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European Climate - Energy Security Nexus: a model based scenario analysis

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Abstract

In this research, we have provided an overview of the climate-security nexus in the European sector through a model based scenario analysis with POLES model. The analysis underline that under stringent climate policies, Europe take advantage of a double dividend in its capacity to develop a new cleaner energy model and in lower vulnerability to potential shocks on the international energy markets.

Keywords : Climate policy scenarios, Energy security

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Introduction

It is usually considered that the development of national or regional energy policies should be based on three pillars: energy security, environmental sustainability and economic competitiveness. This is particularly true for Europe, where each one of these pillars is brought forward by one dedicated institution, respectively the Directorates General for Energy and Transport, for Environment and for Competition. But this is also true for other countries or regions of the world, as the development of sound energy policies is often considered as based on trade-offs, aiming at the right balance between potentially conflicting goals. The key argument of this paper is to demonstrate that these targets may be put into convergence, according to the policy hypotheses retained at the global and regional level. In particular, the adoption and implementation of strong climate change and emission reduction policies may be considered as the most effective way to enhance energy security through a lower degree of dependence of the European energy system on fossil fuels.

In order to explore this “energy security and climate policy nexus”, we use the POLES world energy model. In line with former energy foresight exercises performed at European and world level with this model, we describe a family of scenarios based on consistent sets of exogenous hypotheses on economic growth, energy resources, technology performances and climate policies. The POLES model is not a General

Equilibrium Model, but a Partial Equilibrium Model aimed at describing the energy sector, within a year by year dynamic recursive simulation framework. In this paper, we describe the results of four scenarios in order to illustrate the consequences of different settings concerning climate policies on the fundamentals of the energy markets, both at global and regional level.

The first one is called *Muddling Through* and illustrates the consequences of relatively low intensity and non-coordinated climate policies in the different world regions. This scenario can be used as a reference case, to which stronger policy cases can be compared. The second and third cases respectively identified as *Muddling Through with Europe Plus,* and *Europe goes Alone,* describe situations in which Europe implements gradually stronger climate policies than in the mere *Muddling Through* case, while the rest of the world sticks to low intensity climate policies. Finally, the *Global Regime* scenario illustrates the consequences of coordinated and ambitious climate policy, shared at world level.

The exercise shows that energy policies in the *Muddling Through* case result in a noticeable limitation of emissions compared to *Business As Usual* case. However the global emission level reached in 2050 far exceeds the one that is considered as reasonable in IPCC's AR4. The *Europe Alone* scenario helps to show that in a world with low policy coordination there might still be strong advantages in pursuing an ambitious regional climate policy as it may considerably limit the vulnerability of Europe to events occurring in an otherwise very unstable energy world. The *Global Regime* case not only helps to constrain climate change in an acceptable range but also changes the whole picture of the world energy system in the first half of the century. In particular, the long term sustainability of the oil and gas production profile is significantly improved. Two variants are developed for this case: *Global Regime with two carbon markets* (GR-2M) and *Global Regime with full trade* for carbon (GR-FT) in order to test the consequences of a differentiated or a unified carbon emissions market.

Section 1 of this paper briefly presents the POLES model and the *Muddling Through* scenario, which, although it contains some elements of emission reduction, represents a state of the world that is maybe probable, but surely not desirable from the climate change perspective. Section 2 is dedicated to the presentation of the climate policy alternative scenarios and to the comparative analysis of their results in terms of emission performances and impacts on the world and European energy system to 2050. Section 3 discusses the consequences for the international energy markets and for the energy import profiles of Europe. Section 4 translates the conclusions of this study in terms of risks and vulnerability; it also points to the double dividend that may be associated with a change in the European energy paradigm.

1. The POLES model and the *Muddling Through* projection

The *Muddling Through* projection provides an image of the energy scene upto 2050, resulting from the continuation of ongoing trends and structural changes in the world economy, with only low intensity and non-coordinated climate policies in the different world regions.

Through the identification of the drivers and constraints in the energy system, the model used in this exercise allows the description of the pathways for energy development, fuel supply, greenhouse gas emissions, international and end-user prices, on a year by year basis from today to 2050. The approach combines a high degree of detail in the key components of the energy systems and a strong economic consistency, as all changes in these key components are largely determined by relative price changes at sectoral level. The model identifies 47 regions for the world, with 22 energy demand sectors and about 40 energy technologies – now including generic “high energy efficiency” end-use technologies. Therefore, each scenario can be described as the set of economically consistent transformations of the initial *Business As Usual* projection that is induced by the introduction of policy constraints.

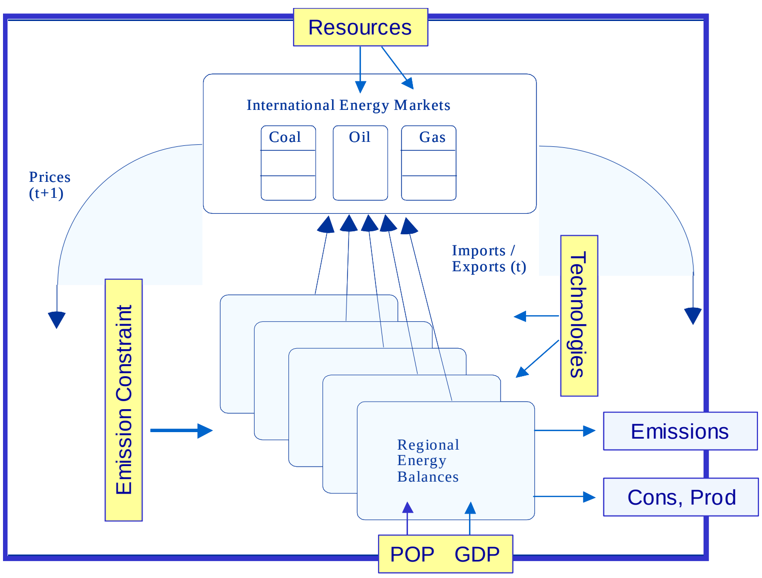
1.1. The POLES model

The POLES model is a partial equilibrium model of the world's energy system that provides a detailed year-by-year projection until 2050 (or in some studies 2100), for the different regions of the world. The model simulates the energy demand for each economic sector, the supply and prices for the primary energy sources on the international markets, and the impacts of innovation, experience effects and R&D in new and renewable energy technologies and major energy conversion systems (electricity or hydrogen-based for the longer term).

The model therefore provides a consistent framework for studying the interconnected dynamics of energy development and environmental impacts. Projections are made on the basis of exogenous economic growth and demographic projections for each region. It takes into account the resource constraints for both oil and natural gas and enables the calculation of greenhouse gas emissions from the burning of fossil fuels and, further on, of the costs (marginal and total) 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 or emission quotas systems. The main limitation of this modelling system is probably that it does not account for macro-economic feedbacks. However, this also allows the production of a relatively robust estimate of the impacts of climate policies on the sole energy sector, while the macro impacts are most often taken into account in joint studies with other energy economy models such as GEM-E3 (NTUA, Athens) or IMACLIM (CIRED, Paris).

Figure 1: The POLES Model Simulation Process



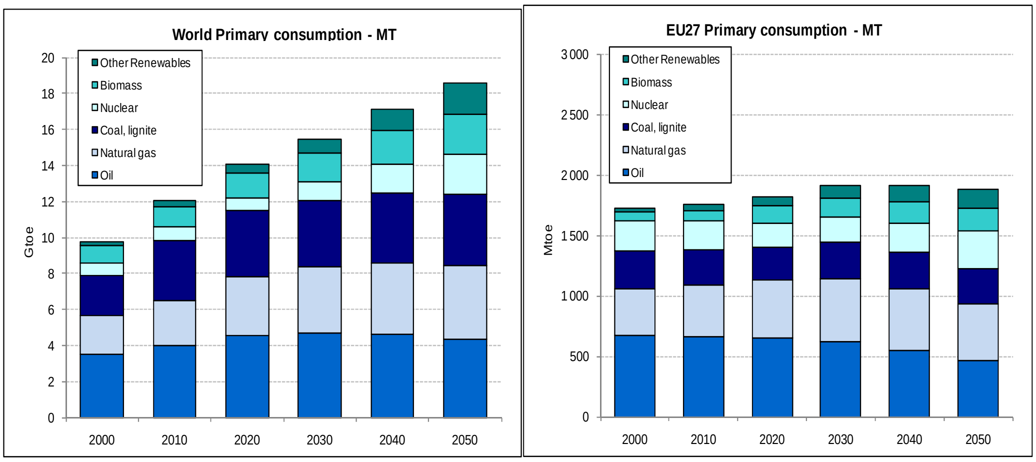
Source: POLES model-LEPII

1.2. *The Muddling Through projection and the comeback of coal*

The *Muddling Through* projection adopts exogenous forecasts for population and economic growth in the different world regions. In order to take into account the current financial and economic crisis, the latest *Muddling Through* case shows a global GDP growth rate in 2009 that is 50 percent lower than in the preceding POLES projections, with a catch-up to formerly considered growth rates in 2013. This corresponds to a world GDP that is in 2015 more than 5 percent lower than considered in previous POLES energy outlooks. This might, however, still be considered as an optimistic view on the capability of recovery of the world economy in the short-medium term. Other hypotheses on world economic growth might be explored through alternative runs of the model.

