former Soviet Union.

The GDP growth in the figure is defined in terms of Market Exchange Rates (MER), as it is the metric used in most of the models involved in the present study. However, some of the models, such as PROMETHEUS, use Purchasing Power Parity to define GDP and hence also GDP growth. The growth rates in these two metrics differ substantially, as can be seen from Table 3.1, where we give growth rates for world GDP in both metrics. For further information on the use of the two different metrics in energy-economic scenarios see (Gruebler et al., 2004) or (Manne and Richels, 2003).

Table 3.1 *World growth rate of GDP, for Market Exchange Rate (MER) and Purchasing Power Parity metrics*

	1990-2000	2000-2010	2010-2020	2020-2030	2030-2040	2040-2050
MER	3.1	3.2	2.8	2.7	2.6	2.5
PPP	3.1	3.0	2.5	2.3	2.1	2.0

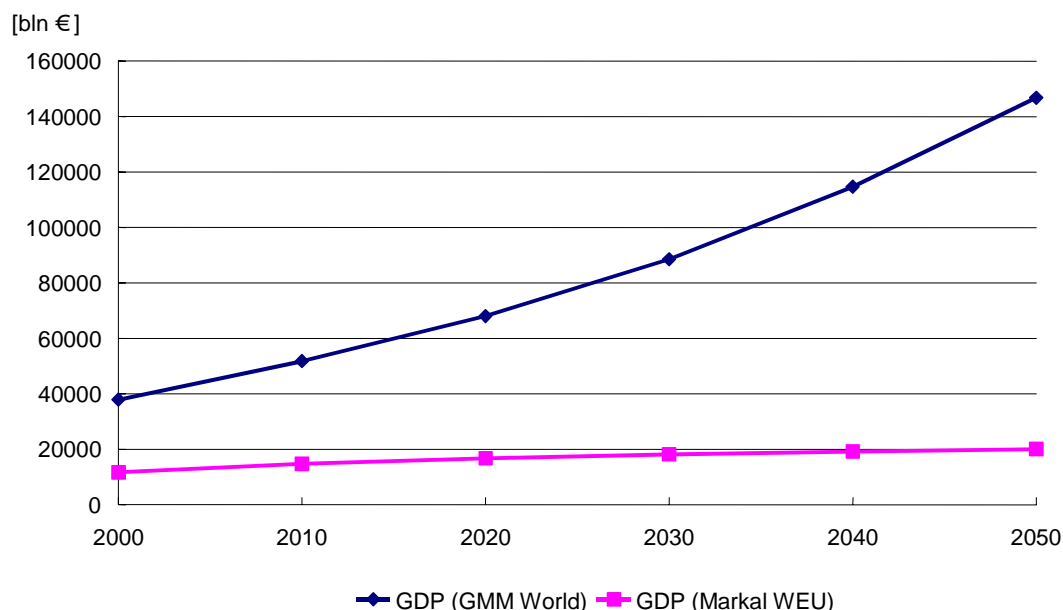


Figure 3.4 Harmonisation of GDP for world (GMM) and Europe (MARKAL) for 2000-2050

### 3.5 Energy prices

In CASCADE MINTS Part 2, only the international prices of oil and, in certain cases, coal are harmonised. The assumptions on these prices are based on results of the POLES model. It should be noted that for coal prices, modelling teams do not necessarily have to use the prices provided by POLES but their assumptions should be in line with the B2 storyline. The reason for this is that coal is regionally available and coal prices may be regionally determined. Figure 3.5 presents the international oil and coal prices for the period 2000-2030 from POLES. It also shows an example, based on MARKAL, of the extrapolation for the international oil price beyond 2030. In the POLES model, the coal price for Europe is set equal to the international coal price. Figure 3.5 presents an example, based on MARKAL, of a regional coal price for Europe that deviates somewhat from the international coal price derived from POLES.

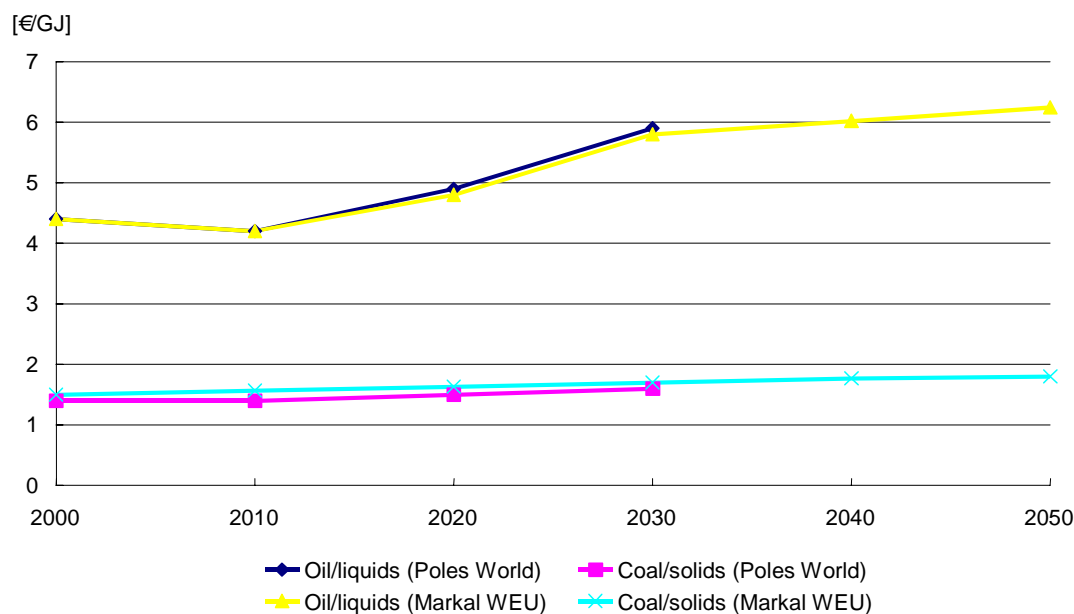


Figure 3.5 Oil and coal prices for the world (POLES) and Europe (MARKAL) for 2000-2030/2050

## 3.6 Policies

### 3.6.1 General guidelines

For the harmonisation of policies in the baseline scenario, some general guidelines are used. First of all, only policies in force or approved on December 31<sup>st</sup> 2003 may be included in the baseline scenario. This means that policies for which the exact implementation is not clear at this date should be excluded. The baseline scenario should only contain instrumented policies so this implies that policy targets (e.g. EU targets for renewable electricity or biofuels consumption) should be excluded. The reason for this is that it should not be assumed in the baseline scenario that such policy targets would, in any case, be achieved. Financial incentives that are included in the baseline scenario will be continued up to the year 2012 and then phased out. Assumptions on the following specific policy fields will be discussed further in the next sections:

- Primary energy sources: nuclear energy, oil, natural gas, and coal.
- End-use of energy carriers: end-use subsidies and taxes, electricity market, renewable electricity, and biofuels.
- Emissions: climate change and emission trading, standards and industry-negotiated agreements on emissions and energy-efficiency for vehicles, and sulphur control policies.

### 3.6.2 Primary energy sources

#### *Nuclear energy*

The contribution of nuclear energy in electricity generation is an area *par excellence* where policies play a decisive role. The political and public attitude towards electricity from nuclear fission differs substantially across the EU Member States. Whereas politicians in a number of countries have decided to phase out the use of fission power plants (e.g. Germany, Belgium) other countries are intent on maintaining or extending existing capacity (e.g. France, Finland). In yet other countries, no policy is formulated.<sup>4</sup>

As becomes clear from a summary by the IEA (IEA, 2001), 8 Member States of the EU15 are rejecting nuclear power as an option. However, in terms of nuclear capacity, these countries correspond to only about 30% of total capacity. On the other hand, due to the lack of competitiveness, the generating capacity in the UK should also be expected to gradually phase out. Thus, on the longer term about 40% of nuclear power generating capacity will be replaced by other options. Most countries advocating a phase out are planning a gradual replacement ending in 2025.

The proposal for harmonisation of nuclear capacity is to use the data in Table 3.2 as an upper bound (maximum installed capacity) for the EU15 region. For the New Member States, a continued use of nuclear power is likely, and it is therefore proposed to use the current capacity level, i.e. 11.9 GW (WEPP, 2003), as upper bound in the baseline scenario (in a policy case in which the future of nuclear power will be investigated, these assumptions will be relaxed). For the rest of the world, no explicit assumption seems necessary in the base case.

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<sup>4</sup> Assuming the market situation in the UK proves to be exemplary for the European Union, nuclear can be expected to undergo a 'voluntary' phase-out. In the UK, nuclear power plants are expected to remain non-competitive, even in comparison to gas-fired power plants (IEA, 2002).

Table 3.2 *Proposed upper bounds for total capacity of nuclear power plants in the EU15 in the baseline scenario (WEPP, 2003)*

Year	2000	2005	2010	2015	2020	2025 and later
Capacity [GW]	123.9	113.8	103.7	93.5	83.4	73.3

### *Oil*

No specific policies are given so policies regarding oil are not harmonised.

### *Natural gas*

Gas market reforms are to be implemented in EU Member States, including the New Member States. This influences the market model, and is expected to result in lower gas market prices, but if this is indeed the case, and if so to what extent, is uncertain. No specific numbers can be deduced from such policy measures. Therefore, modelling teams are free to make their own decisions on the specific translation of current and approved gas market policies in their models.

### *Coal*

Traditionally, the mining industry has received substantial government support in the European Union due to social considerations. Recently, such support schemes have been focussed on the reduction of non-competing production capacity in a socially acceptable way. The support is provided by the country governments, in particular by France, Germany, Spain, and the United Kingdom. For none of these countries the production is truly commercial, resulting in a subsidised production of approximately 85 Mton per annum. Support schemes are partially advocated as being useful in security of supply issues.

France is expected to end production by 2005, while Spain and Germany show no intention to decrease state support. In the latter two countries, production costs are about three times the world market prices. In the UK, a two-year state aid package of up to ca. 160 million Euro in place since 2002, in spite of production costs being close to market prices. No proposal has been made for the harmonisation of coal policies. Therefore, modelling teams are free to make their own decisions on the inclusion of current and approved coal policies.

## 3.6.3 End-use of energy carriers

### *End-use subsidies and taxes*

Most policies regarding the use of energy carriers in the European Union, and indeed in much of the rest of the world, are put into concrete form by means of taxes, or tax exemptions. These are levied on many levels in the energy system: on primary energy carriers, intermediate energy products (such as gasoline) or final energy carriers (like electricity).

The prices of energy carriers in energy system models covering a single country or region, such as MARKAL, are generally specified as world market prices, or resulting from costs of technologies used to extract and/or produce the energy carriers. Taxes and subsidies are mostly excluded from the description in global models, in part because these models describe composite regions, for which it is hard to include the county-specific taxes in a simple way. A secondary reason is that a full quantitative review for all taxes and subsidies for all countries in the world is not at hand. Therefore, subsidies and taxes are not harmonised in CASCADE MINTS.

### *Electricity market*

Electricity market reforms are to be implemented in the EU Member States, including the New Member States. This influences the market model, and is expected to influence electricity market prices. However, as in recent years it has become clear that liberalisation does not necessarily result in lower prices, the effect on electricity market prices is unclear. Some recent developments have even raised concerns over market failures, leading to proposed policies for security of supply. However, no specific numbers can be deduced from these policy measures. Therefore, modelling teams are free to make their own decisions on the specific translation of current and approved electricity market policies in their models.

### *Renewable electricity*

Renewable energy appears to be the area where most concrete measures are in place. The EU Renewable Electricity Directive has set indicative targets for the share of renewable electricity in 2010, and all EU Member States have some type of financial support scheme in place. An inventory of policy measures for renewable electricity can be found in ECN (2003).

Aside from this overview, in the ADMIRE REBUS project a simulation model has been developed for the European market for renewable electricity production (ECN, 2003). A specific policy case studied using this model is the case where present national support policies in the EU15 (such as feed-in tariffs) are continued unmodified up until 2010. These results in approximately 18% share of renewables in the European gross electricity consumption, compared to a 22% target, a finding which is comparable to several other studies.

Given the fact that most policies are implemented via fiscal measures, which are country-specific and therefore hard to parameterise as a direct effect on prices in an aggregate model, the proposal for harmonisation of renewable electricity policies is to use the outcome of the ADMIRE-REBUS study with the extrapolation of current policies up until 2010 as lower bounds for technologies. The results from this study can be regarded an aggregate representation of the effect of the variety of current and approved support policies, and are therefore suitable as lower limits for the renewable electricity production in Europe, up until 2010. This would imply the bounds as given in Table 3.3 should be implemented in the models<sup>5</sup>. It should be noted that the numbers given are activity levels, which is the logical limitation given that many of the fiscal measures are stimulating production, rather than installation of capacity.

Table 3.3 *Activity levels of renewable energy systems from the ADMIRE-REBUS model, under the assumption of unchanged policies until 2010*

[GWh]	2000	2005	2010
Biomass	26,773	60,075	99,751
Geothermal electricity	4,303	5,337	5,827
Large Hydro (>10 MW)	265,208	272,585	276,942
Small & Medium Hydro (<10 MW)	38,341	43,596	46,186
Photovoltaics	98	884	1,632
Tidal	580	580	580
Wind, off-shore	108	1,254	3,085
Wind, on-shore	16,812	61,043	108,777

From the activity levels capacity levels can be deduced, and the values from the ADMIRE-REBUS study are given in Table 3.4. As the study primarily calculates activity levels, these capacities should be considered as indicative levels, rather than actual bounding levels.

<sup>5</sup> The data can be given in more detail: both in years (annual data) as well as in countries.

Table 3.4 *Capacity level of renewable energy systems from the ADMIRE-REBUS model, under the assumption of unchanged policies until 2010*

[MW]	2000	2005	2010
Biomass	4,039	8,749	14,474
Geothermal electricity	756	937	1023
Large Hydro (>10 MW)	85,364	87,946	89,471
Small & Medium Hydro (<10 MW)	9,766	11,158	11,799
Photovoltaics	83	753	1,320
Tidal	255	255	255
Wind, off-shore	35	399	1,062
Wind, on-shore	8,610	28,001	49,143

The harmonisation proposal of renewable electricity policy assumes that current incentive policies will be continued until 2010, but not thereafter. In stead, from 2010 onwards, a generic carbon tax of 10 €/tCO<sub>2</sub> is introduced for the EU (see Section 1.6.4). It may turn out that after 2010 electricity production using renewable options is not competitive, but given the activity in 2010, a total abandonment of these options is unlikely. In such cases, it is left to the discretion of the modelling teams to decide whether bounds should be used from 2010 onwards to simulate consistent behaviour of producers. As the assumption is that explicit investment subsidies are phased out after this year, one may assume that from 2010 onwards the commercial viability will determine installation of new capacity.

### *Biofuels*

A particular source of renewable energy is the application of biomass. As a result of the broad variety of possible applications for biomass (particularly in the electricity, transport, petrochemical sectors), an equally broad range of policy frameworks is relevant for biomass. In a current EU-project a list of policies relevant for application of biomass is compiled (VIEWLS, 2004). From a first inventory of biofuel policies, there appear to be few specific instruments aiming at large scale introduction of biofuels. Whenever such instruments are in place, they generally take the form of tax exemptions for transport fuels, and hence are not to be included in the baseline scenario (in compliance with earlier remarks on taxes as policy instruments). Therefore, biofuels policies are not harmonised in CASCADE MINTS.

## 3.6.4 Emissions

### *Climate change and emission trading*

The policy assumptions include some expectations regarding climate change policy. Since climate change policy is considered an important issue and is not treated as a separate policy case in Part II of the CASCADE MINTS project, some representation of climate policy/emission trading for the region of Europe should be included in the baseline scenario. Therefore we propose to assume a generic carbon tax of 10 Euro<sub>2000</sub>/tonne CO<sub>2</sub> as from the year 2012 (constant value over time). This applies to the region of Europe (including Central and Eastern European Countries).

In the US, there are no viable proposals on constraining carbon emissions except for the voluntary target reduction rate of carbon intensity announced by the President a few years ago. Therefore the US baseline will not include any additional climate policies.

For other regions/countries, the Kyoto Protocol status of ratification is used as a reference.<sup>6</sup> This means that for e.g. Japan and New Zealand, who have ratified/accepted the Kyoto Protocol, climate policy is also assumed in the baseline scenario. However, for Australia this assumption is not made. Canada has ratified and should be with the ratifying countries, when using world

<sup>6</sup> See <http://unfccc.int/resource/kpstats.pdf> (status March 17, 2004).

models. However, mostly Canada is treated as part of the North American region, and cannot be separated from the US.

*Standards and industry negotiated agreements on emissions and energy-efficiency for vehicles*

Standards and industry negotiated agreements that are in force or approved on December 31<sup>st</sup> 2003, such as the car industry negotiated agreements on CO<sub>2</sub> emissions, are to be included in the baseline scenario. This section will discuss the automobile industry negotiated agreements and European standards on CO<sub>2</sub> and other emissions, and energy-efficiency in further detail.

The associations of European, Japanese and Korean automobile manufacturers, ACEA, JAMA, and KAMA respectively, have committed themselves to achieving substantial reductions in CO<sub>2</sub> emissions from passenger cars. The CO<sub>2</sub> emission targets, as stated in the Recommendations of the European Commission, will be included in the policies that will be harmonised. Table 3.5 lists the targets for each association. These targets apply to the average of new cars sold by the members of the associations in the EU, including vehicles replacing conventional cars and passenger cars not producing CO<sub>2</sub> emissions or using alternative fuels. It should be noted that the intermediate target ranges for 2003/2004 are indicative.

Individual members of ACEA should place on the market models emitting 120 g/km CO<sub>2</sub> or less, by the year 2000. For members of JAMA and KAMA, these models should be introduced by the earliest possible date after the year 2000. The overall objective of the Community strategy is to attain a CO<sub>2</sub> emission target of 120 g/km CO<sub>2</sub> on average for newly registered passenger cars by 2005, and at the latest 2010. This objective is to be achieved by these three agreements with the automobile industry, combined with research activities. Fiscal measures regarding passenger cars are to be implemented as well to make cars more CO<sub>2</sub> efficient.

Table 3.5 *CO<sub>2</sub> emission targets for ACEA, JAMA and KAMA for passenger cars*

[g/km CO <sub>2</sub> ]	Intermediate target 2003	Intermediate target 2004	Final target 2008	Final target 2009
ACEA	165-170		140	
JAMA	165-175 <sup>7</sup>			140
KAMA		165-170		140

In the United States, the Corporate Average Fuel Economy (CAFE) standards for passenger cars and light trucks were established in 1975 to improve the fuel economy of new vehicles. More information on these CAFE standards can be found on the website of the Office of Automotive Affairs of the US International Trade Administration.<sup>8</sup>

The European Union has established emission regulations for CO, HC, NO<sub>x</sub> and PM emissions for new light-duty vehicles (cars and light commercial vehicles) and for heavy-duty diesel engines, and diesel and gas engines. More information on these emission regulations can be found on the website of Dieselnets.<sup>9</sup>

*Sulphur control policies*

The B2 scenario includes implicit sulphur control policies. Only the MESSAGE model includes assumptions on these policies. Table 3.6 shows the assumptions on energy-related SO<sub>2</sub> emis-

<sup>7</sup> The Official Journal sets an upper bound for the intermediate target of 170 g/km CO<sub>2</sub>, whereas monitoring reports of the JAMA commitment states an upper bound for the intermediate target of 175 g/km CO<sub>2</sub>.

<sup>8</sup> [www.ita.doc.gov/td/auto/cafe.html](http://www.ita.doc.gov/td/auto/cafe.html)

<sup>9</sup> [www.dieselnets.com/standards/eu/ld.html](http://www.dieselnets.com/standards/eu/ld.html) (Light-duty Vehicles) and [www.dieselnets.com/standards/eu/hd.html](http://www.dieselnets.com/standards/eu/hd.html) (Heavy-Duty diesel engines, diesel and gas engines).

sions derived from the B2 scenario that may be included in the baseline scenario, for various regions. These assumptions are based on results from IIASA (source IPCC (2000)).

Table 3.6 *Assumptions on energy-related SO<sub>2</sub> emissions in the B2 scenario (IIASA-B2)*

[MtS]	OECD	REF	ROW	ASIA	WORLD
1990	21.48	16.16	5.82	16.02	59.48
2000	14.37	12.72	8.03	23.47	58.59
2010	9.08	8.39	6.84	27.50	51.80
2020	3.09	4.22	6.18	26.39	39.88
2030	1.85	2.06	5.29	23.66	32.86
2040	1.40	1.38	3.94	20.47	27.19
2050	1.06	2.78	3.02	13.73	20.59
2060	0.86	2.66	2.81	10.43	16.76
2070	0.70	2.59	2.44	7.79	13.52
2080	0.68	2.67	2.01	6.74	12.10
2090	0.72	2.74	1.89	6.60	11.95
2100	0.67	2.76	1.92	6.13	11.48

### 3.6.5 Regional assumptions

Due to large variety of the models and the regions and countries included in them, it will not be possible to harmonise on such a detailed level within the CASCADE MINTS project. Therefore, only a few general guidelines will be given regarding regional assumptions:

- EU candidate countries will gradually implement EU policies (completed in 2020).
- Norway and Switzerland will follow overall trends of EU policies.

In order to realise as much harmonisation of policy assumptions as possible, it is important for models dealing with the same region(s) to make sure that their policy assumptions are similar.



## 4. BASELINE GLOBAL ENERGY OUTLOOK

### 4.1 Introduction

The developments of the energy system of Western Europe, and more in particular of the European Union, cannot be considered independent of global trends. In particular, the success or failure of policies aimed at addressing global issues such as increased atmospheric CO<sub>2</sub> concentration levels, security of supply, and proliferation will be highly dependent on what happens in the rest of the world. Therefore, in the case studies performed in the Cascade-Mints project, a number of models have been included that address developments in other regions of the world. In some cases these models specifically address a separate region, for example in the case of the NEMS model, while in other cases the models describe a regionalised version of the world, as was described in Chapter 2.

Below, an overview of the outcome of various models under baseline conditions will be given. First, a number of global trends will be discussed, that may serve as a background against which the developments of the European Union may be gauged. For the most striking results, the developments in the North American energy system will be reviewed. In particular, some issues of interest such as the development of carbon intensity and security of supply will be addressed.

In the discussion below, the PROMETHEUS models stands out, and will not be directly included in the various discussions. The model provides the only stochastic description, which makes it particularly suited for addressing issues where chance plays an important role, such as the likelihood that a certain event (such as a 100% increase in CO<sub>2</sub> concentration) will occur.

### 4.2 World primary energy

The total primary energy consumption to a large extent is determined by the driving forces that were subject to harmonization of the baseline assumptions. However, as the various models offer different descriptions of the world, the levels will differ, in some cases substantially. Instead of viewing the different outcomes as a handicap for consistent analysis and robust conclusions, it should be thought of as a bonus, because the different descriptions reflect different views in the way in which the world could develop, even if basic economic developments and energy policy parameter are harmonised.

#### 4.2.1 Primary energy consumption more than doubles

The different projections are shown in Figure 4.1 for five world models. There are clear similarities in the outcomes of four of the models, as they project a steady growth leading to a more than doubling of primary energy consumption in 2050 compared to the 2000 level. The lower level of one of these five models (DNE21+) can largely be explained by the exclusion of non-marketed energy use (biomass) by the model. Similarly, the difference between the results presented here and those of the SRES study (SRES, 2000) can be largely explained by the way in which contributions from renewable and nuclear energy sources are accounted for. In the SRES results a direct equivalence methodology was used, according to which the primary energy use was equalized to the input for these sources. In the present study, these renewable and nuclear energy sources are accounted for using substitution equivalents, by introducing efficiency factors of 3 for electricity generation.

Although the trends in most models are similar, the final outcomes differ substantially as the growth rate in the models show large variations. The average annual growth rates of the three

bottom-up energy system models vary between a little under 1.7% per annum to over 1.9% per annum. These differences are a reflection of the different dynamics in each of the models, and can be regarded as indicative for the impact of uncertainties in the future energy system.

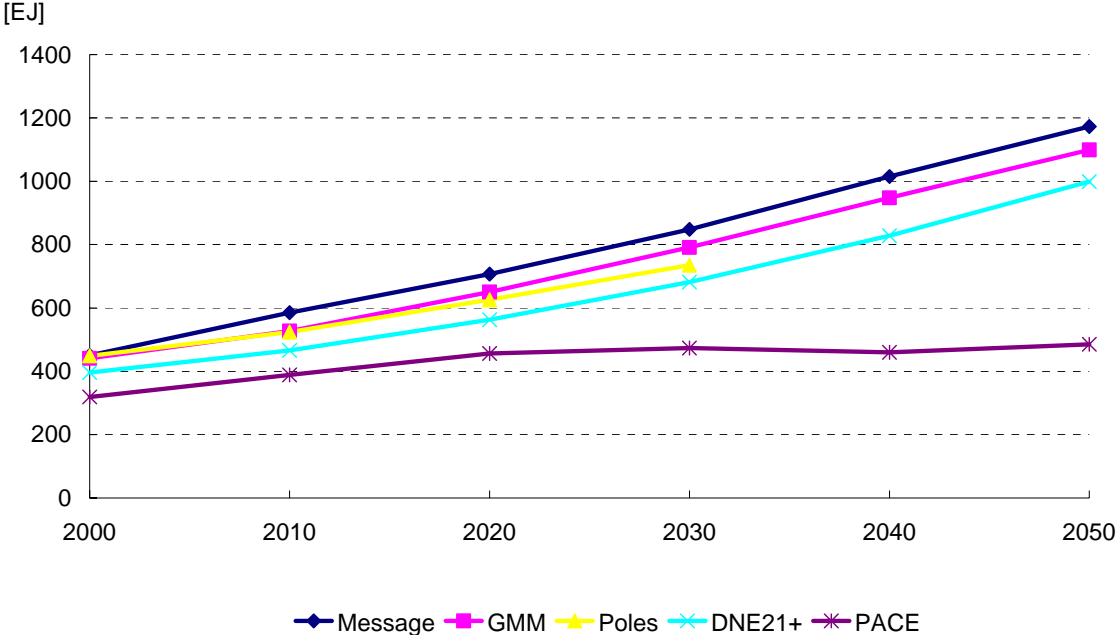


Figure 4.1 Total global primary energy consumption for the various models

In Figure 4.1, the model outcomes for PACE differ substantially from those of the other bottom-up energy system models. The main reason is that PACE, in the version used for the current simulation exercise, does not provide an explicit representation of primary energy from renewables and nuclear power. Shifts in primary energy supply away from fossil-fuel based production are represented in a top-down fashion by continuous substitution of fossil fuel inputs through non-energy inputs, in particular capital. Also, there are some effects from using the GTAP database of 1997 as proxy for 2000 economic data. However, a comparison of trends between the bottom-up models and the top-down model may be still meaningful, although given the remark above one should be careful in interpreting differences. From such a comparison, it is clear that until 2020 the results of PACE in this way are very similar to that of the other models, but that from this year onwards the trend as projected by PACE differs substantially, resulting in a demand level in 2050 that is almost half as small as the level projected by the other models.

#### 4.2.2 Fossil fuels remain dominant

Policies in general will not primarily be aimed at reducing energy consumption, but rather at mitigating the results of energy use, such as increasing CO<sub>2</sub>-concentrations, or decreasing security of supply. Therefore, some policies will have an impact on the mix of energy sources, rather than influence the overall primary energy use. From the policy perspective, it thus may be interesting to compare the mix of primary energy sources used. On the global scale, this is illustrated in Figure 4.2, where the outcome of various bottom-up models is shown.

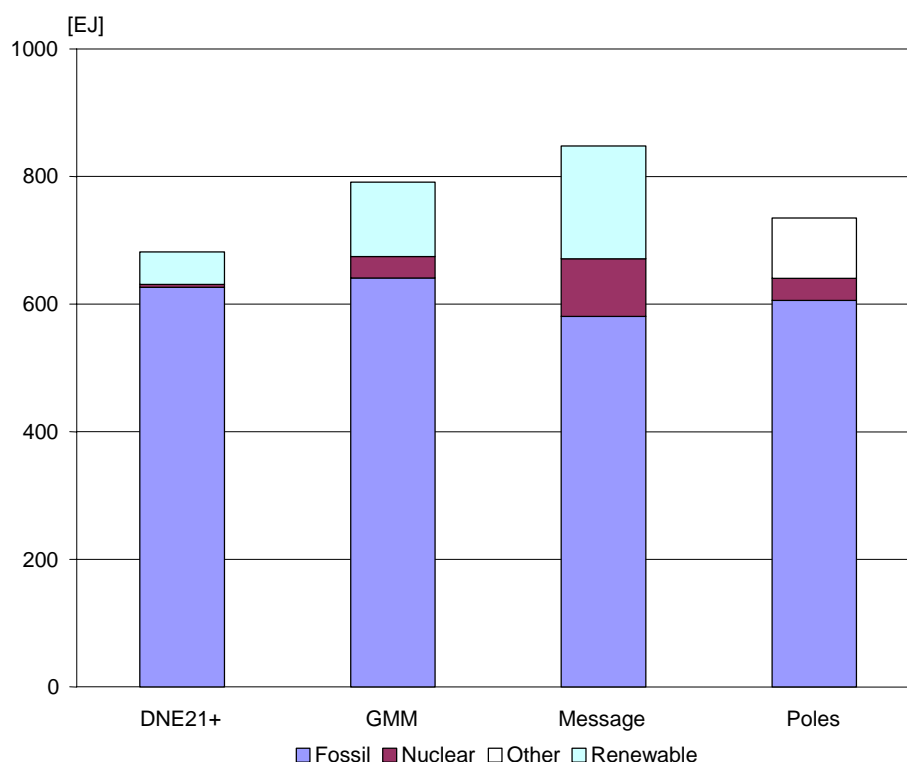


Figure 4.2 *Mix of primary energy use in various models, where we distinguish between major categories: fossil, nuclear, renewables, and other; in the year 2030*

It is clear that although the overall energy consumption can be of the same order of magnitude, the contributions of the various fuel types may differ substantially<sup>10</sup>. Several factors can contribute to these differences in primary energy demand.

