The european energy system in the context of long term climate policies

Patrick Criqui, Silvana Mima, Alban Kitous

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Patrick Criqui
Silvana Mima
Alban Kitous

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LEPII
BP 47 - 38040 Grenoble CEDEX 9 - France
1221 rue des Résidences - 38400 Saint Martin d'Hères
Tél.: + 33 (0)4 76 82 56 92 - Télécopie : + 33 (0)4 56 52 85 71
lepii@upmf-grenoble.fr - http://www.upmf-grenoble.fr/lepii

Université Pierre Mendès-France Grenoble
Sciences sociales & humaines

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

THE EUROPEAN ENERGY SYSTEM
IN THE CONTEXT OF LONG TERM CLIMATE POLICIES

Patrick CRIQUI, CNRS Senior Research Fellow, LEPII, University of Grenoble-CNRS

Patrick.Criqui@upmf-grenoble.fr

Silvana MIMA, Research Fellow, LEPII, University of Grenoble-CNRS

Silvana.Mima@upmf-grenoble.fr

Alban KITOUS, Research Fellow, energy modelling, ENERDATA S.A., Grenoble

Alban.Kitous@enerdata.fr

Abstract

The future of the European energy system will strongly depend on a future world energy context that will be dominated by two key challenges. The first challenge corresponds to the necessity of meeting the energy needs of a growing population in Asia, South America and Africa, while some key energy resources – oil and natural gas – enter in a process of increasing scarcity. The second challenge results from the need to rapidly adjust the structure of the world energy system in order to meet the tightening constraints induced by the will to limit anthropogenic climate change. Both issues are clearly strategic for Europe as on the one hand the Union will have to master a growing import dependency from the international markets and neighbouring regions, and as on the other hand it intends to take the lead on the international scene for climate change mitigation policies.

Analyses of world long term energy scenario show that the growing scarcity on hydrocarbon supply will not solve the climate change problem as it will rather result in increased coal consumption. Conversely seriously addressing the climate change challenge will imply lower fossil fuel consumption, allow an extension of oil and gas reserves and lead to a real double dividend in terms of sustainability: by climate change mitigation and by reduced tensions and risks of crises on the oil and gas markets. Similarly, ambitious GHG abatement scenarios for Europe will allow limiting the Union's import dependency, which is of course one key element of overall security. Thus, addressing the fossil fuel emissions abatement issue clearly appears as a top priority on the agenda. In this paper we focus on what GHG emissions mitigation policies mean for the European energy system within a global framework

1. Introduction

It is now more and more acknowledged that avoiding climate change will be a globally less costly strategy than dealing with its effects: "Dealing with climate change is an imperative for today, not an option for tomorrow" (Beckett, 2006 ; Stern, 2006). To meet the goals of the Framework Convention on Climate Change, which aims at "stabilizing greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (article 2, UNFCCC, 1992), several European countries, recently echoed by the European Commission (Communication of January 10, 2007) are currently proposing that the emissions of industrialized countries be cut to a third or a fourth of their current levels, and that the growth of emissions in the developing countries be significantly limited (De Boissieu, 2006). The resulting global emissions profiles would then enable CO2 concentrations to be stabilized at levels around 450 and 550 p.p.m.v. (CO2 only), according to the scenario, i.e. less than twice the pre-industrial level of 270 p.p.m.v. in 1800.

Aiming to take the lead in the fight for limiting climate change, the European Union's leaders have recently agreed to slash carbon dioxide emissions by 20% from 1990 levels by the year 2020 and to produce a fifth of its total energy via renewable sources by the same date (decision of the European Council, March 8-9, 2007). This agreement is part of broader target of Europe's overall goal of limiting the average temperature increase to less than 2 °C above the global temperature prior to the industrial era. The corresponding global emissions profiles should then enable greenhouse gas concentrations to be stabilized at 450 p.p.m.v. or below (CO2 only).

In this paper we try to identify the implications of different climate policies on the global and European energy system. We will show that aggressive policy measures may manage not only to reduce greenhouse gas emissions (and therefore global warming) but also to alleviate the risks on the availability and the upward pressures on the price of crude oil and natural gas. The "carbon value", which is introduced in energy models corresponds to the price signal that is needed to trigger the investment required to lower greenhouse gas emissions. As such, it provides a proxy for the intensity of GHG abatement policies that may also be based on other instruments, such as Policies and Measures and technical standards. The carbon value serves to measure the effort necessary to reduce emissions in every sector of the economy and provides a good idea of the amount of socially-responsible investment required to protect the world's climate.

The Section 2 of the paper provides a description of the Reference scenario based on some key assumptions on macroeconomic growth, and the implications for the global energy system of two carbon constraint scenarios. Section 3 is focused on the consequences for the European energy system in a world context, with the aim of describing the long term impacts of the recent decisions at the EU level.

2. World energy system under a growing carbon constraint

In this paper we use the POLES model to carry out a comprehensive analytical study of these implications of meeting the two challenges of growing oil and gas scarcity and reducing GHG emissions.. We adopt a particular focus on Europe within the world energy context. POLES is a partial equilibrium model of the world's energy system that provides a detailed year-by-year projection of the energy outlook until 2050, for 47 countries and regions of the world. The model simulates the energy demand for each economic sector, the supply and of prices for the primary energy sources on the international markets, and the impact of innovation, experience effects and R&D in renewable energy technologies and major energy conversion systems (electricity or hydrogen-based for the longer term).

This model therefore provides a consistent framework for studying the dynamics between energy and the environment. On the basis of the exogenous economic growth and demographic projections for each region and the resource constraints for both oil and natural gas, it then enables the calculation of greenhouse gas emissions from burning fossil fuels and of the marginal cost of reducing emissions in the various countries or regions. It thus makes possible the simulation of various emission constraint scenarios, and the identification of the consequences of introducing a carbon tax and assess emissions trading systems.