The projection is based on consistent assumptions on the availability of fossil energy resources and on the costs and performances of future technologies. In this kind of scenario, a standard discount rate of 8 percent is used to simulate investment decisions in the energy sector. Figure 2 describes the dynamics of the world and European energy system, in the initial settings considered in the *Muddling Through*.

Figure 2: *Muddling Through* Case – World (left) and Europe (right) Gross Inland Energy Consumption



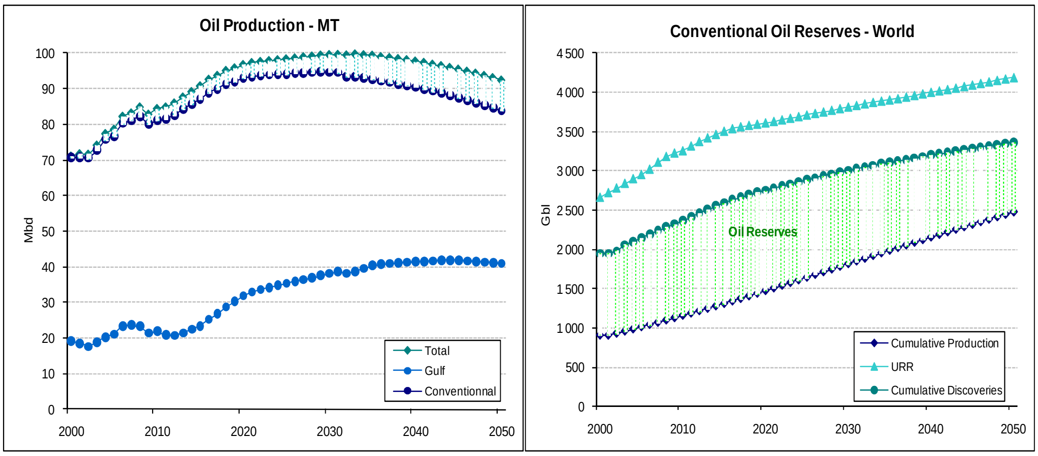
Source: POLES model, LEPII, SECURE project

The key outcome of the *Muddling Through* case is almost a doubling of world energy consumption from 2000 to 2050, with a levelling-off of world oil and gas production after 2030. In spite of a significant development in nuclear energy, biomass and other renewables, which in 2050 represent more than one fourth of world Gross Inland Energy Consumption (GIEC), the primary source that most gains in importance is coal, which passes from 2.2 Gtoe to 4 Gtoe between 2000 and 2050. One can note that this is already much less than in the *Business As Usual* runs. As for Europe, the dynamics in GIEC is much less pronounced with an increase from 1.7 Gtoe to only 1.9 Gtoe between 2000 and 2050. There again one notes a levelling-off of oil and gas consumption, the progress of renewables and the penetration of coal, although with a more modest magnitude than at world level.

1.3. The probable unsustainability of the Muddling Through: upstream and downstream constraints

In many respects, however, this scenario is hardly sustainable in the long term. First of all, the level of oil production is high, peaking at slightly less than 100 Mbd in 2030 for conventional oil (Figure 3). This is a high level, which implies very high levels of total cumulative conventional oil production, from 900 Gbl in 2000 to 2,500 Gbl in 2050 (Figure 3).

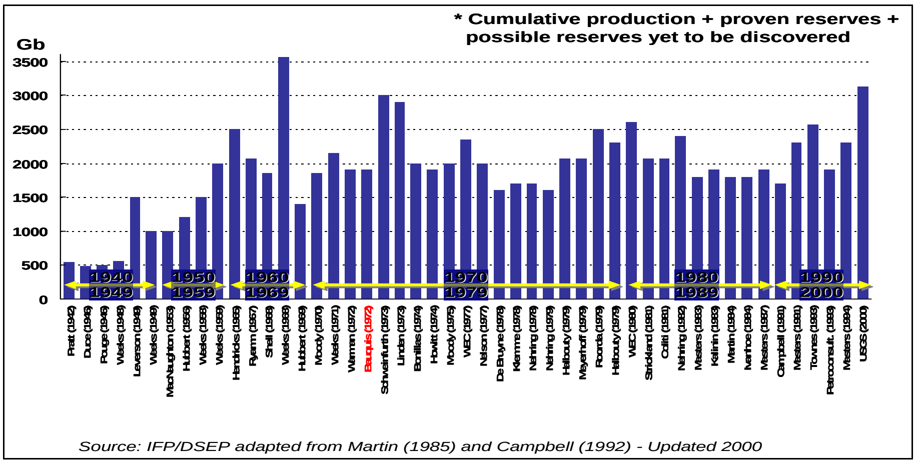
Figure 3: *Muddling Through*, flows of world oil production (left), stocks of resources and reserves (right)



Source: POLES model, LEPII, SECURE project

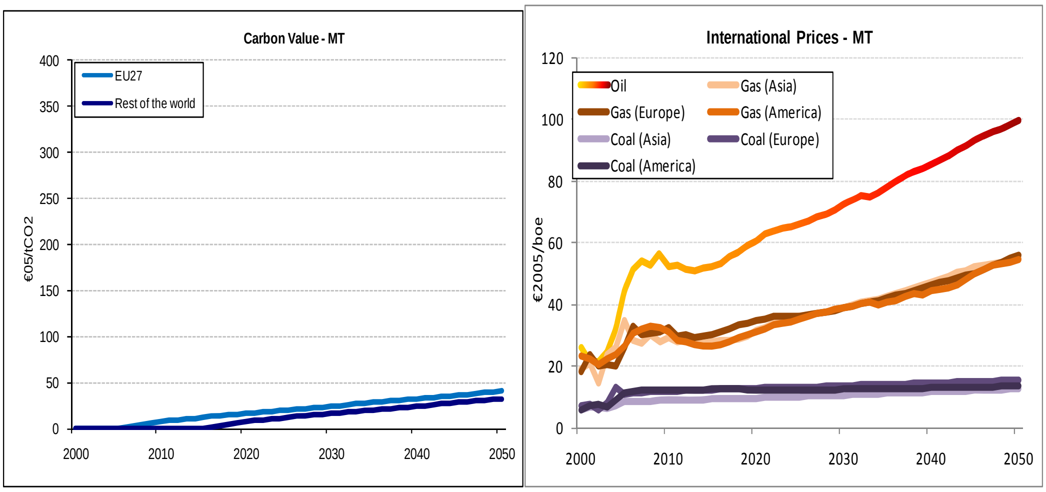
This is indeed a level that corresponds to the middle of the range of total Ultimate Recoverable Resources estimates for conventional liquids as identified by the Institut Français du Pétrole (Figure 4). Furthermore, it supposes about 3,500 Gbl of total cumulative discoveries in order to maintain a minimum level of reserves.

Figure 4: Estimates of conventional oil Ultimate Recoverable Resources (source P.R. Bauquis, 2006)



The consistency of the long run oil projections of the POLES model with the taking into account of resource limits is made possible by the expected increase of recoverable resources through significantly enhanced recovery rates in the different production regions. Nevertheless, the implied hypotheses for oil production in the Gulf region seems to be extremely optimistic as it supposes more than a doubling in 2030 and beyond. This increase in Gulf oil production to more than 40 Mbd from 2030 to 2050 is probably questionable, not only from the resource and production capacity perspective, but also for reasons related to the geopolitical and internal political dimensions of the oil industry development in this region. This is why the smooth path for oil price increases that is associated with this scenario can be considered as a relatively optimistic hypothesis, although it ends at more than 100 €/bl in 2050, structurally (Figure 5).