- As compared to the other models, MESSAGE has a larger contribution from non-fossil fuels. This is due to more optimistic assumptions concerning technological improvements and deployment of renewable technologies. Another reason is the inclusion in MESSAGE of constraints on sulphur emissions (see also Section 3.6.4).
- The time horizon assumed (2000/2050 or 1990/2100), which is important for models with a perfect foresight.
- The application of endogenous learning or the (exogenous) assumptions on development of technology costs. For example in GMM, the learning performance of the fossil technologies like IGCC and NGCC is significant in the baseline, therefore the fraction of fossil fuels in the primary energy mix is rather high.

This shows that policy measures and RTD support may be of substantial influence, and that the future development of use of energy sources may substantially be influenced by policies, something that will be illustrated for selected topics in due course of this project.

### 4.2.3 Security of supply will become a world wide issue

An important issue in the years to come will be the increasing dependence on oil from the Middle East. In Figure 4.3 we show the percentage of the total world oil production that is produced in the region of which the Middle East is part. The regional specification differs between the five models shown<sup>11</sup>, resulting in somewhat different contributions in 2000, ranging from 50%

<sup>10</sup> Note that the class 'other' in the POLES results includes the renewable options.

<sup>11</sup> As four out of five models aggregate the Middle East with Latin America, we have decided to use a similar aggregation for the fifth model (DNE21+) that does provide separate numbers for the Middle East region.

to 58%. Although the five models show a different behaviour of the evolvement of the production, in all models the contribution from the Middle East region grows, and becomes substantially larger in most models. This indicates that the world as a whole becomes more and more dependent on the resources of one specific region. This raises the question whether under these conditions the security of supply can be safeguarded.

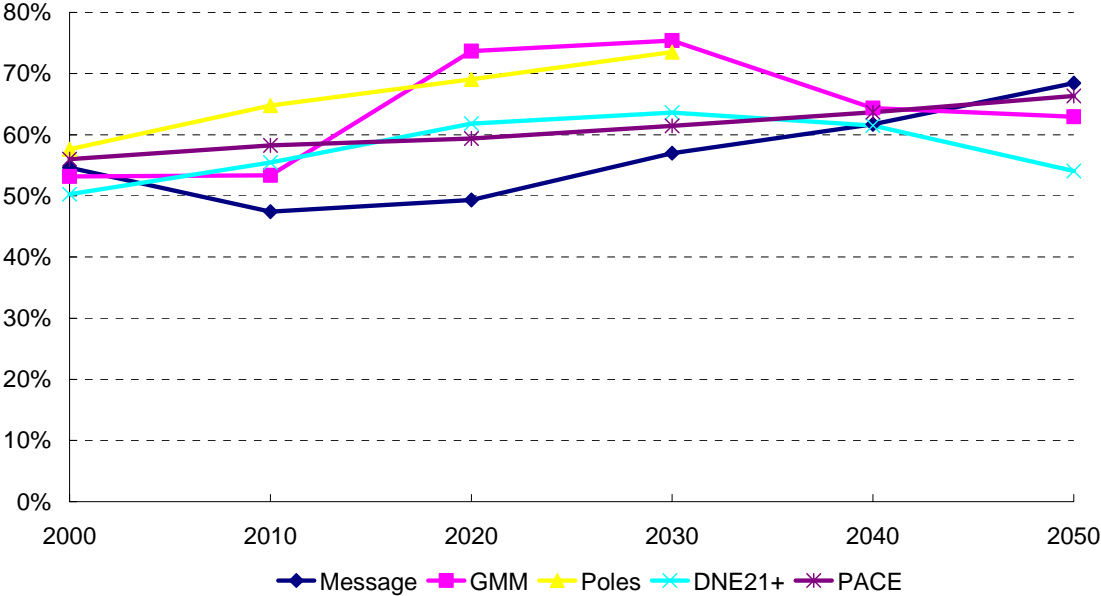
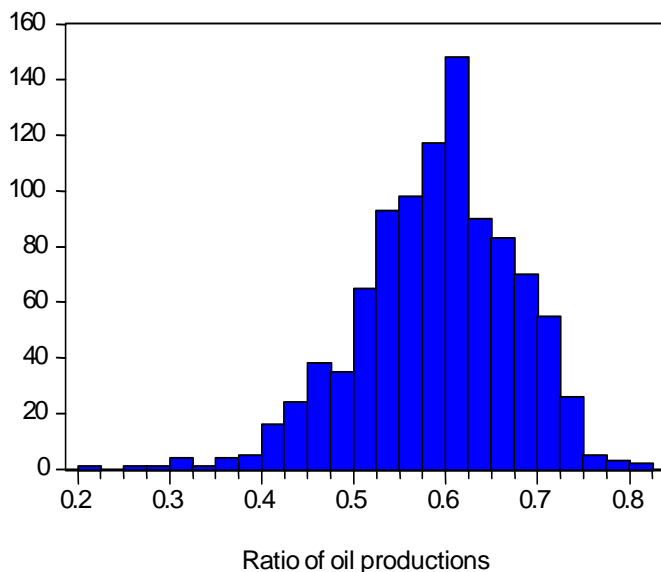


Figure 4.3 *Percentage of the total world oil production that is produced in the region encompassing the Middle East*

Some refinements are in place with respect to the regional dependence of oil production. On the one hand, the dependence on the Middle East is less severe as one might think at first, as the regions used in Figure 4.3 include some other important oil producing countries. On the other hand, the increase in dependence may be stronger than presented in the figure, as the relative contribution from the Middle East in the region used for the comparison may grow. For the one model, DNE21+, for which we have more detailed information at hand, this is indeed the case, as the contribution from the Middle East and North Africa grows from 35% in 2000 to some 55% in 2030. It decreases again after this period, to a little over 40% in 2050, which is in line with the expectation that a steep rise in oil production should in the long run be accompanied by a decline, as the overall reserves dictate the possible cumulative production.

Given the recent interest in Security of Supply issues, it is clear that a more detailed analysis of the issue would be welcome. Such an analysis should not only encompass a more detailed regional representation of oil production, but would also benefit much from an analysis of trade flows. For example, the rise of economies in the Far East, such as India and China at the one hand put more pressure on scarce resources, but on the other hand may lead to a more diverse import mix for Europe and the USA, as unconventional resources may become more attractive.

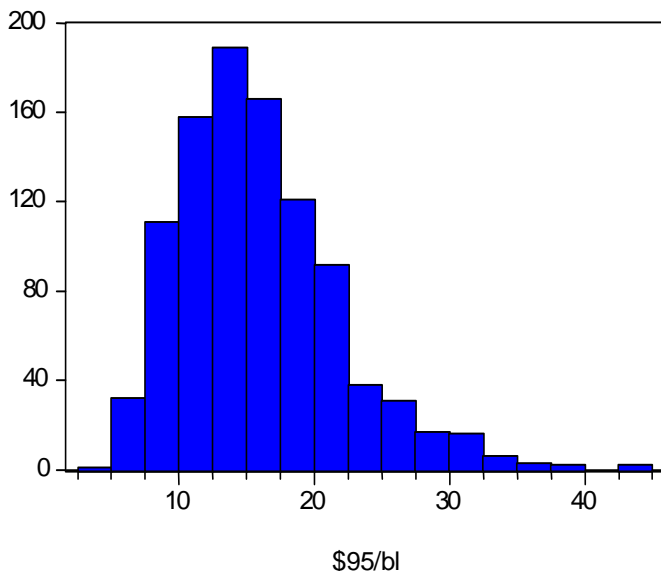
The stochastic model PROMETHEUS is particularly suited for analyses of the security of supply, as it can give insight in the likelihood that this security is disrupted. Under the assumptions set out in Chapter 3, the probability that by 2030 the Middle East produces more than half of the annual oil consumption is over 85%, as illustrated in Figure 4.4. Stated otherwise, it is quite unlikely that the importance of the Middle East in the world oil consumption decreases.



Source: PROMETHEUS

Figure 4.4 *The probability distribution for the ratio of Middle East oil production to total World oil production (mean: 0.59, standard deviation: 0.084)*

Given that this (at present) rather unstable region tends to remain dominating in the oil production, it comes as no surprise that there is a substantial probability that a sudden price hike in the oil price will occur. As can be deduced from the results shown in Figure 4.5, the probability that a price hike of more than 15 US\$ will occur, is almost 50%. For comparison, our oil price scenario (see Section 3.5) assumes that in the period 2000-2050, the oil prices are in the range of 4.2 and 6.2 €/GJ, which is equivalent to a range of ca. 26 to 38 US\$/barrel<sup>12</sup>. Considering this oil price range, a 15 US\$ price hike would mean an increase of ca. 40-60% within a three-year period.



Source: PROMETHEUS

Figure 4.5 *Probability distribution of the maximal increase in oil price in any three-year period between 2000 and 2030 (mean: 15.9, standard deviation: 5.904)*

<sup>12</sup> The energy content of one barrel of oil is 6.12 GJ.

#### 4.2.4 Coal production grows faster than oil and gas production

In Figure 4.6 the world oil production is shown for the five world models considered here. Most models show similar trends, in that production continues to grow, although the rate differs. Models that project a faster initial growth tend to slow down towards 2050. In general, the oil production grows less than primary energy demand.

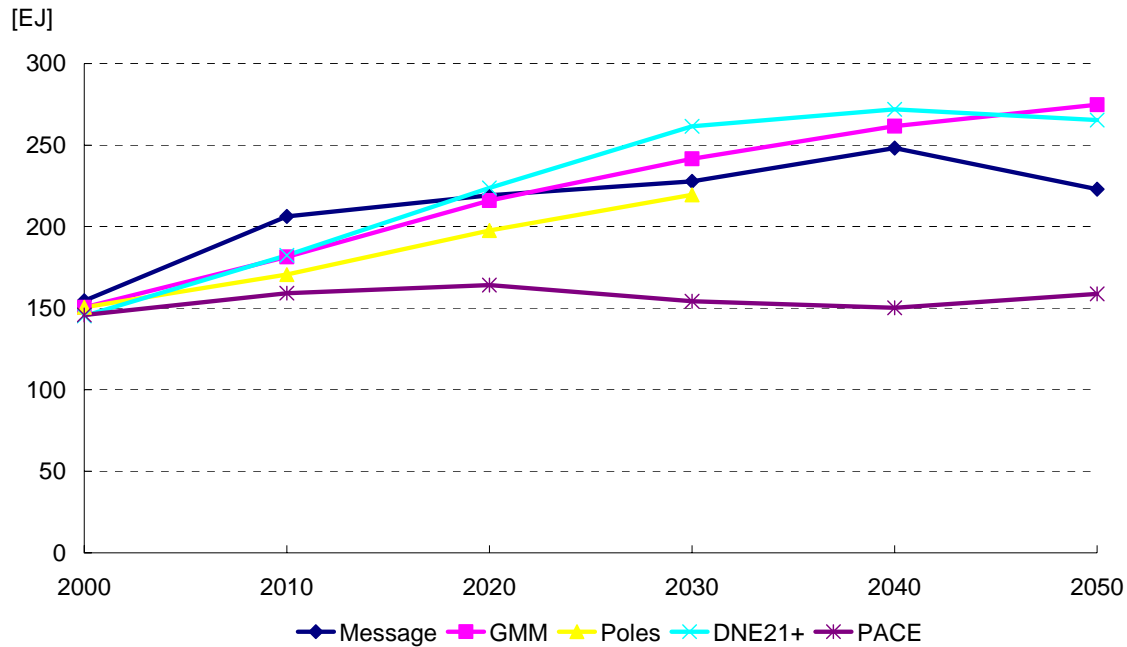


Figure 4.6 World oil production for the various models

In Figure 4.7 the world production of coal is shown, as calculated using GMM, chosen to represent the trends in most world models. Of particular importance is that the main growth of production takes place in Africa and Asia, as well as in the EEFSU (Eastern Europe and Former Soviet Union) region. Moreover, there is a doubling of production from 2000 to 2030 in the models under consideration. MESSAGE again provides the exception, due to its sulphur constraints.

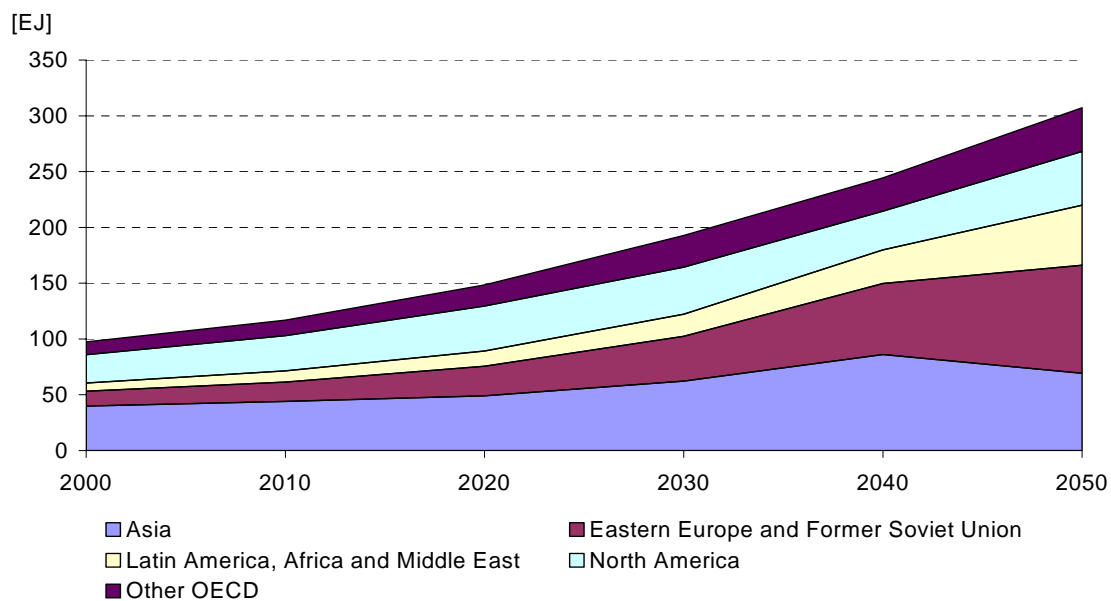


Figure 4.7 World coal production per region, according to GMM

The role of gas will be substantial in the future energy system, even in the present case where only limited action is taken to reduce the carbon content of the system.<sup>13</sup> The different models predict different levels of consumption, ranging from a little over 200 EJ up to some 360 EJ, by in 2050. The largest deviation is exhibited by DNE21+, and primarily seems due to a later onset of gas demand. This notwithstanding, the growth in gas consumption for all models is roughly in line with the growth in total energy consumption, i.e. the relative contribution of gas does not change significantly on the global scale.

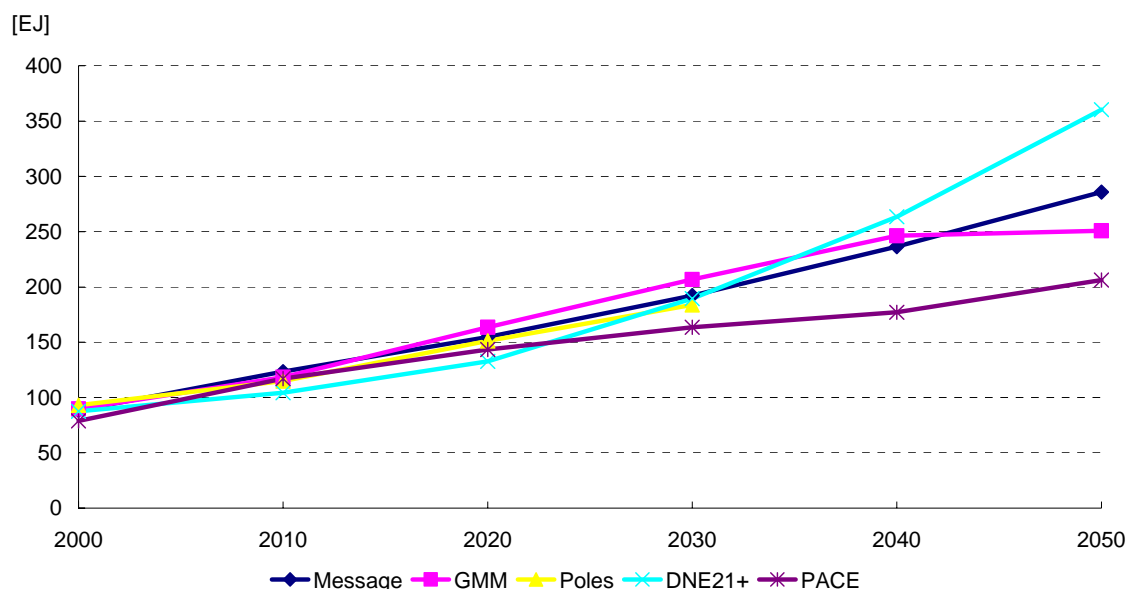
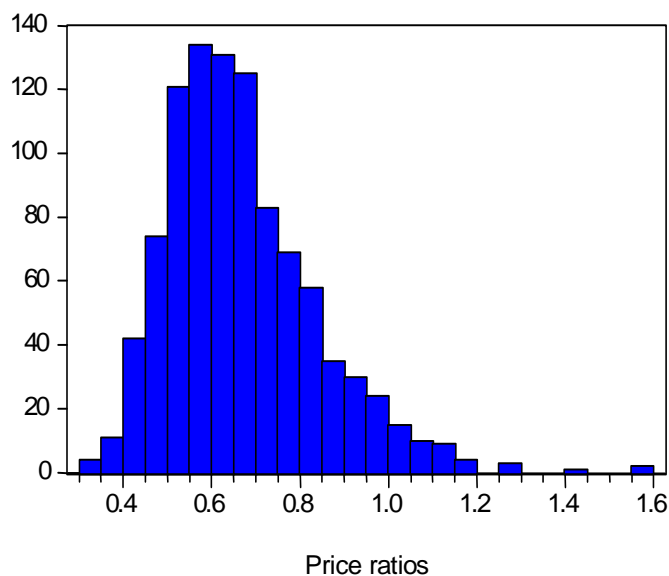


Figure 4.8 World gas production for the various models

For gas consumption, again the stochastic model PROMETHEUS may provide additional insights. For the potential role of gas, its relative price as compared to the oil price is highly relevant. In most models presented here, the gas price remains higher than the oil price. However, in principle the chance that the international gas price becomes lower than the international oil price is substantial, and an analysis using PROMETHEUS results shows that this chance is approximately 95%, as can be seen from Figure 4.9. This rather high probability may be due to the increasing dependence on oil from the Middle East, noted in Section 4.2.3. If this is indeed the underlying reason, the high probability is an indication that Security of Supply is likely to be a more severe issue for oil than for gas - which would be furthermore in line with the status of reserves.

<sup>13</sup> Different world models have dealt differently with the 10 €/tCO<sub>2</sub> carbon tax in Europe from 2012 onwards, due to their differing regional aggregations. Most models have applied it to the (larger) region containing Europe, with the exception of MESSAGE, because it would be too strong an assumption to apply it to the complete OECD region.



Source: PROMETHEUS

Figure 4.9 *Probability distribution of the ratio of the gas to oil price in 2030 (mean: 0.67, standard deviation: 0.17)*

### 4.3 Improvements in energy intensity

At present, the gross inland consumption of energy per capita shows a large divergence between the developed world, most noticeably North America, Japan, and Western Europe, and the developing countries. A similar statement holds for the distribution of energy intensities over the world. In line with the assumptions of the harmonised B2 scenario (see Paragraph 3.4), income differences are expected to remain large. On the other hand, the assumption of relatively homogenous technological developments over the world induces a converging trend for energy intensities.

The representation in Figure 4.10 aims at illustrating these points. The figure shows the growth in consumption per capita as a function of the energy intensity<sup>14</sup>, from GMM, chosen to represent the trends observed in all models<sup>15</sup>. In the baseline, reflecting a world where no additional action is taken to increase equity, differences remain in the levels of the indicators, but the trends are similar. The per capita consumption increases in all regions in the world. At the same time, the energy intensities tend to move towards lower values, indicating a more effective use of energy for generating GDP worldwide.

<sup>14</sup> Energy intensity is defined as (primary) energy consumption over gross domestic product.

<sup>15</sup> Which is only partially the case, as the regional specification may yield different views on the interregional differences. Particularly, aggregating over all OECD will yield substantially different conclusions.



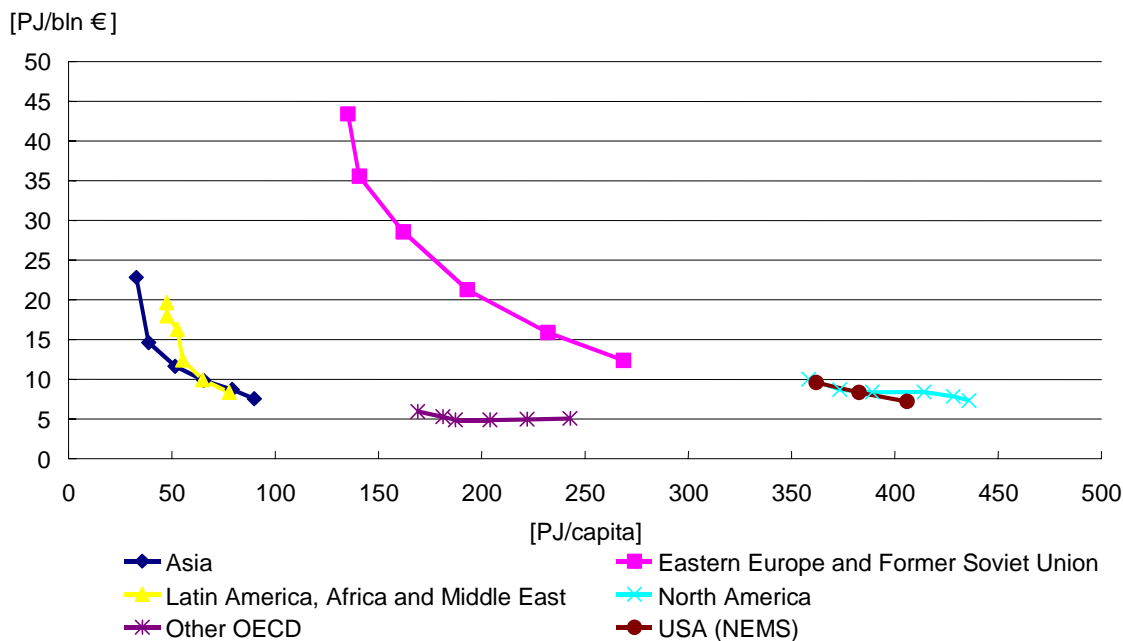


Figure 4.10 Energy intensity as function of the gross energy consumption per capita for the various regions in GMM and NEMS (USA). The Other OECD region includes Europe. Other models show similar trends for the various regions.

One should be careful in interpreting effects in energy intensity, in particular on the level of individual countries. As developing countries industrialize, the use of energy initially increases. In particular, a shift from non-marketed to marketed energy will occur, and thus if non-commercial energy is excluded from the model the substitution will enhance this effect, leading to even higher (and actually non-existing) rises in energy intensity. In later stages of development, the decrease as depicted in Figure 4.10 occurs. That such increases are not observed in the figure is due to the regional aggregation level, which we use as the interest of the project lays mainly in European and regional trends, rather than on the behaviour of individual (developing) countries.

A more speculative conclusion from the figure would be that there appear to be roughly two tracks along which economies can evolve. This is even clearer from Figure 4.11, where the energy intensity is shown as function of the gross domestic product (GDP), on a double logarithmic scale. One path seems to be defined by the combination of EEFSU (mainly former Soviet Union) and NAME (mainly USA), and is characterized by relatively high GDP, but also high energy intensities. The other path is defined by the three other regions, and combines low energy intensity with relatively low GDP. The improvement in energy intensity seems to be roughly independent of the path, except for the region OECD when the apparent minimal value of 5 PJ/G€ is reached.

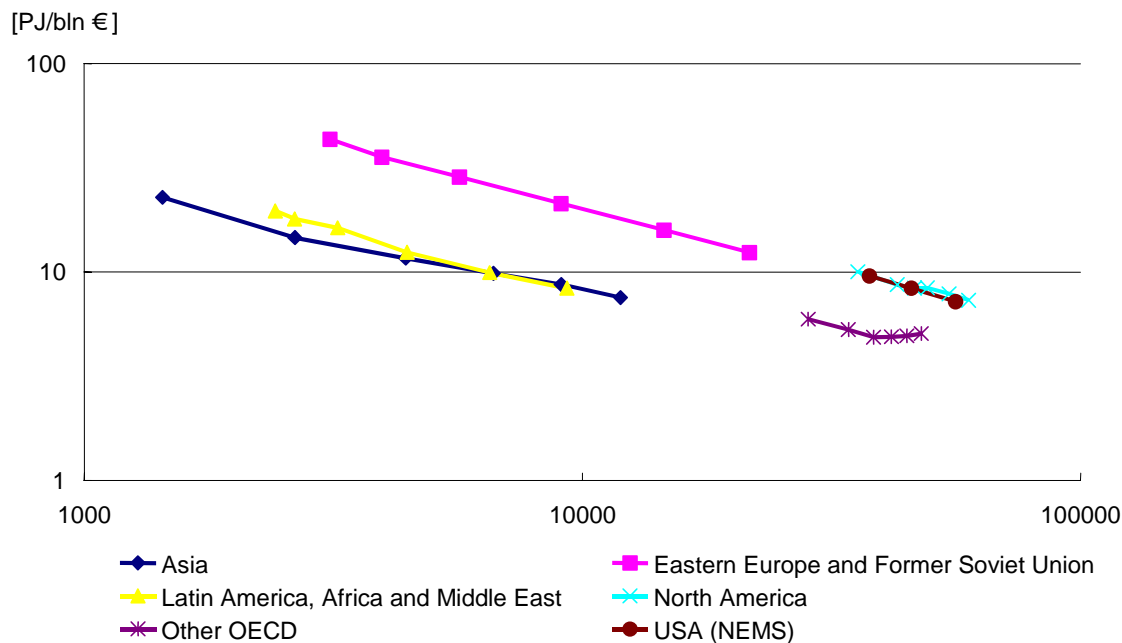


Figure 4.11 *Gross inland consumption per unit of GDP as function of the GDP per capita for the various regions in GMM, and for the USA according to NEMS. Other models show similar trends*

#### 4.4 World final energy and electricity consumption

In the previous sections, developments in the primary energy consumption were shown. As was seen, this may provide insight into a number of global developments and trends, such as CO<sub>2</sub> emissions and security of supply issues. However, some of the developments will not directly be reflected in such a parameter; for example, the shift in or towards ‘secondary fuels’, such as electricity or hydrogen, will not be captured in an analysis focussing only on primary energy use.

##### 4.4.1 Consensus on the growth of final energy demand, but not on the level

A more appropriate variable for such issues as what shifts in demand may occur, is the final energy demand. This also provides insight into the sectoral distribution of energy use. The final global energy use summed over all sectors in the various models, is shown in Figure 4.12.

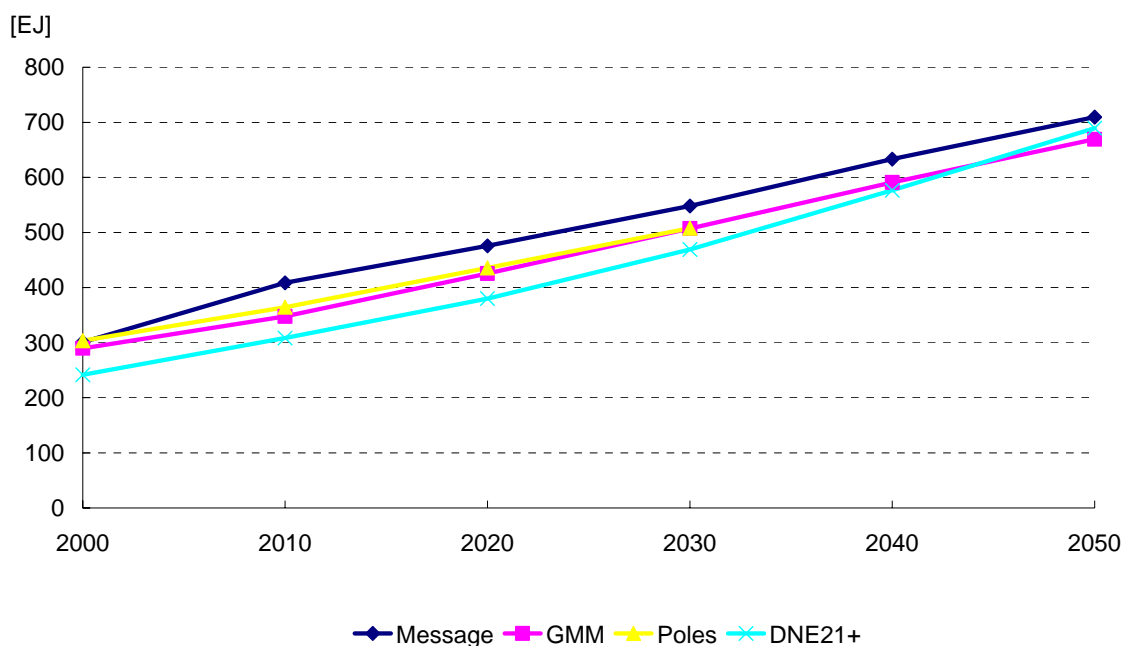


Figure 4.12 Total final energy consumption for the various world models

The total final energy use shows only small deviations among models, albeit that DNE21+ starts at a lower value. This is due to the fact that non-commercial energy is not included in this model. The similarity in result is to be expected, as the final energy demand is driven by variables that were harmonized, such as the population, GDP and world oil prices. Note that as compared to the figures on primary energy use, the PACE model is left out, because this (hybrid) model does not provide data on final energy demand.

## 4.5 World electricity and hydrogen production

The power sector is expected to play an increasingly important role in the energy systems of the world. In the industrialised world, the sector already plays a significant role, and this will increasingly be the case. Moreover, on a global scale growth is expected to be considerable for a second reason. As the standards of living in more and more countries is raised to a level comparable to that of the OECD, the energy system will tend to move to become a reflection of the present system of the industrialised countries. Both the increasing importance of the power sector, and the fertile grounds it may provide for policies regarding renewable energy systems, make it a sector of prime interest when considering the future developments of the energy system.

Aside from electricity, hydrogen could in principle play a significant role in the energy system as secondary energy carrier. Its nature as physical energy carrier gives it advantages over electricity, in particular when storage plays a role. This is the case when supply and demand does not match, either temporal or regional, and in mobile applications such as transport. Compared to derivatives of primary energy sources (fossil fuels or biomass) it has the advantage that no local or global pollution need be caused. For these reasons, the expectations with respect to the role of hydrogen in the energy system will be highlighted below.