The Reference scenario provides a vision of what the world's energy scene might be in 2050, if no severe emission abatement policies were taken. This vision is based on exogenous assumptions that are plausible on the basis of identified trends and constraints. It is not a forecast, but simply a possible and coherent projection of energy demand, supply and prices in the different world regions. This projection is then used to develop scenarios for more active policy frameworks in order to contain climate change in more acceptable proportions. We first present the exogenous assumptions on which our Reference scenario is based and then its main implications in terms of energy consumption, oil prices and greenhouse gas emissions. The following subsections are dedicated to the analyses of two alternative carbon constraint case and to the identification of their impacts on energy markets and technology developments.

2.1 Key assumptions and carbon constraint scenarios

Projecting long-term energy profiles involves assumptions on a set of exogenous variables, principally: future population by region, expected economic growth, non renewable energy resources, and finally potentials, costs and performances of new energy technologies. The population growth assumptions are derived from the United Nations demographic forecasts (UN, 2004). The world economic growth outlook results from CEPII[1] projections. The US Geological Survey (USGS, 2000) and the German institute BRG (BGR, 2004) are the sources of information used for oil and gas

[1] Centre d'Etudes Prospectives et d'Informations Internationales"

Ultimate Recoverable Resources. It provides a set of estimates and attached probabilities that are consistent on a world and region-by-region basis. Technological developments regarding energy technology costs and performances are derived from the TECHPOLES database, which is designed to gather and prepare validated information on the technologies' costs and performances.

The macroeconomic assumptions illustrate a complex process of catch-up and convergence in which the dynamics of economic growth varies according the level of the economic development of the country: while in industrialised countries the per capita GDP growth level stabilises at around 2% p.a., the growth in emerging regions corresponds to a dynamics of fast increase in per capita GDP growth in the first stage of the emerging from the poverty, followed by a deceleration in economic growth when the economy becomes mature (see Figure 1).

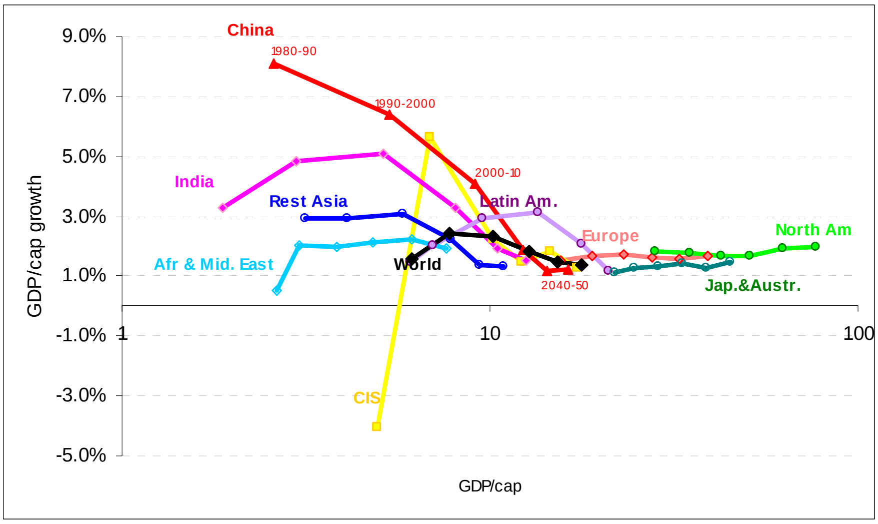

Figure 1 : GDP per capita growth per decade, 1980-2050

The different scenarios developed in order to explore emission reduction pathways (GRP study, Criqui et al., 2003) and the various energy alternatives for the future (WETO-H2, 2007) concur on the fact that, in order to limit climate change, industrialized country emissions should be reduced by a factor of two to four by 2050 and that the growth in emissions of developing countries should be significantly limited. Since the long-term climate targets in several European countries are now based on such scenarios, their main implications for the global energy system should be examined.

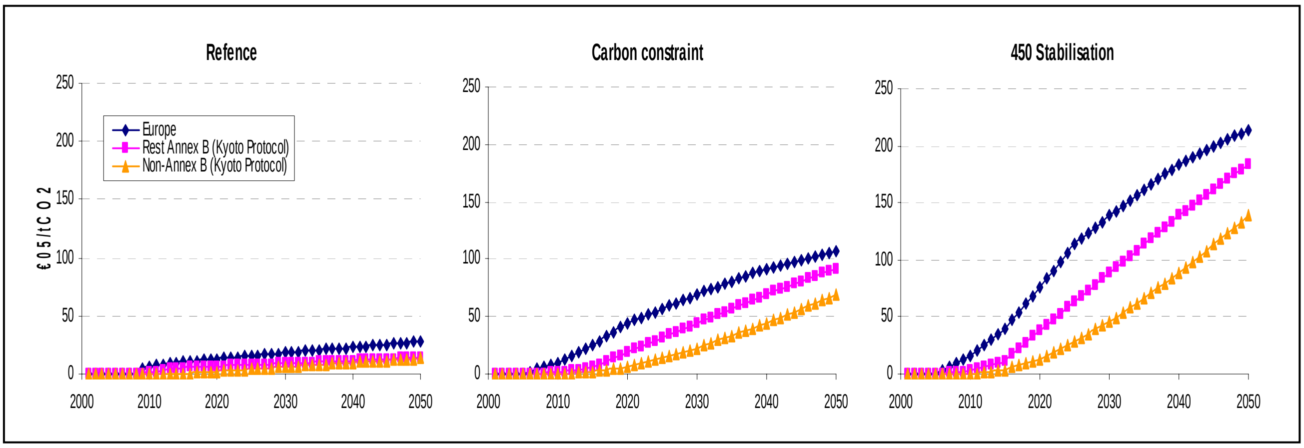

Figure 2 : The carbon value as a proxy for the intensity of climate policies

We tackle this issue by developing two alternative scenarios, with two different sets of assumptions on the carbon value, i.e. on the intensity of mitigation policies in the different regions of the world (see **Figure 2**). It should be noted that this carbon value is a kind of proxy variable that is a synthesis of the various instruments, be it taxes, emissions quotas, policies and other measures that may be combined to achieve the desired result, in a "dose-response" type approach. This paper describes the results of two alternative outlooks and provides an analysis of the implications of high carbon values scenarios on the global energy system, as resulting from the comparison with the Reference Case.