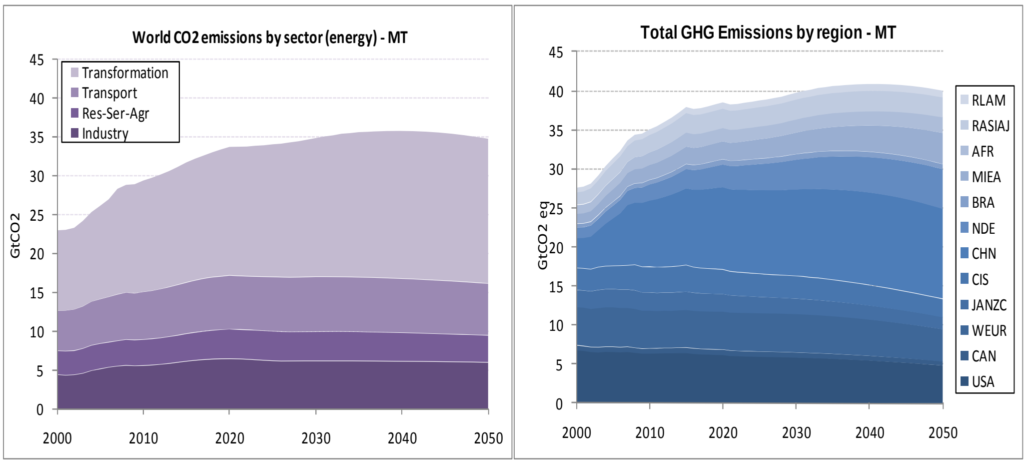
Figure 5 : Carbon value and international energy price trajectories (MT)



Source: POLES model, LEPII, SECURE project

The second reason for which the *Muddling Through* is probably not sustainable results from the implied CO2 emission level for the energy sector (Figure 6).

Figure 6: World CO2 emissions from energy, by sector and by region



Source: POLES model, LEPII, SECURE project

Emissions indeed double over the period considered, which would place this scenario in the very high range of the IPCC scenarios: a type VI scenario in the Table SPM.5 of AR4 (see above Table 1), i.e. a mean temperature increase at equilibrium between 5 and 6°C.

Table 1: IPCC-AR4 Stabilization scenarios

Table SPM.5: *Characteristics of post-TAR stabilization scenarios [Table TS 2, 3.10][a]*

Category	Radiative forcing (W/m^2)	CO_2 concentration[c] (ppm)	CO_2-eq concentration[c] (ppm)	Global mean temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity[b), c)] (°C)	Peaking year for CO_2 emissions[d]	Change in global CO_2 emissions in 2050 (% of 2000 emissions)[d]	No. of assessed scenarios
I	2.5-3.0	350-400	445-490	2.0-2.4	2000-2015	-85 to -50	6
II	3.0-3.5	400-440	490-535	2.4-2.8	2000-2020	-60 to -30	18
III	3.5-4.0	440-485	535-590	2.8-3.2	2010-2030	-30 to +5	21
IV	4.0-5.0	485-570	590-710	3.2-4.0	2020-2060	+10 to +60	118
V	5.0-6.0	570-660	710-855	4.0-4.9	2050-2080	+25 to +85	9
VI	6.0-7.5	660-790	855-1130	4.9-6.1	2060-2090	+90 to +140	5
						Total	177

Source: IPCC, AR4, SPM

2. Alternative Climate Policy Scenarios and Their Impacts on the International Energy Markets

Three scenarios are used in the this study in order to characterize contrasted states of the world from the perspective of the "energy security and climate policy" nexus. They allow in particular the illustration of the consequences of differentiated energy policies on the fundamentals of the world energy system.

2.1. Alternative Scenario Definition

The *Muddling Through with Europe Plus* (MT E+) scenario supposes a failure in the efforts to develop a common framework of targets, rules and mechanisms for climate policies. Only weak domestic climate policies are implemented without any strong element of coordination of the different actions. But the case supposes that Europe goes beyond the mere *Muddling Through* policy, with a carbon value that is significantly rising from 8 €/tCO2 in 2010 to 89 €/tCO2 in 2050, instead of only 40 €/tCO2 in

MT. The resulting picture is one of lower emissions in Europe than in the *Muddling Through*, but world emissions in 2050 are still above 51percent compared to 2000, which still corresponds to a Type IV scenario in the AR4 typology (see Table 2).

The third scenario, *Europe Alone,* supposes that Europe goes alone with a really stringent climate policy line, while the rest of the world continues on the same line as in *Muddling Through.* In that case it is supposed that the carbon value in the rest of the world is unchanged, while it is set in Europe at 178 €/tCO2 in 2050 (see Table 2).

Table 2: Scenarios for Exploring the Energy Security – Climate Policy Nexus

	MT	EA	GR-2M	GR-FT
Scenario	**Muddling Through**	**Europe Alone**	**Global Regime with 2 Markets : Annex 1 + Non Annex 1**	**Global Regime with Full Trade**
Carbon Value (€/tCO2)	**EU** : 8 in 2010 40 in 2050 **RoW** : 10 years lag / EU	**EU** : 8 in 2010 178 in 2050 **RoW** : as in Muddling Through	**Ann 1** : 16 in 2010 392 in 2050 **Non Ann 1** : 1 in 2010 257 in 2050	**World** :7 in 2010 380 in 2050
EU27 CO2 emissions : **2020 / 1990** **2050 / 1990**	-4% -21%	-20% -60%		
Annex 1 CO2 emissions: **2020 / 1990** **2050 / 1990**			-25% /year 2000 -80% /year 2000	
World CO2 emissions : **2020 / 1990** **2050 / 1990**	+ 67% + 72%	+63% + 59%	127% /year 2000 - 50% /year 2000	127% /year 2000 - 50% /year 2000
AR4 Scenario Profile	Type IV > 600 CO2e	Type IV > 600 CO2e	Type II > 500 CO2e	Type II > 500 CO2e

Source: SECURE project

Finally, the Global Regime scenarios correspond to the stabilization profile of GHG concentrations, below 450 ppmv for CO2 and 500 ppmv for all GHG gases. This is simulated through a world emission profile that ends up in 2050 at 50 percent of 2000 CO2 emissions. This is the Factor 2 reduction in 2050 emissions at world level, which is often advocated in international negotiations by the proponents of strong climate policies. In compliance with this global profile, two variants have been considered. In the Global Regime Two Markets (GR-2M) variant, the reductions in Annex I countries are set at -25 percent in 2020 and - 80 percent in 2050, compared to 2000. Reductions in the non-Annex I countries are determined as the residual for the global Factor 2 reduction. It corresponds to a case in which Annex 1 countries adopt a strong target and leave room for some emission increases in Non Annex 1 regions, as they do not use flexibility mechanisms to comply with this target. In the Global Regime Full Trade (GR-FT) variant, the same world emission profile is simulated while considering one world carbon price that is obtained either by a unified world carbon tax or by a global market for carbon emission trading.

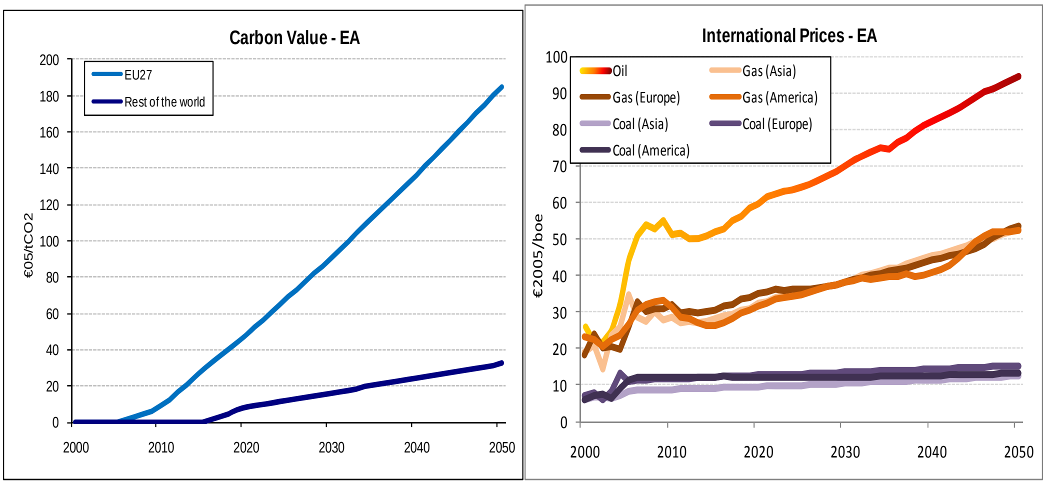
2.2. Scenario Results

As the *Muddling Through with Europe Plus* scenario is an intermediate case aimed at covering the range of policies between *Muddling Through* and *Europe Alone,* we will leave this case aside and only provide a description of the consequences of the two most contrasted emission reduction scenarios, i.e. *Europe Alone* and *Global Regime.*

2.2.1. Europe Alone (EA)

This scenario aims at studying the impacts on the energy system of a strong climate policy in Europe, in spite a non-cooperative international framework with climate policies in the rest of the world that still correspond to the *Muddling Through* framework. In this setting, the carbon value at the end of the period is six times higher in Europe than in the rest of the world (Figure 7).

