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Four Futures for Energy Markets and Climate Change

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Abstract

Future developments in energy and climate are highly uncertain. In order to deal with these uncertainties, we developed four long-term scenarios based on the recently published economic scenarios *Four Futures of Europe*: STRONG EUROPE, GLOBAL ECONOMY, TRANSATLANTIC MARKET and REGIONAL COMMUNITIES. In this study, we explore the next four decades. Although the report focuses on Europe, global aspects of energy use and climate change play a significant role.

The next decades, global reserves of oil and natural gas will likely be sufficient to meet the growing demand. Therefore, there is no need to worry about a looming depletion of natural energy resources. The use of fossil energy carriers will, however, affect climate because of the emissions of greenhouse gasses. In order to mitigate global increases of temperature, emissions of greenhouse gasses should be reduced. Developing countries should contribute to that effort. On the one hand they will be major emitters in the near future, on the other hand they have the low-cost abatement options.

Korte samenvatting (in Dutch)

Toekomstige ontwikkelingen in energie en klimaat zijn met grote onzekerheid omgeven. Om met die onzekerheden om te gaan zijn vier scenario's uitgewerkt. Deze scenario's zijn gebaseerd op de onlangs door CPB gepubliceerde economische scenario's *Four Futures of Europe*: Sterk Europa, Globaliserende Economie, Transatlantische Markt en Regionale Samenlevingen. In deze studie wordt 40 jaar vooruit gekeken. Weliswaar ligt de nadruk daarbij op Europa, maar de mondiale aspecten van energiegebruik en klimaatbeleid spelen nadrukkelijk een rol.

De komende decennia zullen er voldoende voorraden aan gas en olie zijn, ondanks dat de vraag naar energie blijft toenemen. Zorgen over een aanstaande uitputting van de fossiele voorraden zijn daarom niet terecht. Wel zal de verbranding van fossiele brandstoffen via de emissies van broeikasgassen tot meer klimaatverandering leiden. Om de wereldwijde temperatuurstijging te beperken, is terugdringen van de uitstoot van broeikasgassen nodig. Substantiële bijdragen daaraan van ontwikkelingslanden zijn nodig om dat doel te bereiken, enerzijds omdat deze landen in de nabije toekomst tot de grote vervuilers zullen behoren, anderzijds omdat emissiereducties daar goedkoop zijn.

Contents

Preface

Thinking about future energy use brings to the fore two kinds of concerns. Oil and gas supplies are finite and depletion of natural resources may have negative feedbacks on energy use and economic growth. Prolonged burning of fossil fuels is expected to lead to further global warming and the negative impacts from climate change may affect environment and economy. The policy challenge for the coming decades is to combine strong economic growth and a clean environment.

This study answers key questions related to future energy use. Will natural resources become depleted in the near future? What climate impacts can be expected? What does a successful climate policy look like? Given the fundamental uncertainties on future economic growth, technology and climate change, a scenario approach is appropriate to answer these questions. This study offers four scenarios for future energy markets and climate change based on the more general scenarios in “Four Futures for Europe”, the recently published scenario study by CPB. This set of scenarios will serve as input for a number of follow-up studies analyzing e.g. policies on sustainability and spatial planning.

This study is a joint project between CPB and RIVM-MNP. In this way we benefited from expertise in different fields: economic analysis and the assessment of climate impacts. On a common field of interest, like energy, our approaches sometimes differ. Inevitably, an analysis as presented here cannot come about without a certain amount of compromise between conflicting insights. Time consuming as it may be, we are happy with the balanced result.

This study was written by Johannes Bollen (RIVM), Ton Manders (CPB) and Machiel Mulder (CPB). Others have provided useful contributions. Bas Eickhout of RIVM explored the possible environmental impacts of energy use on climate. Mark Lijesen of CPB provided some valuable inputs for the analysis of electricity markets. Dale Rothman surveyed the existing scenario literature. We thank in particular Detlef van Vuuren of RIVM who did a heroic job in harmonising economic insights with energy developments. Henri de Groot, Nico van Leeuwen, Arjan Lejour, Paul Tang (CPB) and Tom Kram, Joop Oude Lohuis, and Bert Metz (RIVM) are acknowledged for comments on various parts of this study. We thank Dick Morks and Simone Pailer for support in the final stages of the project.

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Summary

Scope of the research and main conclusions

Future developments in energy and climate are highly uncertain. In order to deal with these uncertainties, we developed four long-term scenarios based on the recently published economic scenarios *Four Futures of Europe*: STRONG EUROPE, GLOBAL ECONOMY, TRANSATLANTIC MARKET and REGIONAL COMMUNITIES. In this study, we explore the next four decades. Although the report focuses on Europe, global aspects of energy use and climate change play a significant role.

The next decades, global reserves of oil and natural gas will likely be sufficient to meet the growing demand. Therefore, there is no need to worry about a looming depletion of natural energy resources. The use of fossil energy carriers will, however, affect climate because of the emissions of greenhouse gasses. In order to mitigate global increases of temperature, emissions of greenhouse gasses should be reduced. Due to their strongly growing use of energy in the near future, developing countries should contribute to that reduction.

Driving forces

Main driving forces affecting future energy markets and environment are economic growth, demographic developments, technological improvements and environmental policies. Global energy demand is projected to grow in all scenarios. In a high growth scenario such as GLOBAL ECONOMY, primary energy demand is projected to grow at an average annual rate of 2.3%. A scenario with a stringent climate policy, such as STRONG EUROPE, shows a practically zero growth. All scenarios project energy demand to grow stronger in developing countries than in industrialised countries. Looking at output growth alone hides some important differences among regions and sectors. Regions with a high energy use per unit of output (energy intensity) are projected to grow at a relative high rate. The pace of technological improvements in the various sectors follows mainly from the level of economic growth. As a result, increasing efficiency in power generation and end-use of energy partly offsets the upward trend in energy demand caused by economic growth. Climate policy, aiming at limiting the negative impact of climate change, exerts a downward pressure on energy demand.

Resource scarcity

Resource scarcity, however, is unlikely to have a major influence on energy markets in the next decades. The reserves of oil in the Middle-East could approach their depletion before 2040, in particular in a scenario with high economic growth. Even in that case, the global supply of oil can be secured by non-conventional sources, such as tar sands in Canada. Therefore, absolute scarcity on the supply side will probably not raise the real price of oil in the next decades. In addition, a structural increase of the price of oil is not foreseen due to demand responses which would be induced by such an increase. The same holds for the price of natural gas. Geopolitical factors, however, may hamper the growing importance of natural gas, especially in Europe.

Impact on the environment

Global emissions of GHGs will rise in all scenarios as world economy expands, except for Strong Europe because of an assumed successful climate policy. In all scenarios, more than half of the emissions will come from developing countries. Over the next 40 years, cumulative emissions of greenhouse gases do not yet lead to large differences in concentration and global warming. However, that doesn't alter the fact that the next 40 years will likely show more changes in temperature than the past century. Using average assumptions regarding climate sensitivity, the (average global) temperature in 2040 could rise by approximately 1.6 ^{0} Celsius above pre-industrial level. Hence, the target of 2^{0} Celsius, set by the European Union, will likely not be exceeded in the next 40 years. However, emissions before 2040 get a process going which determines the changes beyond. Beyond 2040, global warming will exceed the 2 ^{0} Celsius target, unless climate policy or low economic growth curbs emissions.

An increase of temperature incurs biodiversity losses. The latter depends also on changes in land-use, deforestation, population, and the structure of production. Until 2040, differences among scenarios follow mainly from differences in the structure of economic growth. Losses will be larger in scenarios with higher economic growth. Impacts on water stress differ among scenarios. At the global level, water stress will increase, because global demand for water will increase more than the available supply. Developing countries regions will be faced with more water stress, because of a rapid economic growth enhancing the demand for water, and an on average decreasing precipitation surplus. The OECD will show less water stress as technology improvements will reduce the demand for water, and water supply will locally improve because of an increase of the precipitation surplus.

Climate change policy

Stabilisation of the concentration of greenhouse gases at a level of 550 ppmv (which is approximately double the pre-industrial level) under median climate sensitivity assumptions[1] will stand a good chance to meet the long-term EU target for global warming. To keep temperature changes below the EU target, emission reductions should not be delayed much longer, unless economic growth is low. Before 2025, the upward trend in emissions should be turned into a decline in order to reach that target. Global energy-related carbon emissions in 2040 should be almost 20% below the 2000 level. Given the strongly growing emissions of developing countries, their participation in any abatement coalition would be necessary.

[1] This is based on the climate sensitivity parameter, which is the equilibrium temperature effect of a doubling of CO2 equivalent concentration of greenhouse gases in the atmosphere. The IPCC gives a range of 1.5 to 4.5 °C, with 2.5 °C as the best guess. The latter value is adopted in this analysis.

To keep costs manageable, all low-cost options have to be exploited. In this respect, energy-efficiency improvements appears to be efficient options for curbing emission of greenhouse gases, followed by fuel-switching. The role of coal will diminish, but with large reductions even the share of natural gas will come under pressure. Carbon capture and storage and biological sequestration are projected to play a limited role. Exploiting alternative sources of energy is important. In STRONG EUROPE, the share of non-fossil fuels (biomass, nuclear, wind, sun and hydropower) may increase to almost 25%, compared to 6% in 2000.

A cap-and-trade system could be an efficient way of realising emission reductions. The costs for each country depend on the allocation of assigned amounts of emissions. We show that allocating emission allowances on an equal-per-capita basis can make some developing countries even better off than without the climate policy. The income gain from the export of emission allowances to developed regions could more than compensate for the loss associated with emission reductions. Energy exporters will be worse off, because fossil energy demand and prices will fall.

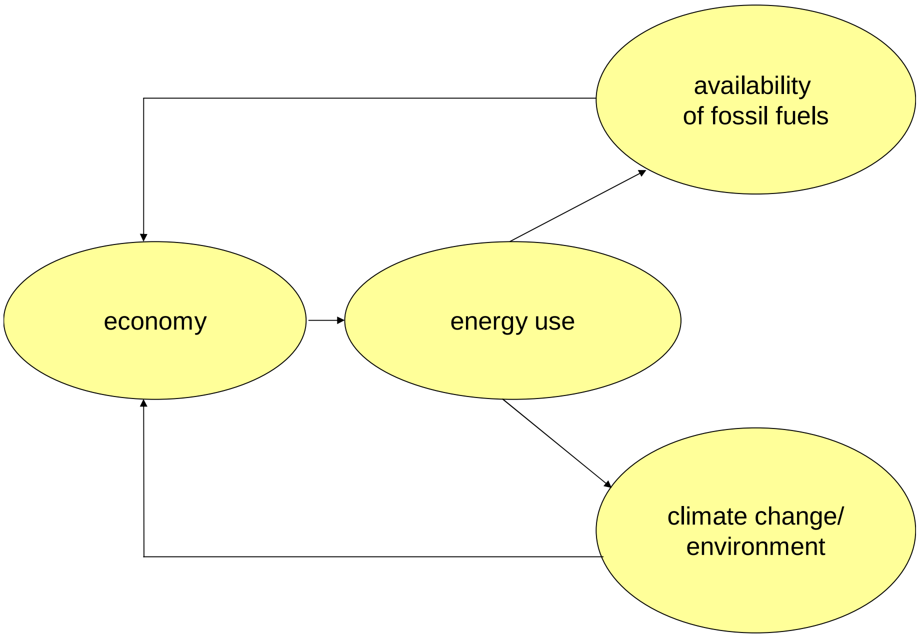
The costs of mitigation depend on the stringency of the target and on the economic growth in the underlying scenario. In STRONG EUROPE, we project the global GDP-loss in to be less than 2%, with a carbon tax at the level of 450 US$/tC. Associated effects on real national income range from a loss of 7% in the Middle East and countries in the Former Soviet Union to a small gain in Asian and African countries. The EU15 could face losses of 2% of GDP.

1 Introduction

1.1 The central role for energy

Energy is one of the keys to economic development and in order to explore future European economies, a profound analysis of the role of energy is necessary. Societies are fuelled by energy and future economic growth will ask for increased availability and use of energy. The ever-growing demand for energy will put a growing claim on natural resources and the environment. Natural resources are not infinite and oil and gas reserves can be expected to become depleted over time. Another growing concern is the impact of energy use on the environment. The combustion of fossil energy leads to emissions of greenhouse gases and evidence is mounting that this results in global warming. There may be important feedbacks on energy use and the economy. Physical disruptions in the supply of energy and large variations of the price of energy significantly affect economic growth. Climate change may lead to a large range of hazards, like deterioration of biodiversity and increased water stress. When thinking about energy in the future, one cannot neglect the adverse effects and possible feedbacks.

Figure 1.1 **Economy, energy and natural resources**



These impacts pose a challenge to policymakers. Sound policy calls for interference by national and international institutions to either adapt to the changes of the environment or to respond by trying to mitigate the negative effects.

This study focuses on the link between economic development and environment, in which energy is the pivot. We assess future energy markets and related climate change. Although these issues can only be treated on a global scale, we pay special attention to Europe. In doing so, this study is a based on *Four Futures of Europe*, the recently published CPB scenario study (CPB, 2003). It is a platitude to say “Europe’s future is uncertain”, as stated in this scenario study. All elements concerning energy markets and climate change are cursed with uncertainty. This holds for the driving forces behind economic development, technology, the availability of fossil resources, and the impacts through climate change on the environment. To cope with these uncertainties, we apply a scenario approach. We construct sets of consistent and appealing assumptions to explore possible future developments. We merge uncertainties that are correlated into a storyline and from these storylines we derive general characteristics of the scenarios. Finally, we translate developments and quantify possible future developments.

1.2 Key questions

Thinking about the role of energy in the future raises a number of questions regarding the economy, resource availability, energy markets and the environment.

Economy

The economic setting determines future energy demand to a large extent. Economic growth boosts energy demand, despite the fact that energy use per unit of output tends to decrease with higher output. Especially the catching-up by developing countries is an important driving force for global developments on energy markets. Without additional restrictions, global energy demand can be expected to grow further. Structural shifts are also important. There are large differences in energy consumption per unit of output between sectors. Services use relatively less energy than industrial sectors. The shift towards a more service oriented society thus substantially influences energy demand.

Key questions

- What can we expect about future economic growth in both Europe and the world?
- How strong will societies shift towards services?

Resource Availability and energy markets

Combustion of fossil fuels involves the depletion of non-renewable resources: oil and gas. But as coal reserves will not deplete, this may impact non-renewable resources such as oil and gas markets in the future. At a global level resources for oil and gas are more than sufficient to meet future demand. However, at a European level a mismatch between supply and demand is quite conceivable. For its oil, Europe is largely dependent on the Middle East. Supply security will partly depend on geo-political factors. Growing tensions between Western societies and the Arabic world might lead to restrictions in supply and higher prices. A similar argument may also apply to the gas market. With rapidly declining European gas reserves, import dependency is expected to rise. There may be important feedbacks on the economy and energy use. Physical disruptions in the supply of energy and large variations of the price of energy may significantly affect economic growth.

Key questions

- What could future energy demand and supply look like?
- When will the reserves of oil and natural gas be depleted, both on global level and regional levels? Who will supply our energy in the future?

Environment

Energy draws heavily on renewable resources: the environment. Evidence is growing that the increased use of energy and its associated emissions of greenhouse gases will induce climate change. Global warming may have serious impacts. According to recent projections by IPCC, global temperature can be expected to rise by 1.5 to 4.8 degrees Celsius before the end of the century. In the wake of these changes all kinds of negative impacts can be expected. Environmental effects of energy use are serious and hard to manage. The global society is increasingly aware of this problem and initiatives to limit the emissions of greenhouse gases are being taken. Climate policy to beat global warming may in its turn have serious consequences for demand and structure of energy demand, and can be quite different for Europe as opposed to the rest of the world.

Key questions

- How will energy demand influence the global climate and the environment?
- What will a climate policy to limit dangerous distortions of the environment look like?
- What will be the impacts for economic developments and energy markets?

1.3 Driving forces and key uncertainties

Economic growth and structural change

Future energy demand is determined by economic growth. However, there is no one-to-one relation. Energy intensity, the use of energy per unit of output, links energy and economic development. Energy intensities vary across sectors and regions. In manufacturing relatively more energy is used than in service sectors, developing countries are less efficient than industrialized countries. Hence, structural changes towards more service-oriented societies lead to a decoupling of energy and economic growth; the catching-up by developing countries is an important driving force leading to increased use of energy. Uncertainties about future economic growth, by sector and by region, contribute to a large extent to uncertainties about energy demand.

Geopolitics

The geopolitical situation might lead to constraints in energy supply. Europe and the USA will become more and more dependent on the Middle East and Russia for their oil and gas supply. Continuing and increasing tensions between the Western world and its main suppliers might drive up oil and gas prices. Furthermore, an unrestricted supply of gas asks for huge investments in pipeline infrastructure. A troublesome relation with Russia might pose a threat to these investments.

Energy technologies

Technology is an important factor. More efficient conversion techniques in electricity production and more efficient use of energy in final energy services, like transport and heating, will all lead to a downward pressure on energy demand. Not only will technological change result in the use of less primary energy per unit of output (a lower or improved energy intensity), but also to changes in the energy structure, e.g. fuel-switching. Related questions are: How easily can we shift from conventional oil resources to non-conventional resources like shale oil and tar sands? Is large scale non-carbon energy, like solar and wind, feasible? Is there a future role for nuclear and will hydrogen technologies turn transport upside down? In this study we will not assume major breakthroughs in energy technology. Future developments will be based on current trends in energy efficiency improvement and fuel switching.

Policies on energy market competition, supply security of energy, and the environment

Future policy will clearly affect future energy demand. Serious climate policy will curb the emissions of greenhouse gases. A low-emission society would lead to a dramatic shift in the energy system. Options range from a reduced demand and improved efficiency in energy conversion to substitution of fossil energy non-carbon fuels, like biomass, solar and wind energy or nuclear power. Although some first steps are taken to fight global warming, it remains unclear when and in which way future steps will be taken. Other policy plans may also affect future energy markets. Competition policy and policies regarding security of supply will influence energy prices and production capacity. Policies may be conflicting. Energy policy is mainly designed to provide a sufficient and low-cost energy supply. Its main goals are to enhance energy security and to overcome scarcities from exhaustible resources. Climate policy on the other hand discourages the use of fossil energy and leads to expensive energy. It will be a challenge for policy makers to design plans that serve both goals. Technology development aiming at less dependency on conventional sources and low carbon emissions seems a promising course to take.

1.4 Why scenarios?

Preparing for an unknown future

The only thing we can be sure of is that existing trends will not continue into the far future. This casts serious doubt on the use of a single reference scenario. The fundamental uncertainties related to the long term future make questions about future developments only to be answered by using scenarios. Scenarios can be seen as conceivable and consistent stories of the future. Those scenarios refer only to long-term, structural developments driven by fundamental changes. Developments in the short term, like fluctuations of the price of oil, are not taken into account. Although those developments are not the subject of this analysis, we realise that short term fluctuations in production or consumption can have major effects on prices and hence on the economy. The same holds for macroeconomic policies in the short term dedicated to mitigate economic consequences of environmental policies. Those short term effects are not part of our analysis, which does not mean that they are negligible.

Why should CPB and RIVM-MNP develop global scenarios?

We are not the first to produce future projections of energy use. Well-known are the IPCC SRES-scenarios. Only recently, IEA produced its World Energy Outlook 2002 and the European Commission published European energy and transport trends to 2030. There is a pragmatic reason for developing our own set. Our work follows on the scenario study Four Futures of Europe by CPB. There is a need for scenarios on energy markets and prices based on the Four Futures study, which can be input for Dutch national policy analyses on infrastructure, environment and spatial planning. A number of future studies will address issues of energy and sustainability in the Netherlands, using the international context of this study.

Linking Energy markets and the Environment to the Four Futures

This study develops four scenarios to assess the impact of economic development on energy use and the environment. These scenarios are based on four, more general scenarios for the future of Europe published recently (CPB, 2003). These scenarios differ with respect to two key uncertainties: international cooperation and the response of governments to the pressure on the welfare state. The scenarios are labelled STRONG EUROPE, REGIONAL COMMUNITIES, TRANSATLANTIC MARKET and GLOBAL ECONOMY. In contrast to this mainly European study we will discuss most aspects from a more global perspective. This is inherent to the issues we are interested in, for example: climate change is a global problem, energy use in all regions matters. Still we will pay special attention to Europe

Time horizon and new climate policies

The time horizon of the scenarios is 2040, based on the time horizon of the general scenario study. From an environmental perspective, however, this is a rather short period. As will become clear in this report, several environmental impacts of economic developments have a lead time of several decades. Therefore, we extend the time horizon up to 2100 in those cases where it is necessary for a proper analysis.

Scenarios serve as a tool for policymakers to design future policies. This does not mean that the scenarios are policy-free in the sense that only policies currently in place are kept unchanged. New policies that fit into the storyline of the scenario are taken into account. This applies most prominently for STRONG EUROPE, in which policies address the climate change issue.

1.5 Demarcation of the study

Touching upon such a broad area as energy and its impacts on environment, one has to restrict oneself. Exploring the link between energy and non-renewable resources, this study focuses on total use of energy, the markets of oil, natural gas, and electricity, and highlights effects of energy use on environment.

Energy use, emissions and the oil market are analysed on global level, while the analysis of the natural gas market and the electricity market refer to the situation in Europe. The coal market will not be included here because this market does not face structural uncertainties in the long term (see IEA, 2002), yet the interactions between the coal, oil and gas markets have been analyzed in an integrated way.

In discussing the link between energy use and environment, we focus on three environmental issues: biodiversity, water stress and acid rain pollutants. They share the characteristic that they are strongly energy-related. Changes in biodiversity and increased water stress directly stem from climate change.

Merely focusing on the link energy use – emissions – climate change, would, however, draw a partial picture. It is not only energy use that drives these effects. Land use changes also play an important role. Not only is land use a main source of greenhouse gas emissions. Biodiversity and to a lesser extent water stress depend directly on land use.

We also pay attention to the acid rain pollutant SO_2 resulting from energy use. Acidification is, in contrast to climate change, more a local than a global environmental problem. However, important linkages exist as acid rain pollutants tend to decrease global warming. Policies directed at reducing emissions of acid rain pollutants therefore will frustrate policies to fight global warming. On the other hand climate policies reduce the use of coal, and thus also help to solve the acidification problem.

1.6 Linking economy, energy markets and the environment; the model approach

The use of different models

In order to quantify the scenarios, we use several models. Figure 1.1 gives an overview of the different models and their linkage. The models are a general equilibrium model of the GLOBAL ECONOMY called WorldScan, a system-dynamic model of global energy demand called TIMER, IMAGE to assess the environmental impacts from climate change and models for the global market for oil and the European markets for electricity and natural gas, and. By using these models simultaneously, the story lines of the scenarios are translated into quantitative time paths of production, consumption, and prices of energy, and the resulting emissions of greenhouse gases and their impact on the environment.

WorldScan

WorldScan is a dynamic general equilibrium model for the world economy (CPB, 1999). Different world regions and production sectors are distinguished. The model is used to construct long-term scenarios and to perform policy analysis. WorldScan models both the demand and the supply side of the energy markets in a rather aggregated way. The model helps to assess the effects of economic growth, technological change and (climate) policy on regions and sectors. For the simulations in this study two versions of the model were used. The general version is used to quantify the general economic scenarios. The energy version is put into action to quantify the energy scenarios and to analyse climate policy. This latter version has sufficient detail on the energy side of the economy to cope with energy related CO_2 emissions. Climate policy is modelled by imposing a carbon tax on the use of energy. Given an exogenous limit on the emissions of energy-related CO_2 and given the coalition of regions engaged in abatement, the model evaluates the corresponding carbon tax as a shadow price.

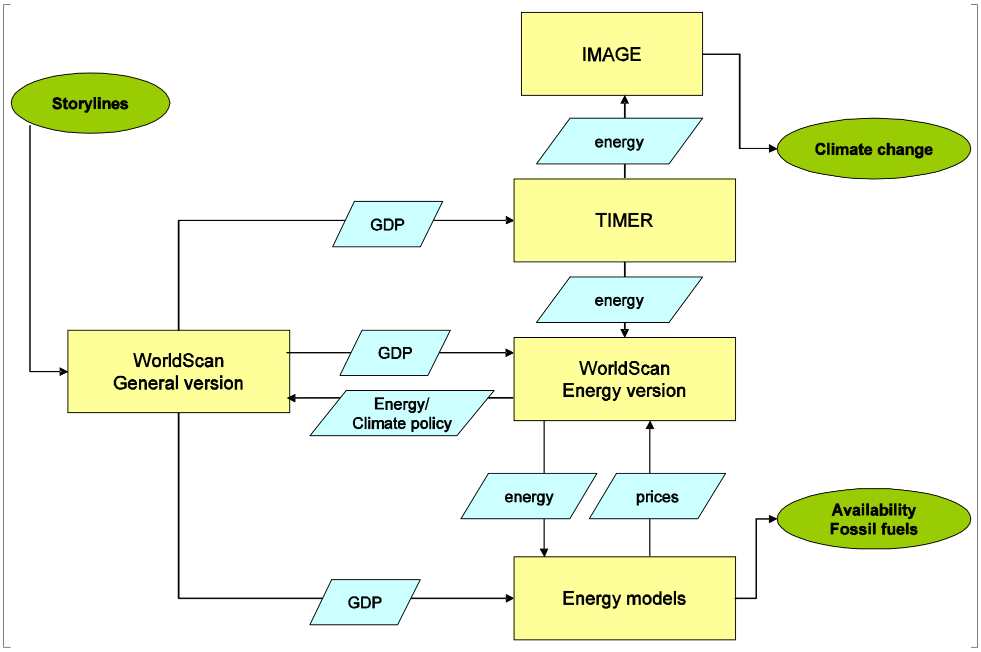
TIMER/IMAGE

TIMER is used to determine the demand for energy at sectoral and regional level by using rather specific information regarding technological opportunities to reduce energy use (see de Vries *et al*., 2001). It is a global system-dynamic energy model which has been developed to study the long-term dynamics of the energy system, in particular, transitions to systems with low carbon emissions (Image-team, 2001). Within the model, a combination of bottom-up engineering information and specific rules and mechanisms about investment behaviour and technology are used to simulate the structural dynamics of the energy system. Impacts on the environment, notably biodiversity and water stress, are evaluated using the IMAGE model. This Integrated Model to Assess the Global Environment (IMAGE) is a dynamic integrated assessment modelling framework for global change. The main objectives of IMAGE are to contribute to scientific understanding and support decision-making by quantifying the relative importance of major processes and interactions in the society-biosphere-climate system (Eickhout, den Elzen, and Kreileman, 2002).

Energy markets

The energy markets are analysed in detail with a partial-equilibrium model of the global oil market and a partial-equilibrium model of the European natural gas and electricity market[2]. In these models, prices of these energy carriers are endogenous. Special features of both models are the analysis of the structure of the market and factors on the supply side. The models pay explicit attention to the imperfect competition on the markets which are due to constraints on networks, and concentration and collusion on the supply side. In addition, the modelling of the supply of natural gas and oil includes relations, although rather simple, between commodity prices and activities in exploration. This dynamic characteristic of the models enables us, for instance, to explore the effect of resource scarcity on prices and consumption.

Figure 1.2 Organisation of the model analysis



Soft linkage

How is the combined use of all these models organised? Starting point are the four European scenarios from *Four Futures for Europe*. These general scenarios are quantified using the general version of WorldScan. The main drivers from the scenarios, like GDP, structural change and trade, are fed both into the energy version of WorldScan and into TIMER. Based on these general scenarios, TIMER calculates energy demand by carrier consistent with the general

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[2] See www.cpb.nl for more details about these models.

scenarios. Energy paths from TIMER are used to determine demand for energy with WorldScan on a disaggregated European level. In an iterative process with partial models for the oil, gas and electricity markets the economic availability of energy carriers is assessed, adjusting market prices. In this way a consistent picture of energy demand, supply and energy prices emerges. The IMAGE model assesses impacts on climate and environment. Conversely, IMAGE produces the emission profile consistent with a long term climate goal. This reduction profile is fed into WorldScan (and TIMER) to analyse consequences for the economy and the energy structure.

Units, dimensions and definitions

Concerning energy and emissions, a confusing number of definitions and dimensions circulates. Unless explicitly stated otherwise, in this report we use the following units:
Energy demand is expressed in tonnes of oil equivalents (toe), 1 Mtoe = 1 Million toe, 1 toe = 41868 TJ or 41868 10^{12} J.
Emissions are expressed in gigatons of carbon (GtC), 1 GtC = 1 Giga or 10^9 tonnes of carbon. Sulphur emissions are expressed in teragrammes of sulphur, 1 TgS = 10^{12} gram of Sulphur.
Concentrations of greenhouse gases in the atmosphere are expressed in parts per million metric volumes CO_2-equivalent (ppmv CO_2-equivalent).
Carbon taxes are expressed in constant prices in 1997 US dollars per tonne of carbon ($/tC). This may be expressed in dollars per ton CO_2 by multiplying the tax by 12/44 (the share of carbon in the atomic weight of CO_2).

1.7 Structure of this study

The development of European scenarios for energy and climate is not an isolated exercise. Not only are our scenarios based on the more general CPB scenarios, they also have some overlap with existing scenarios. Chapter 2 explores the landscape of the existing scenarios on energy and climate and describes our new European energy and climate scenarios. We describe how the driving forces behind energy markets develop in each scenario. Chapter 3 presents the scenario results in terms of demand for energy and energy intensity. Not only global developments are sketched, we also compare Europe (EU15) with the USA and non-OECD regions. The development of energy markets and prices of energy carriers is the subject of chapter 4. Chapter 5 explores the consequences for the climate and three energy related environmental problems: biodiversity, water stress and acidification. Chapter 6 focuses on climate policy, being one of the uncertainties driving future energy development. Chapter 7 concludes.