The Reference scenario (REF) provides a plausible projection of future energy use and carbon emissions until 2050, assuming that the current main trends continue and that climate policies remain limited in their ambition. The first alternative scenario, or Carbon Constraint case (CC) simulates abatement policies that would drive CO2 emissions in 2050 back to their 2000 level. The second scenario proposed, or 450 p.p.m.v. Stabilisation" (450S), examines a carbon constraint situation that is much more severe, but would allow to meet Europe's overall goal of limiting the average temperature increase to less than 2 °C above the global temperature prior to the industrial era. This involves stabilizing concentration levels at 450 p.p.m.v. or less. In this case the industrialized countries would indeed have to reduce their emissions in 2050 down to a quarter of what they were in 1990 to achieve this profile.

2.2 The energy and CO2 emissions outlook

The world energy system adapts to these different levels of CO2 emissions constraints. With an implied low carbon value, the REF scenario clearly reveals a steady increase in the consumption of energy. Fossil fuels continue to account for almost 70% of the global energy balance in 2050 (compared to 80% today). Furthermore, the REF scenario foresees a significant comeback of coal, which is abundant worldwide and maintains its market share while both oil and natural gas see their market shares decline over the period, as new reserves and sources of supply become increasingly scarce and prices correspondingly higher. This scenario implies that emissions are almost doubled in 2050 and would clearly be incompatible with keeping climate change under control, since carbon concentration profiles would in that case correspond to about 900 p.p.m.v..

Higher carbon taxes produces the desired effect on CO2 emissions, which in the Carbon Constraint case go back in 2050 to their the current level, while they are cut by half from 2000 to 2050 for the 450 Stabilization scenario; in the latter case industrialized country emissions are reduced by a factor of four compared to today and those of the developing countries by about 10%. The introduction of a high carbon tax is particularly effective in reducing the demand and use of fossil fuels, which in the 450S case only account for less than half of the global energy supply in 2050, as renewable and nuclear energy technologies become increasingly widespread.

