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WETO 2030

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FOREWORD

With the launch of the *European Research Area*, I have underlined the need to provide the EU with a common system of scientific and technical reference for policy implementation particularly for aspects related to sustainable development.

This World Energy, Technology and climate policy Outlook (WETO) is a clear example of a fruitful collaboration between European researchers (ENERDATA and IEPE in France, BFP in Belgium and IPTS) helping decision-makers to define their long-term policies.

Starting from a set of clear key assumptions on economic activity, population and hydrocarbon resources, WETO describes in detail scenarios for the evolution of World and European energy systems, power generation technologies and impacts of climate change policy in the main world regions or countries. It presents a coherent framework to analyse the energy, technology and environment trends and issues over the period to 2030, focusing on Europe in a world context.

I would like to highlight three of the key results of this work:

First, in a Reference scenario, i.e. if no strong specific policy initiatives and measures are taken, world CO_2 emissions are expected to double in 2030 and, with a share of 90%, fossil fuels will continue to dominate the energy system;

Secondly, the great majority of the increase in oil production will come from OPEC countries and the EU will rely predominantly on natural gas imported from the CIS.

Lastly, as the largest growing energy demand and CO_2 emissions originate from developing countries (mainly China and India), Europe will have to intensify its co-operation, particularly in terms of transfer of technologies.

The analysis of long-term scenarios and a particular attention to the energy world context, is an important element for efficient energy, technology and environment policies towards a sustainable world.

Philippe Busquin
Member of the European Commission
Responsible for Research

KEY MESSAGES

Reference scenario

- The WETO study describes a Reference scenario that provides a description of the future world energy system, under a continuation of the on-going trends and structural changes in the world economy (a "business and technical change as usual" context). The scenario results should be seen as a **benchmark** for the assessment of alternatives, particularly with respect to resources, technologies and environmental policy. A sound understanding of the long-term issues is a key element in establishing future research and technological development priorities in the field of energy and environment. The Reference scenario does represent a baseline performance which can be bettered if appropriate policies are put in place.

- **World energy demand** is projected to increase at about 1.8%/year between 2000 and 2030. The impact of economic and population growth (respectively 3.1% and 1%/year on average), is moderated by a decrease in the energy intensity of 1.2%/year, due to the combined effects of structural changes in the economy, of technological progress and of energy price increases. Industrialised countries experience a slowdown in the growth of their energy demand to a level of e.g. 0.4%/year in the EU. Conversely, the energy demand of developing countries growths rapidly. In 2030, more than half of the world energy demand is expected to come from developing countries, compared to 40% today.

- The world energy system will continue to be dominated by fossil fuels with almost 90% of **total energy supply** in 2030. Oil will remain the main source of energy (34%) followed by coal (28%). Almost two-thirds of the increase in coal supply between 2000 and 2030 will come from Asia. Natural gas is projected to represent one quarter of world energy supply by 2030; power generation provides the bulk of the increase. In the **EU**, natural gas is expected to be the second largest energy source, behind oil but ahead of coal and lignite. Nuclear and renewable energies would altogether represent slightly less than 20% of EU energy supply.

- Given the continued dominance of fossil fuels, **world CO_2 emissions** are expected to increase more rapidly than the energy consumption (2.1%/year on average). In 2030, world CO_2 emissions are more than twice the level of 1990. In the EU, CO_2 emissions are projected to increase by 18% in 2030 compared to the 1990 level; in the USA the increase is around 50%. While the emissions from developing countries represented 30% of the total in 1990, these countries are responsible for more than half the world CO_2 emissions in 2030.

- Sufficient **oil reserves** exist worldwide to satisfy the projected demand during the next three decades. However the decline in conventional oil reserves may constitute a preoccupying signal beyond 2030. It is only partly compensated by an increase in the reserves of non-conventional oil. The reserves of natural gas are abundant and expected to increase by around 10%. There is no constraint on coal reserves over this time horizon.

- **World oil production** is projected to increase by about 65% to reach some 120 million bl/day in 2030: as three quarters of this increase comes from OPEC countries, OPEC accounts for 60% of total oil supply in 2030 (compared to 40% in 2000).

- **Gas production** is projected to double between 2000 and 2030. However, regional disparities in gas reserves and production costs are expected to modify the regional gas supply pattern in 2030: about one third of the total production will originate from the CIS, while the remaining production will be almost equally allocated among other regions.

- **Coal production** is also expected to double between 2000 and 2030,with most of the growth taking place in Asia and in Africa, where more than half the coal would be extracted in 2030.

- The **oil and gas prices** trend corresponds to a significant increase from current levels: the oil price is projected to reach 35 €/bl in 2030 with gas prices at 28, 25 and 33 €/bl in 2030 on the European/African, American and Asian markets respectively. The regional gas price differentials are expected to diminish significantly, reflecting more comparable gas supply mixes. The coal price is expected to remain relatively stable at around 10 €/bl in 2030.

- The **final energy demand** will grow at a similar pace to the gross inland consumption. As all **sectors** are expected to experience similar growth, their share in final demand will remain roughly constant at world level: around 35 % for industry, 25 % for transport and 40 % for the residential and tertiary sectors. The energy demand by sector shows different patterns according to the regions: in developed countries, energy demand in the services sector is the fastest growing segment; in developing countries, all sectors experience sustained growth at 2 to 3 %/year.

- **Electricity** continues its penetration in all regions, accounting for almost a quarter of final energy demand; coal declines in industrialised countries; biomass is progressively phased out in developing countries. **Oil** remains the dominant fuel, with a share ranging from 40 to 50 % in 2030 according to the region.

- **Electricity production** increases steadily at an average rate of 3 %/year. More than half of the production in 2030 will be provided by technologies that emerged in the nineties and afterwards like combined cycle gas turbines, advanced coal technologies and renewables.

- The share of **gas in power generation** increases steadily in the three major gas-producing regions (CIS, Middle East and Latin America) and the share of coal decreases in all regions, except in North America where it stabilises and in Asia where it increases significantly. The development of **nuclear** power does not keep pace with total electricity production: its market share comes down to 10 % in 2030. **Renewables** covers 4 % of the production (from 2 % in 2000), mainly because of a rapid progression in electricity production from wind.

Sensitivity to changes in hydrocarbons resources and technology developments

- With **lower hydrocarbons resources**, oil and gas prices are projected to be much higher than in the Reference at around 40 €/bl for oil in 2030. This induces a lower world energy demand (-3%), which particularly favours coal and non-fossil energies, and curtails demand for natural gas (-13%) and oil (-6%). As a result, world CO_2 emissions are 2% lower than in the Reference.

- Conversely, **increased gas resources** would lead to a drop in gas prices to 16, 20 and 28 €/bl in 2030 on the American, European and Asian markets respectively. Oil price decreases only slightly reflecting the limited potential for substitution between oil and gas. Although the world energy demand is slightly affected (+1.5%), the fuel mix is substantially modified in favour of natural gas (+21%, against -9% for coal, -3% for oil and -4% for primary electricity).

- **Accelerated technology developments for electricity generation** lead to significant changes in the structure of electricity production. Important though the power sector may be, it only accounts for about one third of world CO_2 emissions. Technologies only addressing this sector thus have a limited impact on total CO_2 emissions. The availability of advanced technology, however, can have considerable impact on the cost to meet emission reduction targets.

EU gas market in a world perspective

- The **EU gas market** is rapidly expanding and growth is expected to continue in the next two decades, driven by the "dash for gas" for power generation. Nevertheless, the EU contribution to world gas consumption is expected to decrease steadily.

- **World gas reserves** are abundant but concentrated in two world regions, the CIS and the Middle East, where gas production is projected to grow considerably during the next thirty years. In contrast, the European gas resources are limited and production is expected to decline steadily beyond 2010, resulting in an increasing dependence on external gas supplies.

- **Natural gas demand** is also projected to increase in the other world regions: some of them with limited or declining gas reserves will become net importers leading to important changes in the world gas trade patterns. For instance, the rapid growth of gas demand in Asia is expected to have some influence on the EU gas supply pattern in 2030: while Asia is projected to rely predominantly on gas supplies from the Middle East, the EU and Accession countries may import more than half their natural gas needs from the CIS.

- This outcome may translate into higher **supply risks** for the EU. These risks could however be limited through different actions as outlined in the EC Green Paper, like the multiplication of gas transport routes, the further integration of the European gas network, and a continuous dialogue with gas producing countries. Long-term contractual LNG supplies are projected to increase but more moderately and from more diverse sources in Africa and the Middle East.

Impacts of climate change policies

- By attaching a **carbon value** to fossil fuel use, CO_2 emissions in 2030 are 21 % lower than in the Reference at world level and 26 % lower in the EU and Accession Countries. At the world level and in most regions, this reduction is achieved by equal reductions in energy demand and in the carbon intensity of energy consumption.

- In the **carbon abatement case**, more than half of the world energy demand reduction is achieved in the industry sector. The **decrease in carbon intensity** comes mainly from the substitution of gas and biomass for coal and lignite and to a lesser extent oil; gas demand remains roughly stable as fuel switching in favour of gas takes place. In contrast, the consumption of biomass increases significantly and nuclear progresses considerably while large hydro and geothermal remain stable; finally, wind, solar and small hydro jump up by a factor of 20.

CHAPTER 1

CONTEXT AND METHODOLOGY

1.1 THE REFERENCE SCENARIO

The Reference scenario of WETO provides a coherent picture of the evolution of energy supply and demand by world regions, as only driven by the economic fundamentals, over the next thirty years. The framework of hypotheses was chosen so as to reflect the state of the world in a "business and technical change as usual" perspective, which can serve as a benchmark for the economic evaluation of the future EU policy options related to energy supply and demand, and to carbon constraints. For this purpose, the Reference does not take into account specific energy or environment policy objectives and measures beyond what is actually (2000) embodied in "hard decisions" (investment actually made, regulation actually enforced in law and voluntary agreements actually signed). This means in particular that the reduction objectives in the Kyoto Protocol, the phase-out of nuclear planned or envisaged for the future in some countries, the targeted share of renewables or the future modifications planned or envisaged in the economic instruments (e.g. coal subsidies) are not part of the Reference. The reference does neither aim at predicting what will happen or what is the most probable future, nor at illustrating the EU policy targets, but rather at identifying and sizing the possible problems and constraints raised by a business as usual development, that EU and member countries will have to face. For instance, with respect to CO_2 emissions, this reference shows the emissions gap that needs to be closed with further measures after the decisions of the EU to ratify the Kyoto Protocol.

This outlook is based on the results of the POLES model. This simulation model, developed and used under different EC programmes since 1994, allows to elaborate long-term energy supply and demand projections for the different regions of the world under a set of consistent assumptions concerning, in particular, economic growth, population and hydrocarbon resources (Box 1).

Projecting long-term energy profiles involves a large number of assumptions. The population growth assumptions are derived from the United Nations demographic forecasts. The world economic growth outlook results from CEPII projections (« Centre d'Etudes Prospectives et d'Informations Internationales"). The US Geological Survey is the source of information used for oil and gas Ultimate Recoverable Resources. It provides a set of estimates and attached probabilities that are consistent on a world and region-by-region basis. Technological developments regarding energy technology costs and performances are derived from analyses elaborated in the framework of other projects within the European Commission's Research Directorate-General (TEEM[1] project, 2000).

[1] Capros P., guest Editor, *Energy Technology Dynamics and Advanced Energy Systems Modeling (TEEM: a program funded by the European Commission, Directorate General Research),* in International Journal of Global Energy Issues, Special Issue, Vol. 14, Nos. 1-4, 2000.

All projections in WETO refer to seven world regions and seven countries or group of countries. The world regions are the North America, Japan/Pacific, CIS/CEECs (Community of Independent States / Countries of Central and Eastern Europe), Latin America, Africa/Middle East and Asia. The countries or group of countries under focus are the European Union, either in its existing size with 15 countries or including the Accession Countries, USA, Japan, Brazil, China and India. The composition of each world region is provided after Chapter 6.

The detailed description of the results of the Reference scenario for the world energy system to 2030 are presented in Chapters 2 and 3.

1.2 UNCERTAINTIES

The Reference scenario, as any other baseline projection involves many uncertainties that may considerably change the world energy development pattern in the next three decades. Two of these uncertainties will be considered in this report: the resource estimates for oil and gas and the development for new electricity production technologies.

Resource availability

The uncertainty on oil and gas resources is taken into account through two variants:

- The low oil and gas resource case is designed to test the sensitivity of the projections to more pessimistic assumptions on hydrocarbon resources, and to assess the consequences of higher oil and gas prices on energy demand and supply to 2030.

- The high gas reserves case is designed to simulate a situation where gas prices are structurally lower than oil prices. For that purpose, the assumptions of the Reference are used for oil resources, while higher estimates are considered for gas resources.

Both cases are examined and analysed against the Reference Scenario, so as to provide insights on their main impacts on the world energy system in general and on the energy system of the EU in particular (Chapter 4).

Technology development

Beside the uncertainties on hydrocarbon resources, Chapter 4 also explores the uncertainty on the future development of power generation technologies. More precisely, it provides an assessment of the potential impacts of accelerated technological changes through different technology cases. Each case combines consistent sets of alternative hypotheses regarding the future costs and performance parameters (e.g. conversion efficiency, availability factor, safety requirement) of selected power generation technologies, based either on fossil fuels, nuclear energy or renewable energy forms.

The methodology used to develop and analyse the technology cases consists in three steps: first, the identification of possible technological breakthroughs affecting clusters of technologies, then the use of expert judgment to translate these breakthroughs into more optimistic performance trajectories, and third the assessment of the impacts of these alternative cases against the Reference. The assessment encompasses changes in fuel supply, in the competitive position of power generation technologies, and in global and power generation CO_2 emissions at the world and regional level.

This report presents four technology cases:

- The "gas" case, which assumes enhanced availability of natural gas and introduces further improvements for combined cycle gas turbines and fuel cells.

- The "coal" case, which involves major improvements in advance coal technologies, namely supercritical coal plants, integrated coal gasification combined cycle plants and direct coal firing plants.

- The "nuclear" case, which assumes a breakthrough in nuclear technology in terms of cost and safety. It has an influence on standard large light water reactors but especially on new evolutionary nuclear reactors.

- The "renewable" case, which supposes a major improvement in renewable energies notably wind power, biomass gasification, solar thermal power plants, small hydro and photovoltaic cells.

1.3 POLICY ISSUES

Finally, this report analyses in more detail two important issues regarding the long-term energy, technology and climate policy developments of the European Union. The first one relates to the future of natural gas in the EU in a context of growing demand in the other world regions and of uncertainty on resources and investments in transport infrastructure. The second one deals with the impacts to 2030 of the introduction of a carbon constraint at world level on EU and other world regions' energy balances and technology developments.

The EU gas market in a world perspective

Over the last ten years, the world demand for gas has grown rapidly. Gas demand increased the most rapidly for several reasons, including price competitiveness, environmental advantages over other fossil fuels and abundant resources. The rise in gas consumption has been particularly remarkable in the power generation sector. As the Reference projects the continuation of this trend through 2030 – although at a lower pace by the end of the projection period – it is worth asking how the projected growing market for gas, combined with the decline of gas production in Europe, will affect the outlook of gas supplies to 2030 and what the impacts will be on the security of supply in the EU.

The POLES model provides a valuable tool for addressing the above issue. Its world dimension makes explicit not only the linkages between the gas demand growth and the decrease in gas production in the EU, but also the demand for gas in the other world regions and the characteristics of the regional gas markets (e.g. prices, pipeline and Liquefied Natural

Gas transport routes between the producing and consuming regions). The latter are key elements in the determination of the allocation of world gas resources among consuming regions.

Chapter 5 describes the projected evolution of the EU gas market in the Reference Scenario in terms of gas demand, gas supply portfolio, world gas trade and transport between pipelines and Liquefied Natural Gas.

Energy related CO_2 emissions constraints and long-term energy development

The Reference Scenario does not ensure that emissions reduction objectives are met–for the Kyoto First Commitment Period (2008-2012). Therefore the Reference represents a benchmark for the identification of the gap further measures need to close in the 2008 to 2012 time horizon and the debate and setting of commitments beyond 2012.

Chapter 6 is more particularly devoted to climate policy issues. It is divided into two parts, according to the time horizon considered. In the first part, the focus is on the Kyoto First Commitment Period and most of the attention is paid on the evaluation of the Reference against the Kyoto targets. A short discussion on the implementation of the Kyoto Protocol and on the state of affairs of international negotiations is also included.

The second part provides a description and a detailed analysis of a CO_2 abatement scenario (2030). This carbon abatement case is designed to simulate and assess the potential impacts of world CO_2 reduction policies on the future development of energy balances and technologies. This case is defined through the introduction of a "carbon value" that is differentiated by main world regions and time horizons. More precisely, the carbon values are determined so to reflect possible regional differences in implementing the Kyoto targets in 2010.

Box 1: The POLES Model[2]

The model structure corresponds to a hierarchical system of inter-connected modules and involves three levels of analysis:

i. International energy markets;
ii. Regional energy balances;
iii. National models[3] on energy demand, new technologies and renewable energy, power generation, primary energy supply and CO_2 emissions.

The dynamics of the model is based upon a recursive simulation process, in which energy demand and supply in each national or regional module respond with different lag structures to international prices variations in the preceding periods. In each module, behavioural equations take into account the combination of price effects, technico-economic constraints and trends.

There are fifteen final energy demand sectors (covering the main industrial branches, transport modes, the residential and service sectors), twelve large-scale power generation technologies and twelve new and renewable energy technologies.

Oil and gas supply profiles in the largest world producing countries are dealt with a discovery process model in which oil and gas production depends on the dynamics of the drilling activity and discovery of new reserves, given the existing resources and the cumulative production. Coal, supply is essentially demand driven.

The integration of import demand and export capacities of the different regions are ensured in the international energy market module, which balances the international energy flows. One world market is considered for oil (the 'one great pool' concept), while three regional markets (America, Europe/Africa, and Asia) are identified for gas and coal so as to account for regional differences in cost and market structures. The changes in international prices of oil, gas and coal are determined endogenously in this module. The international price equations take into account the relevant variables associated to short-term adjustments in price levels, such as the Gulf capacity utilisation rate for oil, and to medium and long-term variables such as the Reserve on Production ratio for oil and gas, or the trend in productivity and production costs for coal.

[2] For more information www.upmf-grenoble.fr/iepe/textes/POLES8p_01.pdf

[3] The POLES model identifies thirty-eight world regions or countries, of which the 15 countries of the EU and the largest countries (USA, Canada, Japan, China, India, Brazil, etc.).

CHAPTER 2

ENERGY AND TECHNOLOGY TRENDS TO 2030

2.1 KEY ASSUMPTIONS

The Reference scenario

The Reference scenario aims at providing a description of the future world energy system, as if the on-going technical and economic trends and structural changes were to continue. In this respect, it constitutes the appropriate benchmark for the economic assessment of future energy and climate policy options.

The Reference scenario was designed with the following philosophy:

- The main drivers in the future development of the world energy system will remain the demography and economic growth (Gross Domestic Product). As the on-going trends for these two sets of variables are differentiated across the main world regions, their continuation results in significant changes in the regional structure of population, GDP, energy demand and associated emissions.

- Technical change has been a continuous phenomenon through history, although this process may be submitted to slowdowns or accelerations. Thus, any projection of the economic system has to take into account the consequences of the continuous improvement in the technologies' economic and technical performances. As far as energy technologies are concerned, the hypotheses considered in the Reference indeed take into account technological progress, at least along the lines of past improvements (hypotheses of breakthroughs are considered elsewhere in the technology cases).

- The availability of energy resources is clearly a potential constraint for the development of fossil fuel use in the long term, or at least it is a factor that can bring tensions on the international energy markets and drive the energy prices up. Coal resources are known to be overabundant, at least for the next century. But huge uncertainties surround any assessment of the recoverable oil and gas resources at the world and regional level. The Reference scenario uses median estimates for resources that are identified at the regional level, with values that are globally well accepted by the experts, in a "business as usual" perspective.

- As far as energy and climate policies are concerned, the Reference scenario only includes the consequences of policy measures, which are actually (2000) embodied in "hard decisions" (investment actually made, regulation actually enforced in law and voluntary agreement actually signed). It is even considered by judgement that some measures may not benefit of a full implementation over the projection period. Thus the Reference does not include the compliance to the policy decisions or announcements made by governments, including the European Commission, or industries, such as the Kyoto commitments, the targeted share of renewables[4], the nuclear phase-out in Germany or Belgium, or the removal of existing economic instruments (eg subsidies or taxes). This is logical as the cost of these policies, which are being implemented or will be implemented in the near future, can only be assessed by comparison with a reference scenario that is free of such constraints or commitments.

As any model, POLES, the model used in this study, is a simplified representation of reality, mostly based on the fundamental economic relations involved in the world energy system. Some important factors, which may have a decisive impact on the future development of the world energy system, are either ignored or at least not explicitly dealt with in the model, because too complex or impossible to quantify. Among these factors: the geopolitical drivers and constraints that have already played a major role on the energy scene, such as the industries' regulation and organisation schemes, which have changed significantly in the past twenty years.

As a consequence, the "business and technical change as usual" energy evolutions depicted by the Reference are mostly driven by changes in economic fundamentals that reflect rational economic behaviours. How these evolutions would modify the geopolitical constraints or foster complementary changes in the industries' regulation and organisation schemes, and, therefore, which policy response they may induce, is out of the scope of the Reference generated by POLES.

The dynamics in world population and economic growth

The combined growth in the world population and economy will remain key driving forces in the development of the energy sector over the next decades. The population outlook used in the WETO study is based on the UN population prospects[5]. The economic outlook has been prepared by the CEPII[6] and is based on a simple growth model that takes into account the accumulation of physical and human capital in the different regions considered.

The resulting picture of the world population and GDP[7] to 2030 reflects a combination of continuing trends and of important structural changes. The key features of these dynamics can be summarised as follows:

- World population growth rate will continue to decrease over the projection period from 1.5 %/year in the past decade to 1 %/year over the 2000 to 2030 period. This results in a total population of 8.2 billions in 2030, from 6.1 billions in 2000.

- On average, world economic growth will be, slightly above 3 %/year for the next thirty years, a figure comparable to the past thirty years (3.3 %/year from 1970 to 2000 and 3.0

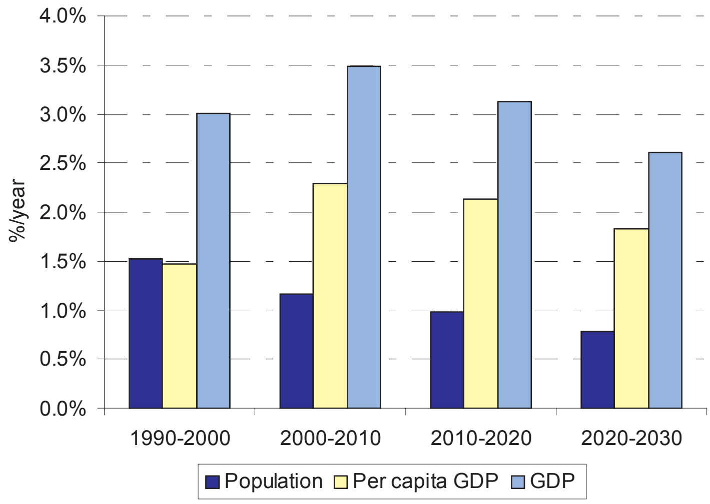
[4] The EU target is 12 % of gross consumption for renewable energy in 2010, as outlined in the European Directive (2001/77EC of the European Parliament and the Council of 27 October 2001) on the Promotion of Electricity from Renewable Energy Sources in the Internal Electricity Market.
[5] United Nations, *World Population Prospects, The 2000 revision,* UN Department of Economic and Social Affairs, Population Division, New York, 2001.
[6] IEPE, CEPII, CIRED, *Analyse des stratégies de Réduction des Emissions de gaz à effet de Serre*, ARES project, GICC Programme of the French Ministry of the Environment, 2002.
[7] All GDP figures in this study are calculated using a constant 1995 Purchasing Power Parity system.

% from 1990 to 2000, due in particular to the transition process in the CEEC and CIS region during the past decade).

- This is made possible by acceleration in the average per capita GDP growth that is particularly marked in the 2000-2010 decade, and is largely due to the projected economic recovery in the CEEC and CIS region.

- The combination of the continuous slowdown in the growth rates of the population and per capita GDP results, after the initial upsurge, in an economic growth rate that is weakening over time, from 3.5 %/year in the first decade, to 3.1 %/year and finally 2.6 %/year between 2020 and 2030 (Figure 2.1).

Figure 2.1: World population, per capita GDP and GDP growth

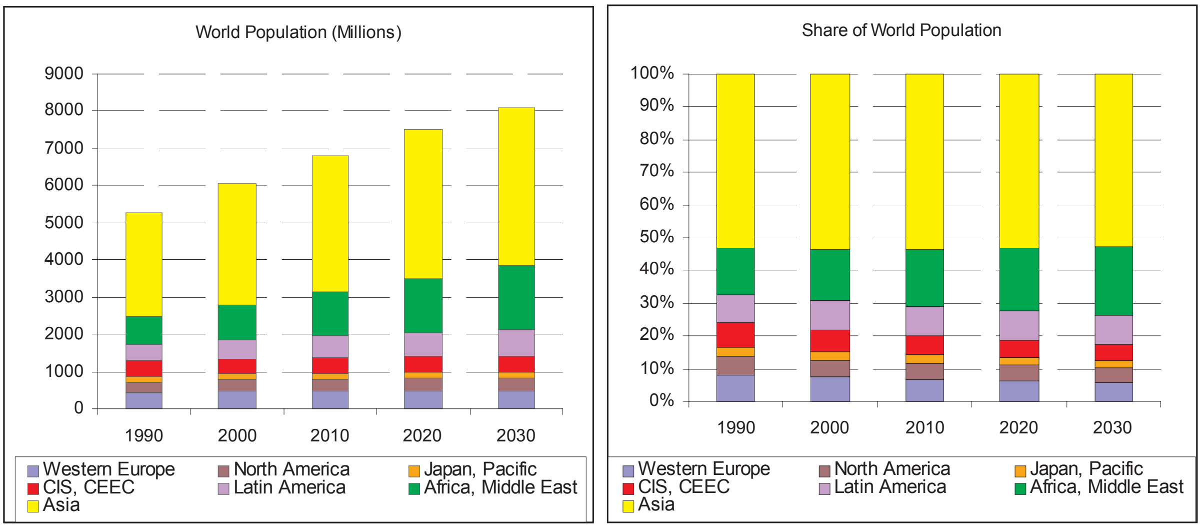


The structure of world population

As noted above, the increase in world population will slowdown over the next thirty years, and in some regions of the industrialised world the population will even decrease in absolute terms. This is the case of the EU after 2010, while this decrease only begins after 2020 in the CEEC and CIS region and in the Japan and Pacific region.

However the world population structure does not change that much over the projection period, as most regions only incur a 1 to 2-percentage points loss in their share. Only two regions experiment an increase in their share: Latin America (with a very limited gain of 0.4 percentage point) and the Africa and Middle-East region, whose share of world population goes from 16 % in 2000 to 22 % in 2030 (Figure 2.2).

Figure 2.2: World population, by region



GDP growth projections and changes in relative per capita GDP

The simple growth model that has been used to project the GDP of the different world regions is based on the hypothesis of a convergence in the GDP growth rates, subject to conditional hypotheses on investment rates in physical and human capital. The hypotheses used for the GDP projections intend to reflect the particular conditions of each country or region.

Box 2: GDP forecasts

The GDP projections used in the POLES model scenarios are provided by the CEPII (Centre d'Etudes Prospectives et d'Informations Internationales), a research centre of the French Government specialised in international economic analysis, modelling and forecasting.

GDP forecast by world region relies on a neo-classical growth model with exogenous technological progress and an explicit consideration of the human capital.

The main assumption of the model is the convergence in labour productivity towards a long-term equilibrium in a closed economy. The active population being exogenous, the forecast depends on three key factors: physical capital, human capital and technology level incorporated in labour. The physical capital is a function of the investment rate. The human capital is a function of the school enrolment, linked to the GDP per capita. The convergence in the labour productivity variation is due to an assumption of a decreasing marginal output of the physical and human accumulated capital.

Investment rates and school enrolment are different by country and the growth of the technology level incorporated in labour is higher for developed countries.

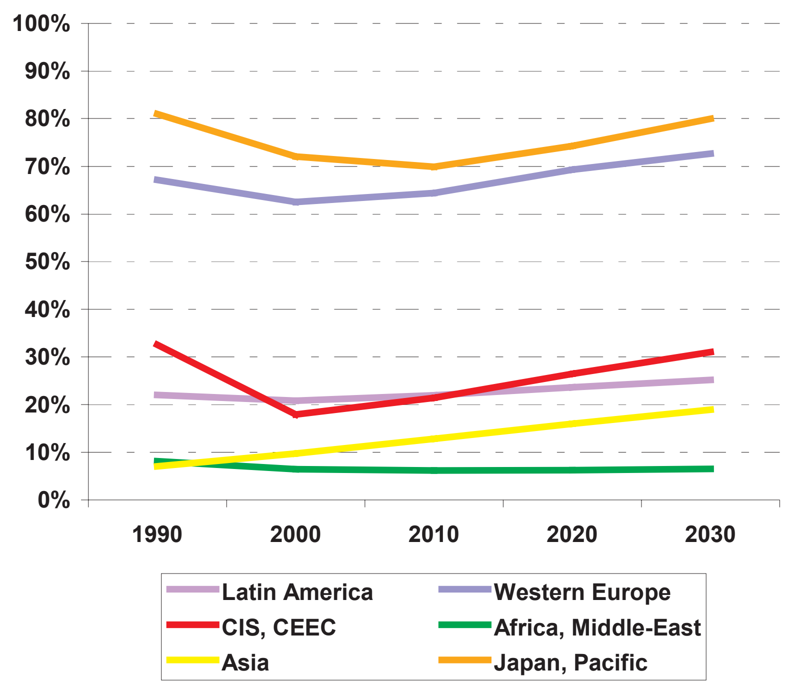
When translated into per capita GDP levels, the projections show a slight convergence across the different world regions. This convergence can be analysed by calculating the ratio of each region's per capita GDP on that of the higher income region, i.e. North America (Figure 2.3):

- After the 1990-2000 decade during which Western Europe and the Japan and Pacific regions lost some ground comparatively to North America, the projection results in some catch-up of these two regions in the next decades. The Japan and Pacific region recuperates its position of 1990 in 2030 (80 % of the North American level) while Western Europe slightly improves it (from 68 to 72 %).

- As far as the economies in transition are concerned, the per capita GDP ratio relatively to North America follows a much more uneven trajectory, with a huge drop from 1990 to 2010 (from 32 to 18 % of North American level). A sustained recovery follows, without however allowing a full recovery to the 1990 level (31 % in 2030).

- The trajectories of the developing regions are contrasted. While Asia sees a significant improvement in its per capita GDP ratio (from 8 to 19 % of the North American level between 1990 and 2030), the convergence process of Latin America is much more limited (from 20 to 25 %). The Africa and Middle East region does not experiment any convergence, as its per capita GDP represents a stable 7.5% of the North American level over the period.

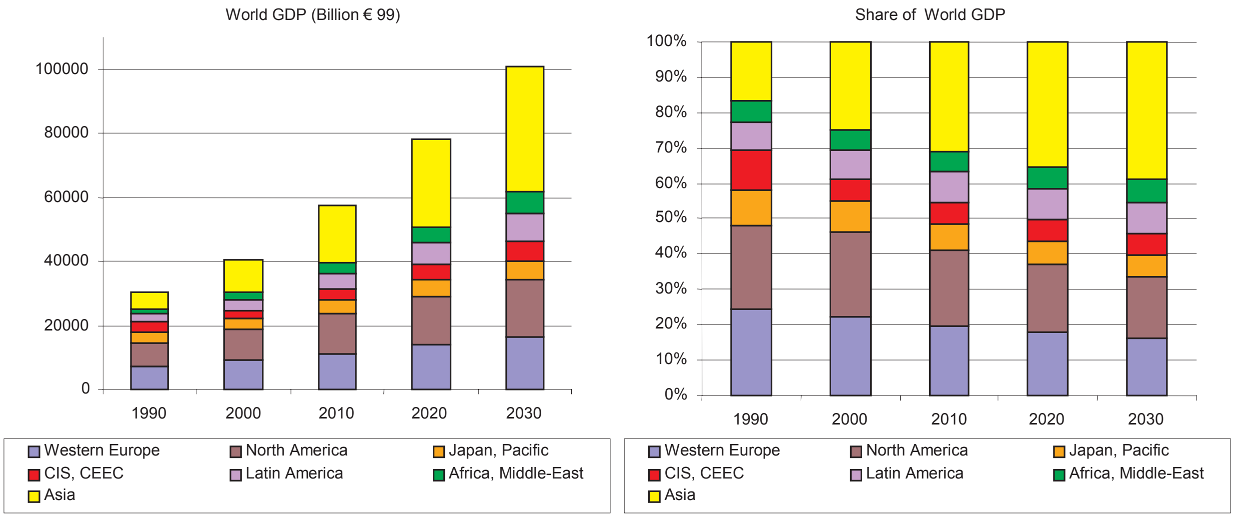
Figure 2.3: Per capita GDP by region as a percentage of North America



The structure of world GDP

The combination of population and per capita GDP growth results in an average world growth rate of 3.1 %/year over the projection period, with significant changes occurring in the world GDP structure. While the industrialised countries of the West and of the East (CEEC and CIS) represented up to 70 % of total world GDP in 1990, this share is already brought down to 62 % in 2000 due to the transition process in the economies in transition. In spite of the projected economic recovery in that region, the share of the industrialised countries continues to decline all over the projection and ends up with 45 % of world GDP in 2030 (Figure 2.4).

Figure 2.4: World GDP



The developing countries' share of world output thus significantly increases over the period. Although most of the gains take place in the Asia region, this new balance in the world economy is a key driving force in the WETO projections. During the next thirty years indeed, the economic and energy scene is likely to be influenced by the growth in developing regions. They will progressively become dominant, not only in the overall economic production, but also in energy consumption, production and CO_2 emissions.

Key assumptions

- The WETO Reference scenario provides a description of the future world energy system, under a continuation of the on-going trends and structural changes ("business and technical change as usual" context). The scenario results should be seen as a benchmark for the assessment of alternative cases, particularly with respect to resource, technologies and environmental policy.
- World population will reach 8.2 billions in 2030, from 6.1 billions in 2000. On average, world economic growth will be slightly above 3%/year for the next thirty years, a figure comparable to that of the past thirty years.
- Technological progress continues along the lines of past improvements, without hypotheses of major breakthroughs.
- Median estimates are considered for the assessment of recoverable oil and gas resources by region, with values that are globally well accepted by the experts in this field and account for technological progress in upstream oil and gas technologies.
- The Reference scenario only includes the consequences of the energy efficiency or environmental policies and measures that have already been decided up to now. It does not include a full compliance to the policy decisions or announcements made by governments – including the European Commission – or industries. In particular, the compliance to the Kyoto commitment of the various countries is not introduced as a constraint.

2.2 INTERNATIONAL ENERGY PRICES

Oil and gas prices increase throughout the projection period

The long-run evolution of the international oil and gas prices is simulated in the POLES model, reflecting basically the dynamics and lagged adjustments of world demand and supply (see Box 3). The global picture for oil and gas prices[8] in the Reference is illustrated in Figure 2.5.

Box 3: Oil, gas and coal prices modelling

The oil price is calculated at world level, the oil market being described as “one great pool”. It is considered as depending in the short term on the variations in the capacity utilisation rate of the Gulf countries and in the medium and long term on the world average Reserve on Production ratio.

The gas price is calculated for three regional markets: the American market, the Euro-African and the Asian market. The gas price on each market then depends partly on a gas to oil price factor but principally, for the long term, on the variation in the average Reserve on Production ratio of the core suppliers of each main regional market.

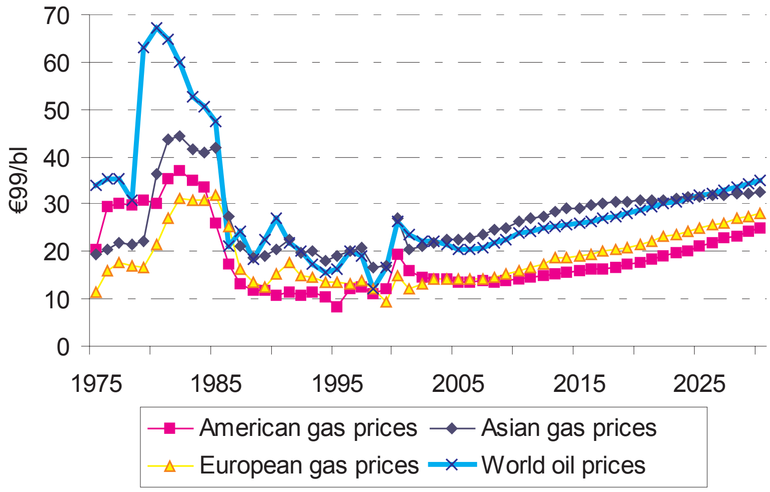
The coal price is also estimated for the same three regional markets. It is obtained by calculating the average price of the key suppliers on each market, weighted by their market shares. The average price of the key suppliers is derived from variations in mining and operating costs (function of per capita GDP increase and of a productivity trend) and from the capital and transport costs (both depending on the simulated production increases, as compared to a "normal" expansion rate of production capacities).

Figure 2.5 shows a decline in oil price until the middle of the current decade, compared to the high level of 2000. This decline is largely due to the moderate oil demand. Later on, the oil price increases relatively sharply to 24 €/bl in 2010 before a phase of more moderate but steady increase until 2030. The oil price reaches 29 €/bl and 35 €/bl in 2020 and 2030 respectively[9]. In fact, before 2010 a new period begins for the oil market, in which the oil production of the Gulf countries has to grow beyond its maximum historical level of about 23 million bl/day. Consequently, the Gulf oil producers need by that time to continuously develop new production capacities, while the reduction in Reserve on Production ratios at world level exerts an upward pressure on oil price. However, the price-path obtained from the model only indicates a trend that is consistent with the relative dynamics of world supply and demand and do not pretend to provide a precise oil price forecast. In particular, the projection do not account for possible geopolitical events that many times in the past proved to affect the price level.

[8] All prices are in € of 1999 (equivalent to US$ of 1995).

[9] In 2030 this represents a doubling over the average oil price in the nineties and a level that is significantly higher than in EU energy outlook published by DG Energy and Transport. This is because these forecasts reflect more optimistic views both on oil and gas endowments at world level, with resource hypotheses similar to those used for natural gas in the high gas resources case (§ 4.1.2.).