### 4.5.1 Electricity increasingly important

As indicated in the introduction to this section, the power sector will play a significant role in the world energy system. As can be seen in Figure 4.13, the world models considered here all show very similar trends for the expected growth of energy demand. Certainly, the difference

between the various models is maximally around 7% from the average value, both in 2030 (POLES), and in 2050 (GMM). Such differences are substantially smaller than the difference in some other outcomes discussed in the preceding paragraphs, such as the primary energy consumption. This is related to the assumptions on the end-use demands for electricity consuming sectors (usually given exogenously in the baseline). Note however that these assumptions have not been harmonised in the CASCADE MINTS project, although some models are using the same end-use demands as defined for the SRES-B2 scenario.

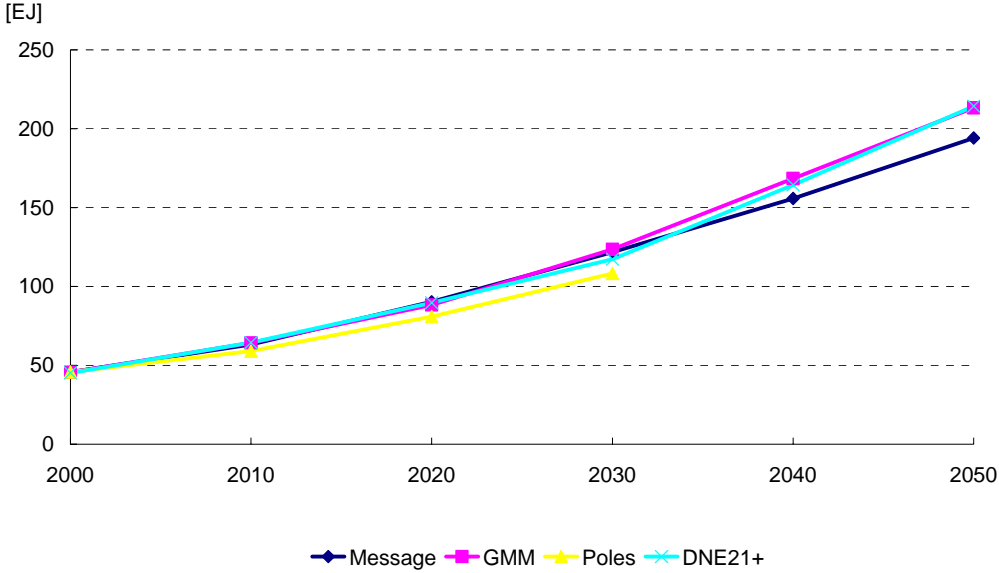


Figure 4.13 Electricity demand in the world models show very similar trends

At present, there is a large regional variation in the importance of the power sector in satisfying the final energy demand. Whereas in the industrialised world (OECD), it currently contributes as much as one-fifth of the final energy demand, in the rest of the world its contribution ranges between a mere 11 to 13%, as can be seen from Figure 4.14 below. The trends in growth furthermore seem to be roughly the same worldwide, leading to a similar proportion in 2050 between the OECD-region and the other regions. The levels are substantially higher, with almost 40% of the demand in the OOECD region being supplied by electricity.

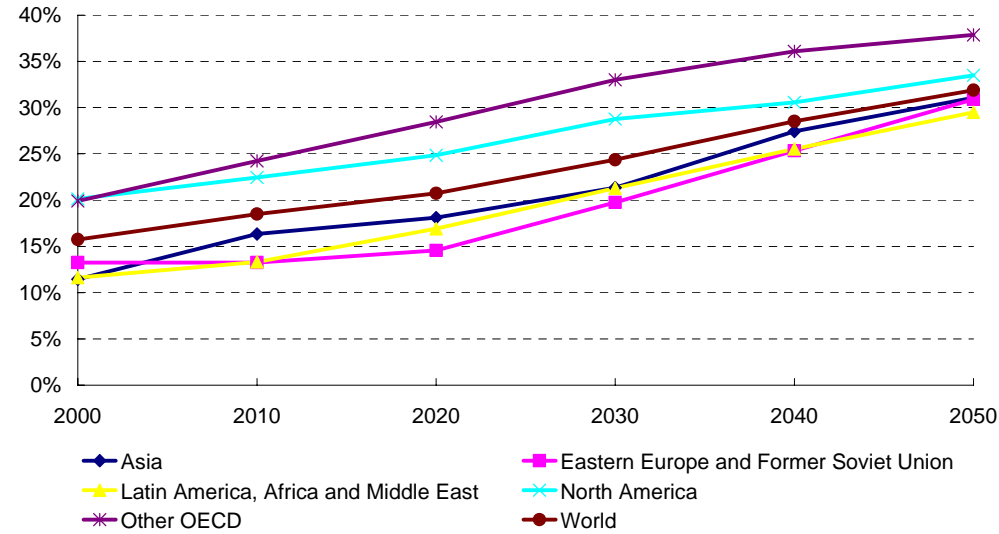


Figure 4.14 Contribution of electricity to the final energy demand in the five world regions distinguished in GMM, and in the world as a whole

#### 4.5.2 Much uncertainty on the future of renewables and nuclear power

While there is little controversy over the consumption of electricity, there is huge uncertainty over which technologies will be the dominant ones in 2050. Most of the models however seem to agree that gas and coal technologies will play a significant role by 2050, with only one marked exception<sup>16</sup>. The agreement is completely lost when considering renewable energy sources, where contribution from these sources to the total electricity demand ranges from 10% to a quarter, and nuclear power, where it varies between 0-20%.

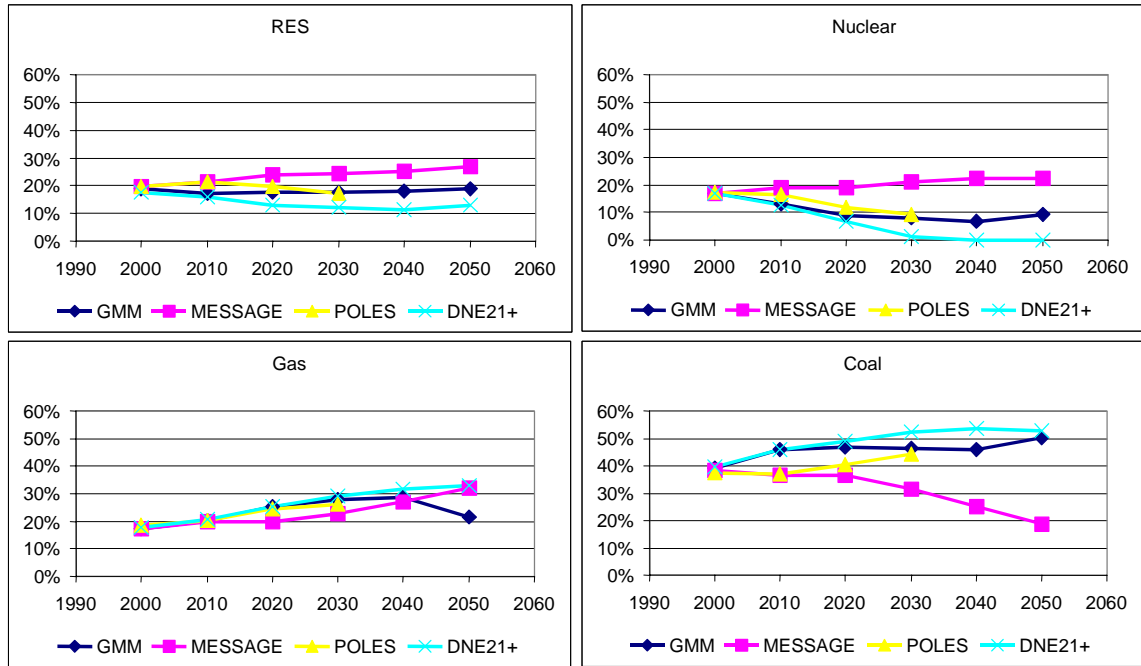
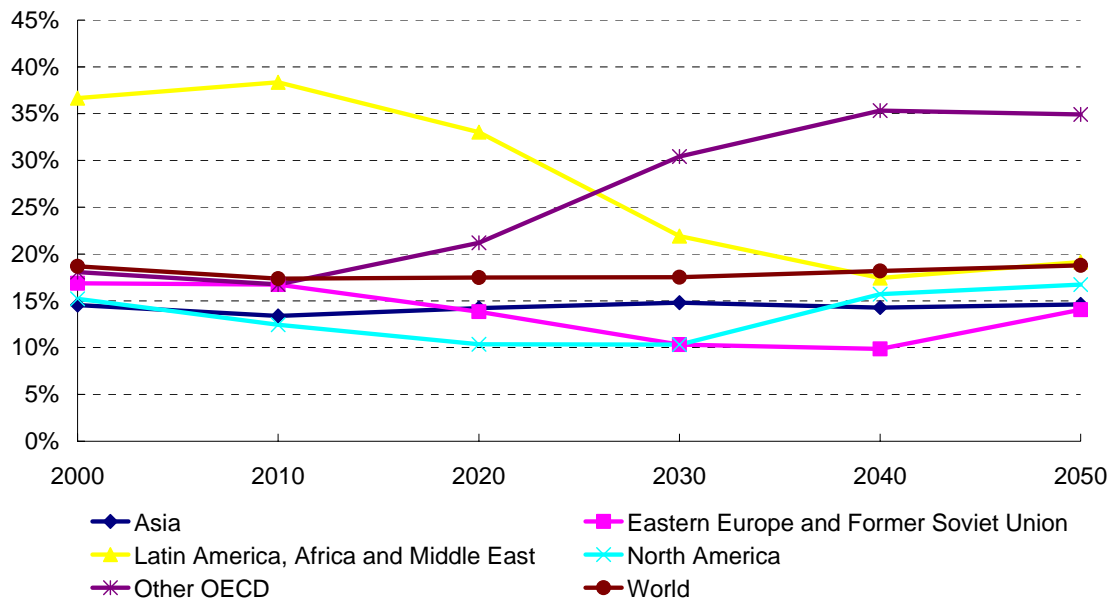


Figure 4.15 Contribution from renewable energy sources (RES), nuclear energy, gas, and coal in the power sector as percentage of total electricity generated generally shows widely varying trend, reflecting uncertainty on the future electricity system

Based on the results presented here, both for renewables and for nuclear the results of GMM can be used as some average value. We therefore use this model to investigate the role of renewables and nuclear on a more local scale. In Figure 4.16 and Figure 4.17 the regional contribution from renewables and nuclear, respectively, are shown for the regions in GMM. A remarkable feature for the relative contributions from renewables is that, although the world levels are practically constant, there are large changes on a local level. Thus, the regional variations serve to show that global trends in some cases may be misleading, or at the very least disguise changes in the underlying systems.

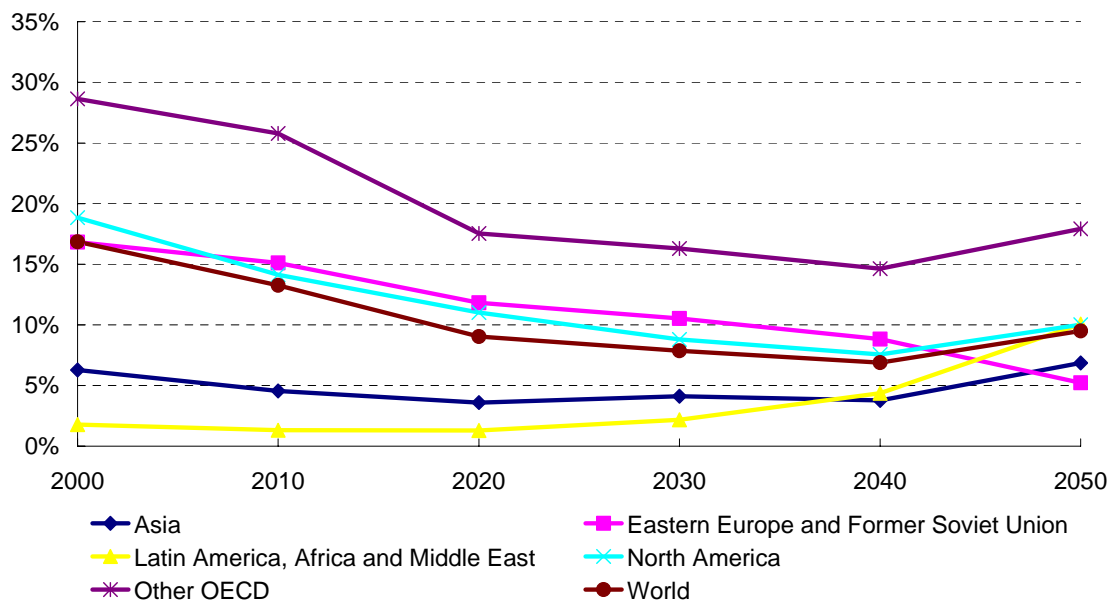
The changes in the contribution from renewable energy systems (RES) are such that an *apparent* shift from the LAFM region (Latin America, Africa and Middle East) to the OOECD (EU, Japan, Australia, and New Zealand) occurs. In reality such a shift does not exist, as there is no relation between the energy systems of the regions that could cause such a shift. In stead, the demand for electricity in the LAFM region grows too fast for renewables to keep up with this growth, and large hydropower, with limited growth potential, is the dominating renewable option. For these reasons, the relative contribution of renewables in the power sector is expected to diminish. At the same time, the policies in the OOECD region are such that an increased importance of RES is the result.

<sup>16</sup> The exception again being the results from MESSAGE, due to the sulphur policies and the larger role of biomass ethanol.



Source: GMM

Figure 4.16 Contribution from renewable energy sources to the power sector: percentage of total electricity generated, for the regions in GMM.



Source: GMM

Figure 4.17 Contribution from nuclear energy to the power sector: percentage of total electricity generated, for the regions in GMM.

#### 4.5.3 Hydrogen plays a modest role, at best

As mentioned, hydrogen may develop as an alternative to electricity and combustible fuels due to its unique character as transportable clean energy vector. However, in a baseline scenario one would not expect hydrogen to fulfil its full potential, as the conditions needed for successful penetration of hydrogen are absent. Main reason why hydrogen would play a modest role at best is that the production costs are high.

Figure 4.18 shows the projected production levels of hydrogen in three world models, currently including hydrogen production. The figure confirms the expectations, in that the contribution of hydrogen remains relatively small. This holds even in the most promising case, where the contribution amounts to roughly 3% of total demand in 2050, which indeed is modest when compared to for example the contribution of electricity, being of the order of 30%. The figure also illustrates that there is a huge uncertainty in the future role of hydrogen, as the production of hydrogen differs by orders of magnitude in 2050, for the three models.

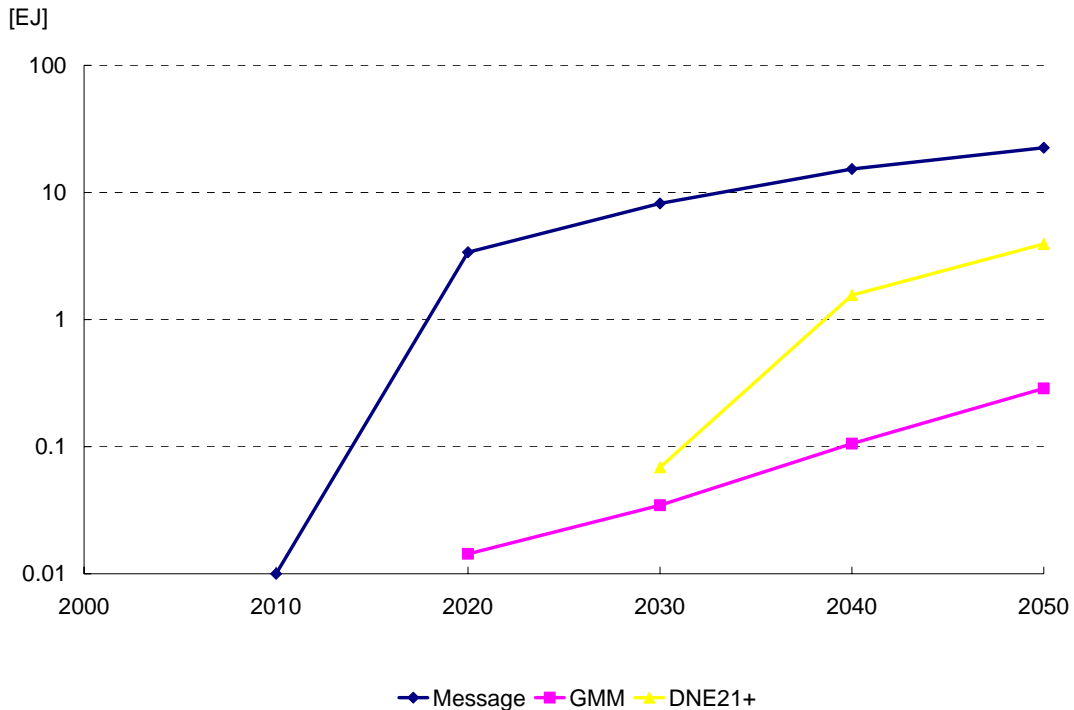


Figure 4.18 *Total production of hydrogen in three world models shows a large variation, both in the level and in the time of uptake. Note the logarithmic scale*

Part 1 of the CASCADE MINTS project will be to provide a more extensive and consistent description of the hydrogen into the models, via the introduction of a more detailed technological description. It is expected that such modifications will enable a more extensive analysis of the role hydrogen may play in the transition towards a sustainable energy system. From this first analysis, we may conclude that there will be some room for hydrogen; in the course of the project, this will be up for further investigations.

## 4.6 Energy-related CO<sub>2</sub> emissions

### 4.6.1 CO<sub>2</sub> emissions are directly related to the primary energy mix

In this section the results of the MESSAGE, GMM, and DNE21+ models are discussed. The POLES model does also provide the required emission results (only up to 2030), but these are mostly in line with results from GMM and only discussed separately if they show a different trend.

Energy-related CO<sub>2</sub> emissions are expected to increase by ca. 65-100% in the period 2000-2030 (1.7-2.4% per year) and even by ca. 85-170% in the period 2000-2050. This is in line with results from the PROMETHEUS model indicating a nearly 85% probability that energy related CO<sub>2</sub> emissions worldwide more than double between 1990 and 2030. Although the primary energy use projected by MESSAGE is 20% higher than that of DNE21+ in 2050, the CO<sub>2</sub> emissions are ca. 25% lower. The level of CO<sub>2</sub> emissions of GMM and DNE21+ is similar in 2050,

although the primary energy use of GMM is ca. 10% higher. These variations can be explained from differences in the primary energy mix. For example, in 2030, the use of non-fossil energy sources is almost twice as high in the MESSAGE model, as compared to the GMM model. This is amongst others the result of the constraints on sulphur emissions included in MESSAGE, but also due to more optimistic assumptions regarding technological improvements. The relatively high CO<sub>2</sub> emissions in the DNE21+ model are due to a decline of nuclear capacity and its replacement mainly by coal.

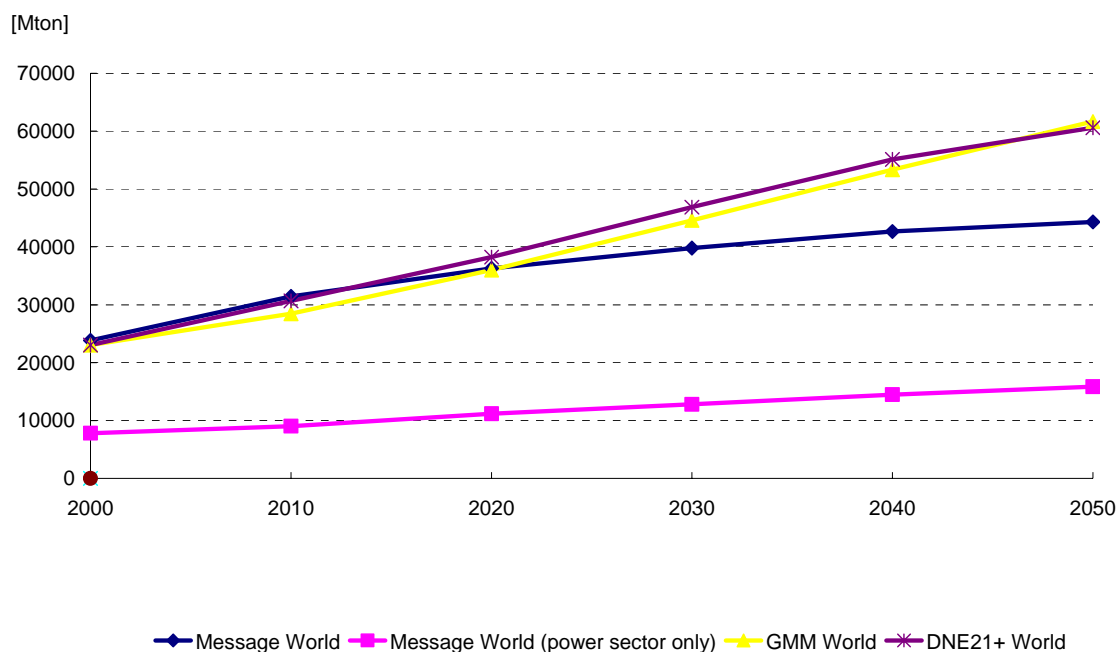


Figure 4.19 Energy-related CO<sub>2</sub> emissions on global level; total and power sector only for 2000-2050

The MESSAGE model is the only model, from which CO<sub>2</sub> emission results for the power sector are available. On average, the CO<sub>2</sub> emissions from the power sector show a similar trend as compared to the total energy-related CO<sub>2</sub> emissions up to 2030. Beyond 2030, the CO<sub>2</sub> emissions from the power sector increase faster than the total CO<sub>2</sub> emissions, which results in a doubling of CO<sub>2</sub> emissions in the period 2000-2050.

#### 4.6.2 Varying developments for CO<sub>2</sub> emission indicators

Several indicators can be used to gain more insight into the drivers for the development of CO<sub>2</sub> emissions over time. First, the indicator ‘CO<sub>2</sub> emissions per capita’ provides insight into the relationship between CO<sub>2</sub>-emissions and population size. Using this indicator, the development of CO<sub>2</sub> emissions can be decoupled from population growth. Since the population growth is harmonised in CASCADE MINTS, CO<sub>2</sub> emissions per capita mainly depend on differences in CO<sub>2</sub> emissions.

In 2030, the CO<sub>2</sub> emissions per capita are ca. 20-50% higher as compared to the base year 2000. Beyond 2020, the models show diverging trends. For MESSAGE, the model with the highest share of non-fossil energy sources and the slowest growth of the use of fossil fuels, the level of CO<sub>2</sub> emissions per capita remains almost constant in the period 2030-2050, about 20% higher than the level in 2000. In the case when the use of fossil fuels increases substantially and the use of non-fossil energy sources remains reasonably modest, the CO<sub>2</sub> emissions per capita increase much more, by approximately 70% in the period 2000-2050. The increase of the global level of the CO<sub>2</sub> emissions per capita is mainly due to a strong increase of this indicator in Eastern Europe and the former Soviet Union.



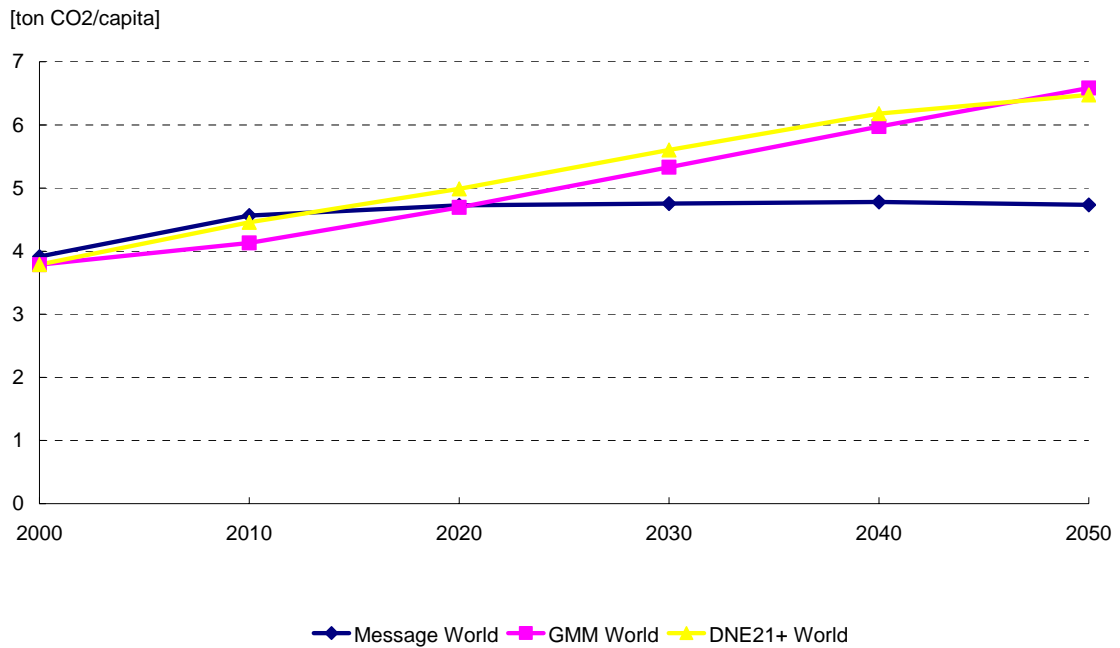


Figure 4.20 Development of CO<sub>2</sub> emissions per capita in the period 2000-2050

The indicator ‘CO<sub>2</sub> emissions per unit of GDP’ refers to the CO<sub>2</sub> that is emitted for the production of one unit of GDP. Figure 4.21 shows that the carbon intensity of GDP is expected to decline over time. Since world GDP is harmonised in CASCADE MINTS, variations between models regarding carbon intensity of GDP mainly depend on variations in CO<sub>2</sub> emissions and differences in regional aggregation. The downward trend in carbon intensity of GDP is due to a higher economic growth as compared to the increase of CO<sub>2</sub> emissions. The MESSAGE models projects the strongest decline i.e. a 50% lower carbon intensity of GDP in 2050 as compared to 2000, whereas the results of the other models show a decrease of 30% in 50 years’ time. POLES projects a relatively strong decline in the first 20 years but reaches the same level of carbon intensity of GDP in 2030 as MESSAGE. The main contributors to the decrease of the global level of carbon intensity of GDP are Asia, Eastern Europe and the former Soviet Union.

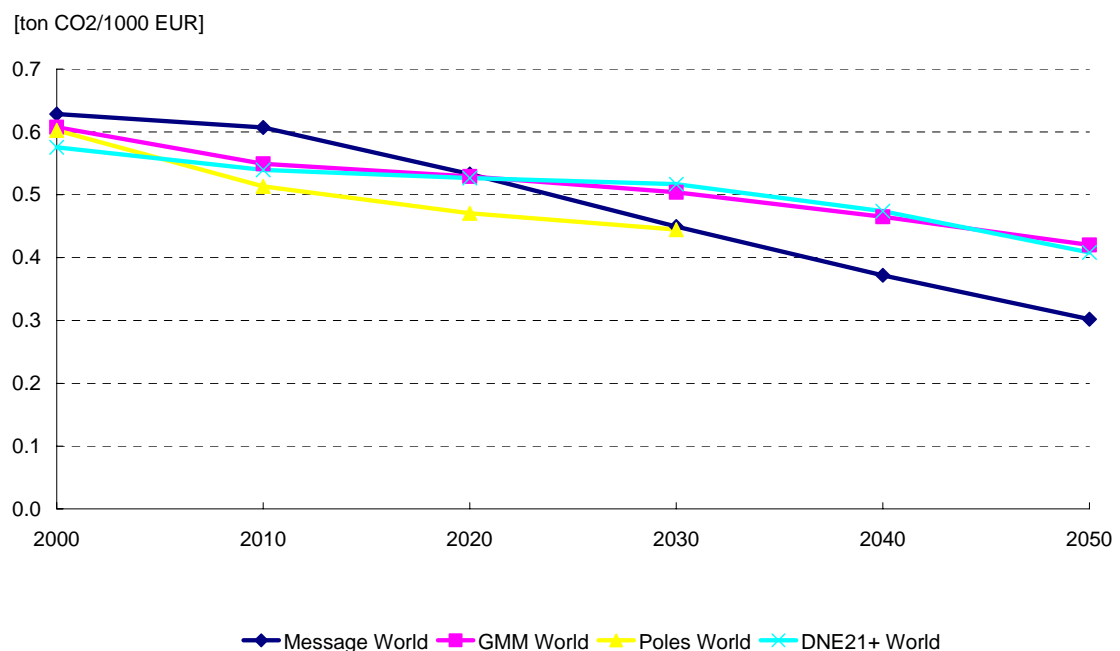


Figure 4.21 *Development of CO<sub>2</sub> emissions per unit of GDP in the period 2000-2050*

CO<sub>2</sub> emissions are strongly related to primary energy consumption, which is captured in the indicator ‘CO<sub>2</sub> emissions per GJ primary energy use’. For example, in case the fuel mix remains constant, the CO<sub>2</sub> emission per GJ energy consumption would also remain roughly constant, and so would the indicator. As can be seen in Figure 4.22, the models considered here show different trends for this indicator. Whereas GMM and POLES predict a slow increase of the indicator, MESSAGE shows a considerable decline with 30% in the period 2000-2050. The trend displayed in MESSAGE is mainly driven by the shift towards CO<sub>2</sub> free energy sources (or sources low in CO<sub>2</sub>). The DNE21+ model projects the highest CO<sub>2</sub> emissions per GJ, which is due to the very small shares of renewable energy sources and nuclear energy in the primary energy mix.