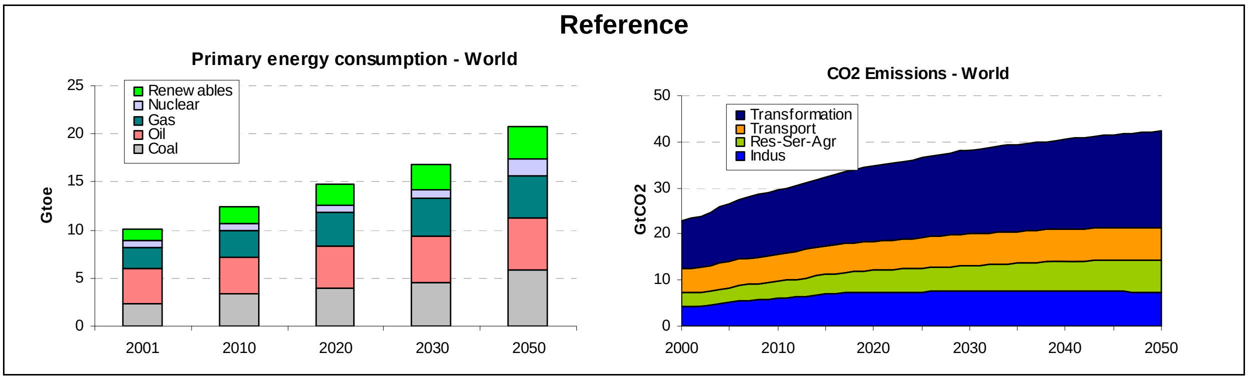

Figure 3 : World primary energy and CO2 emissions

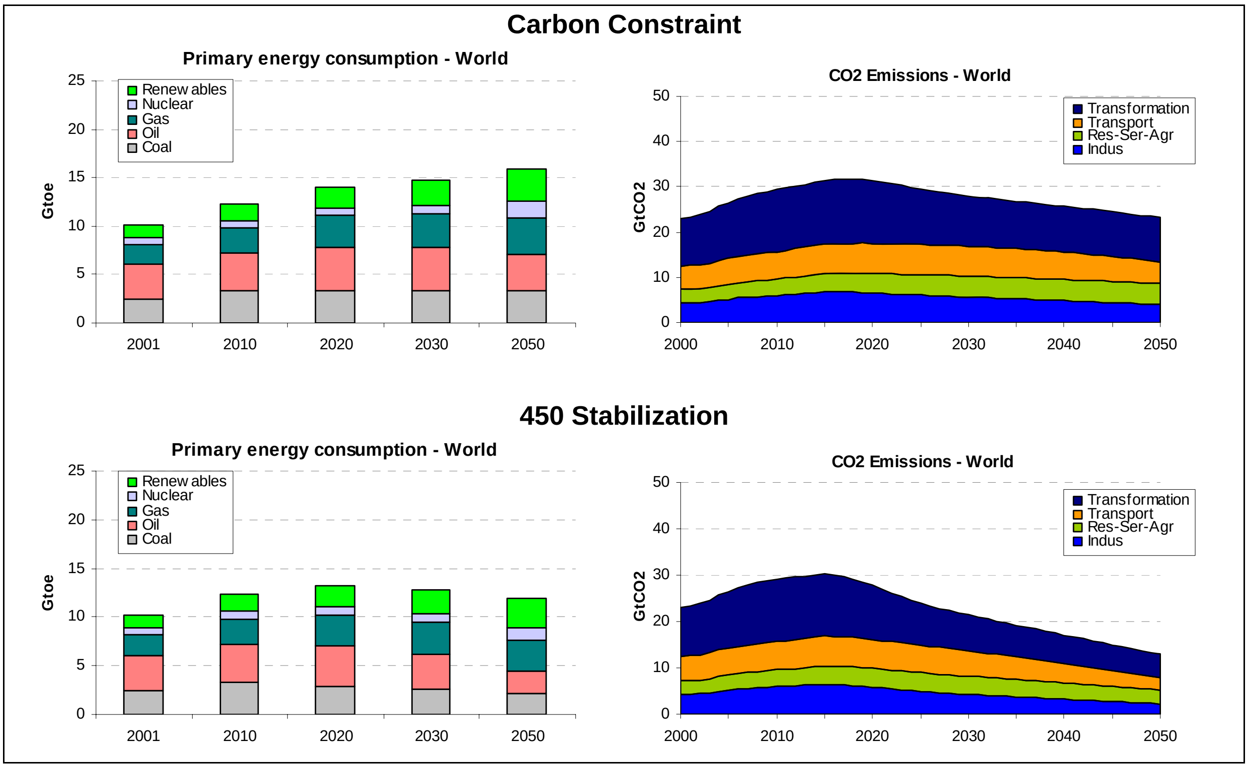

Figure 4 (cont.): World primary energy and CO2 emissions

2.3 The increased sustainability in international oil and gas markets

In terms of supply, conventional oil production in the REF case increases until 2030, then it stabilizes and begins to decline around 2050. The model's peak oil is therefore relatively flat and correspond to a very limited expansion in production, since the stabilization level is only 20% more than current production. To enable this stabilization of conventional global oil supply, the Gulf countries have to more than double their production. The growth in global oil consumption and production, which is strongly constrained by higher prices, will therefore essentially be enabled by the rapid increase in the production of non-conventional petroleum sources expected around 2030 (i.e. extra-heavy oils in Venezuela and tar-sands in Canada). In the 450S scenario oil production begins to decline in 2020 as the high and still increasing carbon tax weighs increasingly on the demand. In the Carbon Constraint case, oil production is situated in an intermediate position compared to the REF and 450S scenarios.

In the REF scenario, crude oil would cost approximately $90/bl by the end of the period. This is much higher than the cost of developing alternative liquid fuels from non-conventional sources, such as extra-heavy oils, tar sands, oil shale and even synthetic fuels from coal. This is clearly why the projection includes a high level of non-conventional oil production. Further more, this high price level is necessary not only to stimulate supply but also to significantly slow down the growth in global demand. One major results of this set of simulation is that in the two alternative scenarios, but particularly in the 450S case, the oil price follows a much lower path and even decreases by the end of the simulation period at 60$ and less than 40$/bl, respectively in CC and 450S.

The price of natural gas also increases in REF, but not as much since the resource constraint is relatively less severe, or rather shifted in time. The natural gas price decreases from 60$/boe in the REF to 42 and 31$/boe in the alternative scenarios. As for the case of oil, following strong emission abatement paths strongly reduces the demand for fuels, which would alternatively be in growingly scarce supply. Low emission profiles also allow enhancing significantly the sustainability of primary energy resource markets.

It should however be noted that these lower prices are only reached for oil and natural gas suppliers, and are not reflected in the prices charged to end-users and consumers since in general these have to pay the carbon tax or permit price. Moreover, it is the high level of this tax that will considerably reduce the demand for fossil fuels, alleviate the pressure on oil and natural gas resources and make all low CO2 options less expensive, at the user or industry level.