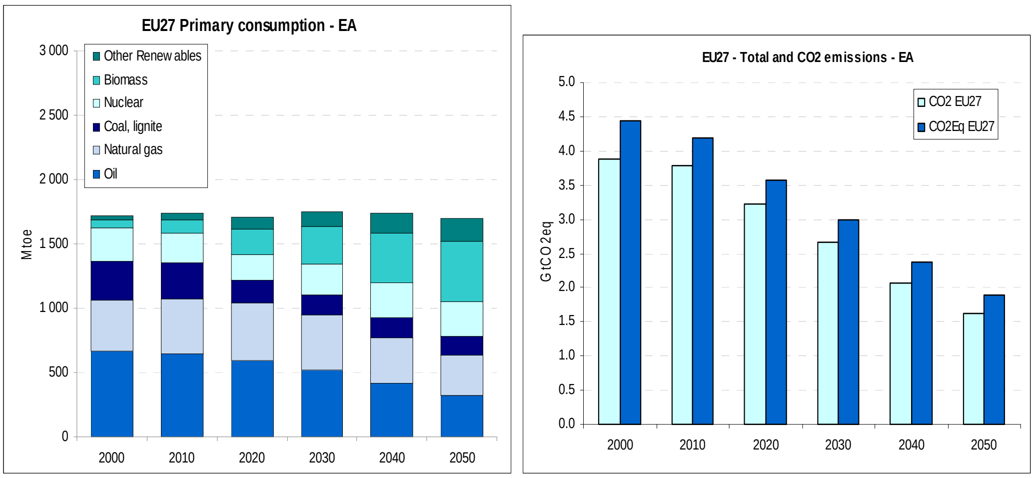
Figure 7: Carbon Value and International Energy Price Trajectories (Europe Alone)



Source: POLES model, LEPII, SECURE project

In this scenario, world gross inland consumption and international energy prices are hardly impacted compared to the preceding scenario, as Europe only represents a limited and diminishing fraction of the world energy system, i.e. 9 percent of total GIEC in 2050.

Figure 8: Europe Gross Inland Energy Consumption and CO2 emissions in *Europe Alone*

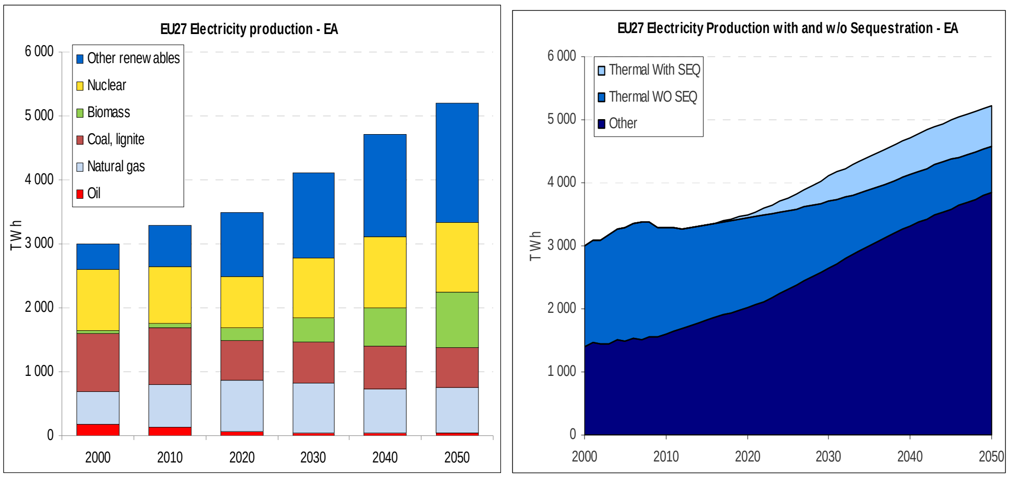


Source: POLES model, LEPII, SECURE project

Conversely, in this scenario, the European energy system is profoundly altered by the introduction of a significant carbon value. Total energy consumption remains quite stable during the period. But the fuel-mix in total supply is quite different: fossil energy sources, which represent in 2000 79 percent of total GIEC are reduced to 71percent in 2020 and to

46 percent in 2050. The electricity system also incurs radical changes and is a major contributor to the reductions of carbon emissions in Europe (Figure 9).

Figure 9: Europe electricity generation mix and role of Carbon Capture and Storage in *Europe Alone*



Source: POLES model, LEPII, SECURE project

Electricity production increases all over the projection period from 3,000 TWh in 2000 to 5,200 in 2050. This indicates that the electrification of the energy balance is one important dimension of emission abatement policies in the energy sector. This is easily explained by the following reasons: first, the penetration of non-CO2 power generation options allows reducing considerably the CO2 content of the average kWh; second, stimulated by the high carbon value, Carbon Capture and Storage (CCS) develops after 2020 and represents almost 47 percent of total thermal generation in 2050. This explains why electricity is almost carbon-free in Europe by the end of the projection period and why the role of the electricity sector is so prominent in emission abatement policies.

2.2.2. Global Climate Regime (GR)

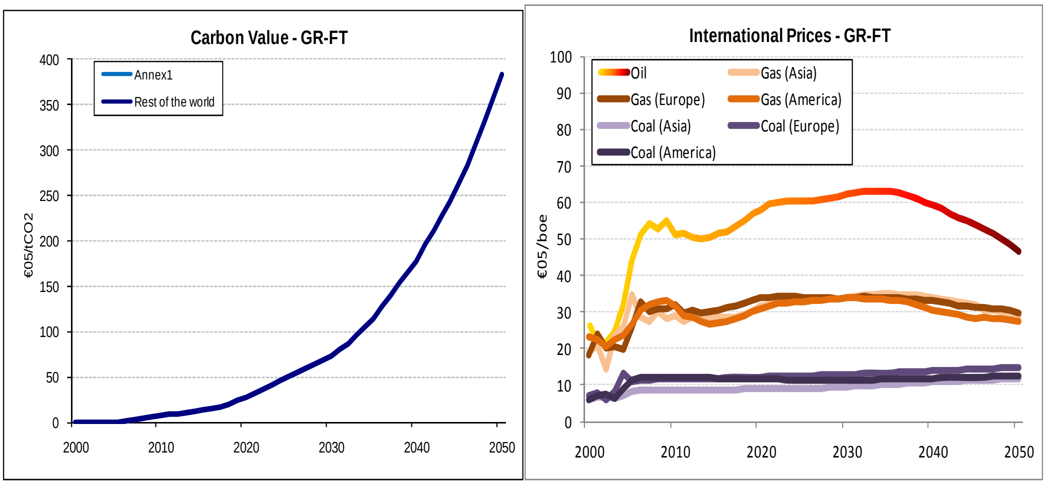
The main feature of this scenario is the introduction of a global cap on emissions. The *Global Regime* scenario reflects a state of the world with ambitious climate targets, aiming at an emission profile of Type II in the AR4 typology. Emissions indeed double over the period considered, which would place this scenario in the very high range of the IPCC scenarios: a type VI scenario in the Table SPM.5 of AR4 (see Table 1), i.e. a mean temperature increase at equilibrium between 5 and 6°C (see above Emissions indeed double over the period considered, which would place this scenario in the very high range of the IPCC scenarios: a type VI scenario in the Table SPM.5 of AR4 (see above Table 1), i.e. a mean temperature increase at equilibrium between 5 and 6°C.

Table 1). It allows stabilizing concentrations below 450 CO2-only and 500 CO2-equiv. and is indeed characterized by a 50 percent reduction in global emissions.

In the variant *Global Regime with Two Markets* (GR-TM), Annex 1 countries reduce their emissions by 25 percent in 2020 and 80 percent in 2050. These reductions are triggered by a rapidly increasing carbon value, which increases from 16 €/tCO2 in 2010 to 68 €/tCO2 in 2020 and to 392 €/tCO2 in 2050. The corresponding carbon value in non-Annex 1 countries is significantly lower at 10 €/tCO2 in 2020 and 257€/tCO2 in 2050.