2 Four scenarios

Stressing fundamental uncertainties about future developments, we develop four scenarios in line with the general scenarios developed by CPB. As key uncertainties for future energy demand and related emissions, we distinguish demographic and economic growth, technological progress, geopolitical stability and energy and environmental policies.

2.1 Introduction

The long-term scenarios for energy markets and climate change form a part of CPB's scenarios on international economy, demography, technology and institutional settings (CPB, 2003).

Recent years saw a fair amount of energy scenarios being reviewed and developed. Seminal is the Special Report on Emission Scenarios by the Intergovernmental Panel on Climate Change (IPCC, 2000). In this report, not only an extensive overview of existing scenarios is given, also a number of new developed scenarios are presented. More recent exercises are the International Energy Agency's World Energy Outlook 2002 (IEA, 2002) and the European Energy and Transport Trends to 2030, developed under auspices of the European Commission (European Commission, 2003).

Given this fairly large amount of scenarios, one might ask why there is a need to develop a new set. The main reason is that we want pictures of energy and environment to be consistent with the underlying socio-economic developments as developed in the general CPB-scenarios. Ultimately, these scenarios will provide input for more specific scenarios for the Netherlands, exploring developments within the Dutch economy, use of space, and environment.
Our focus is on Europe, in contrast to the IPCC scenarios, which only distinguish the broad OECD aggregate. We aim to have a scenario period up to 2040. This restricts the use of the World Energy Outlook and the European Energy and Transport Trends, since these scenarios run till 2030 only. Furthermore we do not want to merely extrapolate from historical trends. Our scenarios are of an exploratory character. It may be true that the future is uncertain. However, when assessing the medium or long-term future, the only thing we can be sure of is that merely extrapolating existing trends will give us the wrong picture.

Before unfolding our scenarios, we first review part of the existing landscape of energy scenario exercises. We summarise a number of quantitative scenarios and discuss the overall pattern in key-determinants and output. Next, we explain the general scenarios which form the base for our energy scenarios. Important driving forces are socio-economic developments, geopolitical instability, technological progress and future energy and environmental policy. All these driving forces are cursed with uncertainty. The art of scenario making is to combine uncertain drivers into a compelling set to create a plausible and interesting scenario. We cover these driving forces and indicate what choices are made in each scenario. In doing so, this chapter prepares the ground for the quantitative treatment of the scenarios in subsequent chapters.

2.2 Lessons from the literature

In order to place the current study in context, we draw some lessons from recent scenarios. A lot of ground has been covered by IPCC Special Report on Emissions Scenarios (IPCC, 2000). This review emphasised quantitative scenarios that provide estimates of emissions of carbon dioxide and other greenhouse gases. We have gone beyond this to consider scenario exercises that are primarily narrative based or may not include emission estimates, but which provide further insight into energy futures. In addition, we have looked for more recent exercises that were not included in that review. In this section we restrict ourselves to some highlights from a number of quantitative scenarios. A full overview can be found in a separate survey (Rothman, 2004).

Baseline, exploratory and targeted scenarios

Scenarios can differ from the perspective they take in discussing the future. Specifically, they can differ as to whether they focus on expected, possible, or targeted futures. *Baseline* scenarios present an image of ‘business-as-usual’ or ‘conventional development’ and are closely related to historical notions of forecasts and/or predictions. They can be seen as somewhat more complex versions of trend extrapolations, in that they do consider some planned policies and other expected developments. They are frequently used to perform sensitivity analyses on particular assumptions and to test the effect of specific policy choices.

A second group, which we will refer to as *exploratory* scenarios, investigates a range of possible, if not necessarily, likely futures. This can reflect a desire to prepare for different eventualities, but more fundamentally reflects an increasing awareness that uncertainty about the future implies that it is more appropriate and defensible to consider multiple baselines than to presume we can know what is the ‘most likely’ future. In addition to comparing the basic results for each of these, sensitivity and policy analyses can be explored in each of the possible futures. Finally, the third group, which we will refer to as *targeted* scenarios, includes exercises in which specific targets are set and the scenario is either forced to meet these or particular policy actions are implemented in an attempt to meet these.

As example of baseline scenarios, we examine the baseline scenario from European Energy and Transport Trends to 2030 from the European commission (European Commission, 2004) and the reference scenario from World Energy Outlook 2002 from IEA (IEA, 2002). As examples of exploratory scenarios, we include in our review the SRES scenario set, developed by IPCC

(IPCC, 2000). Two other sets of exploratory scenarios, we take in to account, are the scenario developed by the United Nations Environmental Programme (UNEP) and a number of scenarios developed by IIASA and the World Energy Council (WEC).

Characteristics of some scenario's

Both baseline scenarios from IEA and EU assess likely economic, energy and CO2 trends to 2030. The EU-baseline focuses on individual European countries, IEA has a broader perspective, although the European Union is distinguished as a separate region. Government policies and measures that have been enacted, though not necessarily implemented, as of mid-2002 are taken into account. The EU-baseline assumes continued economic modernisation, substantial technological progress, and completion of the internal market in Europe. Existing policies on energy efficiency and renewables continue; the fuel efficiency agreement with the car industry is implemented; and decisions on nuclear phase-out in certain Member States are fully incorporated. No new policies to reduce greenhouse gas emissions, e.g. to reach the Kyoto targets, are implemented.

The IPCC-SRES scenarios are an example of exploratory scenarios. Dividing future worlds along the axis of regionalisation-globalisation and the axis economy-environment results in four scenario families. A1: this family assumes increased globalisation, with an economic emphasis; it is subdivided into A1B (balanced development of energy technologies), A1FI (fossil intensive development of energy technologies), A1T (technology advances in energy technologies, particularly carbon free sources). A2: this family assumes increased regionalisation, but maintains an emphasis on economic development. B1: this family assumes increased globalisation, but with a more environmental and social emphasis. B2: this family assumes increased regionalisation, but has an emphasis on environmental and social concerns.

The UNEP scenarios explore an array of possible futures for the environment to 2032 and beyond. Markets First: assumes a strong pursuit of market-driven globalisation, trade liberalisation, and institutional modernisation, assuming that social and environmental concerns will be addressed by increased growth. Policy First: assumes strong top-down policy focus on meeting social and environmental sustainability goals by harnessing the market and other mechanisms. Security First: assumes a lack of action to address social and environmental concerns leading to rising problems, which are responded to by authoritarian rule imposed by elites in fortresses, leaving poverty and repression outside. Sustainability First: envisions the bottom-up development of a new form of globalised cooperation to address economic, social, and environmental concerns, leading to fundamental changes in most societies.

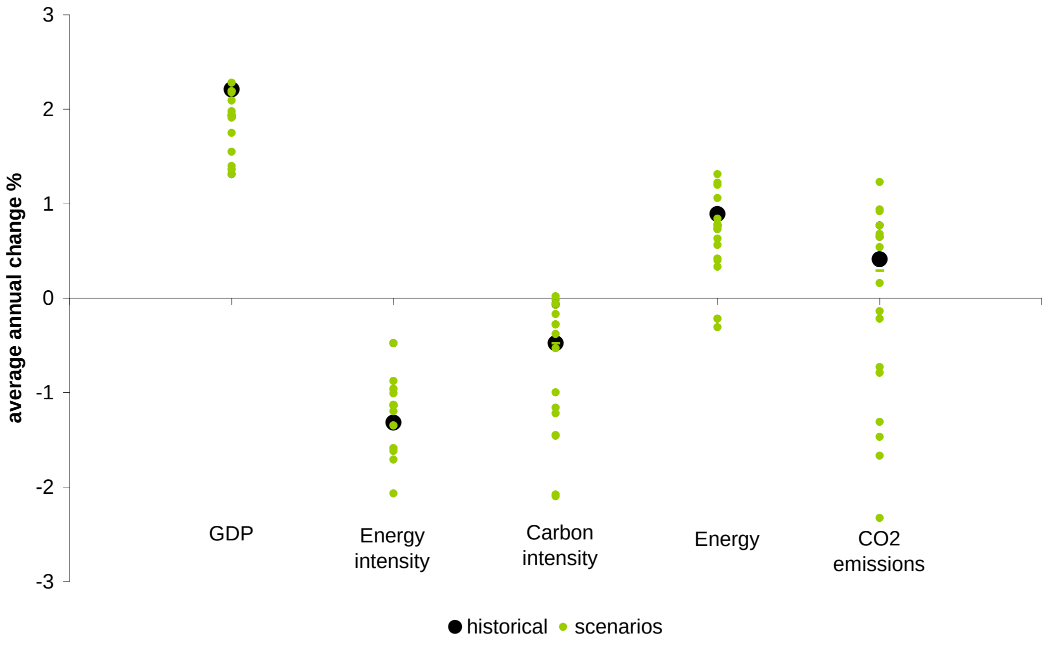
All of the studies reviewed provide detail on the future of energy and all of the exercises examined emphasise the medium to long-term. Thus, although they do have something to say about policy decisions in the near future, their emphasis is on the importance of these for longer term developments. The SRES scenarios look out to the end of the century, as is appropriate for their intended use in global climate change studies. Most of the scenario sets adopt a global perspective at the highest level, which makes sense given the interconnections of the energy system and the other issues of concern.

Key determinants and key outputs

The developments within any scenario reflect different assumptions about how current trends will unfold, how critical uncertainties will play out, and what new factors will come into play. Of these, assumptions about demographic and economic growth are at the root of most long-term scenario studies. The degree of international cooperation (economic, political, and cultural) and institutional focus are important determinants in scenarios that have important international policy elements. Finally, environmental policy, technological change, and fuel markets are of particular importance for energy and environmental scenarios.

For the scenarios that provide quantitative information Figures 2.1 summarises some of the key determinant and outputs for Europe[3]. This scatter diagram plots changes in output, energy intensity and carbon intensity for the different scenarios. Resulting changes in primary energy demand and CO_2 emissions are also shown. The data specifically show the average annual growth rates for the three components of the Kaya Identity[4]: output (GDP), energy intensity (EI), and carbon intensity (CI). The sum of the first two of these is equivalent to the growth in energy use; the sum of all three is equivalent to the growth in carbon emissions (CO_2). For reference historical rates for the period 1980-2000 are also depicted.

Figure 2.1 **Key characteristics of energy and emissions in different scenarios for Europe**



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[3] Recall that the definition of Europe differs in the different studies, which can explain part of the differences.

[4] The Kaya Identity links environmental impact to population, growth and technology. Carbon emissions (CO_2) can be decomposed in population (POP), output per capita (GDP/POP), energy intensity (EI =E/GDP) and carbon intensity (CI = EM/E): CO_2 = POP x (GDP/POP) x EI x CI.

From this diagram, some conclusions can be drawn.

- European output growth is projected to be below historical figures. In spite of this, output growth outweighs improvement in energy intensity. As a result, energy demand rises in most scenarios.
- There seems to be a negative relation between GDP-growth and energy intensity. The higher the output growth, the stronger the improvement in energy intensity. Variation in energy growth is (somewhat) smaller than variation in energy intensity improvement. On a global scale this is even more pronounced.
- Carbon intensity is projected to fall in most scenarios. In general, rates of change are smaller than rates of change in energy intensity. Both trends, Improvements in energy intensity and carbon intensity, have a downward effect on emissions. However, the former seems more important.
- There is a positive correlation between energy intensity and carbon intensity: an improvement in energy intensity goes together with a decrease in carbon intensity. Variation in emission growth across scenarios is larger than variation in energy demand. This applies not only to the European figures, but also on the global level.

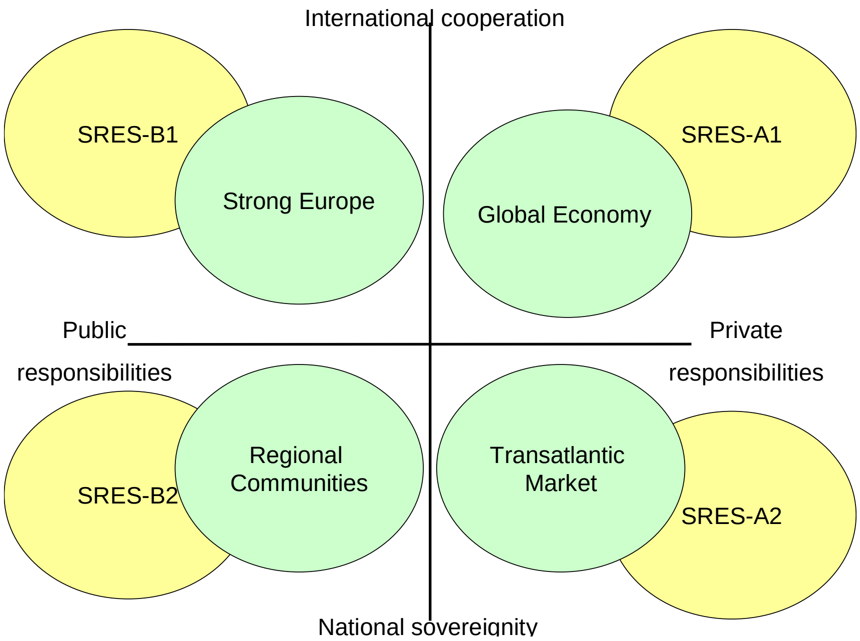
Mutatis mutandis, most conclusions for Europe also hold on a global scale; All scenarios show increasing energy use for the world as a whole; The negative correlation between output and energy intensity is even more pronounced on a more aggregate level; A positive correlation between energy an d carbon intensity applies also to world figures.

All scenarios recognise the continued dominance of fossil fuels over the next few decades. In general, scenarios are less explicit about energy prices. A general picture that emerges is increasing oil prices in exploratory scenarios. Oil prices changes in 2040 range between 50% and 100%. Baseline scenarios present declines until 2010 reflecting a situation of relative oversupply due to lower economic growth and competition among key producers. Moderate rises are projected thereafter, reflecting gradual changes in marginal production costs and supply patterns. Serious supply constraints are not likely to be felt in the relevant period. European gas prices are projected to rise in all scenarios, both exploratory and baseline. A 50% increase in import prices seems to be the lower bound. Assumed trends in gas prices reflect the underlying trend in oil prices, but other, contradictory factors play a role: increasing demand for gas, and the shift from more regional gas markets towards a more global market leading to a decoupling of gas from oil prices.

2.3 Two uncertainties, four scenarios

The long-term scenarios for energy markets and climate change form a part of CPB's scenarios on international economy, demography, technology and institutional settings (CPB, 2003). These general scenarios are developed to explore the future economic development of Europe in general and the Netherlands in particular. The scenarios are called STRONG EUROPE, TRANSATLANTIC MARKET, REGIONAL COMMUNITIES and GLOBAL ECONOMY. To develop these scenarios two key uncertainties concerning the future are combined as is illustrated in figure 2.2. The horizontal axis represents outcomes regarding the response in Europe to various challenges for the public sector. It runs from a focus on *public responsibilities* on the left to a focus on *private responsibilities* on the right. The vertical axis represents the outcomes with respect to international cooperation. It moves from a focus on *national issues* at the bottom to broad *international cooperation* at the top. Figure 2.2 thus yields four combinations in the two key uncertainties. The four quadrants each describe a possible future. In particular, the upper left quadrant represents a world labelled STRONG EUROPE with ample international cooperation and important public institutions. The bottom left marks the scenario REGIONAL COMMUNITIES, combining ample public responsibilities with little international cooperation. The lower right quadrant represents TRANSATLANTIC MARKET, a world with affinity for national sovereignty and ample room for private initiatives. Finally, GLOBAL ECONOMY is given in the upper right quadrant, combining flourishing international cooperation and a move towards more private responsibilities.

Figure 2.2 The four scenarios, relation with IPCC-SRES



More scenarios recently published fit in this conceptual framework. Especially the well-known SRES-scenarios developed by IPCC are closely related. Figure 2.2 illustrates the concordance by mapping the SRES scenarios in our framework.

It is tempting but misleading to compare the scenarios from Four Futures with the four SRES scenarios, all the more since IPCC also divides possible futures along two axes. However, these axes stress slightly different uncertainties. One axis in SRES represents globalisation. It moves from an emphasis on regions and local identity to convergence and increasing interregional interactions. The other axis moves from a focus on equity and the environment to a focus on economic growth. Hence, there is no one-to-one mapping between the two different sets. There are more differences. Four Futures focuses especially on Europe and addresses predominantly institutional and economic questions. SRES is more globally oriented and focuses on emissions and the energy system. Both studies use a different time frame, Four Future has a time horizon of 2040. SRES covers the whole century. Explicit policies to reduce emissions of greenhouse gases are absent in SRES, while climate policy is a key element of STRONG EUROPE. So, despite the similarities, one should be careful in exchanging the scenarios.

2.4 Driving forces behind energy markets

Exploring the future starts with identifying the driving forces between future developments. Several factors determine the development of energy markets. In general, the driving forces can be distinguished in economic growth, geopolitical factors, environmental policies, competition policies and policies regarding security of energy supply. Table 2.1 offers an overview of the development of these driving forces within each scenario. We use pluses and minuses to qualify differences between scenarios.

Economic growth

Changes in labour supply and productivity determine economic growth. Table 2.2 shows average annual growth of GDP in the different scenarios for a number of regions. Historical growth rates for the period 1980-2000 are also given[5]. On a global level, differences in growth between scenarios range from 1.8 % in REGIONAL COMMUNITIES to 3.1% in GLOBAL ECONOMY. Among regions differences in growth are more pronounced. For example, in GLOBAL ECONOMY growth in the EU15 is projected to be four times higher than in REGIONAL COMMUNITIES. Non-OECD countries show a relatively high economic growth in all scenarios.

[5] TRANSATLANTIC MARKET shows the highest growth of global population with an average of 1.3% per year. Population in STRONG EUROPE and GLOBAL ECONOMY lags behind with an annual growth of only 0.8%. REGIONAL COMMUNITIES has a moderate growth with almost 1% per year. Productivity growth is highest in GLOBAL ECONOMY, REGIONAL COMMUNITIES lags behind with only a modest rise in productivity. As a consequence, economic growth is high in GLOBAL ECONOMY and low in REGIONAL COMMUNITIES, while STRONG EUROPE and TRANSATLANTIC MARKET face a moderate growth of the world economy.

The main characteristics of the Four Futures

In STRONG EUROPE European countries maintain social cohesion through well functioning public institutions. Society accepts that the more equitable distribution of welfare limits the possibilities to improve economic efficiency. Yet, governments respond to the growing pressure on the public sector by undertaking selective reforms in the labour market, social security, and public production. Combined with early measures to accommodate the effects of aging, this helps to maintain a stable and growing economy. In the European Union, Member States learn from each others' experiences, which create a process of convergence of institutions among Europe. Reforming the process of EU decision making lays the foundation for a successful, STRONG EUROPEan Union. The enlargement is a success and integration proceeds further, both geographically, economically and politically. STRONG EUROPE is important for achieving broad international cooperation, not only in the area of trade but also in other areas like climate change.

In GLOBAL ECONOMY European countries find a new balance between private and public responsibilities. Increasing preferences of people for flexibility and diversity and a growing pressure on public sectors give rise to reforms. New institutions are based on private initiatives and market-based solutions. European governments concentrate on their core tasks, such as the provision of pure public goods and the protection of property rights. They engage less in income redistribution and public insurance so that income inequality grows. International developments also reflect increasing preferences for diversity and efficiency. Political integration is not feasible as governments assign a high value to their national sovereignty in many areas. Economic integration, however, becomes broader (not always deeper) as countries find it in their mutual interest to remove barriers to trade, invest and migrate. With a limited amount of competences and a focus on the functioning of the internal market, the European Union finds it relatively easy to enlarge further eastwards. Similarly, the negotiations in the WTO are successful. As international cooperation in non-trade issues fails, the problem of climate change intensifies, while European taxes on capital income gradually decline under tax competition.

In TRANSATLANTIC MARKET European countries limit the role of the state and rely more on market exchange. This boosts technology-driven growth. At the same time, it increases inequality in this scenario. The inheritance of a large public sector in EU-countries is not easily dissolved. New markets, e.g. for education and social insurances, lack transparency and competition, which brings new social and economic problems. The elderly dominate political markets. This makes it difficult to dismantle the pay-as-you-go systems in continental Europe. Government failures thus compound market failures. EU member states primarily focus on national interests. Reforms of EU-decision making fail which renders further integration in the European Union difficult. The European Union redirects her attention to the United States and agrees upon transatlantic economic integration. This intensifies trade in services and yields welfare gains on both sides of the Atlantic. The prosperity in the club of rich countries is in sharp contrast to that in Southern and Eastern Europe and in developing countries.

In REGIONAL COMMUNITIES European countries rely on collective arrangements to maintain an equal distribution of welfare. At the same time, in this scenario governments are unsuccessful in modernising welfare-state arrangements. A strong lobby of vested interests blocks reforms in various areas. Together with an expanding public sector, this puts a severe strain on European economies. The European Union cannot adequately cope with the Eastern enlargement and fails to reform her institutions. As an alternative, a core of rich European countries emerges. Cooperation in this sub-group of relatively homogeneous Member States gets a more permanent character. The world is fragmented in a number of trade blocks and multilateral cooperation is modest.

Source: CPB (2003)

It is not only economic growth that determines energy demand. Structural shifts are also of importance. There is a large difference in energy intensity by economic activity. Service sectors use relative small amounts of energy per unit value-added[6]. In all scenarios the services sector gains importance in all regions. However, there are differences among scenarios. In GLOBAL ECONOMY for instance, the shift is most pronounced[7].

Table 2.1 **Driving forces behind energy markets in four long-term scenarios**

	STRONG EUROPE	TRANSATLANTIC MARKET	REGIONAL COMMUNITIES	GLOBAL ECONOMY
Economy				
Macroeconomic growth	+	+	0	++
Structural shift towards services	+	+	+	++
Energy Technology				
Autonomous Energy Efficiency Improvements	+	+	++	++
Conversion efficiency	0	0	+	+
Nuclear	-	+	-	0
Renewables	+	-	+	-
Coal	-	0	--	-
Geopolitical situation*				
Relation EU – Russia / Middle-East	++	-	+	++
Relation EU – USA	+	++	+	++
Environmental policy*				
Global climate change policy	+	0	0	0
National environmental policies	+	0	+	0
Competition policy*				
Competition at energy markets	+	++	+	++
International transportation capacity	++	0	+	++
Policies regarding security of supply*				
Regulation of storage of oil and natural gas	+	++	++	+
Regulation of electricity generation capacity	++	+	++	+

A '+' sign implies a moderate growth or improvement, a '++' sign implies strong growth or improvement, a '0' sign implies low growth or absence of policy, a '-' sign implies deterioration or phasing out.

Table 2.2 **GDP per region per scenario (average annual % change in 2000-2040)**

	1980-2000	STRONG EUROPE	TRANSATLANTIC MARKET	REGIONAL COMMUNITIES	GLOBAL ECONOMY
EU15	2.2	1.5	1.9	0.6	2.4
USA	2.9	1.8	2.5	1.4	2.6
Non-OECD	2.3	4.2	2.0	3.4	4.6
World	2.7	2.5	2.3	1.8	3.1

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[6] In 2000 energy input in services in Europe is about 80 toe per million $ value-added. The average over all sectors is 650 toe per million dollar value-added.

[7] Differences across scenarios are to a large extent related to per capita GDP growth. Higher income per capita leads to a larger share of services in household consumption.

Table 2.3 **Services value-added in 2000 and 2040 (%GDP, excluding taxes)**

	2000	STRONG EUROPE 2040	TRANSATLANTIC MARKET	REGIONAL COMMUNITIES	GLOBAL ECONOMY
EU15	73	82	83	81	85
USA	78	86	87	86	88
Non-OECD	56	73	66	68	74
World	71	79	80	78	82

Energy technology

Improvements in energy technology are major factors in determining future energy demand. Needless to say there are fundamental uncertainties concerning technological progress. Technology improvements can occur at different stages of the production processes to deliver end-use energy services. Power plants can become more efficient in the production of electricity from coal or gas, firms and household may use heat (including transport fuels) and electricity in a more efficient way.

The technology improvements at the end-use stage are caught by the so-called Autonomous Energy Efficiency Improvements (AEEI). In GLOBAL ECONOMY these improvements occur at a highest rate to generate the highest productivity growth rates. In REGIONAL COMMUNITIES the improvements are driven by society's preferences to stabilise on energy use in order to avoid local environmental externalities from energy use and reduce the dependency on foreign imports. In STRONG EUROPE the improvements occur at a lower rate because the world is less focused to solve for any local environmental problems and the climate policy accounts for the necessary reductions of the energy intensities. Finally, TRANSATLANTIC MARKET lacks an environmental drive to enhance production processes in terms of energy productivity. In the non-OECD, the AEEI grows at higher rate than in OECD, mainly through their current inefficient use of energy, thus leading to catching-up of their productivity to OECD levels. This especially true in GLOBAL ECONOMY where 'openness' allows for technology spill-overs. Conversion efficiencies in the electricity sector follow the pattern of the AEEI. An exception is TRANSATLANTIC MARKET, which assumes fewer improvements as compared the AEEI.

We assume no major breakthroughs in energy technology. Hydrogen based fuel cells show great promise for the future, but large scale application requires sharp cost reductions and dramatic technical advances, and hence we have chosen it not to play a major role in our scenarios. Carbon-sequestration could also change the energy picture. Low cost options could strengthen the role of coal in future power generation. However, it is assumed to be of little importance in the scenarios. Only climate policy will entail higher costs for fossil energy, and hence boosts this option to limit the CO_2 emissions in STRONG EUROPE. However, some shifts in technology do happen. Energy production is subject to learning and this determines the cost of production, and hence drives the market share of specific technologies. Technologies will become cheaper as they are applied more intensively and get larger markets shares. Renewable energy (wind solar) and biomass pushed as an alternative in STRONG EUROPE and REGIONAL COMMUNITIES will become more competitive. In TRANSATLANTIC MARKET the use of coal, as an alternative way to satisfy energy demand, leads to downward shifts in the learning curve. Nuclear energy has a limited role to play. In STRONG EUROPE and REGIONAL COMMUNITIES the perceived risks prevent the further use of nuclear energy in electricity production. Nuclear energy is phased out. In GLOBAL ECONOMY intense international relations, provide sufficient alternatives for scarcer conventional oil. There is no direct need for an increased role for nuclear energy. Only in TRANSATLANTIC MARKET with problematical supply of oil and gas from traditional suppliers, there is potentially an increased role for nuclear, although this is counterbalanced by the expansion of coal through its high learning rate.

Geopolitical situation

Geopolitical situations are rather harmonious in STRONG EUROPE and GLOBAL ECONOMY due to the global orientation in these scenarios. As a consequence, good relations exist between the Western countries as large energy consumers and the Eastern countries, especially Russia and the Middle-East region. In STRONG EUROPE however, climate policy affects negatively relations between countries which are highly dependent on exports of oil and the developed world. As climate policy results in a decline in global oil consumption, oil producing countries face a deterioration of their government budget and hence their opportunities for economic development.

In TRANSATLANTIC MARKET, Europe and the United States prefer their mutual cooperation above cooperation with other regions. Political relations between energy consuming and energy producing regions are rather unstable. Governments in the Western countries, therefore, aim at reduction of their import dependency on oil and natural gas. Alternative sources of energy, like nuclear power generation and fuel cells, become more important within the supply of energy.

Environmental and energy policies

A solid global climate policy is only conceivable in STRONG EUROPE, as this is the only scenario which combines global cooperation with environmental orientation (see also Chapter 6). In this scenario, we assume climate policy in accordance with the EU long-term climate objective to keep average global warming below 2 °C[8]. This asks for swift and global action to limit the emission of greenhouse gases. To assure lowest global costs, a cap-and-trade system can be seen as an efficient instrument. Crucial for the distribution of costs is the allocation of emission permits over regions (burden sharing). We assume that after the first budget period of the Kyoto Protocol (2012) a global agreement is reached in which all regions accept assigned amounts of emission rights. In other scenarios it is assumed that Kyoto will water down and no effective restrictions on the use of energy in Europe will take place.

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[8] This target is translated in emission profiles resulting into a stabilisation of CO2-equivalent concentration at 550 particles per metric volume (ppmv) target in 2100.

Environmental policies in REGIONAL COMMUNITIES consist mainly of domestic and regional measures directed to non-climate environmental issues (acidification, emissions of small participles, and depletion of the ozone layer). The other two scenarios do not show any significant environmental policy.

TRANSATLANTIC MARKET and GLOBAL ECONOMY show fierce competition policies, leaving production, transport and trade of energy for private firms. The role of governments in energy markets is restricted to regulation of competition. On the contrary, STRONG EUROPE and REGIONAL COMMUNITIES face rather strong governmental influences in the supply of energy. In addition, due to the absence of fierce competition policy, private firms will obtain significant market power in these scenarios by means of explicit (mergers) or tacit forms of collusion. Competition in TRANSATLANTIC MARKET is however not perfect, as it is in GLOBAL ECONOMY, because of (geopolitical) restrictions on capacity (pipelines and so on) for international transport of energy.

The issue of security of supply is important in REGIONAL COMMUNITIES, due to the restricted opportunities for international trade and the political distrust in the ability of market forces to arrange a secure supply of energy. Policies in this field consist of regulations regarding storage of oil and natural gas and regarding (spare) capacity for the generation of electricity. On the contrary, in GLOBAL ECONOMY hardly any attention is paid to this issue since the excellent international relations and efficient organised markets are believed to secure supply of energy.

In all scenarios, EU policies currently in place will remain unchanged. These policies include among others further development of the liberalised electricity and gas markets in the EU. Moreover, all scenarios assume further improvement of energy technologies, preservation of current levels of energy fuel taxation in real terms, extension of natural gas supply infrastructure and stringent regulation of acid rain pollutants.