Figure 2.5: Oil and gas prices



For gas, the three continental markets - America, Europe/Africa and Asia – continue to be characterised by price levels that are structurally different. These differences reflect diverse levels of development in transport infrastructures and different conditions of supply, particularly the mix between pipeline gas and Liquefied Natural Gas (LNG). For instance, the Asian gas market is significantly dependent on LNG imports; consequently, current gas prices on this market are higher than in Europe and America. However, regional price differentials are expected to diminish significantly over the next 30 years, reflecting more comparable gas supply mixes by 2030. This is due to increasingly interconnected gas markets, with the same producers exporting to different consuming regions. Some difference in price levels however remains – for instance between Europe and Asia – as longer distances and consequent transport cost differentials imply slightly higher prices in the latter case (+18% in 2030).

On the European and African market, notwithstanding a period of relative stabilisation in the middle of the current decade, the gas price is projected to increase regularly to reach 28 €/bl in 2030.

On the American market, the gas price declines first significantly from the high level of 2000, down to 14 €/bl before the year 2010 and then increases again steadily, although more slowly than on the European market, to reach 25 €/bl in 2030.

Contrary to gas prices on the American and European markets, which follow comparable trends, the gas price on the Asian market increases constantly throughout the projection period from 20 €/bl in 2001 to 33 €/bl in 2030.

According to the mechanism of oil and gas prices formation (see Box 2), the price movements mainly depend on the variation of the Reserve on Production (R/P) ratio, which constitutes a long-term indicator of the balance between demand and supply. Nevertheless, the Gulf production capacities are also taken into account for the projection of oil price, as well as a partial oil-indexation term for the calculation of gas prices. The latter parameter is however assumed to be of decreasing importance throughout the projection period.

Figure 2.6 shows the evolution of the R/P ratios on the different markets: the international market for oil and the three regional markets for gas.

As regards to oil, the rather stable profile of R/P in the short-run explains – together with the moderate oil demand and increasing production capacities in the Gulf – why the oil price trend is decreasing from 2000 to the middle of the decade. Afterwards, the smooth but steady decline in R/P in the long run drives the oil price trend upwards.

The pattern of the oil R/P ratio (and consequently the trend in oil price) can be put in relation with the evolution of the world oil demand: the more pronounced decrease in oil R/P ratio during the second half of the decade corresponds to a marked increase in world oil demand, while the more moderate decrease from 2010 onwards can be related to a relative saturation of oil demand in OECD countries and a less buoyant demand in developing countries.

The Reserve on Production ratios for gas and their evolution throughout the projection period, illustrate the peculiarities of the different markets:

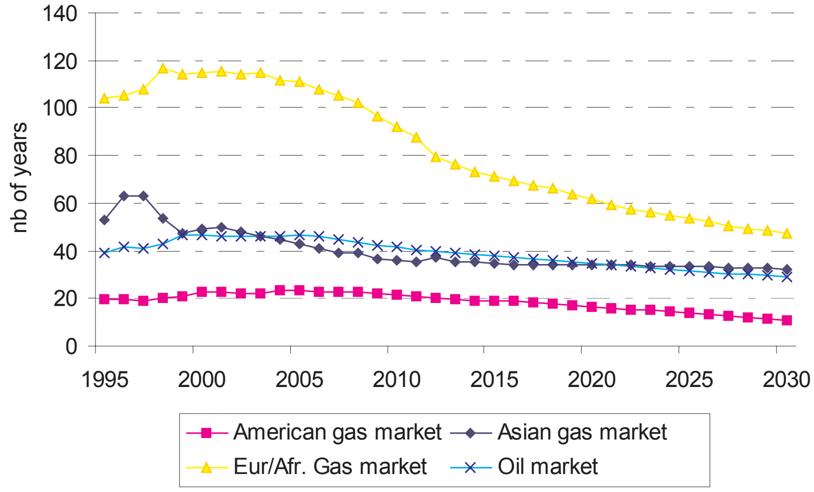
- The American market is characterised by low values of the R/P ratio (about 20 years over the last decade) compared to those of the other markets (above 40 years). The decline of the R/P ratio in the long run, together with the steady increase in oil price - although to a lesser extent - explains the increasing profile of gas price from the middle of the decade onwards.

- The Asian market has an intermediate R/P ratio. Contrary to the other two markets, its R/P ratio decreases continuously throughout the projection period. However, the smoother decrease at the end of the projection period explains the lower price increase compared to the American and European markets.

- The Europe/Africa market shows the highest R/P ratios[10], most particularly over the 1990-2005 period, when they range from 100 to 120 years. In 2000, there was a factor 2 between the R/P ratios in the European and Asian markets and a factor 6 relative to the American market. The gap is nevertheless projected to shrink progressively over time: in 2030, the difference between the European and Asian R/P ratio is reduced to 1.5, while the difference between the European and American R/P ratio is brought down to a factor of 3. The sharp decrease in the R/P ratio in the Europe/Africa market reflects relatively unbalanced long-term dynamics of supply and demand in this region.

[10] This is weighted average of the R/P ratios of the key suppliers.

Figure 2.6: Oil and gas reserve on production ratios



International coal price remains relatively stable

Coal price is independent of oil price and is assumed to remain so. Moreover, and contrary to oil and gas, coal supply will not be subject to resource constraints over the projection period. Therefore, in the POLES model, the evolution of coal price is derived from the development of production costs of the key producing countries (Box 2).

The Reference scenario projects stable, then slowly increasing, coal prices to reach levels of about 10 €/bl in 2030. This represents increases of 15 to 35 % from current price levels, according to the market considered. These limited increases in world coal prices, in spite of a sustained growth in consumption, reflect the extreme abundance of coal resources in many regions, as well as the possibility of significant productivity increases in coal production: in the next decades, the modernisation and mechanisation of coal production will exert a significant downward pressure on prices.

Key conclusions

- The oil and gas prices trend corresponds to a significant increase from current levels until the end of the projection period: oil price is projected to reach 35 €/bl in 2030.
- A similar statement holds for gas prices, at 28, 25 and 33 €/bl in 2030, respectively on the European/African, American and Asian markets.
- The regional gas price differentials are expected to diminish significantly over the next 30 years, reflecting more comparable gas supply mixes.
- The coal price is expected to remain relatively stable at around 10 €/bl in 2030.

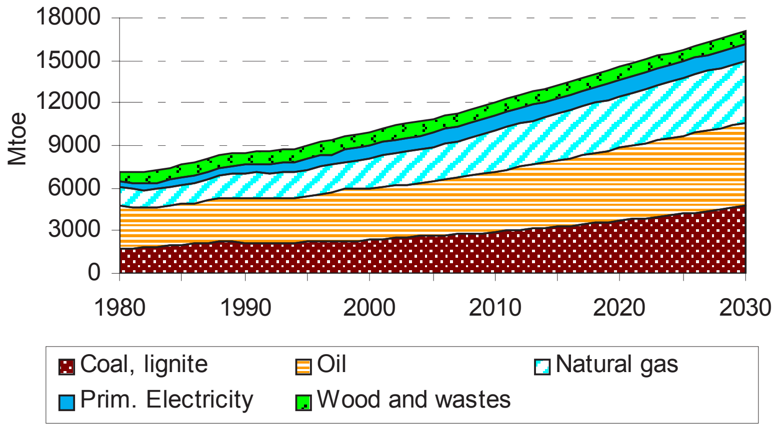
2.3. GLOBAL OUTLOOK FOR ENERGY AND CO_2 EMISSIONS

2.3.1 World energy consumption

Global trends

In the Reference, the picture of the world energy scene in 2030 mainly reflects an expanded vision of the current system. However, some significant changes occur, particularly in the relative shares of the main world regions and of the primary energy sources. These changes are associated, respectively, to different population and economic growth dynamics and to higher energy prices and more efficient technologies. The world energy consumption is projected to increase by some 70% over the 2000-2030 period (Figure 2.7). This translates into an average increase of 1.8%/year to be compared with 1.4%/year over the 1990-2000 period.

Figure 2.7: World energy consumption



In 2030, fossil fuels (coal, lignite, oil and natural gas) are projected to represent 88% of world energy consumption. This percentage is greater than the 81% share observed in 2000. Despite a rapid growth of coal and gas utilisation, oil still represents the largest share (34%) of the world gross inland consumption (GIC) in 2030:

- Oil demand increases at a rate similar to the one observed during the decade 1990-2000 (i.e. 1.6%/year) and demand reaches 5.9 Gtoe in 2030.

- Natural gas demand increases by 3%/year on average between 2000 and 2010 and by 2.1%/year afterwards. The share of natural gas in total consumption extends to 25% in 2030 from 21% in 2000.

- Coal demand is also projected to grow rapidly over the next thirty years. Between 1990 and 2000 the growth of coal consumption was 0.9%/year but after 2000 it goes up to 2.1%/year until 2010 and then to 2.5%/year until 2030 as it becomes more competitive than other fuels.

The change in the fossil fuel shares impacts considerably on the carbon intensity of the world energy system and on the associated CO_2 emissions, as discussed in section 2.3.2.

Nuclear energy increases slightly in absolute terms. During the 1990-2000 decade the growth of nuclear was 2.7%/year, but this rate weakens to 0.9%/year over the projection period. In 2030, nuclear represents 5% of the world GIC, compared to 7% in 2000.

The share of large hydropower and geothermal energy stabilises at 2% of world GIC. Wind, solar and small hydropower increase together by 7%/year between 2000 and 2010 and then by around 5%/year until 2030. In spite of the marked acceleration in the diffusion process of these renewable sources and because of their limited initial penetration, their market share represents less than 1% of world GIC in 2030. Conversely, wood and wastes consumption decreases steadily during the projection period, but its share in world GIC (5% in 2030, to be compared with 9% today) remains higher than the share of the new renewable sources.

Globally, energy from renewable sources is projected to cover 8% of world energy requirements in 2030. This is less than the 13% share observed in 2000 and is essentially due to the continuous decline of traditional biomass consumption in Asia and Africa, due to increased urbanisation, deforestation and substitution to modern energies in rural areas. Actually, the evolution of the share of renewables in total energy consumption shows contrasted patterns across regions, while the EU with a regular increase achieves the highest progression among industrialised regions.

The detailed results of the Reference scenario by regions are provided in Annex 2.

Key indicators of the world energy consumption

The gross inland consumption is the sum of the final energy demand and the energy demand for electricity production and other energy transformations. The final demand is modelled at the level of various sectors. In each sector, energy demand is driven by economic activity variables and price changes and trends (see section 3.1). The energy demand for electricity production results from the simulation of power generation technologies (see section 3.2). The dynamics of the GIC can be analysed through the evolution of three factors: population (POP), Gross Domestic Product/capita (GDP/POP) and the energy intensity (GIC/GDP). Under this decomposition, the Gross Inland Consumption is described as: POP x GDP/POP x GIC/GDP

In the WETO Reference, the gross consumption increases at 1.8%/year between 2000 and 2030, as population grows at a rate of 1%/year and the per capita GDP at 2.1%/year, while the energy intensity of GDP decreases by –1.2%/year. The projections show that at the world level and in most regions, the GDP/capita mainly influence the energy consumption growth. Nevertheless, in Africa, Latin America and Asia, the demography represents an important factor of the energy demand growth.

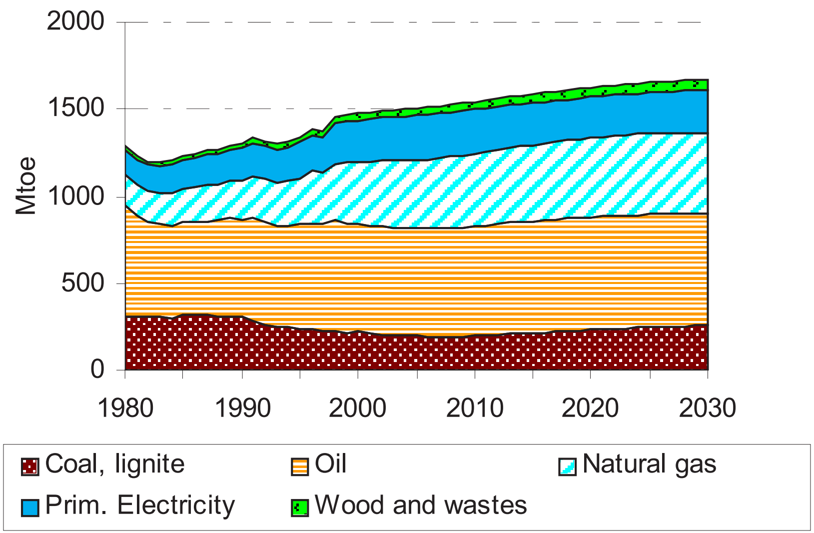
Regional trends

The analysis of regional trends indicates that a major structural change will occur in the worldwide distribution of the GIC over the next decades. The most outstanding element stemming from the Reference is the slowdown in the energy consumption growth in the industrialised countries and the sustained high growth in the developing countries. These combined trends lead to a new balance in the regional structure of the world GIC: the share of developing countries shifts from 40% to 55% over the projection period.

In the EU, population is expected to be stable over the projection period. Therefore, the 0.4%/year increase in energy consumption is mainly due to the impact of the per capita GDP growth (1.9%/year) that is partially compensated by the 1.4%/year decrease in the energy intensity of GDP. The projected growth for the EU thus reveals a relative saturation of equipment ownership (cars, refrigerators, etc.) but not a full stabilisation of the energy demand: total GIC reaches about 1.7 Gtoe in 2030, from 1.5 Gtoe in 2000.

The above analysis remains valid when the Accession countries are included. In these countries, the projected economic growth per capita is higher but the decrease in energy intensity is also more significant due to large efficiency gains. These indicators balance each other and the regional trend is not significantly different from the EU picture.

Figure 2.8: EU energy consumption



In terms of fuels shares, the contribution of natural gas strongly increases from 2000 to 2030, at the expense of coal, lignite and oil. At the end of the period, natural gas represents 27% of EU total energy consumption and becomes the second fuel used, behind oil (39%), but ahead of coal and lignite (16%)[11].

[11] The WETO Reference projects a fuel mix that is different from the one described in the EU energy outlooks published by DG Energy and Transport. In particular, the share of gas is lower in WETO, while the share of coal is higher. This is explained by two key factors. First of all, the price of gas, relatively to that of coal, is higher in WETO due to expected less abundant gas resources; this translates into a better cost competitiveness of coal-based electricity generation when GHG emission constraints are ignored. Secondly, the gas consumption is limited by a slower nuclear phase-out in Germany, Belgium and Sweden, as the WETO Reference only considers the retirement of nuclear power plants at the end of their operating lifetime.

In North America the energy intensity of GDP decreases by 1.3%/year, a rate similar to what is projected in the EU. As a result, the energy consumption rises by 0.7%/year on average, almost twice faster than in the EU. Coal experiences a steady growth of 1.1%/year on average resulting in a share of coal of 28% in 2030. This evolution contrasts with the situation of the other industrialised countries where coal consumption stabilises or decreases gradually: indeed coal, because of more favourable economic conditions, continues to develop on the electricity market.

In the CIS and CEEC region, the economic recovery drives the energy demand up. The energy intensity is projected to decrease substantially (-2.3%/year) in the 2000-2010 decade, reflecting the large potential for energy efficiency gains. The energy consumption per capita returns to its 1990 level around 2020. Gas holds an increasing share in the total energy demand of the region, exceeding 50% in 2030, mainly at the expense of coal and oil.

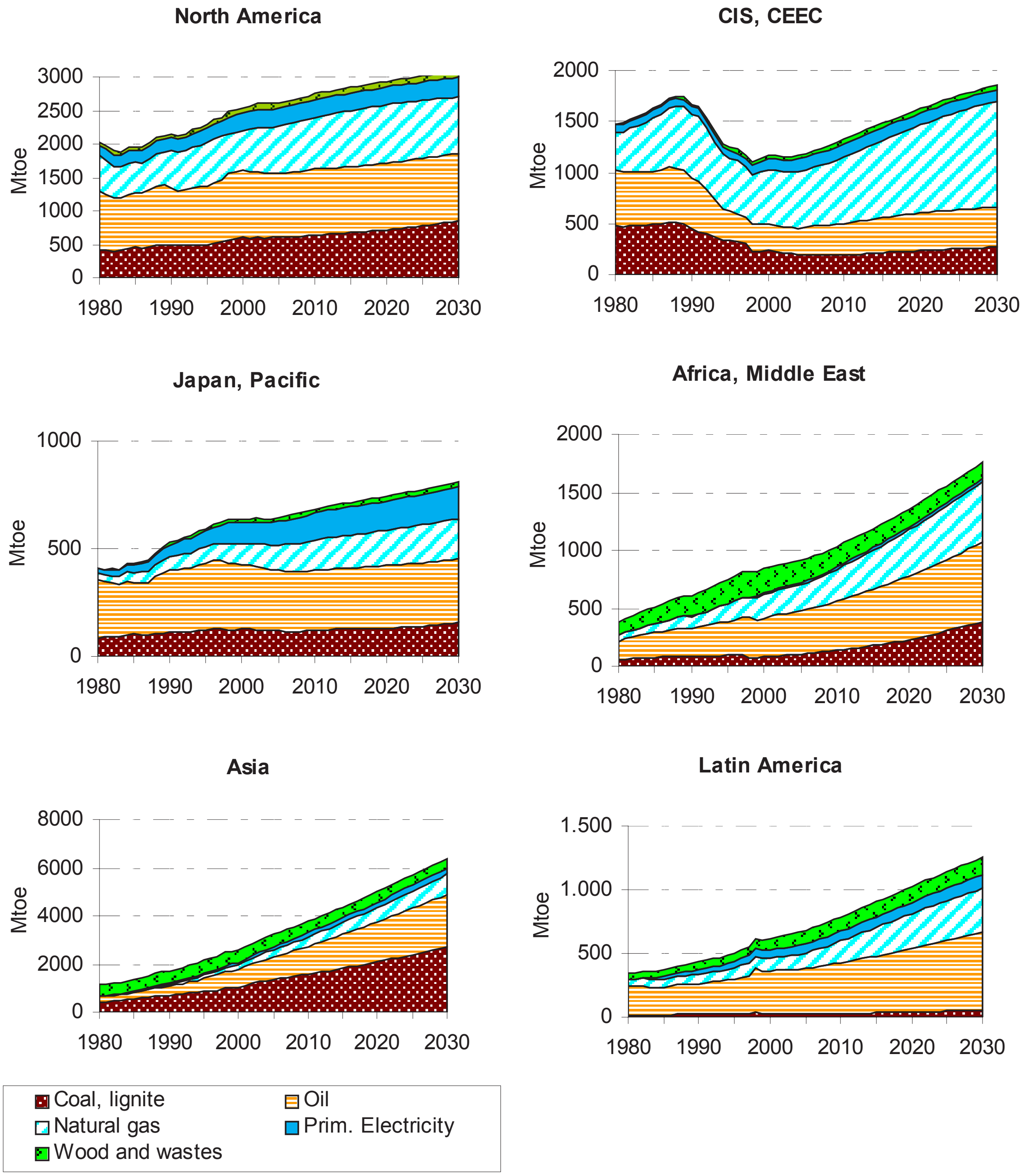
In the Japan and Pacific region, the energy demand pattern is similar to the trends observed for the other industrialised regions but the decrease in the oil market share is more rapid; oil is replaced by natural gas and primary electricity (nuclear in Japan and renewable in Australia).

Asia experiences the most rapid energy demand increase among all regions because of a. strong economic growth (progression of 3.7%/year for the per capita GDP between 2000 and 2030). The energy intensity of GDP decreases annually by 1.5% on average with the greatest gains occurring in the 2000-2010 period. Energy consumption in this region reaches exceeds 6 Gtoe in 2030 with a per capita consumption significantly lower than in the EU (1.5 versus 4.6 toe/year). Because of the abundant resources in the region, the share of coal remains high (42%) and does not change significantly. In contrast, the shares of oil and gas increase rapidly to the expense of biomass that is almost phased out (6% of GIC in 2030 compared to 30% in 1990).

In the Africa and Middle East region, the energy consumption per capita remains below 1 toe with very different energy profiles among countries, in particular between Africa and the Middle East. As in the most populous countries, energy is used to meet the essential needs, the energy intensity reduction is projected to be lower than in the other developing regions. Oil remains clearly the dominant energy source (39%). In contrast, the shares of gas and coal (mainly in the South African sub-region) increase while the consumption of biomass decreases sharply from 25% in 2000 to 8% in 2030.

In Latin America, finally, energy demand grows by 2.4%/year on average between 2000 and 2030, with the energy intensity of GDP decreasing by 0.8%/year. The significant feature is the slight decrease in the share of oil that is compensated by a strong penetration of gas, an abundant resource in the region.

Figure 2.9: Energy consumption in the other world regions



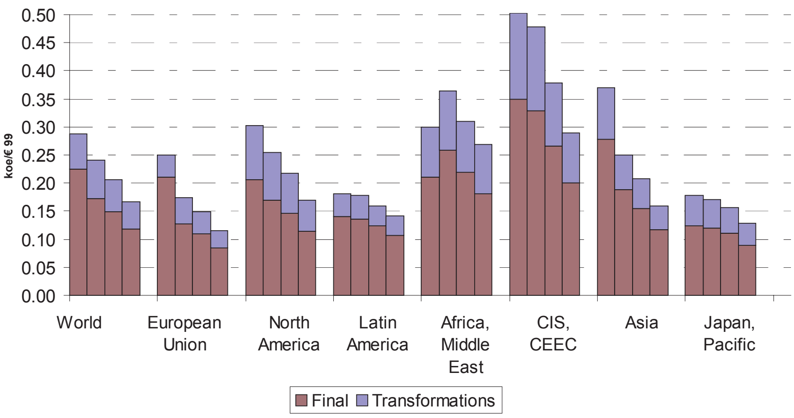
Regional overview of energy intensity trends

Figure 2.10 illustrates the evolution of the energy intensity of GDP in the different regions over the projection period. The energy intensity, measured as the GIC per unit of GDP, is an aggregate indicator of the link between economic growth and energy consumption. Its level and variation are the combined results of very different factors: the stage in the economic development process, energy efficiency and energy price patterns, climate, geography, culture and lifestyles.

The total energy intensity is expected to decline, at the world level, by 1.2%/year over the projection period, which is less than the 1.6%/year decrease observed from 1990 to 2000. Substantial differences appear between regions. In all regions but Asia the intensity improvements accelerates from past trends in the current decade. Asia continues to decrease its energy intensity but the particularly rapid fall of 2.9%/year observed from 1990 to 2000 in this region is somewhat reduced beyond 2010. The CIS and CEEC region reveals large potentials for energy intensity gains with an annual decrease of 2.3%/year between 2000 and 2010.

At world level, the improvements in energy intensity in relative terms are essentially driven by the reduction of the intensity of final energy demand. This is the case in the EU, in Latin America and in the Africa and Middle East region. On the contrary, in North America, in the Japan and Pacific region, in the CIS and CEEC region and in Asia, the decreases in final and transformation sector energy intensities are comparable; to a large extent this reflects important efficiency gains in the power generation sector.

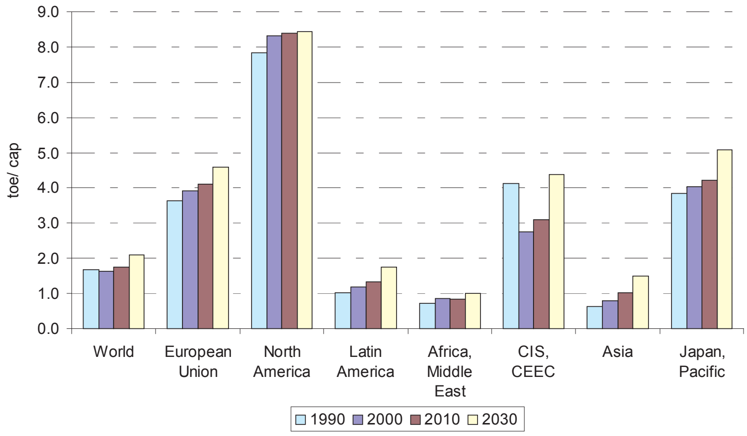
Figure 2.10: Total and final energy intensity (1990, 2000, 2010, 2030)



Regional overview of per capita energy consumption trends

Apart from the particular case of the CIS and CEEC region during the 90's, the per capita energy consumption steadily increases in all regions (Figure 2.11). Only in North America the progression tends to slow down over the 2010-2030 period, which may reflect marked saturation effects, but no region experiences a stabilisation of its per capita energy consumption. Despite the strong increase in energy consumption in the developing countries, the magnitude of the gap in the per capita energy consumption between developing and industrialised countries remains stable with a range of 1 toe/cap in the Africa and Middle East region to 8.4 toe/cap in North America in 2030. Nevertheless, the ratio between the highest and lowest levels of per capita energy consumption is projected to decrease to 8 in 2030 from 10 in 2000.

Figure 2.11: Energy consumption per capita



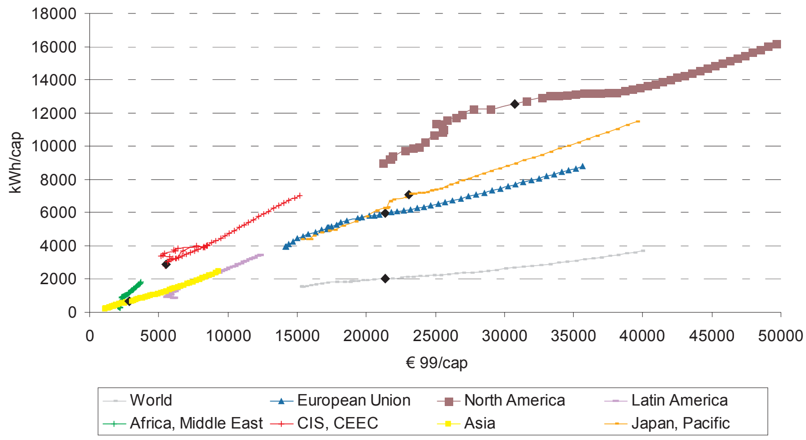
Trends in energy-related services

In the analysis of long-term energy trends, it is important to identify the ultimate services that energy consumption provides. In this respect, the consumption is broken down into three main services: electricity uses, transport uses (motive power) and thermal uses.

- *Electricity uses per capita*

At world level, the per capita electricity demand rises at sustained rates with the per capita GDP over the projection period: 1.2%/year between 1990 and 2000, 1.4%/year in the next decade and up to 2.2%/year from 2010 to 2030 (Figure 2.12). In the industrialised countries, electricity demand follows closely the economic activity as it did in the past. The EU, North America and the Japan and Pacific region experience a relative slowdown of the progression between 2000 and 2010 but the growth is faster beyond 2010 (respectively 1%/year and 1.6%/year in the EU, 0.3%/year and 1%/year in North America, 1.1%/year and 1.9%/year in the Japan and Pacific region). Electricity demand per capita grows much faster in Asia (4.2%/year on average over the projection period) and in the CIS and CEEC region (2.7%/year). Electricity demand also increases strongly in the Africa and Middle East region (2.4%/year) and in Latin America (2.6%/year) although with lower rates than in Asia.

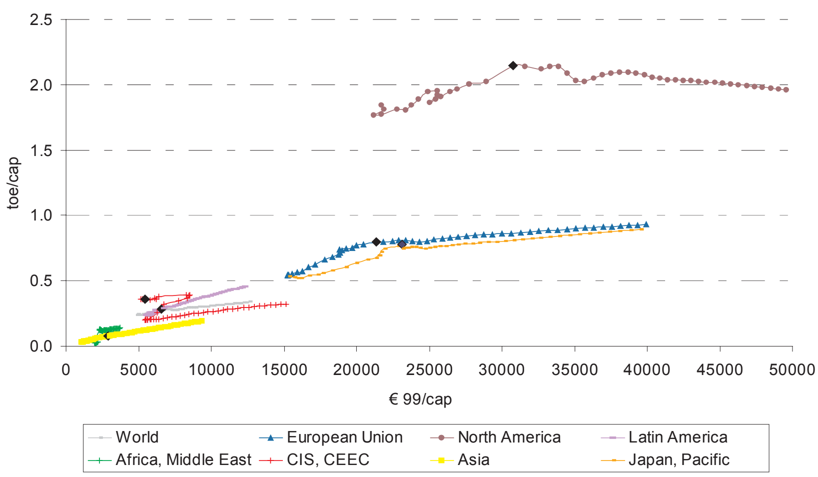
Figure 2.12: Electricity use and GDP per capita, 1980-2030



- *Transport energy use per capita*

The per capita transport energy use also increases steadily but the progression slows down slightly from 0.9%/year between 1990 and 2000 to 0.7%/year over the projection period (Figure 2.13). North America is the only region where a decrease is projected beyond 2000. The potential for energy efficiency gains in vehicles is large in this region while already high equipment rates reduce the diffusion of vehicles. In the EU similarly, the impact of rising income on demand diminishes slightly in the second half of the projection. This reflects rising saturation effects and constraints on road traffic such as congestion and limits to infrastructure development as well as long-term adjustment of the vehicle stock to increasing oil prices. For all other regions, a relative slowdown of the increase in the indicator is projected for the 2010-2030 period relative to the 2000-2010 period but the increase in China and India is nevertheless considerable (around 3%/year).

Figure 2.13: Transport energy use and GDP per capita, 1980-2030

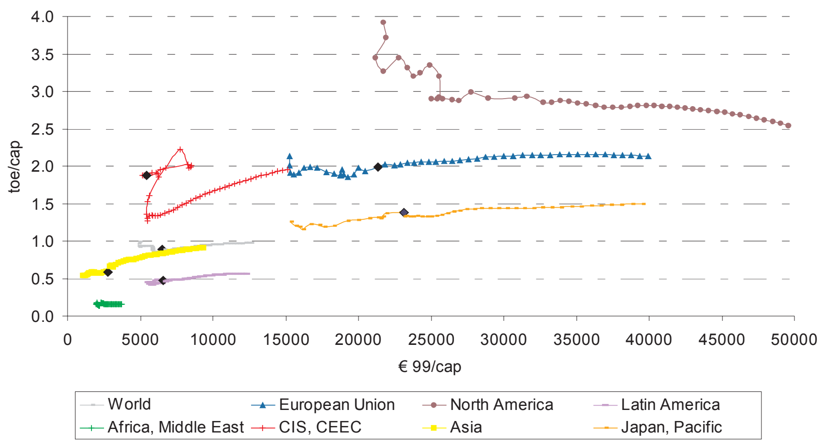


- *Thermal uses per capita*

The thermal uses per capita mimics the increase in per capita GDP, reversing the decreasing trend observed from 1980 until the late 90's. As a result, the per capita thermal uses in 2030 return to the level of 1980 (Figure 2.14).

In the EU, after a decrease until the late nineties, the per capita thermal uses increase moderately up to 2010 and then evolves relatively independently from the per capita GDP behaviour. The trend in the Japan and Pacific region is comparable to the trend in the EU. In North America instead, the decrease observed until 1995 is much larger than in the EU; it is followed by a stabilisation between 1995 and 2015 and then by a slight but steady decrease until 2030. The CIS and CEEC region is projected to show a rapid increase in the per capita thermal uses since the year 2000 when its economy starts to recover from the years of restricted consumption and economic recession. In the industrialised countries, the relative stabilisation of this indicator compared to the per capita GDP reflects essentially the saturation in household heating and the transformation of these economies towards less energy demanding industrial production structures. On the contrary, the increase in Asia and Latin America reflects the increase in thermal uses in response both to rising income levels and to rapid growth in manufacturing output.

Figure 2.14: Thermal uses and GDP per capita, 1980-2030



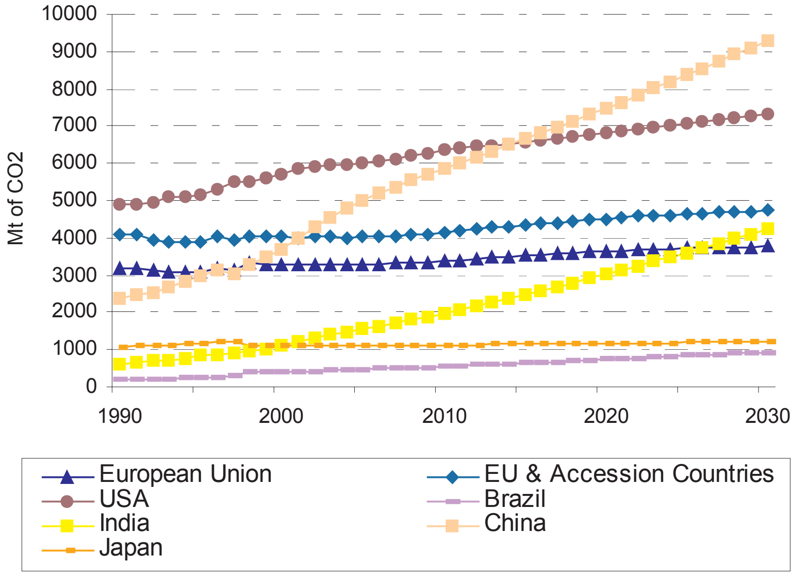
2.3.2 Energy related CO_2 emissions

Global CO_2 emissions more than double between 1990 and 2030

This section examines the dynamics of the energy-related CO_2 emissions that reflects the increase in fossil fuel combustion underlined above. On a world scale, CO_2 emissions more than double over the 1990-2030 period, from 21 to 45 Gt of CO_2. The regional shares also change significantly: in 1990, the emissions from the industrialised regions represented 70%

of CO_2 emissions; this share decreases to 42 % by 2030. By then China is the largest world CO_2 emitter in absolute terms but not relative to population.

Figure 2.15: Energy-related CO_2 emissions



Emissions growth in developing countries is expected to be extremely rapid, whereas developed and industrialised regions undergo a more moderate growth or even a decline. For instance, India experiences a six-fold increase (5%/year). The emissions in the other developing regions increase in a range of 200- 350%.

CO_2 emissions of the CIS and CEEC decreased spectacularly during the economic recession of the nineties, with a drop in emissions of 41% and 22% respectively in the 1990-2000 period. Only in 2030 do their CO_2 emissions reach again the level of 1990. The EU, the Japan and Pacific region and North America experience a more moderate but still substantial growth of their emissions with increases of 18%, 32% and 50% respectively.

The contrasted CO_2 emission trends in the different regions reflect a large number of factors including economic growth, population, fuel mix as well as historical and policy related elements.

Three determinants of CO_2 emissions dynamics

The CO_2 emissions dynamics can be analysed through the decomposition into three factors: the GDP, the carbon intensity of the gross inland energy consumption and the energy intensity of GDP (CO_2 emissions = CO_2 emissions/GIC x GIC/GDP x GDP).

Usually, the GDP and the energy intensity have opposite effect on CO_2 emissions but up to now, the growth in GDP dominated resulting in increases in energy consumption and associated emissions.

While natural gas and oil use emits approximately 30% and 25% less CO_2 per unit of energy than coal, electricity produced from nuclear, hydro, solar and wind is almost CO_2 emission free, at least at the operational stage. The energy produced by biomass combustion is considered as CO_2 neutral, as far as a re-growth process compensates for the re-emission of the carbon captured during the biomass growing. In summary, decreasing the carbon intensity of energy consumption will imply increasing the share of low CO_2 energy sources and decreasing that of CO_2 intensive sources.

CO_2 emission increases the most in developing countries

China experiences the largest economic growth over the 40-years period and becomes the major world emitter of CO_2 in 2030. While its GDP is multiplied by ten between 1990 and 2030, making of China the largest economy in the world, this remarkable economic development impacts dramatically on the energy consumption. During the same period, China is also projected to be the most successful region in decreasing the energy intensity of the GDP, with a reduction of 66% relative to the 1990 level (see Figure 2.16). In spite of this major change, energy demand still increases by nearly 250% over the period. The third factor, the carbon intensity of energy consumption, increases by 12% and leads to an additional rise in China's CO_2 emissions beyond the energy demand growth. In total, CO_2 emissions are projected to increase by 290% relative to the 1990 level. In terms of energy mix, it appears that, though China succeeds in reducing the share of coal in its energy consumption by 3%, the carbon intensity of total consumption increases because the relative share of traditional biomass decreases substantially, as in every fast developing country.

Similar conclusions can be drawn for the other developing regions as all countries experience a large growth in GDP and a decrease in the energy intensity of GDP. Yet, the latter effect does not compensate for the former and as a result, the total energy consumption increases considerably and so do the energy-related CO_2 emissions.

The carbon intensity of energy consumption increases in all developing regions, reinforcing the trend in CO_2 emission growth. In India, in South East of Asia, in Africa and Middle East, the share of traditional biomass decreases and the increment in energy demand is mostly met by fossil fuels. India sees the greatest increase in the share of coal and the most limited increase in the share of natural gas. This results in the sharpest projected increase in the carbon intensity of the total consumption (+79%) of all developing regions. In spite of the substantial reductions in the energy intensity, India thus experiences the strongest increase in CO_2 emission of all regions, namely a six-fold increase.

The growth in the carbon intensity of the energy consumption is much more moderate in Latin America, where a 7% increase is projected. This change is explained by trends that are different from those of the other developing regions. While the supply of CO_2-free energy produced by hydropower plants and biomass does not keep pace with energy demand, the decline in their market share is however compensated by a relatively low carbon source, natural gas, in place of coal or oil. Even under a scenario with substantial economic growth and significant expansion of the energy supply, the energy demand in Latin America appears the least carbon intensive in 2030.

CO_2 emissions increase in industrialised countries at a slow pace

Energy demand increases in the industrialised countries but not as much as in the developing countries. The lowest growth appears in the CIS (8%) and the highest reaches 51% in the Japan and Pacific region.

All industrialised regions decrease the carbon intensity of their consumption with the only exception of North America. In that region, the share of oil in the energy consumption decreases but this reduction is almost entirely compensated by an equal increase in the share of coal use, while the share of other primary energy sources remains stable. The overall result in 2030 is an increase in the carbon intensity of 7%. Together with the 40% increase in the energy demand itself, this leads to a 50% increase in CO_2 emissions above the 1990 level.

In the EU, the shares of coal and oil decrease respectively by 7% and 4% and the share of natural gas increases by 10%, leading to a drop in carbon intensity of energy consumption of a modest 6%. However, due to the increase in energy consumption, total CO_2 emissions increase by 18% between 1990 and 2030.

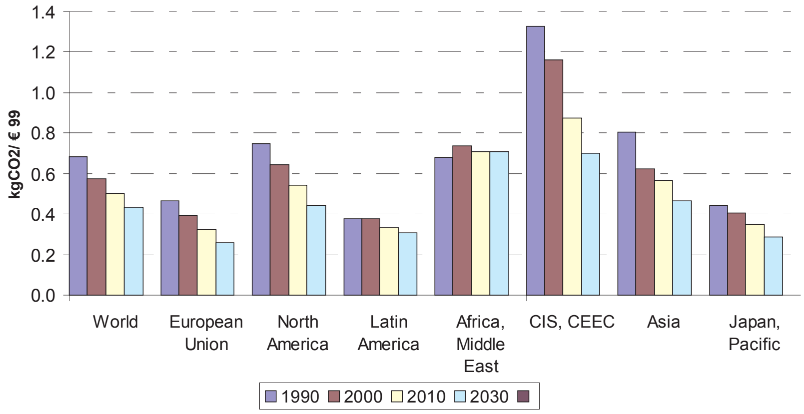
In the Japan and Pacific region, Japan decreases the carbon intensity of its energy consumption by 12%. The share of coal in Japan decreases marginally, by less than 1% in 2030. Instead the share of oil decreases substantially by 18% and the share of natural gas rises of 12%. Furthermore, the Reference projects a considerable growth in the electricity production by nuclear energy: 29% of the electricity produced in 2030 compared to some 19% in 1990. Nevertheless, despite the substantial decrease in carbon intensity, CO_2 emissions still increase by 32% relative to the 1990 level as a main consequence of the increase by 51% of the energy demand.