In the second variant, *Global Regime with Full Trade* (GR-FT), it is supposed that the abatement program follows the principle of the equalization of Marginal Abatement costs, as would result fromthe introduction of a unique carbon value, through a global carbon market or a unified international carbon tax. In this framework of hypotheses, the resulting carbon value increases rapidly to 28 €/tCO2 in 2020, 73 in 2030, 178 in 2040 and 383 in 2050. One can emphasize the fact that the carbon value that is necessary to induce radically new trajectories in the world and European energy system is one order of magnitude higher than the value used in the *Muddling Through,* low intensity policy case. This corresponds to the fact that the *Global Regime* scenario reveals the need for radical changes in the energy systems: indeed 400 €/tCO2 correspond approximately to one additional euro per litre of gasoline in typical European conditions.

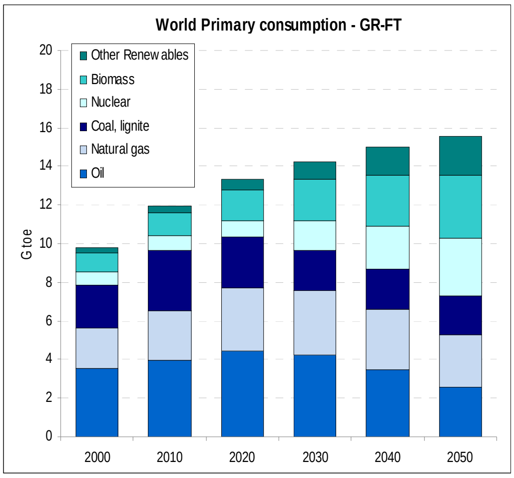
Figure 10: Carbon Value meeting the emission cap and endogenous international energy prices in *Global Regime* (GR-full trade)

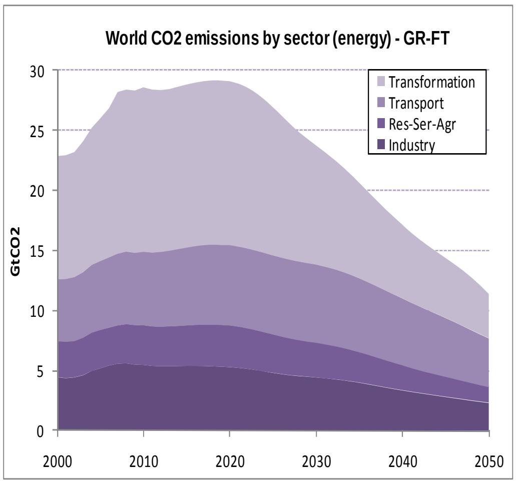


Source: POLES model, LEPII, SECURE project

While the European Gross Inland Energy Consumption and fuel-mix are not significantly different from the one simulated in *Europe Alone* (as presented in Figure 8), major changes occur in the global energy picture. World energy consumption is reduced by about one fourth compared to the one projected in the *Muddling Through*. As a result, the total amount of fossil fuels (coal, oil and gas) that is consumed at world level in 2050 is 8 percent lower than the one of 2000 (Figure 11). Due to its relatively low carbon content, natural gas consumption in 2050 is still higher than in 2000, but coal and oil consumption are lower.

Figure 11: World Gross Inland Consumption and CO2 emissions by sector in the *Global Regime* (GR-FT)





Source: POLES model, LEPII, SECURE project

In order to reduce global emissions by 50 percent, this scenario supposes a significant development of Carbon Capture and Storage. By 2050, almost 44 percent of total gross emissions are captured, with almost 90 percent of CCS occurring in the electricity sector and the rest in industry and hydrogen production.

As a consequence of the low levels of consumption for the different fossil fuels in 2050 relatively to 2000, the prices of fossil fuels can be expected to be much lower in this scenario than in the *Muddling Through* or even *Europe Alone* scenarios. Indeed, the endogenous price mechanisms in the model result in a stabilization of international energy prices, at a level that is only 10 to 20 percent superior to current level, all along the projection period.

This leads to the main intermediate conclusion at this stage: climate policies, if they are ambitious and effective, will have a significant impact on the demand/supply balance for fossil fuels at the international level. In turn, this new balance of the global energy economy will certainly have significant impact on the range and variations in the international prices of

3. Impacts on International Energy Trade and on Europe's Energy Security

In this section, we first analyze the consequences of the different scenarios in the perspective of Europe's dependence upon the international markets and consider the corresponding value of energy imports. In the second stage, we focus on natural gas imports and analyze the profile and sources of these imports in a geopolitical perspective.

3.1. World Oil Supply and Trade

The profile of oil production is an important feature of any long-term energy scenario. Because it is easy to transport, store and use, oil has been for many decades the "swing energy source" for balancing energy supply and demand. For that reason, the price of oil often serves as a reference price for other energy sources. As discussed above, the *Muddling Through* projection suggests that this balancing role may become more problematic in the future, due to increasing difficulties in balancing oil demand and supply. According to the POLES simulations, the world has emerged from a 20-year period of relatively cheap and abundant oil that began after the 1986 counter-shock. In the view of many observers and more recently also of insiders of the oil industry, the oil market in the next decade may undergo successive waves of structural changes that can be summarized as follows:

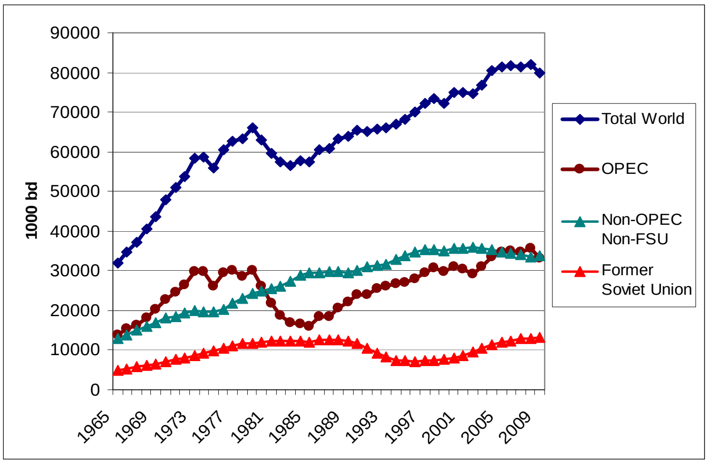
In the short-term, the international market dynamics will be much influenced by the lack of surplus production capacity and by the peak in production in non-OPEC countries (a phenomenon that has been delayed in the past decade by production increases in the CIS).

In the medium-term, the critical concern will be the extension of OPEC's countries production capacities well beyond their historic maximum (i.e. 35 Mbd in 2008).

In the long-term, the peak in OPEC and Gulf production may constrain the global consumption of oil, even if non-conventional oil is strongly developed (as it is already in the *Muddling Through* case).

This vision of the future of world oil is indeed consistent with a close analysis of recent trends in world oil production that clearly shows the levelling-off of oil production in non-OPEC non-CIS regions (Figure 12)

Figure 12: Oil production, world and main regions, 1965-2009



Source: BP Statistical Review 2010

The conventional and non-conventional oil production profiles in the *Muddling Through* scenario, as illustrated in the top row of Figure 13,