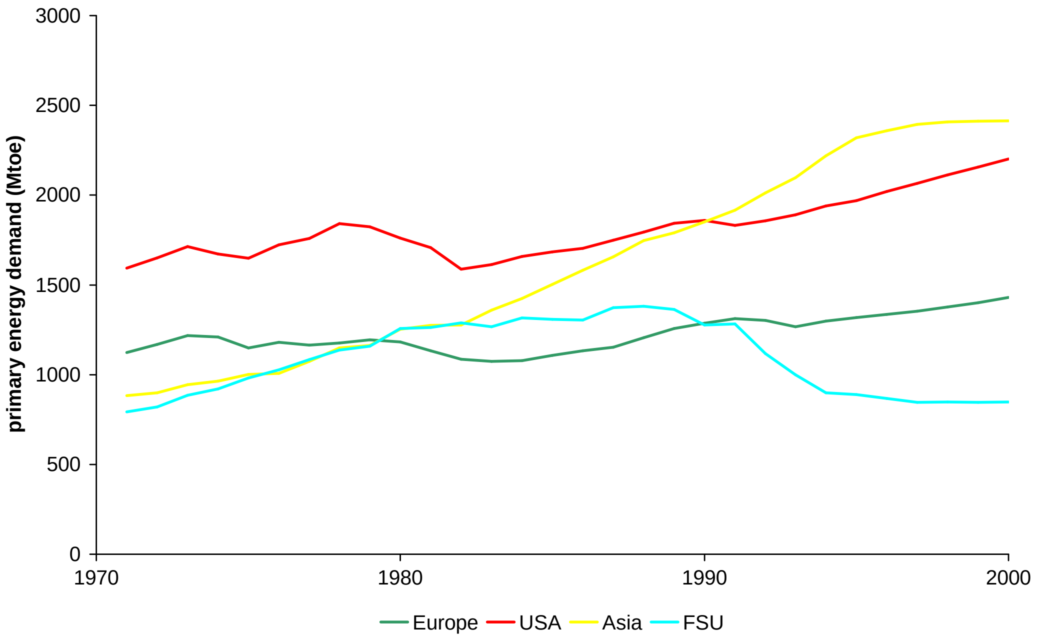
3 Use of energy

Total primary energy use can be projected to rise in the coming decades, despite the fact that energy use per unit of output decreases with higher output levels. Increased efficiency and structural shifts are important determinants for the improvement in energy intensities. In Europe growth in energy demand lags far behind energy demand in developing regions

3.1 Economic development and the use of energy

This chapter describes the development of energy demand in the four scenarios. Total energy use will continue to grow. Not only in advanced societies, but even more rapid growth can be expected in developing countries. Demand for energy has been rising in the past. Figure 3.1 shows demand for primary energy in a number of regions in the period 1970-2000[9]. Where industrialised countries showed a moderate growth, developing countries took the lead with a growth rate almost double the world average. The economic recession in the Former Soviet Union and Eastern Europe had a downward pressure on energy demand.

Figure 3.1 Primary energy demand in selected regions, 1971-2000



Energy use is driven by population, economic growth and technology. We factor energy demand into output and energy per unit of output, the energy intensity[10]. The energy-intensity,

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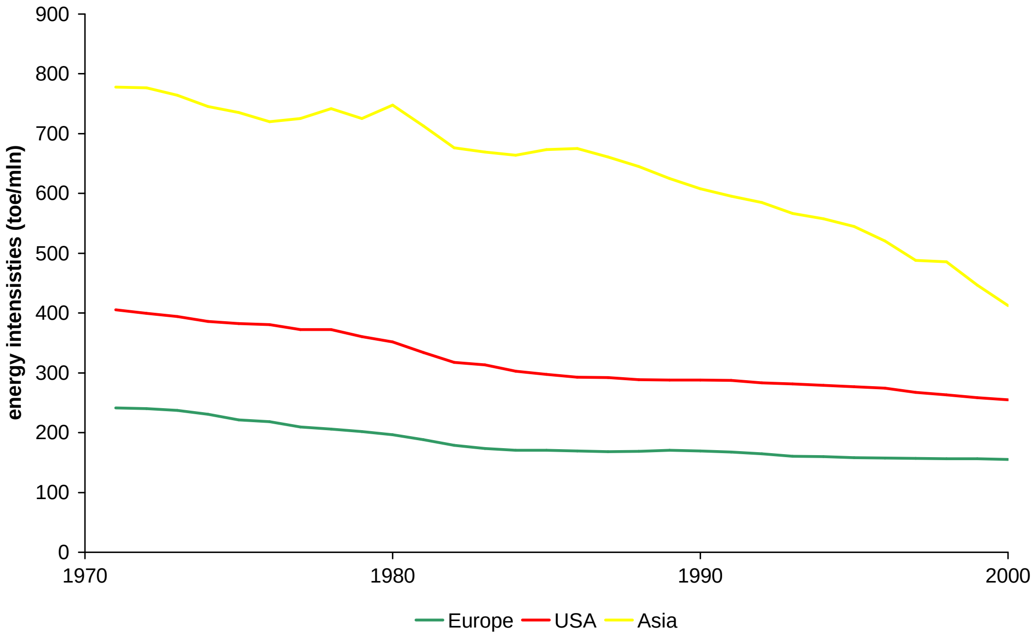
[9] Figure 3.1 shows primary energy demand, including traditional bio fuels like wood. This energy source is of importance in Asia and Africa, although its share can be expected to decline in the future. Correcting for this source lowers the demand for Asia considerably, but the pattern of high growth remains intact.

[10] Energy demand (E) can be decomposed in population (POP), output per capita (GDP/POP) and energy intensity (E/GDP), the so-called KAYA-identity E = POP x (GDP/POP) x (E/GDP).

for its part, depends on the price of energy, relative to other inputs in production, and on (exogenous) technological change. Structural effects are important. An economy with a strong shift towards services sees a large drop in energy-intensity and a corresponding moderate growth in energy use. In general, a positive relation exists between economic growth and structural shifts towards the service sector. Consequently, economic growth decreases energy intensity by means of structural changes. In addition, economic growth coincides with a higher level of investments raising the level of energy efficiency.

Figure 3.2 illustrates the development of energy intensities in Europe, the US and Asia between 1970 and 2000.

Figure 3.2 **Energy intensities in selected regions, 1971-2000**



Large differences exist between energy intensity among regions. In general, rich countries have lower energy intensity than less developed regions. Energy efficiency tends to decrease with economic development. A lower energy use per unit of output reflects adoption of more efficient technologies as well as shifts towards less energy intense activities. In Europe and the US improvement in energy intensity appears to be strongest in the seventies and eighties. In later years this change is less pronounced. This strong decline in energy intensity reflects the strong efficiency gains in the wake of high energy prices. With economic growth energy intensities can be seen to improve over time; rich countries have lower energy intensities and from development over time, one can see that with economic growth energy intensity decline, both in rich and poor countries. Still as Figure 3.1 shows, rich countries use more energy per capita than poorer societies.

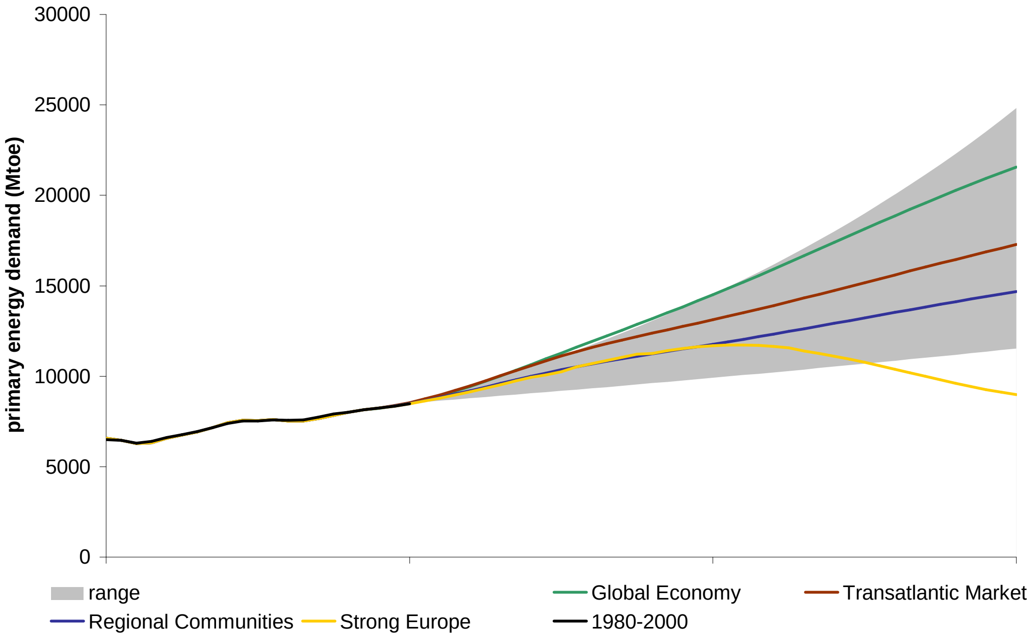
To explain energy use, two trends interact. Higher output drives up energy demand. Economic development leads to improvement in energy efficiencies. The former trend dominates and total energy use can be expected to rise.

3.2 Energy demand

Global energy demand

Figure 3.3 shows the development of global primary energy demand in the four scenarios. The historical growth in the period 1980-2000 is also shown[11]. The grey band shows the range of recent scenarios from the literature review.

Figure 3.3 Global primary energy demand, 1980-2040



All scenarios, except for STRONG EUROPE, show a prolonged growth in energy demand. GLOBAL ECONOMY sees the largest increase with an average annual growth of 2.3%. In STRONG EUROPE, the use of energy hardly grows. Initially there is still some growth. However, the introduction of a fierce climate policy results in trend reversal. After the first budget period of the Kyoto Protocol, emissions targets becoming more and more binding. Taxes on the use of carbon rise from 25 to 450 dollars per ton carbon in 2040. As a consequence, there is a strong substitution away from energy.

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[11] Traditional biomass in not included. This affects the annual growth rates, especially in non-OECD regions. In 2000 traditional biomass accounted for 21% of total primary energy. Its share is expected to decline to a mere 7% in the future.

Table 3.1 **Use of primary energy (average annual % change in 2000-2040)**

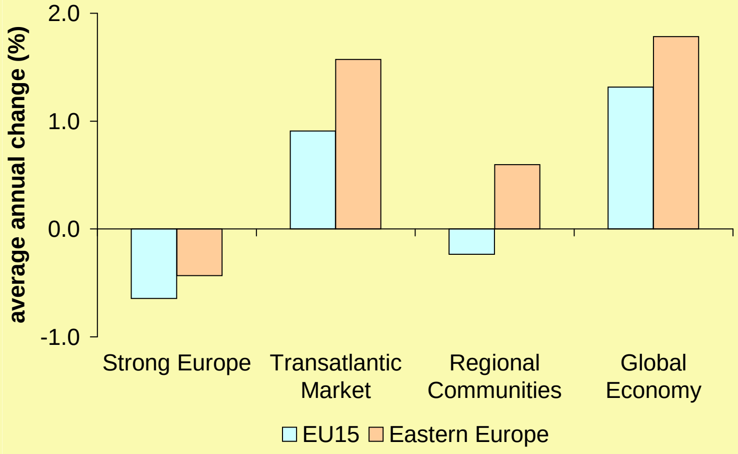
	1980-2000	STRONG EUROPE	TRANSATLANTIC MARKET	REGIONAL COMMUNITIES	GLOBAL ECONOMY
EU15	1.0	– 0.6	0.9	– 0.2	1.3
USA	1.1	– 1.1	1.1	0.2	0.8
Non-OECD	1.5	0.9	2.4	2.3	3.2
World	1.3	0.1	1.8	1.4	2.3

Regional energy demand

There are large differences between regions. Table 3.1 shows the development of the demand for primary energy in the four scenarios by region for Europe, the USA and non-OECD regions. To put the figures in perspective, historical trends are also provided in the table. Considerable differences exist between industrialised regions and development countries. Non-OECD regions show the strongest growth in energy demand in all scenarios.

New member states

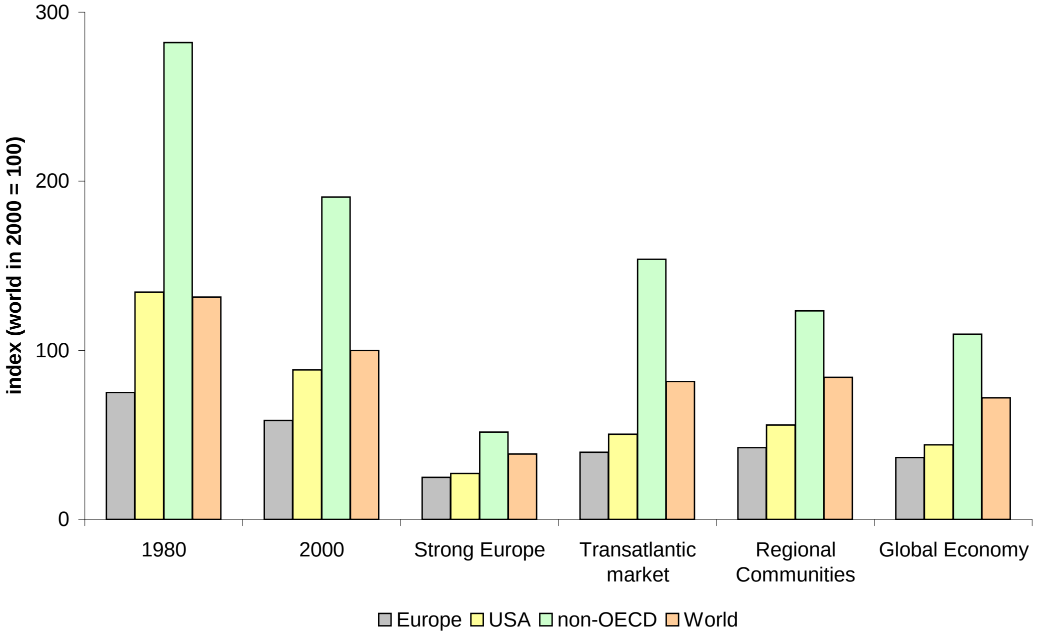
In 2004 ten new member states will join the European Union. Although, the focus in this study is especially on the old member states (EU15), one might ask the question, how will energy markets in the new member states develop? Of course, this depends on the starting position of these member states and on the development of the main driving forces. We take Eastern Europe (Poland, Czech Republic, Slovakia, Hungary, the Baltic States, Romania and Bulgaria) as a proxy for the new member states. In 2000 energy use per unit of demand in Eastern Europe is almost five times higher than in the EU15. This leaves much room for improvement in the coming decades. On the other hand, output per capita in Eastern Europe is much lower. In our scenarios the higher growth in Eastern Europe outpaces the stronger improvement in energy intensity: energy demand grows at a higher rate in Eastern Europe than in Western Europe.



3.3 Energy intensities

Differences in energy demand can be partially explained by differences in energy intensity. Table 3.2 presents energy intensities for the period 1980-2040. The energy intensity for the world as a whole in 2000 is indexed at 100.

Figure 3.4 **Energy intensities by region in 1980, 2000 and in the four scenarios in 2040**



There are large differences between regions. Europe has the lowest energy use per output, non-OECD the highest. These energy intensities reflect a number of underlying factors, including energy efficiencies and economic structure. A country that is highly efficient in all sectors, like the Netherlands, may specialise in heavy industry and still come up with high energy intensity. Also the question how much of the economic activity within a country is captured in income estimates is relevant. Developing countries quite often have a high share of energy intensive activities for which the economic activity does not show up in the official GDP. This causes an upward bias in non-OECD indices.

Between 1980 and 2000 energy intensities fall in all regions. Table 3.2 presents annual changes in energy intensity for these regions in the period 1980-2000 and for the scenarios. In the OECD the average decrease was about 1.4% per year, resulting mainly from a high energy conservation rate (about 1.4% per year). This high rate was driven mainly by high energy prices in the 1980s and government policies to increase savings in the use of energy. In fact, energy intensity improvement rates were above 2.0% per year during the 1980s. As conservation rates fell in the 1990s also the primary energy intensity improvement rate declined to 1.0% per year. A second factor contributing to the improvement of energy intensity has been the steady declines in energy production, in particular in the electric power sector. The non-OECD countries historically show a wide range of energy intensity trends, with sharp declines in some countries (e.g. almost 5% in China resulting from strong efficiency improvements and rapid sectoral change) but increasing nearly constant intensities in others (as a result of opposing trends of efficiency improvement and industrialisation).

Table 3.2 Energy intensity per region per scenario (average annual % change in 1980-2000 and in 2000-2040)

	1980-2000	STRONG EUROPE	TRANSATLANTIC MARKET	REGIONAL COMMUNITIES	GLOBAL ECONOMY
Europe	– 1.4	– 2.1	– 1.0	– 0.8	– 1.2
USA	– 1.8	– 2.9	– 1.4	– 1.1	– 1.7
Non-OECD	– 0.8	– 3.3	– 0.5	– 1.1	– 1.4
World	– 1.5	– 2.4	– 0.5	– 0.4	– 0.8

This downward trend is projected to continue in all four scenarios. However, the improvement rate in Europe is in most scenarios less than the 1980-2000 rate. This is the result of lower energy prices (and thus lower conservation rates). Moreover, in all scenarios the sectoral change towards the services sector slows down during the 2000-2010 period – which also has a negative impact on the rate of intensity improvement. STRONG EUROPE is a special case. Energy intensities fall at a much stronger rate due to stringent climate policy. Especially in STRONG EUROPE drops in energy use can be explained by substitution Climate policy levies a tax on the use of fossil energy. Production sectors substitute other inputs for expensive energy. In GLOBAL ECONOMY average energy intensity improvement is 1.2% - which, compared to the other scenarios is a result of stronger trends towards less energy-intensive industries but also stronger efficiency improvement in electric power generation. These developments follow partly from the rising energy prices (see Chapter 4).In REGIONAL COMMUNITIES the energy intensity improvement is particularly low as the lower economic growth rates does not lead to a similar decline in demand for energy-services.

Compared to Europe, energy intensity improvement rates are generally somewhat higher in the USA which can be mainly explained by the higher base year value, giving more room for improvement. Again, for non-OECD countries the situation is diverse, with an improvement rate of 3.3% in STRONG EUROPE, as result of climate policies, but only ranging from 0.5-1.1% in the other scenarios. Important factors here are sectoral changes (mostly from industrial to service economy having a strong downwards influence on energy intensity), fuel shifts (from traditional fuels to commercial fuels, from coal to oil and natural gas, in both cases resulting in declining intensities) and technology improvement. In Europe and in the USA, the decrease in energy-intensity in STRONG EUROPE is low compared to other regions. The main reason is that the OECD buys its way out, i.e. with a global market for emissions permits, industrialised regions will pay other, developing regions to comply with its targets. In return, the sellers of emission permits reduce emissions below their targets, their energy intensities fall the most.

Structural effects play an important role in explaining shifts in energy intensity. Services sectors use considerably less energy per unit of output than heavy industries. The more societies become service oriented, the stronger the downward bias on energy-intensities. There are differences between scenarios. Except for in STRONG EUROPE, energy intensities match the share of services rather well (see Table 2.3). In GLOBAL ECONOMY the share of services is the highest, energy intensities are among the lowest. In non-OECD regions services are least important in TRANSATLANTIC MARKET, accordingly, energy intensity is the highest.

Of course there is more to explain shifts in intensities. Technological progress is another important driving force behind declining energy intensities. Production sectors tend to use less energy per unit of out put as economies expand. This so-called Autonomous Energy Efficiency Improvement (AEEI) is assumed to vary only slightly between the scenarios. For OECD regions, this AEEI ranges from 0,8% per year in STRONG EUROPE to 0.6% in GLOBAL ECONOMY. Non-OECD regions are assumed to have a somewhat higher AEEI.

3.4 Carbon intensities

From the previous section we know how the fossil energy markets will develop. Below, the consequences are illustrated of the contribution of the demand for fossil energy to emissions of greenhouse gases, i.e. we show the carbon intensity for different scenarios.

Table 3.3 Carbon Intensity (average annual % change in 2000-2040)

	1980-2000	STRONG EUROPE	TRANSATLANTIC MARKET	REGIONAL COMMUNITIES	GLOBAL ECONOMY
Europe	– 0.4	– 0.6	– 0.1	– 0.5	– 0.1
OECD	0.0	– 0.9	– 0.1	– 0.5	– 0.1
Non-OECD	– 0.3	– 0.6	0.0	– 0.3	– 0.1
World	– 0.2	– 0.7	0.0	– 0.3	0.0

Historically, the global carbon intensity declined, mainly through the phase-out of coal in the energy mix in the OECD, which accounted for almost 60 percent of the global CO_2 emissions. In STRONG EUROPE this declining trend will be pursued through the climate policy that will result in emission reductions in especially the non-OECD region through emissions trading (what’s more important, energy reductions or fuel switches?). In REGIONAL COMMUNITIES there will be no climate policy, but the willingness of countries to internalise the costs of local environmental problems such as local ambient health problems and acidification will cause countries to especially reduce the use of coal. In both the TRANSATLANTIC MARKET and the

GLOBAL ECONOMY there is no environmental awareness, and hence carbon intensities will grow at a low rate.

Underneath the global developments lie different patterns evolving in both the OECD and the Non-OECD region. The order of the changes of the carbon intensity across scenarios is the same, but the Non- OECD region will reduce the carbon intensity at a lower rate than the OECD, and even the sign of the rate of change differs. Whereas the OECD will remain pushing to reduce the carbon intensity in all scenarios (except for the TRANSATLANTIC MARKET scenario), on the other hand the non-OECD region will increase their carbon intensity. The reason is that in the OECD coal will be phased out of the economy through protocol agreements on acidification, and the less carbon-intensive fuels such as gas become more important. The carbon intensity improvements by the non-OECD region lie below those of the OECD, because the non-OECD region will expand their production capacity at a much higher rate than the OECD. And this in turn implies more reliance on traditional fossil fuels of the Non-OECD region compared to the current demand for these fuels. The OECD will increase their carbon intensity in the TM scenario as opposed to the declining trend in the GLOBAL ECONOMY scenario due to limited possibilities to import oil, and hence the price differential between the locally produced coal and globally traded oil will widen in favour of coal.

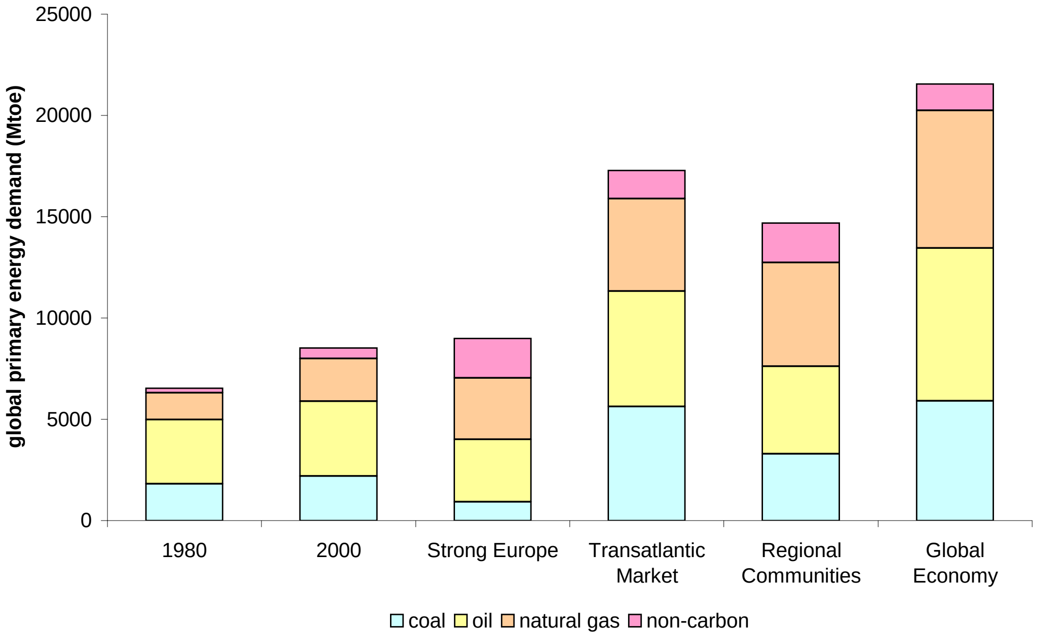
The carbon intensity changes in the EU will follow the OECD average, but lie in GLOBAL ECONOMY and STRONG EUROPE above the OECD average because the current fuel-mix in the EU is less carbon-intensive.

3.5 Energy demand by carrier

Figure 3.4 shows the global use of primary energy by carrier in the four scenarios. For each scenario the demand in 2040 for coal, oil, gas and the broad aggregate of non-carbon fuels is shown. Also, a decomposition of primary energy along the same lines is presented for 1980 and 2000 to put future developments in perspective.

STRONG EUROPE shows the largest changes. Not only the historic rising trend reverses, there also is a strong shift from carbon intensive to carbon extensive fuels. Gas is a substitute for coal; biomass and renewables are substitutes for all fossil fuels. Climate policy and its corresponding carbon tax bring about these radical changes. All scenarios show a rising share of natural gas in total primary energy demand, both in absolute and in relative terms. Biomass and renewables become more and more important over time. Although not as dramatic as in STRONG EUROPE, but even in TRANSATLANTIC MARKET the demand for these fuels doubles. Oil becomes less important. Its share in primary energy demand declines in all scenarios. Here, we restrict ourselves to these general remarks. More specific developments dealing with gas and oil will be dealt with in Chapter 4.

Figure 3.5 **Global use of primary energy use in the four scenarios**



3.6 The whole picture

This study is about future energy developments and its impacts on natural resources. Table 3.4 summarises some of the elements determining future energy demand and emissions. In this table energy and emissions are decomposed along the Kaya-identity. The table shows annual rates of change of GDP, energy intensity and carbon intensity. The resulting changes in energy demand and energy-related CO_2 emissions are also given[12]. In this way, Table 3.4 brings together the different elements, as discussed in earlier sections.

Energy use is driven by economic growth and developments in energy intensity. A high GDP-growth tends to be accompanied by a relative strong drop in energy intensity. Many factors determine the decrease in energy intensities. The ongoing shift towards more service oriented economies leads to a downward bias on energy intensities. Furthermore, technological change leads to more efficient use of energy. Prices also matter. A stringent climate policy drives up (fossil) energy prices and induces a substitution of energy for less expensive inputs.

Projections for the average annual growth rate of energy demand range between 0.1% and 2.3%. This means that in a high growth scenario, like GLOBAL ECONOMY, energy use may quadruple in the next 40 years. In a modest growth scenario, like REGIONAL COMMUNITIES, demand still doubles. Effective climate policy, inherent in STRONG EUROPE, ultimately leads to a trend reversal. Energy demand in 2040 hardly exceeds demand in 2000.

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[12] Emissions will be dealt with in Chapter 5 more comprehensively.

Greenhouse gas emissions follow energy demand closely. STRONG EUROPE is the exception. In this scenario, energy and emissions drift apart as a result of a climate policy in line with the long term goal of the European Union. High carbon taxes will lead to fuel-switching.

There are large differences over regions. Developing countries will catch up in the next decades. This will make them the largest consumers of energy and at the same time the largest source of greenhouse gas emissions. While in 2000 almost half of global energy demand comes from OECD-countries, in 2040 this share decreases to a mere on-third.

Table 3.4 Elements of the KAYA-identity, World 1980-2000 and 2000-2040 (annual growth rates)

	1980-2000	STRONG EUROPE	TRANSATLANTIC MARKET	REGIONAL COMMUNITIES	GLOBAL ECONOMY
GDP	2.7	2.5	2.3	1.8	3.1
Energy intensity	– 1.5	– 2.4	– 0.5	– 0.4	– 0.8
Carbon intensity	– 0.2	– 0.6	– 0.1	– 0.3	0.0
Energy use	1.3	0.1	1.8	1.4	2.3
Emissions[a]	1.2	– 0.5	1.7	1.1	2.3

[a] Energy related CO2 emissions

Table 3.5 presents similar numbers for Europe. Growth in European energy demand falls short of global demand. This is due to lower GDP-growth and stronger improvements (stronger decline) in energy intensity. STRONG EUROPE is the exception. As a result of the outsourcing of the emission abatement to developing countries, energy intensities in Europe decrease less than the world average.

Table 3.5 Elements of the KAYA-identity, Europe 1980-2000 and 2000-2040 (annual growth rates)

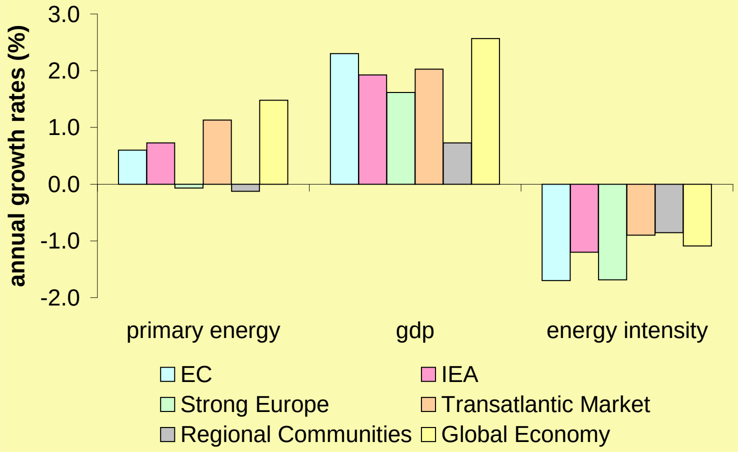
	1980-2000	STRONG EUROPE	TRANSATLANTIC MARKET	REGIONAL COMMUNITIES	GLOBAL ECONOMY
GDP	2.2	1.5	1.9	0.6	2.4
Energy intensity	– 1.4	– 2.1	– 1.0	– 0.8	– 1.2
Carbon intensity	– 0.4	– 0.6	– 0.1	– 0.5	– 0.1
Energy use	1.0	– 0.6	0.9	– 0.2	1.3
Emissions	0.6	– 1.3	0.8	– 0.7	1.2

Our scenarios compare quite well with scenarios from the literature as reviewed in Chapter 2 (in particular, Figure 2.1). Developments in European GDP, energy and carbon intensities fall well within the range presented there. In general, improvements (declines) in carbon intensities seem to be rather low. Our scenarios explicitly do not expect major breakthrough in energy conversion. Hence the role of non-carbon fuels remains limited. Compared to our scenarios, the EU reference scenario seems rather optimistic with relative high GDP-growth and strong declines in energy intensities (see also text box).