Finally, in the CIS and CEEC region, the shares of coal and oil decrease and the share of natural gas increases more rapidly than in the EU. This shift induces a reduction of some 10% in the carbon intensity. Together with a moderate increase in GDP and a decrease in the energy intensity of GDP, CO_2 emissions reach similar levels in 2030 than in 1990.

The carbon intensity of the GDP decreases significantly in all regions but in Africa

Figure 2.16 shows the regional disparities in the carbon intensity of GDP but illustrates also the significant reductions projected in the Reference. At world level, the drop is about 40% between 1990 and 2030. The reductions are particularly substantial in the EU, North America, the CIS, CEEC region and in Asia. In contrast, the carbon intensity of the GDP remains roughly constant in the Africa, Middle East region.

Figure 2.16: Carbon intensity of GDP



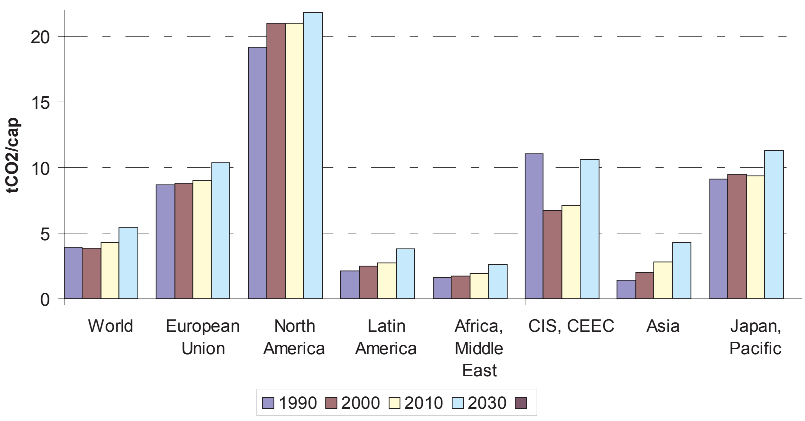
However, the reduction in the carbon intensity of GDP does not compensate for the pronounced increase in the revenue in the different regions. As a result, growing CO_2 emissions are projected.

CO_2 emissions per capita increase, but mostly at the end of the projection period

The regional differences in CO_2 emissions per capita as well as the evolution over the 1990-2030 periods are illustrated in Figure 2.17. Developing countries' per capita emissions remain well below those of the industrialised regions in absolute levels, North America remaining the largest emitter per inhabitant. Whereas, CO_2 emissions per capita increase slightly between 2000 and 2010, the increase is more significant over the 2010-2030 period.

Finally, it is worth underlining that the gap between the highest (North America) and lowest (Africa and Middle East region) levels of CO_2 emissions per capita is projected to be reduced to 8 in 2030 from 12 in 2000.

Figure 2.17: CO_2 emissions per capita



Key conclusions

- World energy consumption is projected to increase at about 1.8%/year between 2000 and 2030. This growth is driven by economic and population growth (of respectively 3.1% and 1%/year on average), whose impacts are nevertheless moderated by a decrease in energy intensity of 1.2%/year, due to the combined effects of structural changes in the economy, of technological progress and of energy price increases.

- Industrialised countries experience a slowdown in their energy demand growth (0.4%/year in the EU). Conversely, the energy demand of developing countries is growing rapidly. In 2030, some 55% of the world energy demand is expected to come from developing countries, compared to 40% now.

- The world energy system will continue to be dominated by fossil fuels. In 2030, fossil fuels are expected to represent almost 90% of total energy demand. Oil remains the main source of energy (34%) followed by coal (28%). Almost two-thirds of the increase in coal demand between 2000 and 2030 comes from Asia. Natural gas is projected to represent one quarter of world energy demand by 2030; power generation provides the bulk of the incremental gas demand.

- In the EU, natural gas is expected to be the second energy source, with a share of around 27% in 2030, behind oil but ahead of coal and lignite. Nuclear and renewable energies would altogether represent slightly less than 20%.

- Given the continued dominance of fossil fuels, world CO_2 emissions are expected to grow rapidly, at a rate slightly higher than energy consumption (2.1%/year on average). In 2030, world CO_2 emissions are more than twice the level of 1990. In the EU, CO_2 emissions are projected to increase by 18% in 2030 compared to the 1990 level. In the USA, the increase is around 50%. While the emissions from developing countries represented 30% of the total in 1990, these countries will emit more than half the world CO_2 emissions in 2030.

2.4 PRIMARY FUEL SUPPLY

2.4.1 Simulation of oil and gas discovery

The POLES model provides a relatively detailed simulation of the oil and gas discovery process. This feature is in particular essential to the endogenous calculation of international oil and gas prices. In broad terms, the modelling oil and gas supply is based on the following sequence (see Box 4):

- The Ultimate Recoverable Resources (URR) of oil and gas are simulated from a base year value on the basis of the impact of increasing recovery rates (price dependent);
- Discoveries increase with cumulative drilling (also dependent);
- Reserves are equal to the total discoveries minus the past cumulative production;
- For all regions except the Gulf, the production depends on a price dependent Reserve on Production ratio.

2.4.2 World oil supply

Figure 2.18 describes the conventional oil development profile in the Reference. Sufficient oil reserves exist to satisfy the projected oil demand over the next three decades. The production increases by about 65% to reach some 120 million barrels per day in 2030. About thousand billion barrels will be needed to satisfy the cumulative oil demand over the 2000-2030 period.

The total conventional oil reserves decline between 2000 and 2030 by some 22%. More precisely, oil reserves start declining from the middle of the current decade. This decline is however limited by the increase in URR due to the increase in recovery rates (from 30-40% in 2000 to 50-70% in 2030, depending on the region), induced partially by autonomous progress and by oil price increases: in 2030, world oil URR end up at 4500 Gbl. As the production level is increasing during the projection period, the world Reserves to Production ratio decreases from 40 years to 18 years: in the model simulation this is the key driving force explaining the increase in oil price from the end of the current decade onwards (see Section 2.2).

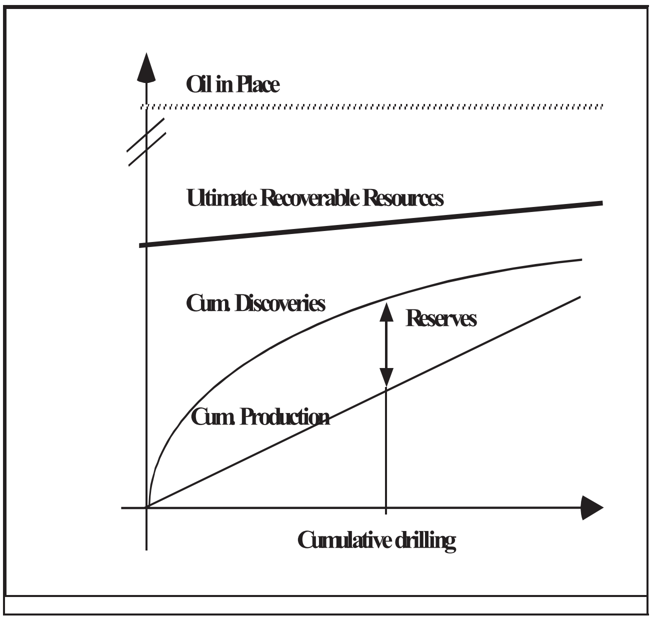
Box 4: The simulation of oil and gas reserves

The modelling of oil and gas reserves and production is carried out in three stages in the POLES model.

First, the model simulates the level of oil and gas resources discovered each year (cumulated discoveries) as a function of the Ultimate Recoverable Resources and of the cumulative drilling effort. URR are not fixed as considered usually: they are the product of the oil and gas in place for a base year (from USGS estimates[12]) and of a recovery ratio that increases with the price and an autonomous technological trend. The drilling effort is also a function of the price and a trend.

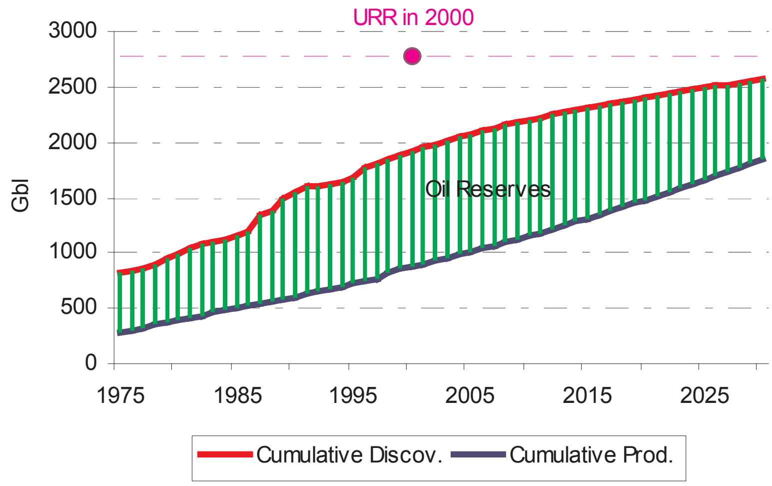
Second, the reserves are equal to the difference between the cumulative discoveries and this cumulative production for the previous period.

Finally, the model calculates the production. For oil, it results from applying a Reserve on Production ratio in the "price-taker" regions, while the "swing-producers" balance between the oil demand and supply. For gas, it is derived from the simulated demand.



[12] U.S. Geological Survey *World Petroleum Assessment-2000, Description and Results,* USGS World Energy Assessment Team, Denver, 2000.

Figure 2.18: World conventional oil resources



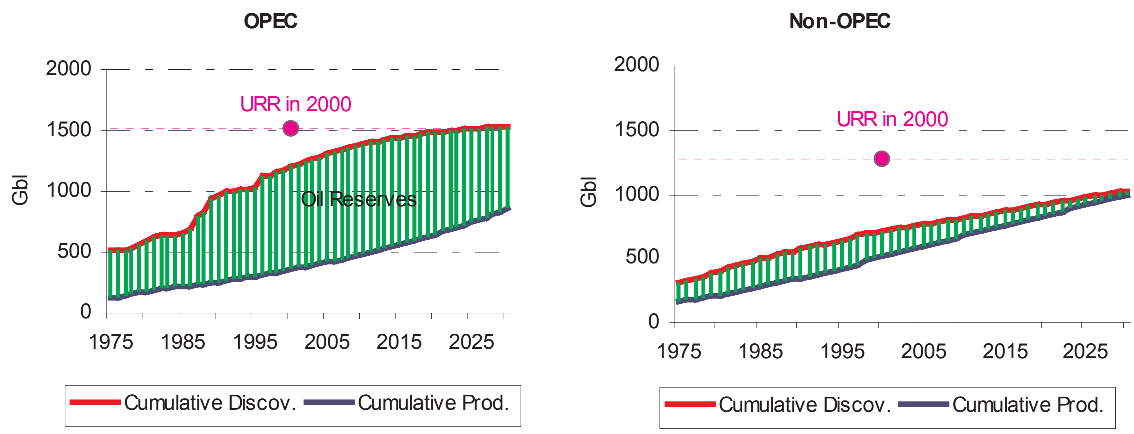
The development of oil supply shows different pictures for OPEC and non-OPEC countries (Figure 2.19), illustrating the different patterns of behaviour of oil producers. Countries outside OPEC are considered as “price-takers” and their production only depends on their own reserves and production capabilities. In contrast, OPEC countries are modelled as “swing-producers” and their oil production is determined by the difference between total oil demand and the production of non-OPEC countries (conventional and non-conventional oil).

Gains in production are expected for both OPEC and non-OPEC producers (respectively +108% and +10% between 2000 and 2030), and one quarter of the production increase are expected to come from non-OPEC countries. This basically reflects the resource and Reserve on Production constraints that are expected to severely limit non-OPEC production in the coming decades. Non-OPEC production in 2030 is projected to be 3 millions barrels per day higher than it was in 2000, against 33 for OPEC. As a result, OPEC countries, which currently provide 40% of total oil supply (of which 27% from the Middle East), will account for 60% in 2030 (of which 46% from the Middle East). These developments are opposite to the ones observed since 1975 when the production of non-OPEC countries increased the fastest (respectively 1.8%/ year on average for non OPEC and 0.2% for OPEC).

In contrast to oil production, discoveries progress more in non-OPEC countries, at least during the last 20 to 25 years of the projection period when oil price begins to increase.

These contrasted developments of oil production and discoveries in these two areas have a direct influence on oil reserves: the latter decline more significantly in non-OPEC than in OPEC countries (respectively -84% and –19% between 2000 and 2030) despite similar recovery rates. Thus, although more than 80% of world’s oil reserves were already concentrated in the OPEC countries, this percentage will reach 95% at the end of the projection period. This increasing dependence on OPEC resources raises questions in terms of probability of occurrence and geopolitical feasibility that are out of the scope of the WETO study.

Figure 2.19: OPEC and non-OPEC conventional oil resources

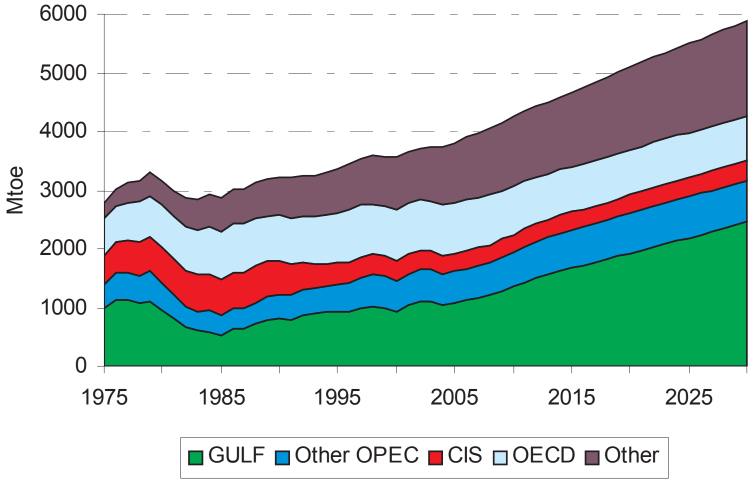


The production of non-conventional oil, which is currently negligible (1% of total oil production worldwide), is projected to represent about 10 million barrels per day in 2030. Furthermore, the reserves of non-conventional oil increase steadily (contrary to the reserves of conventional oil which decline) to cover one third of total oil reserves in 2030.

The evolution of oil production by main region illustrates the increasing share of OPEC countries in world oil supply (Figure 2.20). Oil production shows the highest increase in the Gulf countries (+160% over the projection period) where there are plenty of low-cost resources. It is projected to more than double in all OPEC countries but Venezuela where the increase is limited to 50% over the 2000-2030 period. On the contrary, it rises moderately in the CIS (+5%) and even declines in OECD countries (-15%) and notably in the USA (-5%).

Ten countries cover three third of total oil demand in 2030 (Saudi Arabia, Iraq, Iran, CIS, USA, UAE, Kuwait, Venezuela, Canada and Brazil. In North America, the US production decline is more than offset by production increases in Canada. Brazil’s production is projected to rise the most: its share in total oil production increases to 5% in 2030 from 1% in 2000.

Figure 2.20: World oil production

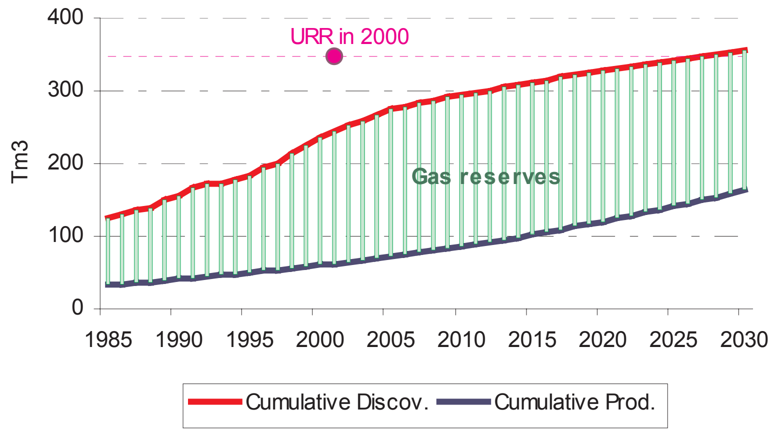


2.4.3 World gas supply

The outlook for gas supply is different from oil in several respects. First, gas reserves are expected to increase over the projection period (+9%) while oil reserves decline. Second, the reserves are more widely distributed among regions for gas than for oil. However, as for oil, more than half of gas reserves are located in few countries, namely the CIS and the Gulf region. Third, the recovery rate for gas is and will continue to be higher than for oil: it increases over the projection period from 80% in 2000 to around 94% in 2030.

The rapid growth in natural gas reserves observed in the past is projected to continue for the current decade, followed by a moderate but steady decrease (Figure 2.21). Progress in drilling activity contribute to increase gas discoveries by around 1.4%/year over the period. Some 100 Tm^3 of additional production will be required to meet the cumulative demand from 2000 to 2030. This is equivalent to about two third of the proven gas reserves at the end of 2000.

Figure 2.21: World gas resources



About 68% of existing gas reserves are located in the CIS and in the Gulf region. Moreover, gas reserves are expected to grow in both areas over the projection period (+14%) so that their share in world reserves will reach 72% in 2030 (Figure 2.22). Total gas discoveries are projected to reach similar levels at the end of the projection periods; on the contrary, cumulative production in the Gulf region will be less than half the CIS level in 2030, reflecting disparities in supply costs to final markets. The CIS is projected to cover about one third of the cumulative gas demand over the 2000-2030 period, compared to slightly more than 10% for the Gulf region. Similarly to oil, this result raises questions in terms of probability of occurrence and geopolitical feasibility that are out of the scope of the WETO study.

Figure 2.22: Gas resources in the CIS and the Gulf

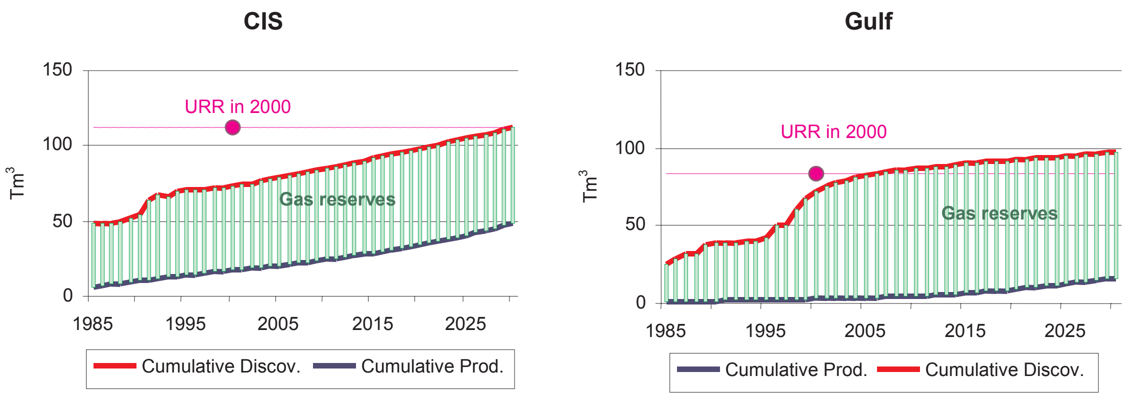
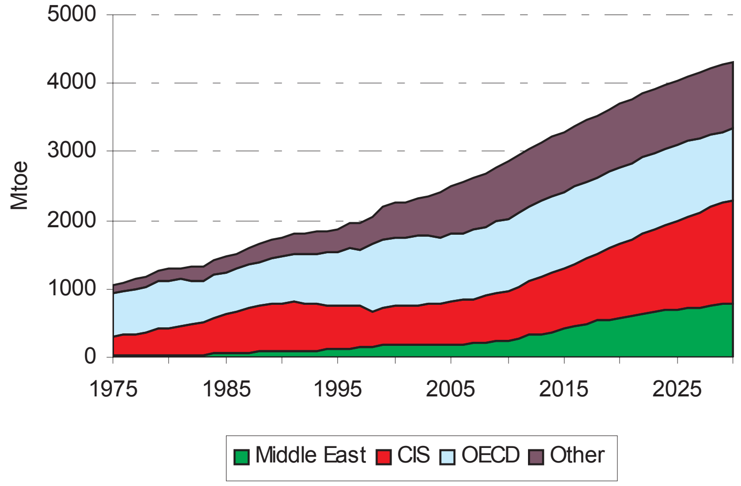


Figure 2.23 shows the development of gas production by main region. It illustrates not only the remarkable increase in gas production but also the important changes in the regional allocation of total gas supply over time.

It is worth pointing out the moderate increase in production taking place in the OECD region (+3% between 2000 and 2030) as compared to the significant increases in the other regions, and more particularly in the Middle East (+470%). Although the OECD region accounted for around 15% of the world's total gas reserves at the end of 2000, it accounted for more than 40% of the world's total production, followed by the CIS with 28%. In 2030, the picture looks quite different: about one third of the gas production will come from the CIS and the remaining production is projected to be almost equally allocated among the OECD, the Middle East, and the other gas producers in Latin America and Asia. Furthermore, the ten largest gas producers in 2030 will ensure more than 80% of the world's total production. But contrary to oil, the ten largest gas producers in 2030 remain more evenly distributed among the different world regions, although the CIS represents more than 40% of their total production.

Figure 2.23: World gas production

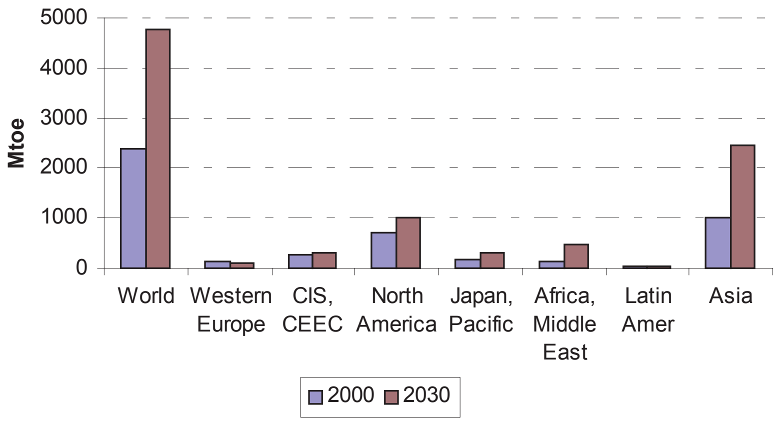


2.4.4 World coal supply

The distribution of coal reserves is more evenly distributed than for oil and gas. Significant reserves exist in North America, in Asia, in Africa and in the Pacific region. Important coal reserves also exist in Russia but coal production and transport costs are there considerably higher than in the other regions, resulting in relatively low production levels compared to the other regions with abundant coal reserves.

In the present outlook, coal supply is not subject to resources constraints and the production is essentially demand driven and follows the primary demand for coal. Coal production is expected to grow by 2.3%/year on average over the projection period, mostly in Africa and Asia (respectively 4.5% and 3%/year). In contrast, production will continue to decline in the EU (-0.8%/year). In 2030, more than half the world's coal production will originate from Asia, and most particularly from China (35%), while the USA will remain the second producer with a share of about 20% (Figure 2.24).

Figure 2.24: World coal production



Key conclusions

- Sufficient oil, gas and coal reserves exist worldwide to satisfy the projected demand during the next three decades. The decline of conventional oil reserves is compensated by an increase in the reserves of non-conventional oil. The reserves of natural gas are abundant and expected to increase by around 10%. Coal reserves are enormous and do not constitute a constraint to coal demand at the horizon of 2030.

- World oil production is projected to increase by about 65% to reach some 120 million bl/day in 2030: three quarters of the production increase will come from OPEC countries, where the largest part of oil reserves is concentrated. As a result, OPEC would account for 60% of total oil supply in 2030 (compared to 40% in 2000).

- World gas production is projected to double between 2000 and 2030. However, regional disparities in gas reserves and production costs are expected to modify the regional gas supply pattern in 2030: about one third of the total gas production will originate from the CIS while the remaining production is projected to be almost equally allocated among OECD countries, the Middle East, and the other gas producers in Latin America and Asia.

- World coal production is also expected to double between 2000 and 2030, the growth taking place mostly in Africa and in Asia. This latter region is projected to cover more than half the total coal production in 2030.

CHAPTER 3

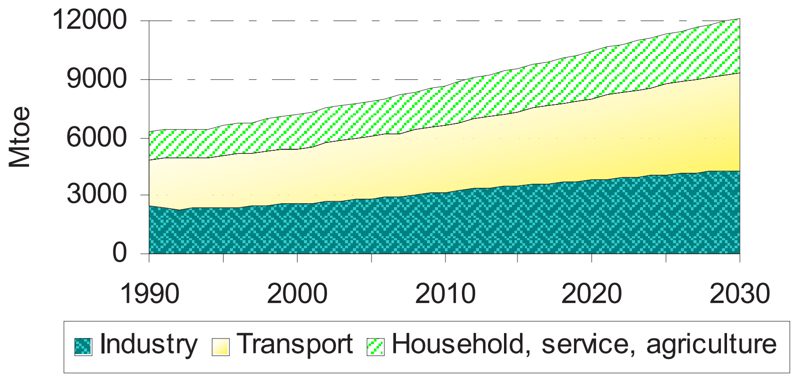
SECTORAL OUTLOOK

3.1 ENERGY DEMAND

3.1.1 Global trends

World final energy consumption is projected to grow by 1.8 %/year on average over the projection period (Figure 3.1); however, the growth declines from 2 %/year during the first decade to 1.5 %/year over the last two decades. This progression is similar in the three final demand sectors between 2000 and 2030 but the pace of increase varies significantly between the different sectors. Energy demand from industry increases the most over the 2000-2010 period with 2.4 %/year on average and then slows down to reach 1.2 %/year over the last ten years of the projection period. Energy demand for transport increases more regularly by 1.7 %/year up to 2010 and by 1.5 %/year beyond. The household, service and agriculture sector experiences a steady increase of its energy demand with an average increase of 1.9 %/year.

Figure 3.1: World final energy consumption



There are few changes in the fuel shares over the next thirty years. The only notable changes are the increase in the share of electricity from 15 % in 2000 to 22 % in 2030 and the decrease in the share of renewables from 13 % to 6 % due to the significant shift from traditional biomass to fossil fuels and the penetration of electricity in developing countries.

3.1.2 Regional trends

The evolution of final energy demand shows contrasted patterns from one region to the other in relation to their level of industrial development. In the EU, the final energy demand is projected to increase by 0.5 %/year (i.e. less than one third the growth in world final demand) whereas, at the opposite side of the range, final demand in Asia increases by 3 %/year over the projection period (see Figures 3.2 and 3.3). Among industrialised regions, the EU is projected to have the lowest increase, with a more rapid progression for the household, service and agriculture sector (0.7 %/year) than in transport (0.4 %/year) and industry (0.3 %/year).

The household, services and agriculture sector is the principal contributor to the projected growth of final energy demand in the industrialised countries, whereas all final demand sectors contribute almost equally to the demand growth in developing countries. The worldwide fastest growing segment of final demand is transport in Asia with an average increase of 3.9 %/year over the projection period.

Changes in fuel mix vary according to the region but oil remains the dominant fuel in most regions with stable shares ranging from 40 to 50 %. Oil is principally used for transport in industrialised countries, which is a major difference with developing countries where oil is also largely consumed in industry. The share of solid fuels in final energy demand decreases significantly in all regions but in Asia, where it remains constant, and in Africa, where it increases slightly. The share of electricity increases in all regions either at the expense of fossil fuels in industrialised countries or at the expense of traditional biomass in most developing countries. Electricity experiences the fastest growth, among energy forms and world regions, in Asia with 5.1 %/year on average. In the Africa and Middle East region and in Latin America, the electricity demand increases also significantly, above the world average.

Figure 3.2: EU final energy consumption

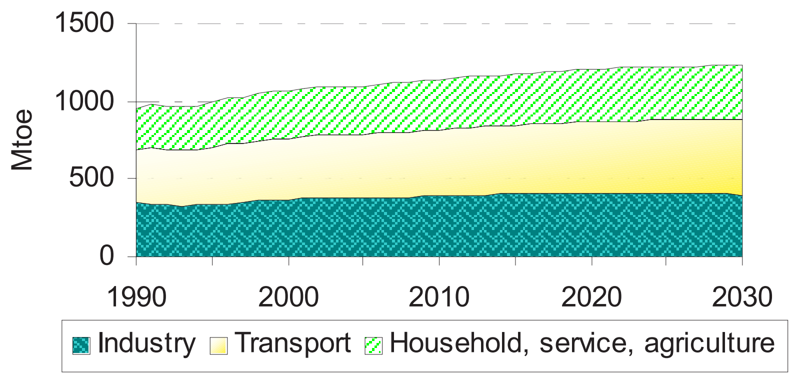
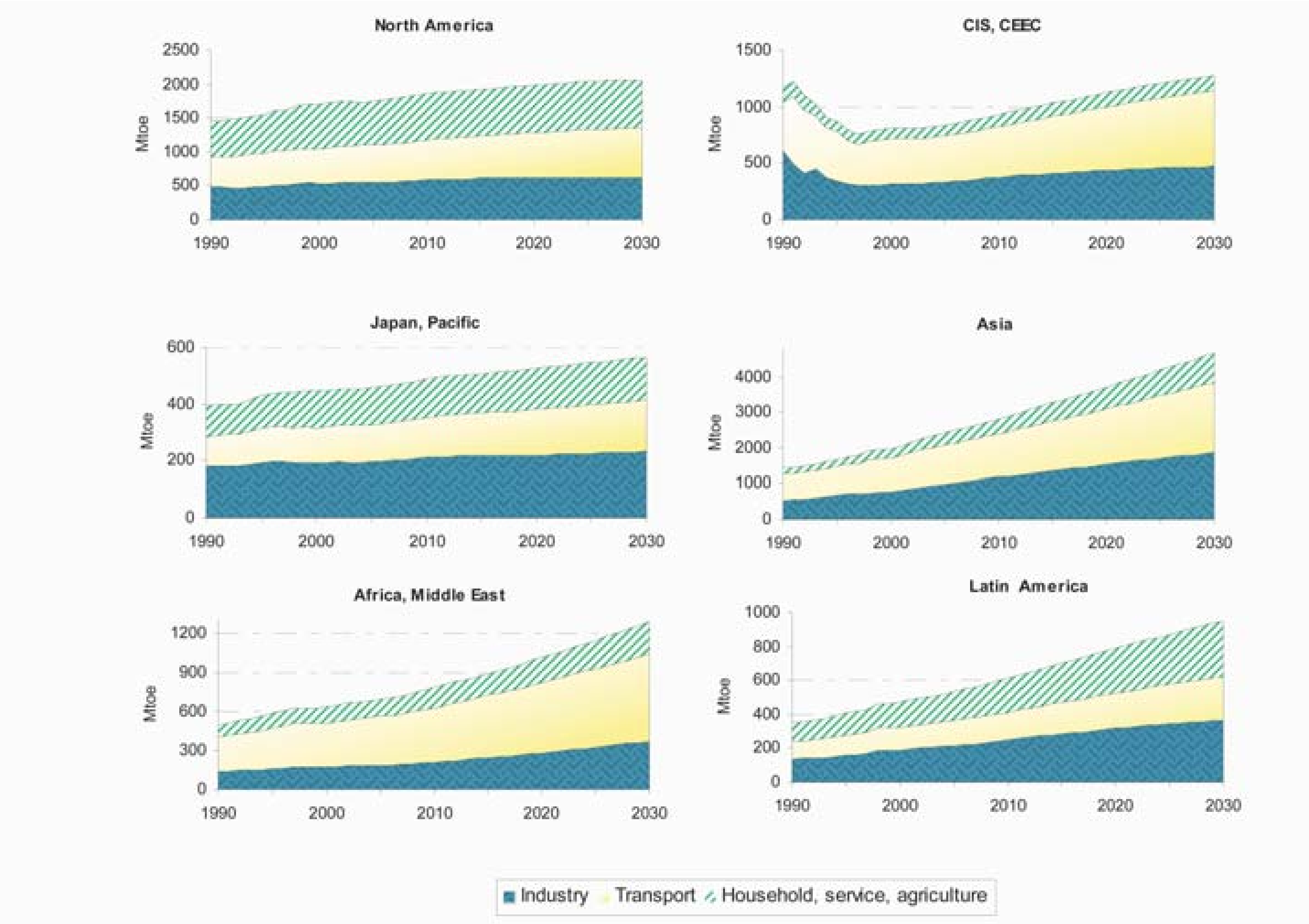


Figure 3.3: Final energy consumption in the other world regions



In the POLES model, the total final energy demand is allocated into four main sectors: industry, transport, households and services including agriculture. Industry is broken down into 4 branches (steel, chemicals, non metallic minerals and others). Transport considers 6 modes (passenger/road, road/goods, rail/passenger, rail/goods, air and others). In industry, households and services, the model separates thermal uses from captive uses of electricity. The demand is basically modelled in each sub-sector through econometric relations, integrating short term and long-term price effects as well as technological trends (see Box 5).

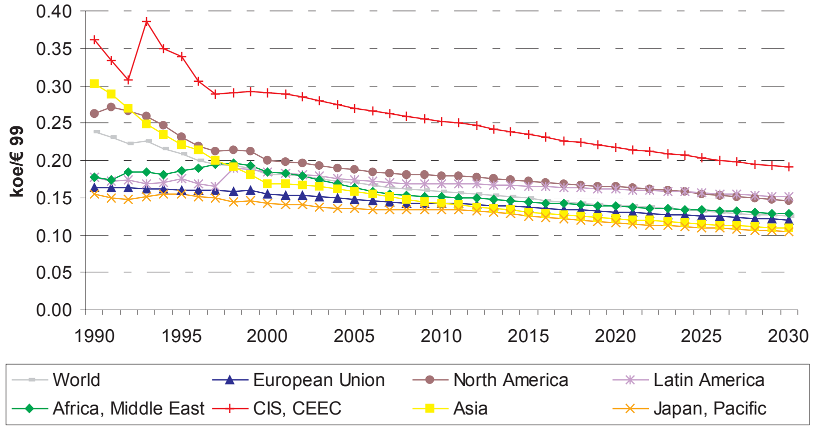
Box 5: Modelling of final energy demand

Final energy demand is represented in the model as follows. Two standard equations are used to calculate on the one hand the total energy demand for each sector and on the other hand the demand for each individual fuel in the sector. The variation of the final energy consumption is a function of:
- an income or activity variable with an income elasticity.
- a short-term price response to the variation in the average price of the sector over the two previous years with a short-term price elasticity. This short-term effect mainly reflects behavioural changes.
- a long-term price effect which is supposed to be investment-driven and therefore includes an asymmetry factor and a distributed lag corresponding to the duration of the price effect, with a long-term elasticity.
- an autonomous technological trend.

3.1.3 Industry

At world level, the energy intensity of industry (Figure 3.4) decreases by 1.2 %/year on average over the projection period. This means that the energy productivity of industry is progressing by 1.2 %/ year: more value added can be produced with less and less energy .The greatest improvements in the energy productivity are expected in Asia (1.5 %/year) and in the CIS and CEEC region (1.4 %/year). North America and the Japan and Pacific region are projected to have progression of around 1 %/year The EU, with an annual average reduction of 0.9 %, has the slowest energy intensity decrease among industrialised regions. However, in absolute terms, the EU has low levels of energy intensity compared to most world regions: in the nineties, together with the Japan and Pacific region, it experienced the lowest level of energy intensity. Beyond 2010, it will only be overtaken by Asia where energy intensity is projected to decrease significantly in industry. Despite a continuous and significant decline, the energy intensity of the CIS and CEEC's industry is projected to remain the highest in the world. Finally, since the energy intensity is projected to decrease the least in Latin America, industry in this region becomes more energy intensive in 2030 than in most other regions.

Figure 3.4: Energy intensity of the industry sector



The industrial sector is very diverse from the point of view of energy use. The POLES model accounts for a breakdown of the sector into four main industrial activities: iron and steel, chemical, non-metallic and other industries. Fuel substitution is modelled according to the structure of the different industrial sub-sectors.

Remarkable improvements in the energy efficiency of steel production are expected in most steel producing countries or regions. Nevertheless, significant differences remain among countries as to the level of energy use per unit of steel produced in 2030. The most efficient steel industry is and remains located in the EU despite relatively low energy efficiency improvements over the projection period. In the USA, no significant declining trend is expected and this country remains at the second place after the EU in terms of energy efficiency. Brazil experiences some energy efficiency gains after 2015 but its steel industry remains the most energy intensive: it consumes twice as much the amount of energy required to produce one ton of steel in the EU in 2030. India and China continue their rapid declining trend and reach intermediate levels of energy efficiency in 2030. The iron and steel industry in Japan is characterised by some losses in energy efficiency up to the middle of the projection period, mainly due a reduction of steel production below the optimal level of steel plants' capacity.

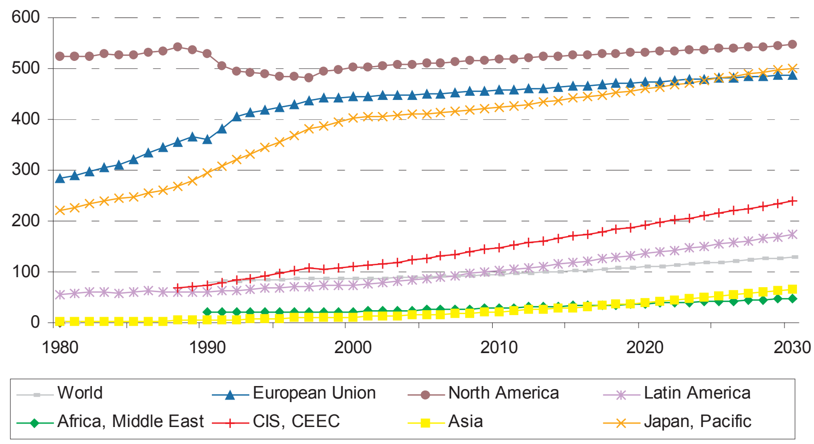
Steady decreases in the energy intensity of both chemical and non-metallic industries are expected in all regions. Moreover, the decreases are such that the regional differences in energy intensity are reduced in 2030 compared to 2000.

3.1.4 Transport sector

The slower increase in the overall energy use in transport, compared to past trends, results from a combination of competing factors. On the one hand, the Reference projects for all regions a growing number of cars per inhabitant. Between 2000 and 2030, the growth reaches 1.3 %/year on average at world level with extreme figures ranging from 6 %/year in Asia and

0.3 %/year in the EU and North America where car ownership saturates around one car per driving license (Figure 3.5). Over the projection period, the ratio between the number of cars per inhabitant in developed and developing regions is projected to decrease from 22 to 10.