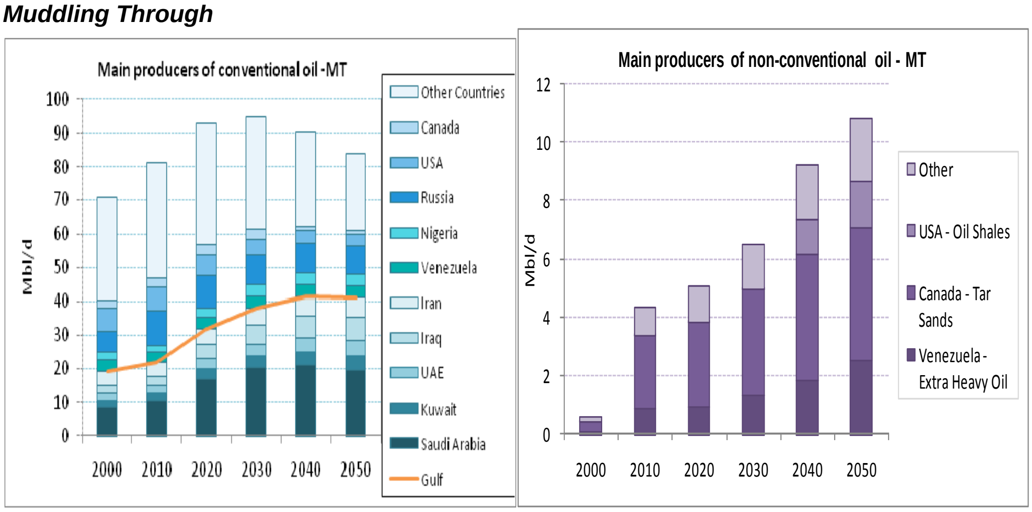
- Non-OPEC production was still increasing before 2010 due to new capacities in the CIS (notably in Kazakhstan); between 2010 and 2020 it is stabilized at 48 Mbd but after that date it begins to decline to only 30 Mbd in 2050.
- As demand increase remains strong in the next decades, particularly in the emerging economies, the balance of supply and demand implies that production in both the Gulf and the rest of OPEC doubles from now to 2040 and then stabilizes until 2050.
- Similarly, the production of non-conventional oil, mostly from extra-heavy oil, tar sands and by the end of the projection also oil shales, becomes competitive and provides more than one tenth of total production in 2050.
- As a combination of these different trends, the production of conventional oil peaks at 95 Mbd in 2030, while non conventional oil represents at that date 6 Mbd. After 2030, conventional production progressively decreases to 83 Mbd in 2050, but part of the retreat in conventional oil is compensated by an increase in non conventional production to about 11 Mbd.
- The global oil production profile thus resembles the so-called oil plateau anticipated by many observers of the oil scene, with a maximum production after 2030 at 101 Mbd and then a slow decline to about 94 Mbd in 2050.

The world oil production profile is hardly affected by the introduction of a strong carbon constraint in the *Europe Alone* case (see Figure 13, middle row). Conventional oil production levels off between 2020 and 2030, while non conventional oil production is about 10 percent lower in 2050 than in the *Muddling Through* case.

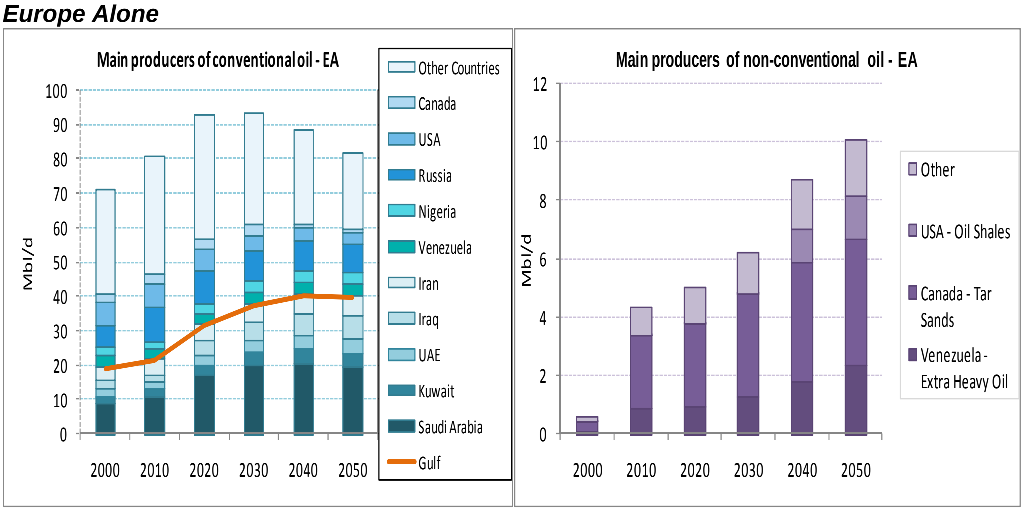
The situation is, of course, very different in the *Global Regime* where conventional oil tops in 2020 with a strong decline after that date, while non-conventional oil hardly increases over the projection period (see Figure 13 bottom row). This is clearly the result of a "peak demand" introduced by strong carbon constraints in all world regions. High fossil fuel prices at consumer level are very high in that case due to the price of carbon, and oil demand is significantly reduced by the development of high efficiency and low emission options in transport (electric and hydrogen vehicles).

Figure 13: Main producers of conventional oil (left) and non-conventional oil (right)

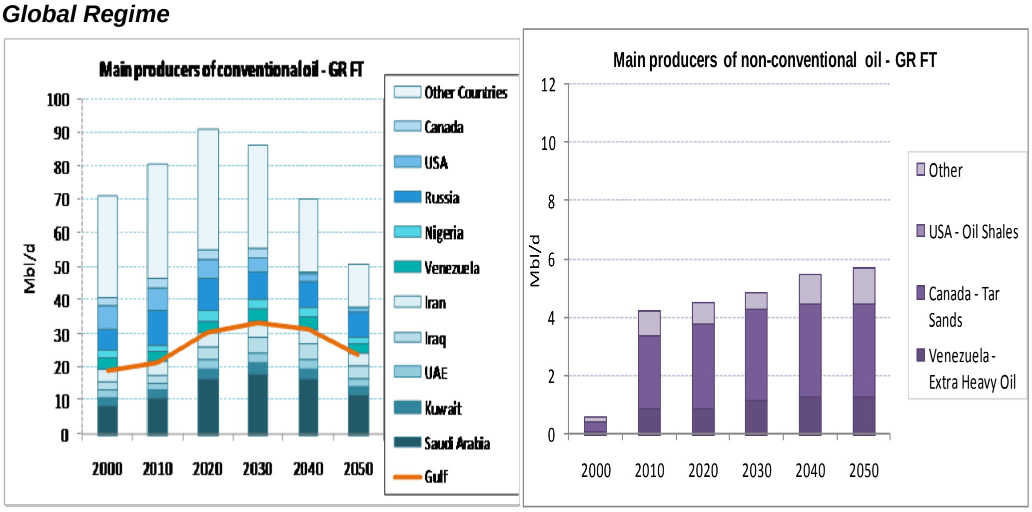
Muddling Through



Europe Alone



Global Regime



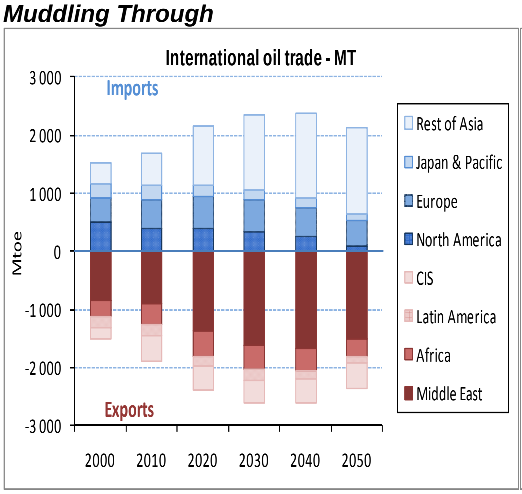
Source: POLES model, LEPII, SECURE project

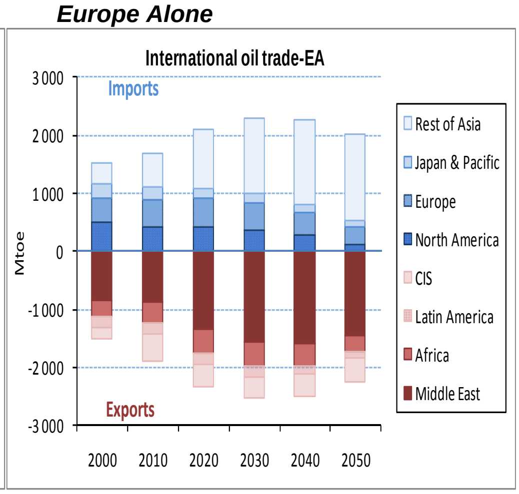
The increase in oil energy consumption upto 2050 appears to be limited even in the *Muddling Through* case. However, due to the general decline in non-OPEC production the international trade in oil increases from about 1.5 Gtoe today to more than 2.3 Gtoe in 2030 and 2040 (see Figure 14, where flows are measured between the main world regions). This is partly the consequence of the increase in consumption, but also of the concentration of production in the OPEC countries and more particularly the Gulf. In 2050, four regions are net exporters of oil, with the Middle East representing three-fourth of total exports. The other exporting regions are the CIS, Latin America and Africa. One can note the reduced imports of North America, which are due to the large supply of non-conventional oil from Canada. Again the world situation is hardly affected in the Europe Alone case.