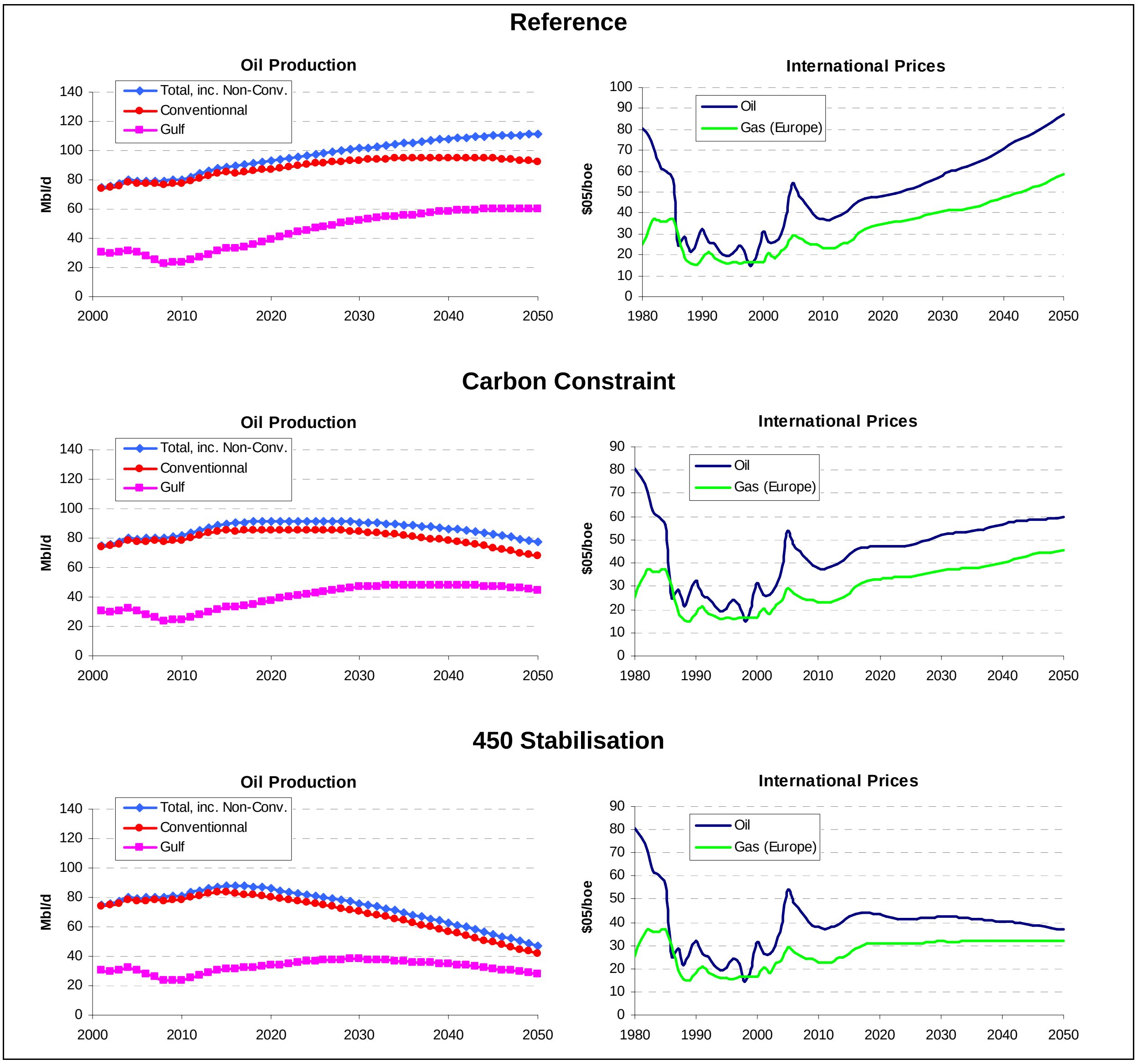

Figure 5 : The impacts on oil demand/production and the international energy prices

One of the most noteworthy differences between the REF scenario and the 450S scenario is that, the increasing rarity of crude oil in the REF scenario only slightly reduces the growth of overall fossil energy consumption since it translates into a considerable increase in the use of coal with potentially severe consequences for the global climate; whereas in a scenario with a severe carbon constraint oil becomes more abundant and cheaper. This is probably the most significant double-dividend or "win-win" strategy element identified so far for ambitious climate policies based on mitigation.

2.4 The contribution of the different "emission abatement wedges"

In order to reduce carbon emissions, the energy system has to be restructured in two different ways, firstly by modifying the demand for energy – in terms of level and in quality – and secondly by changing the structure of supply, in particular the electricity system, which stands at the crossroads of primary sources and final consumption of energy carriers. Measures that modify the demand for energy include switching to low-emission alternative energy sources and, in the longer term, further reducing consumption by developing and deploying more efficient “Very Low Emission” equipment or durable consumer goods in the transportation, construction and manufacturing sectors.

The second type of measures includes four different options for "decarbonizing" electrical power production. The first is to substitute natural gas to coal and heavy oil, while the other three options involve three distinct types of solution: the use of renewable energies (e.g. wind, solar power, hydropower and biomass); the development of nuclear power (using current technology reactors or new "fourth-generation" reactors); and finally CO2 capture and storage for large thermal power plants.

All of these actions are used to achieve the carbon emissions reduction target in the CC and in 450S (see Figure 6) their respective contribution to emissions reduction varies over the period. Initially, the bulk of reductions is obtained by substituting natural gas for coal and crude oil in those applications where it is easier, and in the generation of electrical power. Then cleaner power production technologies (Carbon Capture and Storage, renewable energies and nuclear power) are developed sufficiently to enable much of the reductions up to 2035. Towards the end of the period, the penetration of "Very Low Emissions" demand technologies (for which the time required for deployment depends largely on the relatively long life of buildings) will progressively bring significant contribution to emission reductions.

It should be noted that renewable energies and nuclear power make an increasingly large contribution to the reduction effort, whereas the impact of carbon capture and sequestration technologies diminish at the end of the period due to the increasing costs of storage sites and CO2 losses upon capture that ultimately make these technology options sensitive to a high level of carbon tax.

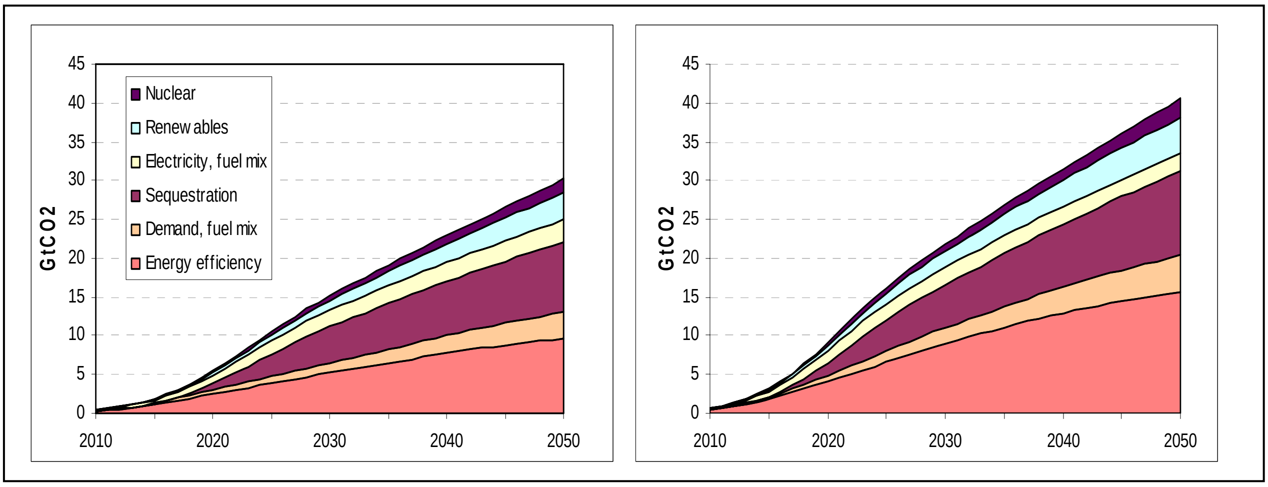

Figure 6 : The emission abatement wedges to reduce CO2 emissions

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

3. The European energy system

The Reference and different emission abatement cases provide a hopefully consistent framework for the analysis of the dynamics of the European energy system in different policy contexts. This section is dedicated to the analysis of the main transformations to be brought to this system in order to comply to the recent quantitative targets set out by the Commission and the European Council and to longer term objectives.