Figure 3.5: Number of cars per 1000 inhabitants



The number of kilometres travelled per car slightly decreases in most regions. This trend is to be associated more to the expansion of the car stock and to shifts in transport modes in favour of aviation or rail, rather than to a reduction in the demand for transport. This is particularly true in North America and Europe, where the average distance per car is already close to saturation levels (because of constraints in time-budgets), and where substitutions to fast modes (air, fast trains) are already taking place on long distances.

On the other hand, significant improvements of the specific consumption of cars tend to decrease the energy demand. Over the projection period, the average consumption of car decreases by 9 % in the EU even though the negotiated agreements[13] with the automobile industry is not taken explicitly into account in the Reference. In the USA, the specific consumption decreases by 18 % over the same period but remains higher than in the EU. Such technical evolutions have been observed in these regions for the past twenty years, but their impact on the fuel demand has been partly offset by a regular increase in the average size of vehicles (at least since 1986, when the oil price dropped). In the Reference, the increasing tensions on the price of oil on the international market curve down the size effect.

Overall considered, the increase in energy demand for transport results principally from the growing number and size of vehicles that is only partially compensated by gains in the specific consumption of cars.

3.1.5 Household sector

The thermal energy use per household is expected to decrease in the industrialized countries with important improvements in energy efficiency. In the developing countries, at the exception of China that follows the trends of industrialized nations, the thermal energy use

[13] Negotiated agreements concluded with the European (1999/125/EC), the Japanese (2000/304/EC) and the Korean car manufacturers (2000/303/EC).

slightly increases, as the efficiency gains are not fully compensated by the steady increase of population and the development of the household sector. In the EU and Japan, non-electric energy use in households is no longer linked with the growth in income level over the projection period.

The increasing use of electrical appliances and lighting in all regions is expected to significantly soar the energy use. The energy use per household increases significantly in the developing countries but in absolute terms, the quantity of energy required grows the most in the industrialised countries.

In terms of the total energy use per dwelling, the consumption remains roughly constant in the EU and Japan whereas it slightly drops in the other world regions as greater efficiency gains occur.

3.1.6 Services and agriculture

The service and agriculture sector exhibits impressive energy demand growth rates in all world regions. In industrialised countries, this sector develops steadily and a continuous average reduction of around 1 %/year in energy intensity of services is expected for thermal uses. In Brazil and India, remarkable reductions in energy intensity of respectively 2.4 and 4.2 %/year are projected and these figures contrast with the increase of 0.4 %/year in China, where space heating needs are developing.

On the contrary, the energy intensity of services for captive uses grows in all regions and countries. The fastest increases are expected in India (3.3 %/year) and China (2.7 %/year) while lower increases are projected in the EU (0.9 %/year) and in the USA (0.5 %/year). The evolution of energy demand in the services and agriculture indicates that the gains in energy efficiency projected for thermal uses are more than counterbalanced by the increase in the demand for captive uses consuming principally electricity.

Key conclusions

- The world final energy demand is expected to grow at a similar pace as the gross inland consumption (1.8 %/year). Moreover, at world level, all final sectors are expected to experience similar energy demand growth. As a result, the share of the sectors in final demand remain roughly constant at around 35 % for industry, 25 % for transport and 40 % for the residential and tertiary sectors.

- The sectoral energy demand shows different patterns according to the regions: in developed countries, energy demand in the services sector is the fastest growing segment of final demand; in developing countries, all sectors experience sustained demand growth above 2 to 3 %/year.

- There are some changes in the fuel mix over the next 30 years. The most notable changes are the remarkable increase in the share of electricity in all world regions, the continuous decline of coal in developed countries and the steady decrease in the use of biomass in developing countries. However, electricity accounts for less than a quarter of final energy demand in 2030, with oil remaining the dominant fuel with a practically constant share ranging from 40 to 50 % according to the region.

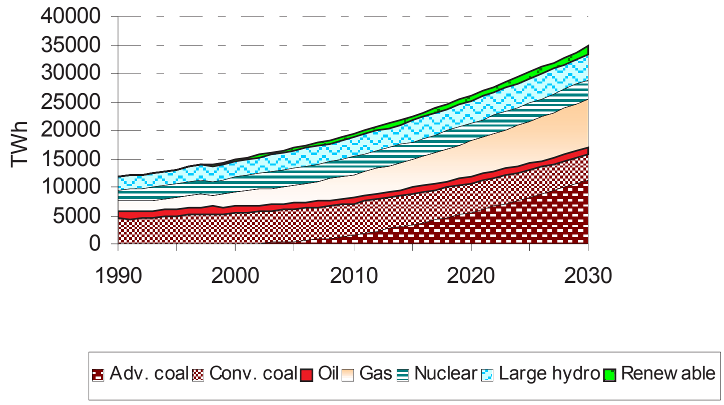
3.2 POWER GENERATION AND RENEWABLE TECHNOLOGIES

3.2.1 Global trends

In the Reference, the world electricity demand and production rise steadily at an average rate of 3 %/year over the projection period, to a level 2.3 times higher in 2030 than in 2000. The level of detail in the POLES model allows the detailed analysis of the evolution of the power generation technology mix.

The modeling of power generation capacity planning and power plant management in the POLES model is described in Box 6.

Figure 3.6: World power generation



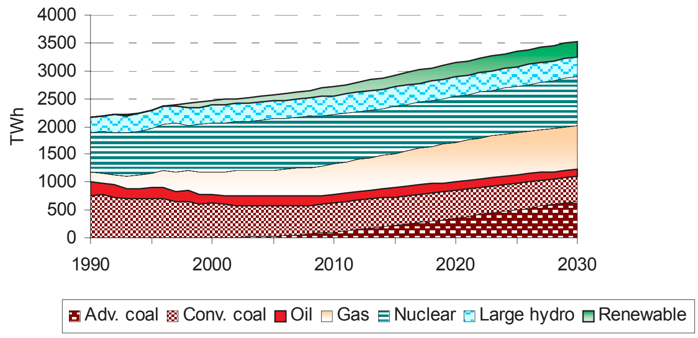
More than half the total electricity production in 2030 will be provided by technologies that emerged in the nineties and afterwards like gas combined cycle turbines, advanced coal technologies and renewables. These two fossil fuel-based technologies are expected to largely replace conventional thermal power plants by the end of the projection period. The share of conventional coal in power generation is expected to decrease from 36 % in 2000 to 12 % in 2030 while the share of gas increases from 16 % to 25 % and advanced coal takes a share of 33 % in 2030.

In spite of a continuous expansion, the development of nuclear power does not keep pace with total electricity production: nuclear world market share comes down to 10 % of total electricity production in 2030, from 18 % in 2000. The same applies, although to a lesser extent, to large hydropower, whose market share decreases from 19 % to 13 %. On the contrary, the share of other renewable technologies is expected to increase from 2 % to 4 % despite the rapid increase in solar and wind power of about 11 %/year at world level.

The general trend in the EU is similar to the evolution at world level (Figure 3.7). However, the penetration of advanced coal is more limited - 19 % of total electricity production in 2030

- while renewable technologies are projected to represent 8 % in 2030[14]. It is worth underlying here that the Reference does not include any specific policy measures in favour of renewables and that the penetration of these technologies is based solely on their potential, cost and performance. Similarly, recent decisions at national level on a progressive phasing out of nuclear production are not accounted for in the Reference; nevertheless, the share of nuclear power is projected to decrease from 35 % in 2000 to 25 % in 2030.

Figure 3.7: EU power generation



Box 6: Modeling of power generation

The expected capacities for the different plant categories are simulated by taking into account the future electricity demand and the relative costs of the different categories of power plants. These total costs per kWh (fixed and variable costs) are calculated for six reference load factors (from 730 to 8760 hours), while taking into account investment and fuel costs. The total electricity demand and load curve, anticipated to a t+10 years horizon, are also simulated by the model, as an extrapolation of current demand and load curves.

Primary electricity sources, such as hydro and nuclear electricity, are supposed to be used in priority for producing the base-load part of the demand curve. All other types of power generation plant are considered as competing (in t+10) for the fulfillment of the remaining part of the base-load and of the expected load curve. On the basis of total cost comparisons a “screening curve”-like process makes it possible to derive the desired capacities for each type of plant in the future.

Once the planning of new capacities is simulated, the model deals with power plant management and electricity production for the “actual” simulated demand at time t. A type of “order of merit” process is used, ensuring that, once the capacities are installed, then the management of the power plant types will supply sufficient electricity for the load curve, while using in priority the plants with the lowest variable cost (and not total costs).

[14] In particular, the Reference does not fully account for respect of the European Directive of 2001 fixing an indicative target of 22 % of electricity produced from renewable energy sources in 2010.

The evolution of the power generation mix shows contrasted regional patterns mainly influenced by the endowment in coal and gas resources (Figure 3.8): the share of coal decreases in all regions except in regions with abundant coal in North America, where it stabilises, and in Asia, where it increases significantly; the share of gas increases steadily in the three major gas producing regions (CIS, Middle East and Latin America); the share of oil remains small and even tends to zero in North America and in the Japan and Pacific region.

More specifically, advanced coal power production increases very rapidly in North America and reaches 37 % of total electricity production in 2030. Globally, the share of coal remains stable at more than 50 % of total electricity production, advanced coal mainly substituting conventional coal.

Asia will continue to rely heavily on coal for power generation (more than 60 % of total electricity production) and advanced coal power plants are expected to represent no less than three quarter of total coal-based electricity production.

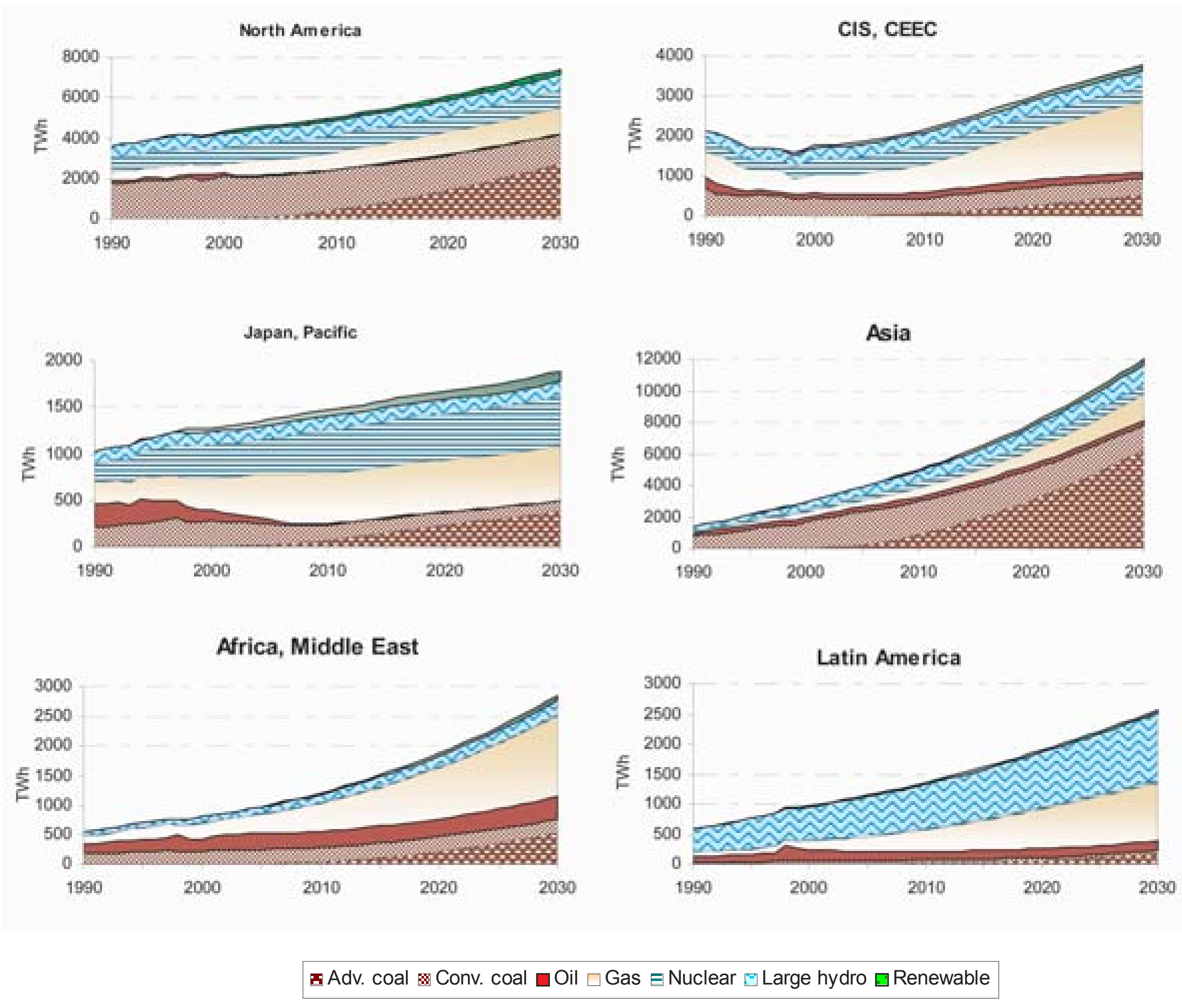
In the CIS and CEEC, with the availability of abundant gas resources, the share of gas increases significantly and this fuel is expected to represent the largest share (47 %) in 2030. On the contrary, nuclear power is expected to decrease from 21 % in 2000 to 10 % in 2030 as the existing plants will be progressively replaced by gas power plants.

In the Japan and Pacific Region, the shares of gas and nuclear increase, principally at the expense of oil.

In the Africa and Middle East region, the most significant development is the increase in the gas share from 33 % in 2000 to 48 % in 2030; on the other hand, advanced coal is expected to represent 19 % of total electricity production in 2030.

Contrary to what happens in most world regions, coal-based electricity production is marginal in Latin America where power generation is expected to rely almost equally on gas and large hydro power plants.

Figure 3.8: Power generation in the other world regions



3.2.2 Renewables

The diffusion of renewables in the POLES model depends on their performance, costs and potential (See Box 7).

At world level, the growth of electricity production from biomass, solar, wind and small hydro is remarkable (more than 4 %/year on average) although no policy targets for renewables (as for instance the EU Directive of 2001) have been taken into account in the Reference. The growth is the most pronounced for solar and wind, whose production is expected to increase at an average rate of about 11 %/year over the 2000-2030 period (Figure 3.9). In spite of this quick development and because of very low initial levels, electricity from renewable sources is not expected to exceed 3 % of world total electricity production in 2030 (16 % when large hydro and geothermal are included).

Figure 3.9: World electricity production from renewables

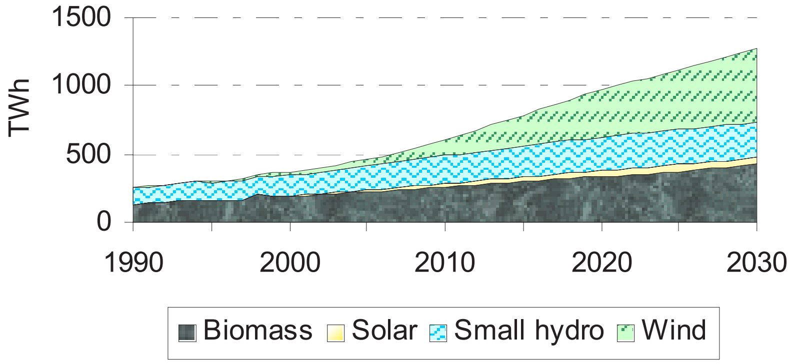
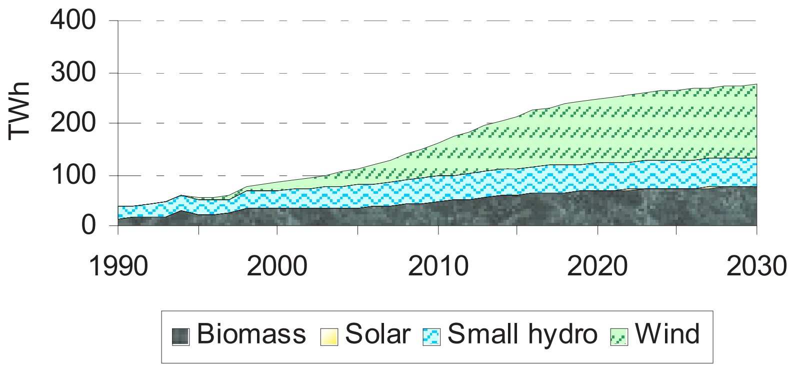


Figure 3.10 displays the outlook for electricity production from renewables (excluding large hydro and geothermal) in the EU. The development of wind is the most significant feature together with a low contribution of solar photovoltaic. However, this expansion steadily remains below the world growth rate with an increase of about 7%/year. Power generation from small hydro and biomass increases steadily covering together half the electricity produced from renewables in 2030, the other half being fulfilled by wind power production.

Figure 3.10: EU electricity production from renewables



The prospects for the other world regions are illustrated in Figure 3.11.

In North America, wind is expected to grow rapidly over the projection period and to cover 55 % of the electricity produced from renewables in 2030; instead, electricity from biomass will drop to 30 % in 2030 from slightly less than 70 % in 2000.

In the CIS and CEEC region, biomass continues to be the dominant renewable energy source for electricity production with more than 50 % ahead of wind and small hydro.

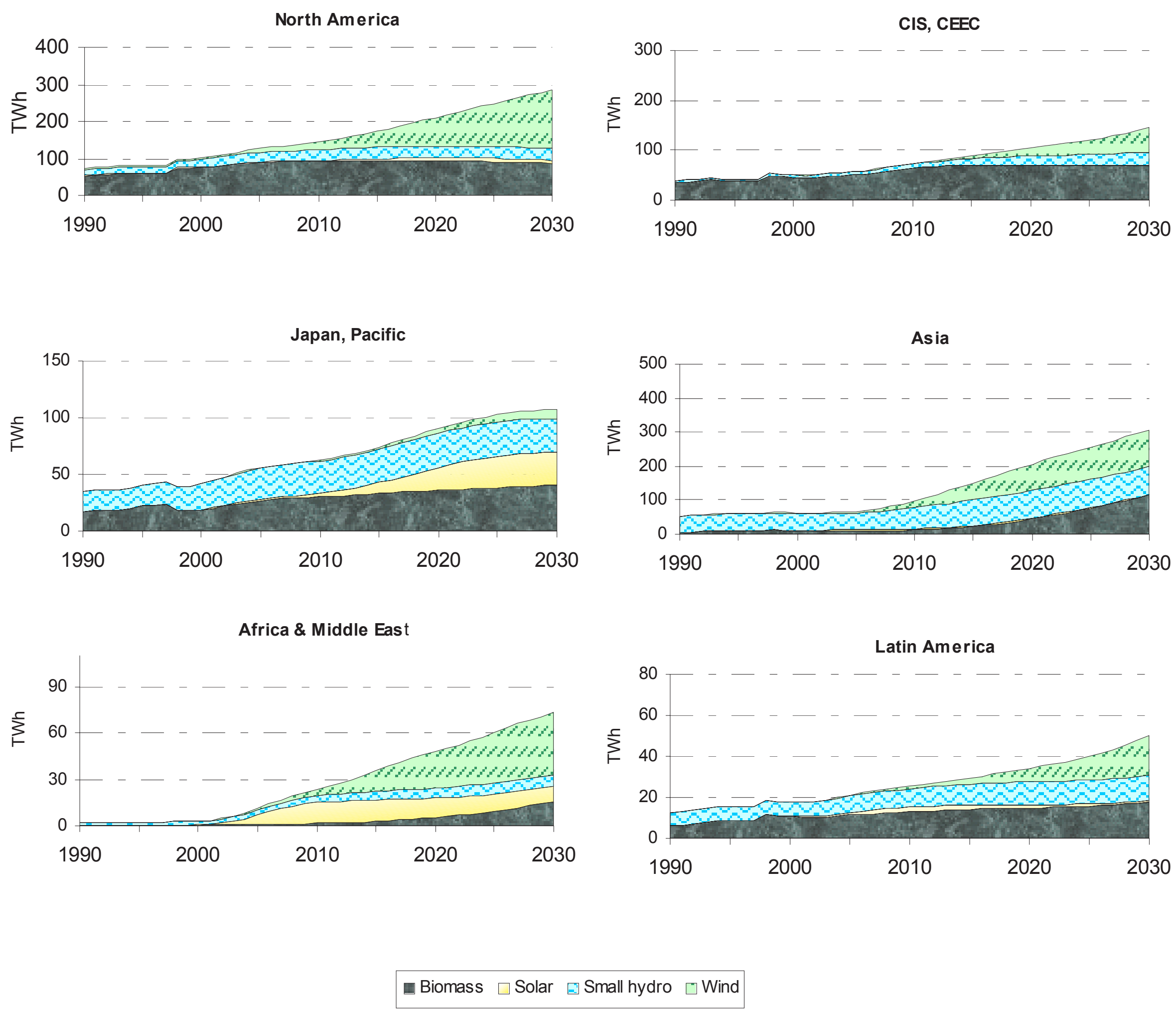
In the Japan and Pacific region, the most significant evolution is the expected development of solar photovoltaic. On the contrary, wind power production is modest compared to the outlook for wind in the rest of the world; in 2030, power generation from renewables is distributed almost evenly between biomass, small hydro and solar.

In Asia, wind and biomass power production grows significantly at respectively 14 % and 8 %/year over the projection period, whereas electricity production from small hydro remains stable; in 2030, each of the above renewable energy source represents one third of total electricity generated from renewables.

Power generation from wind also increases rapidly in the African and Middle East region and reaches more than 50 % of electricity produced from renewables in 2030. The growth of solar photovoltaic is also notable but less significant than for wind.

In Latin America, wind power generation is developing steadily beyond 2010. In 2030, electricity produced from renewables is almost evenly allocated between biomass, small hydro and wind.

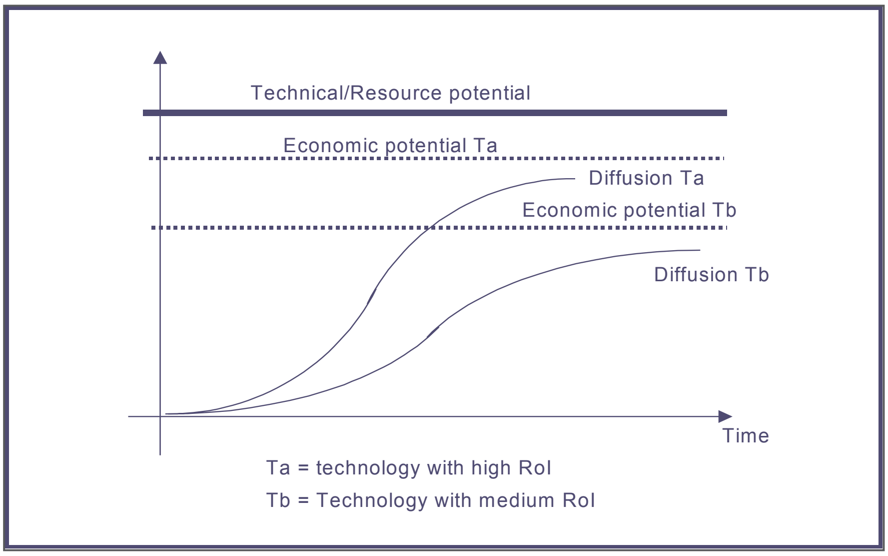
Figure 3.11: Electricity production from renewables in other world regions



Box 7: Modelling the diffusion of new and renewable energy technologies

The diffusion of new and renewable technologies is determined by a logistic curve function of two key factors: the size of the economic potential and the length of the diffusion process, which are different according to the technology.

The size of the economic potential is determined by the share of the technical potential that turns out to be economically competitive under the conditions simulated by the model (investment cost of the technology considered, cost of the alternative conventional solutions). This share is a function of the average payback period for the considered investment: the lower is the payback period (i.e. the more cost-effective the technology) and the larger the share of the technical potential that is considered as an economic potential.



The speed of the diffusion process is defined through the “take-over time”, i.e. the time that is necessary to go from a 10% to a 90% market penetration, and is a function of a maximum take-over time and of the actual payback period. As a consequence, the shorter the payback period, the quicker is the diffusion process.

Key conclusions

- World electricity production rises steadily at an average rate of 3 %/year. More than half the total electricity production in 2030 will be provided by technologies that emerged in the nineties and afterwards like gas combined cycle turbines, advanced coal technologies and renewables.
- The share of gas increases steadily in the three major gas-producing regions (CIS, Middle East and Latin America) and the share of coal decreases in all regions except in North America where it stabilises and in Asia where it increases significantly. The development of nuclear power does not keep pace with total electricity production: nuclear world market share comes down to 10 % of total electricity production in 2030.
- World electricity production from renewables is expected to rise from 2 % in 2000 to 4 % in 2030, mainly because of a rapid increase in the electricity production from wind.

CHAPTER 4

ASSESSMENT OF UNCERTAINTIES

The Reference scenario provides a picture of the future world energy system under a set of broadly accepted assumptions as to, among others, the general macro-economic background, future energy and environmental policies, energy prices and resources, and the technico-economic development of energy technologies. Considerable uncertainty remains however on these hypotheses and may change the course of world energy development in the next three decades. Two important uncertainties are examined in detail in this chapter and assessed against the Reference: the resource estimates for conventional oil and gas (section 4.1) and the pace of development of some key energy technologies (section 4.2). The goal of this analysis is to evaluate the sensitivity of the reference energy projection according to these uncertainties.

4.1. OIL AND GAS RESOURCES

As to the hydrocarbon resources, the Reference assumes current conventional wisdom on oil and gas availability. However, to assess the sensitivity of the Reference scenario to other hypotheses on hydrocarbon resources and examine their impacts on international oil and regional gas prices and consequently on the world energy system, two alternative cases have been designed: a low oil and gas resources case (Low case) and a high gas resource case (High case).

The principal source of information for the design of these two cases is the USGS 2000 study. Indeed, besides the median estimate for oil and gas endowments (in terms of Ultimate Recoverable Resources), used in the Reference, this study also provides alternative resources estimates. On the one hand, low estimates attaching a 95% probability to a "pessimistic" view concerning the oil and gas recoverable resources. On the other hand, it describes a state of the world in which the resource constraint is supposed to be considerably alleviated (Figure 4.1). This is supposed to happen with a 5% probability[15].

These alternative hypotheses on oil and gas Ultimate Recoverable Resources have an impact on the projected oil and gas reserves and production levels, and consequently on oil and gas prices and demand.

[15] The interpretation of the above probabilities is as follows: there is a 95% probability that actual resources are higher than the low estimates, there is a 50% probability that actual resources are higher than the median estimates, and there is a 5% probability that actual resources are higher than the high estimates.

Figure 4.1: Ultimate Recoverable Resources in the Reference and Resource cases[16]

(Gbl)	OIL	GAS
Low	2127	1597
Median	**2708**	**2157**
High	3651	3116

Low case

Reference

High case

4.1.1 Low oil and gas resources

The Low case allows testing the sensitivity of the Reference scenario to low hydrocarbon recoverable resources at world level and assessing the impact of higher oil and gas prices on the world energy system to 2030.

The impact on oil and gas ultimate recoverable resources, reserves, production and prices

Changes in the key variables describing oil and gas development in the Low case compared to the Reference are described in Tables 4.1 and 4.2.

The impact of lower estimates for the Ultimate Recoverable Resources of conventional oil is particularly strong for countries outside the Gulf and OECD. As far as gas is concerned, the most significant impact is for countries outside the CIS and OECD regions. However, the difference in oil and gas URR is decreasing over time: as oil and gas prices are higher than in the Reference, progress in recovery rates is also higher. Also, reserves and production of non-conventional oil are significantly higher than in the Reference.

In the Low case, the structure of world oil production is considerably modified with the exception of the Gulf whose production represents constantly 40% of world production in 2030. On the contrary, the OECD share is 6% in the Low case instead of 12% in the Reference, and the other oil producers 18% instead of 34%. Finally, the share of non-conventional oil grows to 18% from 8% in the Reference.

[16] The URR estimates are based on the technology of 2000. Along the simulation path of the model, recovery technologies are supposed to improve, thus increasing the quantity of oil and gas that can be recovered.

Table 4.1: Oil supply: Low case versus Reference

OIL	2010	2020	2030
URR			
Gulf	-13%	-11%	-10%
OECD	-21%	-19%	-18%
Other	-26%	-24%	-22%
World	-20%	-18%	-16%
Oil reserves			
Gulf	-20%	-34%	-52%
OECD	-43%	-51%	-47%
Other	-28%	-41%	-50%
Non conventional	20%	34%	16%
World	-18%	-23%	-31%
Oil production			
Gulf	40%	36%	9%
OECD	-37%	-51%	-47%
Other	-22%	-35%	-46%
Non conventional	27%	67%	153%
World	-2%	-2%	6%
R/P ratio	-15%	-20%	-28%
Oil price	9%	16%	22%

URR: Ultimate Recoverable Resources

Lower gas availability also results in a different structure of world gas production but the modifications are less pronounced than for oil; the most important change concerns gas production in North America whose share in the total decreases to 11% from 18% in the Reference at the 2030 horizon.

As a result of the above-described changes in oil and gas availability and production patterns, oil and gas prices are higher in the low resource case: about 20% in 2030 compared to the Reference for oil, and between +20% and almost 60% for gas, depending on the market considered.

Table 4.2: Gas supply: Low case versus Reference

GAS	2010	2020	2030
URR			
OECD	-19%	-18%	-17%
CIS	-25%	-25%	-24%
Other	-30%	-30%	-29%
World	-26%	-25%	-25%
Gas reserves			
OECD	-36%	-46%	-54%
CIS	-6%	-14%	-26%
Other	-34%	-37%	-40%
World	-26%	-31%	-37%
Gas production			
OECD	-11%	-15%	-42%
CIS	13%	4%	-2%
Other	-2%	-2%	-5%
World	-2%	-5%	-13%
R/P ratio	-25%	-28%	-27%
Gas import price			
American market	7%	25%	57%
European market	11%	13%	28%
Asian market	3%	6%	22%

URR: Ultimate Recoverable Resources

The impact on the world energy system and CO_2 emissions

Higher oil and gas prices in the Low case result in a very different outlook for the world energy system in 2030: the energy intensity of the GDP and Gross Inland Consumption are lower than in the Reference scenario (-3% in 2030) as are CO_2 emissions (-1.9% in 2030) (Table 4.3).

As this case is more coal intensive than in the Reference, the magnitude of the impact is higher for the Gross Inland Consumption than for CO_2. Notwithstanding this evolution, the influence of higher fuel prices on the global energy demand dominates and CO_2 emissions are lower than in the Reference scenario.

In general terms, a lower availability of oil and gas resources at world level translates into a reduction of the global demand for these fuels and to a larger penetration of coal. Natural gas is the most penalised fuel in terms of consumption and market share. The demand for natural gas is 13% lower than in the Reference. This decrease is the combination of a drop in electricity produced from natural gas of one fifth in 2030 and a reduction of gas demand for final uses of some 10%. The share of gas for electricity production represent no more than 23% in 2030, compared to 28% in the Reference. The oil consumption growth slows down: 1.4%/year on average over the period 2000-2030, compared to 1.7%/year in the Reference.

The decrease in oil and gas demand is compensated by larger quantities of coal (+7 %) and to a lesser extent by the development of non-fossil energies, with an increase of slightly less than 4% of nuclear and renewables in 2030.

Table 4.3: World energy consumption and CO_2 emissions: Low case versus Reference

	2010	2020	2030
Energy intensity of GDP	-1.7%	-2.4%	-3.0%
CO2 emissions	-1.9%	-2.4%	-1.9%
Gross inland consumption	-1.7%	-2.4%	-3.0%
Coal, lignite	-0.3%	1.7%	7.4%
Oil	-3.2%	-5.2%	-6.4%
Natural gas	-2.7%	-5.1%	-13.0%
Other	0.8%	1.8%	3.8%

4.1.2 High gas resources

The High case uses the upper range estimate for the ultimate recoverable gas resources and the median estimate for oil, both to account for uncertainties on the resources level and to provide a scenario where gas prices are structurally lower than oil prices.

The impact on gas resources, reserves, production and prices

The simulation of the high gas resource case provides a significantly different picture of world gas development to 2030, as illustrated in Table 4.4. The Ultimate Recoverable Resources of gas for the base year is 44% higher than in the Reference. However, due to the impacts of price on recovery rates, symmetrical to those described in section 3.1.1, the difference in Ultimate Recoverable Resources is decreasing over time. The impact is particularly strong for Latin America (+83% in 2030), China (+74% in 2030) and the CIS (+40%). The additional gas resources are unevenly distributed geographically, about half of them occurring in the CIS with large additions also recorded in Iran and Latin America.

By 2030, reserves and production levels are respectively 45% and 20% higher than in the Reference. As a result, the reserve to production ratio increases. In particular, gas reserves in North America are notably higher than in the Reference.

Table 4.4: Gas supply: High case versus Reference

GAS	2010	2020	2030
URR			
OECD	32%	31%	30%
CIS	42%	41%	40%
Other	50%	49%	48%
World	43%	42%	42%
Gas reserves			
OECD	52%	92%	124%
CIS	8%	16%	28%
Other	5%	27%	43%
World	11%	30%	45%
Gas production			
OECD	4%	19%	35%
CIS	2%	5%	7%
Other	12%	12%	23%
World	7%	12%	20%
R/P ratio	4%	16%	20%
Gas import price			
American market	-14%	-25%	-39%
European market	-14%	-21%	-28%
Asian market	-14%	-15%	-16%

In the High case, the Middle East represents 13% of world gas production in 2030, instead of 16% in the Reference, the CIS 31% instead of 35%, and the OECD region 27% instead of 24%. As a whole, the High case portrays a world with a lesser degree of dependence on gas supply from the Middle East and the CIS.

As a consequence of the above trends in reserves and production levels, and in spite of the higher demand for natural gas, natural gas prices are lower by 16% and up to 40% depending on the regional market considered. More precisely, gas prices in the High case are projected to be 16, 20 and 28 €/bl in 2030, respectively on the American, Euro-African, and Asian markets.

The impact on the world energy system and CO_2 emissions

As expected, the High case provides a fully different (nearly opposite.) picture of the world energy system at the 2030 horizon, compared to the Low case. The world energy outlook described in the Reference is also affected by the lower gas prices resulting from the worldwide abundance of resources. The major change concerns the share of the different fuels in gross inland consumption: the demand for natural gas is 20% higher than in the Reference (Table 4.5). Gas replaces principally coal (-8.5%) but also some quantities of oil (-3%) and non-fossil energies (-4%). As a result, natural gas increases its market share in 2030 to 30%, from 25% in the Reference.

In contrast, total energy demand and CO_2 emissions are only slightly affected by the low gas prices. The average energy intensity of the economy and total energy demand are 1.5% higher than in the Reference in 2030, while CO_2 emissions are 0.2% lower. The latter figure shows that the replacement of coal by natural gas, a fuel with lower carbon intensity, compensates for the increase in gross inland consumption and for the decrease in non-fossil energies, principally nuclear.

Table 4.5: World energy consumption and CO_2 emissions: High case versus Reference

	2010	2020	2030
Energy intensity of GDP	0.1%	0.9%	1.5%
CO2 emissions	-0.8%	-0.4%	-0.2%
Gross inland consumption	0.1%	0.9%	1.5%
Coal, lignite	-4.2%	-5.9%	-8.5%
Oil	-0.9%	-1.8%	-2.9%
Natural gas	5.7%	12.2%	21.2%
Other	0.2%	-0.9%	-3.7%

Key conclusions

- With lower oil and gas resources than the Reference, oil and gas prices are projected to be much higher than in the Reference, around 40 €/bl in 2030. This induces a lower world energy demand (-3%), which benefits particularly coal and non-fossil energies, to the disadvantage of natural gas (-13%) and oil (-6%). As a result, world CO_2 emissions are 2% lower than in the Reference.

- Increased availability in gas resources would lead to a drop in gas prices to 16, 20 and 28 €/bl in 2030, respectively on the American, European and Asian markets. In contrast, the oil price decreases only slightly underlying low substitution possibilities between oil and gas. Although the world energy demand is slightly affected (+1.5% compared to the Reference), the fuel mix is substantially modified in favour of natural gas (+21%, against –9% for coal ,-3% for oil and -4% for primary electricity)

4.2. TECHNOLOGY DEVELOPMENT FOR POWER GENERATION

Besides the availability of fuels and the related fuel prices, assumptions on the development of energy technologies play a crucial role in the analysis of future energy systems. The ability to reduce greenhouse gas emissions and especially the cost of the corresponding policies will largely depend on the available technologies. Alternative proposals to the Kyoto protocol even call for a multi-lateral agreement on research and development (R&D) in order to accelerate the development of new energy technologies and thus provide cheap options for the reduction of greenhouse gas emissions. This section provides a closer look on the role of energy technologies in carbon emissions and emission reduction. The purpose is to determine to what extent technology development or accelerated technology substitution can reduce energy-related greenhouse gas emissions by applying more efficient technology and changing the fuel-mix.

Technology development and learning

Forecasting technology development is a highly speculative activity, especially for a long-term time horizon. However, considerable efforts have been recently made to improve the modelling of technology development in energy models. The simplest approach relies exclusively on exogenous forecasts based on expert judgement on technology development and economic performance[17]. It can be replaced by a description of technology cost dynamics which allows to endogenise, at least partially, technological change in energy models[18]. For WETO the method applied takes into account the "learning by doing" effect and also the impact of R&D on technology development. This approach yields projections of technology development which are consistent with historic trends (see Figure 4.2). The WETO Reference thus contains a coherent set of assumptions with respect to technology development.