Four Futures compared with IEA and EU

Recently, IEA produced its World Energy Outlook 2002. For the first time, projections for the European Union were made. In 2003, the European Union made an assessment of energy and transport trends up to 2030. It is informative to compare our scenarios with these recent baseline projections. The figure shows annual growth rates for the period 2000-2030 for the EU baseline (EC), the IEA outlook, and for our four scenarios.

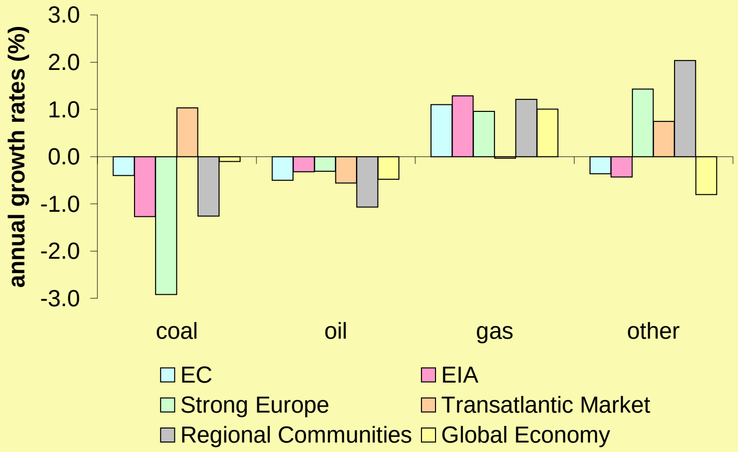
Primary energy, GDP and energy intensity according to EC, IEA and Four Futures



Primary energy demand in EC and in IEA grows at a similar rate. However, the main determinants, GDP and energy intensity, show quite different patterns. Compared to IEA, EC is more optimistic about GDP-growth and improvements in energy intensity. Our scenarios show large variation in GDP growth, with GLOBAL ECONOMY exceeding both EC and IEA and REGIONAL COMMUNITIES dropping far behind. Improvements in energy intensity lag behind EC and IEA projections, with the exception of STRONG EUROPE. As a result GLOBAL ECONOMY and TRANSATLANTIC MARKET show a higher growth in energy demand than EC and IEA. STRONG EUROPE and REGIONAL COMMUNITIES hardly show any growth at all for EU15.

All scenarios show an increase in the share of gas and a decline in the share of coal and oil. TRANSATLANTIC MARKET is the exception. Gas demand (and oil demand) in this scenario lags behind, in favour of coal. The aggregate of non-carbon energy gains importance in STRONG EUROPE, TRANSATLANTIC MARKET and REGIONAL COMMUNITIES, but its share declines in IEA, EC and GLOBAL ECONOMY.

Share of Coal, oil and gas according to EC, IEA and Four Futures



4 Energy markets

In line with the four scenarios, we sketch future paths for supply and demand of oil, natural gas and electricity. Within the next decades, depletion of conventional oil and natural gas is not expected. However, European import dependency will grow. Production of oil will concentrate more and more in the Middle-East. The Former Soviet Union and Northern Africa will become Europe's main suppliers of natural gas. Dramatic price increases are not projected.

4.1 Introduction

The key question regarding energy markets in the long term concerns the availability of energy. This availability is challenged by economic growth as the latter coincides with increasing demand for energy while most energy is still derived from non-renewable resources. Consequently, economic development affects the physical amount of fossil fuels available for mankind. Less clear, however, is whether economic growth diminishes the economic availability of energy carriers. Will prices of fossil fuels rise as result of depletion in the next decades, or will technological improvements and substitution within demand for energy compensate for the depletion effect on energy prices? This question will be answered for the (global) oil market (Section 4.3) as well as the (European) natural gas market (Section 4.4). In both sections, attention is paid to climate policies and its impacts on demand for energy and prices of fossil fuels.

The final section of this chapter is dedicated to the electricity market. As electricity is a secondary energy carrier, depletion is not at stake here. The core questions regarding this market are by which techniques and fuels electricity will be produced and how the price of this energy carrier will develop.

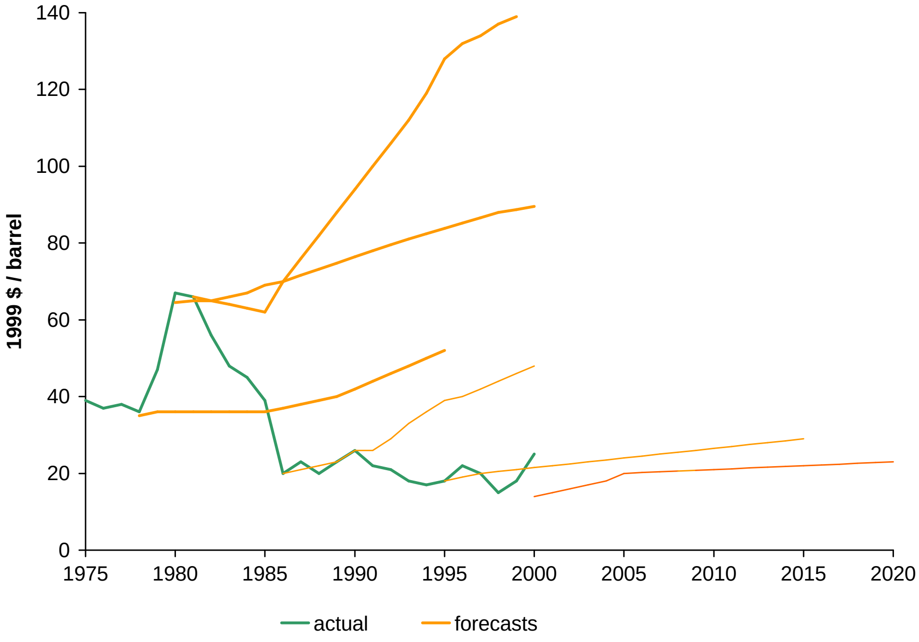
Before we will answer these questions, a reflective section is put in. This chapter starts with an analysis of forecasts made in the past in order to derive some lessons for our scenarios.

4.2 Lessons from past predictions

Most pas scenario studies regarding energy markets focussed on the oil market, while scenarios of the natural gas and electricity market are relatively scanty and only have appeared recently. The bulky literature containing forecasts and scenarios of the global oil market offers a good opportunity to learn from past research. What is the track record of the forecasts produced in the past? Which factors explain differences between forecasts and real figures?

To start with the first question: oil market forecasts made in the past decades show a very poor track record. Most price forecasts have been much higher than the actual levels. Huntington (1994) reports that almost all oil market models over predicted the actual oil price strongly the actual real oil price in 1990 was no more than one-third of projections made at the beginning of 1980s. Lynch (2002) shows, as an example, the evaluation of oil price forecasts made by the US Department of Energy (DOE) (see Figure 4.1). All DOE forecasts produced since the late seventies expected rising oil prices. At the top of the price peak in 1981, DOE forecasted a price of 140 dollars a barrel for the year 2000. Since then, the forecasts have continuously been lowered. In 1990, DOE expected an oil price of more than 40 dollar in 2000. As we know now, the actual oil price in 2000 was about 20 dollars per barrel. The latest forecast of DOE shows an oil price of 25 dollars in 2020.

Figure 4.1 **Oil prices: forecasts of the US Department of Energy (DOE) and actual levels**



Source: Lynch (2002)

The over prediction of oil prices presented by many oil market analysts followed mainly from underestimation of the price elasticity of both the consumption of oil and the supply from non-OPEC countries. As, according to Huntington (1994), the structure of most world oil models has not changed much, we should be aware of the “risk that the rising oil price path over the next decades being projected by many world oil models may simply an artefact of past biases – over predicting demand and under predicting supplies outside the cartel – carried further into the future”.

In a recent paper, Lynch confirms this conclusion by giving more evidence on largely over predicted oil prices. Most forecasters expected rising prices through the nineties, while "throughout most of the history of the oil industry, prices were mean reverting, around approximately $14 per barrel" (Lynch, 2002). The high-price forecasts followed partly from misinterpretation of the Hotelling rule, which states that net mineral prices (gross prices minus marginal costs) should rise at the real rate of interest. This rule is based on the neoclassical economic assumption that resource owners maximise the discounted profits from extraction and sale of the resource (Cleveland et al., 1999). In the oil market, however, the price was and is not determined by the marginal costs but by market power while the marginal costs of the marginal producers (in the Middle East) are almost zero. According to the Hotelling rule, this net price should rise with the real rate of interest which would result in a price path which is not justified by the real scarcity.[13]

The Hotelling rule could hold if the size of the mineral in the ground is limited and well known. As a matter of fact, both conditions are not satisfied. As Adelman (2002) states, "a mineral stock at any moment reflects current knowledge – science and technology – hence current costs. As knowledge and costs change, so must the stock, mostly up sometimes down." Reserves of minerals as oil are thus not limited, but endogenous. Moreover, the size of the reserves are all but perfectly known, which is illustrated by the fact that different types of reserves exist, each one characterised by the probability of occurrence.

Other sources for the high price forecasts are pessimism about resource availability and, again, systematic underestimation of non-OPEC production. Pessimism about availability of resources stems partly from the widespread Hubbert approach. This approach is entirely based on geophysical factors, comparing the ultimate recoverable resources (URR) with historical production. "Hubbert-type predictions of energy production assume there is a finite supply of energy that is measurable; however, estimates of resources and reserves are inventories of the amounts of a fossil fuel perceived to be available over some future period of time." (McCabe, 1998) Adherents of the Hubbert approach, such as Campbell (1997) and Bentley et al. (2003), expect that global production of oil will reach its peak within a relatively small number of years, after which production declines inescapably.

Estimates of URR are static, based on historical data, without giving sufficient attention to technological improvements raising the recovery factor of fields and decreasing the costs of depletion. Consequently, estimates of URR expand by time. Lynch finds an annual growth rate of the ultimate recoverable oil resources of 2%. Similar statements can be made regarding other primary energy resources. Stern (2002) concludes, in his research of the security of European natural gas supplies, that "despite substantial increases in production, most countries have greater – and some substantially greater – remaining reserves in 2000 than they did in 1981."

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[13] Despite its clear economic underpinning, the Hotelling rule has a poor value in explaining prices of resources in practice. One of the reasons for this is that "prices are often distorted as a consequence of taxes, subsidies, exchange controls and other governmental interventions." (Perman, et al., 1999). In addition, the Hotelling rule refers to the *net* price (i.e. market price minus marginal production costs), which is not directly observable.

Quoting McCabe (1998), we conclude, therefore, that “production histories of fossil fuels are driven more by demand than by the geological abundance of the resource”.

Another explanation for the tendency to overestimate future prices is the fact that the impact of depletion on production capacity is overstated. Using micro data on depletion and production capacity to predict macro production ignores the impact of new field discoveries and improved infrastructure and technology. Nearly all economic models have proved to be too pessimistic about the production of oil.

What lessons can be drawn from the past experiences with oil markets forecasts? Several authors conclude, including the above mentioned, that competition among producers and technological improvement will reduce the costs of extraction, counterbalancing the rising costs due to depletion. Moreover, the price sensitivity of demand will prevent a strong increase of the oil price in the medium and long term. Consequently, quoting again McCabe (1998), “there appears little reason to suspect that long-term price trends will rise significantly over the next few decades”. This view is getting more and more followers: “recently, an assumption of flat prices has become common in long-term forecasts”. (Lynch, 2002).

4.3 Oil market

4.3.1 Consumption

Figure 4.2 shows the global annual consumption of oil during the period 1980 - 2040. In the past two decades, oil consumption grew with an average annual rate of 0.8%. In the eighties, global consumption declined due to the high oil prices at that time. After the decline in the oil price in 1985, oil consumption rose again. The current level of global consumption of oil is approximately 75 million barrels a day.

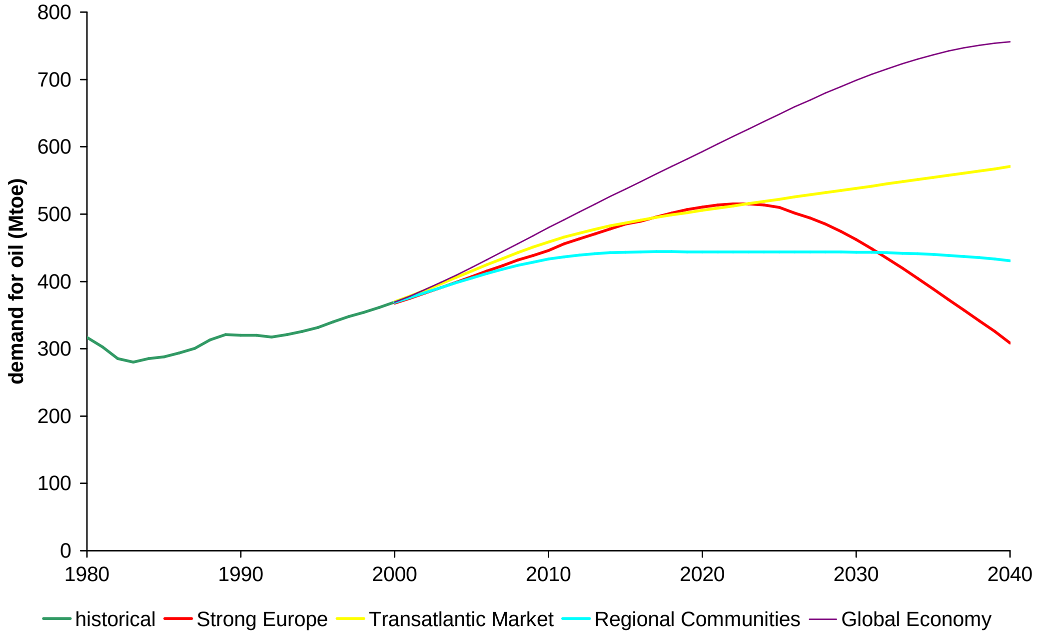
In GLOBAL ECONOMY, strong economic growth spurs the demand for all types of energy including oil. Global demand for oil reaches 155 million barrels a day in 2040, which represents an annual growth of 1.8%. TRANSATLANTIC MARKET, with a lower annual economic growth (see table 2.x) shows a global consumption of oil in 2040 of approximately 130 million barrels a day (1.4 % per year), while consumption in REGIONAL COMMUNITIES stays flat at a level of about 80 million barrels. The relatively low level of consumption in REGIONAL COMMUNITIES stems mainly from the low economic growth and national environmental policies.

Oil consumption in STRONG EUROPE increases in the first part of the period, but decreases later on to the current level of almost 80 million barrels in 2040 (i.e. a zero growth after four decades). The zero-growth in STRONG EUROPE is the result of the fierce environmental policy leading to high carbon taxes at the end of the scenario period (see figure 4.x). In the first half of this period, oil production in STRONG EUROPE is growing due to the economic growth, but afterwards production (and consumption of course) declines due the high end user prices.

4.3.2 Production

Figure 4.3 depicts the origin of the supply of oil historically since 1980 and in the four scenarios.[14] From 1980 to 2000, total production increased from 62 to 75 million barrels per day. The increase in global oil production in this period was mainly due to the fields in Europe (+140%), South America (+ 90%), Asia (+60%) and Africa (+33%). Production from the Middle-East region showed a small increase (+10%), while Russian production declined strongly (– 40%). The high oil prices in the eighties raised production from non-OPEC countries, decreasing the market share of the OPEC members. In the nineties, OPEC restored this loss of production. The decline in the Russian oil production resulted from the strong economic downturn in this country after structural political changes. These changes caused lower domestic industrial demand and a decline in drilling and capital investment. Following privatisation in the mid-1990s, Russia should see increases in production in the future. For a further increase in production, the oil sector needs substantial investments as the sector is plagued by aging equipment, poorly developed fields, and deterioration of transport infrastructure, as well as a confusing tax and legal environment.

Figure 4.2 **Consumption of oil; historically and in four scenarios, 1980-2040**



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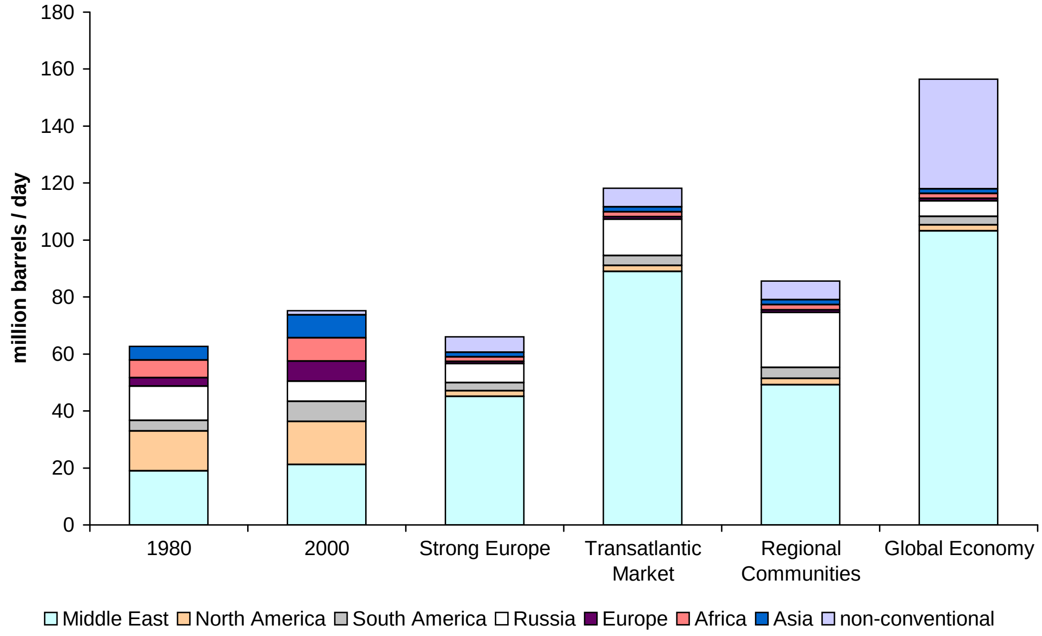
[14] Recall that future production is based on current proven reserves as well as undiscovered reserves. The former is, of course, insufficient to meet the production levels foreseen in these scenarios. As has been the case in the past, exploration activities add additional fields and additional oil from existing fields to the proven reserves. This dynamic process, in which the price of oil is a trigger for its pace, is incorporated in the models used in this scenario study. In our analysis, we used data from IEA (2002) stating that current global proven reserves amount to 959 billion barrels and the undiscovered resources amount to 939 billion barrels.

Figure 4.3 **Production of oil, historically (1980 and 2000) and in four scenarios (2040)**



As seen in Figure 4.3, in the future the Middle-East and Russia will increase their production and market share due to depletion of the fields in other regions. In the first decade the depletion of oil fields is compensated by new additions following from exploration activities. Afterwards, several oil fields, among others those in Europe and the USA, will be depleted, while the size of new additions will become insignificant. Consequently, the share of the Middle-East region in global oil production rises. In GLOBAL ECONOMY, however, reserves in the Middle-East reach however their low point at the end of the period due to the high production in the years before. As a result, the market share of the Middle-East region in GLOBAL ECONOMY in 2040 is lower than in TRANSATLANTIC MARKET (see Figure 4.4).

In the second part of the scenario period in GLOBAL ECONOMY, non-conventional fields become a major source of oil in this scenario, as investments will be more and more directed to the development of production from tar sand fields and other non-conventional fields in Canada, Venezuela and Russia. This development is enhanced by technological improvements significantly decreasing the costs of production at these fields. In 2040, production of this kind of oil reaches a level of 35 million barrels per day in GLOBAL ECONOMY. In the other scenarios, production of non-conventional oil increases as well but at a much lower pace.

Production and exploration determine the extent of the discovered reserves. In the past two decades, the size of proven conventional reserves increased with approximately 50% (see Figure 4.5). The size of proven reserves is mainly determined by demand developments, as was concluded by McCabe (1998) and others. Increasing demand and hence production raise

The role of OPEC in the four scenario's

The institutional structure of the oil market has been extremely important for the development of the oil price in the past decades. In that period, oil producing countries organised in OPEC tried to influence the price of oil by strategically withholding oil from the market. The track record of OPEC shows some successes, albeit this cartel has been less effective than is often thought. “The two major successes attributed to OPEC – the price rises in 1973 and 1979 – had more to do with the market conditions prevailing at these precise moments than to an OPEC show of strength. (…) The OPEC golden age was neither in 1973 nor in 1979, but in 1974-8 when the oil price was held almost constant at a time of emerging surplus supplies; and in 1982-5 when a catastrophic fall in prices due to a huge supply surplus was moderated into a slow gradual decline.”(OIES, 2003).

In the short term, the efficacy of OPEC policy depends on, as history has shown, market circumstances. If the market is tight, OPEC could ‘sail with the wind’ and steer prices onto a higher path. If, on the contrary, total supply is abundant, OPEC has difficulties in realising its targets. In the long term, the role of OPEC on the oil market is determined by the global demand for oil, on the one hand, and the availability of oil in the producing countries on the other. These factors differ fairly among the four scenarios.

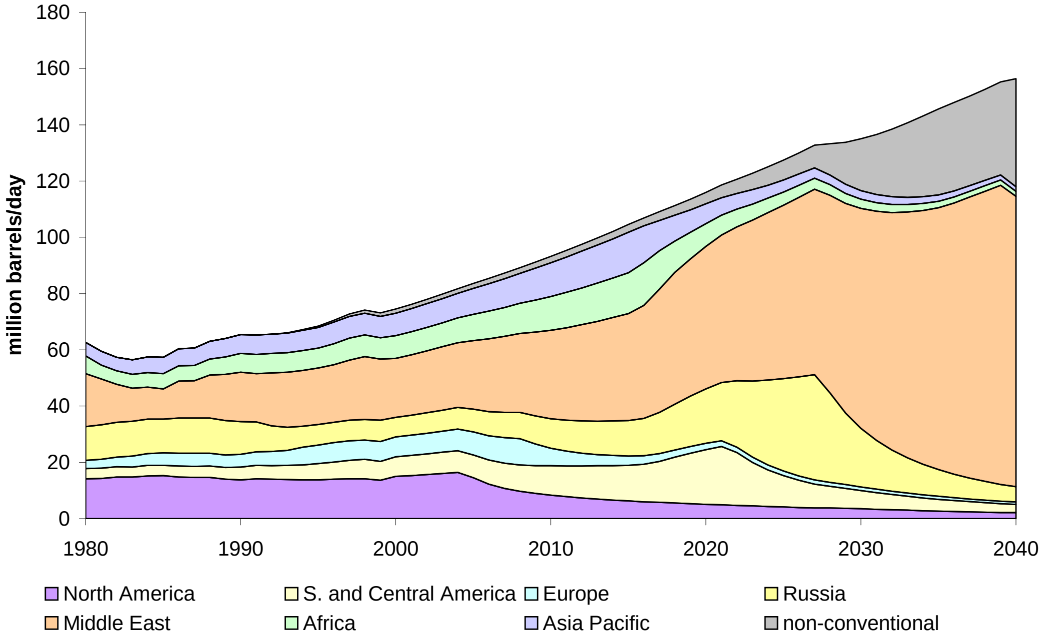
In GLOBAL ECONOMY, oil fields in most regions outside the Middle East region become depleted around 2020, giving the countries in the Middle East a larger market share. By the end of the scenario period, however, even the fields in the Middle-East region reach their bottom. Consequently, the swing capacity of these fields is lower and, hence, the capability to dominate the market. Moreover, supply from non-conventional fields expands steadily, raising competition on the oil market.

In the other scenarios, exploitation of fields outside the Middle East region proceeds for a longer period, as global demand for oil is at a lower level. As a consequence, market power of the major oil producing countries is challenged. This holds in particular for STRONG EUROPE due to the decline in oil consumption in this scenario. This decline could have a serious impact on the economies and societies of the oil producing countries.

Concluding, the oil producing countries remain significant players on the oil market in all scenarios in this and the next decade. The scenarios differ, however, in the pace and the factors by which their market power is challenged. In GLOBAL ECONOMY the market power of the Middle East oil producing countries will grow in the first half of the scenario period, but decline afterwards due to depletion and the growing supply from non-conventional sources. In the other three scenarios, market power of OPEC is negatively affected by the relatively low demand for oil.

exploration activities and hence the size of proven reserves. Eventually, proven reserves are of course determined by geological constraints, but these constraints will not be active before the end of the scenario period. Even in GLOBAL ECONOMY, with the strongest growth in oil production, proven reserves of conventional oil measures approximately 300 billion barrels in 2040, which is about 30% of the current level of proven reserves. Besides these reserves, large proven reserves of non-conventional oil will be available (see box ‘Non-conventional oil’).

Figure 4.4 **Production of oil; historically and in GLOBAL ECONOMY, 1980-2040**



Non-conventional oil

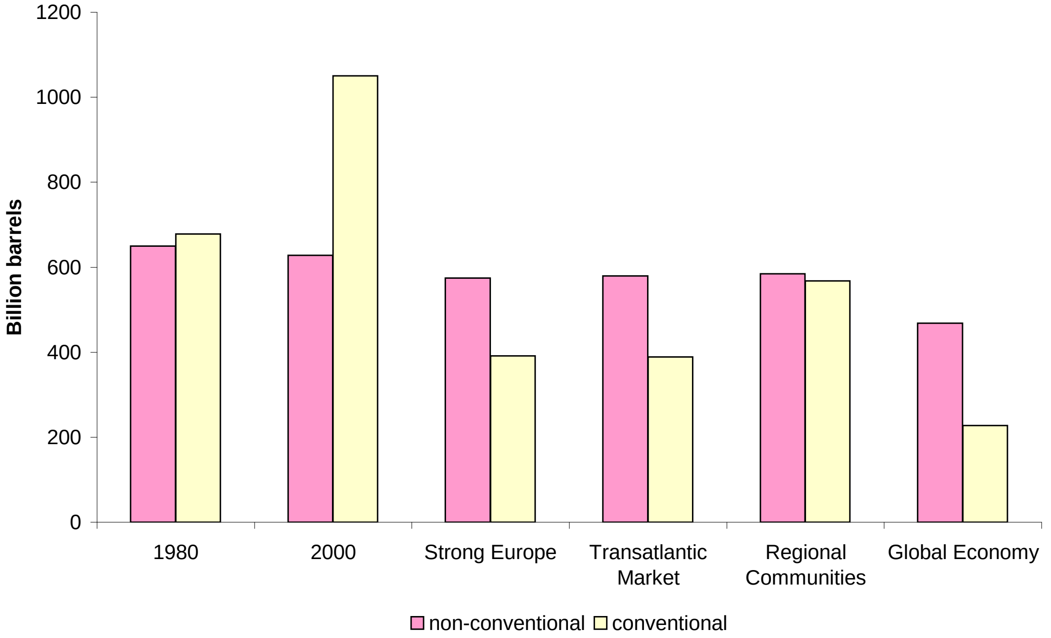
Non-conventional oil differs from conventional oil as the former is produced while the latter is extracted. Non-conventional oil includes “oil shale, oil sands-based extra heavy oil and bitumen and derivatives such as synthetic crude products, and liquids from natural gas” (IEA, 2003).

Canada and Venezuela possess approximately 580 billion barrels of recoverable non-conventional reserves, which is more than the entire reserves of conventional crude oil in the Middle East region (IEA, 2002). In Canada, the oil is produced from oil-sands deposits. From these deposits, natural bitumen is extracted. Afterwards, it is mixed with lighter hydrocarbons and processed in a refinery into upgraded crude oil. In Venezuela, extra-heavy oil is used as basis for the production of crude oil.

The production costs of non-conventional have decreased in the last decade. Currently, costs are approximately 15 dollars a barrel. It is expected that the costs will decrease towards 10 dollar in near future. Due to several difficulties related to the production of non-conventional oil, in particular related to the need of water and electricity, and environmental impacts, extending the level of production takes a long period of time. The World Energy Council concludes, therefore, in his recently published ‘Drivers of the Energy scene’, “although the resource base is large, and technological progress has been able to bring costs down to competitive levels, the dynamics do not suggest a rapid increase in this supply, but, rather, a long and slow growth over several decades.”

Current global production of non-conventional oil is slightly above 1 million barrels a day. In its latest World Energy Outlook, the IEA (2003) expects that the production of non-conventional oil will grow to almost 10 million barrel a day in 2030.