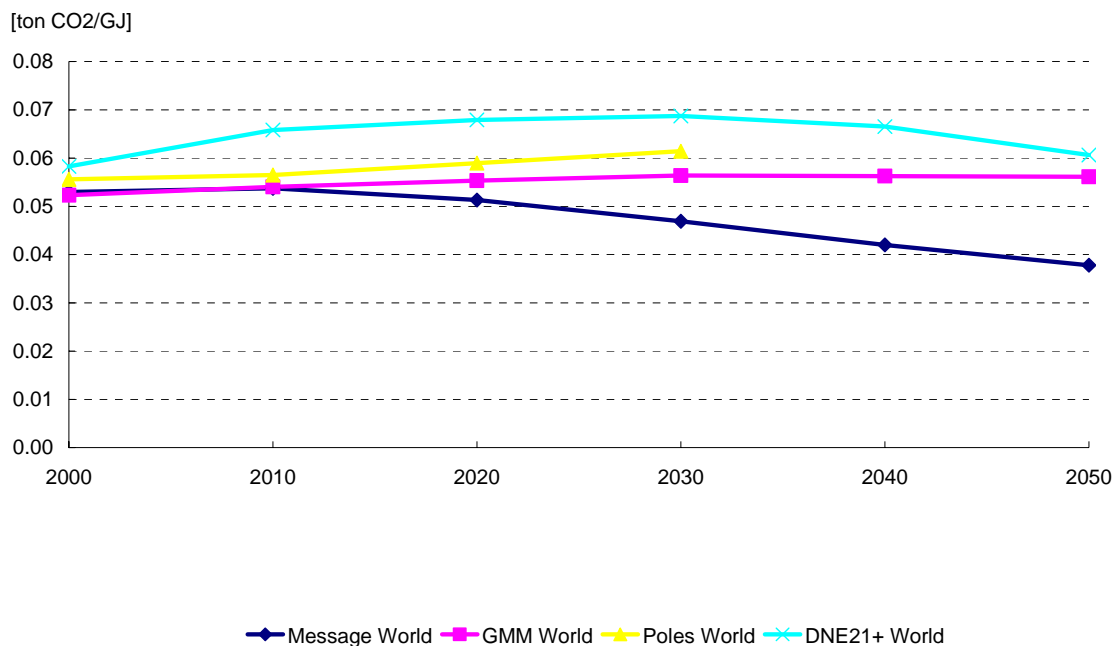


Figure 4.22 *Development of CO<sub>2</sub> emissions per unit of gross inland energy consumption in the period 2000-2050*

The indicator ‘CO<sub>2</sub> emissions per kWh’ enables more insight into the development of CO<sub>2</sub> emissions from the power sector, independent of the growth of electricity production. This indicator is provided only by MESSAGE. In 2000, this CO<sub>2</sub> emission factor is ca. 0.50 kg CO<sub>2</sub>/kWh. Due to the increased use of low-CO<sub>2</sub> or CO<sub>2</sub> free energy sources for electricity production, the CO<sub>2</sub> emissions decline by almost 35% up to 0.33 kg CO<sub>2</sub>/kWh in 2030. In the period 2000-2050 the emission factor decreases by almost 50%, up to 0.25 kg CO<sub>2</sub>/kWh in 2050.

#### 4.7 Other GHG emissions

None of the models reports separately on the development of N<sub>2</sub>O emissions. Only MESSAGE provides information on the development of (energy-related) CH<sub>4</sub> emissions. The growth of CH<sub>4</sub> shows a similar trend as compared to the CO<sub>2</sub> emissions for this model, and so do the total GHG emissions. The total CH<sub>4</sub> emissions are ca. 77 Mton in 2000, rising to ca. 140 Mton in 2050. Between 2000 and 2020 the model projects the strongest growth of CH<sub>4</sub> emissions.

#### 4.8 NO<sub>x</sub> emissions

GMM only provides results on the NO<sub>x</sub> emissions from the power sector and can therefore not be compared to the results from MESSAGE. According to MESSAGE, the NO<sub>x</sub> emissions de-

crease by almost 35% in the period 2000-2050, which is due to the increasing use of cleaner primary energy sources that cause no or low NO<sub>x</sub> emissions. In the power sector, reported upon by GMM, the combustion of fossil fuels remains more important, which leads to increasing NO<sub>x</sub> emissions. In 2050, NO<sub>x</sub> emissions are twice as high as compared to the base year 2000.

#### 4.9 SO<sub>x</sub> emissions

For energy-related SO<sub>x</sub> emissions results are presented for the energy system as a whole (MESSAGE) as well as for the power sector individually (GMM). Here, again, results from the two models are difficult to compare. MESSAGE shows a strong decreasing trend for total SO<sub>2</sub> emissions, i.e. almost a 50% decrease in the period 2000-2050. This is the result of sulphur control policies that are included in the MESSAGE baseline.

On the global level, the power sector currently has a share of around 45% in total energy-related SO<sub>2</sub> emissions. The relatively high SO<sub>2</sub> emissions from the power sector and the increasing trend over the period 2000-2040 projected by GMM are due to the high share of coal in the energy mix for electricity generation, i.e. ca. 65% of the fuel input.

## 5. BASELINE OUTLOOK FOR EUROPE

### 5.1 Introduction

In this chapter on baseline developments in Europe, the following models are considered: PRIMES, POLES, MARKAL, NEMESIS, TIMES-EE, PACE and DNE21+. Sometimes the European situation will be compared to the US, based on results from the NEMS model. For other models results were not available at the time of writing. Moreover, not all models generate results at the same level of detail, and therefore most graphs are based on results of a selection of models. Most of the models that focus on Europe currently have a time horizon towards 2030, with the exception of MARKAL, DNE21+ and PACE. For reasons of cross-model comparability, the scope of this chapter is limited to the period up until 2030. Since most of the models intend to extend their time horizon in the course of the CASCADE MINTS project, more extended baseline results will become available later.

The starting point for the analysis is the region Western Europe (WEU) since this is the most commonly used region in the models under consideration, as summarised in Table 5.1. Western Europe is generally defined as the EU-15, Norway, Switzerland and Iceland. However, there are small differences in the definition of this region in the various models. In the PRIMES model, the region WEU excludes Iceland. For NEMESIS the WEU region refers to the EU-15 plus Norway, while PACE and NEWAGE include Turkey in the WEU region. Differences in region definition may partly explain differences in results. Wherever relevant, the PRIMES results for the EU30 region, which is defined as Western Europe (excl. Iceland), the 10 new EU Member States, Bulgaria, Romania and Turkey, will be taken into account in the discussion of baseline results. Some models also distinguish a region ‘Central Europe’ which corresponds to the New Member States in this region plus the countries of former Yugoslavia, but excludes the Baltic States. It is noteworthy that the regional coverage of most models does not correspond with the borders of the European Union. The present EU-25 is covered by only one model - PRIMES. This is particularly important when issues related to security of supply are being considered.

Table 5.1 *Regional coverage in European models*

	PRIMES	POLES	MARKAL	NEMESIS	TIMES-EE	PACE	NEWAGE-W	DNE21+
• EU-15	✓				✓		✓	✓
• Western Europe (WEU)	✓	✓	✓	✓	✓	✓	✓	✓
– EU-15	excl.			excl.		incl.	incl. Turkey	incl. Malta
– Norway	Iceland			Switzerland		Turkey		
– Switzerland				Iceland				
– Iceland								
• New EU Member States	✓							
• Central Europe:		✓				✓	✓	
– Eastern Europe								
– former YUG								
• EU25	✓							
• EU30:	✓							✓
– EU25								incl
– Norway								Croatia,
– Switzerland								Ukraine,
– Bulgaria								excl
– Romania								Cyprus
– Turkey								

## 5.2 Primary energy consumption in Europe grows less than world energy consumption

As shown in

Figure 5.1 the primary energy consumption projections of the different models show only a very moderate increase, except for PACE and NEMESIS which project a decrease. For NEMESIS this decrease can be attributed to the effect of the carbon tax. In addition to the impacts of the carbon tax, the decrease in primary energy consumption in PACE can be attributed to the fact that PACE only takes into account primary energy consumption from fossil fuels while primary energy consumption from nuclear and renewables are not explicitly accounted for. Finally, NEWAGE-W shows a trend comparable to most other models, but the absolute value is much lower, because only three types of fossil fuels are distinguished, and renewables and nuclear are not accounted for. On average, European energy demand is projected to increase by at most 0.5% per year between 2000 and 2030, whereas world energy consumption grows with some 1.7% (based on POLES). For the EU-30 the projections are comparable to the trend for Western Europe. Energy consumption growth is expected to be slightly higher in the new EU Member States than in Western Europe.

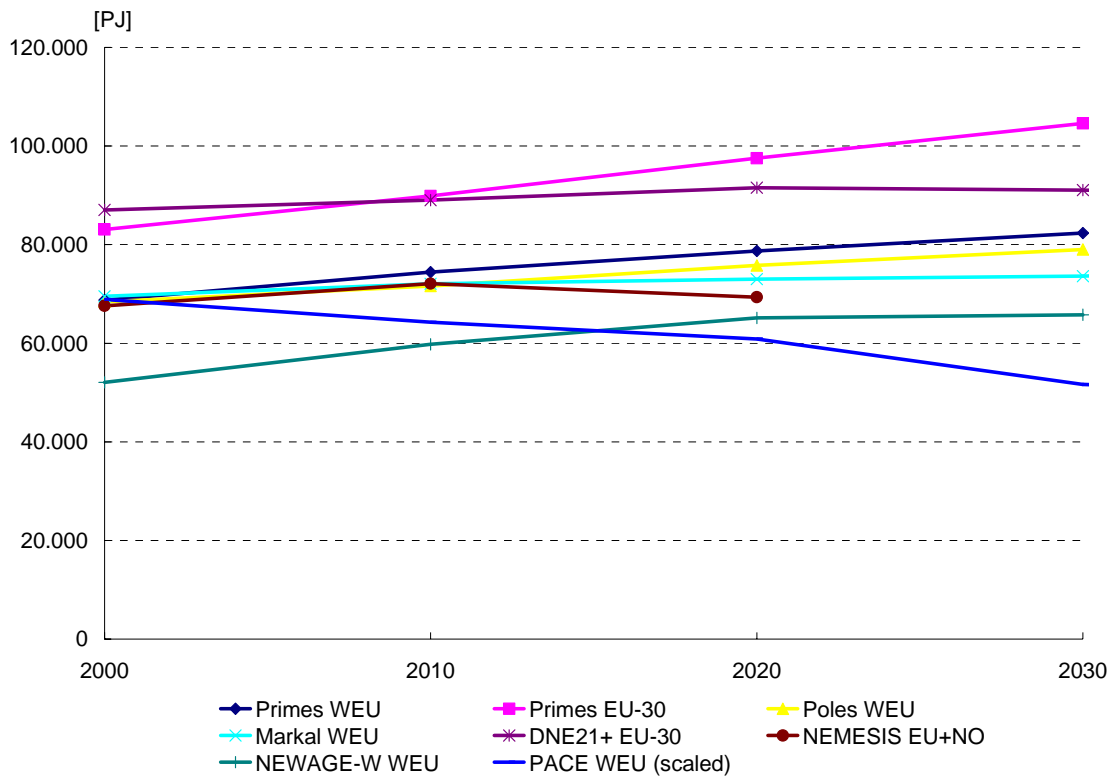


Figure 5.1 Total primary energy consumption

## 5.3 Primary consumption grows less than GDP, but faster than population

The primary energy intensity relates the total amount of energy used in a region to the GDP. It measures the amount of primary energy required to generate one unit of GDP. Changes in this indicator reflect both efficiency changes in the transformation sector and at the level of final consumers.

Figure 5.2 illustrates the general expectation that in the next 30 years, the combined effect of energy price increases, changes in the sectoral structure of the economy, and technical efficiency improvements indicate that less primary energy is needed to create one unit of GDP. As can be seen from the PRIMES results, this effect is stronger in the new Member States. The high level of the energy intensity in the base year indicates that there is a lot of room for effi-

ciency improvements. As is shown by the steep decrease in intensity for this region, this potential for improvement is to a large extent exploited: while for 2000 the intensity for the NMS region is roughly three times that of Western Europe, in 2030 the fraction has diminished to approximately a factor two, and the level is comparable to that of the world as a whole. In the US, primary energy intensity is some 30% higher than in Western Europe, and is decreasing at a rate similar to Europe; therefore not much change in regional differences is expected in the next two decades.

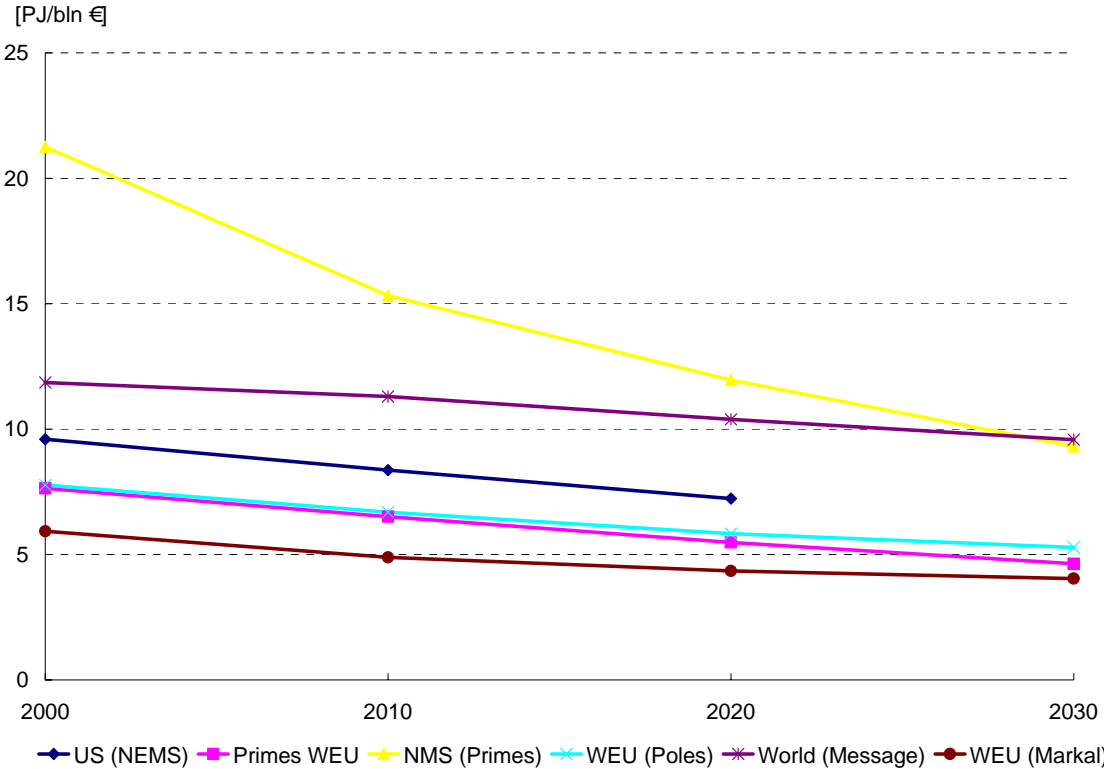


Figure 5.2 Primary energy intensity (Gross inland consumption/GDP) compared for Western Europe, the new Member States, the US and the world. Other models show similar trends

On the other hand, the indicator that compares the growth of primary energy consumption to population growth (Figure 5.3) shows an increasing trend. This implies that the energy needs of the average European citizen are still increasing steadily. These observations hold not only in Western Europe but also in the rest of the world. However, there are large differences in the level of this indicator. American residents use approximately twice as much energy as western Europeans, and no structural change is expected. On the other hand, in the new Member States, energy consumption per capita starts at a lower level, but, according the PRIMES model, shows the highest rate of increase.

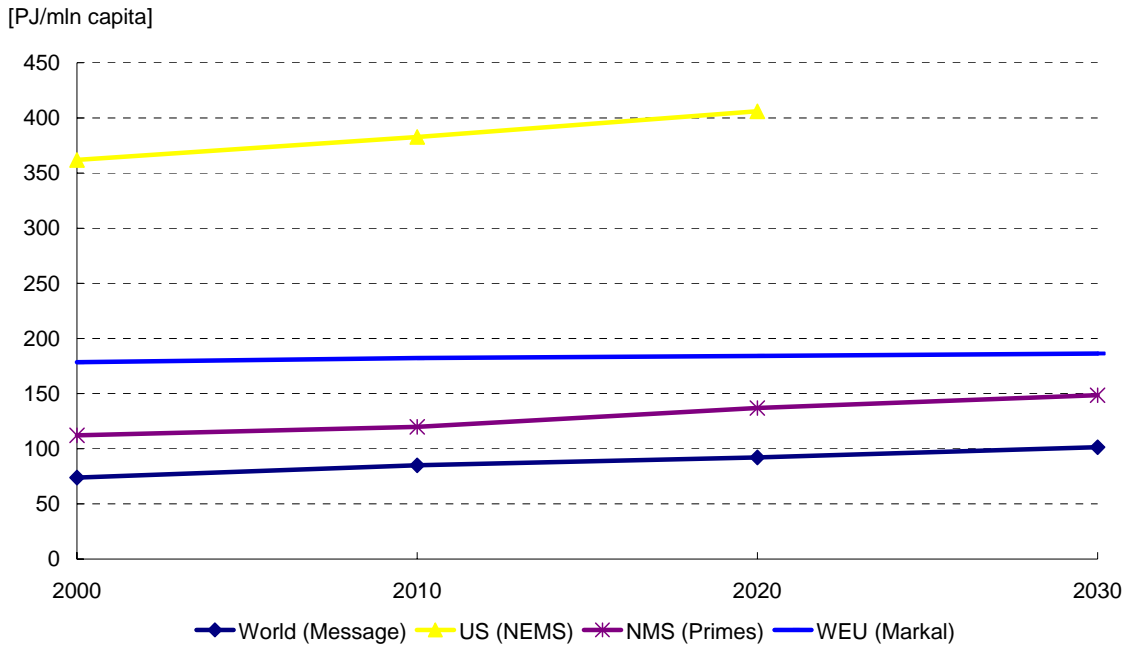


Figure 5.3 *Gross inland consumption/capita compared for Western Europe, the new Member States, the US and the world. Other models show similar trends*

#### 5.4 Primary consumption is still dominated by fossil fuels

As illustrated in Figure 5.4, Western Europe's primary energy consumption in 2000 was dominated by fossil fuels, particularly oil and natural gas, which together accounted for almost two thirds of total consumption.

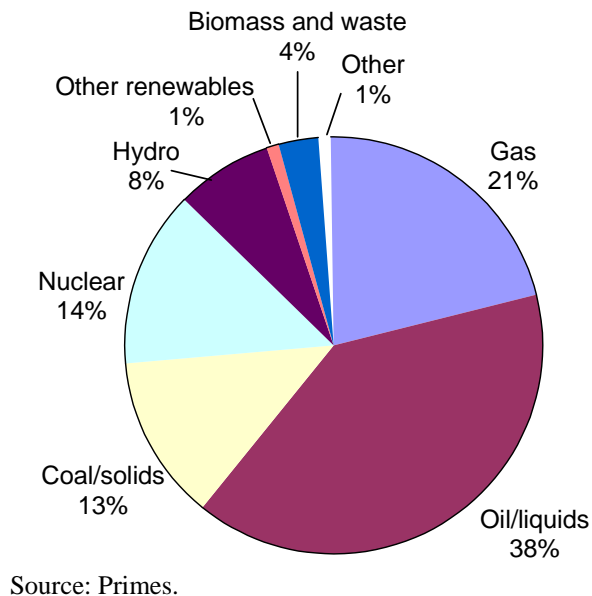


Figure 5.4 *Primary consumption by fuel in Western Europe in the year 2000; total 68,771 PJ*

No major change is expected in the baseline scenario. All projections indicate that by 2030, fossil fuels will still have some 70-75% share in the primary energy mix, although models show different contributions of the different fossil fuels. Figure 5.5 illustrates the 2030 fuel mix in Western Europe as projected by several models. Europe will still primarily rely on oil, but the share of natural gas will significantly increase. The growth of gas demand is expected by all

models, and analysed further in Section 5.5.4. Oil consumption is expected to stabilise or to decrease slightly towards 2030 (MARKAL and DNE21+). Coal consumption is more or less stable according to Primes and Poles, while MARKAL and DNE21+ project a significant increase in 2030 compared to the 2000 level. Not surprisingly, there is hardly any hydrogen in the baseline, and only beyond 2030.

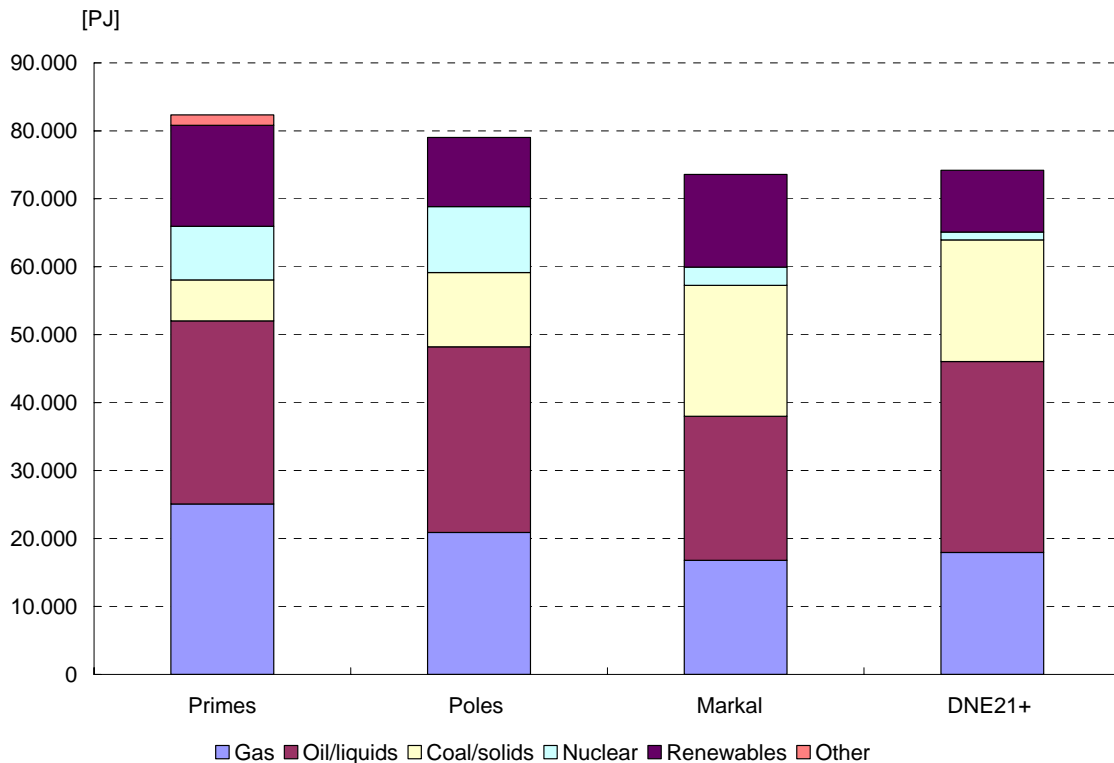


Figure 5.5 Primary energy consumption by fuel in Western Europe in 2030<sup>17</sup>

Remarkable is that MARKAL and DNE21+ expect nuclear energy to be phased out in the baseline, although no explicit phasing out policies have been included (see Section 3.6). This reflects that costs for nuclear power are in these models too high to be competitive. Thus, the different projections on the share of nuclear in the future energy system reflect some uncertainty on the role it may play under present circumstances.

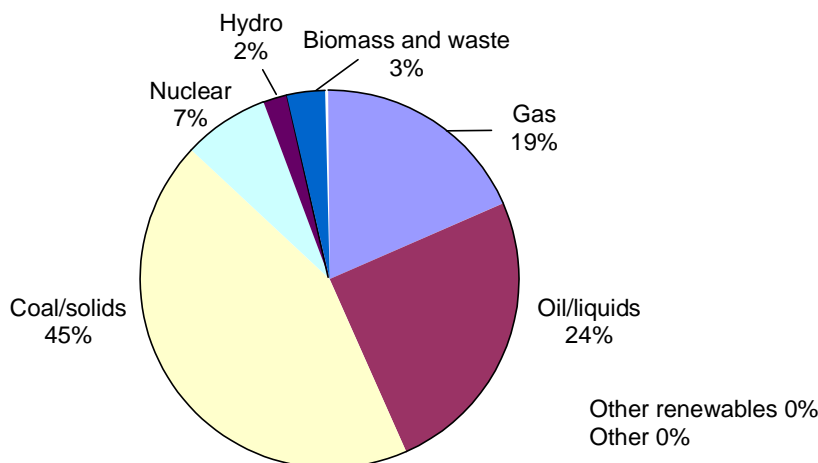
The Primes model projects a 16% share of renewables<sup>18</sup>, whereas most other models expect some 10-12% share in the primary energy mix. Apart from a steady contribution of hydropower, wind power shows a significant growth.

Comparing the present fuel mix of primary energy consumption in Western Europe to that in the new Member States (Figure 4.3), it is clear that the dominance of fossil fuels is even larger with a share of almost 90%. Particularly the share of coal is much larger in new Member States. The share of nuclear and renewables is smaller in the new Member States than in Western Europe, and the contribution of wind and solar energy is negligible. Of course it should be noted that the size of total primary energy consumption in the new Member States is small compared to that in Western Europe; 8.4 EJ and 68.8 EJ respectively in the year 2000.

<sup>17</sup> Results of the other models could not be included for various reasons. NEMESIS has a time horizon until 2020, PACE and NEWAGE-W only distinguish three energy carriers: gas, oil and coal.

<sup>18</sup> Measured according to the substitution principle. If the Eurostat convention was used, the share would be lower.





Source: Primes.

Figure 5.6 *Primary consumption by fuel in the new Member States in the year 2000; total 8,380 PJ*

In the next decades the energy system of the New Member States is expected to move towards the energy system of the EU15. Consequently, the relative importance of coal will diminish, as new, additional generation capacity will be covered mainly by natural gas and renewables. This will probably be due to the carbon tax in the baseline scenario. The Primes model projects the growth of energy consumption in the new Member States to be slightly higher than that in Western Europe after 2010. Given the relatively small size of the energy consumption in the new Member States compared to Western Europe, the fuel mix of the EU30 will not be dramatically different from that in Western Europe. The share of fossil fuels is projected to be 70-75%, to which coal contributes some 9%.

### 5.5 Import dependency will increase significantly

In the year 2000 the import share in primary energy consumption ranges from 35-50% in different models. All models project this indicator to increase significantly; 2030 values range from 50-75% and a further increase is expected towards the year 2050. Differences between these import shares may be explained by:

- Differences in assumptions on the availability of indigenous resources.
- Timing of use of indigenous sources.
- Use of renewables in different models.
- Use of coal, and origin of coal used.
- A methodological issue: the Primes results show lower import dependency because they do not include the effect of imported nuclear fissile material.

In the next sections we will examine the background of these developments for oil and natural gas respectively.

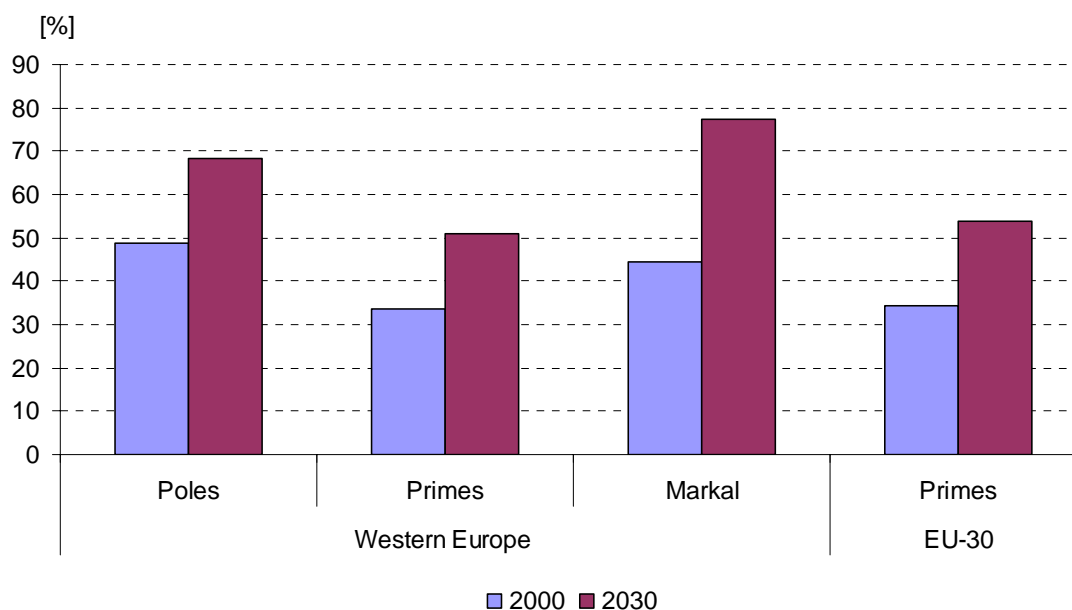


Figure 5.7 Net imports as share of gross inland consumption

### 5.5.1 Diversity in the European primary fuel mix relatively constant

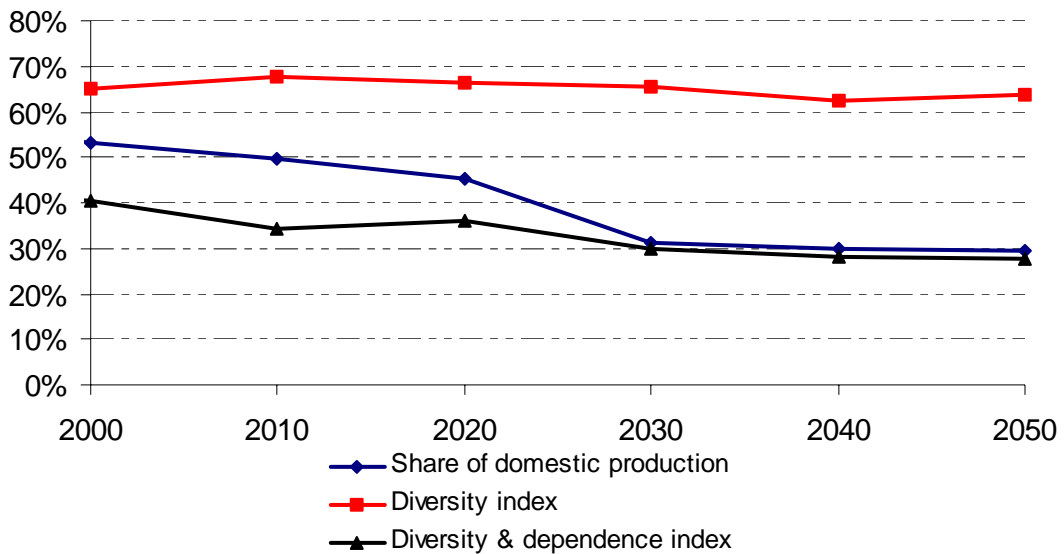
Security of supply is not only reflected in the dependency on imports, although this is an important issue. Other factors to be considered are the level of diversification, inversely related to the dependence on a few primary fuels, and the correlation between these fuels in terms of costs and availability. Several attempts have been made to design indicators that capture these considerations in a compact way.