For the technology cases it is assumed that accelerated technology development, or technological breakthroughs, may occur for certain clusters of technologies. To describe the enhanced technology performance, the conversion efficiency, total investment cost[19], as well as operation costs are changed. Here it is assumed that these breakthroughs present a deviation from the trajectory of technology development as applied in the Reference. Expert judgements have been used to define a possible albeit optimistic set of assumptions for improved technology performance up to the year 2030. The technology cases thus use a hybrid approach applying exogenous technology improvements to a set of consistent endogenous projections on technology development. The model used is able to estimate the amount of additional

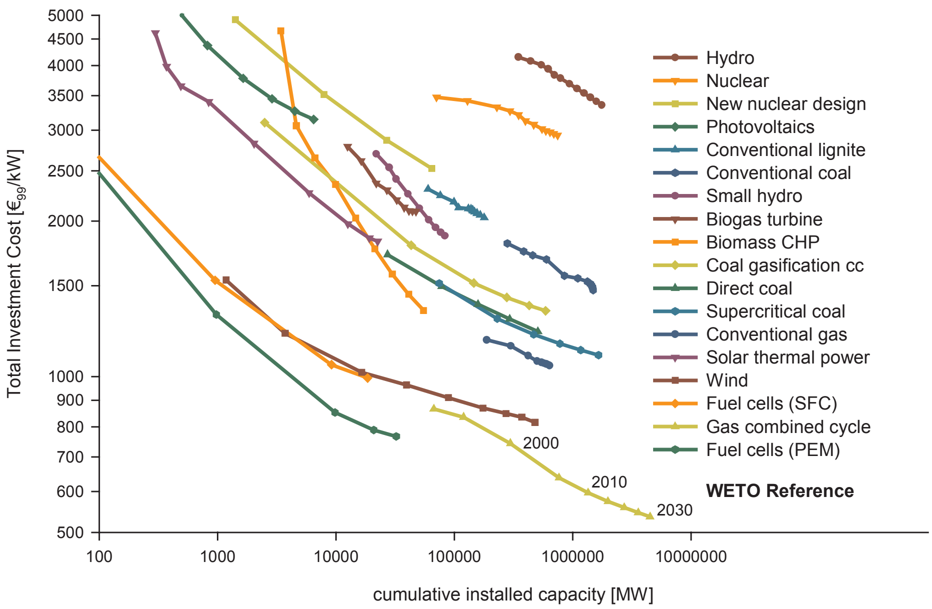
[17] E3-TDB, the database on energy technologies used in the POLES model has been developed under several research projects under the JOULE programme of the European Commission (Bess M. et al., *Technology Database E3TDB*, *in* International Journal of Global Energy Issues, Special Issue, Vol. 14, Nos. 1-4, pp. 398-403, 2000).

[18] See Kouvaritakis N., Soria A., Isoard, S., *Modeling energy technology dynamics: methodology for adaptive expectations models with learning by doing and learning by searching*, in International Journal of Global Energy Issues, Special Issue, Vol. 14, Nos. 1-4, pp. 104-115, 2000

[19] The cost figures presented hereafter refer to **total investment costs**, i.e. they include the so-called overnight construction costs (the cost of the equipment) plus financial costs that accrue during the construction time, as well as decommissioning costs.

R&D necessary to bring about accelerated technological progress. However, the focus of the technology cases is to analyse the impact of a defined technological breakthrough rather than the issue of higher R&D investments or more focussed technology policies to provoke technological development. For this reason the hybrid approach has been chosen and the link between R&D and technology improvement is not treated in this study.

Figure 4.2: Learning curves for power generation technologies[20] up to 2030



The technology cases can be summarised as follows:

- The "Gas case", which assumes enhanced availability of natural gas and introduces improvements for gas turbine combined cycle plants and fuel cells.

- The "Coal case", which involves major improvements in advanced solid fuel burning technologies, namely Supercritical coal plants, Integrated coal gasification combined cycle plants and direct coal firing plants.

- The "Nuclear case", which assumes a breakthrough in nuclear technology in terms of cost and safety. It has an influence on standard large light water reactors but especially on a new evolutionary nuclear design.

- The "Renewable case" involves a major effort in renewable energies notably, wind power, biomass gasification, solar thermal power plants, small hydro and photovoltaic cells.

[20] The learning curves or progress curves show the historic development of investment cost for the energy technologies over the total cumulative installed capacity and their projections up to the year 2030 for the WETO Reference. The symbols indicate time steps of five years.

All the cases are technology scenarios looking exclusively at technologies for electricity generation. They are focused on changes in the technology portfolio on the supply side and do not analyse policies and technologies on the demand side. Whilst this can be considered a limitation of the exercise at the same time it provides better consistency in the assessment of a given breakthrough.

4.2.1 Gas

This case combines modifications in the performance and costs of some key technologies and an expansion of world ultimate gas resources. This latter was carried out by following the 5 % probability upper estimate for undiscovered resources and corresponds to the high gas reserves case (High case) as described in the previous section. The technology side of the case gas powered technologies based on gas turbines have been dealt with:

– **Gas turbine combined cycle (GTCC).** This is already the most successful power generating technology in the Reference contributing about 22 % of total generation by the year 2030. This gain in share achieved in the face of substantial increases in natural gas prices is mainly due to the major improvements in techno-economic performance incorporated already in the Reference: i.e. a 40 % decrease in capital costs mainly due to an increase in efficiency from around 53 % at present to 59 %. For the gas case capital costs are reduced by a further 20 %, specific fixed operation costs reduced by 20% and efficiencies raised to 63 %.

– **Gas turbine combined cycle for combined heat and power**. It is another gas-turbine dependent technology that sees relatively sluggish performance in the Reference due to higher gas prices. For the technology case apart from the lower gas prices this technology is assisted by a two point increase in both electric and steam conversion efficiency but also by a 20 % reduction in specific capital cost, fixed and variable operating costs.

This technology case represents a radical alternative in terms of world energy market configurations due to the enhanced natural gas resource base. Already the High case sees a reduction of global CO_2 emissions of -0.1%. With the changed assumptions on technologies as introduced in the Gas case global emission the emission reduction reaches -1.6%.

As described in the section on the High Gas Resources case (High case), in spite of much higher cumulative production, world reserves are more than one and a half times their reference level in 2030 resulting in much lower bulk gas prices. This has strong impacts for low to medium loads (residential/commercial electricity) where due to the suitability of GTCC to meet such demand, electricity prices have fallen on average world-wide by nearly 10%. In spite of an increase in consumption, electricity generation stays at the same level since gas turbines for combined heat and power generation as well as fuel cells are used to a much higher extent in industry so that distribution losses are reduced.

Within the power generating sector, many considerable changes occur world-wide. Generation from gas turbine combined cycle plants increases considerably bringing their share to 28% of total generation instead of 22% in the Reference. This increase is achieved at the expense of super critical coal (-1080 TWh) and the other coal technologies (-820 TWh) but also of nuclear (-1700 TWh, 60 % of which the new nuclear design which finds little room to develop). Combined heat and power from combined cycles sees its contribution increasing by

35%. On the other hand, many renewable sources of electricity see their shares reduced (eg wind power plants by 10%).

The Gas case has produced weak results as far as CO_2 emissions is concerned. The emission reduction vis-à-vis the Reference is -1.6%. This is due partly to the uneven geographical distribution of the enhanced resources resulting in the gas not being available at sufficiently cheap prices where it could have made the biggest impact (the big Asian coal users China and India). For some other regions assuming higher resources implies that prices tend to stay relatively lower during the simulation time horizon, causing demand to expand, particularly from the power generating sector. Also this effect limits the impact of the advanced gas technology on the reduction of CO_2 emissions.

Table 4.6: Assumptions and results of the Gas case

	2000	2010			2030		
		Reference	Gas case	Change	Reference	Gas case	Change
Gas turbine combined cycle							
Total investment cost [$€_{99}$/kW]	745	587	548	-7%	533	427	-20%
Efficiency [%]	53.5	57	57	0%	59	63	7%
Electricity generation [TWh]	1311	5240	6111	17%	8334	10409	25%
Total							
Electricity generation [TWh]	15639	20159	20175	0.1%	36621	36720	0.3%
CO_2 emissions [Gt]	6794	8184	8162	-0.3%	12562	12359	-1.6%
CO_2 emissions [Gt] from electr. generation	2318	2457	2412	-1.8%	4298	3990	-7.2%

4.2.2 Coal

The coal case analyses the effect of improvements of advanced coal based energy technologies. The following technologies have been considered:

- **The supercritical coal power plant.** This power plant type achieves high conversion efficiencies applying supercritical steam conditions (higher pressure and temperature of the steam). Special materials are necessary that can withstand these conditions. In the reference case the conversion efficiency achieved in 2030 is 49 % and specific capital cost of the technology is around 1100 €/kW with low operating and maintenance costs (by coal fired power plant standards). This technology is the "winning" coal technology in the Reference gaining about 20 % of world total central power generation and 30 % of world coal generation by 2030. For the purpose of this case the efficiency was increased to 55 % and the capital cost brought down to 800 €/kW by 2030 while a 10 % reduction in operation and maintenance (O&M) costs was also introduced.

- **The integrated coal gasification combined cycle power plant (IGCC)**. This technology applies coal gasification with combustion of the coal gas in a gas turbine and the recovery of waste heat in a boiler. The technology in the Reference reaches about 50 % efficiency and costs 1350 €/kW by 2030 with still relatively high operating and maintenance costs of about 87 €/kW. In that case, it achieves a penetration of about half the importance of supercritical coal. In the Coal case the techno-economic performance of this type of plant is substantially improved to reach 54 % efficiency by 2030 while achieving 28 % reductions in capital and 10% in fixed O&M costs.

– **The direct coal fired combined cycle plant**. Like the IGCC plant this technology is applying a gas turbine and a steam turbine in a combined cycle. However, the coal is directly burnt in the gas turbine without previous gasification.. The presence of coal particles inside the turbine poses technical problems, which still have to be solved. Therefore, it is assumed that this technology will be available only after 2015. This technology is costing 1250 €/kW, reaching 50 % thermal efficiency by 2030 with relatively low operating costs. It achieves a penetration comparable to the IGCC plant in the Reference. A capital cost of 960 €/kW and an efficiency of 54 % is retained for the scenario resulting in cost performances similar to those of the IGCC plant.

A salient effect of this case is a noticeable displacement of gas-fired combined cycles by coal-fired power plants even in regions with access to reasonably cheap gas prices. Coal-fired power plants exhibit a competitiveness threshold with respect to combined cycles for loads higher than 6500 hours/year in the Reference, whereas in the advanced coal case this threshold moves to around 4500 hours/year. The development over time of electricity generation cost of a supercritical coal plant and a gas combined cycle plant can be seen in Figure 4.3.

Figure 4.3: Cost of electricity: gas combined cycle versus supercritical coal technology

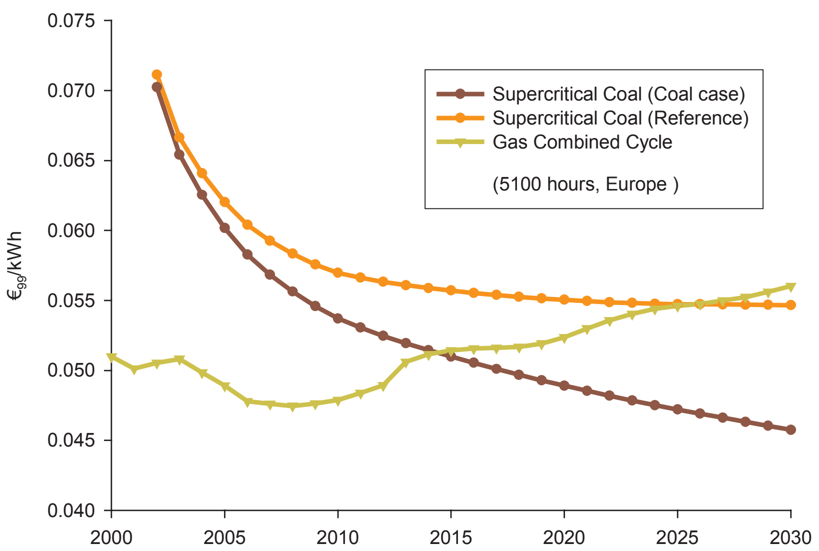


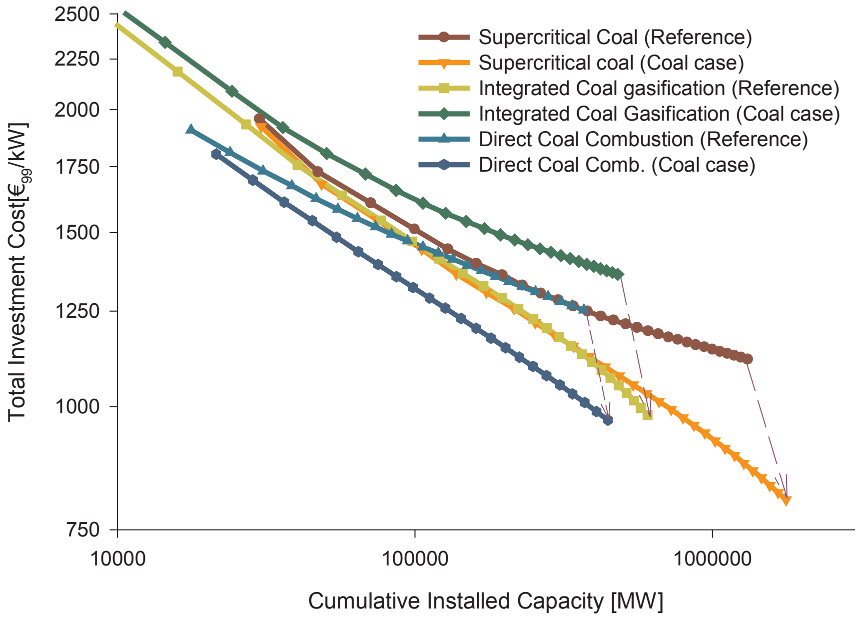
Table 4.7: Assumptions and results of the Coal case

	2000	2010			2030		
		Reference	Coal case	Change	Reference	Coal case	Change
Supercritical coal							
Total investment cost [€$_{99}$/kW]	1970	1303	1181	-9%	1117	805	-28%
Efficiency [%]	44	46	47.7	4%	49	55	12%
Electricity generation [TWh]	0.009	1391	1518	9%	6989	8608	23%
Integrated Coal Gasification (IGCC)							
Total investment cost [€$_{99}$/kW]	2631	1805	1637	-9%	1361	980	-28%
Efficiency [%]	43.5	49	49	0%	49.8	54	8%
Electricity generation [TWh]	0.11	355	396	12%	3101	3752	21%
Direct coal							
Total investment cost [€$_{99}$/kW]	n.a.	1733	1696	-2%	1252	969	-23%
Efficiency [%]	n.a.	46.5	50	8%	49.3	54	10%
Electricity generation [TWh]		n.a.	n.a.		1893	2140	13%
Total							
Electricity generation [TWh]	15639	20159	20167	0.0%	36621	37006	1.1%
CO_2 emissions [Gt]	6794	8184	8170	-0.2%	12562	12560	0.0%
CO_2 emissions [Gt] from electr. generation	2318	2457	2443	-0.6%	4298	4309	0.3%

The Coal case produces no change in world CO_2 emissions, with relatively high regional differences: a decrease in Asia (-1.0 %), an increase in Western Europe (1.4 %) and the OECD as a whole (0.8%), and stagnation in the rest of the world. Advanced coal plants are more efficient and therefore produce considerably less CO_2 per kWh than conventional coal-fired plants. However, this is offset in some regions by the fact that clean coal plants also become cheaper and therefore often are preferred to nuclear and gas-fired plants which produce even less CO_2 per kWh. Coal consumption in power stations increases by 5 % while gas consumption decreases by 14 %, oil by 13 % and nuclear generation by 6 %.

Concerning new coal technologies the largest change occurs for the supercritical coal plants. Supercritical coal's share of world centralised power generation goes up from under 20 % to around 25 % while the increase in IGCC generation is less marked (share up from 9 % to 11 %). The improvements supposed for the Direct Coal combustion plants are insufficient to significantly increase its cost-competitiveness. Thus, its contribution remains at 5.5%. The results are reflected in the learning curves for the Coal case (Figure 4.4).

Figure 4.4: Learning curves for advanced coal technologies



The advanced coal technologies replace very substantially gas combined cycle generation (-1300 TWh). Since already in the Reference the bulk of coal based electricity generation comes from new technologies (78%) the potential for replacement of these technologies by new coal technologies is limited. Indeed, the generation from conventional coal technology is reduced by only 85 TWh. The new coal technologies act as a break for the development of new nuclear design power plants (-36%), while conventional nuclear plants are less affected. Also severely affected are the biomass gasification combined cycle plants (-18 %) and wind power generation (-10 %) mainly due to the lower base load electricity prices (nearly 10 % lower). International coal prices are 5-7 % higher which is clearly not sufficient to reduce significantly the competitiveness of the new coal technologies.

4.2.3 Nuclear

This case has been implemented by altering the techno-economic characteristics of the two types of nuclear power plants considered in this study:

- **Standard large Light Water Reactor (LWR).** In the reference case this plant type is supposed to exhibit capital costs slightly increasing over time due to increased investment in security measures. In the technology case, the investments as well as O&M costs are assumed to be about 35 % lower as compared to the Reference in 2030.

- **New evolutionary nuclear design**. This technology is assumed to be introduced gradually after 2010 in the Reference and costs about 30 % less to construct than the LWR by to 2030 thanks primarily to its inherent safety characteristics. In the Reference it gained a substantial share of the total nuclear market (approx. 12 %). For the nuclear technology case this type of plant is assumed to be 35 % cheaper to construct and 35 % to operate than in the Reference.

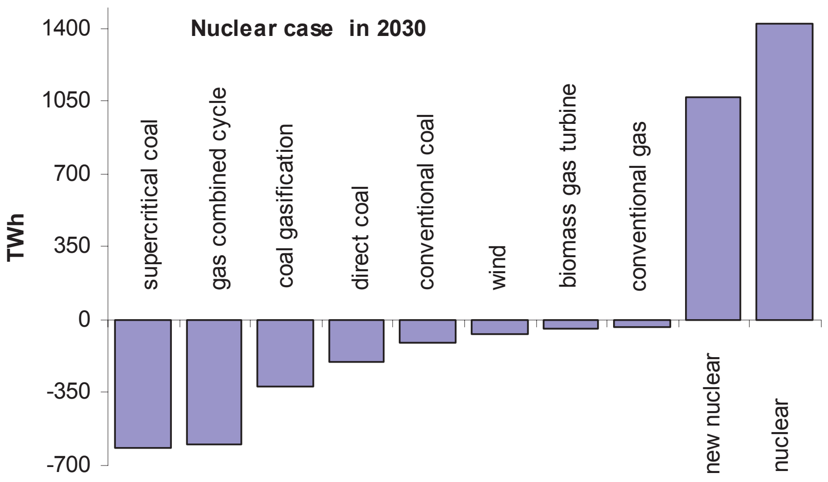
Table 4.8: Assumptions and results of the Nuclear case

	2000	2010			2030		
		Reference	Nuclear case	Change	Reference	Nuclear case	Change
Light Water Reactor (LWR)							
Total investment cost [$€_{99}$/kW]	3632	3574	3159	-12%	3639	2365	-35%
Electricity generation [TWh]	2627	3155	3158	0%	2832	4253	50%
Advanced Nuclear Design							
Total investment cost [$€_{99}$/kW]	n.a.	6770	5980	-12%	2560	1663	-35%
Electricity generation [TWh]	n.a	n.a.	n.a		377	1443	283%
Total							
Electricity generation [TWh]	15639	20159	20225	0.3%	36621	36849	0.6%
CO_2 emissions [Gt]	6794	8184	8202	0.2%	12562	12214	-2.8%
CO_2 emissions [Gt] from electr. generation	2318	2457	2473	0.7%	4298	3984	-7.3%

These changes have an important impact on the market penetration of these plants. In the Reference they become less and less competitive in most regions of the world even for the high annual loads. In the nuclear technology case, they become generally cost-attractive *vis-à-vis* combined cycle gas turbines at around 5500 hours/year and *vis-à-vis* supercritical coal technologies in the region of 4500 hours/year. The competitiveness gains are particularly marked for the new nuclear design. It is worth noting, however, that the changes in costs are phased in gradually and that power plants and especially nuclear ones are characterised by a slow capital turnover.

The overall effect of this technology case is a worldwide reduction of CO_2 emissions in 2030 of 2.8% (4.6 % in the OECD). At global scale there is considerable increase in nuclear electricity generation. Overall nuclear contribution increases from 9 % to over 15.5 % (from 16 % to 37 % in the OECD). Nuclear power – an expensive option in the Reference projection – penetrates into the high to medium annual loads displacing coal and gas fired electricity production (see Figure 4.5). The relatively important reduction in GTCC just reflects its fundamental contribution in middle and high loads in the reference case. International coal prices are 5-10 % lower while gas prices are down 3-8 %. World oil prices stand virtually unaffected (-1 %) since most of the changes implied by this technology case occur within the electricity sector where petroleum plays a small role.

Figure 4.5: Impact of the nuclear case on the electricity generation by technology



4.2.4 Renewables

This case is different from the previous ones in that it is not organised around a single technological breakthrough or a generic cluster of technological developments. It is rather representative of a situation where a major R&D effort would be directed on decentralised renewable technologies producing drastic improvements in their techno-economic characteristics of a number of them. The main technologies affected in this technology case are:

– **Biomass gasification for electricity** production in small scale (less than 25 MW) combined cycle plants. In the Reference, the specific capital cost of this technology is reduced by 15% and the conversion efficiency increased from to 43 %. Under these circumstances the contribution of this technology is growing at an average 5.5 %/year. For this technology case, specific capital costs are assumed to be cut by 30% by 2030 with some further improvements in efficiency and operating costs. The impact of these changes is a doubling of the contribution of this technology in 2030, albeit with an inflexion of growth towards the end of the period due to the limited availability of cheap biomass resources.

– **Photovoltaics.** In the Reference, their capital cost is drastically reduced from about 15000 €/ kW in 1990 to 4400 €/kW by 2010 and 3200 €/kW by 2030. Specific fixed O&M costs are halved between the present and 2030. Impressive as these reductions are they leave the cost of electricity produced at a generally uncompetitive level and the technology had a relatively symbolic contribution. The Renewable Case implies a halving of 2030 reference costs, which translates into a reduction of the cost of the kWh delivered to around 17 €ct. This cost, although still not generally competitive as compared with network electricity, allows at least the development of niche markets and leads to a contribution of around 32 TWh worldwide by 2030. Of these only about 6 TWh are produced in developing countries despite the fact that on average they enjoy better insolation conditions.

– **Molten Salt Tower Solar plant** with storage. This is the main solar thermal power technology considered with a capital cost reduced to 2050 €/ kW and a capacity factor of 36 % by 2030 in the Reference. In the technology case these figures reach 1450 €/kW and 38 % respectively, and the total electricity generation is 119 TWh worldwide. Though this figure is relatively modest, it does not represent the full potential impact of this technology as by 2030 it is still in the stage of rapid take off in industrialised countries and has not even entered that stage in developing countries where most of the physical potential exists.

– **Small hydro.** In the Reference, it is assumed to be a mature technology registering insignificant gains over the projection period. Capital cost are halved in this technology case and hence its contribution rises from 250 TWh to 380 TWh worldwide by 2030. However by the end of the period the technology displays clear signs of saturation as the best available sites are gradually exhausted.

– **On-shore wind turbines** (over 500 kW capacity). In the Reference relatively modest reductions in capital costs from 1000 €/kW to 820 €/kW in 2030 are assumed with improvements in capacity factors to a range of 12-30 % depending on the site. The technology case by contrast implies a reduction of capital costs to two thirds of their present level and further significant increases (+ 25 %) in capacity factors. These developments render wind power highly competitive, in spite of its intermittent character and lead to massive development worldwide. This development is furthermore fairly evenly distributed, with about half occurring in industrialised countries.

Table 4.9: Assumptions and results of the Renewable case

	2000	2010			2030		
		Reference	Renewable case	Change	Reference	Renewable case	Change
Photovoltaics							
Total investment cost [$€_{99}$/kW]	6457	4373	3936	-10%	3146	2202	-30%
Electricity generation [TWh]	0.02	0.26	0.33	27%	0.88	2.04	132%
Biomass gasification							
Total investment cost [$€_{99}$/kW]	2368	2198	1978	-10%	2087	1461	-30%
Electricity generation [TWh]	0.11	255	218	-15%	169	371	120%
Wind turbines							
Total investment cost [$€_{99}$/kW]	996	911	820	-10%	816	571	-30%
Electricity generation [TWh]	23.6	171	230	35%	710	2016	184%
Total							
Electricity generation [TWh]	15639	20127	20159	0.2%	36621	35802	-2.2%
CO_2 emissions [Gt]	6794	8184	8150	-0.4%	12562	12188	-3.0%
CO_2 emissions [Gt] from electr. generation	2318	2457	2432	-1.0%	4298	3917	-8.9%

In addition to the above the renewable case includes three more technologies where the improvements implied are insufficient to produce a significant impact. These are low temperature passive solar, which due to insufficient cost reductions remains a niche option, rural photovoltaic, which becomes uncompetitive with network connection and therefore faces a shrinking market potential as electrification proceeds.

The Renewable case results in a 3 % reduction in worldwide CO_2 emissions (3.2 % in Asia and 2.4 % in the EU). This is primarily achieved by an across the board reduction in centrally produced electricity (-1600 TWh of coal fired -950 TWh of gas fired and -180 TWh of nuclear generated electricity world-wide).

World oil prices are hardly affected (around -1 %) but wholesale gas and coal prices are more substantially reduced (around - 5 %) allowing for some increase of the consumption of these fuels outside the power generation (especially in industry). This phenomenon partially offsets the substantial reductions in power generation. Generally this technology case has major implications for new and renewable technologies but fails to produce a major impact on CO_2 emissions in the 2030 horizon because these technologies are mostly applicable to the power sector and often (being mostly intermittent) even a limited section of this sector. In addition, the some of the renewable technologies become truly competitive only towards the end of the period, thus having little time to display their full potential.

4.2.5 Impact on CO_2 emissions

The technology cases as described in section 4.2 provide a closer look on the role of energy technologies in carbon emissions and emission reduction. The different assumptions on technology development lead to significant changes in the electricity production structure (Figure 4.10). The impact on total global CO_2 emissions, however, is limited. The maximum reduction vis-à-vis the Reference was 3%. The technology cases as defined here do not offer definitive solutions for the global CO_2 emission problem. There are many reasons for this. Some of them are inherent to the way these cases were set up, whereas other are related to the structure of energy markets.

Table 4.10: Summary of the impact of the technology cases

	Electricity generation						**Total**
	based on						
changes as compared to Reference in 2030	**Gas**	**Coal**	**Nuclear**	**Renewables**	**Total generation**	**CO_2 emissions**	**CO_2 emissions**
Gas case	**21.6%**	-12.2%	-5.3%	-10.5%	0.3%	-7.2%	-1.6%
Coal case	-16.0%	**15.0%**	-6.5%	-10.2%	1.1%	0.3%	0.0%
Nuclear case	-7.1%	-8.1%	**77.5%**	-9.9%	0.6%	-7.3%	-2.8%
Renewable case	-12.3%	-8.8%	-2.4%	**132.0%**	-2.2%	-8.9%	-3.0%

Key conclusions

- The different assumptions on technology development lead to significant changes in the structure of electricity production. However, the technology cases defined here do not offer definitive solutions for the global CO_2 emission problem.

- This is largely because the technology cases are defined in terms of clusters of technological breakthroughs affecting only a part of the energy market, basically the power generation sector. Important though the power sector may be, it only accounts for about one third of world CO_2 emissions. Technologies addressing only this sector can be expected to have an impact limited by this share.

- The extension of these energy technology cases to other important CO_2 emitting sectors should be a priority in the future. An area where such an impact of a cluster of emerging technologies could be convincingly found is in road transport. Also new technologies in industrial energy-intensive sectors as well in the residential and tertiary sector could be analysed.

- Cases involving major improvements in fossil fuel technologies produce low impacts on CO_2 emissions because of two opposing effects. On the one hand, advanced fossil-fuelled technologies reduce specific carbon emissions due to enhanced conversion efficiency. On the other hand, they make fossil-fuel technologies more attractive due to lower costs and therefore foster the use of fossil fuels. Therefore, scenarios involving non-fossil energy delivered markedly better a greater impact on CO_2 emissions.
- It is hard to see how clusters of energy technologies could by themselves make a major impact on the global CO_2 problem if they are not accompanied by major policy initiatives albeit market related ones. Combining the technology cases with internalisation of external costs through taxation would magnify the impact and tend to neutralise some of the more ambiguous side effects quite apart from the fact that these policy instruments can by definition act on a much wider front. Section 6.3 is showing that advanced technologies can have a considerable impact on the cost of meeting emission reduction targets.

CHAPTER 5

EU GAS MARKET IN A WORLD PERSPECTIVE

In the EU, natural gas has been the fastest growing component of the energy consumption over the last ten years. At world level, the increase in gas demand has also been remarkable. The increasing synergy between gas and electricity generation was, without any doubt, a key determinant of this remarkable evolution. As the Reference projects the continuation of this trend at world level through 2030, it is worth asking how the projected growing market for gas, combined with the decline of gas production in Europe, will affect the outlook of European gas supplies to 2030 and what the impacts could be on the security of natural gas supply in the EU.

The chapter starts with a description of the projected evolution of EU gas demand in the Reference and compares this evolution with past trends in the EU and with the evolution in the other world regions. In this analysis, particular attention is given to the prospects of gas use in electricity generation. In the next section, the projected changes in gas production levels by world region and in gas supply patterns for the EU and the other regions are described and analysed, as well as the consequences in terms of inter-regional gas trade and gas transport infrastructures (i.e. pipelines versus LNG). Finally, the last section deals with the implications for the security of natural gas supply in the EU and describes how the uncertainties on gas resources may affect the security.

In this chapter, the EU gas market is examined under two configurations: the present European Union of 15 Member countries (EU) and the enlarged EU including the 12 Accession countries[21] (EU + Acc. Countries).

5.1 GAS DEMAND

EU contribution to world gas consumption

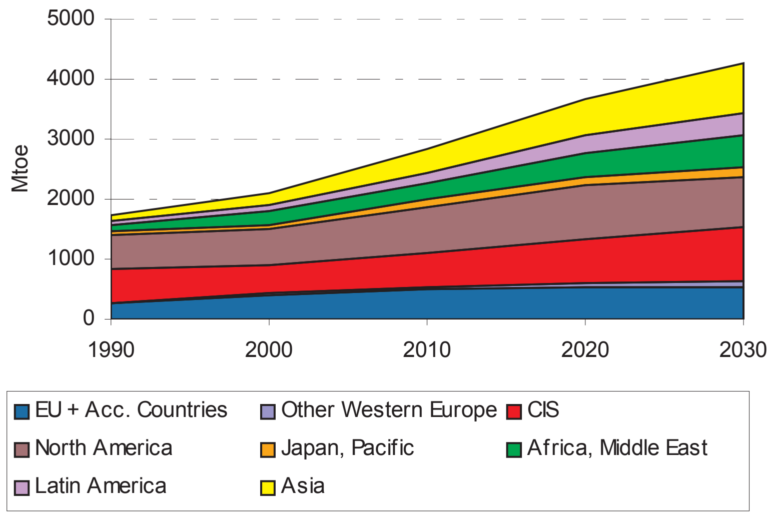
The WETO Reference projects a significant increase in the world demand for gas. Over the period 2000-2030, gas demand is expected to double, reaching 4.3 Gtoe in 2030. This increase is the result of the remarkable growth of 3%/year on average from 2000 to 2010 followed by a slightly lower growth of 2.1%/year over the period 2010-2030. On average, the gas demand growth through 2030 will be higher than during the last ten years, namely 2%/year. However, it is worth pointing out that, during that period, the world natural gas consumption growth was substantially reduced due to a considerable decrease in the CIS's consumption.

The pace of growth shows however contrasted patterns between world regions (Figure 5.1). For instance, the EU's contribution to this impressive rise in gas demand is minor compared

[21] Hungary, Poland, Czech Republic, Slovakia, Latvia, Estonia, Lithuania, Slovenia, Romania, Bulgaria, Malta and Cyprus.

to the contribution of certain regions, in particular Asia and the CIS, which represent the bulk of the increase.

Figure 5.1: World gas demand



In fact, the EU gas demand is projected to increase more slowly than the world average, at 0.8% per year over the outlook period[22], but also in comparison to the last ten years when it grew at an exceptional average annual rate of 4.9%. The growth rate is slightly higher, namely 0.9%/year, when the Accession countries are included. Despite this apparent low growth, natural gas remains the second fastest growing primary source[23] in the EU. For the sake of comparison, coal and oil primary demands are projected to increase respectively by 0.5% and 0.2%/year. The EU is with North America the region where gas demand increases the least. The average rate of increase in North America is projected to be 1.2%/year for the next thirty years.

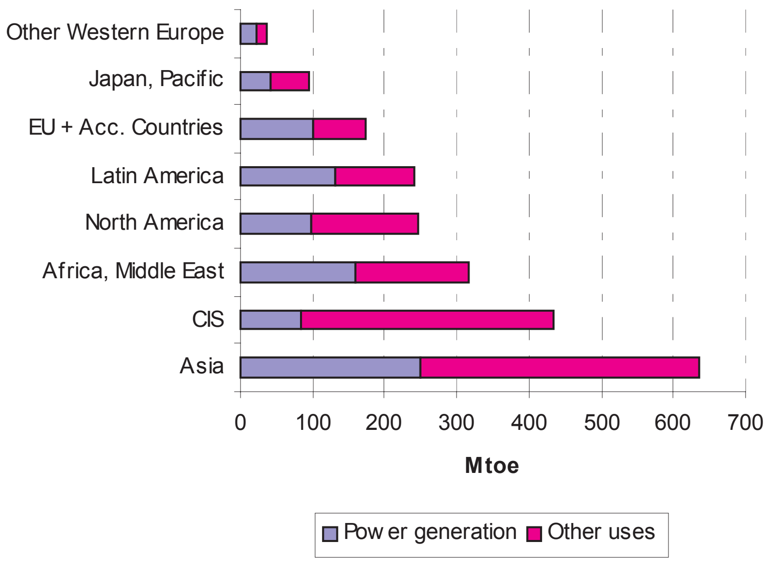
On the opposite side of the range, the projections of natural gas consumption show a rapid growth in Asia and Latin America, above 4%/year between 2000 and 2030. On the other hand, the average growth in the CIS, Africa, Middle East, Japan and Pacific ranges from 2.3 to 3%.

The largest increments in gas demand compared to the present situation are therefore expected in Asia and Latin America. In fact, about one third of the increase in world gas demand over the next thirty years comes from Asia. In contrast, Latin America accounts for 12% of the incremental gas demand as it starts from a smaller share of world gas consumption in 2000. EU with Accession countries contributes to 7% of the increase in world gas demand over the outlook period (Figure 5.2).

Consequently to the above regional trends in natural gas demand, the share of developing countries in the world gas demand increases to 40% in 2030 from around 25% in 2000.

[22] 1.7% per year on average between 2000 and 2010, and 0.4% thereafter.
[23] The fastest growing component is wind energy but its share in GIC remains small.

Figure 5.2: Gas consumption increase from 2000 to 2030



Although the EU gas demand is projected to grow moderately compared to the recent trend, it is progressing faster than the gross inland energy consumption. Therefore, the share of natural gas in total energy requirements is still expected to grow to 27% in 2030 from 24% in 2000.

Furthermore, primary gas consumption in EU grows faster than final gas demand, principally because of the increasing preference for gas as a power generation fuel and the increasing penetration of electricity in the economies. Several factors contribute to slow the progression of gas used by final consumers: the moderate growth of the overall final energy demand due to a steady decrease in final energy intensity, and the saturation of gas demand for several end-uses, like space and water heating in the residential and tertiary sectors, reflecting the maturity of the gas market in many European countries.

Increase of gas in the EU power generation

As stressed in the above section, the driving force behind the gas demand growth in the EU is the increased consumption of natural gas for power generation[24]: electricity production is expected to contribute to more than 50% of incremental gas demand between 2000 and 2030.

More generally, in all world regions except the CIS, over 40% of incremental gas demand results from the expansion of gas for power generation. In contrast, the largest part of incremental gas demand in the CIS results from final gas uses (Figure 5.2). This particular situation in the CIS comes from the fact that although gas-based electricity production increases significantly, at an average rate above 4%/ year, the replacement of old gas-fired

[24] Power generation includes here electricity generated by CHP power plants.

plants with more efficient combined cycle gas turbines limits considerably the rise in gas use for power generation.

In the 1990s, the EU, similarly to most world regions, experienced a rapid rise in the market share of natural gas in electricity production: in 2000, about 20% of total electricity was generated from natural gas compared to 12% in 1990. Low capital costs and high conversion efficiency of gas turbine technologies; environmental concerns and competitive gas prices were the driving factors behind this remarkable change. This evolution was also characterised by a growing interconnection between European gas and power industries. The implementation of the European Parliament and Council Electricity and Gas Directives[25] introducing greater competition into EU Member States' electricity and gas markets is expected to perpetuate this trend, provided that power plants operating on natural gas remain competitive compared to other technologies, principally advanced coal technologies.

In fact, the use of natural gas for the production of electricity depends on several factors including the future electricity demand growth, the need for new generation capacity, the evolution of the prices of competing fuels (particularly coal) and the evolution of the costs of new power generation technologies

Between 2000 and 2010, natural gas is projected to account for the largest share (nearly 70%) of the increase in electricity production in the EU. As a result, some 27% of electricity should be produced from gas-based power generation and CHP plants in 2010 (Table 5.1). The favourable outlook for gas is projected to continue in the Reference scenario up to 2020: over this period, the projected increases in real gas prices will not remove the competitive advantage of natural gas compared to other generation fuels or energy forms. On the contrary, expectations for the period 2020-2030 are that advanced coal technologies may account for the bulk of incremental electricity demand, the net result being a stabilisation of the share of natural gas based electricity production at 2010 level.

The Reference shows similar developments in Japan, Pacific and North America. However, in these regions, larger investments in advanced coal power plants from 2020 to 2030 compared to those in combined cycle gas turbines lead to a slight decrease of the gas market share for electricity generation in 2030.

In contrast, the share of gas-based power generation continues to rise steadily over the projection period in the other regions. At the world level, the share of gas use for electricity generation and combined heat and power production is expected to rise to 28% in 2030 from 18% in 1990 and 19% in 2000.

[25] Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity; Directive 98/30/EC of the European Parliament and of the Council of 22 June 1998 concerning common rules for the internal market in natural gas.

Table 5.1: Share of electricity generated from natural gas

	1990	2000	2010	2020	2030
European Union	12%	22%	27%	29%	27%
CIS, CEEC	35%	30%	36%	44%	49%
North America	15%	14%	22%	24%	20%
Japan, Pacific	24%	31%	40%	37%	35%
Africa, Middle East	25%	34%	39%	47%	49%
Latin America	10%	15%	29%	38%	40%
Asia	5%	12%	13%	16%	17%
World	**18%**	**19%**	**25%**	**28%**	**28%**

In all regions and over the 2000-2030 period, gas-based electricity production is progressing more rapidly than total electricity production: 4% and 3% per year respectively at world level; 1.9% and 1.2% per year respectively for the EU. The outlooks are the same for coal-based electricity. These trends result principally from the projected moderate increases of electricity produced in nuclear and hydro power plants. As a consequence, the share of these electricity generation technologies in total world electricity production decreases considerably to 24% in 2030, from 37% in 2000, to the benefit of gas and coal power plants and to a lesser extent of wind turbines.