Figure 4.5 **Proven reserves; historically (1980 and 2000)and in four scenarios (2040)**



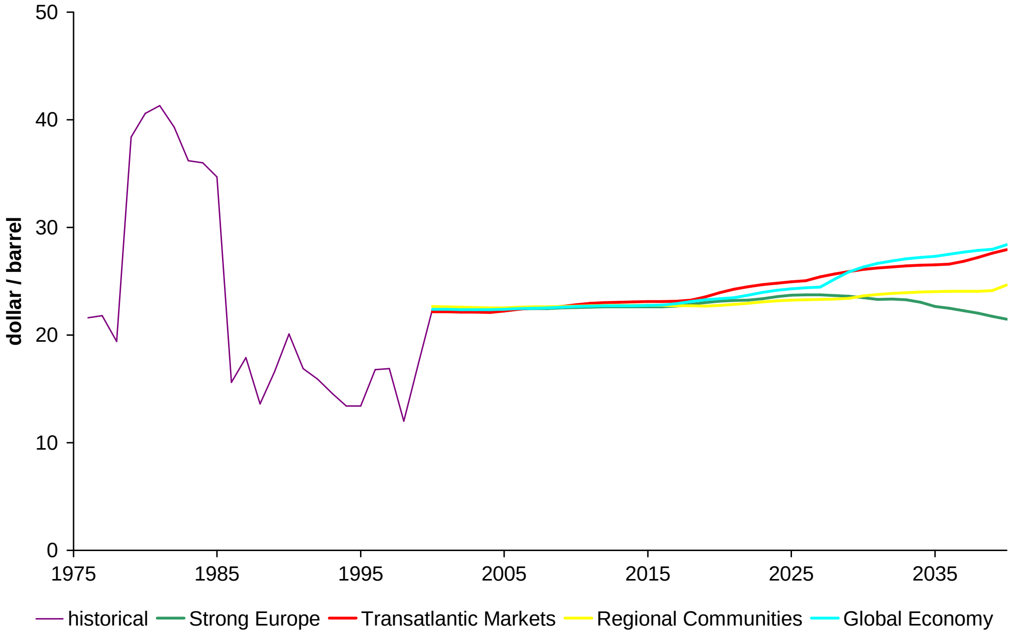
4.3.3 Price

Although levels of production differ significantly among the scenarios, structural levels of the price of oil are rather equal. Strong expansion of oil demand in GLOBAL ECONOMY affects prices and hence supply. Consequently, oil producing countries invest more in exploration and production capacity, as has been the case in past decades (see section 6.2). Although conventional oil reserves near their depletion in this scenario, non-conventional oil reserves will be still abundant and sufficient to satisfy the demand for oil. Summarising, technological developments and market incentives prevent a ‘Hubbert peak’ in global oil production with a rather flat price pattern as result (see also Ryan, 2003).

The price of oil (in real terms, 2000$) rises from about 22 dollars per barrel (which is the average level in real terms since 1975) in 2000 to around 30 dollars in 2040 in TRANSATLANTIC MARKET (see Figure 4.6). In GLOBAL ECONOMY the increase in the real oil price is somewhat smaller due to well-established international political relations. The relatively high price in TRANSATLANTIC MARKET and GLOBAL ECONOMY follows from the combination of high economic growth and absence of environmental policy measures.

In REGIONAL COMMUNITIES, the average annual price remains at the fairly constant level of 22 dollars a barrel. This flat pattern results primarily from the low economic growth and, hence, the low demand for oil. STRONG EUROPE shows more long-term volatility. In the first two decades, the price of oil rises because of the impact of economic growth, while the environmental policy is relatively weak in this period. The (shadow) price of emissions of carbon dioxide lies in the range of 5 to 10 dollars per ton (see Chapter 6). Afterwards, however,

Figure 4.6 **Average annual price of oil; historically and in four scenarios, 1975 - 2040 (all prices in 2000-$)**



environmental measures become fiercer, raising the (shadow) price of emissions to a level of approximately 125 dollars per ton carbon dioxide.[15]

As a consequence of the rising (shadow) price of the use of oil products, the demand for oil declines. We assume that the oil-producing countries in this region will continue striving for control of the market. This could imply that the level of production by these countries is partly based on the marginal costs of the marginal producer outside the Middle East. As a result, the price of oil tends to that cost level, which is approximately 20 dollars a barrel.

Although the long-term price of oil is expected to be rather flat in all scenarios, large short-term fluctuations are conceivable and very probable, as history has taught us. Disruptions within supply, caused for instance by geopolitical factors, are able to cause significant changes in the prices. In the medium and long-term, supply will, however, restore, supplemented sometimes by demand responses, bringing the price back to the long-term path. After all, history has shown that long-term price elasticity of demand, as well as supply, is fairly high, though the short-term elasticities are rather small causing the high volatility in the price of oil in the short run.

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[15] Besides these levies on the use of oil, the end-user prices of oil products (and other energy products) include several other taxes in most countries currently. This holds, in particular, for the transport sector where, in some cases, more than 50% of the gross price follows from governmental levies. In all scenarios, these levies stay in place, albeit in a scenario-specific pattern.

4.4 Natural gas market in Europe

4.4.1 Demand

Natural gas is an attractive fuel. It is relatively clean and competitively priced. In the past, demand for gas has gone up more than any other fuel. This rising trend can be expected to continue in the coming decades. However, two critical uncertainties may play an important role: resource availability and policies to curb greenhouse gas emissions. At a global level, gas resources are more than sufficient to meet increases in demand. The proven reserves of natural gas exceeds current production approximately 60 times, while the remaining reserves, which include proven reserves, expected reserve growth, and undiscovered resources, are “equivalent to between170 and 200 years of supply at current rates (IEA, 2002).

At the level of the European Union, however, a mismatch between resource endowment and demand could emerge in the near future. Output from the United Kingdom and the Netherlands will dwindle over the coming decades. Therefore, the dependency of the European Union on imports is going to rise. The EU imports are likely to come from the main current suppliers: Norway, Russia and Algeria. This asks for increased investment in pipeline infrastructure and sound contacts with European main suppliers. Flagging relations with these regions would frustrate high imports. However, as gas-exporting countries will need the proceeds of the sales of natural gas, these countries have also an incentive to invest in stable relations (Stern, 2002).

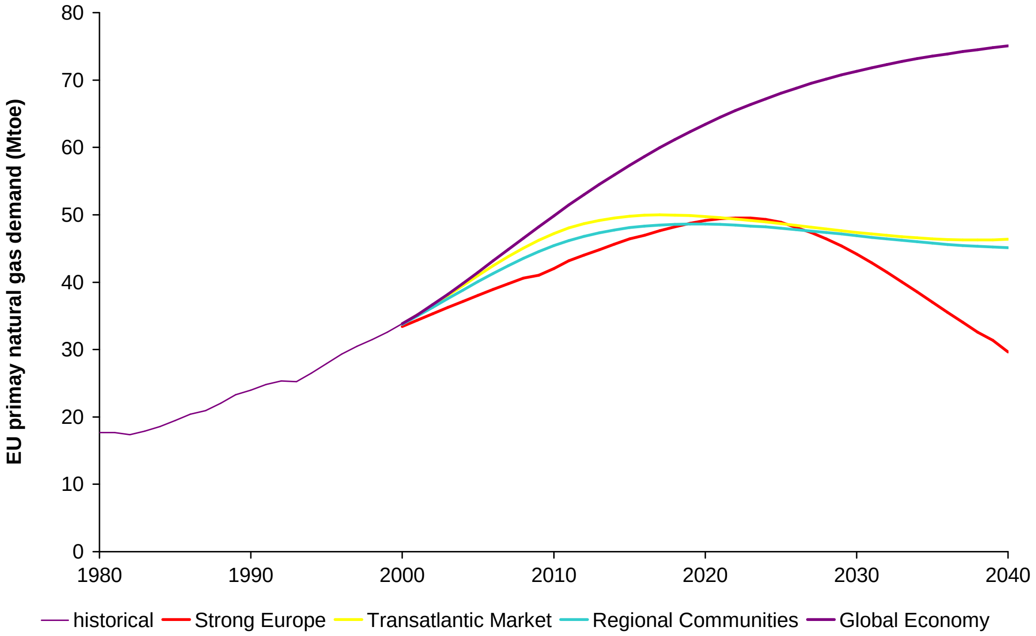
Another crucial factor is whether a stringent climate policy will be introduced. Such a policy could result in fuel-switching, e.g. substituting coal for gas in power generation, which reduces emissions of carbon dioxide, but raises the consumption of natural gas. However, it is also conceivable that stabilisation of the concentration of greenhouse gases at a safe level will ask for a more fierce transition and a more prominent role for carbon free options, like wind and solar energy.

Thinking about future energy demand, it is thought-provoking to construct scenarios along those critical uncertainties. In TRANSATLANTIC MARKET, geopolitical factors play a crucial role. The emphasis is on intense relations between Europe and the United States, relations with Russia and the Middle-East will be strained. STRONG EUROPE captures another uncertainty: climate policy will ask for a transition in energy production.

Figure 4.7 shows demand for natural gas in the European Union in the period 1980-2040. Historical growth for the period 1980-2000 is shown and projections for the future growth in the four scenarios are given. In the past, demand for gas increased annually by approximately 3%. In GLOBAL ECONOMY, this trend is pursued. In the first decades of the scenario period growth is projected to be even 4% per year. Later, this growth decreases. Not only is economic growth lower in those years, also expected price increases imply that gas looses its competitive position in favour of coal in electricity production.

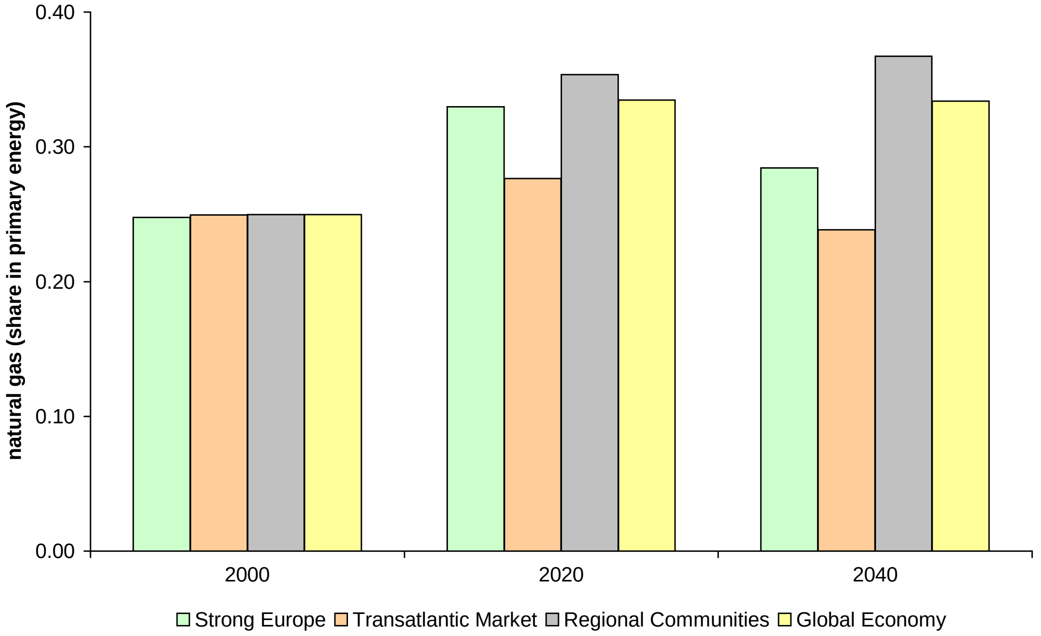
TRANSATLANTIC MARKET and REGIONAL COMMUNITIES, initially, show an increasing demand, but in both scenarios the growth comes to a halt in the second scenario period. The reasons for this stagnation in both scenarios differ. In TRANSATLANTIC MARKET, it is the constrained supply and corresponding higher gas prices that put a downward pressure on demand for gas; in REGIONAL COMMUNITIES, it is low economic growth that drives down energy demand. In STRONG EUROPE, gas demand is projected to decline whence restrictive climate policy takes off.

Figure 4.7 **Demand for natural gas in the European Union; historically and in four scenarios, 1980 – 2040**



The share of gas in primary energy demand grows substantially in most scenarios. Figure 4.8 is illustrative. This figure shows demand for gas as a percentage of total primary energy demand in 2000, 2020 and 2040 for the four scenarios. REGIONAL COMMUNITIES has the largest share of gas. An emphasis on the local environment in this scenario will induce a stronger substitution from coal towards cleaner gas in this scenario. In STRONG EUROPE, electricity demand is curtailed significantly, due to climate policy from 2010 onwards. As a consequence, important reductions in fossil fuels are from natural gas. Gas-fired generating plants will no longer be needed. An increase in renewable-based capacity also helps to save gas. Again, the lagging behind of the gas share in TRANSATLANTIC MARKET is due to supply restrictions and higher prices.

Figure 4.8 **Share of natural gas in primary energy in the European Union; historically and in four scenarios, 2000, 2020 and 2040**



4.4.2 Production

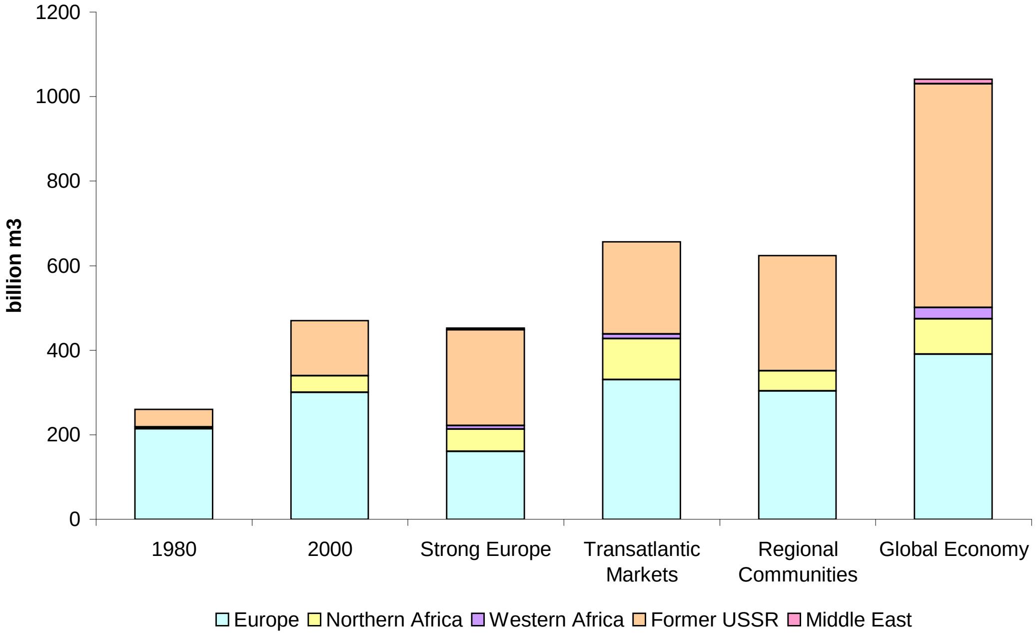
Around 2020, gas fields in the Netherlands and the United Kingdom are depleted, but Norway has still huge amounts of gas. Production in Norway is almost equal to the new discoveries, resulting in a stable volume of discovered reserves. Norway’s gas supplies are however fairly expensive, due to the remote off-shore position of the fields. Consequently, Europe’s internal production declines in the first part of the scenario and stabilises afterwards.

The growing gas consumption and the decreasing production within the European Union imply that Europe’s dependence on natural gas import is going to increase. This holds true for all scenarios. Imports mainly originate from Norway, Russia, but also from Algeria and Iran. In GLOBAL ECONOMY, Western Europe imports approximately 85% of its consumption in 2040.

4.4.3 Price

The price of natural gas in liberalised markets, like the United Kingdom, has declined in recent years as a result of growing competition. In our scenarios, we assume continuation of the liberalisation process in all European countries, leading to more competitive market outcomes. This holds particularly for GLOBAL ECONOMY and TRANSATLANTIC MARKET, in which scenarios governments strive strongly for competitive markets. In the other two scenarios, however, regulation of this network sector is less successful in realising adequate conditions for effective competition. Nevertheless, this scenarios show also more suppliers

Figure 4.9 **Consumption of natural gas in OECD-Europe by origin, historically (1980 and 2000) and in four scenarios (2040)**



coming from several directions to the European market. In addition, competition will be raised by the growing importance of liquefied natural gas, making importing countries less dependent on natural gas transported by pipelines.

Consequently, all scenarios show a fairly flat pattern in the average annual price over the current decade, because of favourable competitive conditions, on the one hand, and abundant supply of natural gas on the other (see Figure 4.10).[16] However, when fields in Europe will become depleted by the end of this decade, the price could increase. This holds especially for GLOBAL ECONOMY and TRANSATLANTIC MARKET. In the latter scenario, the relatively high increase in price after 2010 is due to not well-developed relations between Western countries and the main gas producing countries, raising the scarcity of natural gas in the former countries. The natural gas producing countries direct, in this scenario, their exports more to the Far East as, in particular, China will show a strong increase in the consumption of natural gas.

In STRONG EUROPE, price of natural gas shows a small decrease at the end of the period due to declining energy consumption caused by the high carbon taxes (see Chapter 6). The rather weak impact of the declining consumption of natural gas on the price follows primarily from the market structure. As governments do not succeed, in this scenario, in imposing fully effective regulation measures regarding the natural gas market, the major firms on this market will be

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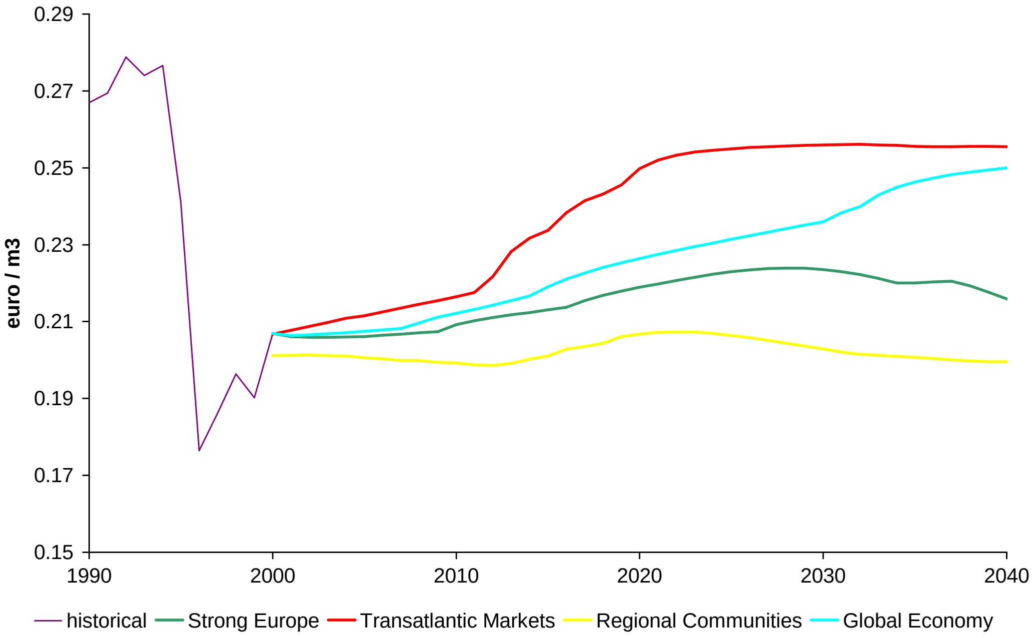
[16] The prices at the beginning of the scenario period are set on the level in 2000. Historical levels do not make much sense because of the dramatic structural changes within the European gas market recently. The price presented in this report refers to an average price for the several consumer groups. The commodity prices for large users are significantly lower (approximately 0.15 euro/m3 or 4 dollar/mbtu) and for small users higher (approximately 0.25 euro/m3 or 7 dollar/mbtu).

able to a certain extent to execute market power. In a more competitive setting, the decline in natural gas demand would lead, of course, to more significant reductions of the price.

Figure 4.10 **Price of natural gas in Europe; historically and in four scenarios, 1990 - 2040 (wholesale prices, average of all consumer groups, excluding vat and environmental taxes)**



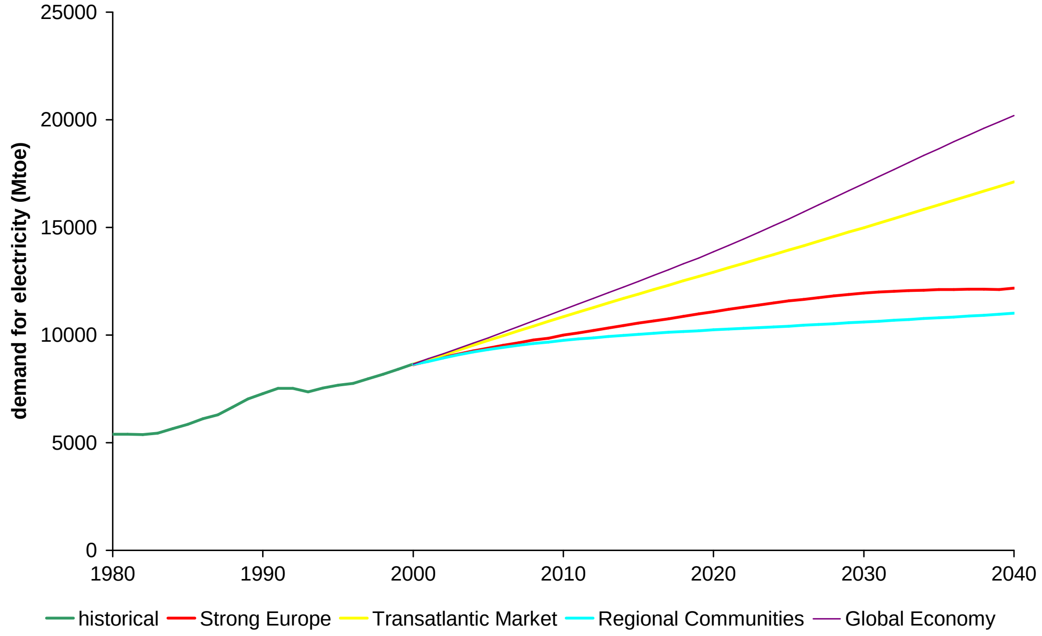
4.5 Electricity market in Europe

4.5.1 Consumption

In the past, consumption of electricity followed GDP-growth fairly closely as improvements in efficiency of appliances were compensated for by an increasing use of electrical appliances driven by electricity, a process called ‘electrification’. Future consumption of electricity will also be strongly related to the level of economic growth. “Whatever the increased performance of appliances such as refrigerators, the same basic rule still seems to apply to electricity, namely that consumers will use as much energy as we can afford. In fact, (…), electricity trends against GDP display a linear relationship.” (WEC, 2003)

As GLOBAL ECONOMY of all scenarios knows the highest economic growth, it will also show the largest growth in consumption of electricity (see Figure 4.11). Electricity consumption within the European Union grows modest in TRANSATLANTIC MARKET. The other scenarios show a fairly flat pattern, due to the fierce climate policy and the low growth of the economy respectively.

Figure 4.11 **Consumption of electricity in the European Union; historically and in four scenarios, 1980 – 2040**

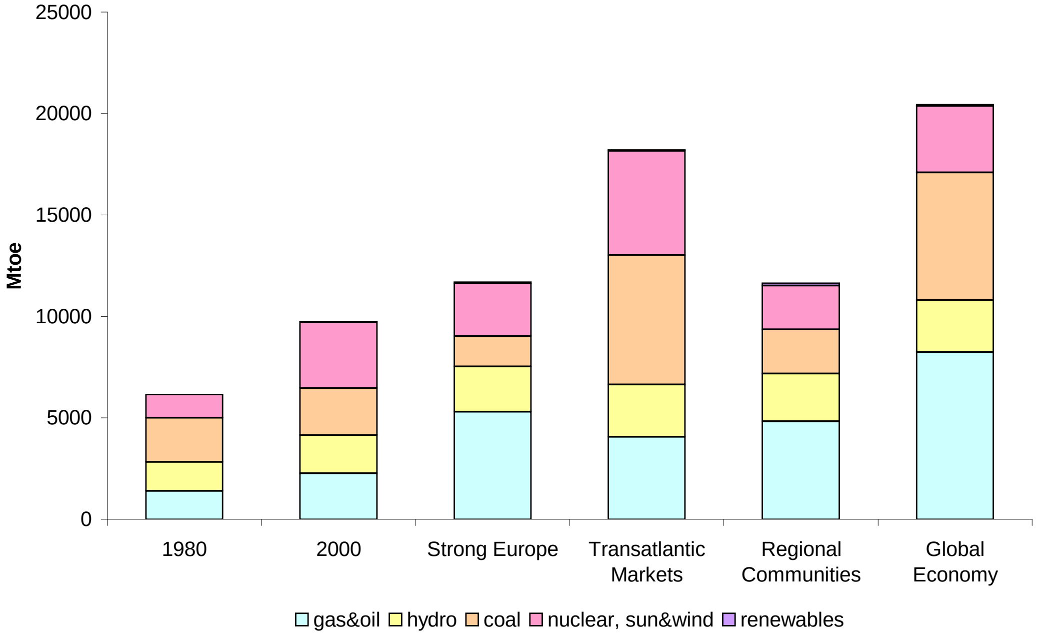


4.5.2 Production

The European electricity market becomes and stays highly competitive in TRANSATLANTIC MARKET and GLOBAL ECONOMY. Anti-competitive tendencies, like increasing concentration of suppliers, are adequately opposed by government regulations. In STRONG EUROPE, competitiveness develops less since governments are largely directed to environmental and equity issues. However, the reduction in demand due to the fierce environmental policies has a reducing impact on the abilities of producers to control the market. The environmental policy could, thus, have a positive side-effect on the degree of competition. Competition increases also in REGIONAL COMMUNITIES, due to the current regulation measures, but is hampered by insufficient international coordination of competition policies.

The fierce global climate policy in STRONG EUROPE has significant effects on the generation of electricity (see Figure 4.12). Coal-fired production fades away, while the production by gas fired plants and sustainable techniques (wind, solar) increase strongly. It is supposed in this scenario that nuclear power production is partly phased out in Europe. Although nuclear power is a relatively expensive technique if all costs are taken into account, this technique will maintain a position as supplier of base load in GLOBAL ECONOMY. In that scenario and especially in TRANSATLANTIC MARKET, the costs of storage of nuclear waste are not fully taken into account making nuclear power a competitive source of electricity.

Figure 4.12 **Production of electricity by technique in Western Europe, historically (1980 and 2000) and in four scenarios (2040)**



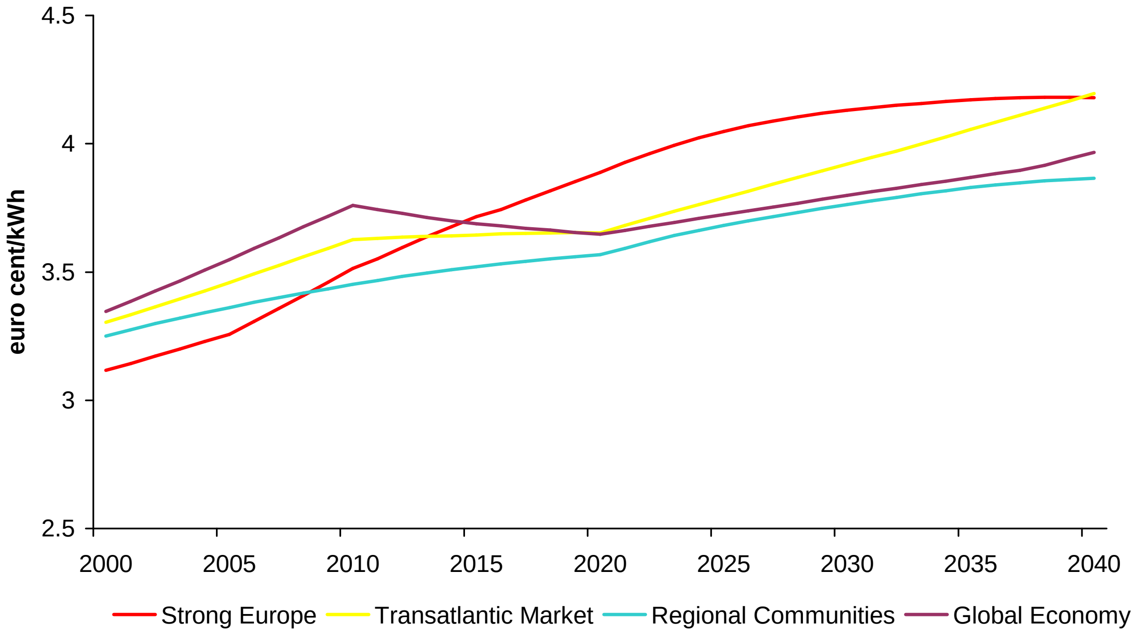
Renewable generation techniques play a role of increasing importance in TRANSATLANTIC MARKET and STRONG EUROPE. In the former scenario, the growing importance of renewables (wind, solar, biomass, etc.) follows from several factors, notably restricted supply of fossil energy carriers, high economic growth and hence large energy demand and strong technological growth. The latter two factors are absent in REGIONAL COMMUNITIES, which leads to a limited role of these renewable techniques in this scenario.

In GLOBAL ECONOMY, supply of gas and oil is abundant and prices of these energy carriers are relatively low, causing a growing role of plants fired by these energy carriers. The increase in demand in TRANSATLANTIC MARKET is mainly accounted for by coal-fired and nuclear electricity generation, as the price of natural gas is relatively high.

4.5.3 Price

The decrease in the average marginal cost of electricity production, combined with a high level of competition in the integrated European electricity market in GLOBAL ECONOMY and TRANSATLANTIC MARKET keeps prices more or less stable, despite the surge in demand. Increasing concentration in the market causes the small price peak around 2010. In later years, further integration into a single European electricity market will offset this effect. Although STRONG EUROPE shows also plenty supply of oil and gas, environmental policies lead to substitutions within energy production towards sustainable techniques. These substitutions follow particularly from governmental restrictions imposed on nuclear and coal-fired generation. As a result of these restrictions and substitutions, marginal costs rise and, hence, the price of electricity.