3.1 Matching the emission constraint target to 2020 and beyond

In this sub-section, we focus on Europe[2] and the impacts of the above-described scenarios on its Total Primary Energy Supply (TPES) and related CO2 emissions. The primary energy consumption of Europe in the REF case is increasing only slightly up to 2050, from 1900 Mtoe to 2350 Mtoe, as over the period the energy intensity decreases by 45%. While the share of nuclear and coal remain stable, the share of oil decreases and the share of renewables and gas increase. CO2 emissions roughly stay at their 2000 level over the period. In the CC and the 450S both the TPES and the energy mix are significantly modified: the energy system becomes more efficient and less carbon intensive.

In the CC scenario, the primary energy use is reduced by 15% in 2030 and 27% in 2050 compared to the REF (Figure 5). In 2050 the share of coal decreases to 11%, vs 16% in the REF case, mainly to the benefit of renewables (24%, against 18% in the REF). The 450S case leads to an even less energy-intensive economy, with the primary energy use being reduced by 43% in 2050 (the energy intensity decreases by 70% over 2000-2050). Fossil fuels still represent 55% of the TPES (68% in the REF): this is mainly oil still used in transport (although competing there with electricity) and coal & gas in the electricity sector where they are associated to CCS technology.

The combination of reduced TPES and less carbon intensive energies entails stronger CO2 emissions reductions for Europe, which reach in 2020 -20% (compared to 2000) for CC and -30% for S450, and respectively -50% and -72% in 2050. One can notice that the transformation sector (mostly electricity production) is the most impacted, as the transport and residential-tertiary sectors are less reactive to the "carbon value". This is mostly due to the level of existing taxes in these sectors that lead to relatively lower changes induced in user, compared to those in the industry and power sector.

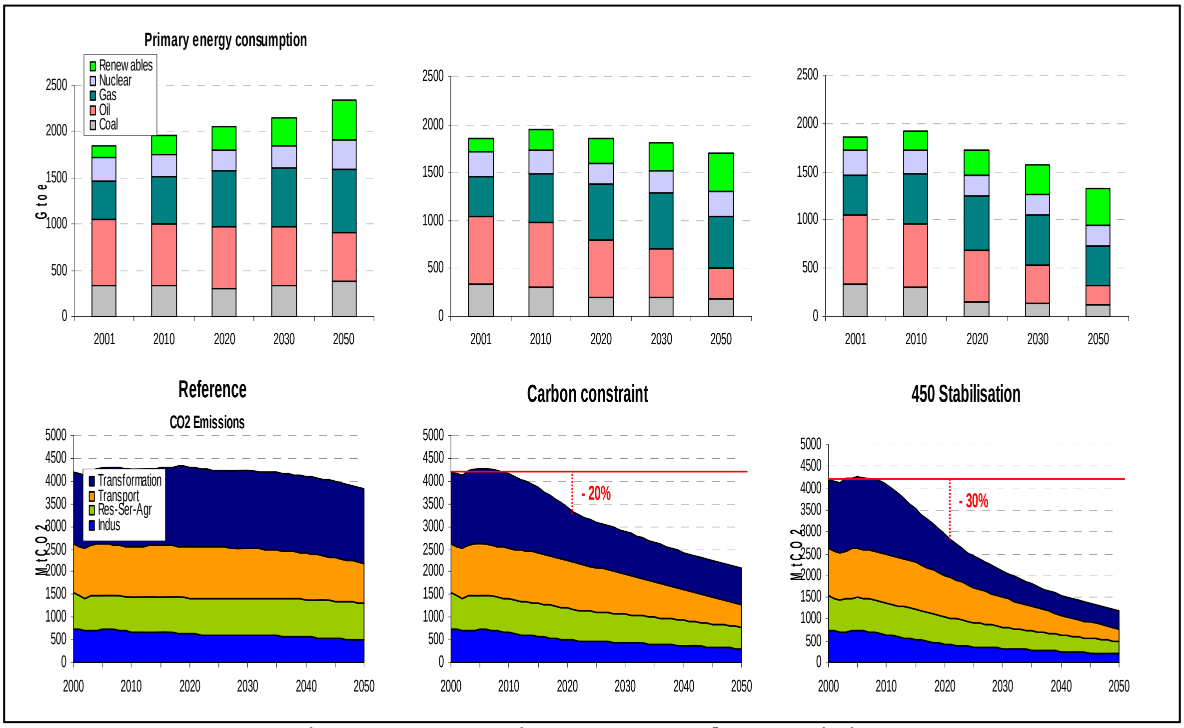

Figure 7. Europe primary energy and CO2 emissions

[2] Europe includes : EU27, Former Yugoslavia, Switzerland, Noway, Iceland.

3.2 Status of additional quantitative objectives of the European Commission: the 20-20 rule for 2020

In addition to the emissions targets, the EU Commission – followed by the Council – has set additional energy and climate goals by 2020[3] and in particular: energy demand should be 20% lower than in a "business as usual" scenario, and renewables should represent 20% of the European TPES (these targets are actually aimed at the EU27 only, but have here been extended here to all Europe). The two carbon constrained scenarios show that these two objectives are almost consistent with the transformations of the European energy system implied by the CO2 emission targets: indeed the energy demand is reduced in 2020 by 10% in the CC and by more than 15% in the 450S compared to the Reference, while at the same time renewables share reaches almost 15% in both cases in 2020 (Figure 6).

However, this exercise also underlines the fact that to some respect, the "20-20 for 2020" rule goes beyond the CO2-only policies, particularly as far as the renewable energy targets are concerned. This may imply that these discrepancies will be reduced in the future through some dedicated policies aimed at accelerating energy efficiency and the diffusion of renewables (white and green certificates, feed-in tariffs, taxes on energy consumption, CAFÉ-type standards on vehicles). The discrepancy may also be justified by the fact that accelerated renewable development also brings important co-benefits on top of CO2 emission reduction, in terms of energy self-sufficiency, overall cleanness of energy supply, industrial competitive advantage and finally positive economic externalities at local level.