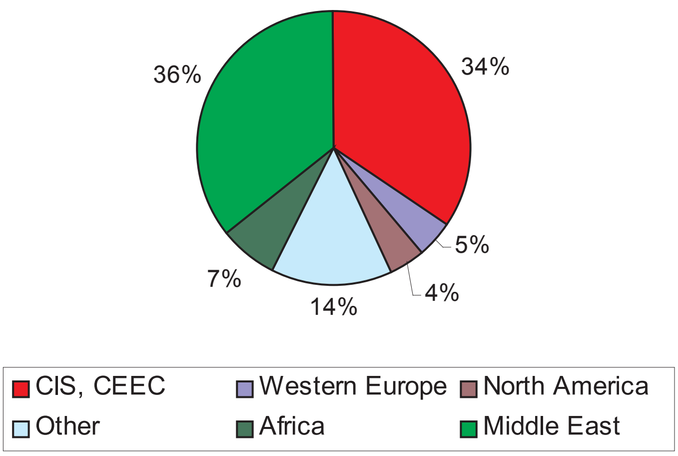
Finally, gas input to power generation grows less rapidly than gas-based electricity production, reflecting the increase in the average conversion efficiency of gas-fired power plants. The difference is particularly impressive in the CIS where the conversion efficiency of existing gas-fired power capacities is very low compared to new gas-fired technologies. Gas input to power generation in the CIS grows at an annual average rate of 1.6% over the projection period while the growth of gas-based electricity production is 4.3% per year. In the EU, North America, Japan and Pacific the two growth rates are much closer.

5.2 GAS SUPPLY

Gas reserves

The most recent assessment of world natural gas reserves, some 164 Tm^3 in 2001, indicates that natural gas is an abundant energy source. However, 70% of these reserves are located in two world regions: the CIS and the Middle East. Western Europe represents 5% of the world's proven gas reserves and North America 4%.

Figure 5.3: Gas reserves[26]



Gas production

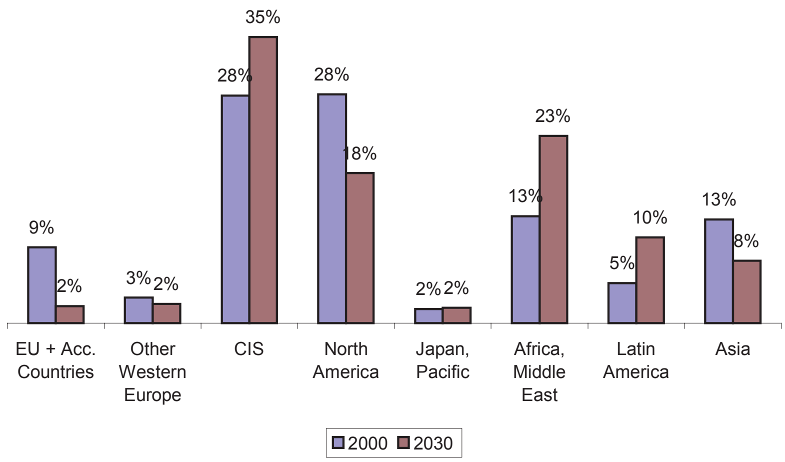
To meet the fast growing demand for natural gas at world level, production should double between 2000 and 2030. WETO shows that natural gas production is expected to increase in all regions except in the EU where gas production is projected to decrease by half and would represent no more than 2% of world gas production in 2030, compared to 9% in 2000 (Figure 5.4).

The major increases in natural gas production will occur in Latin America (more than four times the 2000 production level in 2030) and in Africa, Middle East (more than three times). In 2030, the CIS will be the lead gas producer with over one-third of world gas production, followed by Africa and Middle East (23%), North America (18%) and Latin America (10%).

It is worth pointing out that gas production in the two main producing regions is not only driven by increased gas demand in regions with limited gas resources, but also by the growing domestic gas requirements. In fact, more than 50% of the natural gas produced in the CIS, Africa and Middle East will remain inside the regions.

[26] As 1st January 2001; source: Cedigaz, *Preliminary estimates*, March 2002.

Figure 5.4: Share of gas production

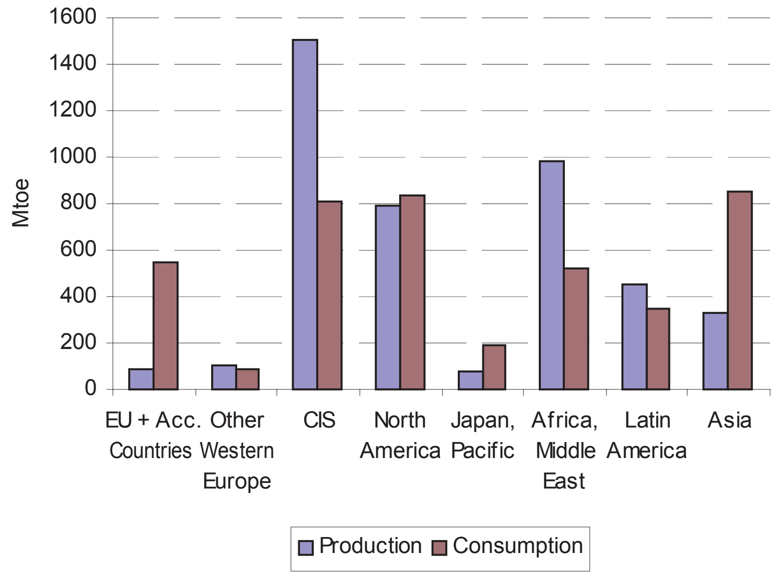


Despite the steady increase in gas production in North America and Asia, of 9% and 23% respectively over the period 2000-2030, the shares of these regions in world production should decline because of a faster progression in the other large producing regions.

Natural gas production in the EU including the Accession countries is concentrated in the Netherlands and the United Kingdom. In 2000, it covered slightly more than 50% of the region’s gas demand (this percentage goes up to 66% if Norway's gas production is included). The remaining demand was met essentially by pipeline imports from Norway, the CIS and Algeria, and by LNG from Algeria and Nigeria. The other net importing region in the world in 2000 is Japan, Pacific. About two third of gas consumption in this region was covered by LNG imports mainly from the South East of Asia and the Middle East. Elsewhere in the world, gas production is sufficient to meet gas needs within the defined regional areas.

In the longer term, the regional imbalance between consumption and production is not only expected to increase in the EU, the Accession countries and Japan, but also to take place in Asia and to a lesser extent North America. In contrast, the CIS, Africa, Middle East, the Pacific region and Latin America would remain (or become - for Latin America) net exporting regions (Figure 5.5).

Figure 5.5: Gas consumption and production in 2030



The dependence of the EU and Accession countries on extra-regional gas supplies increases steadily throughout the projection period: the region's gas imports are projected to more than double between 2000 and 2030. In 2030, the EU gas production would represent less than 16% of the region's natural gas requirements. In other words, gas dependence of the EU with the Accession countries could reach 80% within 30 years.

The growing demand for gas in all regions combined with regional disparities in gas reserves and production costs will thus foster the development of inter-regional gas trade and increase the linkages between regional markets. The WETO outlook shows that inter-regional trade would represent some 36% of gas consumed worldwide in 2030, compared to 14% now. This will imply new investments in long distance pipelines from producing to consuming regions and significantly increased LNG trade and investments in LNG infrastructure.

One key question then is how the huge amounts of gas made available to meet the world gas demand will be allocated between the regional consumption areas, or put in other words, to what extent the rapid growth in gas demand in developing regions with limited gas reserves (e.g. Asia) will affect the long-term EU gas supply pattern.

Gas trade between Europe and the CIS

In the POLES model, the market shares of gas exporter on each regional market are determined endogenously on the basis of the production and transport costs of the various gas exporters and gas prices on the regional markets: America, Europe/Africa/Middle-East and Asia (Box 8). Moreover, the export potential of gas producers accounts for the evolution of gas demand in the producing countries or regions.

Regional disparities in gas reserves, supply costs, prices and demand growth lead to changes over time in regional supply patterns, as reflected by the gas trade matrices. These matrices provide information about intra- and inter-regional gas trade within and between seven regions (Table 5.2). The level of integration of gas transport infrastructure and supply in Europe leads to consider Western, Central and Eastern Europe as one regional market, referred to in the following as “Europe”. Nevertheless, separate figures for EU’s internal and external supplies within the region (exclusively from Norway) are provided where possible.

Box 8: The simulation of gas trade and production

While the gas discoveries and reserves dynamics are modelled in a way that is similar to that used for oil, the gas trade and production are simulated in a more complex process that accounts for the constraints introduced by gas transport routes to the different markets. Three main regional markets are considered for gas price determination, but the gas trade flows are studied with more detail for 14 sub-regional markets, 18 key exporters and a set of smaller gas producers.
The natural gas trade and production is modelled on the one hand on the basis of the capacities from each producer to each sub-regional market and on the other hand on the actual quantities supplied by each producer for the demand simulated by the model.

First the model calculates the total new capacities required by each market. Then, the projected capacities along the different routes depend on the gap between the price on the considered market and a cost benchmark, associated to each route: the larger this gap, the higher the incentive to develop new capacities. A constraint allows limiting the possible “crowding out” effect of new entrants on the different market.

The actual capacities are then derived from projected in the previous five years period, with a constraint ensuring that new capacities will not induce a rapid exhaustion of the available reserves of the considered producer.

Finally the model allocates the market shares of the major exporters on each market, on the basis of the variable transport costs on each route.

Natural gas supply projections in the Reference scenario show that EU external gas supplies should continue to arrive primarily from the CIS, Norway and North Africa (Algeria and Libya). Other sources of imports into the EU are the Middle East (mainly pipeline gas via Turkey) and LNG from Nigeria but their combined share is not expected to exceed 10% in 2020 and 5% in 2030 of imports.

The relative contribution of these core gas suppliers for the EU is however projected to change in the next thirty years. Starting from 28% in 2000, the share of the CIS is expected to increase steadily to reach 54% of gas requirements in Western Europe and CEEC. This increase translates into a tripling of traded volumes with the CIS during the projection period.

The share of gas supplies from Africa and Middle East would reach a peak of 22% in 2020 and then decrease to 15% of the European gas demand in 2030. This decrease is concerning mainly supplies from the Middle East, which are exported mostly towards Asia after 2020. On the contrary, the share of gas imports from Africa (mainly Algeria and Nigeria) is expected to remain stable up to 2030, ranging from 10 to 15% of Europe’s gas requirements. Twice the volumes of gas currently imported from Africa and Middle East would be exported to Europe in 2030.

Gas supplies from Norway would double over the next ten years, reaching 23% of European gas requirements in 2010, and then decrease slightly but constantly until 2030. For that time horizon, imports from Norway would represent the same market share as in 2000, namely 15% of the European gas market.

Table 5.2: Gas trade matrix

2000 Importing regions / Exporting regions Gm3	North America	Latin America	Europe	CIS	Africa, Middle East	Asia	Japan, Pacific	Total production
North America	659	0	0	0	0	0	2	**661**
Latin America	1	116	0	0	0	0	0	**117**
Europe	0	0	294	0	0	0	0	**294**
CIS	0	0	137	521	0	0	0	**658**
Africa, Middle East	2	0	62	0	239	0	8	**311**
Asia	0	0	0	0	0	246	75	**321**
Japan, Pacific	0	0	0	0	0	0	41	**41**
Total consumption	**662**	**116**	**493**	**521**	**239**	**246**	**126**	**2404**

2010 Importing regions / Exporting regions	North America	Latin America	Europe	CIS	Africa, Middle East	Asia	Japan, Pacific	Total production
North America	837	5	0	0	0	0	4	**846**
Latin America	31	187	0	0	0	0	0	**218**
Europe	0	0	304	0	0	0	0	**304**
CIS	0	0	204	613	0	5	0	**822**
Africa, Middle East	0	2	125	0	304	14	10	**455**
Asia	0	0	0	0	0	425	121	**546**
Japan, Pacific	0	0	0	0	0	0	63	**63**
Total consumption	**868**	**194**	**633**	**613**	**304**	**444**	**198**	**3254**

2030 Importing regions / Exporting regions Gm3	North America	Latin America	Europe	CIS	Africa, Middle East	Asia	Japan, Pacific	Total production
North America	866	16	0	0	0	0	4	**886**
Latin America	73	372	0	0	0	62	0	**507**
Europe	0	0	220	0	0	0	0	**220**
CIS	0	0	420	1007	0	265	0	**1692**
Africa, Middle East	1	0	114	0	606	378	8	**1107**
Asia	0	0	0	0	3	187	188	**378**
Japan, Pacific	0	0	0	0	1	0	90	**91**
Total consumption	**940**	**388**	**754**	**1007**	**610**	**892**	**290**	**4881**

Gas demand in Asia

One key determinant of the long-term gas supply pattern of Europe (and therefore of the EU) is the fast growing gas demand in Asia, and most particularly in China and South Asia. Gas requirements in the whole region is projected to rise at an average rate of 4.6%/year over the 2000-2030 period, the highest growth among the regions. In contrast, gas production in that region will grow much less rapidly at 0.7%/year on average, and most of the gas produced in the South East Asia (Indonesia and Malaysia) will continue to be traded outside the region, mainly to Japan.

As a result, Asia will switch from being a net gas exporter to a net importer around the year 2020. At that time horizon, more than 300 Gm3 would be required externally to meet the region's gas demand; these volumes correspond to half of the total gas requirements. They would come mainly from the Middle East in the form of LNG (70%) and to a lesser extend from the CIS via pipelines (30%). In 2030, gas production is projected to decline dramatically in China and South Asia, resulting in the need for further external supplies, which would then represent some 80% of total gas demand in Asia.

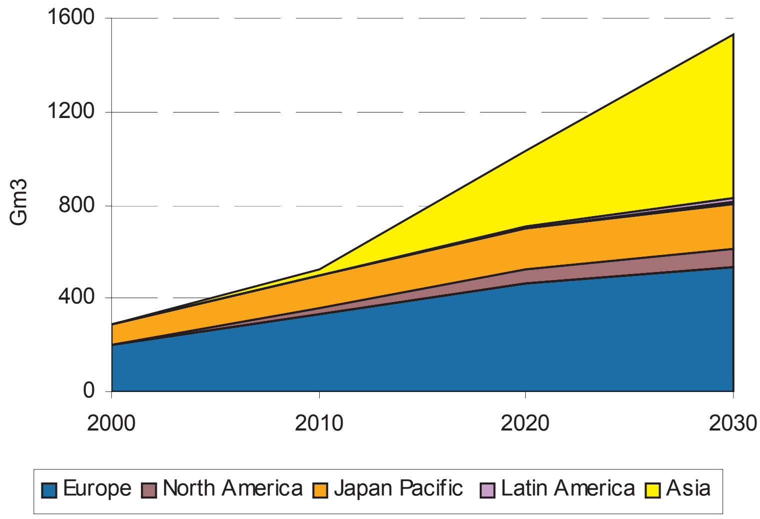
Over a thirty years' time horizon, this evolution in Asia is similar to the projected situation in Europe, where 70% of the region's gas demand would have to be met by external gas supplies. However, in the case of Asia, the bulk of external supplies is projected to come from the Middle East (70%), while in the case of Europe, it would originate principally from the CIS (77%). The significant projected gas exports from the Middle East to the Asian market, at the expense of the European market results from model's comparisons between supply costs from the CIS and the Middle East to the importing regions and between the gas prices on the two regional markets, namely Asia and Europe.

The export position of Asia is another noteworthy difference with Europe. The projections show that Asia increases its gas imports from outside the region during he period 2000-2030, while at the same time it increases also its exports abroad. This situation can be explained by the fact that whereas China and South Asia are net importers of gas, South East Asia is a net exporter to Japan. On the contrary, Europe would not export significant gas volumes outside the region.

Inter-regional gas trade

As a result of the increased dependence of most world regions on external gas supplies, inter-regional gas trade will develop considerably over the period to 2030. At the world level, inter-regional gas trade is projected to be five times larger in 2030 than in 2000. Asia is not only the major contributor to this significant progression but it also becomes the region the most dependent on extra-regional gas supplies. This is a fundamental change compared to the current situation where Europe and Japan contribute to almost 100% of the inter-regional trade (Figure 5.6).

Figure 5.6: Inter-regional gas trade by region of destination



In 2000, gas trade by pipeline accounted for 58% of inter-regional gas flows, reflecting, for the most part, volumes of Russian gas delivered to Europe. On the other hand, Asia accounted for some 70% of total LNG inter-regional trade (mainly deliveries from South East Asia to Japan), followed by Algeria with slightly less than 20%.

During the projection period, traded volumes of both pipeline gas and LNG will increase considerably; however, no significant change in their relative contribution to inter-regional trade is expected, assuming no significant changes to current trade patterns in particular from the CIS (pipeline gas) and the Middle East (LNG)[27]. Gas trade by pipeline would still account for about half the inter-regional gas trade in 2030.

As far as Europe is concerned, pipeline gas deliveries from the CIS would represent 75% of external supplies in 2030, imports by pipeline from North Africa and the Middle East 20% (via among others the pipelines from North Africa under the Mediterranean sea and from Iran via Turkey), the remaining 5% corresponding to LNG deliveries mainly from Nigeria.

It is worth pointing out here that gas trade projections were made on the basis of long-term gas supply conditions where gas prices are indexed partially on the price of oil. As a consequence, the percentage of LNG deliveries projected in 2030 do not account for LNG volumes purchased on a spot or short-term basis, for which markets are expected to develop over time.

[27] These developments are based on likely transport routes, taking into account geopolitical constraints. They may be affected if alternative routes are developed, such as for instance LNG production in Russia or gas pipelines from the Middle East to India, not considered in this study.

5.3 SECURITY OF EU GAS SUPPLY

The security of gas supply covers a large number of aspects and requires therefore a large range of solutions and guarantees. Security is related as much to physical risks as well as to economic risks. As far as gas is concerned, the physical risks are not so much related to the availability of gas resources than to potential political crisis, disruptions in the transport chain (e.g. due for instance to an accident) or uncertainties as to the realisation of the required investments to bring gas from the producing to the consuming regions.

In its Green Paper “Towards a European strategy for the security of energy supply”, the European Commission outlines a strategy to keep the security of EU energy supply to the highest level possible and makes proposals in terms of potential safeguards. The security of gas supply is of course one important element in this strategy, given the expected expansion of natural gas imports in the European energy markets in the long term.

Nevertheless, it is worth pointing out that the projected growth in gas demand not only at EU level but also worldwide, and the rising imbalance between gas production and demand in several world regions do not constitute by themselves a security problem but however increase the risks in terms of price instability or temporary supply disruption. Gas resources are abundant and a potential exists for technological improvements concerning gas production, transport by pipeline, and LNG plants and carriers. However, appropriate policies need to be developed and implemented to limit the risk factors related to geopolitical events or to the requirements of massive investments for gas infrastructure. In this respect, international cooperation and partnerships between EU and Accession countries and key producing countries bringing a stable framework for investment and trade, as well as the diversification of transport routes and further integration of the European gas networks are certainly important elements for the security of EU gas supply.

The WETO outlooks for natural gas in the Reference scenario and in the Resource cases allow bringing to light at least two inter-related aspects of EU gas security: the dependence on imports and the diversity of supply. The increasing dependence of EU and Accession countries on gas imports is described in the different projections as an ineluctable trend. Nevertheless, in face of this dependence, the diversity of supply results from economic mechanisms and/or from political considerations. It concerns both the fuels used to meet the primary energy requirements and the sources of natural gas consumed (e.g. number of supplying countries, number of transport options, share of each major gas supplier).

The examination of selected energy indicators provides the background for a first appraisal of the evolution of the position of the EU including the Accession countries with regard to long-term gas security, and of the influence of the level of available gas resources on this evolution. These indicators include the share of gas in Gross inland consumption and for electricity production, the dependence on gas imports and the diversification of gas supplies (Table 5.3).

Table 5.3: Overview of EU and Acc. Countries position regarding gas security

			Reference		High case (*)		Low case (*)	
	1990	2000	2010	2030	2010	2030	2010	2030
Share of gas in GIC	16%	24%	27%	27%	29%	34%	27%	27%
Share of gas in electricity production	12%	21%	27%	27%	28%	32%	26%	23%
EU external dependence to gas	46%	53%	71%	80%	65%	77%	79%	86%
Share of gas supplies from								
Europe		60%	48%	29%	53%	42%	30%	18%
CIS		28%	32%	56%	29%	46%	46%	61%
Africa, Middle East		13%	20%	15%	18%	12%	24%	21%

(*) High case: high gas resource case; Low case: low oil and gas resource case

Over the period 2000-2030, the share of gas in Gross inland consumption is projected to grow moderately in comparison to the increase observed during the last ten years. This share will remain below 30% except in the High case where it is projected to reach a peak of 34% in 2030. From now to 2020, the share of gas increases principally at the expense of coal's share, while after 2020, the increase is compensated by a decrease in the share of oil, the share of coal meeting again with its level of 2000. However, in the High case, the share of coal remains lower than in 1990 over the projection period reflecting the competitive position of gas through 2030.

The share of gas for electricity generation follows similar evolutions. However, it is worth underlining that in the Low case, the share of gas-based electricity decreases steadily compared to the Reference whereas the shares of gas in gross inland consumption were similar in the Low and Reference projections. This reflects the higher potential for fuel and technology switching in this sector that may result from changes in the relative competitive positions of coal and gas.

As a consequence of the steady gas demand growth and the decline of gas production in the EU through 2030, the dependence of the region to external gas supplies (including supplies from Norway) will raise from 53% in 2000 to 77%-86% in 2030, depending on the assumptions on natural gas resources. The lower percentage in the range corresponds to the High case; in this scenario, EU gas resources are assumed to be higher and are exploited so that the dependence to external gas supplies is reduced. On the contrary, under the assumption of lower gas resources (Low case), external gas supplies would represent more than 85% of EU total gas demand. It is worth pointing here that the dependence of the EU to external supplies is not only a function of gas resources but also of energy efficiency policies. Indeed, improved energy efficiency resulting from technological or behavioural changes may also reduce the dependence on energy in general and in gas in particular. Such reinforced policies are not incorporated in the WETO Reference projections but the Carbon Abatement case discussed in Chapter 6 provides an insight as to the impact improved energy efficiency may have on the external gas dependence of the EU.

Finally, the Reference scenario and the Resource cases show contrasted gas supply patterns. Although in all above projections, the CIS is expected to be the lead gas supplier of the EU countries in 2030, its contribution may vary from 46% in the High case to slightly more than 60% in the Low case. The major difference between the cases rests mainly on the respective shares of the CIS and Europe (including Norway) in total gas supply. In the High case, the shares are comparable (around 44%), whereas, in the Low case, the share of CIS is more than three times the share of Europe. On the other hand, supply countries located in Africa and in the Middle East would represent no more than 20% of gas demand in EU and Accession countries.

Key conclusions

- The EU gas market is rapidly expanding and growth is expected to continue in the next two decades. The expansion of gas in the EU is determined principally by the surge of gas use for power generation. Nevertheless, the EU contribution to world gas consumption is expected to decrease steadily.

- World gas reserves are abundant but concentrated in two world regions, the CIS and the Middle East, where gas production is projected to grow considerably during the next thirty years. In contrast, the European gas resources are limited and production is expected to decline steadily beyond 2010, resulting in an increasing dependence on external gas supplies.

- Natural gas demand is also projected to increase in the other world regions: some of them with limited or declining gas reserves are expected to become net importers leading to modification of the world gas trade patterns. For instance, the rapid gas demand growth in Asia is expected to have some influence on the EU gas supply pattern in 2030: while Asia is projected to rely predominantly on gas supplies from the Middle East, the EU and Accession countries should import more than half its natural gas needs from the CIS region at the horizon of 2030.

- This outcome may translate into higher supply risks for the EU. These risks could however be limited through different actions as outlined in the European Commission Green Paper, like the multiplication of gas transport routes, the further integration of the European gas network, and a continuous dialogue with gas producing countries. Long-term contractual LNG supplies are projected to move up but more moderately and from more diverse sources from Africa and the Middle East.

CHAPTER 6

IMPACTS OF CLIMATE CHANGE POLICIES

In the Reference scenario it is assumed that CO_2 emissions, the predominant greenhouse gas emitted by human activities, occur without complying necessarily with the reduction commitments of the Kyoto Protocol. This key assumption leaves aside the hypothesis of the emergence of policy regimes on climate change mitigation. Negotiations on this regime have filled the international environmental agenda in recent years and many countries have already introduced measures in order to limit the amount of greenhouse gas emitted. In the coming years, more countries are expected to adopt climate change mitigation policies, with the entry into force of the Kyoto Protocol.

If future climate change policies do effectively limit the expected increase in greenhouse gas emissions at world level or even reduce them in the industrialised world, then the global energy system will experience major changes. One would expect on the one hand, important consequences on energy consumption and, on the other hand, significant shifts in the primary and final energy mix. These shifts would indeed correspond to a lower use of carbon intensive sources and technologies and, conversely, to a more rapid development of low carbon power generation and renewable energy technologies. Other technologies, as carbon sequestration, could also emerge; they have however not been taken into account in this study. The purpose of this chapter is to illustrate the main consequences for the global energy system of such a carbon constrained alternative.

6.1 INTERNATIONAL AGREEMENTS

Increasing scientific evidence of human interference with the climate system began to push climate change onto the political agenda in the mid-1980s. In 1990, the Intergovernmental Panel on Climate Change established by the United Nations issued its First Assessment Report, confirming that climate change was indeed a threat and calling for a global treaty to address the problem. This call, translated into the United Nations Framework Convention on Climate Change (UNFCCC), opened to signature in the 1992 "Earth Summit" in Rio de Janeiro. The Convention entered into force in 1994 and counts, a decade after its adoption, 186 governments (including the European Community) as Parties.

The ultimate objective of the UNFCCC is to achieve the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (Art.2). The Convention does not define what levels might be "dangerous", although it does state that ecosystems should be allowed to adapt naturally, that food supply should not be threatened, and that economic development should be able to proceed in a sustainable manner. No concentration target is thus defined but a recommendation for a stabilisation by 2000 of the greenhouse gas emissions in the industrialised countries was adopted.

The rising trend in world emissions called for more action in the direction of the Convention objective. International negotiations continued and in December 1997 the Kyoto Protocol to

UNFCCC was adopted. The most striking element of this Protocol is that most industrialised countries accepted that the average emissions over the 2008-2012 period for a country should not exceed a given amount, defined as a percentage of the country greenhouse gases emissions in the base year, i.e. 1990 for most countries. The list of countries with their emission target appears in Annex B to the Kyoto Protocol. The emission limitation covers a basket of six different greenhouse gases, i.e. carbon dioxide (CO_2), methane (CH4), nitrous oxide (N_2O), hydro-fluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6). As defined in Kyoto, the aggregate commitments in terms of emission reduction should lead to a decrease in the aggregate emissions of the Annex B countries of 5 % from the 1990 level, during the first commitment period, i.e. from 2008 to 2012. The list of commitments is reminded in Box 8 and includes EU countries targets within the EU "burden sharing agreement".

In meeting their commitments, countries that adopted targets may use several policy options. The most straightforward option is to reduce domestically the greenhouse gas emissions. However, the Protocol also contains other options, mainly inspired by the concept of flexibility in the abatement policies and by the corresponding cost reduction opportunities.

First, the Protocol recognises the principle of carbon absorption in the biosphere as a way to compensate for greenhouse gases emissions. Countries are allowed to take into account the absorption of greenhouse gases by their biosphere resources, as long as this capture is additionally induced by human activities. This option is referred to as 'sinks' activities. Additional carbon capture in the biosphere could indeed be less expensive than domestic emission reduction, however the temporary nature of the capture increases the risk of this option from both the economic and environmental point of view.

Second, the Protocol introduces three flexible mechanisms to take advantage of the cost differences for emission reductions between countries. The International Emission Trading (IET) scheme allows countries that emit more greenhouse gas than their total allowances to buy emission allowances from other countries that reduce their emissions beyond their commitment. The two other mechanisms are project-based and referred to as Joint Implementation (JI) and Clean Development Mechanism (CDM). Under both mechanisms, an investor (public or private) from a country with a commitment may obtain carbon credits from the implementation of a project in another country member of the Protocol. Provisions on Joint Implementation concern projects in Annex B countries, particularly those undergoing a transition to a market economy, and the Clean Development Mechanism involves countries that did not adopt commitments in Kyoto.

At the time of its adoption, the Kyoto Protocol left a number of implementation matters undecided. The flexible mechanisms, sinks and compliance provisions were agreed upon in principle but their operational guidelines still needed to be defined. The modalities of the monitoring, reporting and verification systems necessary to assure compliance and the banking provisions for different types of emission allowances also remained to be discussed. The principle of sinks enhancement was accepted but the list of eligible sinks activities and the extent of their use was still undecided.

All these unresolved issues led the countries that adopted targets to delay their ratification of the agreement. On their side, developing countries demanded more concrete rules on how the developed countries would assist them in the adaptation to the adverse consequences of climate change. It took the negotiating countries nearly four years to decide upon these extended guidelines and to make the text on the different instruments of the Kyoto Protocol operational. The rulebook has been completed in November 2001 and is referred to as the Marrakech Accords.

Box 9: Kyoto Protocol emissions targets and EU burden sharing

Country	Target (1990*-2008/2012)
EU-15, Bulgaria, Czech Republic, Estonia, Latvia, Liechtenstein, Lithuania, Monaco, Romania, Slovakia, Slovenia, Switzerland	-8 %
United States	-7 %
Canada, Hungary, Japan, Poland	-6 %
Croatia	-5 %
New Zealand, Russian Federation, Ukraine	0
Norway	+1 %
Australia	+8 %
Iceland	+10 %

Country	Target (1990-2008/2012)
Luxembourg	-28 %
Denmark, Germany	-21 %
Austria	-13 %
United Kingdom	-12.5 %
Belgium	-7.5 %
Italy	-6.5 %
The Netherlands	-6 %
Finland, France	0
Sweden	+4%
Ireland	+13 %
Spain	+15 %
Greece	+25 %
Portugal	+27 %

The Kyoto Protocol will enter into force only if 55 countries ratify the treaty and if these countries account for at least 55 % of the 1990 CO_2 emissions of those industrialised countries listed in the Annex I of the UNFCCC. The limit of 55 ratifications, including ratification from the EU and Japan, has been attained but the second necessary condition is more difficult to fulfil since the United States of America, in spite of their ratification of the Convention, have officially declared in February 2001 that they have no intention to ratify the Kyoto Protocol.

* Some economies in transition have a base year other than 1990.

6.2 A CO_2 EMISSION ABATEMENT CASE FOR 2030

Rationale and definition

In order to explore the long-term consequences for the energy sector of greenhouse emission constraints at world level, a Carbon Abatement case (CA) has been developed up to the 2030 horizon. Its aim is to describe a reasonable hypothesis for the development of CO_2 emissions, while taking into account the different regions' consent to commit themselves in medium-term reductions and the expected reinforcement of climate change policies beyond the year 2010.

The CA case is designed through the introduction of a value for CO_2 emissions within the POLES model, a method that impacts, in theory, identically as the introduction of regional taxes on CO_2 emissions or as a system of CO_2 permits within a world emission trading system. The CA case is defined so as to reach a level of CO_2 emissions in 2030 that is comparable to the emissions projected in the "B1" scenario[28] of the IPCC projections (IPCC, 2001). The IPCC integrated assessment analysis indicates that this type of emission profile assumes the implementation of sustainable development policies in a large amount of sectors of the economy. Such an emission path lies at the upper end of an emission control strategy that would remain compatible with an objective of stabilisation of greenhouse gas concentration around 550 ppmv (twice the pre-industrial concentration) by the end of this century and a global temperature rise of no more than 2°C relative to the year 1850.

In order to take into account the commitments of the industrialised countries for the Kyoto period, the carbon value is differentiated by main regions up to 2010. For Western Europe and the Accession countries a value of 13.5 €/tCO_2[29] is chosen, a lower value (5.5 €/tCO_2) being applied to the other countries that accepted a commitment. No carbon value applies to the CIS - that remains below its target without the implementation of any carbon constraint - and to countries without commitments until 2010. As a consequence, these countries follow the CO_2 emissions trends projected in the Reference until 2010. Between 2010 and 2030 and in order to meet an emission path that remains compatible both with the global concentration target and with long-term EU indicative emission targets[30], a 60 €/tCO_2 carbon value is then implemented in Western Europe and the Accession countries whereas a value of 30 €/tCO_2 applies to the other world regions.

To some extent, the CA case describes a world in which Europe is ahead of the other countries in terms of climate policy. This also means however that the abatement costs accepted are higher, as indicated by the level of the carbon value that is twice the level of the other world regions.

[28] The "B1 family" of scenarios projects world CO_2 emissions from fossil fuel and industrial processes in 2030 of about 41 GtCO_2 per year.
[29] To have the price in €/tC, the figures must be multiplied by 3.66.
[30] From the 6th Environment Action Programme (COM(2001)31), these targets come out as an average emission reduction rate of 1 %/year.

World energy demand and CO_2 emissions

The major changes in world energy-related CO_2 emissions, total energy consumption and fuel switching as resulting from the above-defined alternative case are illustrated in Table 6.1.

Table 6.1: World energy demand and CO_2 emissions

	1990	Ref 2030	CA 2030	% Change CA-Ref
CO_2 emissions ($GtCO_2$)	20.8	44.5	35.3	-21 %
Total consumption (Gtoe)	8.7	17.1	15.2	-11 %
Coal, lignite (Gtoe)	2.2	4.7	2.7	-42 %
Oil (Gtoe)	3.1	5.9	5.4	-8 %
Natural gas (Gtoe)	1.7	4.3	4.3	0 %
Nuclear (Gtoe)	0.5	0.9	1.2	36 %
Renewable (Gtoe)	1.1	1.4	1.8	35 %

The carbon value leads to the achievement of a reduction of about 9 $GtCO_2$ compared to the Reference, i.e. a decrease of 21 %. Nevertheless, both cases project an increase in world CO_2 emissions in 2030 compared to the 1990 level. The average growth between 1990 and 2030 is projected to be 1.3 %/year in the CA case compared to 1.9 %/year in the Reference. It is worth underlying here that the environmental impact of the CA case depends only on the total reduction at world level, while the changes in world energy consumption patterns depend on the reductions implemented at the regional level.

The results of the CA case show that the projected reduction by 21 % of world CO_2 emissions compared to the Reference comes in equal parts, on the one hand from the reduction in energy demand and on the other hand from the decrease in the carbon intensity of the total consumption – which is the result of drastic changes in the world energy mix. The total energy demand decreases from 17.1 Gtoe to 15.2 Gtoe. This reduction needs to be examined in the light of the projected increase of the total consumption from about 8.7 Gtoe in 1990. It also shows that both actions on the energy system, i.e. the slowdown in energy demand growth and the changes in the primary fuel mix, are necessary to achieve significant CO_2 emission reductions.

The 11 % reduction in the carbon intensity of the world total consumption in the CA case reflects the opportunities for fuel substitution in the energy system. As expected, the carbon value affects primarily the fuels with the greatest carbon content, namely coal (-42 %) and oil (-8 %). Natural gas is not affected as the downward pressure on gas consumption is compensated by gas-to-coal substitutions; the market shares lost by coal and oil are compensated with nuclear (increase of 36 %) and renewable energies[31], which increase by 35 % on average over the projection period. Within the renewable, a 20-fold increase for wind, solar and small hydro is expected.

Impacts on regional energy demand and CO_2 emissions

The decrease in the emissions from the EU and Accession countries is greater than the world average (see Table 6.2): 0.4 %/year until 2010 and 0.6 %/year beyond. In 2030, some 1.2

[31] Biomass, wind, solar, small hydro, large hydro, geothermal and wastes are here included into the renewables.

$GtCO_2$ emissions of annual emissions are avoided and this brings the enlarged EU to emissions level nearly 15% lower than the 1990 level. The decrease in the carbon intensity of the total consumption (12 %) is in the range of the world reduction. As it is the case at the world level, the emission reductions come in the enlarged EU in equal parts from the reduction in energy demand and from the decrease in the carbon intensity of the total consumption.

Table 6.2: Energy demand and CO_2 emissions in EU and Accession countries

	1990	Ref 2030	CA 2030	% Change CA-Ref
CO_2 emissions ($GtCO_2$)	4.1	4.7	3.5	-26 %
Total consumption (Mtoe)	1608	2000	1759	-12 %
Coal, lignite	449	387	151	-61 %
Oil	626	727	635	-13 %
Natural gas	262	546	527	-3 %
Nuclear	198	238	322	35 %
Renewable	64	122	191	56 %

Changes in the fossil fuels mix of total energy consumption in the EU and Accession countries are similar to the world pattern. However, as the carbon value is higher in this region, more pronounced changes are projected. The reduction of coal consumption is the largest of all regions in relative terms (-61 %) and the decrease in oil demand is also significant (-13 %). The decrease in supply from these sources is compensated for with nuclear and renewable energy. Demand for natural gas is not significantly changed by the carbon value.

In the other world regions, the carbon value induces a slowdown in CO_2 emissions and energy consumption growth everywhere, but this is more significant in regions with the highest energy intensity. For instance, the decrease in Japan is rather limited compared to the impacts in other regions.

In the Japan and Pacific region (see Table 6.3), the reduction in demand for coal is compensated for by renewable, nuclear and natural gas. Demand for oil decreases slightly.

Table 6.3: Energy demand and CO_2 emissions in the Japan and Pacific region

	1990	Ref 2030	CA 2030	% Change CA-Ref
CO_2 emissions ($GtCO_2$)	1.4	1.8	1.5	-14 %
Total consumption (Mtoe)	537	812	766	-6 %
Coal, lignite	111	160	95	-41 %
Oil	291	291	282	-3 %
Natural gas	61	188	197	5 %
Nuclear	51	135	142	5 %
Renewable	25	45	62	39 %

The largest changes in CO_2 emissions occur in Asia and in North America, with reductions of 4.1 and 2.1 $GtCO_2$ respectively (see Tables 6.4 and 6.5), in spite of relatively low carbon value in the CA case. From one scenario to the other, Asia and North America both experience similar reductions in their emissions by 2030 in relative terms, with about –22 %. These regions also experience the highest percentage of reduction in the carbon intensity of energy consumption with about 12 % decrease in 2030, compared to the Reference: this is largely due to the important reductions in coal use in these two regions.

Table 6.4: Energy demand and CO_2 emissions in Asia

	1990	Ref 2030	CA 2030	% Change CA-Ref
CO_2 emissions ($GtCO_2$)	4.1	18.5	14.4	-22 %
Total consumption (Mtoe)	1736	6369	5604	-12 %
Coal, lignite	709	2698	1649	-39 %
Oil	371	2175	2042	-6 %
Natural gas	74	856	1025	20 %
Nuclear	23	160	304	90 %
Renewable	553	521	694	33 %

The most significant changes in the fuel mix in Asia are the rapid development of nuclear and a higher gas penetration. The increase in renewable results from growth in wind, solar and small hydro energy and also from an increase in biomass energy, as the use of modern biomass now compensates for the decrease in traditional biomass.

North America experiences a large decrease in coal demand and a significant development of renewable and nuclear (Table 6.5).