Finally, the consequences of the *Global Regime* can be synthesized as follows: while oil exports of the four structurally exporting regions are doubled in 2030 compared to 2000, the situation in 2050 is, to a large extent, a return to the 2000 situation, with almost unchanged market shares and a maintained dominance of the Middle East in total exports.

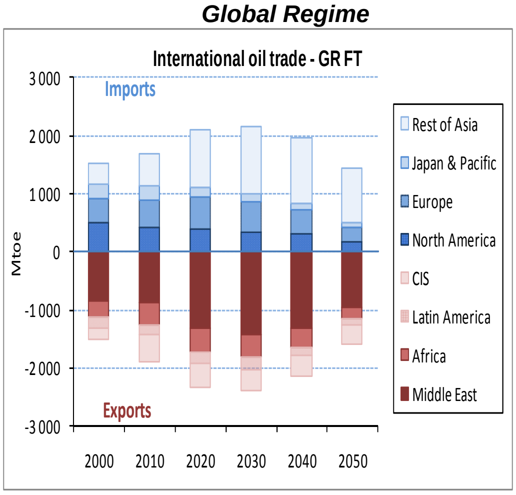
Figure 14: International oil trade

Muddling Through ***Europe Alone***





Global Regime



Source: POLES model, LEPII, SECURE project

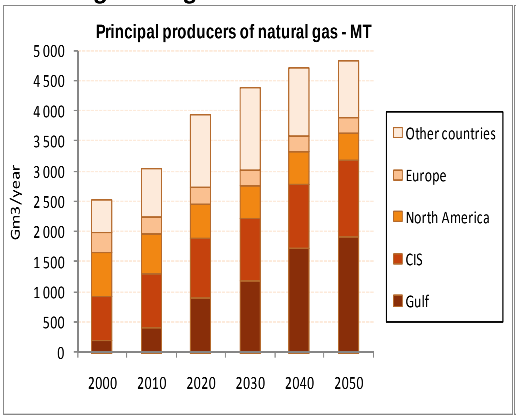
3.2. *World Gas Supply, Trade and European Imports*

One of the key concerns regarding the long-term energy security of Europe is its dependence in terms of gas supply. Natural gas is a key resource, with new perspectives introduced by non-conventional shale gas. Its environmental characteristics are rather favorable, including in the context of GHG abatement policies, as gas-based electricity has a CO2 content that is on average half of that of coal-based electricity (when no-capture and storage option is considered). Natural gas also brings flexibility and diversification of energy supply at the transformation or end-use level.

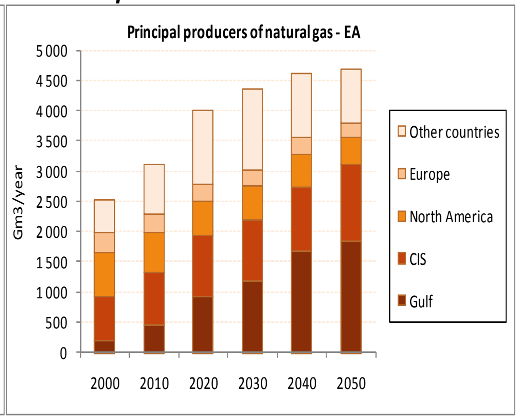
One of the key issues with natural gas supply is that of the transport infrastructure that is highly investment intensive whether in the form of gas pipelines or in terms of LNG facilities at exporting or importing points. The POLES model allows the description, with a relatively high level of detail, of the conditions of supply of the different regions of the world. It takes into account the key variables that explain the development of gas transport infrastructure, with an explicit description of the main routes and of their costs. These routes are developed endogenously, as a function of each region’s demand, supply and gas market price, of the state of the reserves of the suppliers and of the transports costs, pipelines or LNG chains.

Figure 15: Principal Producers of Natural Gas in the Four Scenarios

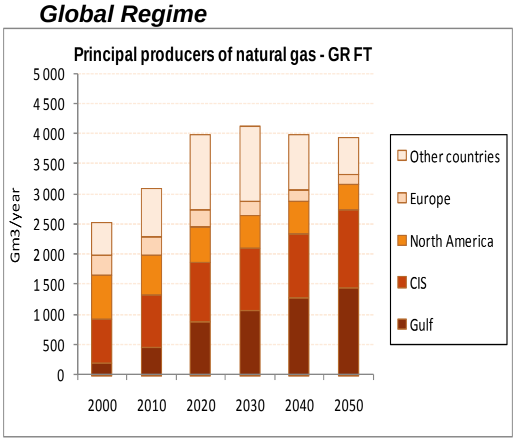
Muddling Through



Europe Alone



Global Regime



Source: POLES model, LEPII, SECURE project

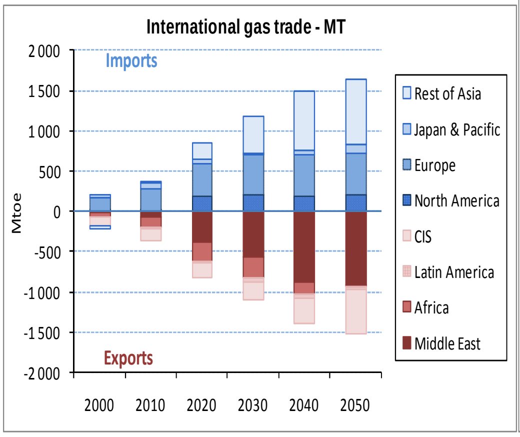
In the *Muddling Through* case, contrary to the oil situation, there is no peak gas before 2050, and by that date world gas production is about twice that of 2000, with 4.8 Bcm (see Figure 15). The Gulf and CIS regions will account for an increasing share of world production in the future, as European and North American production decreases in absolute terms. In particular, gas production in the Gulf region increases from 0.4 Bcm in 2010 to 1.9 Bcm in 2050. Again, the *Europe Alone* case does not introduce noticeable changes at the world level. Only in the *Global Regime* case is world gas production significantly impacted. However, there is still in that case, a significant increase in world gas production, from 3 Bcm in

2010 to 4 Bcm in 2050. The Gulf region and CIS are the main suppliers, with 35 percent each of world gas production.

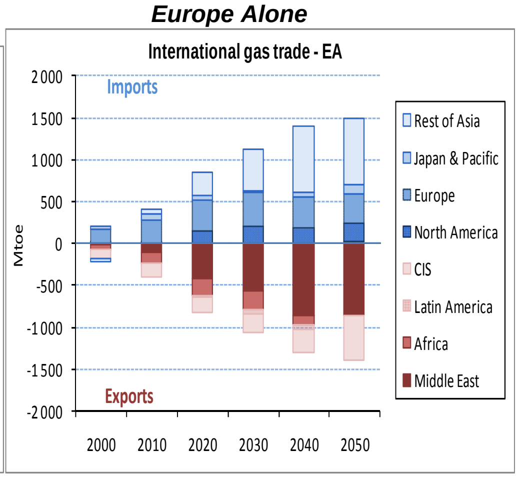
Inter-regional trade in gas increases considerably in the *Muddling Through* scenario as shown in Figure 16, from 0.2 Gtoe today to 1.5 Gtoe in 2050. These figures exclude intra-regional trade. The Middle East and the CIS are by far the largest exporters in 2050. The principal importing regions in 2050 are Asia, Europe and, to a lesser extent, North America; Africa is self-sufficient for its gas supply. The decrease of gas demand in other scenarios is accompanied by reduction of the imports to 1 Gtoe in 2050 in *Global Regime*.