Figure 4.13 **Price of electricity in Western Europe in four scenarios, 2000 – 2040 (average annual price for all consumer groups)**



4.6 Conclusions

Economic growth and environmental policies have significant effects on production, consumption and prices of energy. However, restrictions on the supply side, among which is resource scarcity, do not have a major influence on energy markets in this study. The reserves of oil in the Middle-East could near their depletion before 2040, in particular in a scenario with a high economic growth. Even in that case, the global supply of oil will be secured by non-conventional sources. Therefore, absolute scarcity on the supply side will probably not raise the real price of oil in the next decades. In addition, a structural increase of the price of oil is not highly probable due to demand responses which would be induced by such a increase.

Significant chances could occur within the regional structure of the supply of oil. The current main suppliers from the Middle East region could obtain a bigger share of the global oil market due to depletion of conventional oil fields in other regions. At the end of the horizon of our scenarios, however, their dominant positions will be challenged by the growing production from non-conventional oil fields.

Europe will become more and more dependent on foreign sources of natural gas. This results from the growing consumption of gas, especially in the power sector, and from the depletion of gas fields in Europe. In all scenarios, the import dependency grows to at least 70%. Due to an abundant supply of natural gas in Russia and the Middle East, the supply of this energy carrier will be mainly determined by geopolitical factors.

Electricity demand in Europe could triple in the period up to 2040 in case of high economic growth. The price of electricity could however be rather stable due to technological innovations and increasing competition. The role of gas-fired power plants increases in all scenarios because of economic as well as environmental advantages of this generation technique. This holds especially for a scenario with a fierce environmental policy restricting both coal-fired and nuclear generation. The share of nuclear generation diminishes in all scenarios as result of high costs associated with this technique and the arising of new, small scale, generation techniques. However, nuclear power stays relatively important in a scenario with constrained relations between gas-importing and gas-producing countries.

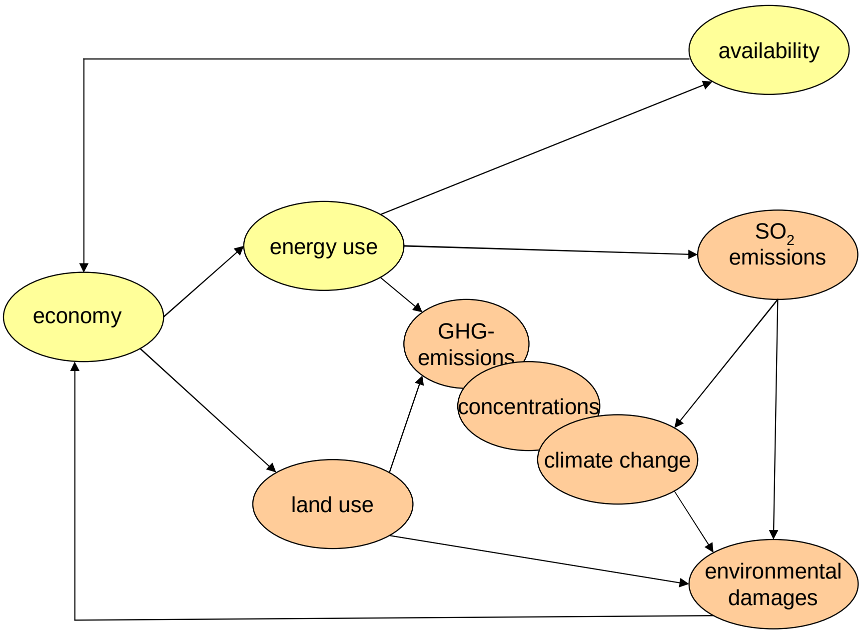
5 Climate and the environment

The atmospheric concentration of greenhouse gases is increasing and will further rise in the coming 40 years from ongoing energy related emissions. In the next 40 years the global temperature increase will exceed the rise observed over the last 100 years. By 2040, climate change will be very similar across scenarios, but beyond 2040 the impacts will not only become larger, but also start to diverge between the different energy futures. While the other energy related environmental impacts do differ across scenarios, this is primarily driven by changes in land-use and water demand. Developing countries bear most of the burden of climate change.

5.1 Introduction

In this chapter we will explore the impacts of energy emissions and climate change in the four scenarios. We will focus our results mainly on the global scale, but will also pay special attention to the results for Europe. Section 5.2 starts with the emissions of the six greenhouse gases (GHGs) as mentioned in the Kyoto Protocol, which can be aggregated in terms of CO_2 equivalent emissions and based on the Global Warming Potential of the different GHGs. Also we will discuss other emissions of polluting gases that indirectly influence the climate system (aerosols and ozone precursors).

Figure 5.1 Analytical Scheme of Chapter 5



Section 5.3 will take a global perspective and analyses the changes in concentration of GHGs in the atmosphere. Given the inertia in the climate system, the differences in climate effects between the four scenarios are very small. Therefore, we will also dwell upon the conceivable long-term effects (2100) of changes in greenhouse gas concentrations; using the IPCC-SRES scenarios (see section 2.3). Section 5.4 will then take a more local perspective on the impacts of climate change. In this study we have restricted our analysis to the climate consequences on biodiversity losses and water stress. Since not only climate change has an effect on these environmental issues, we will broaden our scope whenever needed. Essentially, this means we will also highlight changes in land-use pattern as these dominate the quality of nature (through expansion of agricultural land and an increased interference with ecosystems). The consequences for water stress will be limited to an analysis of changes in the supply of water from precipitation changes and the demand for water by changes in population and economic activities. This chapter concludes with our main findings.

5.2 Greenhouse gas emissions

5.2.1 Global greenhouse gas emissions by land use, industry, and energy for the four futures

Carbon dioxide emissions are the biggest contributor to global warming, and stem from land use (burning wood and biomass), industrial production (e.g. cement production) and most importantly the combustion of fossil fuels for energy production and consumption.

Figure 5.2 shows the global emissions for all scenarios. All scenarios, except for STRONG EUROPE, show a higher level of the global emissions in 2040 compared to 2000. In STRONG EUROPE, emissions will be reduced according to the Kyoto protocol, followed by a global emission strategy aimed at stabilisation of greenhouse gases in the atmosphere at 550 ppmv CO_2-eq[17]. This rather ambitious level corresponds with the objective of the EU climate strategy (see also 5.3.2). Generally, emission abatement policies lead to a de-coupling of carbon dioxide emissions and energy services. It results from efficiency improvements and replacement of coal by renewables, nuclear energy and biofuels. In REGIONAL COMMUNITIES the moderate economic growth and the focus on local environmental problems also leads to some move away from fossil fuel use – and thus to lower GHG emissions. Climate policies do not play any role in the worlds of GLOBAL ECONOMY and TRANSATLANTIC MARKET, and other environmental policies are not making a decisive difference either. In these two scenarios fossil energy consumption and accompanying carbon dioxide emissions grow considerably, leading to a strong divergence of emissions.

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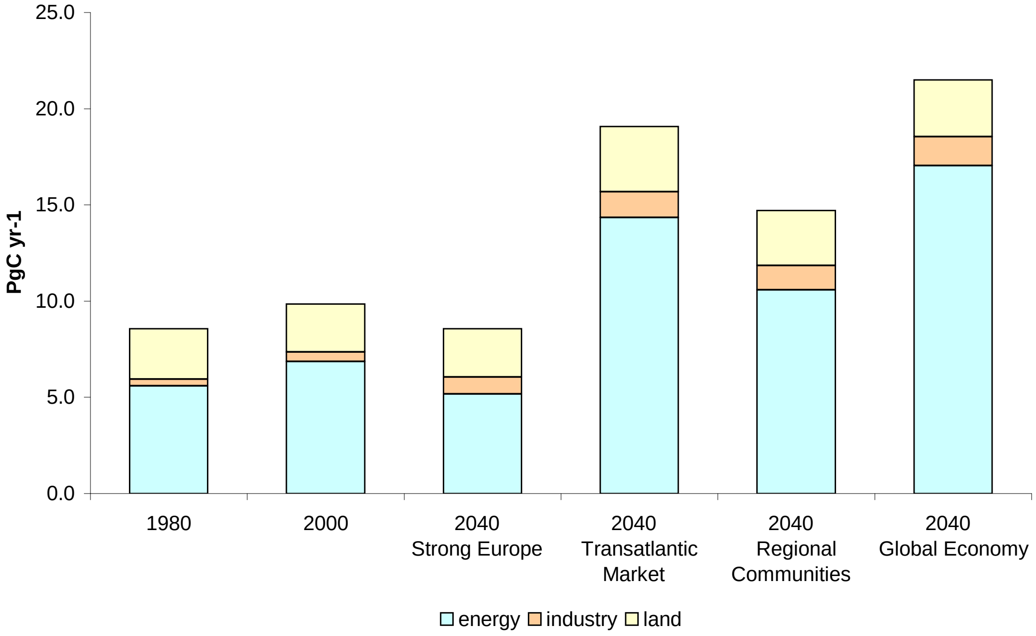
[17] Besides CO_2, the other GHG emissions expressed in CO_2 equivalent are the sum of emissions of CH_4, N_2O, HFCs, PFCs and SF6, aggregated to CO_2 equivalents using scale factors depending on the 100 year global warming potentials (GWPs) provided by the IPCC (TAR Report, 2001). The global warming potential (GWP) describes the cumulative effect of a gas over a time horizon (usually 100 years) compared to that of CO_2.

Figure 5.2 illustrates the dominance of energy related carbon dioxide emissions over carbon dioxide emissions from industrial production and land use. The current share of energy-related emissions in total emissions is about three-quarters. The other two sources become even less important over time in all scenarios without climate policies. This is due to an increase of energy consumption and accompanying carbon dioxide emissions (in lower income regions in particular). Future emissions from industrial production and land use increase at a lower rate in all scenarios. Only in STRONG EUROPE, the global climate policy yields energy-related emissions to remain at around the 2000 level. There is only a limited scope to limit land-use emissions.

Figure 5.2 **Emissions from CO_2, CH_4 and N_2O through energy combustion, industry processes and land-use in al scenarios (in CO_2 equivalents)**



5.2.2 Emission profiles for SO_2 and NO_x

Fossil fuel combustion is also the main source of sulphur dioxide (SO_2) emissions. Coal plays a dominant role, given its relative high sulphur content. Deposition of sulphur dioxide and sulphate is one of the main causes of acidification in soils and water. Acidification is damaging to vegetation, terrestrial and aquatic ecosystems if critical levels are exceeded, and also causes damage to materials, buildings and monuments. In the atmosphere SO_2 with other pollutants convert to fine particles. This leads to higher dust concentrations at the ground level, causing respiratory health problems. But the fine particles in the atmosphere also reflect sunlight, and therefore have a strong cooling effect on the climate. Due to their relative short lifetime in the atmosphere, this effect is concentrated in regions where the emissions occur (mainly in the Northern Hemisphere). However, there will be substantial emission reductions, which are brought about policy measures such as fuel switching or large-scale desulphurisation, which are typically large-scale and in most cases have an all-or-nothing character.

Figure 5.3 plots the global SO_2 emissions for all scenarios. Historically, the global SO_2 emissions were dominated by the USA and Europe, and hence the decline was driven by sulphur policies such as the Clean Air Act in the USA, and UN-ECE Sulphur Protocols for pan-Europe. The global SO_2 emissions of TRANSATLANTIC MARKET lie above GLOBAL ECONOMY. The reason is that the demand for coal in the non-Annex I region dominates the future SO_2 emissions. Currently the OECD ranks among the largest emitters of sulphur dioxide, and sharp reductions will occur for all scenarios over the coming decades due to the Amendments of the Clean Air Act in the USA and the 1999 UN-ECE Gothenburg Acidification Protocol for pan-Europe. In Asia emissions are currently moderately large, and for China very large. The increase of emissions anticipated in India and China is staggering. They play a dominant role in the global increase as foreseen in TRANSATLANTIC MARKET and GLOBAL ECONOMY. Emissions in Asia will continue to grow as the combined result of economic growth and an increasing population. The only way to counter the impacts of the alarming sulphur dioxide emission trends in Asia is the introduction of stringent environmental policies. In two scenarios relatively strict policies are assumed; i.e. in STRONG EUROPE as a side effect of climate policies (emissions trading) and in REGIONAL COMMUNITIES directly driven by concerns over local health effects. The drive of non-Annex I countries to reduce SO_2 emissions in high economic growth scenarios is more important than in low economic growth scenarios because of internalisation of environmental damages in the cost of production. But in GLOBAL ECONOMY the impacts of these policies are completely offset by an increase of activities – which still results in rising sulphur emissions. Finally, STRONG EUROPE is an important example of the synergies that can be gained between changes in the energy system induced by participation in a global emission trading scheme and the reduction of regional and local air pollution.

Emissions of nitrogen oxides (NO_x) stem from the combustion of fuels by freight and passenger transport, biomass burning, and lightning. But also microbiological emissions from soils are a significant source. Emissions of NO_X contribute to acidification and the generation of ozone (O_3) in the troposphere, causing summer-smog with effects on human health, vegetation and materials.

Figure 5.4 presents the emissions in Europe for SO_2 and NO_x. The pattern of NO_x emissions is the same as for CO_2-equivalents. An exception is that in case of NO_x, TRANSATLANTIC MARKET will yield more emissions than GLOBAL ECONOMY. The reason is that GLOBAL ECONOMY exhibits more economic growth, especially in the non-Annex I region, with associated growth in transport demand. This economic growth also triggers the non-Annex I region, especially Asia, to account for environmental externalities in the cost of production and hence increasingly decoupling the growth of emissions from production.

Figure 5.3 **Global SO_2 emissions in all scenarios**

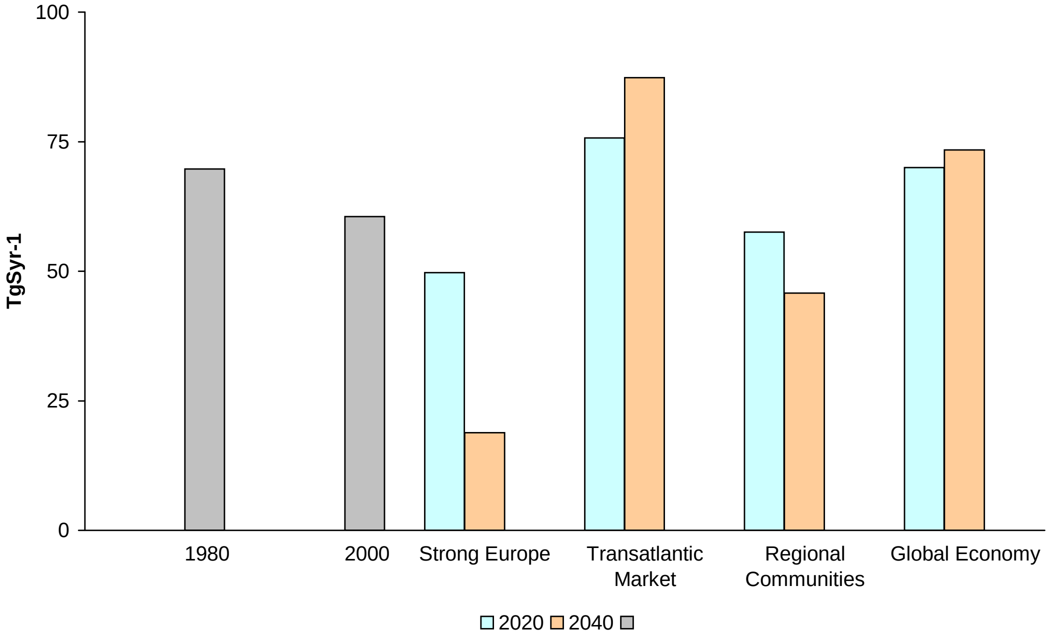
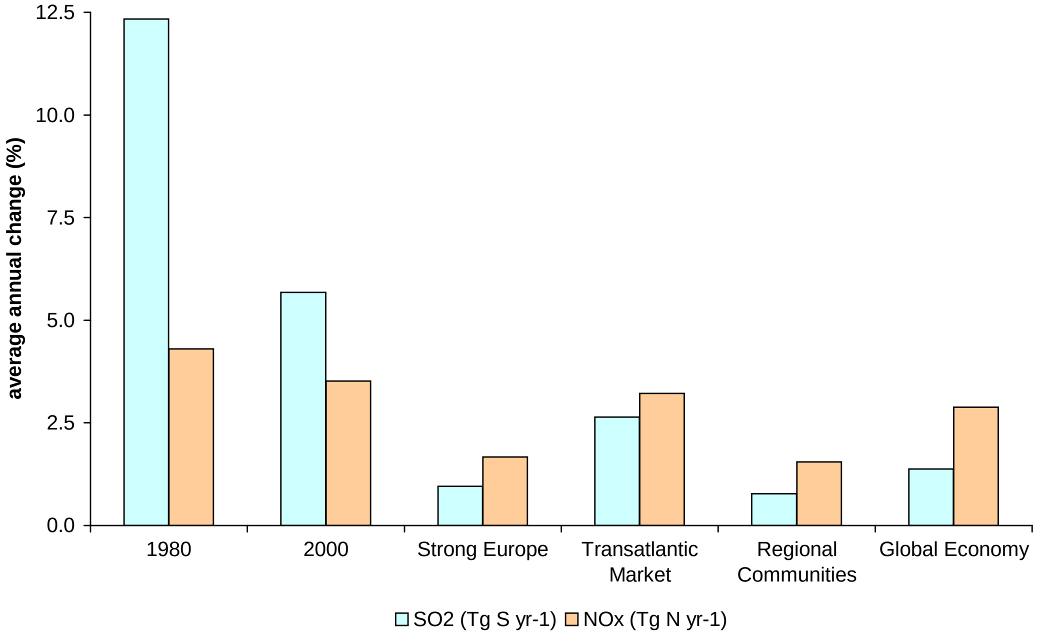


Figure 5.4 **Emissions from SO_2, and NO_x in the EU in all scenarios**



5.3 The Global environment:

5.3.1 Concentration

Carbon dioxide and nitrous oxide (N_2O) have long atmospheric lifetimes and account for more than 80 percent of GHG emissions, and the accumulation of these gases occurs over hundreds of years. Methane (CH_4) accounts for only 15 percent of the GHG emissions, has a much shorter atmospheric lifetime but rather strong impact on the radiative forcing. Therefore, the changes in methane emissions lead rather quickly to changes of concentration level of GHGs[18]. The level of the concentration of CO_2 in the atmosphere in 2040 will be dominated by the accumulation of energy-related emissions of the past and only to a small extent depend on the emissions of the different scenarios. But beyond 2040, the concentration level will increasingly depend on scenario-specific futures of emissions, and the resulting differences in concentrations will also prevail for rest of this century.

Table 5.1 **Global Concentration in 2040 in all scenarios (ppmv, in CO_2 and incl. all Kyoto gases in CO_2 eq.)**

	1980	2000	STRONG EUROPE	TRANSATLANTIC MARKET	REGIONAL COMMUNITIES	GLOBAL ECONOMY
CO_2 eq.	375	423	520	609	558	627
CO_2	340	375	443	485	455	500

Table 5.1 shows the atmospheric concentration of the greenhouse gases covered by the Kyoto protocol in 2040. The concentration level will lie within the relatively narrow range of 443-500 ppmv CO_2, mainly because all scenarios share the same historic accumulation of greenhouse gases and the future global greenhouse gas emissions only gradually diverge between the scenarios. GLOBAL ECONOMY yields the highest concentration, because of the increase in economic activities. STRONG EUROPE marks the lower end of the range. In STRONG EUROPE, the climate policy adopted aims to concur with a long-term stabilisation of greenhouse gases in the atmosphere at 550 ppmv (measured as CO_2-equivalent). The 550 ppmv stabilisation level is associated with a global temperature change that is anticipated to yield limited risks from climate change. At median to low climate sensitivity, the 550 ppmv stabilisation profile will also in the long run comply with the EU-target of 2° Celsius increase above pre-industrial levels (IEPE et al, 2003).

5.3.2 Temperature

The concentration of GHGs in the atmosphere will increase, and in turn with a delay lead to an increase of the temperature level. Besides the temperature level, the rate of temperature change is even more important for sensitive ecosystems. The reason is that ecosystems may not be able to adapt at high rates of temperature change. Research indicates that in order to avoid dangerous climate impacts, the rates of temperature increase should stay below 0.2° Celsius per ten years (WBGU, 2003). Figure 5.5 shows that beyond 2015 the rate of this change will exceed 0.2° Celsius per ten years in all scenarios. Only STRONG EUROPE shows a decline below the 0.2° Celsius at the end of the scenario period.

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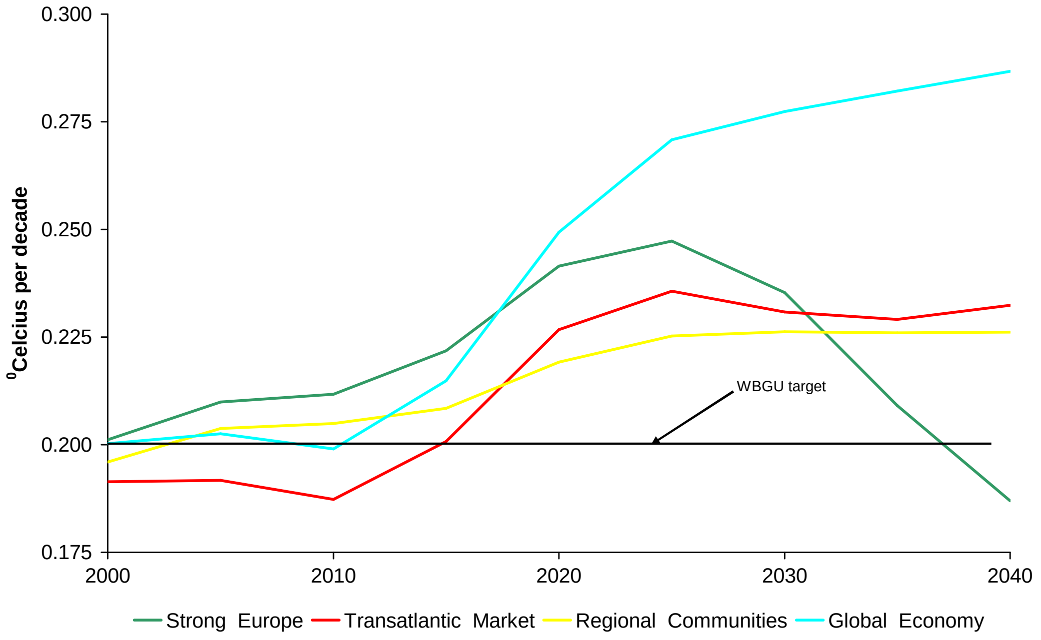
[18] The rules for aggregation of emissions of different gasses is based on their Greenhouse Warming Potential, whereas for concentrations it is based on characteristics with respect to radiative forcing, see IPCC TAR Report (2001) for more details.

Figure 5.5 **The rate of temperature change in all scenarios**



Up to 2020, the rate of temperature change is the highest in STRONG EUROPE. The reason is that CO_2 emissions trading will enhance a fuel switch in Asia away from coal, and therefore reduces the SO_2 emissions, and thus also - on the global level - reduces the temporary cooling effect. At the same time, acidification in Asia will diminish because of the climate policy, which especially reduces the demand for coal. But it needs to be emphasized that the cooling effect from SO_2 emission is a local phenomenon, whereas temperature increases from CO_2 emissions have a global character. The reduced cooling effect will especially be felt in China and India. Still in the long run, the climate policy in STRONG EUROPE will intensify, and thus leads to a declining long-term rate of temperature change. The other scenarios all show for the period beyond 2010 an ongoing increase of the rate of temperature changes. Except TRANSATLANTIC MARKET shows for the 2025-2035 period a declining rate of temperature, which can be explained from a rapid expansion of coal demand in the 2020-2040 period. The highest rates occur in GLOBAL ECONOMY, the compounded effect of high energy demands and sulphur reduction measures.

Figure 5.6 shows the temperature change over time of all scenarios, they follow the GHG concentrations but with considerable delay. Hence, the range between projected climate impacts per scenario for 2040 is smaller than the range of future concentration levels. The temperature change in the year 2000 is equal to 0.6^0 Celsius (compared to the pre-industrial age), and by 2040 will increase to $1.5\text{-}1.6^0$ Celsius for a median climate sensitivity[19]. Hence the coming

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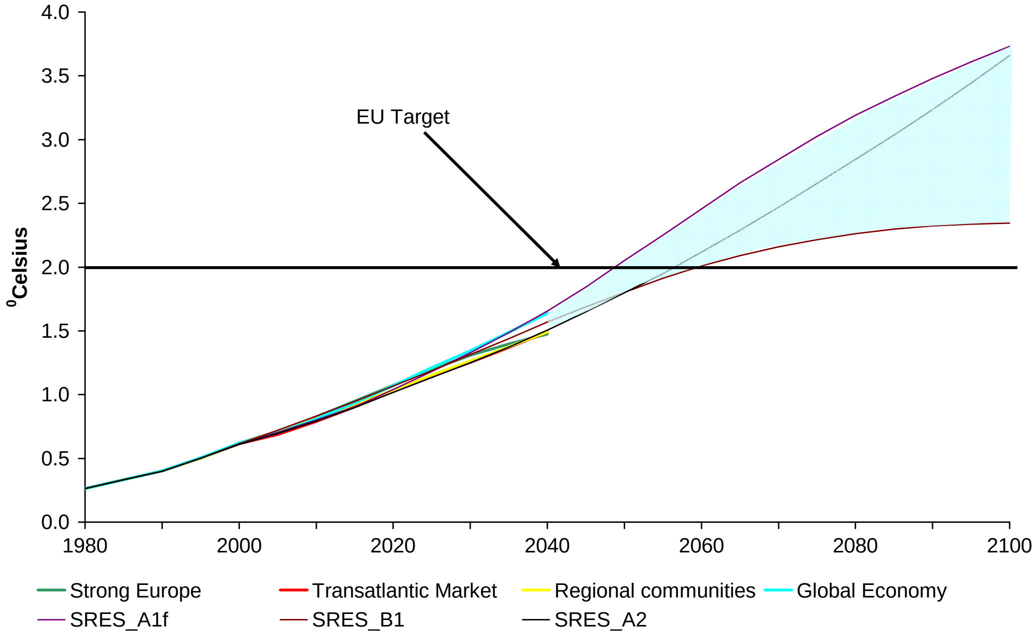
[19] The climate sensitivity is defined as the equilibrium global mean surface temperature increase resulting from a doubling of the CO_2 concentration. Given the many uncertainties in the climate sensitivity, the IPCC has defined a range from 1.5 ° Celsius to 4.5 °Celsius with 2.5 °Celsius as the median value, which is used in this report.

decades will show a considerable more rapid temperature increase than has ever occurred since the start of the industrial age. However, given the greenhouse gas concentrations by 2040, further increases will inevitably follow. It is possible to get some estimate of these already built-in temperature changes by comparing the scenarios of this study to the IPCC-SRES scenarios. With the median climate sensitivity they range from a temperature increase in 2100 of 2.4 to 3.8 ^{0}Celsius compared to the pre-industrial age. In 2040 the upper end of the ranges coincides well with the GLOBAL ECONOMY and the lower end is more close to REGIONAL COMMUNITIES.

Figure 5.6 Global surface temperature change (since the pre-industrial age) in all scenarios



The long-term stabilisation of GHGs in the atmosphere in STRONG EUROPE will, under median climate sensitivity and with a declining rate of temperature change by 2040, may limit temperature increase to 2^0 Celsius by 2100[20]. This implies that the climate policy in STRONG EUROPE still complies in that year with the EU policy target, which aims for global strategies to remain within 2^0 Celsius temperature increase compared to the pre-industrial level.

5.4 The Local environment

5.4.1 Threats to natural vegetation and biodiversity

The rising global temperature will pose a threat to current natural vegetation. Local temperature regimes may become sub-optimal for current species, and migration is a slow process, at times also hampered by natural (mountain ranges, large water bodies) and anthropogenic (urbanised and agricultural land) barriers. The more rapid the temperature increases, the less possibilities plant species have to adapt to changing circumstances. In Figure 5.7, the climate effects on the

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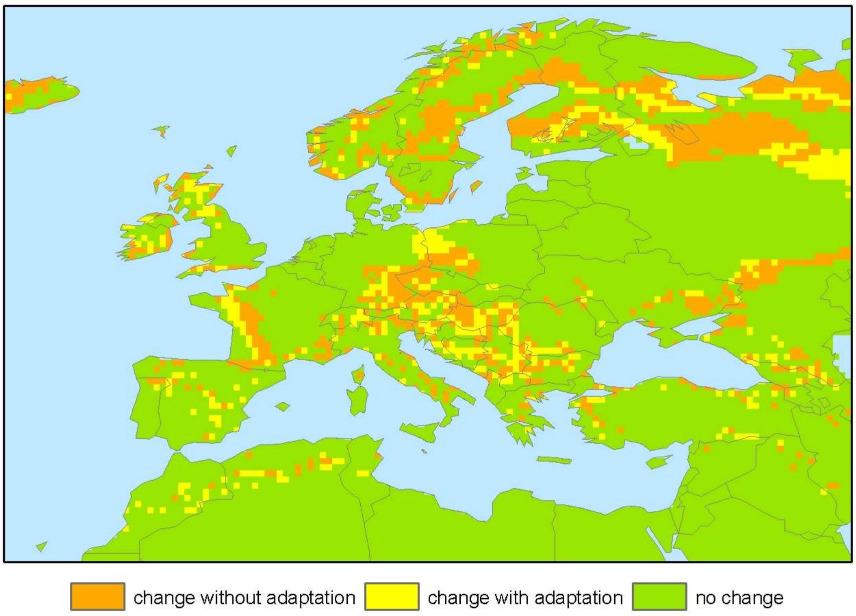
[20] With a low to medium level of climate sensitivity.

natural vegetation are depicted for Europe. When a changing climate forces natural vegetation types to shift, the rate of temperature change becomes very important. When climate change occurs too fast, some natural ecosystems cannot adapt to this rate of change. Consequently, degraded forms of this natural vegetation type will occur, leading to possible negative consequences. If the climate change occurs at a lower rate, ecosystems have more time to shift and adapt to the changing climate. Figure 5.7 maps the threat to ecosystems for Europe. Green areas will experience no extra threat from climate change. The orange areas are the ones that will experience a threat, and hence change without any possibility to adapt. Finally figure 5.7 also includes a yellow category that depicts those areas that will experience climate change but are capable of adaptation.