Table 6.5: Energy demand and CO_2 emissions in North America

	1990	Ref 2030	CA 2030	% Change CA-Ref
CO_2 emissions ($GtCO_2$)	5.3	8.0	6.1	-23 %
Total consumption (Mtoe)	2202	3082	2715	-12 %
Coal, lignite	484	859	446	-48 %
Oil	849	1004	930	-7 %
Natural gas	571	836	815	-2 %
Nuclear	173	225	291	29 %
Renewable	100	172	273	59 %

The CIS sees its emissions reduced by 18 % and remains below its 1990 level (Table 6.6). In this region, emissions reduction comes primarily from reduction in energy demand as large potentials for energy efficiency still exist. However, the decrease in the carbon intensity of the total consumption is lower than the world average, namely 7 % over the projection period**.** As no carbon value is applied before 2010 in this region, it remains therefore with a relatively high level of carbon intensity and the large potential for decrease is not entirely exploited by the end of the projection.

Table 6.6: Energy demand and CO_2 emissions in the CIS

	1990	Ref 2030	CA 2030	% Change CA-Ref
CO_2 emissions ($GtCO_2$)	3.6	3.5	2.8	-18 %
Total consumption (Mtoe)	1356	1465	1305	-11 %
Coal, lignite	289	146	80	-45 %
Oil	415	303	257	-15 %
Natural gas	560	897	800	-11 %
Nuclear	54	76	78	3 %
Renewable	42	45	116	161 %

In the Africa and Middle East region (Table 6.7), the emissions reduction also comes primarily from a reduction in energy demand, as the projected fuel mix of this region in the Reference is based more on oil and gas than on coal. Thus the decrease in the carbon intensity of the total consumption is lower than the world average and the changes in fuel mix are more limited than in most other regions.

Table 6.7: Energy demand and CO_2 emissions in Africa and the Middle East region

	1990	Ref 2030	CA 2030	% Change CA-Ref
CO_2 emissions ($GtCO_2$)	1.2	4.7	3.9	-16 %
Total consumption (Mtoe)	620	1762	1566	-11 %
Coal, lignite	78	378	248	-34 %
Oil	240	690	614	-11 %
Natural gas	109	526	513	-3 %
Nuclear	2	6	7	15 %
Renewable	188	170	213	26 %

In Latin America also (Table 6.8), the decrease in the carbon intensity of the total consumption is lower than the world average and the emissions reduction comes primarily from a reduction in energy demand. Nuclear power develops rapidly in relative terms and the increase in renewable - although greater than nuclear in absolute terms – is relatively modest in comparison to other regions.

Table 6.8: Energy demand and CO_2 emissions in Latin America

	1990	Ref 2030	CA 2030	% Change CA-Ref
CO_2 emissions ($GtCO_2$)	0.9	2.7	2.5	-9 %
Total consumption (Mtoe)	454	1251	1186	-5 %
Coal, lignite	20	58	31	-46 %
Oil	239	605	571	-6 %
Natural gas	76	345	323	-6 %
Nuclear	3	14	23	60 %
Renewables	99	232	248	7 %

Sectoral energy demand

The decrease in final energy demand in the CA case relative to the Reference (-9 %) is slightly lower than the reduction of the world total energy demand (-11 %). The carbon constraint results in a lower final energy demand in all sectors, however, the largest reductions occur in industry (-14 %), followed by households, service and agriculture (-8 %) (Table 6.9). Reductions in energy demand for transport are the lowest with 4 %. This result is easily explained by structural differences in sectoral tax regimes that occur in most regions. Indeed, when the carbon value applies uniformly on all sectors in relation with their carbon content, the average fuel price in industry increases more than in the household sector and significantly more than in transport where tax levels are already very high. Moreover, industry is the final sector, which relies the most on coal so that it can react to the carbon value both by energy demand reductions and by switching to lower carbon intensity fuels. Transport emission reductions are also projected to be more limited than in the other sectors as fuel and technology alternatives remain more expensive.

Table 6.9: Sectoral energy demand

Gtoe	Ref 2030	CA 2030	% change
Final energy demand	12.1	11.0	-9 %
Industry	4.3	3.7	-14 %
Transport	2.8	2.7	-4 %
Household, Service, Agriculture	5.0	4.6	-8 %

Power generation technologies

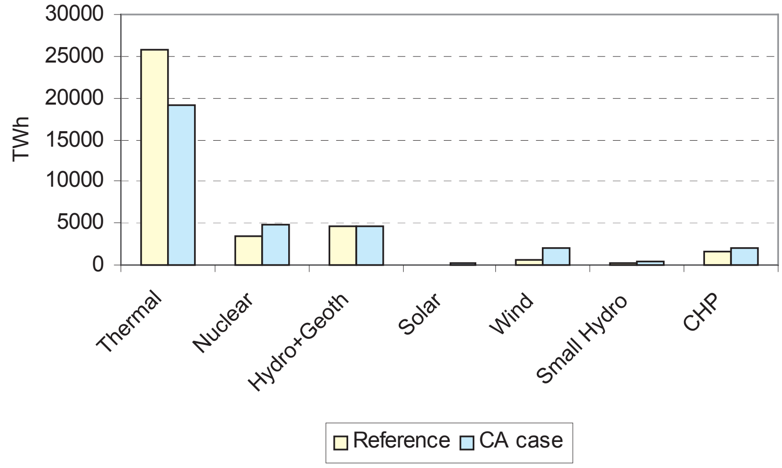
In a context where electricity demand grows at an annual rate twice the growth of final energy consumption and where power generation technologies with very different carbon content are currently competing, the carbon value also results in significant substitutions among fuels and technologies. Table 6.10 shows the effect of the carbon value on electricity generation for the world and the EU and Accession countries.

Table 6.10: Electricity generation

TWh	Ref 2030	CA 2030	% Change
World	34700	31200	-10 %
EU and Accession countries	4350	3940	-9 %

Figure 6.1 shows the change in the fuel mix for electricity generation. In relative terms, the largest impact is for renewable sources: wind (2.7 fold increase), solar (two-fold increase) and small hydro (+60 %). In absolute terms however, the most significant changes occur for nuclear and combined heat and power (CHP), while thermal production decreases significantly.

Figure 6.1. World electricity generation in 2030



Among thermal power plants, the carbon value reduces significantly the development of coal and advanced coal power plants that were the "winner technologies" in the Reference (Figure 6.2). Indeed, while the advanced coal technologies lead to substantial improvement in conversion efficiency and local pollution, their possibilities in terms of CO_2 emissions reduction are limited compared to technologies directly based on less carbon intensive fuels[32]; the share of advanced coal drops from about 45 % of thermal power production in 2030 in the Reference to 25 % in the CA case. On the contrary, gas and biomass power plants increase their share by respectively 48 % and 7 % in 2030.

6.3 CONSEQUENCES OF ACCELERATED TECHNOLOGY DEVELOPMENT

In this section the potential effect of accelerated technology development on the cost of fulfilling environmental targets (in this case a carbon emission reduction target) is examined. For this purpose the assumptions on accelerated technology development as defined in the technology cases described in section 4.2 have been applied to the above carbon abatement case. The carbon values used in the CA case result in lower emissions as compared to the Reference. Subsequently, these lower emission levels have been taken as the emission reduction target[33] with the assumptions on accelerated technology development so as to identify the corresponding carbon values.

Figure 6.2 illustrates the evolution of the carbon values associated to emission reduction for the CA case and for the same emission reduction with the accelerated technology development. The carbon values correspond to the marginal abatement cost and the

[32] When carbon recovery and sequestration are not considered, as is the case in this study.

[33] In the POLES model, emission reduction policies can be simulated in two different ways, either through the introduction of an increasing carbon penalty (a carbon tax) or through the implementation of an emission target, with the endogenous computation of the corresponding carbon value.

hypothetical price that carbon emissions permits would reach in a perfect market for these permits were established. Even if the values shown in Figure 6.2 are marginal and not total cost and do not incorporate all costs and benefits of the respective case, the following comments can be made:

- The accelerated technological development can have considerable impact on the costs of meeting environmental targets. Marginal abatement costs are reduced by up to approximately one third for the technology cases.

- The nuclear scenario produces in the long run (up to 2030) the lowest carbon values. Results by region – not provided here by sake of conciseness – show that cost reductions are more marked in OECD countries, which are better placed to benefit from the technologies concerned.

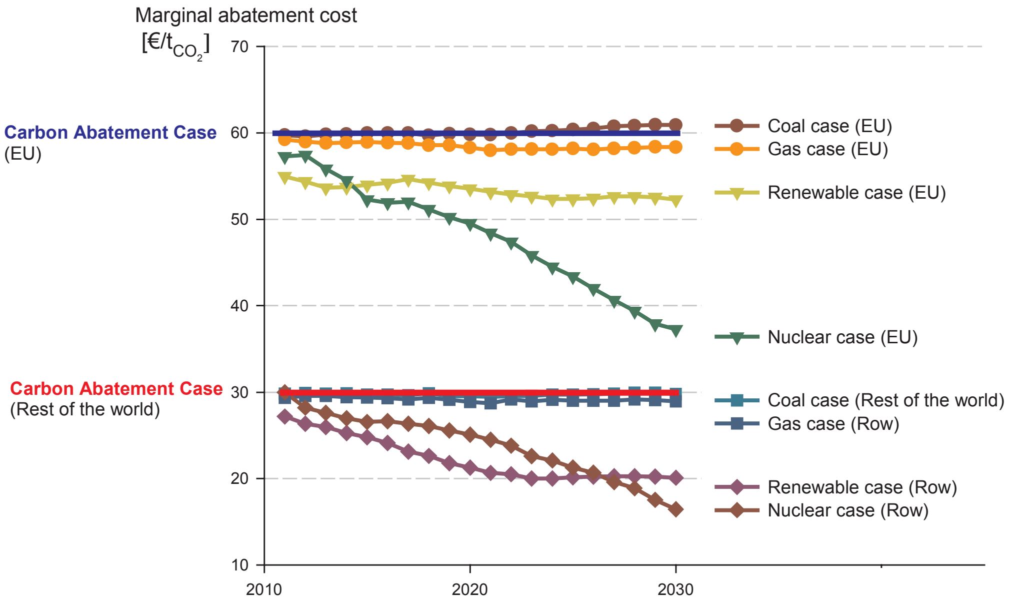
- The renewable scenario, mainly involving non-fossil fuel technologies also has a considerable effect, offering cheap alternative possibilities to fulfil the carbon emission reduction target. Moreover, for the medium term (until 2020) this scenario is the one offering the cheapest opportunities. The impact of the renewable scenario is smaller for the EU since the potential (especially for wind energy) is limited and already used to a large extent in the case without accelerated technology development.

- The clean coal scenario yields carbon values to fulfil the carbon emission target that are sometimes even a little bit higher than the CA Case. This is due to the presence of cheaper coal-based technologies that make comparatively more expensive to renounce to use coal as a primary energy source and, in particular, to produce electricity. However, the total costs corresponding to this scenario would be lower (due to the benefits embedded in the technology case).

- The gas scenario shows less effect on the carbon value than one might expect. Gas technology is already intensively used in the carbon abatement case without accelerated technology development. The higher penetration of gas technology in the Gas case offers cheaper opportunities to generate electricity but these are offset by the higher demand caused by lower gas[34] and electricity prices.

[34] The Gas case assume higher global natural gas reserves which lead to lower gas prices (see scenario definition in chapter 4.2.1).

Figure 6.2: The role of technology to reduce marginal abatement costs



Key conclusions

- With a carbon value on the fossil fuel use, CO_2 emissions in 2030 are 21 % lower than in the Reference. At the world level and in most regions, this reduction is equally achieved by a reduction in energy demand and by a decrease in the carbon intensity of energy consumption.
- More than half of the world energy demand reduction is achieved in the industry sector.
- The decrease in the carbon intensity comes mainly from substitutions away from coal and lignite and to a lesser extent from oil; gas demand remains roughly stable as fuel switching in favour of gas takes place. In contrast, the consumption of biomass increases significantly, nuclear progresses considerably, large hydro and geothermal remains stable; finally, wind, solar and small hydro jumps up by a factor 20.
- Accelerated technology development can have a considerable impact on the cost to achieve emission reductions.

DEFINITION OF REGIONS

WORLD BREAKDOWN INTO 7 REGIONS IN WETO[1]

Western Europe: Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom

CEEC, CIS[2]:

CEEC (Central and Eastern European Countries): Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Macedonia, Poland, Romania, Serbia & Montenegro, Slovak Republic, Slovenia

CIS (Community of Independent States): Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyz Rep., Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan

North America**:** USA, Canada

Latin America**:** Central America (including Mexico), South America and Caribbean

Japan, Pacific**:** Japan, Australia, New Zealand, Papua New Guinea, Fiji, Kiribati, Samoa (Western), Solomon Islands, Tonga, Vanuatu

Asia**:** Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, China, Hong-Kong, India, Indonesia, Lao, Macao, Malaysia, Maldives, Myanmar, Mongolia, Nepal, North Korea, Pakistan, Philippines, Thailand, Singapore, South Korea, Sri Lanka, Taiwan, Vietnam.

Africa, Middle East**:**

Africa: North Africa (Algeria, Tunisia, Morocco, Libya, Egypt) and Sub-Saharian Africa

Middle East**:** Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen

[1] The POLES model identifies thirty-eight world regions or countries, of which the 15 countries of the European Union and the largest countries (USA, Canada, Japan, China, India, Brazil, etc…).

[2] This composite region is used because of lack of data by country for countries of the Former Soviet Union before 1992.

OTHER REGIONS

EU (European Union): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom

Other Western Europe: Iceland, Switzerland, Norway, Turkey

Accession Countries: Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovak Republic, Slovenia

OECD: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany F.R., Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Slovak Republic, South Korea, Sweden, Switzerland, Turkey, United Kingdom, USA

OPEC (Organisation of Petroleum Exporting Countries): Venezuela, Nigeria, Indonesia, Algeria, Libya, Saudi Arabia, United Arab Emirates, Iraq, Iran, Kuwait, Qatar

OPEC Middle East: Saudi Arabia, United Arab Emirates, Iraq, Iran, Kuwait, and Qatar

Gulf: Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Yemen

LIST OF ACRONYMS AND ABBREVIATIONS

€	Euro at 1999 prices (=US$ at 1995 prices)
AAU	Assigned Amount Units
Acc. Countries	Accession countries (to the European Union)
BfP	Bureau Federal du Plan (Belgium)
bl	Barrel
CA	Carbon Abatement
cap	Capita
CC	Combined cycle
CDM	Clean Development Mechanisms
CEEC	Central and Eastern European Countries
CEPII	Centre d'Etudes Prospectives et d'Informations Internationales
CER	Certified Emission Reduction
CHP	Combined heat and power
CIS	Community of Independent States (1)
Cum	Cumulative
DG	Directorate General
EU, EU 15	European Union (15 countries) (1)
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIC	Gross Inland Consumption (=primary energy consumption or Total Primary Energy Supply)
Gm^3	Million cubic meter
Gt	Billion of tons
GTCC	Gas Turbine Combined Cycle
Gtoe	Billion of tons oil equivalent
GWP	Global Warming Potential
IEA	International Energy Agency
IEPE	Institute of Energy Policy and Economics
IET	International Emission Trading
IGCC	Integrated coal gasification combined cycle
IIASA	International Institute for Applied System Analysis
IPCC	International Panel on Climatic Change
JI	Joint Implementation
koe	kilogram oil equivalent
LNG	Liquefied Natural Gas
LWR	Light water reactor
Mt	Million tons
Mtoe	Million ton oil equivalent
O&M	Operation and Maintenance
OECD	Organisation for Economic Cooperation and Development
OPEC	Organisation of Petroleum Exporting Countries
PEM	Proton Exchange Membrane
POLES	Prospective On Long Term Energy Systems

(1) See definition of regions

POP	Population
ppp	Purchasing power parities
ppmv	Parts per million by volume
Prim	Primary (electricity): nuclear, hydro, geothermal, wind, solar
R&D	Research and Development
R/P	Reserve on Production
RMU	Removal Units
SFC	Solid oxide Fuel Cell
toe	Ton of oil equivalent
TWh	Billion kWh
UAE	United Arab Emirates
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
URR	Ultimate Recoverable Resources
US-DOE	US Department of Energy
USGS	United States Geological Survey
WEC	World Energy Council

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ANNEX 1

COMPARISON OF WORLD ENERGY STUDIES

Introduction

This appendix compares the WETO Reference hypotheses and results with the projections provided by other world energy studies. Three institutions carry out forecasts whose scope is comparable to WETO:

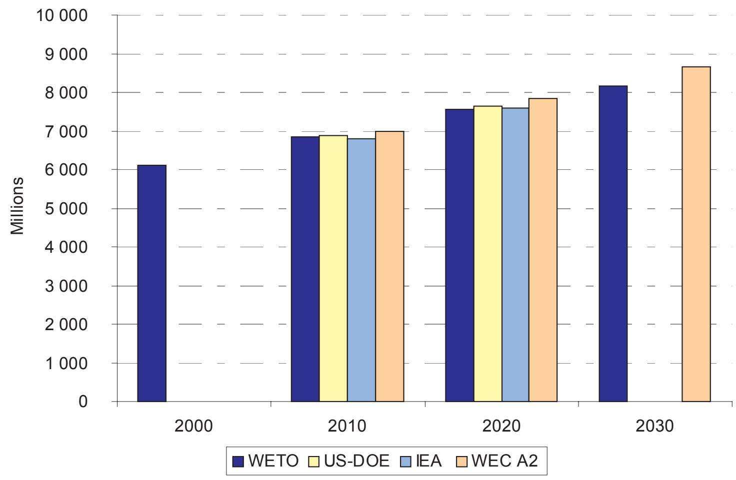
- The International Energy Agency (IEA) also produces a world energy outlook to 2020. Insofar as the 2001 report has been dedicated to energy supply issues, based on the projections of the World Energy Outlook 2000, we use this **IEA 2000** Reference Scenario for comparison.
- IIASA has developed for the World Energy Council a set of scenario projections to the year 2100. For this comparison, we use the **WEC 1998-A2** scenario, which assumes an oil and gas resource availability that is comparable to the one used in the WETO Reference.
- The Energy Information Administration of the U.S. Department of Energy provides yearly updated energy forecasts to 2020 in its International Energy Outlook. For this comparison we used the **US-DOE 2002** Reference Case projection.

The four studies compared here use database and conversion factors that may slightly differ from one model to the other. In order to reduce the resulting discrepancies and to improve the comparability of results, all data have been harmonised while applying the growth rates derived from each study to the initial 2000 values of the WETO study. This allows having a clearer view and a better understanding of the common outcomes and divergences between the studies.

1. World population

With a world population of slightly less than 7 billions in 2010 and around 7.5 billions in 2020, all four studies reflect very similar population projections until this time horizon. For the 2030 horizon, the downward revision of the World Population Prospects operated by the UN in recent years translates into the fact that the WETO study shows a significantly lower projection (8.2 billions) than the IIASA-WEC study of 1998 (8.7 billions).

Population	%/year			Millions			
	2000-10*	2010-20	2020-30	2000	2010	2020	2030
WETO	1.17%	0.98%	0.78%	6 102	6 855	7 558	8 164
US-DOE	1.21%	1.05%			6 882	7 642	
IEA	1.10%	1.10%			6 807	7 594	
WEC A2	1.34%	1.17%	1.00%		6 974	7 834	8 657

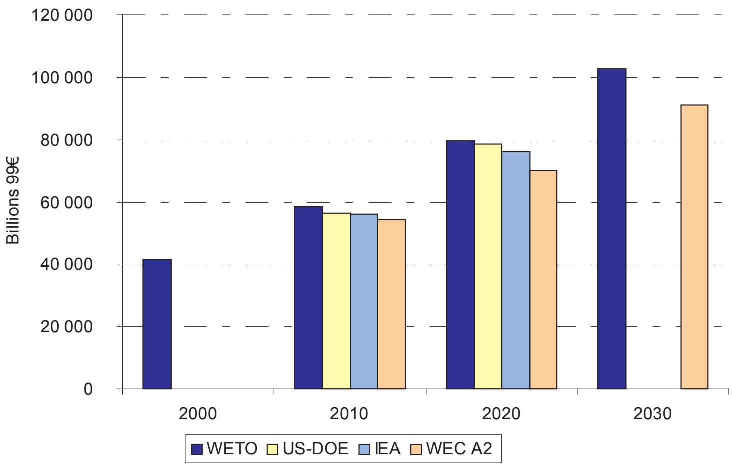


1999-2010 in %/year for US-DOE and 1997-2010 for IEA

2. World GDP

According to three out of the four studies, world GDP will grow, in the next two decades, at a yearly average rate between 3 and 3.5 %. This results in a world GDP of nearly 80 trillions € in 2020, i.e. almost a doubling, as compared with the 2000 level. In the WETO scenario, the continuous slowdown in the average growth rate translates into a linear-shaped GDP profile, with an increase of about 20 Trillions € per decade. As a result, world GDP overpasses 100 trillions € in 2030.

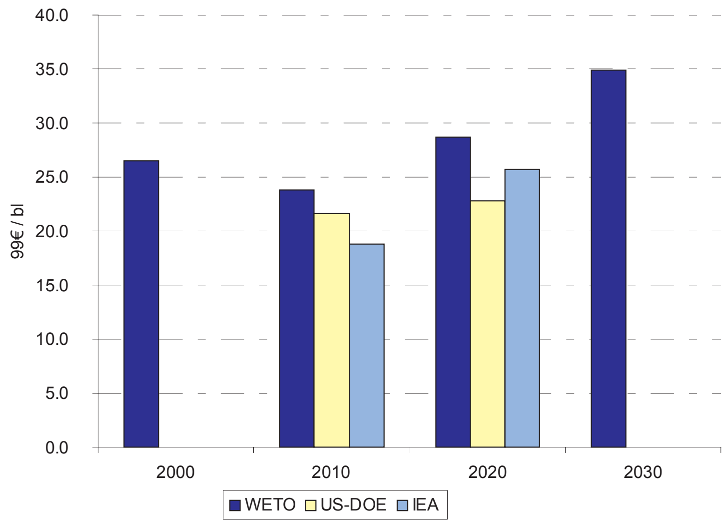
GDP	%/year			Billions 99Euros			
	2000-10	2010-20	2020-30	2000	2010	2020	2030
WETO	3.49%	3.13%	2.62%	41 407	58 350	79 400	102 788
US-DOE	3.17%	3.33%			56 565	78 462	
IEA	3.10%	3.10%			56 191	76 252	
WEC A2	2.74%	2.59%	2.67%		54 240	70 016	91 088



3. *World oil price*

After a ten years period during which world oil price stayed below 20 €/bl, in 2000 it reached a peak of 26.5 €/bl. The three studies elaborating price projections point to a lower oil price in 2010. In 2020 however, two out of three studies show a full recovery from the 2000 level. The WETO endogenous projection of prices shows the highest profile with 29 and 35 €/bl, in 2020 and 2030 respectively. These levels are deemed to be necessary – in the set of the WETO hypotheses and modelling framework – to balance world demand and supply, including that of non-conventional oil resources.

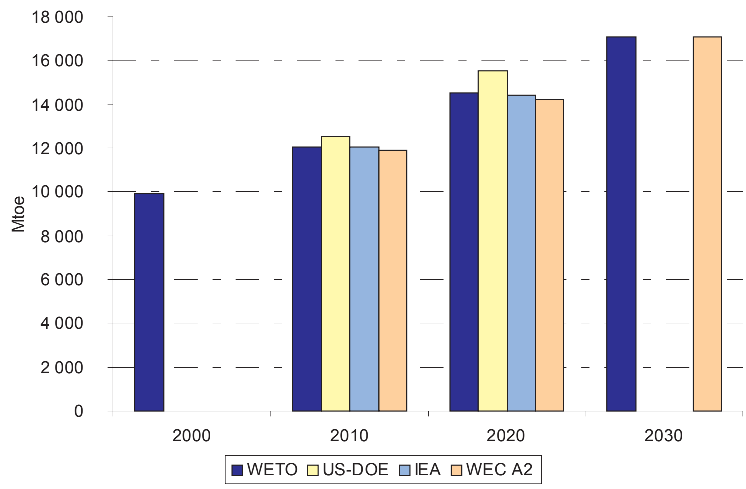
Oil Price	$95/bl=€99/bl			
	2000	2010	2020	2030
WETO	26.5	23.8	28.7	34.9
US-DOE		21.6	22.8	
IEA		18.8	25.7	



4. *World energy consumption*

World total energy consumption levels, as they stem from the harmonisation process used here, show similar levels for the time-period considered, with a typical 12 Gtoe in 2010 and 14.5 in 2020 (only one study displays a significantly higher value, i.e. 15.5 Gtoe for that date) and 17 Gtoe in 2030. However, this proximity in total energy forecasts hides more important differences in the projections for individual energy sources, as analysed below.

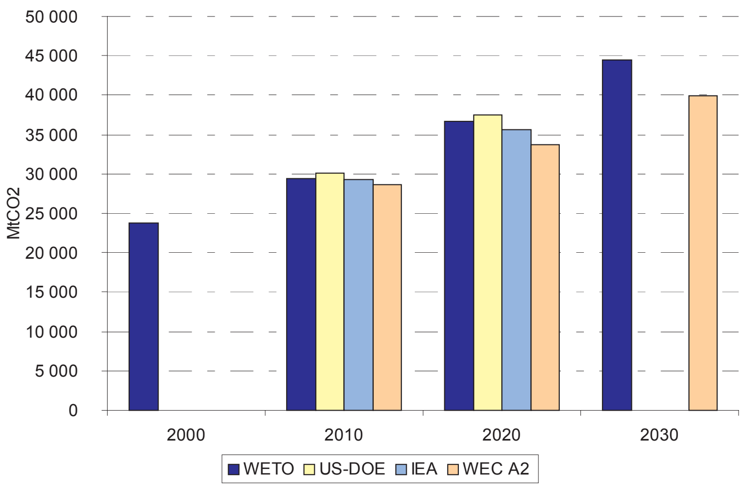
Primary Energy	%/year			Mtoe			
	2000-10	2010-20	2020-30	2000	2010	2020	2030
WETO	1.97%	1.88%	1.64%	9 927	12 062	14 536	17 100
US-DOE	2.34%	2.19%			12 512	15 532	
IEA	1.96%	1.79%			12 054	14 396	
WEC A2	1.84%	1.81%	1.82%		11 915	14 250	17 064



5. World CO_2 emissions

As for the energy consumption, the total projected CO_2 emissions from the combustion of fossil fuels show a reasonable proximity with about 30 Gt CO_2 in 2010 and 35 in 2020. For the last decade of the projection, the difference between the IIASA-WEC and the WETO projections (40 and 45 Gt CO_2 in 2030 respectively) turns out to be important. This reflects a much higher contribution of the traditional biomass and new renewable energy sources in the former study.

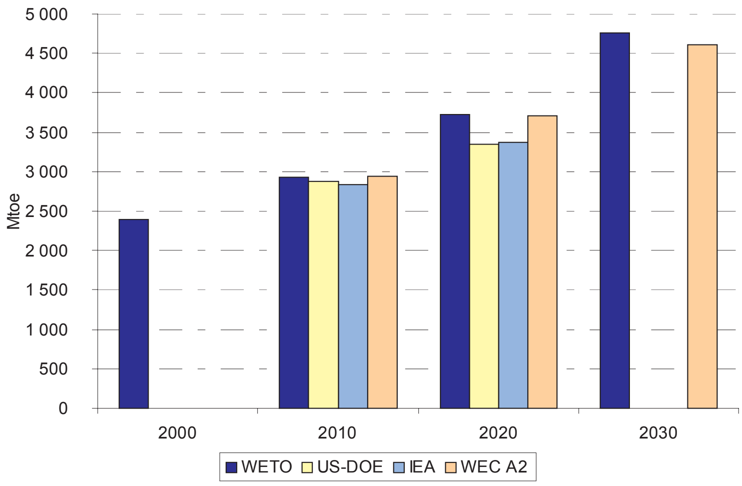
CO2	%/year			Mt CO_2			
	2000-10	2010-20	2020-30	2000	2010	2020	2030
WETO	2.14%	2.26%	1.93%	23 781	29 376	36 738	44 498
US-DOE	2.39%	2.22%			30 130	37 520	
IEA	2.09%	2.00%			29 251	35 666	
WEC A2	1.89%	1.65%	1.66%		28 687	33 792	39 858



6. World coal demand

All four scenarios point to an increase in world coal consumption over the next decades, with a total consumption of about 3 Gtoe in 2010. For the longer term, the WETO and WEC-IIASA projections show structurally higher coal consumption than the IEA and DOE projections for 2020 and the rise of coal continues in the 2020-2030 decade, with average growth rates higher than 2 %/year. In both cases, coal consumption reaches a level of more than 4.5 Gtoe in 2030, corresponding to a doubling from current level. This reflects the assumptions used in these two studies for oil and gas resources and the fact that, in the long run, coal remains the only abundant and cheap fossil source, provided that environmental considerations do not dominate the scenario framework.

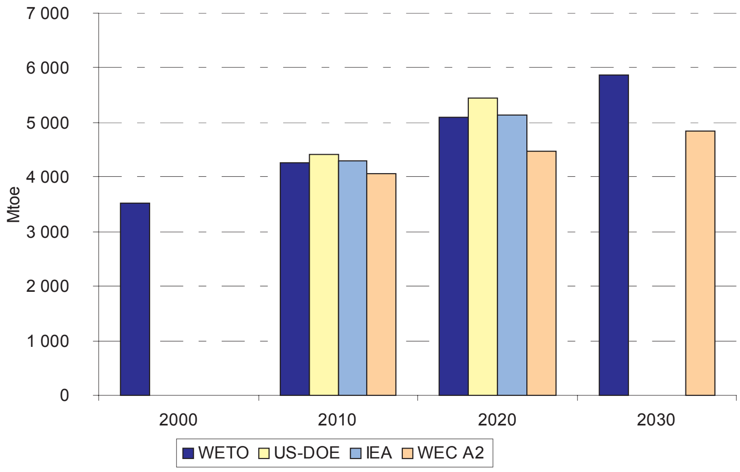
Coal	%/year			Mtoe			
	2000-10	2010-20	2020-30	2000	2010	2020	2030
WETO	2.07%	2.42%	2.48%	2 389	2 931	3 723	4 757
US-DOE	1.88%	1.50%			2 878	3 340	
IEA	1.74%	1.74%			2 837	3 370	
WEC A2	2.13%	2.31%	2.22%		2 949	3 707	4 616



7. *World oil demand*

World oil demand exceeds 4 Gtoe in 2010 in the four studies, and 5 Gtoe in 2020 in three of them. The corresponding growth rates are however at a relatively low level, between 1.5 and 2 %/year. The DOE forecast shows the highest level of world oil demand in 2020 and this is consistent, on the demand side, with the fact that this study also has the lowest oil price for that horizon (23 $/bl).

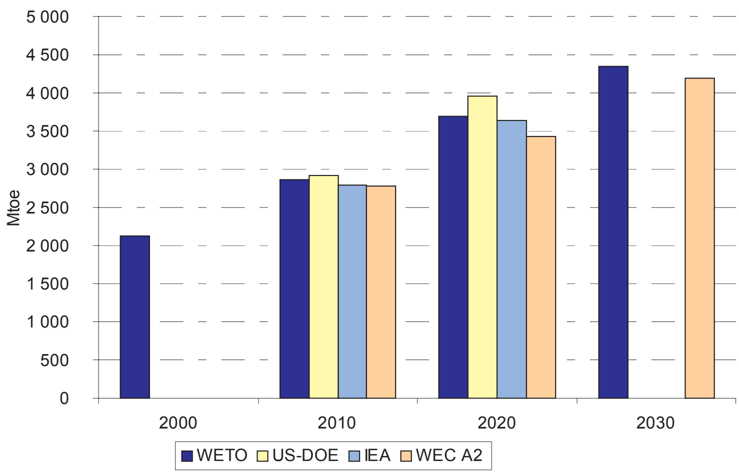
Oil	%/year			Mtoe			
	2000-10	2010-20	2020-30	2000	2010	2020	2030
WETO	1.91%	1.84%	1.43%	3 517	4 250	5 099	5 878
US-DOE	2.28%	2.14%			4 407	5 445	
IEA	2.01%	1.82%			4 293	5 139	
WEC A2	1.44%	0.97%	0.81%		4 057	4 470	4 846



8. *World gas demand*

The natural gas projections show the same differences and similarities than those observed for oil. World gas demand is in a range of 2.8-3 Gtoe in 2010 and 3.5-4 Gtoe in 2020. The average growth rates are however much higher than for oil, with values between 2.5 and more than 3 %/year at least until 2020. This is a clear indication of the strong dynamics that has to be expected for natural gas in the next twenty years.

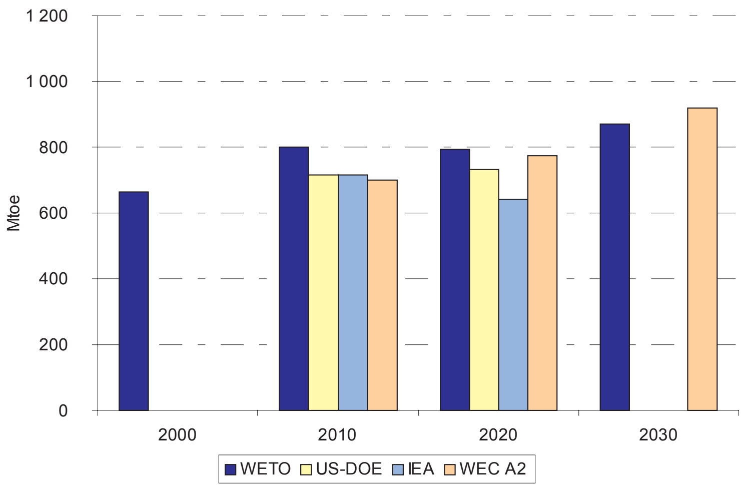
Natural Gas	%/year			Mtoe			
	2000-10	2010-20	2020-30	2000	2010	2020	2030
WETO	3.00%	2.59%	1.63%	2 129	2 860	3 693	4 340
US-DOE	3.19%	3.12%			2 916	3 965	
IEA	2.76%	2.69%			2 797	3 646	
WEC A2	2.72%	2.12%	2.02%		2 784	3 434	4 193



9. World nuclear electricity production

The prospects for nuclear electricity development in the next thirty years appear to be quite limited in the four projections. This is explained by the marked slowdown or even the halt in new plant orders since the 1980s. The WETO scenario however projects some increase in the nuclear power production for the next decade, due partly to the additions of new capacities and partly to improvements in existing plants management and load factors. Between 2010 and 2020 the production is expected to stabilise in the WETO projection before a modest growth recovery between 2020 and 2030, while the IEA outlook points for a rapid retirement of the so called “second generation” plants after 2010. In all cases the contribution of nuclear energy seems to be limited to less than 0.8 Gtoe before 2020 and less than 0.9 Gtoe before 2030.

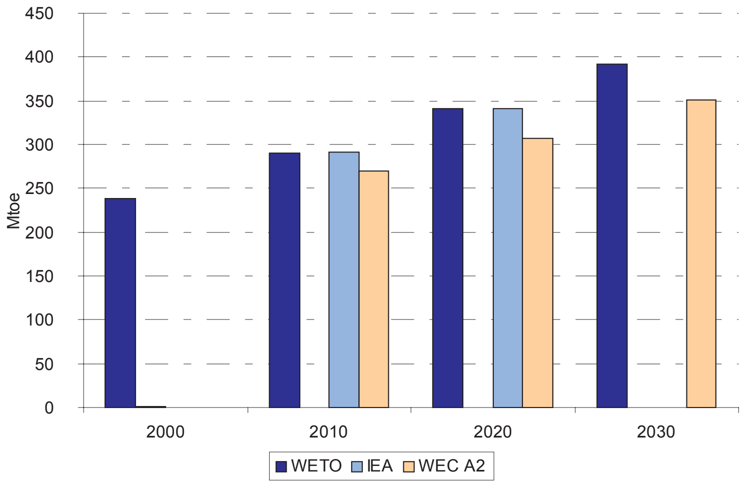
Nuclear	%/year			Mtoe			
	2000-10	2010-20	2020-30	2000	2010	2020	2030
WETO	1.89%	-0.09%	0.96%	663	799	792	872
US-DOE	0.78%	0.22%			717	732	
IEA	0.77%	-1.10%			716	641	
WEC A2	0.52%	1.05%	1.73%		699	776	920



10. World hydro-electricity production

World hydro power production is expected to rise relatively regularly over the period, with for the WETO and the IEA studies average rates of 2 %/year between 2000 and 2010 and 1.6 % p.a. between 2010 and 2020. If the same conversion factors were used for hydro power and for nuclear, then the contribution of hydro power to world energy supply would exceed 1Gtoe in 2020 and 1.4 Gtoe in 2030 according to the WETO projection.

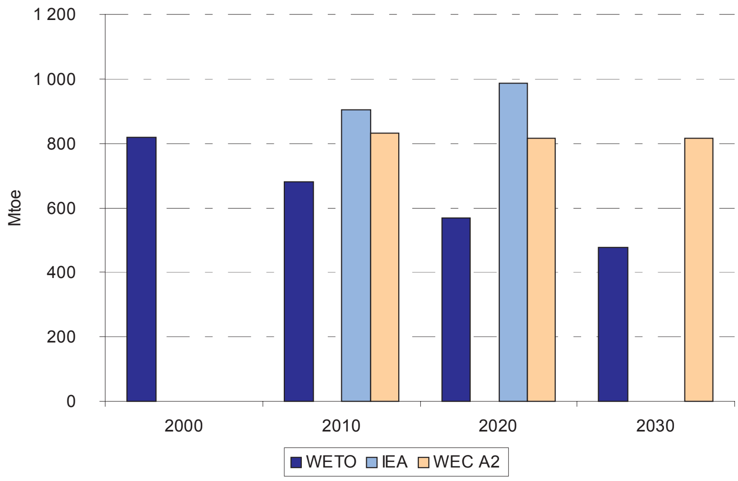
Large Hydro	%/year			Mtoe			
	2000-10	2010-20	2020-30	2000	2010	2020	2030
WETO	1.98%	1.65%	1.40%	238	290	342	392
IEA	2.05%	1.57%			292	341	
WEC A2	1.24%	1.31%	1.36%		270	307	351



11. *World biomass production*

By definition, the contribution of biomass to world energy supply is difficult to measure. It is also difficult to model as the proper dynamics of the corresponding energy sources as well as their links – in terms of substitution processes – with commercial fuels have hardly been explored, and only in field-studies. The three projections providing estimates for this category of fuels indeed show very contrasted profiles, with stability in the IIASA-WEC projection, an increase in the IEA outlook and a continuous decrease, based on the hypothesis of growing urbanisation, in the WETO projection.