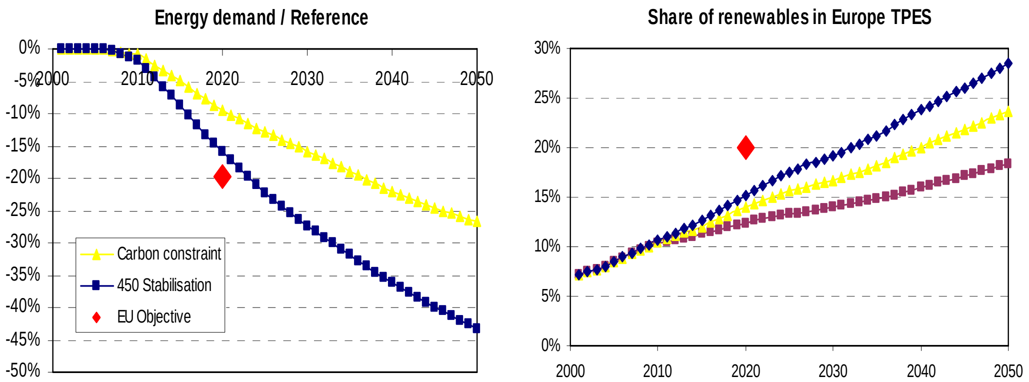

Figure 8. Contribution of CO2-specific policies to other European objectives

3.3 The consequences on EU energy supply

The introduction of CO2 emissions mitigation policies entails lower energy consumption and thus lowers supply-dependency: the energy independence, measure as the ratio of domestic energy production on Total Primary Energy Supply in 2050 increases from 50% in the Reference case to 60% in the CC and 66% in the 450S scenario. However, one would have expected higher gains for European self-sufficiency: to some extent lower international energy prices (see Figure 5) do not encourage the production of expensive domestic fossil fuels in Europe, and therefore the ratios of gas and oil independence are only slightly affected; the ratio actually even decreases for oil.

[3] See : http://europa.eu/press_room/presspacks/energy/index_en.htm

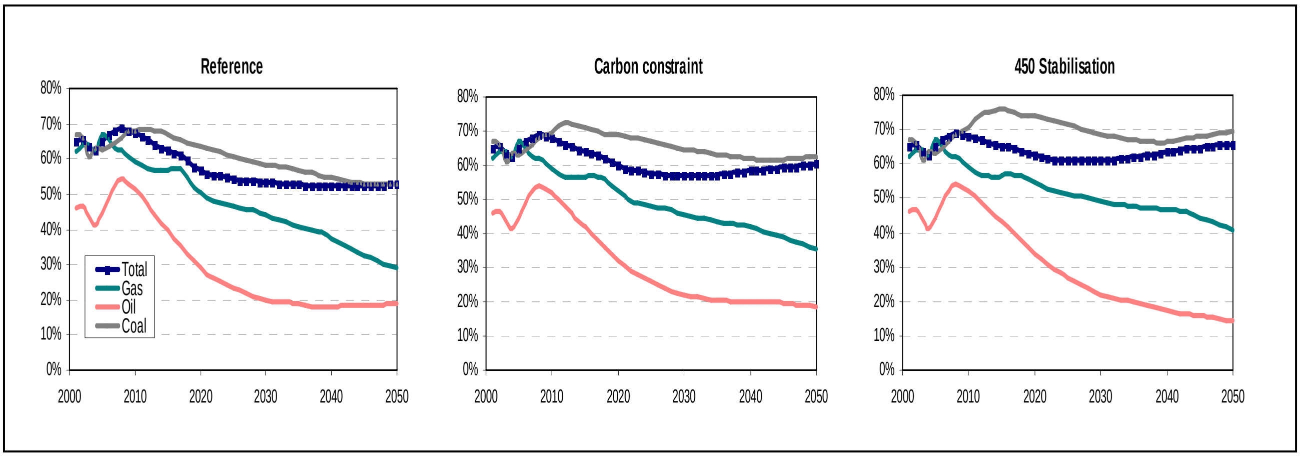

Figure 9. Europe energy independence in the three scenarios

In terms of volumes, however, the outcome is much more significant and "positive" for Europe (Figures 8 and 9): by 2050 oil and gas imports decrease respectively by 40% and 25% in the CC, and by 60% and 40% in the 450S scenario.

Furthermore, the constrained cases lead to a more diverse gas supply for Europe and ensure a higher share of endogenous gas (mostly from Norway), even though in all scenarios Russia remains the main supplier over the entire period (Figure 9).

Consequently, even though the European oil independence decreases and the gas independence is not much affected, the overall level of energy security is greatly improved in the two "climate policy" scenarios.