The Shannon diversity index reflects the *variety* and the *balance* in Europe's portfolio of sources for primary energy consumption.

- Variety refers to the number of fuels available for primary energy consumption. The greater the variety of a system, the greater the diversity.
- Balance refers to the pattern in the spread or the relative importance of each fuel category; the more even the spread; the greater the diversity.

In (Jansen et al, 2004) the mathematical definition and elaboration of this index for measuring portfolio diversity is given. For this report, it suffices to explain that a decreasing diversity index is to be interpreted as a situation in which there is an increasing reliance on only a few energy sources.

The diversity index can be adjusted for the effect of import dependency in the primary fuel mix of a given region. The resulting 'diversity & dependence' indicator, presented in Figure 5.8, combines the information given by the straightforward domestic production share and the Shannon diversity index. The decreasing trend shows that for Western Europe, the supply security is worsened. However, in the period until 2030 the decrease in indigenous production is partly offset by the increased diversification. For Primes, these indicators show comparable trends, although the levels of these indicators are higher, implying less external dependence and more diversity. This is mainly due to the higher share of renewables in the Primes baseline, which makes diversity showing a slight increase towards 2030. It should be noted that the different models show large differences in their projections of Europe's future fuel mix, see Figure 5.4, and thus in their expected level of diversification. Therefore conclusions on these issues can hardly be supported from the baseline projections.



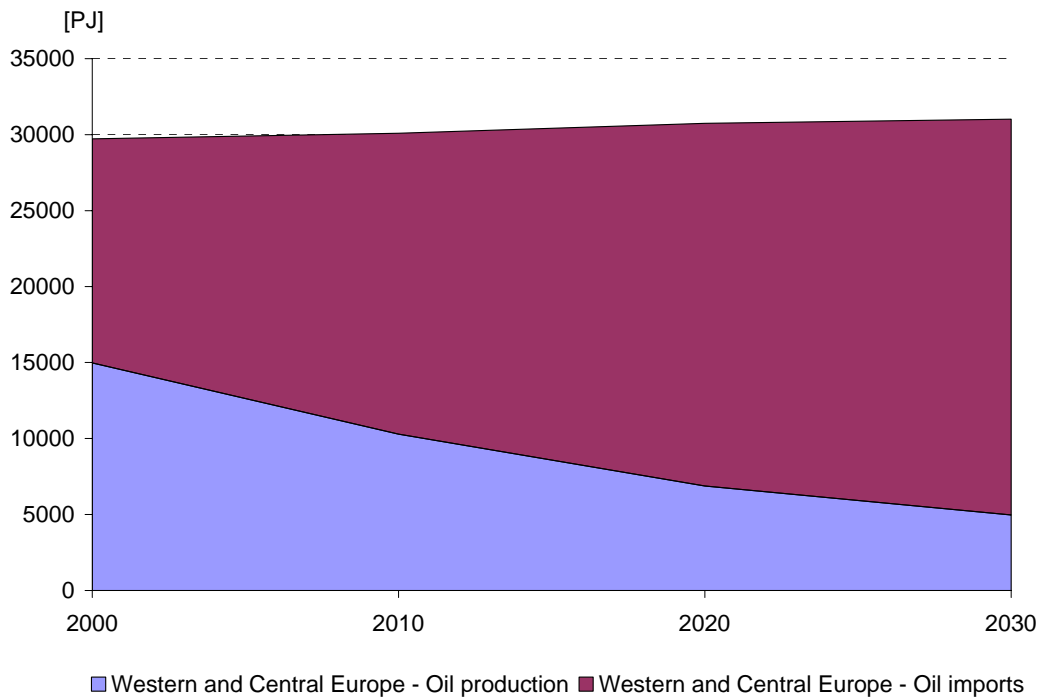
Source: MARKAL

Figure 5.8 *Import dependency and diversity indices in Western Europe*

The policy cases in the CASCADE MINTS project will be used to examine the effect of e.g. a larger share of renewables to improve the overall supply security, as approximated by this indicator.

### 5.5.2 Highest dependency for oil - up to 85%

As shown in the previous sections, Europe's oil consumption is expected to stabilise at about a third of its primary energy consumption in 2030. Domestic production however is expected to decrease due to limited reserves and high production costs, thereby introducing a greater reliance on imports from notably the Middle East. Figure 5.9 illustrates how the import share is expected to increase from 50% to 84% in 2030, as projected by the POLES model for Western and Central Europe together. Other models show a similar trend.

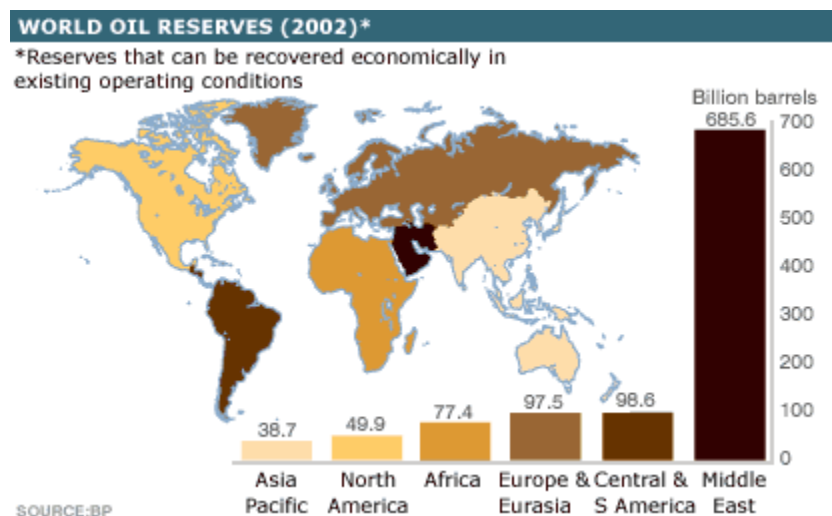


Source: Poles.

Figure 5.9 Oil production and imports in Western and Central Europe

### 5.5.3 Sources of oil imports

In 1999, 51% of oil imports to the EU-15 came from OPEC countries, of which Saudi Arabia, Libya and Iran were largest suppliers. Large non-OPEC suppliers were Norway (21%) and the former Soviet Union (18%) (European Union, 2000). As shown in the graph below, the largest reserves are in the Middle East. As was seen in Chapter 4, the increased dependency on oil from the Middle East one might expect from this build-up of reserves indeed occurs. This may lead to increased concerns about the security of supply on the longer term, particularly given the present uncertain political situation in that region.



Source: BP

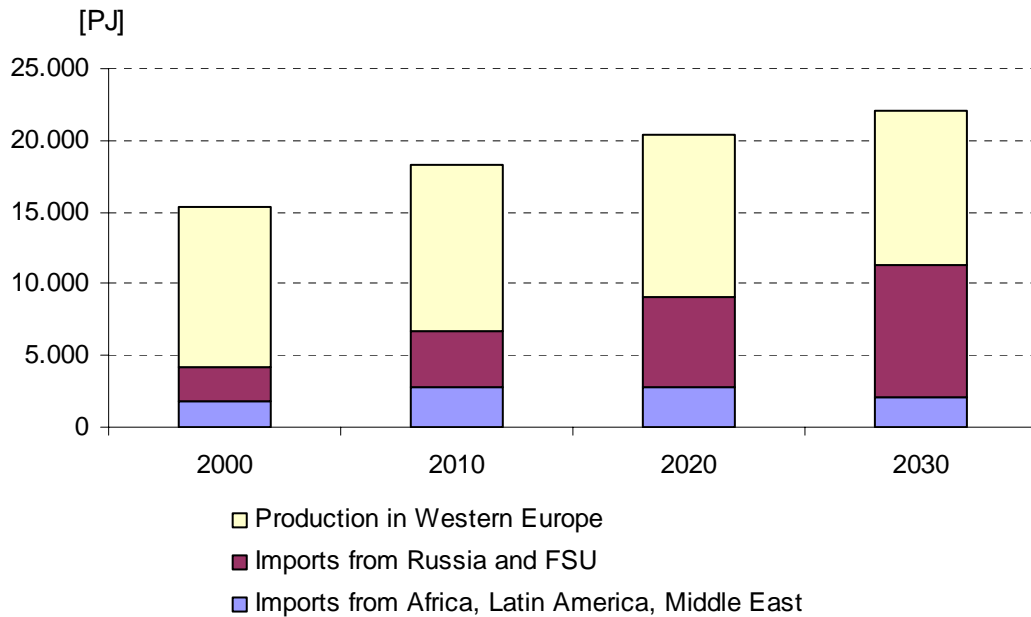
Figure 5.10 World oil reserves

#### 5.5.4 A dash for gas

As described in Chapter 4, the world gas consumption is projected to triple between 2000 and 2050. The gas consumption of Western Europe grows at a slower pace, and different models show different growth rates. The growth is largely due to the increased production of natural gas for power production (see Section 5.7). The share of Western and Central Europe in the world gas consumption is some 22-24%.

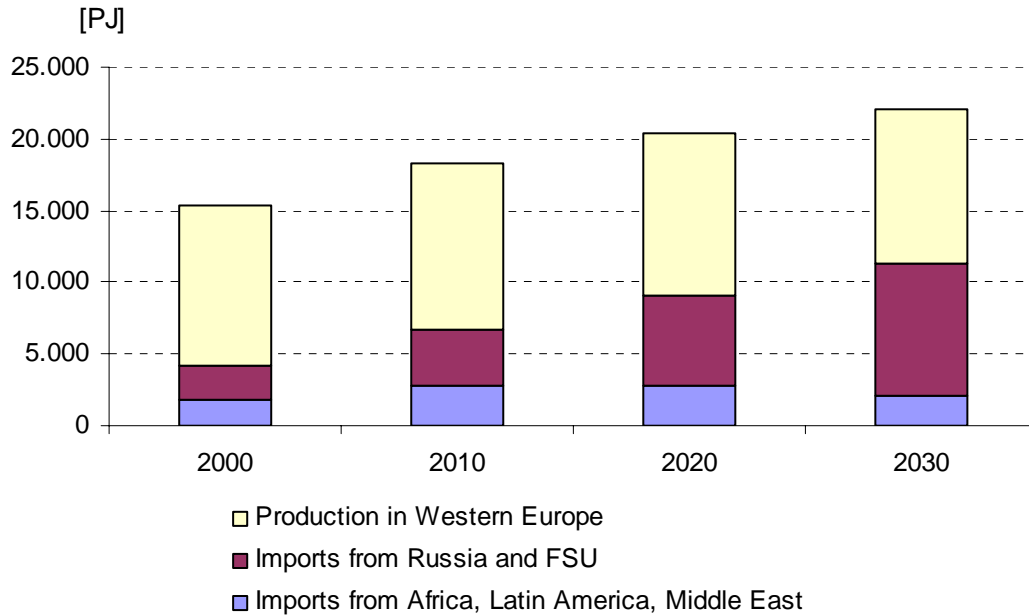
#### 5.5.5 The European response to natural gas demand

The three main natural gas producers within Western Europe are the United Kingdom, the Netherlands and Norway, while Russia and Algeria are the main gas suppliers outside Europe.



Source: Poles

Figure 5.11 illustrates that in the period towards 2030, domestic gas production is expected to decrease slightly, while imports from Russia will grow, thereby increasing the external dependency for natural gas.



Source: Poles

Figure 5.11 *Natural gas production and net imports to Western Europe by region of origin*

In line with this, all models project an increase of the external dependence for gas. Figure 5.12 shows this for different regions and models, illustrating that other models expect an even stronger increase of the import dependency than Poles. Gas supplies from Norway are regarded ‘domestic’ in these analyses, implying that import shares for the EU-15 are still higher. Nevertheless, Norway is already an established and politically stable supplier, so the actual security of gas supply is not affected. However, the accession of the new Member States and their heavy reliance on a single supplier - Russia - does increase the risks related to gas supply security. On the other hand, enlargement is expected to reduce the risks associated with transit of gas across the New Member States towards EU-15 countries (Van Oostvoorn et al., 2003).

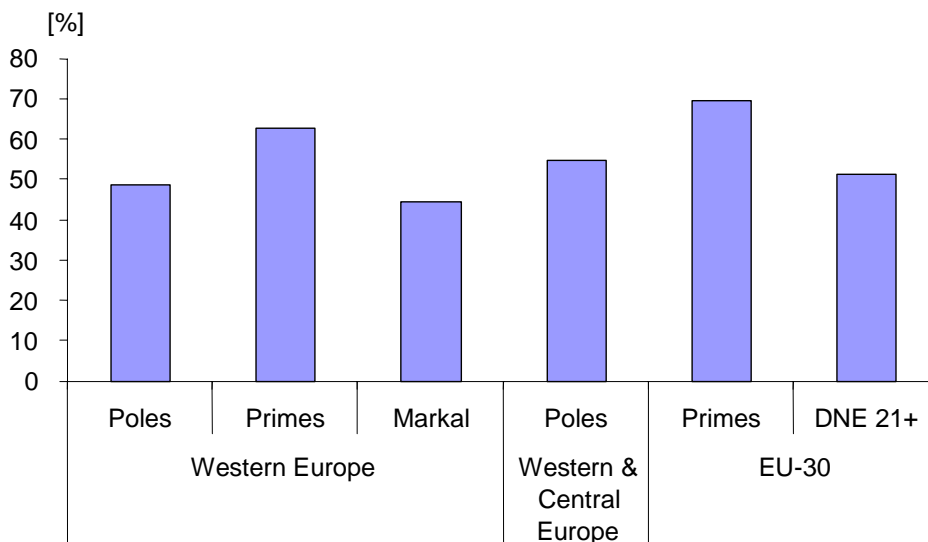


Figure 5.12 *Share of imports in gross primary consumption of natural gas in 2030*

## 5.6 Final energy demand in Western Europe grows less than GDP

Final energy demand in Western Europe grows with on average 0.5-0.8% per year, which is less than a third of the growth in world final energy demand. In the new Member States, final demand grows faster, at a rate of 1% per year. There is a significant difference in the projections for the EU-30 by Primes and DNE21+. The latter model projects a much more moderate growth after 2010. In Primes and MARKAL, final energy demand grows faster than primary consumption. This implies that the transformation sector will become more efficient.

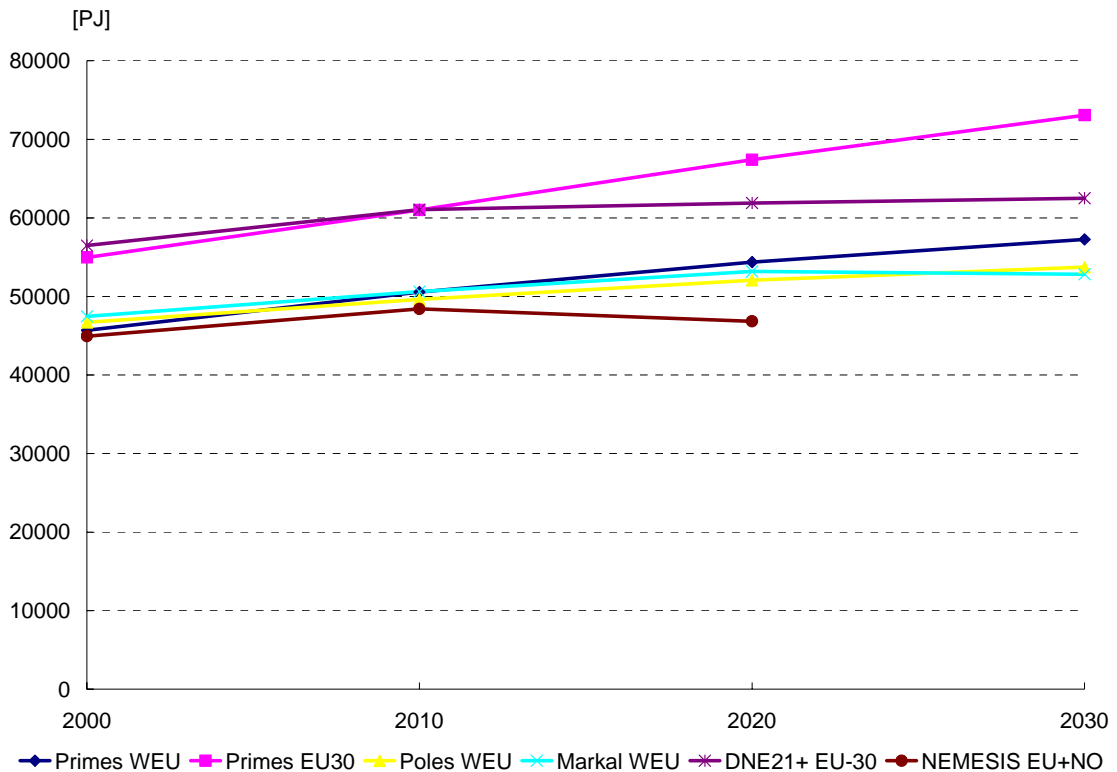


Figure 5.13 Final energy demand in different European regions

Final energy demand in Western Europe grows less than GDP, and therefore all models project the final energy intensity to decrease with some 1.5% annually on average.

Figure 5.14 shows that, according to the Primes model, the New Member States start with a more energy intensive situation in the year 2000. However, their energy intensity decreases faster, at the rate of 2.4%, showing a convergence towards the year 2030. Given the small size of the final energy consumption in the new Member States compared to their Western European counterparts, the energy intensity for the EU-30 is only slightly higher than that for Western Europe. In the US, final energy intensity is almost twice the level of that in Western Europe, and decreasing at the same rate.

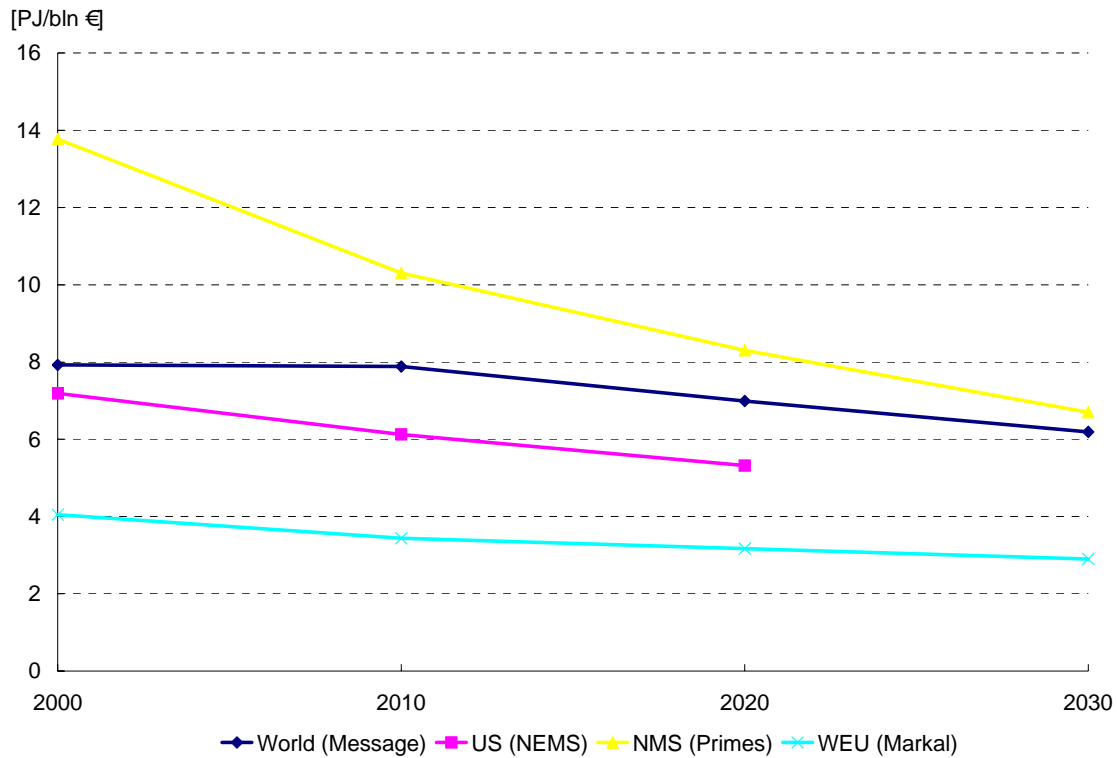
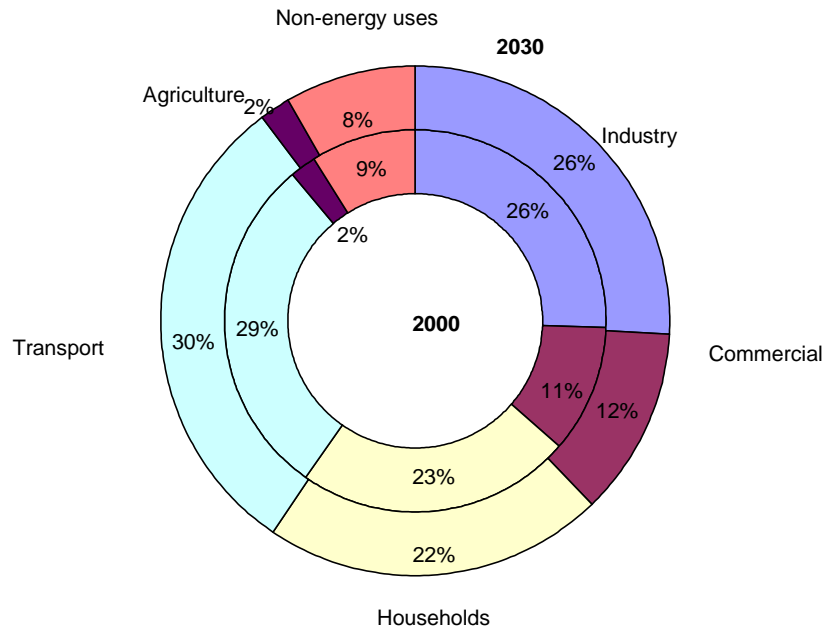


Figure 5.14 *Final energy intensity for Western Europe compared to the world, the US and the new Member States; other models show similar trends*

### 5.6.1 No major change in sectoral structure of final demand

Figure 5.15 illustrates the sectoral composition of final energy demand in the year 2000. The transport sector has the largest contribution to the final energy demand, mainly consisting of oil products, followed by the industrial sector. This sectoral structure of energy demand is not expected to change in the period towards 2030, implying that energy demand in the different end-use sectors shows comparable growth rates. The largest growth in final energy demand is found in the commercial sector with 1.1% per year on average, followed by the transport sector with 0.9% annually, and industry with 0.8% annually.





Source: Primes.

Figure 5.15 *Final energy demand in Western Europe by sector in 2000 and 2030; Total: 45.7 EJ in 2000 and 57.3 EJ in 2030*

### 5.6.2 Final consumption of electricity

In the year 2000, final electricity demand was approximately 18% of total final demand. As illustrated in, most models expect this share to increase slightly to some 22%; MARKAL and DNE21+ providing a lower and an upper estimate respectively. This growth is the continuation of a trend that has been visible in the last years, when the growth of the service sector, and an increase of disposable income in the residential sector caused an increased penetration of electrical appliances in most European countries.

There are differences in expected growth rates of electricity demand. The MARKAL model projects a much more moderate growth rate than the others; and NEMESIS and DNE21+ project a stabilisation beyond 2010 and 2020 respectively. In the new Member States, demand for electricity grows relatively fast at an annual rate of 2.2%, compared to a rate of 1.2 – 1.4% annually for Western Europe. All models indicate that final demand for electricity increases faster than total final energy demand.

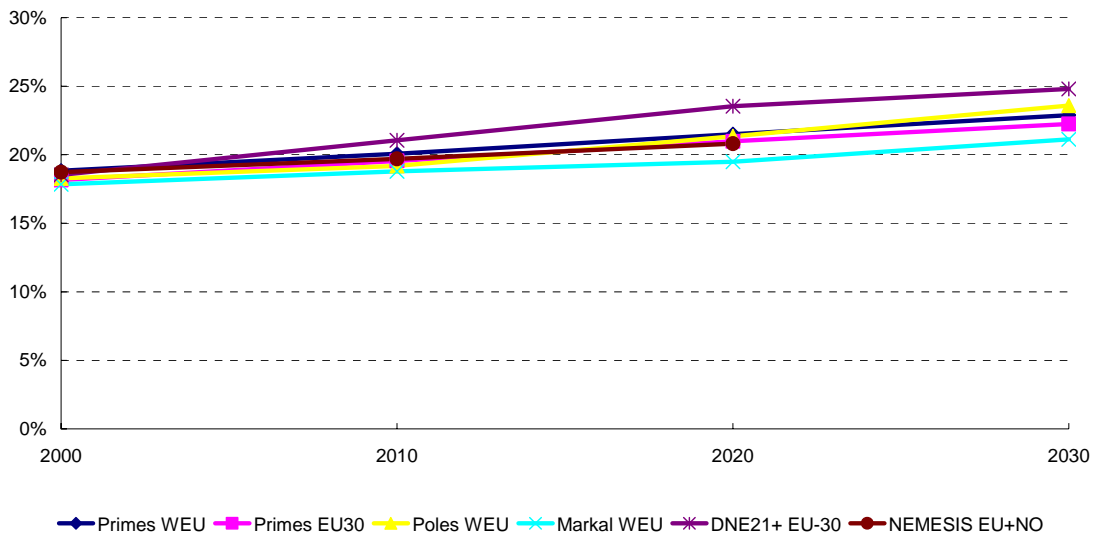
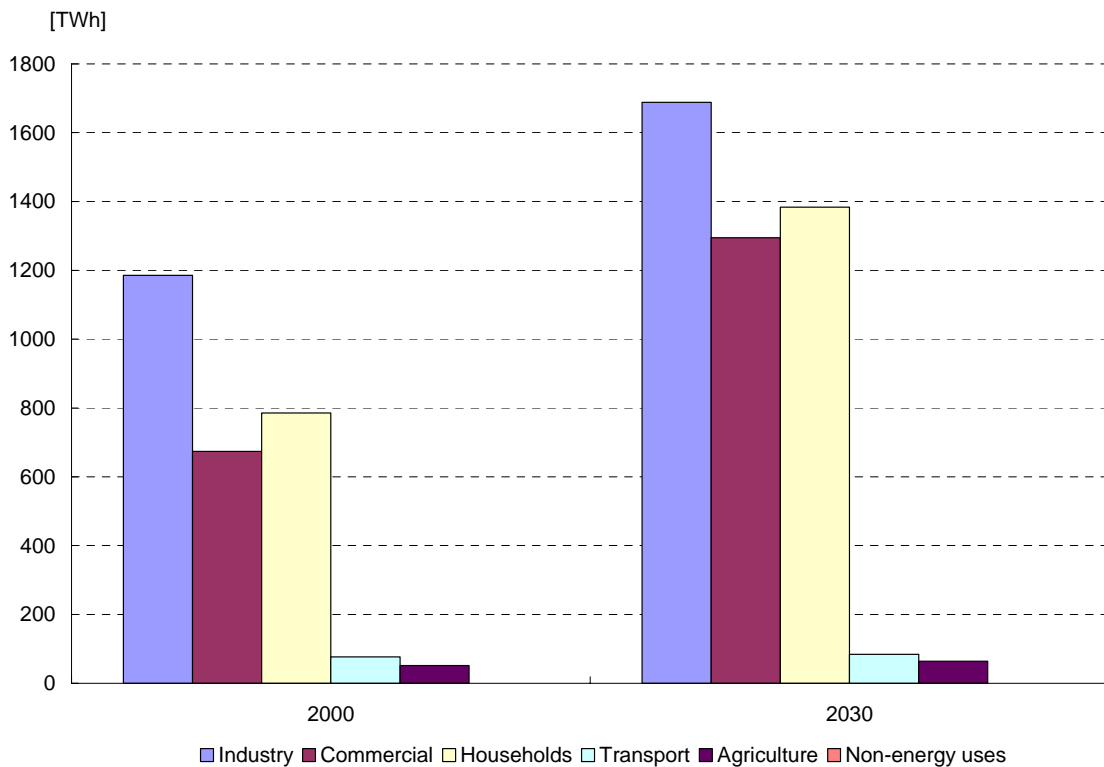


Figure 5.16 Contribution of electricity to the final energy demand

The sectoral structure of final electricity demand does not significantly change over time, as illustrated in Figure 5.17 for PRIMES. There are some indications that the electricity demand of the commercial sector increases faster than that in other sectors. Other models confirm this pattern.

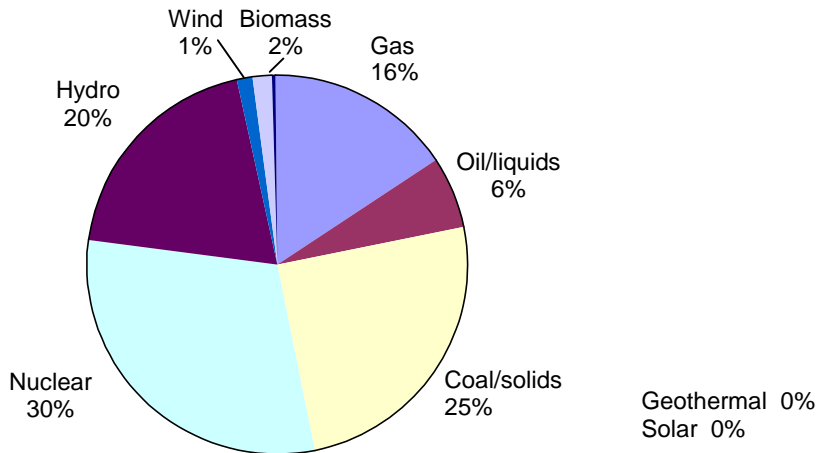


Source: Primes.

Figure 5.17 Final electricity demand by sector in the EU-30

## 5.7 Technologies for power generation in Europe

In Figure 5.18 the composition of the fuels used for electricity production in Western Europe is illustrated. Notable is the large share of nuclear, followed by coal. Renewables have a share of over 20% in the year 2000, including a significant contribution of large hydropower in Norway<sup>19</sup>. In the EU-15 this share is somewhat lower (Norway production 113 TWh).



Source: TIMES-EE.