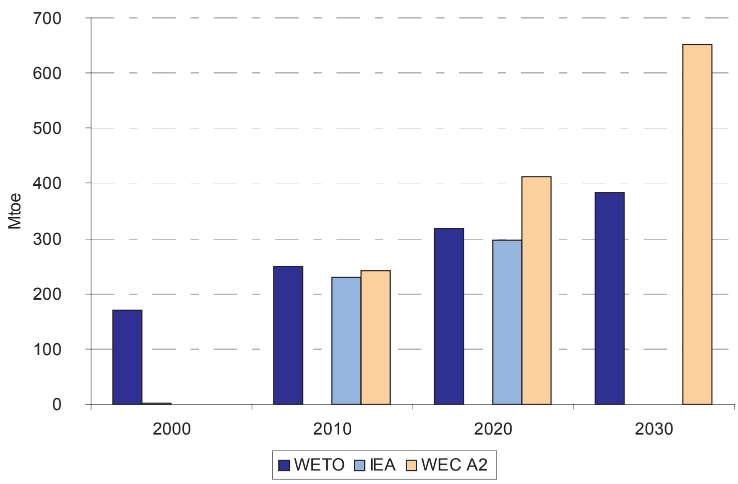
Biomass (non comm.)	%/year			Mtoe			
	2000-10	2010-20	2020-30	2000	2010	2020	2030
WETO	-1.83%	-1.79%	-1.75%	820	682	569	477
IEA	0.98%	0.87%			904	986	
WEC A2	0.16%	-0.23%	0.01%		833	814	815



12. *World other renewable production*

The category of other renewable used for this comparison includes different energy sources from commercial biofuels to micro-hydro systems, wind and photovoltaic. Altogether, they represent not more than 0.17 Gtoe in 2000, with a clear predominance of commercial biofuels. The expected average growth rate is relatively high, i.e. above 3 %/year, for the first 2000-2010 decade. It then slows down in the WETO and IEA projections, while it increases significantly in the IIASA-WEC projection. In the two former studies, the Reference cases do not incorporate any particular emphasis on environmentally friendly policies.

Other Renewable	%/year			Mtoe			
	2000-10	2010-20	2020-30	2000	2010	2020	2030
WETO	3.87%	2.49%	1.87%	171	250	319	384
IEA	3.03%	2.61%			230	298	
WEC A2	3.53%	5.47%	4.70%		242	412	652



ANNEX 2

WETO PROJECTIONS BY REGIONS

World

	1990	2000	2010	2020	2030	%/ year 1990/00	2000/10	2010/30
Overall indicators								
Population (Million)	5248	6102	6855	7558	8164	1,5%	1,2%	0,9%
GDP (G € 99 ppp)	30793	41407	58350	79400	102788	3,0%	3,5%	2,9%
Per capita GDP (1000 € 99/cap)	5,9	6,8	8,5	10,5	12,6	1,5%	2,3%	2,0%
Gross Inland Cons/GDP (toe/1000 € 99)	281	241	206	183	166	-1,5%	-1,5%	-1,1%
Gross Inland Cons per capita (toe/cap)	1,7	1,6	1,8	1,9	2,1	-0,1%	0,7%	0,9%
% renewables in gross inland consumption	13%	13%	11%	9%	8%	-0,2%	-1,8%	-1,4%
Electr. Consumption per capita (kWh/cap)	1,8	2,1	2,4	3,0	3,7	1,1%	1,7%	2,1%
CO2 Emissions per capita (t of CO2/cap)	4,0	3,9	4,3	4,9	5,5	-0,2%	1,0%	1,2%
Transport fuels per capita (toe/cap)	0,26	0,28	0,30	0,32	0,34	0,9%	0,5%	0,7%
Primary Production (Mtoe)	8530	9953	12110	14611	17213	1,6%	2,0%	1,8%
Coal, lignite	1901	2389	2931	3723	4757	2,3%	2,1%	2,5%
Oil	3258	3517	4250	5099	5878	0,8%	1,9%	1,6%
Natural gas	1754	2129	2860	3693	4340	2,0%	3,0%	2,1%
Nuclear	509	663	799	792	872	2,7%	1,9%	0,4%
Hydro,geothermal	193	238	290	342	392	2,1%	2,0%	1,5%
Wood and wastes	904	1002	949	908	900	1,0%	-0,5%	-0,3%
Wind, solar, small hydro	11	15	30	54	73	3,3%	7,1%	4,6%
Gross Inland Consumption (Mtoe)	8668	9980	12043	14514	17065	1,4%	1,9%	1,8%
Coal, lignite	2168	2371	2913	3704	4739	0,9%	2,1%	2,5%
Oil	3104	3591	4250	5099	5878	1,5%	1,7%	1,6%
Natural gas	1747	2127	2859	3689	4323	2,0%	3,0%	2,1%
Primary electricity	746	890	1072	1114	1225	1,8%	1,9%	0,7%
Wood and wastes	904	1002	949	908	900	1,0%	-0,5%	-0,3%
Electricity Generation (TWh)	11945	14865	19339	26122	34716	2,2%	2,7%	2,9%
Thermal	7561	9299	12464	18382	25803	2,1%	3,0%	3,7%
of which:								
Conventional coal, lignite	4412	5516	5532	5154	4325	2,3%	0,0%	-1,2%
Advanced coal technology	0	0	1582	5573	11331			10,3%
Gas	1688	2418	4054	6209	8542	3,7%	5,3%	3,8%
Biomass	132	197	260	335	423	4,1%	2,8%	2,5%
Nuclear	2013	2622	3161	3137	3498	2,7%	1,9%	0,5%
Hydro+Geoth	2246	2771	3371	3971	4562	2,1%	2,0%	1,5%
Solar	1	2	24	44	51	6,6%	31,4%	3,8%
Wind	4	23	117	342	544	19,4%	17,5%	8,0%
Small Hydro	120	149	203	245	258	2,1%	3,2%	1,2%
CHP	519	586	1055	1510	1568	1,2%	6,1%	2,0%
Final Energy Consumption (Mtoe)	6270	7124	8682	10425	12132	1,3%	2,0%	1,7%
Coal, lignite	882	762	1100	1371	1626	-1,5%	3,7%	2,0%
Oil	2540	2998	3609	4339	5041	1,7%	1,9%	1,7%
Gas	960	1102	1423	1704	1859	1,4%	2,6%	1,3%
Heat	179	234	235	236	238	2,7%	0,0%	0,1%
Electricity	832	1083	1442	1974	2621	2,7%	2,9%	3,0%
Wood and wastes	865	945	872	800	748	0,9%	-0,8%	-0,8%
Industry	2411	2524	3190	3800	4289	0,5%	2,4%	1,5%
Transport	1459	1733	2056	2413	2796	1,7%	1,7%	1,5%
Household, Service, Agriculture	2437	2867	3437	4213	5047	1,6%	1,8%	1,9%
CO2 Emissions (Mt of CO2), of which:	20843	23781	29376	36738	44498	1,3%	2,1%	2,1%
Electricity generation	6943	8261	9393	12191	15809	1,7%	1,3%	2,6%
Industry	4752	4390	5674	6665	7302	-0,8%	2,9%	1,3%
Transport	4228	5125	6096	7163	8306	1,9%	1,8%	1,6%
Household, Service, Agriculture	3249	3748	5353	7110	8665	1,4%	3,4%	2,4%

Western Europe

	1990	2000	2010	2020	2030	%/ year 1990/00	2000/10	2010/30
Overall indicators								
Population (Million)	434	456	467	470	468	0,5%	0,2%	0,0%
GDP (G € 99 ppp)	7536	9225	11517	14226	16706	2,0%	2,2%	1,9%
Per capita GDP (1000 € 99/cap)	17,4	20,2	24,7	30,2	35,7	1,5%	2,0%	1,9%
Gross Inland Cons/GDP (toe/1000 € 99)	190	174	148	129	116	-0,9%	-1,6%	-1,2%
Gross Inland Cons per capita (toe/cap)	3,3	3,5	3,7	3,9	4,1	0,6%	0,4%	0,6%
% renewables in gross inland consumption	6%	6%	7%	7%	7%	0,3%	1,0%	0,6%
Electr. Consumption per capita (kWh/cap)	4,7	5,4	6,1	7,2	8,4	1,4%	1,2%	1,6%
CO2 Emissions per capita (t of CO2/cap)	7,8	7,9	8,0	8,8	9,3	0,1%	0,2%	0,8%
Transport fuels per capita (toe/cap)	0,64	0,71	0,73	0,77	0,79	1,0%	0,4%	0,4%
Primary Production (Mtoe)	863	1045	926	809	752	1,9%	-1,2%	-1,0%
Coal, lignite	224	134	107	108	110	-5,0%	-2,2%	0,1%
Oil	212	339	217	129	82	4,8%	-4,4%	-4,7%
Natural gas	156	252	261	220	178	4,9%	0,4%	-1,9%
Nuclear	188	223	227	218	238	1,7%	0,2%	0,2%
Hydro,geothermal	40	44	48	51	54	1,0%	0,9%	0,6%
Wood and wastes	41	48	54	65	71	1,5%	1,3%	1,4%
Wind, solar, small hydro	3	5	11	18	20	7,2%	8,1%	2,9%
Gross Inland Consumption (Mtoe)	1430	1604	1705	1839	1936	1,2%	0,6%	0,6%
Coal, lignite	320	246	224	269	315	-2,6%	-0,9%	1,7%
Oil	615	667	688	716	722	0,8%	0,3%	0,2%
Natural gas	227	379	464	521	537	5,2%	2,0%	0,7%
Primary electricity	227	264	274	269	291	1,5%	0,4%	0,3%
Wood and wastes	41	48	54	65	71	1,5%	1,3%	1,4%
Electricity Generation (TWh)	2420	2762	3118	3707	4279	1,3%	1,2%	1,5%
Thermal	1187	1313	1537	2044	2470	1,0%	1,6%	2,4%
of which:								
Conventional coal, lignite	783	675	551	544	492	-1,5%	-2,0%	-0,6%
Advanced coal technology	0	0	114	378	726		228,7%	9,7%
Gas	183	433	649	882	1021	9,0%	4,1%	2,3%
Biomass	15	35	48	70	80	8,9%	3,1%	2,6%
Nuclear	744	882	899	863	959	1,7%	0,2%	0,3%
Hydro+Geoth	459	507	552	593	623	1,0%	0,9%	0,6%
Solar	0,0	0,1	0,2	0,5	0,8	19,6%	9,5%	7,9%
Wind	1	16	67	139	157	34,0%	15,8%	4,3%
Small Hydro	29	43	61	67	69	4,2%	3,6%	0,6%
CHP	103	191	258	285	269	6,4%	3,1%	0,2%
Final Energy Consumption (Mtoe)	1027	1164	1257	1354	1409	1,3%	0,8%	0,6%
Coal, lignite	99	56	57	67	75	-5,5%	0,2%	1,4%
Oil	517	587	604	629	637	1,3%	0,3%	0,3%
Gas	180	251	290	301	289	3,4%	1,4%	0,0%
Heat	18	24	25	26	26	2,9%	0,3%	0,4%
Electricity	174	210	243	291	338	1,9%	1,5%	1,7%
Wood and wastes	35	36	38	41	44	0,4%	0,5%	0,7%
Industry	372	402	434	463	471	0,8%	0,8%	0,4%
Transport	295	329	350	369	380	1,1%	0,6%	0,4%
Household, Service, Agriculture	374	433	472	522	558	1,5%	0,9%	0,8%
CO2 Emissions (Mt of CO2), of which:	3565	3599	3751	4129	4374	0,6%	0,4%	0,8%
Electricity generation	1047	1026	1013	1236	1429	-0,4%	-0,1%	1,7%
Industry	624	623	641	645	616	-0,5%	0,3%	-0,2%
Transport	843	966	1029	1083	1117	1,4%	0,6%	0,4%
Household, Service, Agriculture	691	720	765	813	819	0,4%	0,6%	0,3%

	1990	2000	2010	2020	2030	%/ year 1990/00	2000/10	2010/30
Overall indicators								
Population (Million)	410	425	428	427	422	0,4%	0,1%	-0,1%
GDP (G € 99 ppp)	3423	2457	3495	4910	6400	-3,3%	3,6%	3,1%
Per capita GDP (1000 € 99/cap)	8,4	5,8	8,2	11,5	15,2	-3,6%	3,5%	3,1%
Gross Inland Cons/GDP (toe/1000 € 99)	493	478	379	331	290	-0,3%	-2,3%	-1,3%
Gross Inland Cons per capita (toe/cap)	4,1	2,8	3,1	3,8	4,4	-3,9%	1,1%	1,8%
% renewables in gross inland consumption	3%	5%	5%	5%	4%	4,2%	0,0%	-0,8%
Electr. Consumption per capita (kWh/cap)	3,9	3,2	4,0	5,5	7,1	-2,0%	2,3%	2,9%
CO2 Emissions per capita (t of CO2/cap)	11,0	6,7	7,2	9,1	10,6	-4,8%	0,6%	2,0%
Transport fuels per capita (toe/cap)	0,37	0,20	0,24	0,28	0,32	-5,8%	1,6%	1,5%
Primary Production (Mtoe)	1627	1375	1480	1889	2405	-1,7%	0,7%	2,5%
Coal, lignite	167	261	214	268	312	4,6%	-2,0%	1,9%
Oil	586	355	331	340	388	-4,9%	-0,7%	0,8%
Natural gas	747	606	746	1102	1529	-2,1%	2,1%	3,7%
Nuclear	68	92	120	103	94	3,1%	2,7%	-1,2%
Hydro,geothermal	24	25	29	32	34	0,7%	1,4%	0,8%
Wood and wastes	35	36	39	41	42	0,4%	0,9%	0,3%
Wind, solar, small hydro	0,3	0,4	0,9	2,8	6,6	2,4%	8,9%	10,3%
Gross Inland Consumption (Mtoe)	1688	1173	1323	1625	1853	-3,6%	1,2%	1,7%
Coal, lignite	446	235	187	234	271	-6,2%	-2,2%	1,9%
Oil	496	264	312	368	390	-6,1%	1,7%	1,1%
Natural gas	628	531	650	862	1035	-1,7%	2,0%	2,4%
Primary electricity	83	108	134	119	115	2,7%	2,2%	-0,8%
Wood and wastes	35	36	39	41	42	0,4%	0,9%	0,3%
Electricity Generation (TWh)	2168	1756	2165	2978	3766	-2,1%	2,1%	2,7%
Thermal	1619	1091	1341	2168	2917	-3,9%	2,1%	4,0%
of which:								
Conventional coal, lignite	690	469	377	449	407	-3,8%	-2,2%	0,4%
Advanced coal technology	0	0	65	259	519		197,2%	10,9%
Gas	625	457	700	1213	1758	-3,1%	4,4%	4,7%
Biomass	34	45	63	70	68	3,0%	3,3%	0,4%
Nuclear	269	365	474	407	372	3,1%	2,7%	-1,2%
Hydro+Geoth	276	296	340	371	400	0,7%	1,4%	0,8%
Solar	0,0	0,0	0,0	0,1	1,0	17,7%	26,7%	39,4%
Wind	0	0	2	15	50	64,8%	31,3%	17,1%
Small Hydro	4	5	9	17	26	2,1%	6,8%	5,5%
CHP	198	95	127	155	177	-7,1%	3,0%	1,7%
Final Energy Consumption (Mtoe)	1192	809	929	1123	1280	-3,8%	1,4%	1,6%
Coal, lignite	194	86	69	72	82	-7,8%	-2,1%	0,8%
Oil	370	178	212	249	277	-7,1%	1,8%	1,3%
Gas	320	230	306	407	471	-3,2%	2,9%	2,2%
Heat	143	177	177	177	177	2,1%	0,0%	0,0%
Electricity	138	116	146	202	257	-1,7%	2,3%	2,9%
Wood and wastes	24	22	18	17	17	-0,8%	-1,9%	-0,4%
Industry	609	315	377	437	473	-6,4%	1,8%	1,2%
Transport	143	91	107	126	142	-4,4%	1,6%	1,4%
Household, Service, Agriculture	422	402	445	560	665	-0,5%	1,0%	2,0%
CO2 Emissions (Mt of CO2), of which:	4377	2857	3058	3877	4476	-4,5%	0,7%	1,9%
Electricity generation	1675	997	929	1264	1495	-5,1%	-0,7%	2,4%
Industry	913	510	593	670	715	-5,7%	2,5%	0,9%
Transport	424	261	308	365	411	-4,8%	1,7%	1,4%
Household, Service, Agriculture	800	600	663	873	1056	-2,8%	1,0%	2,4%

North America

	1990	2000	2010	2020	2030	%/ year 1990/00	2000/10	2010/30
Overall indicators								
Population (Million)	277	304	327	348	365	0,9%	0,7%	0,6%
GDP (G € 99 ppp)	7293	9943	12632	15330	18096	3,1%	2,4%	1,8%
Per capita GDP (1000 € 99/cap)	26,3	32,7	38,7	44,1	49,6	2,2%	1,7%	1,3%
Gross Inland Cons/GDP (toe/1000 € 99)	302	255	217	191	170	-1,7%	-1,6%	-1,2%
Gross Inland Cons per capita (toe/cap)	8,0	8,3	8,4	8,4	8,4	0,5%	0,1%	0,0%
% renewables in gross inland consumption	5%	6%	5%	5%	6%	2,2%	-0,4%	0,2%
Electr. Consumption per capita (kWh/cap)	11,0	12,6	14,1	16,0	18,1	1,4%	1,1%	1,3%
CO2 Emissions per capita (t of CO2/cap)	19,2	21,0	21,0	21,4	21,8	0,9%	0,0%	0,2%
Transport fuels per capita (toe/cap)	1,92	2,12	2,09	2,02	1,96	1,0%	-0,1%	-0,3%
Primary Production (Mtoe)	1914	2164	2410	2623	2849	1,2%	1,1%	0,8%
Coal, lignite	582	694	721	828	1011	1,8%	0,4%	1,7%
Oil	559	533	575	603	651	-0,5%	0,8%	0,6%
Natural gas	500	589	754	830	789	1,6%	2,5%	0,2%
Nuclear	173	205	212	203	225	1,7%	0,3%	0,3%
Hydro,geothermal	52	62	63	65	66	1,8%	0,3%	0,2%
Wood and wastes	47	79	80	84	89	5,5%	0,2%	0,5%
Wind, solar, small hydro	2	2	4	10	17	3,0%	6,9%	7,0%
Gross Inland Consumption (Mtoe)	2203	2532	2744	2934	3082	1,4%	0,8%	0,6%
Coal, lignite	484	613	637	717	859	2,4%	0,4%	1,5%
Oil	850	994	988	1000	1004	1,6%	-0,1%	0,1%
Natural gas	571	588	773	871	836	0,3%	2,8%	0,4%
Primary electricity	252	258	267	264	294	0,2%	0,3%	0,5%
Wood and wastes	47	79	80	84	89	5,5%	0,2%	0,5%
Electricity Generation (TWh)	3681	4348	5032	6083	7412	1,7%	1,5%	1,7%
Thermal	2375	2791	3404	4408	5539	1,6%	2,0%	2,5%
of which:								
Conventional coal, lignite	1783	2126	1998	1739	1445	1,8%	-0,6%	-1,6%
Advanced coal technology	0	0	442	1415	2738		108,7%	9,5%
Gas	392	428	845	1127	1227	0,9%	7,0%	1,9%
Biomass	53	76	93	95	87	3,6%	2,1%	-0,3%
Nuclear	684	812	838	805	909	1,7%	0,3%	0,4%
Hydro+Geoth	602	719	738	754	765	1,8%	0,3%	0,2%
Solar	0,7	1,0	1,5	7,1	8,4	3,4%	4,0%	9,2%
Wind	3	5	21	77	158	4,9%	15,2%	10,7%
Small Hydro	16	20	29	32	32	2,5%	3,6%	0,5%
CHP	169	202	364	429	348	1,8%	6,1%	-0,2%
Final Energy Consumption (Mtoe)	1458	1693	1854	1987	2068	1,5%	0,9%	0,5%
Coal, lignite	65	35	36	39	39	-6,0%	0,2%	0,4%
Oil	774	896	923	930	936	1,5%	0,3%	0,1%
Gas	325	365	436	474	451	1,2%	1,8%	0,2%
Heat	2,2	8,4	8,5	8,6	8,7	14,4%	0,1%	0,1%
Electricity	262	331	395	477	566	2,3%	1,8%	1,8%
Wood and wastes	31	58	57	59	66	6,6%	-0,2%	0,8%
Industry	476	534	589	620	613	1,2%	1,0%	0,2%
Transport	535	646	686	704	719	1,9%	0,6%	0,2%
Household, Service, Agriculture	449	513	579	664	736	1,3%	1,2%	1,2%
CO2 Emissions (Mt of CO2), of which:	5314	6387	6863	7441	7955	1,9%	0,7%	0,7%
Electricity generation	2106	2642	2729	3128	3686	2,3%	0,3%	1,5%
Industry	827	675	747	765	682	-2,0%	1,0%	-0,5%
Transport	1601	1931	2054	2107	2150	1,9%	0,6%	0,2%
Household, Service, Agriculture	695	757	845	920	908	0,9%	1,1%	0,4%

Japan, Pacific

	1990	2000	2010	2020	2030	%/ year 1990/00	2000/10	2010/30
Overall indicators								
Population (Million)	150	158	162	162	159	0,5%	0,3%	-0,1%
GDP (G € 99 ppp)	3168	3699	4356	5287	6302	1,6%	1,6%	1,9%
Per capita GDP (1000 € 99/cap)	21,1	23,5	26,9	32,6	39,5	1,0%	1,4%	1,9%
Gross Inland Cons/GDP (toe/1000 € 99)	170	172	157	141	129	0,1%	-0,9%	-1,0%
Gross Inland Cons per capita (toe/cap)	3,6	4,0	4,2	4,6	5,1	1,2%	0,5%	0,9%
% renewables in gross inland consumption	5%	5%	5%	6%	6%	0,1%	1,0%	0,3%
Electr. Consumption per capita (kWh/cap)	6,1	7,1	8,0	9,6	11,6	1,6%	1,2%	1,9%
CO2 Emissions per capita (t of CO2/cap)	9,1	9,5	9,4	10,1	11,3	0,4%	-0,2%	1,0%
Transport fuels per capita (toe/cap)	0,66	0,80	0,83	0,88	0,94	1,9%	0,3%	0,6%
Primary Production (Mtoe)	248	346	437	522	615	3,4%	2,4%	1,7%
Coal, lignite	113	152	161	219	313	3,0%	0,6%	3,4%
Oil	36	38	66	70	41	0,6%	5,7%	-2,3%
Natural gas	23	37	57	67	80	4,9%	4,4%	1,8%
Nuclear	51	90	118	125	135	5,8%	2,8%	0,7%
Hydro,geothermal	12	13	13	14	14	0,7%	0,3%	0,2%
Wood and wastes	12	15	19	23	25	2,6%	2,5%	1,4%
Wind, solar, small hydro	1,5	2,0	2,8	4,7	5,8	2,4%	3,7%	3,6%
Gross Inland Consumption (Mtoe)	537	635	684	744	812	1,7%	0,7%	0,9%
Coal, lignite	111	128	121	131	160	1,4%	-0,5%	1,4%
Oil	291	297	278	290	291	0,2%	-0,7%	0,2%
Natural gas	61	94	138	165	188	4,4%	3,9%	1,6%
Primary electricity	63	101	128	135	147	4,9%	2,4%	0,7%
Wood and wastes	12	15	19	23	25	2,6%	2,5%	1,4%
Electricity Generation (TWh)	1062	1279	1464	1674	1888	1,9%	1,4%	1,4%
Thermal	703	752	810	968	1121	0,7%	0,7%	1,6%
of which:								
Conventional coal, lignite	208	277	172	140	112	2,9%	-4,7%	-2,1%
Advanced coal technology	0	0	67	228	383			9,1%
Gas	221	342	531	559	582	4,5%	4,5%	0,5%
Biomass	17	18	30	36	40	0,9%	5,0%	1,5%
Nuclear	202	355	467	493	539	5,8%	2,8%	0,7%
Hydro+Geoth	139	150	154	158	161	0,7%	0,3%	0,2%
Solar	0,1	0,2	3,1	19,9	28,5	12,9%	29,9%	11,7%
Wind	0,0	0,1	1,1	4,3	7,9	36,9%	29,8%	10,3%
Small Hydro	18	22	28	30	30	2,3%	2,4%	0,3%
CHP	39	71	78	109	117	6,2%	1,0%	2,0%
Final Energy Consumption (Mtoe)	385	443	487	525	564	1,4%	0,9%	0,7%
Coal, lignite	47	45	58	53	53	-0,5%	2,6%	-0,5%
Oil	219	256	259	271	280	1,5%	0,1%	0,4%
Gas	25	35	47	53	57	3,4%	2,9%	1,0%
Heat	0,6	1,1	1,3	1,5	1,8	7,4%	1,3%	1,6%
Electricity	79	97	111	134	159	2,1%	1,4%	1,8%
Wood and wastes	9	10	10	12	13	0,5%	0,3%	1,5%
Industry	182	191	210	218	231	0,5%	0,9%	0,5%
Transport	107	128	136	144	152	1,8%	0,6%	0,6%
Household, Service, Agriculture	102	124	141	162	181	2,0%	1,3%	1,3%
CO2 Emissions (Mt of CO2), of which:	1364	1496	1512	1640	1806	0,9%	0,1%	0,9%
Electricity generation	442	472	396	481	561	0,0%	-1,7%	1,8%
Industry	338	323	370	359	369	-0,4%	1,3%	0,0%
Transport	300	379	401	427	450	2,4%	0,6%	0,6%
Household, Service, Agriculture	174	189	208	236	257	0,8%	1,0%	1,0%

Africa, Middle East

	1990	2000	2010	2020	2030	%/ year 1990/00	2000/10	2010/30
Overall indicators								
Population (Million)	751	984	1225	1490	1755	2,7%	2,2%	1,8%
GDP (G € 99 ppp)	1707	2313	3335	4745	6553	3,1%	3,7%	3,4%
Per capita GDP (1000 € 99/cap)	2,3	2,4	2,7	3,2	3,7	0,3%	1,5%	1,6%
Gross Inland Cons/GDP (toe/1000 € 99)	363	363	310	286	269	0,0%	-1,6%	-0,7%
Gross Inland Cons per capita (toe/cap)	0,83	0,85	0,84	0,91	1,00	0,3%	-0,1%	0,9%
% renewables in gross inland consumption	30%	26%	19%	13%	10%	-1,5%	-3,3%	-3,3%
Electr. Consumption per capita (kWh/cap)	0,9	0,9	1,1	1,4	1,8	0,4%	2,0%	2,6%
CO2 Emissions per capita (t of CO2/cap)	0,00	0,00	0,00	0,00	0,00	0,7%	1,0%	1,6%
Transport fuels per capita (toe/cap)	0,05	0,12	0,12	0,13	0,14	9,8%	0,0%	0,6%
Primary Production (Mtoe)	1628	2009	2717	3823	4740	2,1%	3,1%	2,8%
Coal, lignite	107	125	185	297	475	1,6%	4,0%	4,8%
Oil	1188	1386	1923	2587	3105	1,6%	3,3%	2,4%
Natural gas	143	275	409	758	986	6,7%	4,0%	4,5%
Nuclear	2,1	3,4	8,8	7,1	5,9	4,9%	9,9%	-2,0%
Hydro,geothermal	6,2	8,2	11,5	15,4	20,4	2,8%	3,3%	2,9%
Wood and wastes	181	211	178	155	143	1,5%	-1,7%	-1,1%
Wind, solar, small hydro	0,3	0,4	3,3	5,1	6,0	3,5%	23,2%	3,0%
Gross Inland Consumption (Mtoe)	620	840	1034	1358	1762	3,1%	2,1%	2,7%
Coal, lignite	78	82	137	227	378	0,5%	5,2%	5,2%
Oil	241	326	425	553	690	3,1%	2,7%	2,5%
Natural gas	110	210	273	398	526	6,7%	2,6%	3,3%
Primary electricity	10	12	22	24	25	2,0%	6,4%	0,8%
Wood and wastes	181	211	178	155	143	1,5%	-1,7%	-1,1%
Electricity Generation (TWh)	559	803	1207	1881	2846	3,7%	4,2%	4,4%
Thermal	476	691	1017	1631	2527	3,8%	3,9%	4,7%
of which:								
Conventional coal, lignite	174	221	247	250	222	2,4%	1,1%	-0,5%
Advanced coal technology	0	0	37	209	532	NA	126,2%	14,3%
Gas	137	268	465	867	1372	7,0%	5,7%	5,6%
Biomass	0	0	2	5	16	8,2%	13,2%	12,0%
Nuclear	8	14	35	28	23	4,9%	9,9%	-2,0%
Hydro+Geoth	72	96	133	179	238	2,8%	3,3%	2,9%
Solar	0	0	13	13	10	22,4%	60,1%	-1,5%
Wind	0	0	4	24	41	42,8%	48,9%	11,9%
Small Hydro	1,8	2,4	4,4	6,4	7,1	2,9%	6,4%	2,5%
CHP	2	4	10	19	19	4,6%	10,2%	3,2%
Final Energy Consumption (Mtoe)	457	598	731	943	1192	2,7%	2,0%	2,5%
Coal, lignite	20	25	68	128	195	2,0%	10,8%	5,4%
Oil	181	232	303	402	508	2,5%	2,7%	2,6%
Gas	36	73	94	121	143	7,4%	2,5%	2,1%
Heat	0,4	0,5	0,5	0,5	0,5	3,7%	0,0%	0,0%
Electricity	40	58	88	138	210	3,8%	4,3%	4,5%
Wood and wastes	181	210	177	153	136	1,5%	-1,7%	-1,3%
Industry	142	171	211	282	371	1,8%	2,1%	2,9%
Transport	99	122	151	193	244	2,1%	2,2%	2,4%
Household, Service, Agriculture	257	341	416	535	671	2,9%	2,0%	2,4%
CO2 Emissions (Mt of CO2), of which:	1217	1708	2358	3373	4652	3,4%	3,3%	3,5%
Electricity generation	379	536	684	978	1413	3,5%	2,5%	3,7%
Industry	201	242	270	335	402	-1,5%	1,1%	2,0%
Transport	275	365	454	578	732	2,9%	2,2%	2,4%
Household, Service, Agriculture	163	283	598	998	1398	5,7%	7,8%	4,3%

Latin America

	1990	2000	2010	2020	2030	%/ year 1990/00	2000/10	2010/30
Overall indicators								
Population (Million)	435	514	589	658	717	1,7%	1,4%	1,0%
GDP (G € 99 ppp)	2498	3455	4940	6783	8840	3,3%	3,6%	3,0%
Per capita GDP (1000 € 99/cap)	5,7	6,7	8,4	10,3	12,3	1,6%	2,2%	1,9%
Gross Inland Cons/GDP (toe/1000 € 99)	182	178	160	151	142	-0,2%	-1,1%	-0,6%
Gross Inland Cons per capita (toe/cap)	1,0	1,2	1,3	1,6	1,7	1,3%	1,1%	1,3%
% renewables in gross inland consumption	22%	21%	22%	20%	19%	-0,2%	0,4%	-0,9%
Electr. Consumption per capita (kWh/cap)	1,1	1,6	2,0	2,6	3,3	3,4%	2,5%	2,4%
CO2 Emissions per capita (t of CO2/cap)	2,1	2,5	2,8	3,3	3,8	1,8%	0,9%	1,6%
Transport fuels per capita (toe/cap)	0,25	0,29	0,34	0,40	0,46	1,7%	1,6%	1,4%
Primary Production (Mtoe)	577	808	1217	1662	2142	3,4%	4,2%	2,9%
Coal, lignite	21	24	24	29	38	1,3%	-0,3%	2,3%
Oil	378	542	815	1100	1407	3,7%	4,2%	2,8%
Natural gas	75	103	192	320	451	3,2%	6,4%	4,3%
Nuclear	3,2	6,3	9,0	8,8	14,1	7,2%	3,5%	2,3%
Hydro,geothermal	34	48	63	79	96	3,5%	2,8%	2,1%
Wood and wastes	65	83	112	124	133	2,5%	3,0%	0,9%
Wind, solar, small hydro	0,5	0,6	1,1	1,7	2,8	1,3%	5,4%	5,0%
Gross Inland Consumption (Mtoe)	454	614	788	1024	1251	3,1%	2,5%	2,3%
Coal, lignite	20	31	30	37	58	4,2%	-0,3%	3,4%
Oil	239	334	398	499	605	3,4%	1,8%	2,1%
Natural gas	76	103	172	274	345	3,1%	5,2%	3,6%
Primary electricity	53	63	76	90	110	1,6%	2,0%	1,9%
Wood and wastes	65	83	112	124	133	2,5%	3,0%	0,9%
Electricity Generation (TWh)	608	974	1355	1895	2561	4,8%	3,4%	3,4%
Thermal	198	386	573	922	1358	6,9%	4,0%	4,4%
of which:								
Conventional coal, lignite	21	49	50	47	50	8,5%	0,4%	-0,1%
Advanced coal technology	0	0	15	61	184			13,3%
Gas	57	138	354	657	950	9,3%	9,8%	5,1%
Biomass	6	11	13	15	18	6,0%	1,9%	1,7%
Nuclear	12	25	35	35	58	7,2%	3,5%	2,5%
Hydro+Geoth	392	555	734	918	1113	3,5%	2,8%	2,1%
Solar	0	0,1	2,2	1,5	0,8	30,6%	38,4%	-4,9%
Wind	0	0,1	1,2	6,5	19,5	34,8%	27,5%	15,1%
Small Hydro	6,3	7,0	8,8	11,2	11,9	1,1%	2,3%	1,5%
CHP	4	7	56	114	124	6,9%	22,3%	4,1%
Final Energy Consumption (Mtoe)	346	469	612	786	950	3,1%	2,7%	2,2%
Coal, lignite	13	15	14	17	19	1,1%	-0,7%	1,6%
Oil	188	254	321	406	492	3,1%	2,4%	2,2%
Gas	39	50	66	94	110	2,5%	2,9%	2,6%
Heat	0	0	0	0	0	14,9%	0,0%	0,0%
Electricity	42	70	103	148	201	5,1%	3,9%	3,4%
Wood and wastes	64	81	109	120	128	2,4%	3,1%	0,8%
Industry	137	189	248	315	365	3,3%	2,7%	2,0%
Transport	115	150	202	264	327	2,7%	3,0%	2,4%
Household, Service, Agriculture	102	129	162	207	257	2,4%	2,3%	2,4%
CO2 Emissions (Mt of CO2), of which:	919	1296	1629	2176	2722	3,5%	2,3%	2,6%
Electricity generation	157	283	311	433	620	6,1%	0,9%	3,5%
Industry	166	220	272	349	383	2,9%	2,1%	1,7%
Transport	321	423	594	784	979	2,8%	3,5%	2,5%
Household, Service, Agriculture	86	107	141	180	212	2,2%	2,8%	2,1%

Asia

	1990	2000	2010	2020	2030	%/ year 1990/00	2000/10	2010/30
Overall indicators								
Population (Million)	2793	3261	3658	4003	4278	1,6%	1,2%	0,8%
GDP (G € 99 ppp)	5168	10317	18076	28120	39890	7,2%	5,8%	4,0%
Per capita GDP (1000 € 99/cap)	1,9	3,2	4,9	7,0	9,3	5,5%	4,6%	3,2%
Gross Inland Cons/GDP (toe/1000 € 99)	336	250	208	177	160	-2,9%	-1,8%	-1,3%
Gross Inland Cons per capita (toe/cap)	0,6	0,8	1,0	1,2	1,5	2,4%	2,7%	1,9%
% renewables in gross inland consumption	32%	22%	14%	10%	8%	-3,6%	-4,4%	-2,7%
Electr. Consumption per capita (kWh/cap)	0,4	0,7	1,1	1,7	2,4	5,8%	4,7%	3,9%
CO2 Emissions per capita (t of CO2/cap)	1,5	2,0	2,8	3,5	4,3	3,0%	3,5%	2,2%
Transport fuels per capita (toe/cap)	0,05	0,08	0,11	0,15	0,19	4,7%	3,5%	2,6%
Primary Production (Mtoe)	1673	2204	2921	3269	3668	NA	2,9%	1,1%
Coal, lignite	688	998	1520	1974	2499	3,8%	4,3%	2,5%
Oil	300	324	323	271	202	0,8%	0,0%	-2,3%
Natural gas	109	267	441	396	328	9,4%	5,1%	-1,5%
Nuclear	23	43	104	128	160	6,3%	9,3%	2,2%
Hydro,geothermal	26	39	62	86	109	3,9%	4,8%	2,9%
Wood and wastes	523	530	466	416	396	0,1%	-1,3%	-0,8%
Wind, solar, small hydro	4	4	7	14	17	1,0%	5,3%	4,1%
Gross Inland Consumption (Mtoe)	1736	2581	3765	4989	6369	4,0%	3,8%	2,7%
Coal, lignite	709	1036	1577	2089	2698	3,9%	4,3%	2,7%
Oil	371	710	1161	1672	2175	6,7%	5,0%	3,2%
Natural gas	74	221	390	598	856	11,6%	5,9%	4,0%
Primary electricity	59	84	171	213	243	3,6%	7,3%	1,8%
Wood and wastes	523	530	466	416	396	0,1%	-1,3%	-0,8%
Electricity Generation (TWh)	1447	2944	4998	7905	11964	7,4%	5,4%	5,1%
Thermal	1002	2274	3782	6239	9871	8,5%	5,2%	4,9%
of which:								
Conventional coal, lignite	752	1699	2136	1985	1598	8,5%	2,3%	-1,4%
Advanced coal technology	0	0	841	3023	6250			10,5%
Gas	73	352	510	906	1632	17,1%	3,8%	6,0%
Biomass	6	11	12	44	114	5,3%	1,0%	12,0%
Nuclear	92	170	413	506	637	6,3%	9,3%	2,2%
Hydro+Geoth	306	449	718	998	1263	3,9%	4,8%	2,9%
Solar	0	0,1	3,6	2,6	1,4	16,4%	48,5%	-4,5%
Wind	0	2	20	77	110	105,5%	24,1%	8,8%
Small Hydro	46	49	62	81	82	0,5%	2,4%	1,4%
CHP	4	15	161	400	513	13,4%	26,8%	6,0%
Final Energy Consumption (Mtoe)	1405	1948	2812	3708	4669	3,3%	3,7%	2,6%
Coal, lignite	444	501	798	996	1164	1,2%	4,8%	1,9%
Oil	292	596	987	1451	1910	7,4%	5,2%	3,4%
Gas	35	98	185	254	337	10,7%	6,5%	3,1%
Heat	15	24	24	24	24	4,8%	0,0%	0,0%
Electricity	98	201	357	585	890	7,5%	5,9%	4,7%
Wood and wastes	522	528	462	398	344	0,1%	-1,3%	-1,5%
Industry	530	756	1168	1533	1858	3,6%	4,5%	2,3%
Transport	166	268	423	613	832	4,9%	4,7%	3,4%
Household, Service, Agriculture	730	924	1222	1562	1979	2,4%	2,8%	2,4%
CO2 Emissions (Mt of CO2), of which:	4086	6438	10204	14103	18512	4,7%	4,7%	3,0%
Electricity generation	1108	2305	3331	4671	6606	7,6%	3,7%	3,5%
Industry	1602	1797	2782	3542	4135	1,7%	4,8%	2,0%
Transport	463	800	1256	1818	2468	5,6%	4,6%	3,4%
Household, Service, Agriculture	640	1092	2133	3089	4016	5,5%	6,7%	3,2%

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