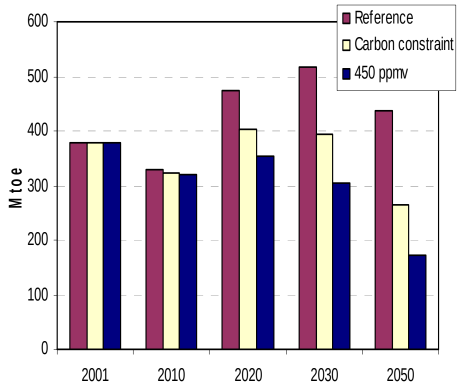

Figure 10. European oil imports

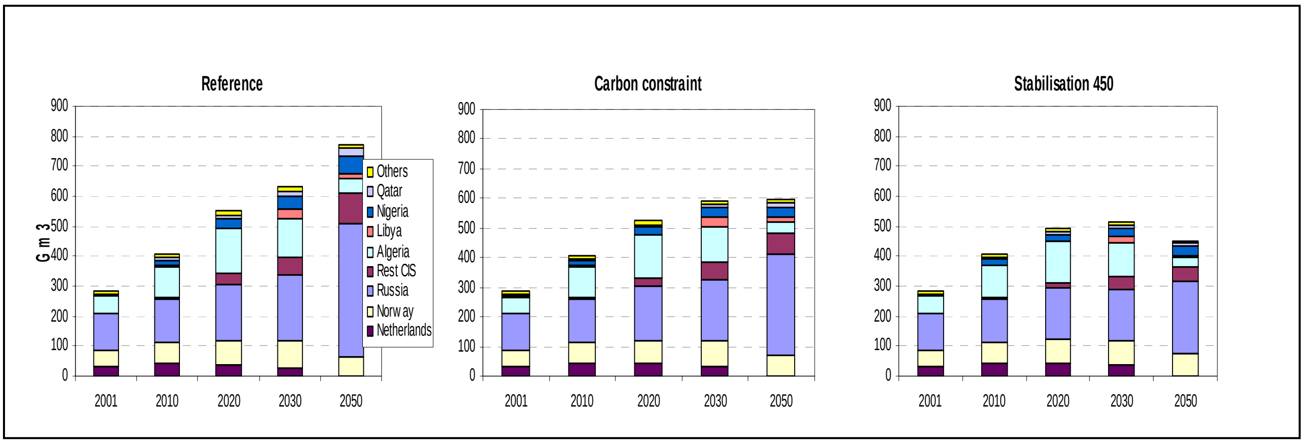

Figure 11. European gas imports

4. Conclusions

This analytical work, which is based on a partial equilibrium model of the world energy sector, shows that a drastic reduction in GHG emissions by 2050 is only possible if active policy measures, corresponding to a steadily increasing carbon value are implemented in the next decades. The range of the carbon value obtained is high, but consistent with considerations of its potential impact on final energy prices and of long-term price elasticities. Even though these scenarios are exploratory, they show that no major option may be neglected if total GHG emissions are to be reduced drastically. These options are: i. Low or Very Low Emission technologies in the building, transportation and manufacturing sectors; ii. an accelerated deployment of renewable energies; iii. new nuclear power capacities and iv. carbon capture and storage for thermal plants. It must be noted that these measures are only likely to be socially acceptable if additional accompanying measures are implemented to make the burden tolerable for both consumers and the business community. The incentive systems will also have to allow for long-term anticipations and adjustments by the decentralised agents.

It comes out of the simulations that if the climate change policies happen to have a significant direct impact on GHG emissions, they will also have a strong impact on international energy markets, in particular on the price of crude oil and, to a lesser degree, of natural gas. The 450S scenario results in a crude oil price that is half that of the REF scenario and that stabilizes at today's levels as higher carbon taxes strongly reduce the demand for fossil fuels. The pressure on conventional oil resources is also reduced, both alleviating the problem of global hydrocarbon resource depletion and decreasing global energy dependency on limited producing regions. The international energy markets are clearly more sustainable in the carbon constrained scenarios.

Our work has thus shown that sustainable energy development depends largely on the ambitiousness and effectiveness of these policy measures. There are of course limits to what can be done mostly because the POLES model, as a sectoral partial equilibrium model, does not allow assessing the carbon constraint's reciprocal impact on the economy. Efforts are currently underway to better understand the structural changes resulting from the adoption of low-emission profiles on the overall economy, technologies and behaviours, by establishing closer links between sector-based models and macroeconomic models and trying to represent the potential characteristics of a "low CO2 society" in greater detail.

In conclusion, a comparison of the Reference scenario with the 450S scenario, which broadly corresponds to the so-called “Factor 4 reduction in Annex 1 countries”, shows that the EU energy and climate targets are probably attainable in the long term, provided that very active policy measures are implemented. These measures will have to establish an increasing carbon price or carbon value, at a level probably exceeding the cost of alternative technologies in the transition phase. This will enable both the needed significant energy efficiency gains and the massive development of low carbon technologies in all sectors. The price to be paid for the safeguard of the planet’s climate will however be significantly reduced by the taking into account of the positive externality corresponding to more sustainable production profiles for oil and gas and, last but not least, less risky and unstable international energy markets.

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Annex: POLES model studies and web-references

- 2004-2005: World Energy Technology Outlook 2050 (WETO-H2, DG-RTD) with ENERDATA, FPB-Belgium, IPTS
  http://ec.europa.eu/research/energy/pdf/weto-h2_en.pdf
- 2003-2004: Emission reduction scenario for France (Factor 4 scenario, Min. of Ind.-F) with ENERDATA
  http://www.industrie.gouv.fr/energie/prospect/pdf/oe-facteur-quatre.pdf
- 2002-2004: Endogenous technical change in a world energy model (SAPIENT + SAPIENTIA, DG-RTD) with NTUA, IIASA, ECN, KUL …
- 2001-2003: Greenhouse emission Reduction Pathways and international endowments in the post-Kyoto perspective (GRP, DG-ENV) with NTUA, RIVM, KUL
  http://europa.eu.int/comm/environment/climat/pdf/pm_summary2025.pdf
- 2001-2003: Economic analysis of the linking of the European EQTS with the international market (Kyoto Protocol Implementation, DG-ENV)
  http://europa.eu.int/comm/environment/climat/pdf/kyotoprotocolimplementation.pdf
- 2001-2003: World energy technology and climate policy framework scenario to 2030 (WETO, DG-RTD) with ENERDATA, FPB-Belgium, IPTS
  http://europa.eu.int/comm/research/energy/gp/gp_pu/article_1257_en.htm
- 2000-2002: Multi-gas assessment of greenhouse gas emission reduction strategies (GECS, DG-RTD) with NTUA, RIVM, KUL, IPTS
- 2000-2001: Economic assessment of climate negotiation options, before and after COP-6 (Blueprints for International Negotiation, DG-ENV)
  http://europa.eu.int/comm/environment/climat/pdf/blueprints.pdf
- 1999-2001: ASPEN a software for the analysis of emission quota trading systems with MAC curves from the POLES model (Min. of Env.-F)
  http://www.upmf-grenoble.fr/iepe/Recherche/Aspen.html