Figure 5.18 *Net electricity generation by fuel in Western Europe in 2000 (total 2698 TWh)*

Expectations on future developments in the fuels and technologies used for power generation differ largely among models, as shown in Figure 5.19<sup>20</sup>. This is due to differences in assumptions on the costs and efficiencies of power production technologies and availability of natural gas resources. In addition, the future of nuclear power largely depends on nuclear policies, and different models deal with this in different ways. It should also be kept in mind that the total amount of electricity production differs substantially among models, see Section 5.6.2.

All models project an increase of the share of natural gas, ranging from 16% (TIMES and MARKAL), 20% (POLES and DNE21+) to 43% (Primes) in 2030. This variation is mainly due to different assumptions on availability and costs of indigenous gas production in Europe. Likewise, all models project a decrease of the share of oil and oil products in power generation to some 1-3%, compared to 6% in 2000. DNE21+ is the exception with a projected share of 17%.

The largest range is observed in the prospects for coal technologies and nuclear power production. Primes projects coal-based power generation to decrease from the current 25% to some 15% while the other models expect (considerable) growth in this sector, possibly to compensate for the moderate shares of natural gas. The share of nuclear is expected to decrease in all models to approximately 20% of the European power generation mix. The exceptions are MARKAL and DNE21+, which project a 3-8% share due to high costs of nuclear power. Finally, the projections for biomass agree in their direction of growth in all models, TIMES and Primes being the most optimistic ones. Whenever a distinction between biomass residues and energy crops is made, the share of the energy crops is larger.

<sup>19</sup> Of total hydropower capacity in Western Europe, approximately 21% is installed in Norway (Lako et al., 2003).

<sup>20</sup> Results from NEMESIS are not shown here, because they are only available for 1990-2020; the trend is however similar to the one projected by Primes.

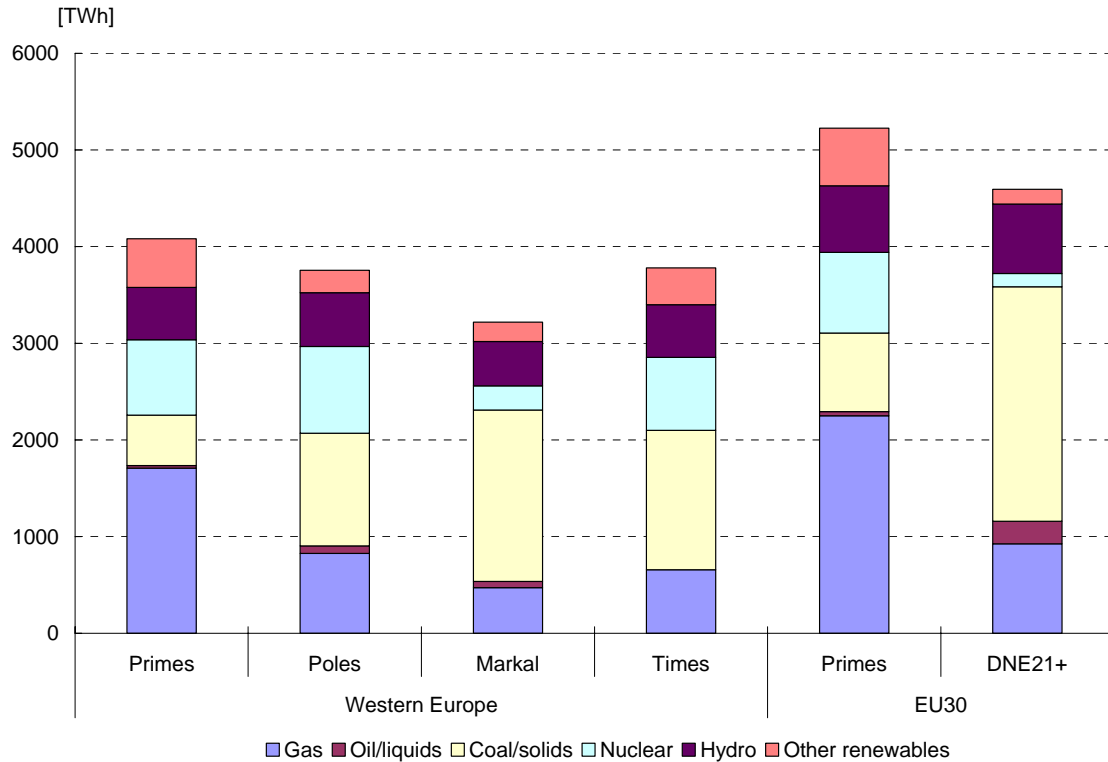


Figure 5.19 Net electricity generation by fuel in Europe in 2030

## 5.8 Energy-related CO<sub>2</sub> emissions

### 5.8.1 CO<sub>2</sub> emissions grow along with primary energy consumption

Figure 5.20 shows the development of energy-related CO<sub>2</sub> emissions for the European models, except TIMES-EE, since this model only calculates emissions for the power sector. CO<sub>2</sub> emissions from the power sector will be discussed later on in this section. On average, the CO<sub>2</sub> emissions are ca. 12% higher as compared in 2030 to the base year 2000, for Western Europe. This means that, on average, the CO<sub>2</sub> emissions grow by approximately 0.4% per year. Beyond 2030, growth of CO<sub>2</sub> emissions becomes less rapid, and even a decrease is observed between 2040 and 2050 (based on MARKAL and DNE21+).

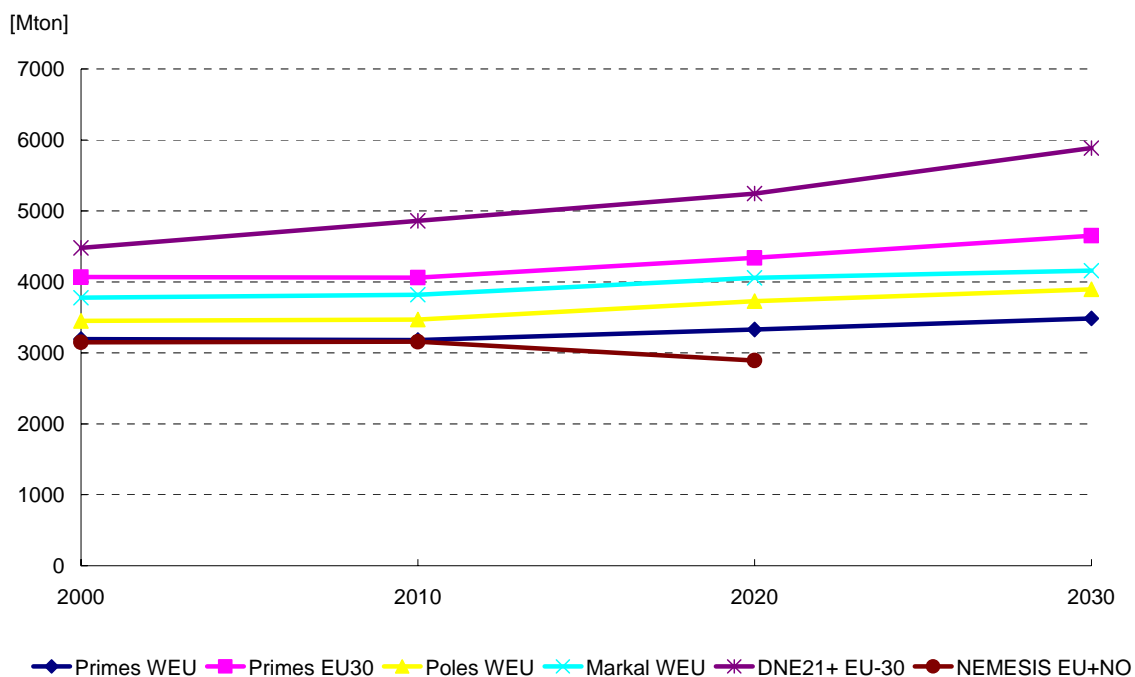


Figure 5.20 Energy-related CO<sub>2</sub> emissions for Europe (WEU/EU-30) for 2000-2030<sup>21</sup>

Variations in projected CO<sub>2</sub> emissions can partly be clarified from slight differences in primary energy consumption, regional aggregations and fuel mix, which also explains the difference in the base year 2000. However, for most models for the Western European region, CO<sub>2</sub> emissions grow at similar rates (9-13%).

NEMESIS is the only model that expects a decline of CO<sub>2</sub> emissions i.e. an 8% decrease in CO<sub>2</sub> emissions in the period 2000-2020. In this model, the primary energy consumption is expected to decline as well, as a result of the carbon tax (see Section 3.6.4), whereas the other models project rising primary energy consumption. In addition to this, coal has a relatively small share in the primary energy mix (based on results for 2020).

A comparison of the emission results from PRIMES for the WEU and EU30 region shows that CO<sub>2</sub> emissions are expected to grow somewhat faster when the new EU Member States and potential future accession countries are included. In the new Member States the CO<sub>2</sub> emissions increase less rapidly as compared to Western Europe in the period 2000-2030, 4% and 9%, respectively. In contrast to this result, the DNE21+ model projects a much faster increase for the CO<sub>2</sub> emissions in the EU30 in the period 2000-2030, partly due to a different regional specification.

There is a striking difference with the projections of global energy-related CO<sub>2</sub> emissions. Here, annual growth rates of ca. 2% per year are observed. This means that in the rest of the world the CO<sub>2</sub> emissions are expected to rise much more rapid as compared to Western Europe. This also means that Europe's share in global CO<sub>2</sub> emissions will decline over time.

Under the Kyoto Protocol, Western Europe is committed to achieving an 8% reduction of CO<sub>2</sub> emissions by 2008-2012, as compared to the level in 1990. For the EU15, Norway, Switzerland, and Iceland together, the total emissions of CO<sub>2</sub> amounted to approximately 3400 Mton in 1990<sup>22</sup>. This means that in the period 2008-2012, the level of total CO<sub>2</sub> emissions (including

<sup>21</sup> The PACE and NEWAGE models are not considered in this section, since these models only takes into account the primary energy categories gas, oil/liquids, and coal/solids.

<sup>22</sup> Based on CO<sub>2</sub> emission level for individual countries for 1990 derived from [ww.climnet.org/resources/kpeng.pdf](http://ww.climnet.org/resources/kpeng.pdf).

non-energy uses) should not exceed a level of approximately 3100 Mton per year. However, Figure 5.20 shows that the energy-related CO<sub>2</sub> emissions alone are already expected to exceed this level, indicating that it will be very difficult to achieve the Kyoto target.

### 5.8.2 Large variety in CO<sub>2</sub> emissions projections power sector

The growth rates for CO<sub>2</sub> emissions from the power sector vary much more among the models as compared to the total energy-related CO<sub>2</sub> emissions, i.e. a 14-32% growth in the period 2000-2030. This corresponds to an annual increase of 0.4-0.9%, which is faster than the growth rate of total energy-related CO<sub>2</sub> emissions. MARKAL projects the highest growth of CO<sub>2</sub> emissions from the power sector, which is due to the higher carbon content of the fuel mix for electricity generation, i.e. the smaller share of natural gas and larger share of coal, as compared to PRIMES and, to a lesser extent, TIMES-EE (see Paragraph 5.6.2).

The results from the PRIMES model for the WEU and EU30 region show similar growth rates, but the growth rate for the New Member States and potential future accession countries is somewhat lower. The declining trend that is observed for NEMESIS is not surprising considering the projections for total energy-related CO<sub>2</sub> emissions and primary energy consumption.

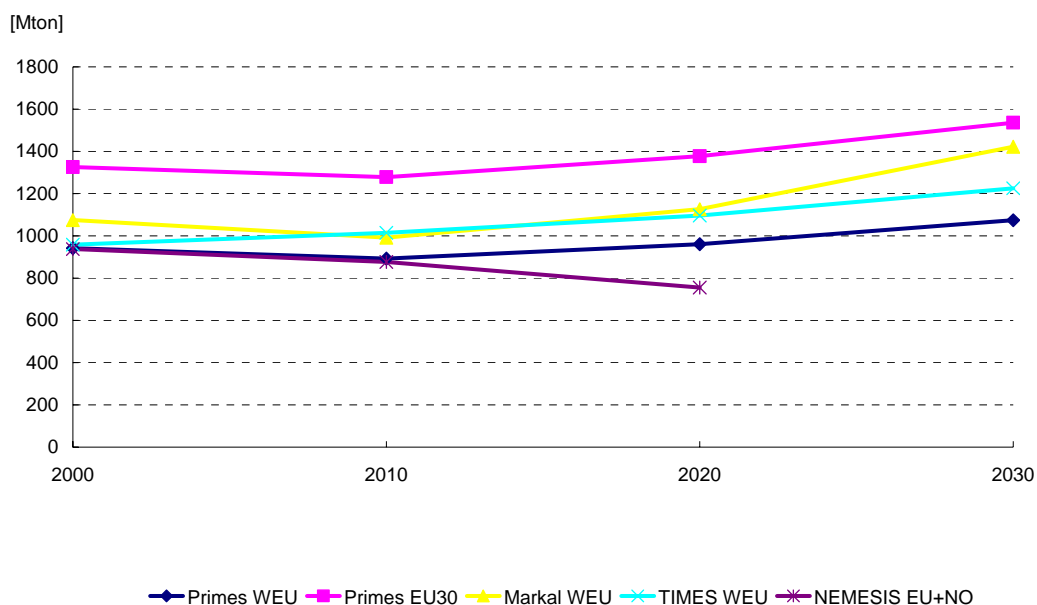


Figure 5.21 CO<sub>2</sub> emissions from the power sector for Europe (WEU/EU-30) for 2000-2030

### 5.8.3 Strong decline in carbon intensity of GDP but constant CO<sub>2</sub> emissions per GJ

The results for the CO<sub>2</sub> emissions per capita show that this indicator is expected to increase by 8-17% in the period 2000-2030 for Western Europe, see Figure 5.22. This implies that the CO<sub>2</sub> emissions grow faster than the population in Western Europe. Beyond 2030, this growth will continue but as of 2040, both MARKAL and DNE21 expect a decline of CO<sub>2</sub> emissions per capita.

Figure 5.22 also shows results for the CO<sub>2</sub> emissions per capita for the new Member States. These are expected to grow somewhat faster in the new Member States as compared to Western Europe. CO<sub>2</sub> emissions per capita for Western Europe are ca. twice as high as compared to the range of the global average. For the US, the CO<sub>2</sub> emissions per capita increase by similar rates as compared to Western Europe, but the absolute value of this indicator is twice as high, or even four times as high as the global average.

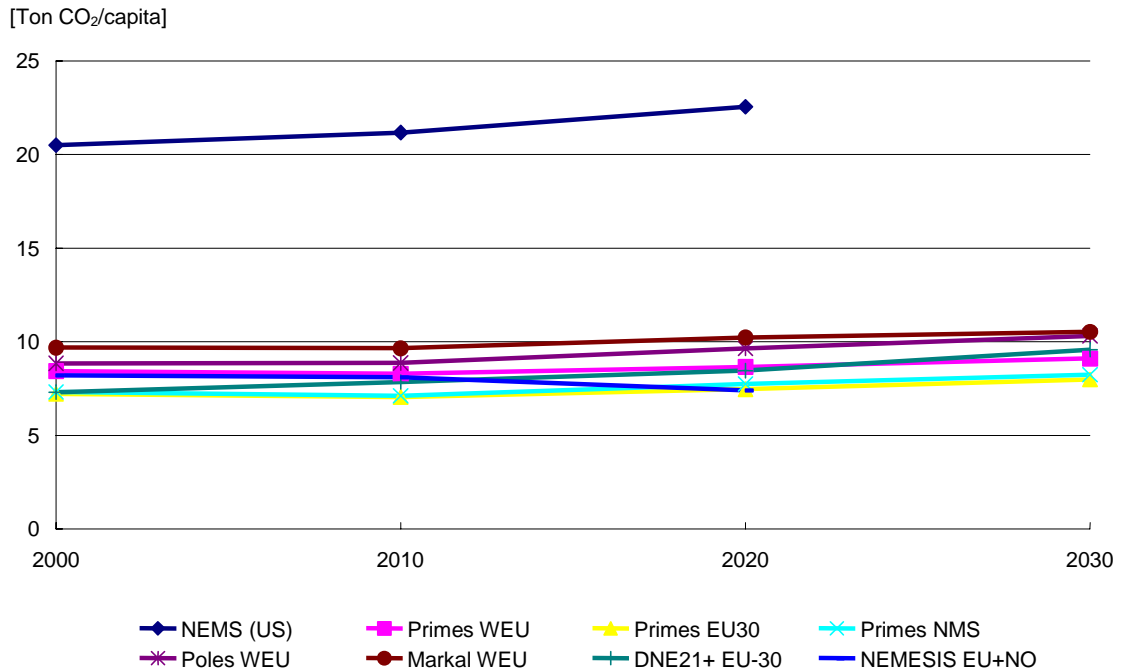


Figure 5.22 CO<sub>2</sub> emissions per capita for WEU/EU-30/NMS/US for 2000-2030

For Western Europe the carbon intensity of GDP is expected to decline by 30-45% in the period 2000-2030. Results from the MARKAL model show that beyond 2030 the carbon intensity of GDP decreases even further. Since the CO<sub>2</sub> emissions increase over time, the downward trend in carbon intensity of GDP is due to a higher economic growth as compared to the increase of CO<sub>2</sub> emissions. The absolute level of the carbon intensity of GDP is in the range 0.21-0.26 tons CO<sub>2</sub> per 1000 Euro in 2030. The global average in the same year is almost twice as high. In 2050, the global average will have approached the 2000 level of carbon intensity of GDP in Western Europe.

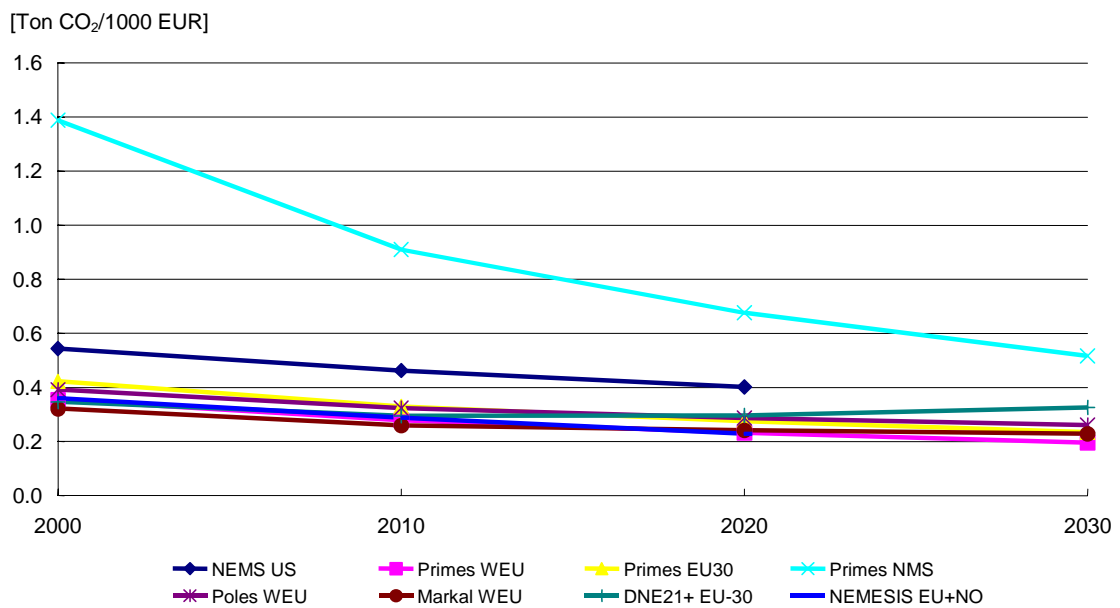


Figure 5.23 Carbon intensity of GDP for WEU/EU-30/NMS/US for 2000-2030

The new Member States currently have a carbon intensity of GDP of ca. 1.4 ton CO<sub>2</sub> per 1000 Euro (PRIMES). This level is expected to decrease very quickly by ca. 2% per year to a level of approximately 0.52 ton CO<sub>2</sub> per 1000 Euro in 2030, which is still twice as high as compared to Western Europe. In the US, the current carbon intensity of GDP is about 0.54 ton CO<sub>2</sub> per 1000 Euro (NEMS). Since the development of this indicator for the US shows a similar trend as compared to Western Europe, the absolute level of carbon intensity of GDP will remain higher for the US on the long term as well.

The carbon intensity of energy use is indicated by the CO<sub>2</sub> emissions per GJ. For Western Europe, most models show a constant trend or a slight decrease in the period 2000-2030. The same conclusion holds for the US. In the new Member States, a decline of 15% is observed. Only MARKAL expects a slight increase of CO<sub>2</sub> emissions per GJ. The average CO<sub>2</sub> emissions per GJ are much lower for Western Europe as compared to the levels for the new Member States and the US, and the global level. For the EU-30, PRIMES and DNE21 project different developments, i.e. a 10-% decrease and a 25-% increase, respectively.

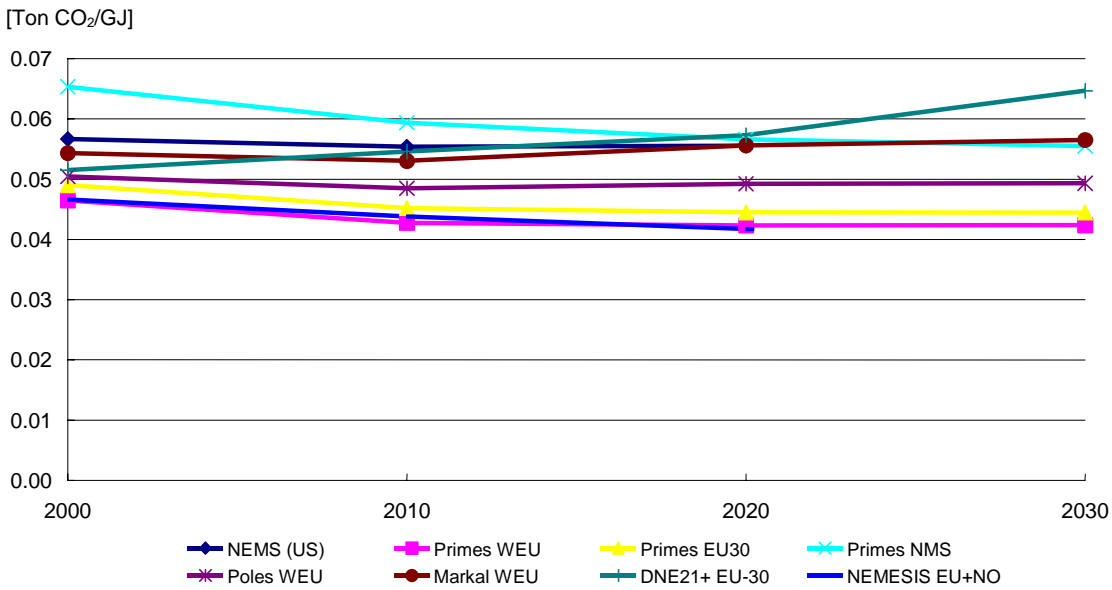


Figure 5.24 CO<sub>2</sub> emissions per GJ for WEU/EU-30/NMS/US for 2000-2030

The general expectation for Western Europe is that the specific CO<sub>2</sub> emissions from the power sector will decline in the period 2000-2030, which will mostly be achieved in the first ten years. For this indicator most models show a decrease ranging from 10-28% by 2020 as compared to the base year 2000, which is continued beyond 2020. Only the MARKAL model shows a different trend. After an initial decline of CO<sub>2</sub> emissions from the power sector, the model expects the emissions to rise again beyond 2010. The relatively high CO<sub>2</sub> emissions per kWh are due to the very large share of coal and the relatively small shares of gas and nuclear energy in electricity generation. In 2000, the absolute level of CO<sub>2</sub> emissions per kWh in Western Europe is about 30% lower as compared to the global average. However, in 2030, this difference no longer exists. For the new Member States the decrease is much higher as compared to Western Europe in the next 25 years, ca. 36% (PRIMES). For the US, the CO<sub>2</sub> emissions are expected to decline as well, but at a much slower rate, ca. 6% in the next 15 years.



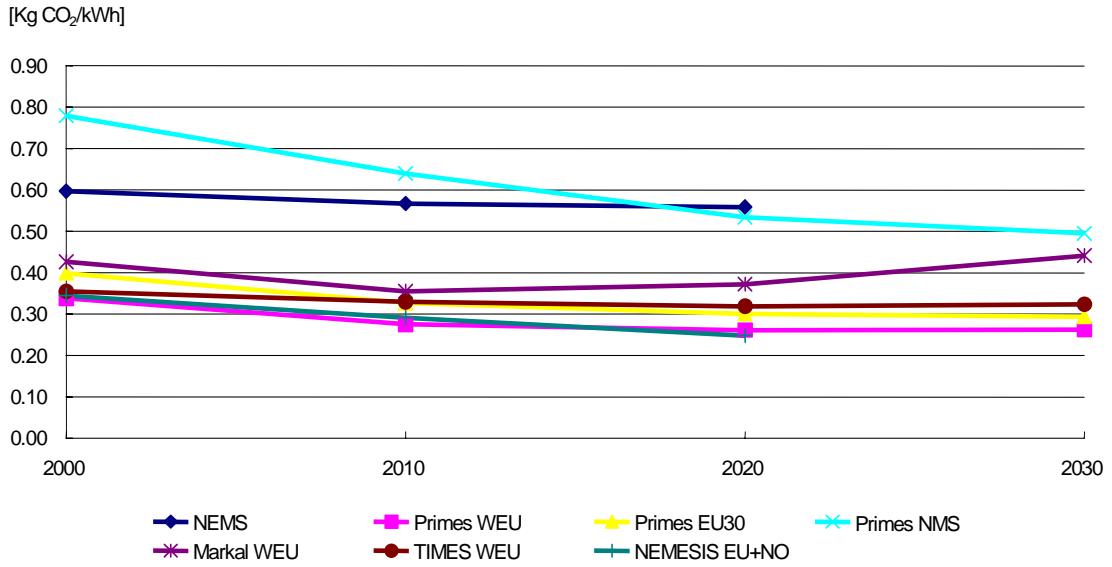


Figure 5.25 CO<sub>2</sub> emissions per kWh for WEU/EU-30/NMS/US for 2000-2030

#### 5.8.4 Relatively high increase of CO<sub>2</sub> emissions from transport sector

Figure 5.26 shows the CO<sub>2</sub> emissions of final energy use split into end-use sectors for 2030 and 2050, for the WEU and EU30 region. If the new Member States are included, the share of the transport sector is slightly larger in 2030 (PRIMES). The results also show that for Western Europe the share of the transport sector in total CO<sub>2</sub> emissions is expected to increase mainly at the expense of the industrial sector.

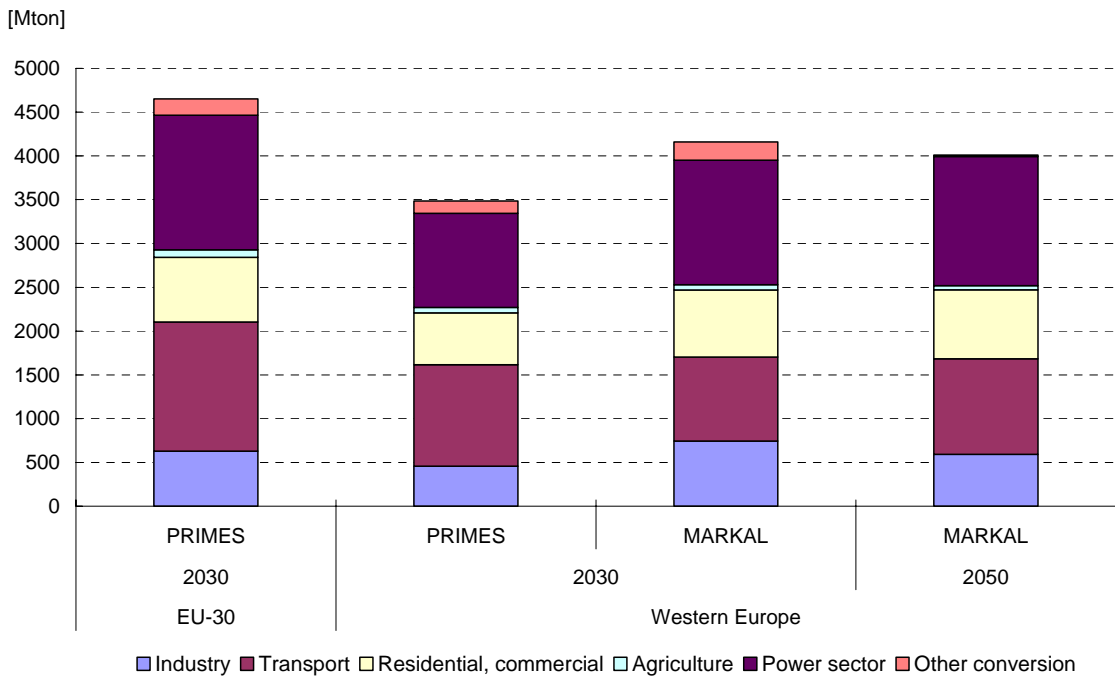


Figure 5.26 Contributions of end-use sectors to total energy related CO<sub>2</sub> emissions for Western Europe and EU-30 for 2030 and 2050

## 5.9 CH<sub>4</sub> emission reduction important to mitigating the greenhouse effect

Among the European models, only MARKAL provides results on the development of other greenhouse gas (GHG) emissions such as CH<sub>4</sub> and N<sub>2</sub>O. Figure 5.27 shows the development of these emissions in the period 2000-2050, compared to the development of total energy-related CO<sub>2</sub> emissions and total GHG emissions (which are calculated in Mton CO<sub>2</sub> equivalents). The CO<sub>2</sub> emissions as well as the N<sub>2</sub>O emissions increase over time. The level of N<sub>2</sub>O emissions, for which the use of fertilisers in agriculture is the principle source, is about 620 kton in 2000. This is projected to increase up to ca. 690 kton in 2050. In contrast to this, the development of total GHG emissions shows a decreasing trend, which means that the increase of CO<sub>2</sub> and N<sub>2</sub>O emissions is entirely compensated by a decrease in CH<sub>4</sub> emissions. The level of CH<sub>4</sub> emissions is ca. 31 Mton per year in 2000. This is expected to decline rather quickly between 2010 and 2020 towards a level of ca. 19 Mton per year, which remains almost constant as from 2020. This decrease is mainly due to reduced methane emissions from disposal sites, as a result of increased recovery of methane. Another possibility is to combust the methane, and possibly utilise the produced heat. This reduces the methane emissions but produces CO<sub>2</sub> emissions, which have a less strong greenhouse effect. Figure 5.27 clearly shows the importance of reducing CH<sub>4</sub> emissions in mitigating the greenhouse effect.