As with temperature changes there are also hardly any differences across scenarios with respect to the threat to vegetation. This also holds for regions and countries outside the EU. Figure 5.7 shows that the EU will be harmed in Central Europe, Southwest of France close to mountainous areas (Pyrenees and the Alps) with vulnerable ecosystems and in Scandinavia and Russia through relative strong temperature changes at higher latitude. The mountainous areas are particularly vulnerable because ecosystems at high altitudes have limited scope to shift much higher.

Figure 5.7 Threat to natural vegetation in 2040 in Global Economy



Uncertainty on the relation between changes of the global concentration of GHGs and global temperature

One of the crucial factors determining changes in global temperature from changes of concentration of GHGs in the atmosphere is the climate sensitivity. The climate sensitivity is described as the equilibrium global-mean surface temperature increase resulting from a doubling of CO_2-equivalent concentrations. The IPCC estimates the range of the climate sensitivity between 1.5 and 4.5 ºC, with a median value of 2.5 ºC (IPCC, 2001). For the median climate sensitivity (used in this study), the climate policy of STRONG EUROPE (550 profile) - if also pursued beyond 2040 - results in about 2℃ increase in the very long run. If the climate sensitivity would be higher, then the EU target cannot be met by the climate policy of STRONG EUROPE. If it were to be lower, then the climate policy can be relaxed to meet the EU target.

However, climate change is just one factor affecting the natural domain. This also depends on other environmental stresses such as changes in land use. To assess the relative importance of this factor, we also broaden the analysis by including impacts on biodiversity from the strongly differing land use patterns in the scenarios. Table 5.2 summarises qualitatively the losses of biodiversity in different regions in all scenarios. Biodiversity depends on land-use, population densities, primary energy use, the rate of temperature change[21], and the clear-cutting of forest. Globally, TRANSATLANTIC MARKET, REGIONAL COMMUNITIES and GLOBAL ECONOMY show the same losses. By contrast, STRONG EUROPE leads to significantly lower losses from land-extensive agricultural production, less deforestation, and the climate policy.

The OECD region will experience fewer losses than non-Annex I because of different reasons. First, the OECD has less ecosystems left today as compared to many non-Annex I regions. Second, population densities will increase in the non-Annex I. Third, as income grows in non-Annex I, their consumption of agricultural goods shift to more land-intensive products, which will lead to more land-use at the expense of forested areas. Finally, also the rate of temperature changes will be higher in the Southern Hemisphere. The benefit in OECD in STRONG EUROPE will even be absolute, mainly because the rate of temperature change will be lower than in 2000. In GLOBAL ECONOMY specialisation away from land use intensive activities will reduce the losses compared to Non-Annex I.

Table 5.2 The Quality of biodiversity by 2040 (compared to 2000)

	STRONG EUROPE	TRANSATLANTIC MARKET	REGIONAL COMMUNITIES	GLOBAL ECONOMY
EU-15	+	-	0	--
OECD	+	--	-	--
Non-Annex I	-	---	---	---
World	0	---	---	---

Legend: 0 = no losses, - = little losses, --- = large losses

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[21] Please note that the rate of temperature change is used in this study to analyse the impacts on biodiversity (and not the absolute level of temperature change).

The reasons for the impacts in the EU to be different than in the OECD differ per scenario. In TRANSATLANTIC MARKET and REGIONAL COMMUNITIES, the EU will grow at a significant lower rate than the rest of the OECD. Thus land demand will also be lower as compared to the rest of the OECD, and biodiversity impacts due to loss of area will be less. In GLOBAL ECONOMY economic growth develops at a comparable rate as in the rest of the OECD and hence biodiversity losses are similar. In STRONG EUROPE the biodiversity gains in the EU will be slightly less than in the rest of the OECD from specialisation in land use intensive activities (see also RIVM 2004). Finally, these results differ somewhat from the heavily debated results presented in Thomas et al (2004), which indicates a loss in the EU equal to 6-20 percent. The major differences with the approach in Thomas et al (2004) are that here changes in the land-use pattern and the possibility of lower global emissions such as in STRONG EUROPE are taken into account. The climate policy in STRONG EUROPE will lower the rate of temperature change by 2040 (compared to 2000) and combined with less demand for land will even lead to a gain in biodiversity in the EU (and the OECD). The biodiversity gain would have been larger if the climate policy (the EU target of 2^0 Celsius temperature increase) would have excluded biomass as an option to reduce CO_2 emissions. The reason is that the expansion of biomass production requires a significant amount of land.

5.4.2 Water stress: precipitation changes and water demand

The rise of the global temperature is a climate effect that will lead to more evaporation and precipitation as the hydrological cycle becomes more intense with higher temperatures. Figure 5.8 illustrates the change in the average annual precipitation surplus (precipitation minus evaporation by vegetation) in 2040 compared to 2000 in the EU. As the precipitation surplus strongly depends on the temperature change, there are hardly any differences across scenarios. There will be more water available in the Northern Europe and less water available in the Mediterranean. At the global level, the precipitation surplus will rise in the Northern Hemisphere, but will decline in the South. The impacts are severely negative in India, and South America, but positive for the USA.

Similar to the biodiversity impacts discussed above, there is more to the water issue than climate change. While climate changes the water supply available for various purposes already at unchanged land-use patterns, other scenario-specific developments influence both supply and demand. Confronting the supply and demand side of water markets in the scenarios illustrate the tensions that will evolve on these markets, represented by the water stress indicator. Water demand, excluding rain-fed agriculture, depends on population, industrial production, electricity production, water demand technologies and irrigation.

The natural capital index in the scenarios

The threat to vegetation and other animal and plant species and land-use changes are two developments that drive changes in biodiversity. To capture the compounded effect, the 'Natural Capital Index' (NCI) is developed (REF!). This index approximates the terrestrial biodiversity of natural ecosystems and agricultural land. Biological diversity – or biodiversity - is the term given to the variety of life on Earth and the natural patterns it forms. This diversity is often understood in terms of the wide variety of plants, animals and micro-organisms. Biodiversity loss occurs when natural ecosystems are reduced through conversion to agricultural or urban use and/or when natural ecosystems are degraded (loss of quality). Such degradation of terrestrial and aquatic systems occurs due to a mix of human influences, such as climate change, chemical pollution, disturbance due to fragmentation from infrastructural developments or due to tourism, hunting and gathering. All such influences reduce both the distribution and the abundance of animal and plant species. A general effect is that the abundance of many rare species declines, while the abundance of some – mostly common – species increases, resulting in increased uniformity.

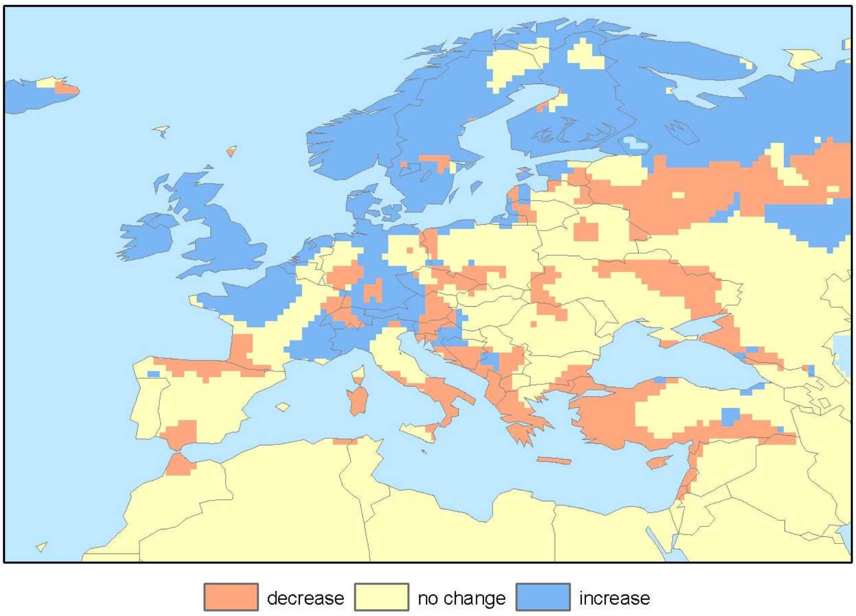
Natural Capital Index in different scenarios (index 2000 = 100)

	STRONG EUROPE		TRANSATLANTIC MARKET		REGIONAL COMMUNITIES		GLOBAL ECONOMY	
	2020	2040	2020	2040	2020	2040	2020	2040
EU-15	89	108	89	90	96	98	86	80
OECD	91	111	87	86	93	94	85	80
Non-Annex I	79	90	77	69	82	73	72	60
World	84	100	82	77	87	83	78	69

The table shows the biodiversity losses expressed in the changes of the Natural Capital Index indicator (indexed to 100 for the year 2000) for different regions. The NCI is determined by a quality index between 0 and 100 on the basis of the age of ecosystems. Natural ecosystems older than 100 years are indexed to a quality value of 100 and this value is linearly decreased to 0 at the age of 0 years (when it is urban area or agricultural land). In addition, these values between 0 and 100 are decreased in relation to the sum of different pressures on the ecosystems. The pressures taken into account, are rate of temperature change, population density and energy use. See the Global Environment Outlook-3 for more details on this approach (United Nations, 2002).

The increases of the demand for water are thus scenario-specific. Table 5.3 below shows the demand for water in different scenarios, but without irrigation. On the global level STRONG EUROPE shows a decline in the demand for water, whereas REGIONAL COMMUNITIES and GLOBAL ECONOMY show a moderate increase in the demand for water. In TRANSATLANTIC MARKET the high population growth and inefficient use of water, lead to the strongest growth in total demand for water, especially in the non-Annex I regions. GLOBAL ECONOMY and REGIONAL COMMUNITIES will both show a moderate increase of water demand at the global level, although there are different underlying causes. Despite high economic growth per capita, GLOBAL ECONOMY has a lower growth of the population, and rapid diffusion of efficient water demand technologies In REGIONAL COMMUNITIES the low population growth reduces water demand, but the electricity production expansions boosts the total demand for water.

Figure 5.8 Precipitation Surplus, changes in 2040 in Global Economy compared to 2000



Although the ranking of the scenarios with respect to the growth rate of water demand is the same for all regions, the level of the growth rate is region-specific. All scenarios show increases of the water demand in the non-Annex I region, because population and economic growth are higher as compared to the OECD. In the OECD, water demand will still fall in Global Economy from the rapid technological development in water-use technologies. High economic growth, if starting from already high consumption levels, is clearly decoupled from the demand for water. And in the OECD the climate policy further lowers the demand for electricity, thus also further lowering the demand for water. In Regional Communities, the EU-15 demand for water declines twice as strong as in the other OECD region, because in the EU economic growth lags behind and local environmental awareness further lowers electricity demand.

Table 5.3 The growth of water demand by households and industries (average annual % change in 2000-2040)

	Strong Europe	Transatlantic Market	Regional Communities	Global Economy
EU-15	– 1.7	0.3	– 1.0	– 1.2
OECD	– 1.5	0.5	– 0.5	– 1.1
Non-Annex I	0.5	2.6	1.4	2.0
World	– 0.5	1.6	0.5	0.6

Water stress is defined here as the long-term average of annual demand -to-supply ratio[22]. This ratio describes how much of the average annual renewable water resources of a river basin are

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[22] This indicator is derived from water stress, including also the demand for water for irrigation purposes (about one third globally). This will be explained in more detail in RIVM (2004).

withdrawn for human purposes. In principle, the higher this ratio is, the more intensively the waters in a river basin are used, which reduces either water quantity or water quality, or even both, for downstream users. According to this variable, water stress decreases when either water withdrawals decrease and/or water availability increases. Below Table 5.4 qualitatively highlights the most important results of this indicator.

It can be seen that in three scenarios global water stress will rise, because the global demand for water will increase stronger than the available supply. Only STRONG EUROPE will show no deteriorating water balance, because the demand will decline. Table 5.4 also shows that at the regional level opposing trends emerge: a worsening of the situation in Non Annex I, and an improvement in the OECD. The reason is that in some parts of the non-Annex I region the precipitation surplus will decline severely, whereas the demand for water will increase very rapidly in all scenarios because of high population and/or economic growth. The OECD position will improve with respect to water stress, because population does not grow much and technologies will reduce the final demand for water. On the water supply side, large parts of the USA and Canada and to some extent also Scandinavia will also see an increase of the precipitation surplus. As a result, table 5.4 shows that the OECD will experience a strong decrease of water stress in GLOBAL ECONOMY and STRONG EUROPE, and a moderate decrease in REGIONAL COMMUNITIES. The ranking of the scenarios with respect to the impacts on the EU is the same as for the OECD, but the impacts are either a lower reduction or a higher increase of water stress. Within the EU, the population of the Mediterranean will be affected in the long run with more water stress, showing up in reduced water quality and less supply, especially with the relatively high economic growth in TRANSATLANTIC MARKET and the slower improvement in water use technologies.

Table 5.4 Water stress without irrigation (compared to 2000)

	STRONG EUROPE	TRANSATLANTIC MARKET	REGIONAL COMMUNITIES	GLOBAL ECONOMY
EU-15	-	++	-	-
OECD	---	0	-	---
Non-Annex I	+	+++	++	++
World	0	++	+	+

Legend: +++ very strong increase, ++ strong increase, + increase, 0 no change, --- very strong decrease, -- strong decrease, - decrease

5.5 Discussion

We highlighted the impacts of climate change for the different scenarios from a global perspective and a regional focus on the EU. This section closely followed the figure presented in the beginning of Chapter 5. We started with explaining the emissions of the most important GHGs, and included a description on sulphur dioxide because of the regional impacts via acidification and its' cooling effect. Then we discussed the concentration of greenhouse gases in the atmosphere, and illustrated rate and level of temperature changes. Next, this chapter included a section on the regional impacts on ecosystems, and water availability given the changes in supply and demand.

Globally, emissions of GHGs will continue to rise in all scenarios as world economy expands, except for STRONG EUROPE because of the assumption of a successful climate policy in this scenario. In all scenarios, the major part of global emissions will come from developing countries. Currently they emit about 50 percent of global emissions but this will increase to 60-70 percent. The main reasons are the higher growth of population and GDP as compared to the OECD.

The impacts on concentration occur with a delay to the change of emissions because of the long atmospheric lifetimes of carbon dioxide and nitrious oxide. Hence, the impacts on concentration in 2040 will not show significant differences across scenarios. This also holds for the key changes in the climate, temperature and sea level, since these will again follow the changes in concentration with considerable delay due to the inertia of the oceans. Even so, the coming 40 years will show more temperature changes than the last hundred years, strongly influenced by the rapid increase of the greenhouse gases accumulation in the atmosphere because of the high emissions of recent history. With median assumption regarding climate sensitivity, the temperature increase will amount to 1.6^0 Celsius compared the pre-industrial level, of which about 1^0 Celsius will occur in the coming decades. Hence, the target of 2^0 Celsius of the EU will not yet be exceeded in the coming 40 years. Still, we also showed that extrapolating the trends beyond 2040 this target will be exceeded shortly after 2040, unless stringent policies are implemented.

The rate of temperature change shows larger variation over the scenarios and the analysis showed that STRONG EUROPE is the only scenario where the rate of temperature change clearly decreases by the end of 2040, offering good prospects to keep the temperature change within the boundaries of the EU target in the longer term perspective. In all scenarios, the rate of temperature change will exceed the sustainable perceived target of 0.2^0 Celsius per decade. Reduction of sulphur dioxide emissions from coal use is an important factor, e.g. China and India where this reduces the cooling effect on climate. Even in STRONG EUROPE this phenomenon pushes the rate above the target level in the initial stages.

The impacts we highlighted in this chapter concern the domain of ecosystems and tensions between supply and demand for water. For ecosystems we analysed the adaptation possibilities of natural vegetation from climate change, broadened with the issue of biodiversity that depends more on land-use changes. On water we assessed the precipitation surplus, and broadened the issue by also looking at the demand side, i.e. demand for water by households and industries.

Both indicators - the adaptation of vegetation and the precipitation surplus - show for the coming decades similar developments over time for all scenarios, as they depend on temperature change (also little differences across scenarios).

However, land-use changes are directly driven by population and economic growth as well as the structural changes within these economies. The biodiversity losses are in turn driven by land-use, and hence mid-term changes on biodiversity do differ substantially across the scenarios. The biodiversity losses in non-Annex I region will be the largest, mainly because of high population and economic growth. The climate policy in STRONG EUROPE will lower the rate of temperature change by 2040 (compared to 2000) and combined with less demand for land this will even lead to a gain in biodiversity in the EU and other OECD regions. In TRANSATLANTIC MARKET and REGIONAL COMMUNITIES the EU will be ecologically be better off than the OECD, a direct consequence of economic growth in the EU being lower than in the rest of the OECD. Finally, GLOBAL ECONOMY has high economic growth, the arable land increases throughout the world at the highest rate, and hence biodiversity losses will be the largest throughout the world.

The impacts from climate change on water stress are scenario dependent because of diverging developments on the demand side. At the global level, the water stress will increase because the global demand for water will increase and outweigh any changes in precipitation surplus. The non-Annex I regions will be faced with more water stress, because rapid population and economic growth drive up the demand for water, and precipitation surplus tends to decline overall, though local and regional variations are large. The OECD will show less water stress as population and economic growth rates are lower and technology improvements will reduce the demand for water. The supply side will improve because of an increase of the precipitation surplus in many areas in OECD countries. The OECD will experience a strong gain in GLOBAL ECONOMY and STRONG EUROPE, and a moderate gain in the REGIONAL COMMUNITIES. Finally the OECD will experience no changes in TRANSATLANTIC MARKET because of a rapidly increasing water demand as economic growth is moderate and there will be less efficiency improvements in the water demand technologies. The ranking of the scenarios with respect to the impacts on the EU are the same as for the OECD, but the impacts are less pronounced. Despite the uncertainties on the exact changes of the precipitation surplus, in all scenarios the vulnerable Mediterranean area accounts for the less favourable result.

6 Climate policy

To keep global warming below the EU target of 2 °C, the upward trend in emissions has to be bent backwards. This calls for swift and global action. A global cap-and-trade system may keep total abatement costs low. However, the distribution of costs over regions depends crucially on the assigned amounts of emissions. Europe will 'realise' part of its abatement effort in developing regions. Nevertheless, domestic action has to be taken. Increasing energy efficiency and fuel-switching will play an important role

6.1 Introduction

The climate is warming as a result of human activity. This is the conclusion reached by the IPCC, the Intergovernmental Panel on Climate Change (IPCC, 2001). The emission of greenhouse gases will inevitably lead to further warming of the earth in the course of this century. The emission scenarios used by the IPCC suggest that the average global temperature could go up by anything from 1.4 to 5.8 degrees Celsius. The same scenarios show a rise in sea levels between 9 and 88 centimetres. Local effects may be more pronounced. The environmental and economic effects of such changes cannot be reliably predicted, but it is reasonable to suppose that there will be far-reaching consequences before the end of the century.

This threat of global warming asks for coordinated action. In the political process under the UNFCCC parties have therefore agreed that the nations of the world will seek to stabilise the concentration of greenhouse gases in order to ensure that dangerous climate change from human interference is avoided. More than 180 nations have signed this convention so far. However, the convention itself is without serious and binding commitments. It does not specify a time frame for collective action and remains vague about what a safe level means. It is merely a framework in which further action still needs to be specified. The Kyoto Protocol, which was adapted in 1997, can be seen as a first concrete step. Developed countries, the so-called Annex I countries, need to reduce their emissions of greenhouse gases 6% below 1990 levels in the period 2008-2012. Despite its ratification by a number of countries, the Protocol has yet to come into force. Since Russia, at least for now, joined the USA Bush in rejecting this global warming treaty, everything is unsettled.

Europe is at the forefront in formulating climate policies. The EU Council indicated in 1996 that the long-term objective of the European Union climate policy was to prevent that global mean temperature increases beyond 2 degrees Celsius over pre-industrial level (European-Council, 1996). To reach that goal, further action – beyond the Kyoto targets – is clearly required. Regarding the Kyoto Protocol, the European Union is preparing itself for the smooth and early implementation. To facilitate compliance with the Kyoto targets, an EU wide system of emission permit trading will come into force in 2005.

The way future climate policy will be shaped is fundamentally uncertain. However to neglect climate policy in a study on future energy scenarios all together would be naïve. Climate policy is basically about limiting the emissions of greenhouse gases. Given that burning fossil fuels is the most important source of greenhouse gases, climate policy will have a serious effect on future energy demand and supply.

We have chosen to incorporate a stylised climate policy in one of the scenarios. STRONG EUROPE seems to be the most feasible candidate. The chances of successfully introducing climate policies are strongly dependent on the storyline of each scenario. As climate policy is a global environmental problem, in regionalised worlds like TRANSATLANTIC MARKET and REGIONAL COMMUNITIES the lack of global cooperation could seriously hinder the formulation and implementation of effective policies. From another perspective, long term climate strategies require a pro-active attitude towards environmental policies. This prerequisite looks less compatible with worlds that have a more reactive attitude towards the environment, in particular TRANSATLANTIC MARKET and GLOBAL ECONOMY. This means that climate policies are only conceivable in these scenarios if either the need for international action is perceived as such a priority that barriers for this particular issue are overcome. The stylised policy we have chosen in STRONG EUROPE aims at stabilising the concentration of greenhouse gases in the atmosphere at a level corresponding roughly with a doubling over pre-industrial levels. This level of concentration is well in line with the EU long term target for global warming, though considerable uncertainties remain. The most cost-optimal implementation is chosen. Globally coordinated action is assumed and emission rights are allocated on an equal per capita basis.

How likely is climate policy?

Given the opting out by the USA and the Russian hesitation to sign the Kyoto Protocol, one might wonder how realistic it is to assume future climate policy. Serious abatement is likely to have significant economic costs and cooperative action has all the makings of a classic free-rider problem. There are strong incentives for individual countries to defect from an agreement, relax its own costly abatement measures and enjoy the benefits of the remaining coalition members' efforts. Evaluating the American objections to Kyoto, one might come up with the following recommendations for an acceptable treaty: costs should be equally shared and full use of flexible mechanisms should be made. This calls for a global abatement coalition in order to exploit all low cost options. It is less clear what a fair burden sharing rule means. Many allocation rules have been suggested in the literature. Equal rights per capita gives every human being the same entitlement to clean air, but this 'fair' allocation rule affects some more than others, depending on the abatement effort a region faces. Generally, developing countries suffer less with equal per capita emission rights. On the contrary, grandfathering emissions rights (based on historical emissions) would benefit large emitters, like industrialised regions. An outcome based allocation rule could in principle take account of expected income losses. Under the Kyoto Protocol industrialised countries realised their historic responsibility and took the burden.

This chapter assesses the consequences of climate policy in STRONG EUROPE. We focus on emissions, economic impacts and, of course, the repercussions on energy markets. We go some steps further and play with variations on this stylised policy. Crucial factors are the stabilisation target, and the underlying scenario. We analyse how climate policy would affect outcomes in another scenario and we relax some of the assumptions concerning the benchmark policy, e.g. the stabilisation target. Given the improbability of global climate policy in TRANSATLANTIC MARKET and REGIONAL COMMUNITIES, we base our analysis on STRONG EUROPE and GLOBAL ECONOMY, only[23].

Stabilisation at 550 ppmv CO_2-equivalent

The long term goal of climate policy is to keep global warming below 2℃ compared to pre-industrial level. This is translated into a constrained emission profile leading to a concentration of greenhouse gases in the atmosphere of 550 ppmv CO2-equivalent, about twice the pre-industrial level. However, there is considerably uncertainty in the climate sensitivity. The temperature change, due to a doubling of CO2-equivalent concentration, can be estimated to be in the range between 1.5 and 4.5 ℃, with a median value of 2.5℃. Are there alternative emission profiles leading to the same 2℃ target? Even a more relaxed emission profile, leading to a concentration of 650 ppmv CO2-equivalent, might meet the 2℃ target. However on has to assume a much lower climate sensitivity and the temperature increase will be realised earlier. Hence, the probability to meet the long term target with these less stringent emissions is considerably lower (Elzen et al, 2003) Is there room for delay? Delaying response first, compensated by more fierce measures later, might in principle lead to the same stabilisation target. However, postponing abatement does not seem very feasible. Waiting much longer would lead to a critical rate of temperature change and possibly an overshooting of the 2C target. It is believed that serious abatement should start in the period 2010-2025.

6.2 Climate policy in STRONG EUROPE

6.2.1 Emissions

The rising trend in global emissions of greenhouse gases has to be reversed in the near future to reach a safe concentration level by the end of the century. In Figure 6.1 the solid red line shows how global emissions of fossil CO_2 would develop in STRONG EUROPE. If no action were taken to prevent climate change, CO_2 emissions would continue to increase, almost doubling between 2000 and 2040.

The green line in the figure shows a course that global emissions of fossil CO_2 should take if the atmospheric concentration of greenhouse gases is to be stabilised by 2100 at the safe level of 550 ppmv. The gap in emission levels, between what would happen with control measures and what would happen without would continue to widen. Control measures continually need to be upgraded in order to maintain a stable concentration. The yellow line represents emissions in developing countries[24], assuming that no control measures are implemented. It can be seen that, without intervention, greenhouse gas emissions from these countries alone will by 2035 exceed the maximum global levels consistent with a stable atmospheric concentration of 550 ppmv.

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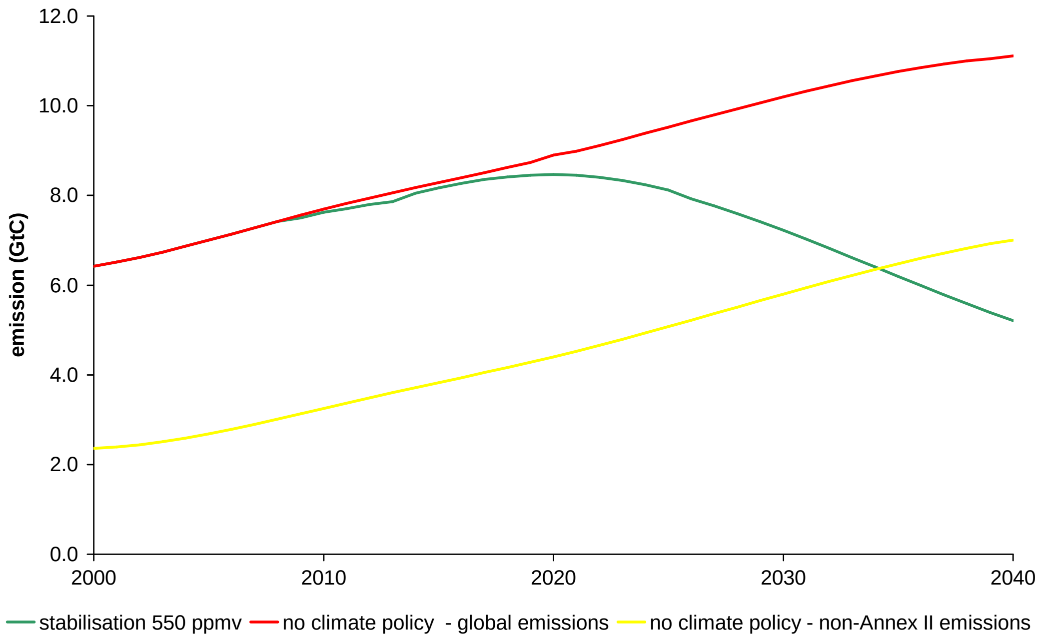
[23] To apply climate policy in GLOBAL ECONOMY, a high emissions scenario, we get an idea of the range of costs. REGIONAL COMMUNITIES is a scenario, in which in European emission fall over time. This makes it unlikely for climate policy.

[24] We apply a rather rough dichotomy between industrialised and developing countries. The group of industrialised countries equals the OECD, Eastern Europe and the countries of the former Soviet Union, the so-called Annex I group. All other countries (non-Annex I) are considered to be developing countries.

The obvious corollary of this is that the industrialised regions cannot possibly achieve stabilisation on their own. In other words, the scope of the Kyoto treaty, which sets modest targets for these nations only, is quite limited in relation to the scale of the problem. Clearly, there is an urgent need for developing countries to adopt climate policies also.

Figure 6.1 **Emissions in STRONG EUROPE**



If not for environmental reasons alone, there are strong economic reasons to involve developing countries in climate change mitigation. Given the potential for relative cheap abatement options in developing countries, it is cost-effective to exploit these opportunities. A cap-and-trade system can be seen as an efficient way. Where a global market in emission rights exists, the distribution of those rights determines the way the burden of climate policy is shared. Following Coase (1960), a marketable scheme will be cost-effective irrespective of how the permits are distributed. Many allocations may be considered (e.g. see Rose et al., 1998, and Elzen et al , 2003). To set the stage, we consider an egalitarian approach to burden sharing: the allocation of emission rights on a per capita basis (equal rights case). From 2012 onwards, after the first budget period of the Kyoto Protocol assigned amounts are assumed to converge and contract to an equal per capita level in 2050. To meet individual emission targets, countries can levy a tax on fossil fuels; coal, oil and gas. This carbon tax is differentiated according to the CO_2 emissions of the fuels (the carbon content). Even if there is no explicit carbon tax, there will be an implicit price on carbon. This shadow price equals the carbon tax.