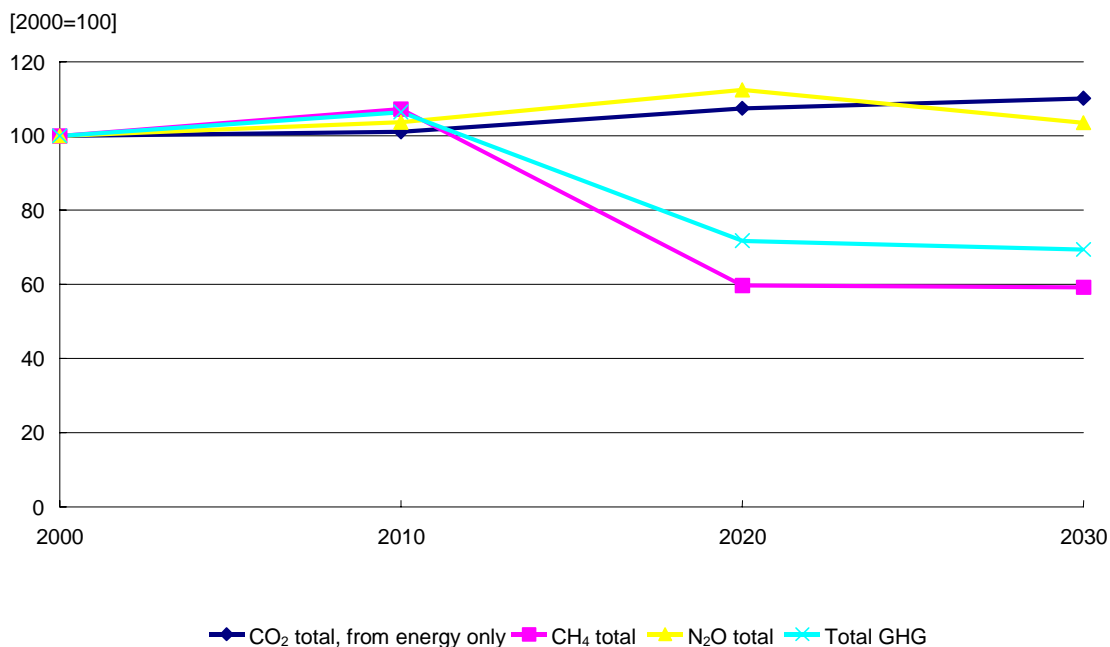


Figure 5.27 Development of total CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and Greenhouse Gas (GHG) emissions (MARKAL)

## 6. KEY MESSAGES

### 6.1 Twelve models use one baseline scenario to provide a comprehensive outlook on future developments

This report has presented the results of an effort by ten renowned modelling teams in Europe, the US and Japan to provide an outlook to possible developments in Europe and at global level. This outlook was based on a common, harmonised baseline scenario, and will serve as a benchmark against which policy scenarios will be compared in later stages of the project.

Given the diversity of the models, a moderate level of harmonisation was chosen. A number of quantitative assumptions – economic and demographic developments, oil prices and current policies – have been harmonised, whereas technology-specific assumptions have not been harmonised. A consistent basis for harmonisation of a baseline scenario was provided by the SRES ‘B2 marker scenario’ (IPCC, 2000). The B2 scenario shows more gradual changes and less extreme developments than other SRES scenarios and can be considered the closest approximation to a ‘dynamics as usual’ scenario, with moderate GDP and population growth.

Because other important driving forces, such as technological change and average improvement of energy efficiency, were not harmonised, the set of baseline results from CASCADE MINTS is broader than the B2 group of scenarios. The added value of these variations is that they reflect uncertainty about future developments. Moreover, the diversity of the models will provide different views on the effectiveness of the policy approaches. It should be noted that all observations fall within the boundaries of the harmonised baseline. The main driving forces - GDP, population and energy prices - have been harmonised, and conclusions that directly rely on implications of these assumptions are beyond the scope of the project.

Notwithstanding the fact that the baseline scenario provides a starting point for further analyses in the CASCADE MINTS Part 2 project, the results of this modelling work, based on a scientific consensus among modellers, already provide a first image of a future world under moderate GDP and population growth, thereby giving first answers to questions such as:

- What are the challenges and weaknesses of current energy supply in Europe, and in the rest of the world?
- In what sense do Europe’s energy supply and consumption differ from other world regions?
- Are current policies sufficient for achieving set targets?
- What are the perspectives regarding global warming?

The timing of this policy research is appropriate, as the European Commission has started a reflection on the actions on climate change for the post-2012 period, especially considering the benefits and costs and taking into account both environmental and competitiveness concerns.

In the next sections an overview is given of the key messages derived from the CASCADE MINTS Part 2 baseline scenario.

### 6.2 World energy trends until 2050

#### *Primary consumption more than doubles*

- World primary energy consumption is expected to more than double in 2000-2050, in line with the assumptions regarding moderate economic and population growth. Asia is the fastest grower and quadruples its energy consumption in 2050.

- Fossil fuels are expected to remain dominant in the world fuel mix by supplying 65-80% of primary energy use. Combined with the growth in primary energy use, this results in an ever increasing speed of depletion of natural resources.
- The worldwide production of coal grows faster than oil and gas production. The main growth of coal production takes place in Africa and Asia, as well as in the Eastern Europe and Former Soviet Union region.
- The growth in gas consumption is roughly in line with the growth in total energy consumption, i.e. the relative contribution of gas does not change significantly on the global scale.

#### *Regional differences remain large*

- At present, the gross inland consumption of energy per capita shows a large divergence between the industrialised world, North America, Japan, and Western Europe on the one hand, and the developing countries on the other hand. Although the per capita consumption increases in all regions in the world, the differences remain large, which is a reflection of our assumption that no additional action is taken to increase equity.
- The present distribution of primary energy intensities, the indicator measuring the average amount of energy needed for the production of one unit GDP, shows a large dichotomy between the developed countries and the developing countries. Energy intensities improve in all regions and their levels converge. This is for a large part the result of the global trend towards increased efficiency in energy consumption. In the developing countries, such improvements may temporarily be offset by the shift from un-marketed energy towards commercial energy, which occurs due to industrialization.

#### *Electricity increasingly important*

- The importance of electricity in satisfying the final energy demand increases in all world regions, leading to an average global contribution of 32% electricity in final energy demand in 2050. However, the present large regional variations, ranging from some 12% in the developing world to 20% in the industrialised world, tends to remain, as the trends in growth seem to be roughly the same world-wide.
- While there is little controversy over the increase in consumption of electricity, there is huge uncertainty over which technologies will be dominant in 2050. Most of the models however seem to agree that gas and coal technologies will play a significant role by 2050. The agreement is completely lost when considering renewable energy sources, where contribution from these sources to the total electricity demand ranges from 10% to a quarter, and nuclear power, where it varies between 0-20%.

#### *Hydrogen plays a modest role, at best*

- Hydrogen may develop as an alternative to electricity and combustible fuels due to its unique character as transportable clean energy vector. However, in a baseline scenario, the conditions needed for successful penetration of hydrogen are absent, and therefore the contribution of hydrogen remains relatively small. There is a huge uncertainty in the future role of hydrogen, as the production of hydrogen differs by orders of magnitude in 2050 among models.

### 6.3 Europe in a global context

#### *Europe in 2030 - what can we expect?*

- In Europe, the primary energy consumption increases by some 20% in 2000-2030, which is a much slower growth than the world average. The reliance on fossil fuels, with a 70-75% contribution to the primary energy mix, is comparable to the rest of the world. Europe's consumption of natural gas is expected to increase significantly, largely due to the increased use of natural gas for power production.

- Less consensus exists on the prospects of oil, coal and nuclear energy. The expectations on consumption of oil vary from stable to a slight decrease. The perspectives of solid fuels and nuclear energy mainly depend on the development of the European fuel mix for power generation. Coal consumption is expected to stabilise or grow. Some models expect nuclear energy to be phased out in the baseline, although no explicit phasing out policies have been included. This reflects that these models assume higher costs for nuclear power.
- Europe's 10 New Member States presently have a 45% share of coal in their primary fuel mix, a great deal larger than in their Western European counterparts. This is balanced by a much smaller share of nuclear and renewables. In the next decades the energy system of the New Member States is expected to move towards the energy system of the EU-15. Consequently, the relative importance of coal will diminish, as new, additional generation capacity will be covered mainly by natural gas and renewables.

#### *Europe uses a lot of energy but does so efficiently*

- Energy intensities can be used for comparing Europe's energy consumption to that in the rest of the world. European residents use 2,3 times as much energy as the world average, and the energy consumption per capita shows an increasing trend, implying that the energy needs of the average European citizen are still increasing steadily. American residents use approximately twice as much energy as western Europeans, and no structural change is expected. On the other hand, in the New Member States, energy consumption per capita starts at a lower level but shows the highest rate of increase.
- Europe's energy intensity, measured as the amount of primary energy required to generate one unit of GDP, is among the lowest in the world. An exception is the situation in Europe's 10 New Member States. The high level of the energy intensity in the base year indicates that there is a lot of room for efficiency improvements. A steep decrease in intensity for this region shows that this potential for improvement is to a large extent exploited: while for 2000 the intensity for the New Member States region is roughly three times that of Western Europe, in 2030 the fraction has diminished to approximately a factor two, and the level is comparable to that of the world as a whole.

## 6.4 Challenge: Security of supply

### *Security of Supply will become a worldwide issue*

- Recognising the continuing global reliance on fossil fuels, an important issue in the years to come will be the increasing dependence on oil from the Middle East. Although the models show different projections of the evolution of oil production, in all models the contribution from the Middle East region grows, and becomes substantially larger. This is confirmed by the results of a stochastic model yielding a more than 85% probability that by 2030 the Middle East produces more than half of the annual oil consumption. This indicates that the world as a whole becomes more and more dependent on the resources of one specific region.
- Given that this (at present) rather unstable region tends to remain dominating in the oil production, it comes as no surprise that there is a substantial probability of sudden increases in the oil price of some 40-60%. Also, one of the models suggests that Security of Supply is likely to be a more severe issue for oil than for gas - which would be in line with the status of reserves.

### *Europe's import dependency will increase significantly*

- For Europe, the observations made for the world have significant implications. Europe's dependence on oil from the Middle East is expected to increase up to 85%. If other world regions also increasingly rely on oil from this region, this may indeed lead to further oil price increases, which will particularly affect the transport sector.

- For natural gas, external dependency will also grow in the next decades. A continuing growth in gas consumption combined with a decrease of gas production in the UK, the Netherlands and Norway, will lead to a higher share of imports from the two main suppliers Russia and Algeria. Additionally, the accession of the new Member States and their heavy reliance on supplies from Russia increases the risks related to gas supply security. On the other hand, enlargement is expected to reduce the risks associated with transit of gas across the New Member States towards EU-15 countries.
- There is another dimension to security of supply than dependency on imported fuels. The level of diversification, inversely related to the dependence on a few primary fuels, and the correlation between these fuels in terms of costs and availability may further influence the sensitivity of Europe to fuel supply disruptions. Preliminary analysis of these issues indicates that an increase in diversification – for instance a growing contribution from renewables – may alleviate the increase in external dependence for oil and gas. It should be noted however that the models show large differences in their projections of Europe's future fuel mix, and thus in the expected level of diversification.

## 6.5 Challenge: Climate change

### *Global CO<sub>2</sub> emissions to double until 2030*

- It is likely that global warming is attributable to human activities, in particular to emissions of greenhouse gases, including emissions of CO<sub>2</sub>. All models project a continuing growth of these emissions. Overall, the CO<sub>2</sub> emissions in 2030 are expected to be approximately twice the level of 1990, the base year of the Kyoto protocol. The largest growth of these emissions is expected to occur in the developing world, in particular Asia.
- There is a large variation in emissions projections between models, related to the differences in the primary energy mix, particularly the share of fossil fuels. This illustrates the uncertainty of developments within the boundaries of the harmonised baseline scenario.
- The carbon intensity of the world economy is projected to decrease with 30-50%. The main contributors to this decrease are Asia, Eastern Europe and the former Soviet Union, where the growth in emissions is compensated with a higher GDP growth. The region encompassing Eastern Europe and the former Soviet Union remains the most carbon intensive one.

### *Western Europe will have severe difficulties complying to the Kyoto protocol*

- Although CO<sub>2</sub> emissions in Western Europe show moderate growth as compared to the global trend, it is not on track towards the target agreed under the Kyoto Protocol. Western Europe is committed to achieving an 8% reduction of CO<sub>2</sub> emissions by 2008-2012, as compared to the level in 1990. This means that in this period, the level of total CO<sub>2</sub> emissions (including non-energy uses) in Western Europe should not exceed approximately 3100 Mton per year. However, all models indicate that the energy-related CO<sub>2</sub> emissions alone are already expected to exceed this level. Therefore additional instruments to those in place by the end of 2003, such as emissions trading with regions outside Annex 1 Europe, based on the JI and CDM instruments, will have to play a key role in meeting Kyoto commitments.
- Beyond 2012, assuming that some type of climate policy is in place in Europe, reflected in a moderate carbon tax of 10 euro/ton CO<sub>2</sub>, emissions are expected to continue their growth with ca. 0.4% per year.
- CH<sub>4</sub> emissions reductions might become important in mitigating the enhanced greenhouse effect. According to one of the models, the increase in emissions of CO<sub>2</sub>, N<sub>2</sub>O, is compensated by a decrease in CH<sub>4</sub> emissions. As a consequence, the overall development of greenhouse gas emissions (in Mton CO<sub>2</sub> equivalents), also shows a decrease. The decline in CH<sub>4</sub> emissions is mainly due to reduced methane emissions from disposal sites, as a result of increased recovery of methane. Another possibility is to combust the methane, and possibly utilise the produced heat. This reduces the methane emissions but produces CO<sub>2</sub> emissions, which have a less strong greenhouse effect.

## 6.6 Strategies and directions

The analysis presented in this report has identified some major challenges that the world is facing today. The findings are in line with the Commission WETO report<sup>23</sup> and the IEA World Energy Outlook 2004 (IEA, 2004). In the next phases of the CASCADE MINTS Part 2 project, several strategies will be explored that may help to counter these developments. These strategies rely on technologies based on renewable energy, nuclear power, CO<sub>2</sub> capture and storage, and hydrogen. All of these have their own characteristics, costs, advantages and consequences, and will be further assessed within the project.

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<sup>23</sup> See [http://europa.eu.int/comm/research/energy/gp/gp\\_pu/article\\_1257\\_en.htm](http://europa.eu.int/comm/research/energy/gp/gp_pu/article_1257_en.htm)

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## APPENDIX A KEY CHARACTERISTICS OF THE ENERGY MODELS

Table A.1 *Models by type*

Model	System boundaries	Top-down/ bottom-up	Endogenous technology learning	Objective	Type	Distinguishing features
<i>Global models, US, Canada</i>						
AIM Asian Pacific Integrated Model	Macro economic	Top-down		The AIM model assesses policy options for reducing greenhouse gas emissions and avoiding impacts of climate change, particularly in the Asia-Pacific region. It can also be used for analysis at the global level.	A recursive dynamic equilibrium model of the world economy.	<ul style="list-style-type: none"> <li>Family of models.</li> </ul>
DNE 21+ Dynamic New Earth 21+	Energy sector	Bottom-up	No, exogenous	The model seeks the trajectory of optimal global energy systems to mitigate global warming.	Global energy systems model, bottom-up type, dynamic optimisation.  DNE21+ has a simple relationship between the energy price and the demand using the long term price elasticity.	<ul style="list-style-type: none"> <li>77-Region world model.</li> <li>Time horizon is 2000 to 2100.</li> </ul>
ETP Energy Technology Perspectives	Energy sector	Bottom-up	(under development)	Supporting the development of WEO 2004 alternative Policy Scenario (which will be a global scenario).	Dynamic Energy System Optimisation.	<ul style="list-style-type: none"> <li>Global 15-regional MARKAL-model.</li> <li>Time horizon: 2050.</li> <li>Linked to IEA WEO scenarios.</li> </ul>
GMM Global Markal Macro	Energy sector	Bottom-up	Yes	To provide a broad platform for analysis of technological progress and related policy insights.	A dynamic linear programming 'bottom-up' model. Technology-oriented model allowing a rich representation of both supply and demand technologies.	<ul style="list-style-type: none"> <li>Multi-regional model.</li> <li>Partial equilibrium (MARKAL-ED) using elastic demands.</li> <li>Time horizon 2000-2050.</li> </ul>
MAPLE (Canada)	Energy sector	Bottom-up	Yes	To undertake analysis of technology, environmental issues and regulations related to energy policies.	Energy-economy equilibrium with imperfect foresight. Each market is modelled according to the way consumers make decisions, e.g., refinery and utility markets are energy	<ul style="list-style-type: none"> <li>MAPLE is a technology-rich model which solves annually for energy economy equilibrium.</li> <li>The baseline assumes current regulations and policies extend into</li> </ul>

Model	System boundaries	Top-down/ bottom-up	Endogenous technology learning	Objective	Type	Distinguishing features
					cost minimizers while residential car choices are based on multiple attributes (logit functions). It is derived from the US model NEMS.	the future; continual progress is assumed in the menu of technologies available for future choices based on historical trend. Actual progress is determined endogenously through consumer choices and endogenous technology improvements.
MESSAGE Model for Energy Supply Strategy Alternatives and their General Environmental Impact	Energy sector	Bottom-up	Yes (optional)	Medium- to long-term energy system planning, energy policy analysis, and scenario development.	Dynamic systems-engineering optimisation model. The model provides a framework to represent an energy system with all its flows and dependencies. It can be used to compute a least cost solution based on exogenous energy demand.	<ul style="list-style-type: none"> <li>• Technology-rich model with a time frame of 1990-2100.</li> <li>• All technologies in the energy system are associated with a number of characteristics such as energy inputs and outputs, capital and operational costs, facility lifetimes, emissions of various types per unit activity, maximum possible penetration rates and start year.</li> <li>• Technological change is represented in two ways: either exogenously in the form of predefined learning rates for different technologies over time as well as endogenously, where costs are reduced as a function of increasing cumulative capacities.</li> </ul>
NEMS (US) National Energy Modeling System	Energy sector	Bottom-up	Yes (for electric power technologies and all other relatively new infant technologies in the building sector)	To develop Annual Energy Outlook and to do analysis of technology, environmental or regulatory energy policies.	Energy-economy equilibrium with imperfect foresight. Each market is modelled according to the way consumers make decisions, e.g., refinery and utility markets are energy cost minimizers while residential car choices are based on multiple attributes (logit functions).	<ul style="list-style-type: none"> <li>• NEMS is a technology-rich model which solves annually for energy economy equilibrium.</li> <li>• The baseline assumes current laws, regulations and policies extend into the future; continual progress is assumed in the menu of technologies available for future choices based on historical trend. Actual progress is determined</li> </ul>

Model	System boundaries	Top-down/ bottom-up	Endogenous technology learning	Objective	Type	Distinguishing features
						endogenously through consumer choices and endogenous technology improvements.
NEWAGE-W	Macro economic	Top-down	No	Analysis of the macroeconomic effects of climate change policies (e.g. CO <sub>2</sub> reduction) on a global level.	Computable General Equilibrium Model (CGE)	<ul style="list-style-type: none"> <li>• Intertemporal.</li> <li>• 33 regions.</li> <li>• 4 sectors.</li> </ul>
POLES	Energy sector	Bottom-up	Yes (optional)	World energy market model. The model structure corresponds to a hierarchical system of interconnected modules and involves three levels of analysis: international energy markets, regional energy balances and national models on energy demand.	It is a recursive simulation model, in which energy markets responds with different lag structures to international price variations. Behavioural equations take into account the price effects, techno-economic constraints and trends.	<ul style="list-style-type: none"> <li>• 38 world regions (being extended to 46).</li> <li>• 15 energy demand sectors.</li> <li>• 12 large-scale power generation technologies.</li> <li>• 12 new and renewable energy technologies.</li> <li>• Endogenous oil, gas and coal prices.</li> </ul>
PROMETHEUS	Energy sector	Bottom-up	Yes	<ul style="list-style-type: none"> <li>• Provides strategic and analytical information on risks and probabilities regarding the variables incorporated in the model or any pre-determined function involving them: energy supply and demand, emissions, international fuel prices, power plant capacities, electricity generation by plant, reserves for oil and gas.</li> <li>• Provides stochastic input (variances, co-variances) to decision tools designed to incorporate risks.</li> </ul>	Stochastic	<ul style="list-style-type: none"> <li>• A self-contained energy model consisting of a set of stochastic equations.</li> <li>• All exogenous variables, parameters and error terms in the model are stochastic with explicit representation of their distribution including on many cases terms of co-variance. It follows that all endogenous variables as a result are also stochastic.</li> <li>• It contains stochastic relations describing technology improvement dynamics (both learning by research and experience).</li> </ul>

Model	System boundaries	Top-down/ bottom-up	Endogenous technology learning	Objective	Type	Distinguishing features
<i>European models</i>						
MARKAL	Energy sector	Bottom-up	Yes	To perform prospective analysis of long-term energy balances under different scenarios.	Dynamic Energy System Optimisation.	<ul style="list-style-type: none"> <li>• Price elastic demand.</li> <li>• Endogenous technology learning.</li> <li>• System cost minimisation.</li> </ul>
NEMESIS	Macro economic	Top-down	No	Assess for sectoral and macro-economic impacts of European policies in the area of Energy, Environment and R&D.	Neokeynesian macro econometric model with detailed energy/environment module for EU-15 countries + Norway.	<ul style="list-style-type: none"> <li>• 30 production sectors.</li> <li>• Endogenous taxes and tradable permits for 3 greenhouse gases.</li> <li>• Endogenous R&amp;D decisions of firms.</li> </ul>
PACE	Macro economic	Top-down	Endogenous TC (under development)	Assessment of economic and environmental impacts of climate change policies (cost-efficiency analysis).	Multi-sector, multi-region dynamic computable general equilibrium (CGE) model.	<ul style="list-style-type: none"> <li>• Bottom-up foundation of power sector.</li> <li>• Rational expectations.</li> </ul>
PRIMES	Energy sector	Bottom-up		Forecasting, scenario construction and policy impact analysis.	Partial equilibrium model of the EU energy system; hybrid model combining engineering orientation with economic market driven representations.	<ul style="list-style-type: none"> <li>• EU-25, Norway and Switzerland.</li> </ul>
TIMES-EE	Energy sector	Bottom-up		Technology assessment and evaluation of climate mitigation strategies in the European electricity sector.	Energy System Optimisation, main focus on the electricity market.	<ul style="list-style-type: none"> <li>• Detailed power generation sector.</li> <li>• Detailed electricity exchange balances.</li> <li>• Consideration of CHP and electricity saving options.</li> <li>• EU-15, Norway, Switzerland, Poland and Czech Republic.</li> </ul>

## APPENDIX B IMPLEMENTATION OF HARMONISED BASELINE ASSUMPTIONS IN MODELS

### B.1 PRIMES

Input	Source	Remarks on if and how the translation was made
GDP	IPCC SRES B2	The GDP projections for EU-25 Member States are based on Economic and Financial Affairs DG forecasts of April 2002 for the short term (2001-2003); <sup>24</sup> and on macroeconomic forecasts from WEFA, <sup>25</sup> adjusted to reflect recent developments, for the horizon to 2030. Furthermore, for the EU-15 additional inputs were taken into account from Member States' stability programmes and long-term projections, stakeholders' consultation, <sup>26</sup> and the results of GEM-E3 model. <sup>27</sup>
Population	IPCC SRES B2	Population data from the B2 scenario family are based on the UN median 1998 population projections.
Energy prices (oil and optionally coal)	POLES	The values for the oil and coal prices provided by POLES were used.
Overall discount rate	Proposal ECN	Not used in PRIMES. Three rates are currently used within the model. The first, used mostly for large utilities, is set at 8%; the second, used for large industrial and commercial entities, is set at 12%; the third, used for households in determining their spending on transportation and household equipment, is set at 17.5%.
<i>Policy assumptions</i>		
Subsidies and taxes	(not harmonised, please indicate if included)	The Baseline scenario includes existing trends and the effects of policies in place and/or in the process of being implemented by the end of 2001; whereas tax rates reflect the situation of July 2002 in the EU-15 Member States.
Coal	Proposal ECN	All new coal plants have all Sulfur dioxide, NO <sub>x</sub> scrubbers as required by law.
Nuclear	Proposal ECN	Differences in current policies of all States as regards nuclear capacity, taking into account policy decisions as regards nuclear phase out in Belgium, Germany, and Sweden and plans concerning nuclear plant refurbishment/closure, as already agreed or under negotiation with the European Commission for the rest countries. <sup>28</sup>

<sup>24</sup> European Commission Economic forecasts, Spring 2002 (EUROPEAN ECONOMY. No. 2. 2002. Office for Official Publications of the EC. ISBN92-894-3357-4; ISSN0379-0991). Also available at: [http://europa.eu.int/comm/economy\\_finance/publications/europeaneconomy\\_en.htm](http://europa.eu.int/comm/economy_finance/publications/europeaneconomy_en.htm).

<sup>25</sup> WEFA (now integrated into DRI-WEFA) is an economic consultancy company which, in the context of the Long Run Energy Modelling framework contract, was subcontracted by NTUA to deliver a consistent macro-economic and sectoral forecast over the horizon to 2020 for the EU-15 Member States and, at a more aggregate level, for candidate countries and EU neighbouring countries (Norway and Switzerland). This projection was delivered in March 2001 and has been used as a benchmark in the context of this study.

<sup>26</sup> Workshop on 'Business-as-usual in energy intensive sectors beyond 2010', organised by Commission services (DG-ENV and DG-TREN), March 2001.

<sup>27</sup> The GEM-E3 model has been constructed under the co-ordination of NTUA within collaborative projects supported by DG-RESEARCH involving CES-KULeuven and ZEW.

<sup>28</sup> Nuclear policy assumptions of Central and Eastern European countries were drawn from the information contained in the 2001 Regular Reports from the Commission on Progress towards Accession, 13 November 2001 (<http://europa.eu.int/comm/enlargement/report2001/index.htm>).

Renewable electricity	Proposal ECN	Energy policies that aim at promoting renewable energy (wind, small hydro, solar energy, biomass and waste) and co-generation are assumed to continue, involving subsidies on capital costs and preferential electricity selling prices. Rather than imposing the indicative targets of the EC renewables electricity Directive <sup>29</sup> for each Member State, the Baseline includes the policy measures in view of such targets in each individual country.
Sulphur policies	IPCC SRES B2	It is assumed that stringent regulation for acid rain pollutants continues, especially for large combustion plants. Similarly, other clean air policies are assumed to continue.
Climate policies	Proposal ECN on Carbon value	For the purposes of the study it is assumed that a carbon tax of 10 Euro2000/tonne CO <sub>2</sub> as from the year 2012 (constant value over time) was implemented in all States.
Efficiency standards for cars		The effects from the voluntary agreement that was reached between the European Commission and the European automobile industry (followed in 1999 by similar agreements with Korean and Japanese car manufacturers).  Concerning the use of biofuels in transportation, it was assumed that all countries would follow EU rules <sup>30</sup> sooner or later. The impact of blending gasoline and diesel with biofuels on final consumer prices was assumed to be negligible, since higher fuel production costs will probably be offset by tax reductions scheduled to be implemented on these fuel blends.
Other	Efficiency improvement in all sectors.	Technological progress, induced both by economic growth and by modernisation of installations in all sectors of the economy, thereby improving the efficiency of the energy system.
	Energy intensity improvement	The restructuring of the sectoral pattern of economic growth, which gradually shifts away from traditional energy intensive sectors and concentrates on high value added activities, thereby improving energy intensity.
	Market liberalisation	The effects from restructuring of markets through the liberalisation of electricity and gas in the EU-15, which proceeds in line with EC directives; liberalisation is assumed to be fully implemented in the period to 2010. <sup>31</sup> Liberalisation of electricity and gas markets is also assumed to take place in New Member States, Bulgaria, Norway, Romania, Turkey and Switzerland to attain compliance with EC directives in the medium term.
	Restructuring of power and steam generation	The restructuring in power and steam generation, which is enabled by mature gas-based power generation technologies that are efficient, involve low capital costs and are flexible regarding plant size, co-generation and independent power production.

<sup>29</sup> European Commission Directive 2001/77/EC of the European Parliament and of the Council on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market. Brussels, 27 September 2001.

<sup>30</sup> European Commission Communication COM (2001) 547 of the European Commission of 07/11/01 on an action plan and two proposals for Directives to foster the use of alternative fuels for transport, starting with the regulatory and fiscal promotion of biofuels. Also at <http://europa.eu.int/comm/energy/library/comm2001-547-en.pdf>.

<sup>31</sup> This country-by-country modelling has focused on the dynamics of the energy system within a country, while considering trade in fuels between countries. An in-depth study of trade developments in electricity and gas would necessitate further work on the PRIMES model, which goes beyond the scope of this study.

Are the results in line with your 'usual' baseline?

- In our 'usual' baseline, it is assumed that no specific new policies and measures aimed at meeting Kyoto targets in 2008-2012, and possible more severe ones in the future, are implemented over the next 25 years. Therefore, the implementation of the carbon tax leads the energy system to a different solution.

Your judgement of robustness or an indication of sensitivities for specific assumptions:

- Different energy prices as well as different macroeconomic assumptions can have a strong impact on the future evolution.
- Policy towards energy efficiency and the promotion of renewable energy sources could change dramatically carbon emissions and improve security of supply.
- Large uncertainties in the power sector concerning nuclear policies.

Possible biases due to model mechanism or inputs:

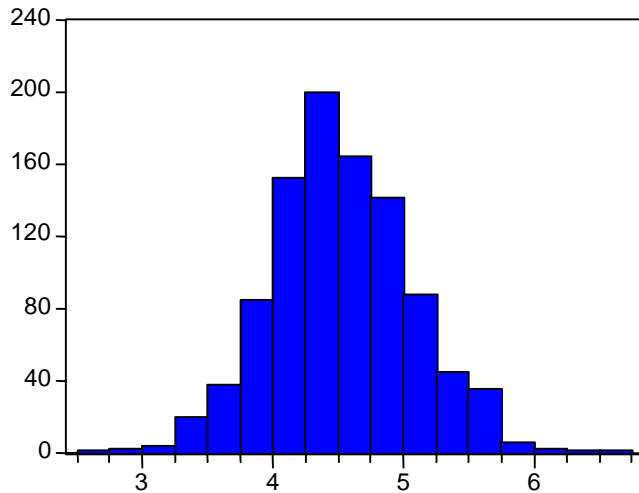
- In PRIMES model, consumer behaviour does not change easily.

Policy messages:

- The EU-30 energy system will need to deal with a number of major challenges over the next 30 years, including issues related to security of supply, tightening environmental pressures, competitive energy prices and significant investment decisions. Even with a carbon tax of 10 Euro/tonne CO<sub>2</sub>, CO<sub>2</sub> emissions in EU-15 remain 4.9% above 1990 levels in 2010.

## B.2 PROMETHEUS

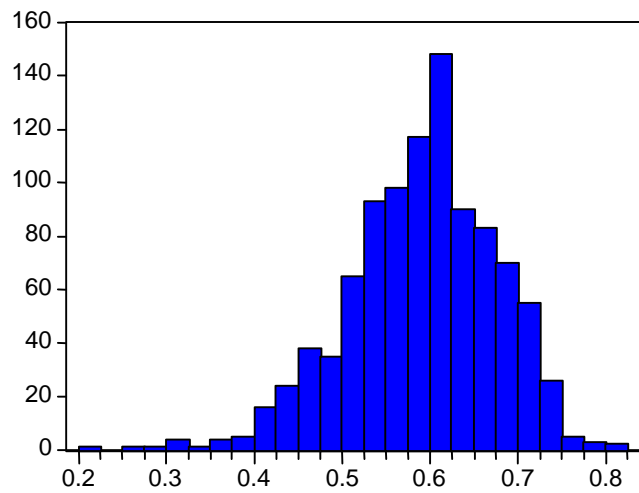
Input	Source	Remarks on if and how the translation was made
GDP	IPCC SRES B2	IPCC SRES B2 scenario growth rates were used (GDP is expressed in ppp).
Population	IPCC SRES B2	UN middle scenario projections were used.
Energy prices (oil and optionally coal)	POLES	Prices are endogenous in PROMETHEUS. However the mean values for oil and coal were calibrated to POLES.
Overall discount rate	Proposal ECN	Not applicable.
<i>Policy assumptions</i>		
Subsidies and taxes	(not harmonised, please indicate if included)	Continuation of present used in real terms.
Coal	Proposal ECN	No specific policy.
Nuclear	Proposal ECN	As in ECN proposal.
Renewable electricity	Proposal ECN	As in ECN proposal.
Sulphur policies	IPCC SRES B2	Not applicable.
Climate policies	Proposal ECN on Carbon value	For the period 2005-2010: <ul style="list-style-type: none"> <li>• EU: a carbon tax was assumed (Mean: 8.02 Euro/tonne CO<sub>2</sub> standard deviation: 6.08 Euro/tonne CO<sub>2</sub>)</li> <li>• Rest of OECD: a carbon tax was assumed (Mean: 1.6 Euro/tonne CO<sub>2</sub> standard deviation: 3.2 Euro/tonne CO<sub>2</sub>)</li> </ul> For the period 2011-2030: <ul style="list-style-type: none"> <li>• EU: (Mean: 10.3 Euro/tonne CO<sub>2</sub> standard deviation: 5.0 Euro/tonne CO<sub>2</sub>)</li> <li>• Rest of OECD: a carbon tax was assumed (Mean: 7.2 Euro/tonne CO<sub>2</sub> standard deviation: 5.2 Euro/tonne CO<sub>2</sub>)</li> <li>• Rest of the World: a carbon tax was assumed (Mean: 1.6 Euro/tonne CO<sub>2</sub> standard deviation: 3.1 Euro/tonne CO<sub>2</sub>)</li> </ul>
Efficiency standards for cars		Not applicable.
Other		



Ratio of  
GDP per Capita (OECD)  
to  
GDP per Capita (RoW)

Mean 4.523613  
 Median 4.490695  
 Maximum 6.500750  
 Minimum 2.582848  
 Std. Dev. 0.535623  
 Skewness 0.161591  
 Kurtosis 3.250657

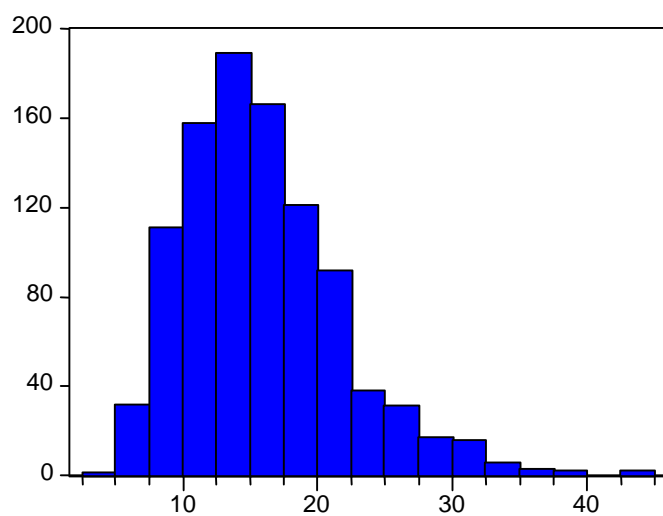
Jarque-Bera 6.865255  
 Probability 0.032302



Ratio of Middle East Oil Production  
to  
World Oil Production

Mean 0.590278  
 Median 0.597440  
 Maximum 0.808676  
 Minimum 0.213393  
 Std. Dev. 0.083965  
 Skewness -0.484350  
 Kurtosis 3.584455

Jarque-Bera 52.53201  
 Probability 0.000000



Maximum increase in Oil Price in  
any 3-years period [\$95/b]

Mean 15.90246  
 Median 15.01488  
 Maximum 43.26549  
 Minimum 3.321730  
 Std. Dev. 5.904048  
 Skewness 1.020350  
 Kurtosis 4.591114

Jarque-Bera 274.8189  
 Probability 0.000000



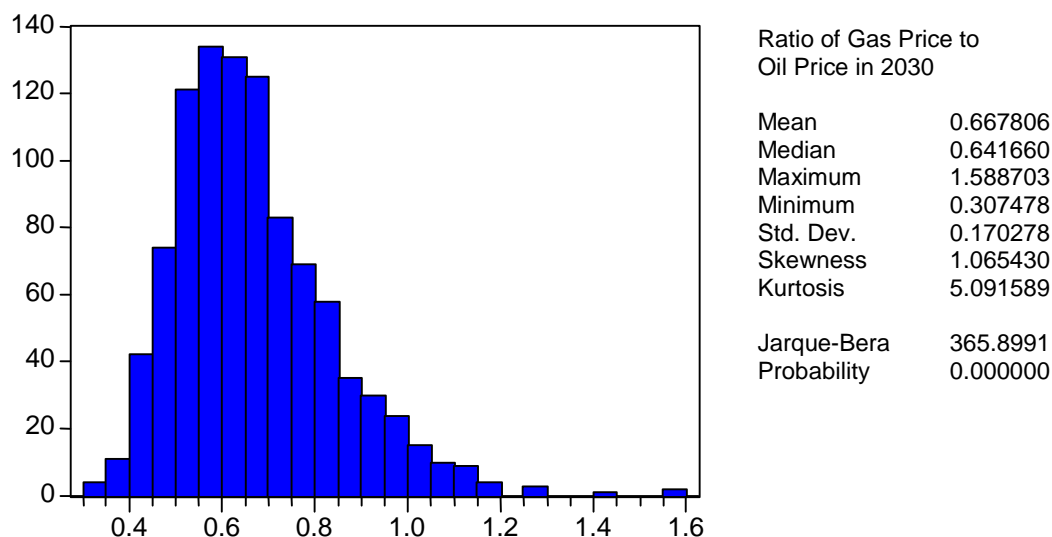


Figure B.1 *Distributions in 2030*

The probability:

- That GDP per capita in the Developing world will be more than one third of OECD GDP per capita in 2030 (currently it is less than one sixth) is slightly higher than 0.3%.
- That the Middle East produces more than half of total world oil production in 2030 is slightly more than 85%.
- That in the next 25 years there will be a price hike (over a short period) of more than (95)\$ 15 per barrel is nearly 50%.
- That the international gas price is lower than the international oil price is around 95%.
- That energy related CO<sub>2</sub> emissions worldwide more than double between 1990 and 2030 is nearly 85%.
- That there is on average de-carbonisation of world GIC between the present and 2030 is nearly 35%.

The correlations of the main world energy economy aggregates are predominantly positive suggesting a certain dominance of an axis: higher economic growth, higher consumption and higher energy prices.

Are the results in line with your 'usual' baseline?

- Main deviations from our usual baseline comes from higher growth in developing countries and lower in industrialised ones retained for CASCADE MINTS.

Your judgement of robustness or an indication of sensitivities for specific assumptions:

- PROMETHEUS results are based on a wide spectrum of possible outcomes by design.

Possible biases due to model mechanism or inputs:

- Could be due to the relative simplicity of model specification. The main source of bias could be due to possible biases in the basic common assumptions retained in CASCADE MINTS.

### B.3 MARKAL

Input	Source	Remarks on if and how the translation was made
GDP	IPCC SRES B2	Fully harmonized (exogenous input to the model).
Population	IPCC SRES B2	Fully harmonized (exogenous input to the model).
Energy prices (oil and optionally coal)	POLES	Fully harmonized world oil, gas and coal prices.
Overall discount rate	Proposal ECN	5%, consistent with ECN proposal.
<i>Policy assumptions</i>		
Subsidies and taxes	(not harmonised, please indicate if included)	No taxes were included.
Coal	Proposal ECN	Dynamic limit on phase-out of coal (relaxed over time).
Nuclear	Proposal ECN	No limitations (capacity limits will be introduced in the new calibrated baseline).
Renewable electricity	Proposal ECN	Lower limit of 18% renewables in electricity for Europe (constraints on electricity per fuel will be introduced during the ongoing calibration).
Sulphur policies	None	No policies were included.
Climate policies	Proposal ECN on Carbon value	€10 per ton CO <sub>2</sub> included for all sources of CO <sub>2</sub> .
Efficiency standards for cars		Accounted implicitly due to assumptions on energy intensity improvements in the mobility sector.

### B.4 MESSAGE

Input	Source	Remarks on if and how the translation was made
GDP	IPCC SRES B2	Fully harmonized (exogenous input to the model).
Population	IPCC SRES B2	Fully harmonized (exogenous input to the model).
Energy prices (oil and optionally coal)	POLES	Endogenous.
Overall discount rate	Proposal ECN	5%, consistent with ECN proposal.
<i>Policy assumptions</i>		
Subsidies and taxes	(not harmonised, please indicate if included)	No taxes were included.
Coal	Proposal ECN	Dynamic limit on phase-out of coal (relaxed over time).
Nuclear	Proposal ECN	No limitations (capacity limits will be introduced in the new calibrated baseline).
Renewable electricity	Proposal ECN	Lower limit of 18% renewables in electricity for Europe (constraints on electricity per fuel will be introduced during the ongoing calibration).
Sulphur policies	IPCC SRES B2	Included as emissions constraints.
Climate policies	Proposal ECN on Carbon value	We are operating with an aggregated OECD region, hence no carbon tax for Europe could be implemented.
Efficiency standards for cars		Accounted implicitly due to assumptions on energy intensity improvements in the mobility sector.
Other		

Are the results in line with your 'usual' baseline?

- This is our central, dynamics-as-usual baseline scenario, which corresponds to the long-term median of the scenario literature for the most important driving forces and scenario results.

Your judgement of robustness or an indication of sensitivities for specific assumptions:

- Uncertainty with respect to the dynamics and pace of technological change, economic growth, and demographic change can lead to considerably different outcomes (particularly in the long term). For a quantification of the uncertainty range see alternative projections illustrated in IPCC-SRES, 2000.
- Climate policies would change the results significantly.

Possible biases due to model mechanism or inputs:

- Perfect foresight.

Policy messages:

- Global carbon emissions are going to increase considerably, if there is no international incentive (regulation) for mitigation.
- Most of the growth in emissions is expected to occur in the developing world.
- There is large inertia in the energy system. Hence, short-term action (technology transfer/creation of niche markets) is needed to foster the introduction of advanced and cleaner technologies, in order to enable that these technologies play a significant role in the long term.

For more details see Riahi and Roehrl, 2000.

## B.5 POLES

Input	Source	Remarks on if and how the translation was made
GDP	IPCC SRES B2	The GDP is in pppEUR00, and it was not reconciliated with the SRES B2, as that is given in market prices. Comparison was made to the CMP2 baseline assumption pppGDP data, on the basis of the growth rates. Average differences are in the range of 0.2-0.4% amongst the given regions. (Considering that the CMP2 baseline assumptions are in 1990USD, the comparison is not straightforward).
Population	IPCC SRES B2	Same as UN reference case.
Energy prices (oil and optionally coal)	POLES	-
Overall discount rate	Proposal ECN	Not used in POLES, discount rates by technology.
<i>Policy assumptions</i>		
Subsidies and taxes	(not harmonised, please indicate if included)	Subsidies are assumed to diminish in long term, so all prices will at least cover costs.
Coal	Proposal ECN	No limit on available resources.
Nuclear	Proposal ECN	Future restrictions are not included.
Renewable electricity	Proposal ECN	The existing subsidies in place are considered in prices and costs. The target share of the EU (2001/77EC) is not included.
Sulphur policies	IPCC SRES B2	-
Climate policies	Proposal ECN on Carbon value	The 10 Euro CV is in place for the EU 27 regions.
Efficiency standards for cars		-
Other		Renewable energy: assumed domestic energy sources , Nuclear energy: fuel assumed all imported, Household energy demand values are included in the commercial sector, Biomass is in one category (no distinction is made for energy crops and residues). The regional exchange file cannot be filled - POLES has world pool for oil, three markets for gas - so the origin cannot be set. The NMS region cannot be created with the present POLES, instead our CEUR region is given as the closest (see remark in the file).

Possible biases due to model mechanism or inputs:

- Generally POLES baselines are coal intensive baselines, resulting in relatively higher carbon emissions.

## B.6 GMM

Input	Source	Remarks on if and how the translation was made
GDP	IPCC SRES B2	Same as IPCC SRES B2
Population	IPCC SRES B2	Same as IPCC SRES B2
Energy prices (oil and optionally coal)	POLES	Energy prices are endogenous to the model.
Overall discount rate	Proposal ECN	5%
<i>Policy assumptions</i>		
Subsidies and taxes	(not harmonised, please indicate if included)	Not included
Coal	Proposal ECN	Not included
Nuclear	Proposal ECN	It is assumed, that in 2050 the minimum nuclear power generation will remain at current global levels.
Renewable electricity	Proposal ECN	Penetration of renewable technologies is bounded by their regional technological potential.
Sulphur policies	IPCC SRES B2	Not explicitly modelled.
Climate policies	Proposal ECN on Carbon value	Carbon tax of 10€/tCO <sub>2</sub> applied in the OOECD region.
Efficiency standards for cars		Not included
<i>Other</i>		

Are the results in line with your 'usual' baseline?

- The underlying storyline for the reference development refers to the SRES-IIASA B2 'dynamics-as-usual' case. The baseline end-use demands and renewable-energy potentials are directly taken from B2 scenario. However, no attempt has been undertaken to calibrate the baseline scenario to match the results of the SRES-B2 scenario. In this respect, the reference development corresponds to a PSI scenario, since the allocation of resources is based on an optimisation performed under conditions of perfect foresight with 'learning-by-doing' considerations (LBD). The baseline is updated to reflect IEA statistics for the base year (2000). Cost specification of some technologies has been revised (e.g. nuclear- and hydro-power, hydrogen production). Additionally, carbon tax for OOECD region has been included in the Baseline. The results are comparable to our previous reference scenario.

Your judgement of robustness or an indication of sensitivities for specific assumptions:

- Since the ETL approach is applied in the power sector, the results regarding technology and fuel mix for electricity generation is highly dependant on the assumptions, particularly on progress ratios and growth rates for the different technologies.
- The reference development for the power sector is coal-intensive. Thus, implementation of explicit sulphur policies might influence significantly results of baseline.

Possible biases due to model mechanism or inputs:

- There is a full global spillover of experience and knowledge transfer across regions assumed in the model. The limitation of ‘learning’ spillovers for selected technologies might change results of baseline.
- Conservation measures are not explicitly modelled.

Policy messages:

- The baseline scenario remains in the median range of assumptions concerning socio-economic and technological developments for mankind and is able to serve as basis for studying policies of interest for the CASCADE-MINTS project. The global primary energy consumption experiences a significant increase and is largely dominated by fossil fuels. Both coal and natural gas experience a substantial growth, with clean coal technology and gas becoming the predominant source by the end of the horizon. Growth of oil remains modest, but it continues to hold a significant contribution. Non-fossil resources slowly gain market share. At the global level, electricity generation experiences a vigorous growth with the bulk of this growth driven by developing regions. On the demand-side it is assumed that the historical shift from non-commercial to commercial fuels and towards more clean and flexible, grid-transported energy carriers at the final-energy level continue in the future.
- Cumulative learning processes constitute important mechanisms of technological change and play a significant role in the diffusion of technologies.

## B.7 PACE

Input	Source	Remarks on if and how the translation was made
GDP	IPCC SRES B2	Adjustments to convex growth profiles
Population	IPCC SRES B2	Yes
Energy prices (oil and optionally coal)	POLES	Yes
Overall discount rate	Proposal ECN	Yes
<i>Policy assumptions</i>		
Subsidies and taxes	(not harmonised, please indicate if included)	As of GTAP 5.4
Coal	Proposal ECN	No explicit policy
Nuclear	Proposal ECN	No explicit policy
Renewable electricity	Proposal ECN	No explicit policy
Sulphur policies	IPCC SRES B2	No explicit policy
Climate policies	Proposal ECN on Carbon value	Yes
Efficiency standards for cars		No explicit policy
<i>Other</i>		

The calibration of our intertemporal multi-sector, multi-region CGE model is based on the GTAP5.4 benchmark year 1997. We take this year to be the year 2000 and do a dynamic calibration in 10-year periods. Due to the differences between 1997 values and 2000 values the absolute level values of the model baseline may substantially differ from the MESSAGE reference baseline (based on the empirical values for 2000) although we employ the same growth rates.

## B.8 NEWAGE-W

Input	Source	Remarks on if and how the translation was made
GDP	IPCC SRES B2	Transformation of MESSAGE GDP from 1990 till 2030 into growth-rates for NEWAGE-W. Remark1: NEWAGE-W is calculating in \$1997. For converting into €2000, it makes a difference, if you first inflate Dollar and than exchange it to Euro or the other way round. E.g. GDP for WEU in the year 2000 is 11730 GEUR2000 (Source: MESSAGE) but is 9180 GEUR2000 (Source: PRIMES). The difference could be a result of that problem. After all I used the conversion factor from the deflator.xls you sent us. This issue could cause some confusion. Remark2: The assumptions for overall COAL Use/Production seems to be a little pessimistic. Remark3: Due to the COAL production projection, the world CO <sub>2</sub> emissions in 2030 are much lower than e.g. in POLES. This effect is intensified by smaller overall GDP growth-rates (compared to POLES). Remark4: Total CO <sub>2</sub> emissions in 1990/2000 seem to be very high, concerning the given Primary Energy consumption in MESSAGE.
Population	IPCC SRES B2	Population is not an input parameter for NEWAGE-W.
Energy prices (oil and optionally coal)	POLES	Included
Overall discount rate	Proposal ECN	5%
<i>Policy assumptions</i>		
Subsidies and taxes	(not harmonised, please indicate if included)	-
Coal	Proposal ECN	-
Nuclear	Proposal ECN	-
Renewable electricity	Proposal ECN	-
Sulphur policies	IPCC SRES B2	-
Climate policies	Proposal ECN on Carbon value	-
Efficiency standards for cars		-
Other		-

## B.9 TIMES-EE

Input	Source	Remarks on if and how the translation was made
GDP	PRIMES / IEA	Fully harmonized (exogenous input to the model)
Population	PRIMES / IEA	Fully harmonized (exogenous input to the model)
Energy prices (oil and optionally coal)	Proposal ECN	Fully harmonized (exogenous input to the model)
Overall discount rate	Proposal ECN	5%, consistent with ECN proposal
<i>Policy assumptions</i>		
Subsidies and taxes	(not harmonised, please indicate if included)	Country-specific taxes (level of 2000) are included.
Coal		National coal policies are reflected.
Nuclear		National nuclear policies are reflected.
Renewable electricity		National policies on renewables are reflected considering lower limit of different renewables in electricity per country.
Sulphur policies		Included in technology description.
Climate policies	Proposal ECN on Carbon value	Carbon tax for Europe is implemented.
Efficiency standards for cars		Only electricity sector is considered.
Other		

Are the results in line with your 'usual' baseline?

- This is our central baseline scenario, which corresponds to other projections like IEA or European Energy and Transport Trends to 2030.

Your judgement of robustness or an indication of sensitivities for specific assumptions:

- Uncertainty with respect to the dynamics and pace of technological change, economic growth, and demographic change can lead to considerably different outcomes (particularly in the long term).
- Climate policies or variations in energy policy assumptions would change the results significantly.

Possible biases due to model mechanism or inputs:

- Perfect foresight
- Competitive markets.

Policy messages:

- Carbon emissions of the electricity sector in Europe are going to increase considerably, if there is no strong international or european incentive (regulation) for mitigation.
- Most of the growth in emissions is expected to occur in the electricity sector of Southern Europe and of Germany and the Netherlands.

## B.10 NEMESIS

Input	Source	Remarks on if and how the translation was made
GDP	IIASA B2 Scenario for Western Europe	
Population	For European area: growth of 0.34% for 2000/1990, 0.16% for 2010/2000 and 0,04% for 2020/2010	
Energy prices (oil and optionally coal)	POLES	
Overall discount rate	5%	
<i>Policy assumptions</i>		
Subsidies and taxes	(not harmonised)	
Climate policies	ECN's proposal on climate policy, by assuming a carbon tax of 10Euro2000/tonne CO <sub>2</sub> from 2012 onwards.	
Efficiency standards for cars	Effects from voluntary agreements between European Commission and the automobile industry (ACEA/JAMA/KAMA) are incorporated.	
<i>Other</i>		

The guidelines for baseline harmonisation were introduced in the bottom-up module of NEMESIS (NEMESIS-EnergyEnvironmentModule, NEEM).

This Energy/environment module is rather detailed (see baseline results sheet A\_base), but with the following limitations:

1. It does not distinguish biomass energy crops and residues; instead we have a global category biomass. Biomass consumption and production are model results.
2. NEMESIS EEM does not include a precise CHP representation and only approximations can be provided. However the fuel for power generation includes the fuels consumed in CHP plants.
3. Hydrogen economy is not yet modelled, thus no hydrogen production can be reported.
4. Shadow prices for gas, oil and coal cannot be reported by NEMESIS EEM (There are no constraints in the model for oil, gas and coal production).
5. Also total system cost cannot be provided. Only investment cost in the power generation sector.
6. Finally regional exchanges are not modelled.

NEMESIS EEM takes as major inputs GDP, sectoral productions, households' final consumption, long term interest rates projections, from the top-down economic model (sheet B\_TD). The economic model baseline is currently being actualised, and the baseline results displayed on sheets A\_base and B\_TD will be modified during the project; they are thus at this stage only indicative on the kind of outputs NEMESIS could provide.



The current economic baseline was built in 2002/2003 using the following assumptions:

- External trade: The world economy was expected to recover after 2003, with sustained growth of China supposed to increase its imports following its entry in WTO.. Asian new developing countries and India were supposed to benefit as well of rising sources of economic growth. In the OPEC, structural reform was expected to give increasing support to growth making these countries more attractive to foreign investors. For NAFTA, Mexico was supposed to continue stimulate the economic activity in this area and besides, United States and Canada were expected to reinforce strongly there growth. For Japan, banking and structural problems were supposed to continue to limit growth potentials during the decade. Sustained growth perspective were expected as well for accessing countries and rest eastern European countries.
- World prices: they were supposed to grow about 2% per annum, with constant exchange rates after 2002.
- Demographic assumptions: In European area, in coherency with World Bank projections, population was forecasted to stay relatively stable, implying a potential drop of working population
- Technical progress: Rates are differentiated by country and production sectors, and driven by R&D expenditures of firms, which were supposed to increase slightly their research effort in reaction to international competition and the limitation of labour supply.
- Interest rates: Nominal rates are still exogenous in the model, and supposed to stay constant at 5%.
- Government Consumption and production of non market services: European states were supposed to continue to reduce their government consumption, and to limit the progression of social expenditures, which were supposed to progress less quickly than GDP after 2010.

The baseline scenario exhibits a strong growth until 2010, pulled-up by extra-European exports (not reported in sheet B\_td) as result of global world economic recovery. In relation with demographic assumptions and economic growth, expected decrease of unemployment leads to a sustained growth of real wages and final consumption, despite the relatively slow rise of total employment. For energy, final intensity was supposed to decrease in response to R&D activities despite a negative (price) substitution effect; for intermediate energy consumption, no gains were expected. Finally, intra-European trade was supposed to continue to reinforce.

For the rest of the period (after 2010), extra European trade was supposed to reduce progressively its growth rate, while World economies are supposed to evolve from strong growth to potential growth rates, and the gap between growth rates of world regions to reduce equally progressively.

At a sectoral level, equipment goods industries were supposed to accompany growth expansion while transportation and market services continue to increase their contribution to overall economic activity, and continued declining contributions of agriculture and intermediate industries, at the exception of chemistry (which includes also pharmacy).

## B.11 DNE21+

Input	Source	Remarks on if and how the translation was made
GDP	IPCC SRES B2	Growth rate of GDP/capita from SRES B2 is used to obtain GDP/capita data for the four regions, and then the GDP/capita is multiplied with the national population to obtain GDP for each nation.
Population	IPCC SRES B2	Population data by nation of TG CIA (Task Group on Scenarios for Climate Assessment ) are used.
Energy prices (oil and optionally coal)		Production cost curves are assumed for fossil fuels according to Rogner, 1997. Their prices are determined endogenously.
Overall discount rate		5%/year
<i>Policy assumptions</i>		
Subsidies and taxes		Not included
Coal		Not included
Nuclear		Not included
Renewable electricity	Proposal ECN	Lower bounds of renewable electricity generation for the EU are adopted according to ADMIRE-REBUS until 2010 and not thereafter.
Sulphur policies		Not included
Climate policies	Proposal ECN on Carbon value	10 Euro/tonne CO <sub>2</sub> is adopted for the EU after 2010.
Efficiency standards for cars		Not applicable
Other		Change rate in hydro power generation is limited within $\pm 5\%/y$ for every region.

Which results are in your opinion worth highlighting?

- The DNE21+ is a 77 region global model of optimization type, a developed version of the DNE21 model. The DNE21+ distinguishes 54 countries and energy-environment policies of these countries are evaluated consistently and on the same basis; interregional energy trade is allowed including coal, crude oil, natural gas, methanol, hydrogen and electricity.

Are the results in line with your 'usual' baseline?

- The results are new but very similar at world level to those of the DNE21 which is reliable in our view.

Your judgement of robustness or an indication of sensitivities for specific assumptions.

- FC vehicles are treated in a tricky way to see how and when the hydrogen substitutes for gasoline. The assumption of their cost reduction affects the results pretty much.

Possible biases due to model mechanism or inputs.

- The model seeks for the future normative in the perfect foresight.

Policy messages

- Nuclear should phase out in no climate policy. Nuclear decreases and then disappears in our baseline results.

## B.12 NEMS

Input	Source	Remarks on if and how the translation was made
GDP	IPCC SRES B2	GDP is based on the US DOE/EIA baseline input assumptions as provided by the Global Insight 'mid' case; definition is based on US government published statistics. The resulting GDP results from the 'mid-growth' GDP case of Global Insight and used in the US DOE revised reference case of April 24, 2004. Since the resulting GDP is adjusted slightly by the feedback with the US energy market, GDP is partly a derived result. That white paper suggested that the two measures of GDP (one used by the EU and the one used by the US government) are different and reconciliation may not be reasonably possible.
Population	IPCC SRES B2	Same as UN reference case.
Energy prices (oil and optionally coal)	POLES	Energy prices in NEMS are internal to the model with partial exception of world oil prices.
Overall discount rate	Proposal ECN	Not used in NEMS – discount rates set by technology, end-use customer class.
<i>Policy assumptions</i>		
Subsidies and taxes	(not harmonised, please indicate if included)	All existing US federal and state taxes and incentive policies have been implemented for the US.
Coal	Proposal ECN	NA - all new coal plants have all Sulfur dioxide, NO <sub>x</sub> scrubbers as required by law.
Nuclear	Proposal ECN	NA – allowed to compete but does not penetrate market.
Renewable electricity	Proposal ECN	Used all existing State and Federal incentives.
Sulphur policies	IPCC SRES B2	Existing Clean Air Act Regulations as enacted.
Climate policies	Proposal ECN on Carbon value	NA
Efficiency standards for cars		Use existing CAFÉ standards for new cars and light trucks.
Other	Electricity pricing and regulation	Deregulated/regulated Electricity markets as currently represented by individual state policies/laws.

Are the results in line with your 'usual' baseline?

- This is our usual but updated baseline, since we agreed that anything endogenous would be left alone.

Your judgement of robustness or an indication of sensitivities for specific assumptions

- Assumed natural gas resource base in the US is an important uncertainty as is the ability of OPEC to stay cohesive. Also, since WOP are determined more by political factors than production cost, actual WOP's are uncertain, based on availability of alternative (unconventional supplies from non-OPEC) and alternative technologies, (Coal to liquids and gas to liquids).
- Carbon policy could dramatically change results of baseline.
- New efficiency standards or CAFÉ standards could dramatically change carbon emissions.

Possible biases due to model mechanism or inputs

- Model assumes consumer behaviour does not change easily (i.e., effective hurdle rates and basis for decisions remain unchanged in the forecast period)

Policy messages

- Voluntary programs don't do very well in most of US markets.