Table 6.1 shows emissions and allocated emission rights in 2000 and 2040 for a number of regions. To get insight in the reduction effort, 2040 emissions in a reference scenario *without* climate policy are also shown (column 2). In this reference scenario, global emissions would almost double between 2000 and 2040. However, stabilisation at 550 ppmv CO_2-equivalent forces emissions down by more than 50% of the reference value. Relative to 2000, global emissions have to decrease by almost 20%. Allocation of emission rights on an equal per capita base grants relative few rights to industrialised countries, which initially have high per-capita emissions. In 2040 Europe is allowed to emit only 0.2 GtC, compared to 1 GtC in 2000. Developing countries can grow still. The combined Asia/Africa region is allowed to emit double the 2000 levels, but less than in the reference case. Emission trading causes actual emissions to diverge from assigned amounts. Regions with high abatement costs will buy emission rights from countries with low abatement costs. These regions will in turn reduce their emissions *below* allocated levels. For example, Europe's actual emissions at 0.6 GtC are three times the allocated amount. Emissions in Asia/Africa are 40% below assigned amounts. World-wide actual emissions equal assigned amounts, of course.

Table 6.1 Emissions and targets in STRONG EUROPE

	Emissions 2000	Emissions without climate policy 2040	Emission targets 2040	Emissions 2040
Europe	1.0	0.9	0.2	0.6
USA	1.6	1.5	0.2	0.7
Former Soviet Union	0.6	0.6	0.2	0.2
Middle-East / North Africa	0.3	1.0	0.4	0.5
Asia / Africa	1.7	5.1	3.5	2.1
World	6.4	11.1	5.2	5.2

6.2.2 Economic consequences of abatement

To bring down greenhouse gas emissions, emission permits will become expensive. In STRONG EUROPE the price of carbon permits is expected to rise to approximately 425 dollars per ton carbon in 2040. Consequently, the gross price of fossil fuels will rise. The price of oil will more than triple. Higher energy prices will have consequences on income and economic growth. GDP will be lower, due to restrictions on economic performance as a result of more expensive energy. However, income transfers as a result of the import or export of emission permits may mitigate the initial effect on GDP. Income may rise in permit exporting countries. Also prices play a part. Real income may change because import and export prices change (terms-of-trade-effects). Energy and energy intensive production will become relatively expensive. As a result, countries biased to these exports will be worse off.

Table 6.2 shows effects on GDP and income of climate policy in STRONG EUROPE. The table shows the cumulative effect on real national income relative to a reference scenario *without* abatement policy. This effect on income is decomposed into an effect on GDP and the combined effect of permit transfers and a terms-of-trade.

Table 6.2 Costs of stabilisation at 550 ppmv in STRONG EUROPE, 2040

	GDP	Permit transfers and terms-of-trade	Income
Europe	– 0,9	– 1.3	– 2,2
USA	– 0,6	– 1.3	– 1,9
Former Soviet Union	– 5,6	– 0.8	– 6,4
Middle-East / North Africa	– 6,9	0.1	– 6,8
Asia / Africa	– 2,2	2.4	0.2
World	– 1,6	0,0	– 1,6

The dramatic shift in energy use and emissions in STRONG EUROPE has only limited effects on GDP and real national income. Climate policy decreases global level of real income in 2040 by 1.6%. A global market for emissions permit is however crucial for reaching this efficient outcome. A global scheme of emissions trading ensures that abatement is taken place at the lowest cost options, e.g. in developing regions.

It should be noted that there is a difference between GDP and (real national) income on a regional scale. Abatement has a downward pressure on GDP. However, negative GDP-effects are partially offset by permit transfers from industrialised regions. Hence for developing countries with strong negative GDP effects, income effects are less severe and may even become positive due to the sale of permits. To assess the effects in real terms it is important to note that term-of-trade effects play a role. If prices of imports increase relative to prices of exports, income in real terms decreases. For energy exporting countries and energy-intensive sectors this effect can be quite severe.

Compared to the reference scenario without climate policy, the GDP effect of the fierce climate policy in the combined Asia/Africa region in 2040 is – 2.2%, while real national income is even 0.2% higher in this region in 2040. In the OECD-region on the contrary, the effect on real national income is larger than the effect on GDP. This latter result follows from the fact that OECD-countries do not take all the abatement measures by themselves, but buy permits from developing countries. Energy exporters suffer under this allocation rule. In the Middle-East and in the Former Soviet Union region income losses are well above 6%. Given these relative large losses for certain regions, one might wonder whether this allocation is feasible. The ‘fair’ assignment of emission rights on an equal–per-capita basis apparently does not work out in the same way for everyone[25]. An outcome based allocation rule might be used to spread effects on income more evenly. Granting energy exporters more emission rights might shift the burden towards industrialised regions (e.g. see CPB, 2001).

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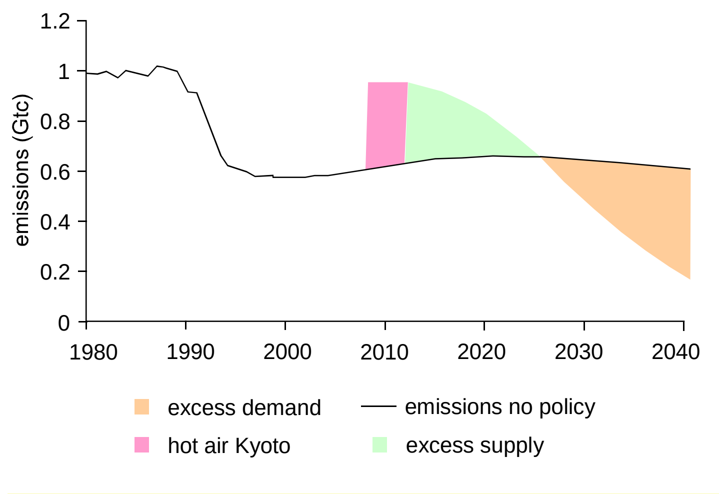
[25] In our assessment, we restrict ourselves to the effect on regions. It may not come as a surprise that within a region energy-intensive sectors (like manufacturing) will be hurt more than energy extensive sectors (like services). In CPB (2003) more attention is paid to sectoral effects.

Hot air in Russia

Emissions in Russia (and all other countries of the Former Soviet Union, FSU) dropped dramatically as a result of the economic recession in the 1990's. Since assigned amounts, according to the Kyoto protocol, were based on 1990 levels of emissions, Russia is blessed with a large excess supply of emission permits (hot air). This excess supply can be sold on the international market for emission permits. If contraction and convergence of emission rights is based on these Kyoto targets, this excess supply can be expected to last for a long time. Russia could decide to 'bank' the excess rights from the early years and 'use' them in later periods. In this way, the pain from serious abatement I later years can be alleviated at the cost of forsaken income from the export of emission rights in the early years. This all depends on whether assigned amounts for Russia are indeed based on Kyoto targets, whether banking over a longer period is allowed for and on the permit price. The permit price depends on the market power selling parties can exercise. In the first budget period of the Kyoto Protocol (2008-2012), countries from the FSU are the only suppliers. Maximising the income from permit sales implies a banking rate of 80%. After the first budget period. More regions with hot air enter the market. Permit prices can be expected to stay low till emission a global level have to be curbed significantly (from 2025 onwards). In our analysis we do not assume full intertemporal optimisation over the whole period. But, it is assumed that, within each five-year period, Russia optimises permit sales and passes unused rights to the next period. In 2040, the FSU has run through all its hot air and bears the full cost of abatement.

Excess targets in Russia in STRONG EUROPE



6.2.3 Climate policy and energy use

Climate policies lead to substantial changes in the energy system. Figure 6.2 shows global demand for energy in STRONG EUROPE. Energy demand in 2040 is compared to the situation in 2000 and to demand in the reference case with no explicit climate policy. In all cases, the contribution by different energy carriers is given.

Increasing energy prices have a strong downward pressure on energy demand. In 2040 global energy demand hardly exceeds demand in 2000. Energy demand is only half of what it would have been in the absence of any abatement policy. Clearly, the reductions in energy use are not similar across the different energy carriers. Energy demand becomes more climate-friendly. The largest reductions occur for coal. In 2000 the share of coal worldwide is still over 25 %. This share diminishes to a mere 10% in 2040. Energy users will substitute 'cleaner' gas and carbon free fuels for coal, the remaining coal consumption being primarily used in electric power stations using carbon capture and storage.

Figure 6.2 **Energy demand in STRONG EUROPE**

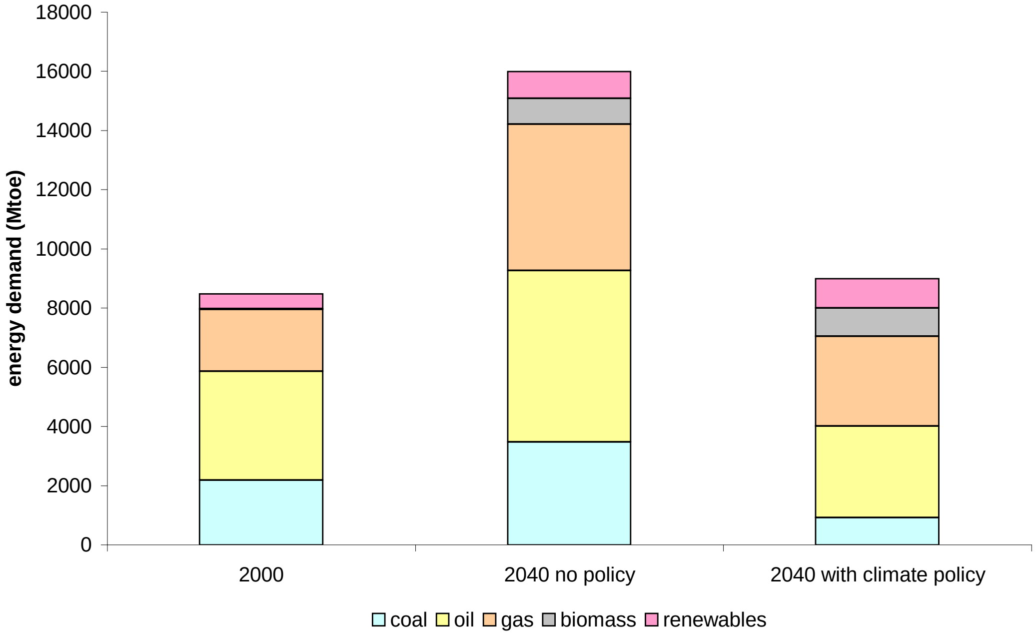
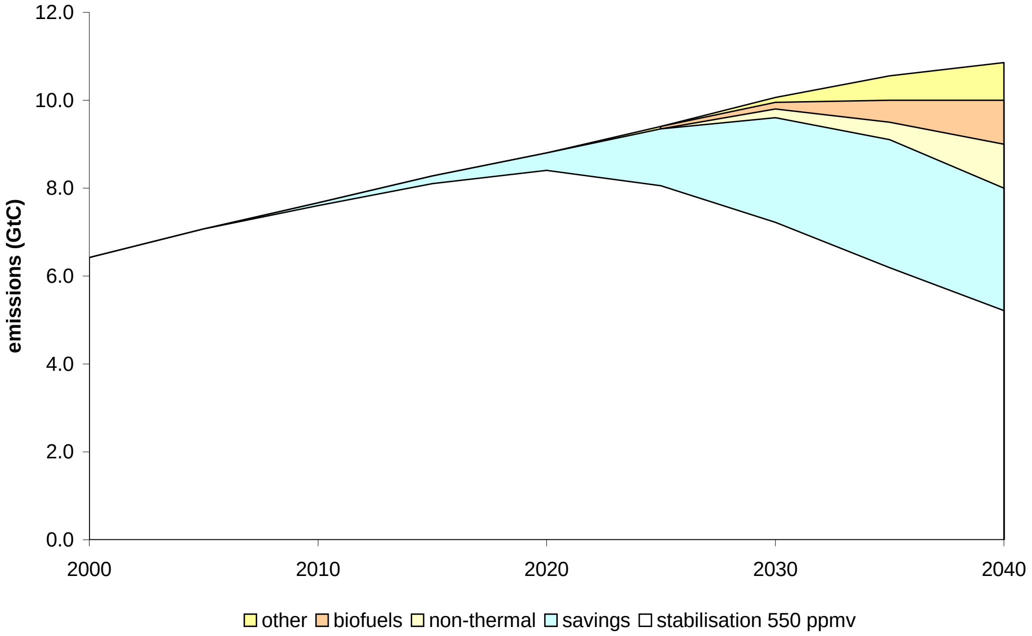


Figure 6.3 **Abatement in STRONG EUROPE**



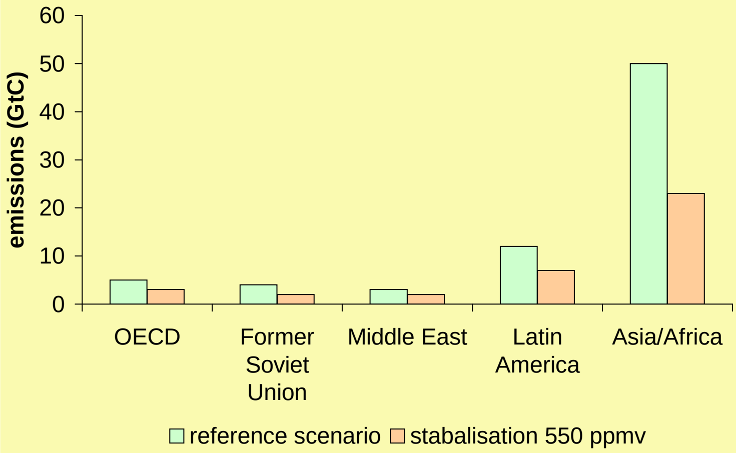
Other energy carriers gain market share. The share of gas increases from 25% in 2000 to 34% in 2040, the share of bio fuels, solar and wind energy more than triples to 22% of total demand energy in 2040.

A number of effects add to lower greenhouse gas emissions. The use of less energy and the use of cleaner energy are the dominating drivers. Figure 6.3 sketches the contribution of energy saving, the role of non-thermal energy (wind and solar) and bio fuels and the effect of other measures (mainly carbon sequestration) in bringing emissions down[26]. The dominant contribution comes from energy savings. Higher energy intensities drive down energy demand and emissions. From 2025 onwards, the role of fuel-switching increases. Bio fuels and non-thermal fuels (solar and wind) contribute in approximately equal parts. Carbon sequestration is projected does not come on the scene before 2025 and even then will only play a limited role (see also box on carbon sequestration). In Europe, where efficiency gains are more limited, fuel-switching has a relatively more important role to play. It should be noted that the dramatic fall in primary energy use does not mean that final energy demand decreases to the same extent. For example, electricity use in 2040 is projected to be only 20% below the reference level and still twice the level in 2000.

Co-benefits

The changes in the energy system result in considerable co-benefits. Less coal use leads to lower emissions of acid pollutants, like sulphur and nitrogen, as a side effect. The figure is illustrative. For STRONG EUROPE it shows 2040 sulphur emissions in different regions, both in the 550 ppmv CO_2-equivalent stabilisation case and in the reference case without climate policy. Reduction of greenhouse gases leads to the reduction of sulphur and nitrogen emissions in the order of 50% to 70%. Co-benefits in developing countries are the largest, given their, initially, high dependency on coal and the lax air pollution control policies in those regions

Sulphur emission in STRONG EUROPE, 2040



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[26] This figure is based on TIMER results. The WorldScan model, on which most results in this chapter are based, only distinguishes between energy saving and fuel-switching. In general, WorldScan assigns a somewhat larger role to energy saving

6.3 Variants on the benchmark policy

In STRONG EUROPE, one rather stylised version of climate policy is chosen. However, economic effects of abatement may vary considerably, depending on the stringency of the policy. Given the uncertainty about future climate policy, this calls for a sensitivity analysis. We explore the consequences of climate policy in the GLOBAL-ECONOMY scenario and play with variations on the benchmark policy. To analyse the influence of the stabilisation level, we apply a more relaxed target: 650 ppmv by the end of this century. This gives us four cases: two stabilisation targets combined with two scenarios.

Table 6.3 Costs of stabilisation in STRONG EUROPE and GLOBAL ECONOMY, 2050

	550 ppmv		650 ppmv	
	STRONG EUROPE	GLOBAL ECONOMY	STRONG EUROPE	GLOBAL ECONOMY
Carbon tax (1997 US$/tC)	426	1212	16	241
Europe	– 2.2	– 6.7	– 0.1	– 1.7
USA	– 1.9	– 5.1	– 0.1	– 1.4
Former Soviet Union	– 6.4	– 16.8	– 0.4	– 5.3
Middle-East / North Africa	– 6.8	– 14.0	– 0.3	– 3.7
Asia / Africa	0.2	– 2.3	0.3	0.6
World	– 1.6	– 5.2	0.0	– 1.0

Table 6.3 presents the effect of climate policy on real national income for a number of regions in the four cases. The corresponding carbon tax is also shown. The cost of stabilisation depends strongly on the stringency of the stabilisation level and the emissions in the underlying scenario. Costs rise increasingly with the abatement effort. In STRONG EUROPE income effects almost vanish if the stabilisation target is relaxed to 650 ppmv. Even without explicit climate policy concentrations of greenhouse gases in the atmosphere will hardly exceed 650 ppmv. In the energy intensive GLOBAL ECONOMY scenario the abatement effort is much larger then in STRONG EUROPE at corresponding stabilisation levels. Accordingly, costs are higher. Global income is more then 5% below the reference level in 2040. Also in this scenario, costs drop with less stringent targets.

6.4 Conclusions

There are many uncertainties concerning climate change policy. Whether coordinated action to beat climate change will be taken before 2040 remains unsure. If countries overcome these barriers, the policy that will crystallise is not clear either. Only stabilisation of the concentration of greenhouse gases at a level double the pre-industrial level is expected to meet the long term EU target for global warming. This calls for imminent action. The commitments agreed upon in the Kyoto protocol are by far not enough. Developing countries have to join any abatement coalition and dramatic changes in the energy system are needed. To keep costs manageable, all low-cost options have to be exploited. A cap-and-trade system is one way to realise this. The burden sharing depends crucially on the allocation of assigned amounts of emissions. We show that allocating emission permits on an equal-per-capita basis can make some developing countries even better off. The income gain from the export of emission permits to developed regions more than compensates for the loss associated with the fierce abatement.

The costs of mitigation depend on the stringency of the target and on the economic growth in the underlying scenario. In STRONG EUROPE we project the global GDP-loss in to be less than 2%. There are serious feedbacks from climate policy to energy use. Not only demand for energy will be restricted, fuel-switching also has an important part to play.

Carbon sequestration

Along with emissions reduction, carbon sequestration may be another option for reducing the CO2 concentration in the atmosphere. One way to sequester carbon involves the direct capture and storage of greenhouse gases from emission sources. Geological sinks include saline formations and depleted oil and gas reservoirs. Forestry measures enhancing the uptake in soils and vegetation (natural sinks) are another option.

Geological sinks can hold thousands of gigatons of carbon (GtC). However to keep costs of transport and sequestration of CO2 low, carbon capture prefers a relatively pure stream of the gas. This makes industrial processes, producing highly concentrated streams of CO2 as a by-product, prime candidates. However costs will rise significantly for power plants, because concentrations are low. In Norway STATOIL showed the commercial successful removal of CO2, a contaminant of the offshore production of natural gas Annually, about 1 MtC is pumped into a sandstone layer at a cost less than $60/tC.

Also, the area of land available for afforestation is huge. Conservative estimates suggest 50 million ha for Latin America, alone. With an estimated carbon uptake between 50 and 200 tC/ha, this implies that a total of 2,5 – 10 GtC can be sequestered in this region. Generally, studies and projects on forest plantation, forest management, and agro forestry show rather low costs. Typical estimates range between 0 and 100 $/tC. However, these costs can be expected to increase further. The opportunity cost of land use will drive up the cost of this option with growing importance.

The magnitude of the role capture and sequestration can play is hard to predict. Efficient climate change policy implies integration of emission reductions in the energy sector and in sinks. Simulations by Benítez and Obesteiner (2003) show that at a given price of 100$/tC Latin America can be expected to reduce two-thirds of its emissions via shift in energy usage and one-third via afforestation (Benítez and Obersteiner, 2003).

Different costs in different models

There is considerable uncertainty about the costs of climate policy. Of course, abatement costs depend on the emission target, assigned amounts and the policy instruments implemented. But even when assessing identical policies, different models show different effects. Not only do key-parameters differ, but model mechanisms may be different, also. Top-down general equilibrium models lack the technological detail of bottom-up models, but do take account of spill-over effects. To illustrate some of this variation four identical stabilisation policies were simulated, both with the general equilibrium model WorldScan and with the bottom-up model TIMER. The table presents the corresponding carbon values. From the table it shows that, in general, TIMER comes up with lower carbon values. The main reason is that TIMER assumes endogenous technological progress making abatement cheaper in the long run. TIMER also exploits more mitigation options, e.g. non-CO_2 greenhouse gases and carbon sequestration. This additional flexibility lowers the carbon value by about 100 $/tC. Especially sharing the burden via reducing methane emission from energy and land use sources turns out to be important. Carbon storage and sequestration has a limited effect, only.

Carbon taxes in different models in 2040, (US$/tC)

	WorldScan	TIMER
Stabilisation at 550 ppmv		
STRONG EUROPE	426	324
GLOBAL ECONOMY	1212	1000[a]
Stabilisation at 650 ppmv		
STRONG EUROPE	16	26
GLOBAL ECONOMY	241	186

[a] TIMER does not allow carbon taxes above 1000 US$/tC, this maximum will be reached in 2037.

7 Conclusions

Building on the four scenarios from *Four Futures for Europe*, we explored the impact of economic growth, demographic developments, institutional changes and technological improvements on energy security, climate change and related issues. We started our study by raising a number of questions with respect to energy markets and climate change related environmental problems. This chapter summarises our findings.

Driving forces

The main driving forces affecting future energy markets and environment are economic growth, demographic developments, technological improvements and environmental policies.

Global energy demand is projected to grow in all scenarios. In a high growth scenario like GLOBAL ECONOMY, primary energy demand is projected to grow at an average annual rate of 2.3%. This growth rate would imply that global demand would more than double in the next four decades. A scenario with a stringent climate policy, such as STRONG EUROPE, shows practically zero growth. All scenarios project energy demand to grow stronger in developing countries than in industrialised countries.

Looking at output growth alone hides some important differences among regions and sectors. Regions with a high energy use per unit of output (energy intensity) are projected to grow at a relatively high rate. This boosts global energy demand. The continuing shift towards a more service oriented society and knowledge spill-overs on energy saving technologies counterbalance this development. The declining importance of energy intensive sectors, like manufacturing, causes a downward trend in energy intensity and energy demand.

Technology may be an important driving force, but in our scenarios no strong diverging assumptions about technology are made. The pace of technological improvements in the various sectors follows mainly from the level of economic growth. As a result, increasing efficiency in power generation and end-use of energy partly offsets the upward trend in energy demand caused by economic growth.

The final driving force we analysed is climate policy. This policy, aiming at limiting the negative impact of climate change, exerts a downward pressure on energy demand.

Resource scarcity

Economic growth and environmental policies significantly affect levels of production and consumption of energy and energy prices. Resource scarcity, however, is unlikely to have a major influence on energy markets in the next decades.

The reserves of oil in the Middle-East could approach their depletion before 2040, in particular in a scenario with high economic growth. Even in that case, the global supply of oil can be secured by non-conventional sources, such as tar sands in Canada. Therefore, absolute scarcity on the supply side will probably not raise the real price of oil in the next decades. In addition, a structural increase in the price of oil is not foreseen due to demand reactions which would be induced by such an increase.

Significant changes could occur within the regional structure of the supply of oil. The current main suppliers from the Middle East region could obtain a bigger share of the global oil market due to depletion of conventional oil fields in other regions. At the end of the horizon of our scenarios, however, their dominant positions will be challenged by the growing production from non-conventional oil fields.

The share of natural gas in primary energy demand will increase. However, geopolitical factors may hamper the growing importance of natural gas, especially in Europe. Europe will become more and more dependent on foreign sources of natural gas. This results from the growing consumption of gas, especially in the power sector, and from the depletion of gas fields in Europe. In all scenarios, the import dependency of Europe grows to at least 70%.

Electricity demand in Europe could triple in the period up to 2040 in case of high economic growth. The price of electricity however could be rather stable due to technological innovations and increasing competition. The role of gas-fired power plants increases in all scenarios because of economic as well as environmental advantages of this production technique. This holds especially for a scenario with a strong environmental policy restricting both coal-fired and nuclear generation. The share of nuclear generation diminishes in all scenarios as a result of high costs associated with this technique and the emergence of new, small scale, generation techniques. However, nuclear power remains relevant in a scenario, such as TRANSATLANTIC MARKET, with geopolitical tensions between gas-importing and gas-producing countries.

Impact on the environment

Global emissions of greenhouse gases will rise in all scenarios as the world economy expands, except in the case of a successful climate policy (STRONG EUROPE) because. In all scenarios, more than half of the emissions will come from developing countries. Currently, these countries emit about 50 percent but this is likely to increase to 60-70 percent due to the relatively high growth of population and GDP. Total cumulative carbon emissions from energy use through 2040 range from approximately 300 GtC to approximately 460 GtC, compared to historical emissions of 350 GtC from 1850 to 2000.

Over the next 40 years, cumulative emissions of greenhouse gases do not yet lead to large differences in concentration and global warming. However, that does not alter the fact that the next 40 years are likely to show more changes in temperature than the past century. Using average assumptions regarding climate sensitivity, the (average global) temperature in 2040 could rise by approximately 1.6^0 Celsius above pre-industrial level. Hence, the target of 2^0 Celsius, set by the European Union, is likely not to be exceeded in the next 40 years. However, emissions before 2040 get a process going which determines the changes beyond. Beyond 2040, global warming will exceed the 2 ^{0} Celsius target, unless climate policy or low economic growth curbs emissions. The rate of temperature change is scenario-specific, especially at the end of the scenario period. The rate of global temperature change increases with the growth of greenhouse gas emissions. But there will also be local cooling effects of SO_2 emissions, which will especially be felt in China and India.

An increase of temperature incurs biodiversity losses. The latter depends also on changes in land-use, deforestation, population, and the structure of production. Until 2040, differences among scenarios follow mainly from differences in the structure of economic growth. Losses will be larger in scenarios with higher economic growth. In STRONG EUROPE climate policy will lower the rate of temperature change by 2040 (compared to 2000) and, combined with less demand for land, this will even lead to a gain in biodiversity in OECD. The EU will be ecologically better off than the rest of the OECD, mainly because their economic growth will be lower. The latter region, however, will likely be less affected by climate change than the Southern hemisphere.

Impacts on water stress differ among scenarios. At the global level, water stress will increase, because global demand for water will increase more than the available supply. Developing countries regions will be faced with more water stress, because of a rapid economic growth enhancing the demand for water, and an on average decreasing precipitation surplus. The OECD will show less water stress as technology improvements will reduce the demand for water, and water supply will locally improve because of an increase of the precipitation surplus. The effects range from a strong improvement in OECD in GLOBAL ECONOMY and STRONG EUROPE to hardly any changes in TRANSATLANTIC MARKET. Generally, the impacts on water stress will be worse in the EU than in the OECD as a whole. The vulnerable Mediterranean area accounts for this result.

Climate change policy

Realisation of the emission reduction targets in the Kyoto Protocol would only have a marginal effect on climate change. However, the experience with new institutions and arrangements, like monitoring and emission trading schemes, can prove useful. Early investment in this kind of arrangements will get societies in the right lane for global action after the first budget period of the Kyoto Protocol.

Stabilisation of the concentration of greenhouse gases at a level of 550 ppmv (which is approximately double the pre-industrial level) under median climate sensitivity assumptions[27] will stand a good chance to meet the long-term EU target for global warming.

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[27] This is based on the climate sensitivity parameter, which is the equilibrium temperature effect of a doubling of CO2 equivalent concentration of greenhouse gases in the atmosphere. The IPCC gives a range of 1.5 to 4.5 °C, with 2.5 °C as the best guess. The latter value is adopted in this analysis.

To keep temperature changes below the EU target, emission reductions cannot be delayed much longer, unless economic growth is low. Before 2025, the upward trend in emissions should be turned into a decline in order to reach that target. Global energy-related carbon emissions in 2040 should be almost 20% below the 2000 level. Given the strongly growing emissions of developing countries, their participation in any abatement coalition would be necessary.

To keep costs manageable, all low-cost options should be exploited. In this respect, energy-efficiency improvements appears to be efficient options for curbing emission of greenhouse gases, followed by fuel-switching. The role of coal will diminish, but with large reductions even the share of natural gas will come under pressure. Carbon capture and storage and biological sequestration are projected to play a limited role. Exploiting alternative sources of energy is important. The role of non-carbon fuels has to be increased. In STRONG EUROPE, the share of non-fossil fuels (biomass, nuclear, wind, sun and hydropower) may increase to almost 25%, compared to 6% in 2000.

A cap-and-trade system could be an efficient way of realising emission reductions. The costs for each country depend on the allocation of assigned amounts of emissions. We show that allocating emission allowances on an equal per-capita basis can make some developing countries even better off than without the climate policy. The income gain from the export of emission allowances to developed regions could more than compensate for the loss associated with emission reductions. Energy exporters will be worse off, because fossil energy demand and prices will fall.

The costs of mitigation depend on the stringency of the target and on the economic growth in the underlying scenario. In STRONG EUROPE, we project the global GDP-loss in to be less than 2%, with a carbon tax at the level of 450 US$/tC. Associated effects on real national income range from a loss of 7% in the Middle East and countries in the Former Soviet Union to a small gain in Asian and African countries. The EU15 could face losses of 2%.of GDP.

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