Figure 16: International gas trade

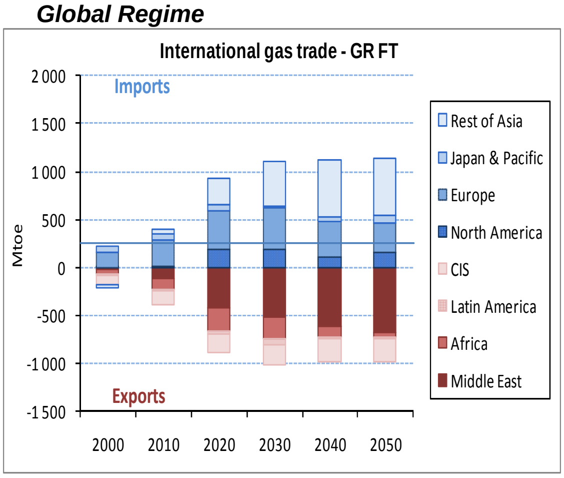
Muddling Through



Europe Alone



Global Regime

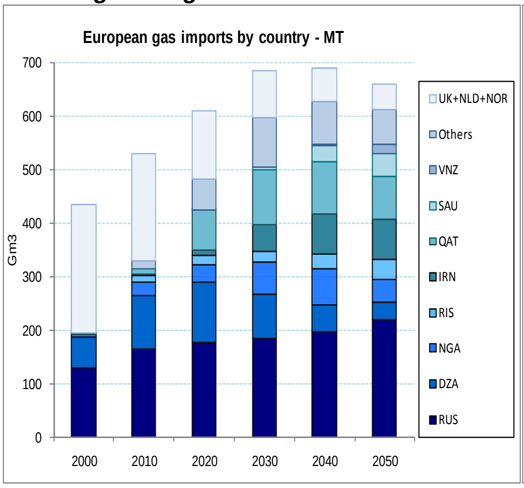


Source: POLES model, LEPII, SECURE project

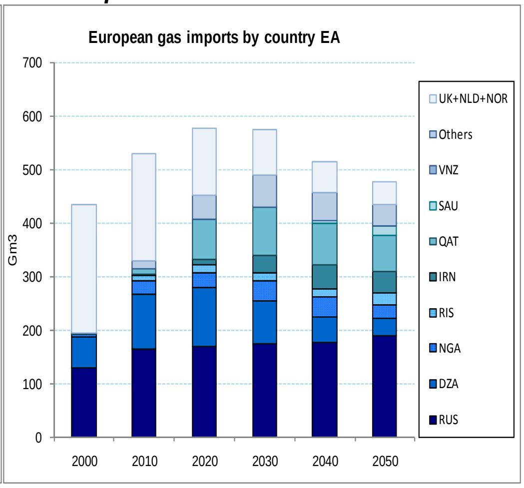
The simulation of different conditions of international energy markets and European energy system in the POLES scenarios allows the display of very different profiles for Europe's future natural gas supply (Figure 17). In the *Muddling Through* scenario, Western Europe's total gas imports (i.e. gas consumption minus supplies from UK, Netherlands and Norway) are expected to increase dramatically over the next decades, from 200 Bcm to 650 Bcm in 2050. This happens, in spite of a total demand that is levelling off at about 700 Bcm between 2030 and 2040, but this is due to the reduction in regional domestic production from Norway, UK and Netherlands, which are divided by a factor of almost four between 2000 and 2050, from 240 to 50 Bcm. While supply from Russia increases from 130 Bcm to 219-226 Bcm in these two scenarios, European gas supply also increasingly depends on new supplies from Nigeria, the Commonwealth of Independent States (mostly Kazakhstan), and Iran.

Figure 17: Europe's Natural Gas Supplies in the Four Scenarios

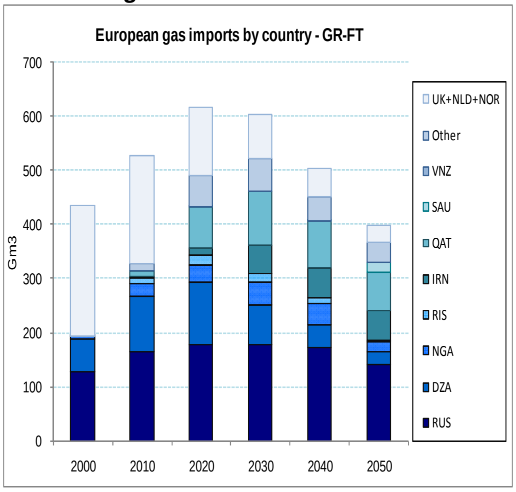
Muddling Through



Europe Alone



Global Regime



Source: POLES model, LEPII, SECURE project

The picture is quite different in the *Europe Alone* and *Global Regime* cases: due to the carbon constraint, total gas demand of Western Europe is much lower after 2020 than in the two preceding cases. In 2050, it is even lower than in 2000 with about 400 Bcm in *Global Regime* scenario. To a large extent, this reduction of total demand weighs on the new suppliers that would play an important role in the *Muddling Through* scenario, i.e. Saudi Arabia, Venezuela, Nigeria, Kazakhstan and Iran. Imports from Russia still represent about 200 Bcm in 2050 in both scenarios.

In conclusion of this analysis of long-term natural gas supply of Europe, one has indeed to emphasize the fact that the volume of Russian exports to Europe appear to be relatively stable in the different scenarios, at least until 2040, when they reach a level of about 200 Bcm in the four cases. Only after that date do the results differ significantly, with exports that are 30 to 40 percent higher in the *Muddling Through* than in the *Europe Alone* and *Global Regime* scenarios*.* Russia seems, however, to keep a comparative advantage in the supply of Europe in the carbon constraint cases.

3.3. World Coal Supply and Trade

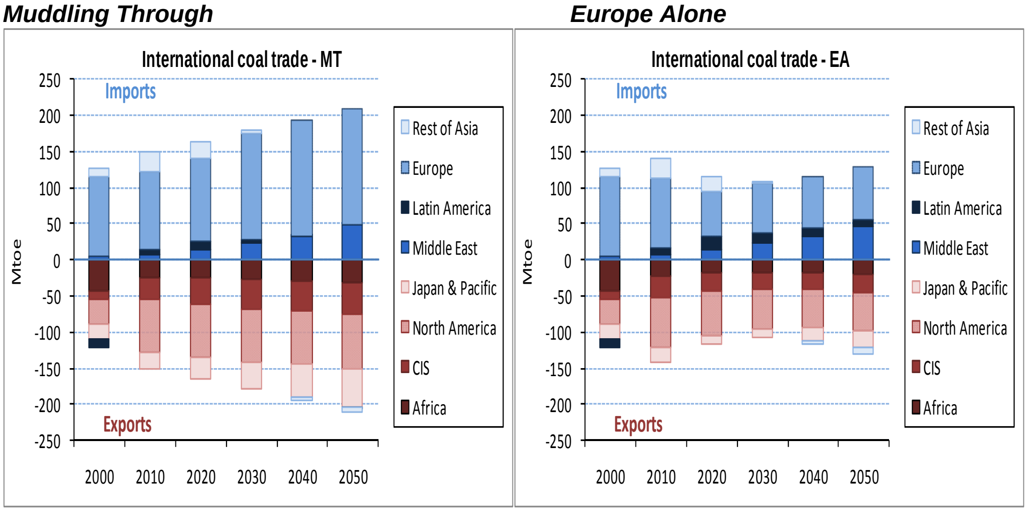
In spite of resources that are more widely distributed than those of oil and gas, international coal trade doubles over the projection period in the *Muddling Through* (Figure 18) scenario. The high volume of trade reflects the strong comeback of coal in a double context of relative scarcity and high prices of oil and gas, accompanied by only moderate GHG emission constraints. The situation changes in the *Europe Alone* and *Global*

Regime scenarios. Coal trade remains almost stable during the period in the *Europe Alone* scenario and it even decreases compared to current levels in the *Global Regime* scenario.

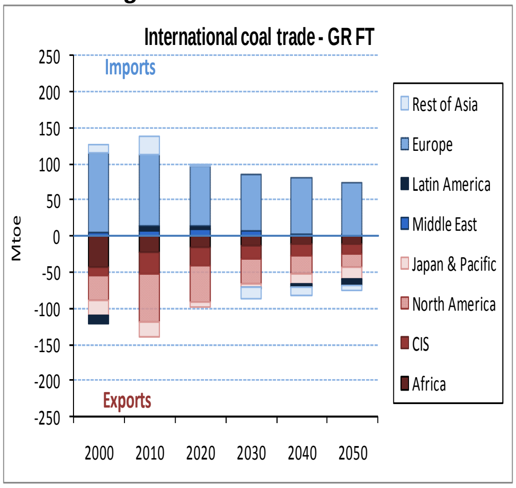
Europe remains the major importer, representing more than 80 percent of net imports during the whole period in all scenarios except in the *Europe Alone* case, in which other world regions continue to intensively use coal. However, European coal imports shrink from the *Muddling Through* scenario to the others, due to changes in the structure of the electricity generation and final consumption in favor of decarbonised energies and cleaner technologies.

Figure 18: International Coal Trade

Muddling Through ***Europe Alone***



Global Regime



Source: POLES model, LEPII, SECURE project

The four main exporting regions are North America, the Pacific, Africa and the CIS. Because of the rapid growth in consumption, Asia becomes a net importer late in the period. Their share remains nearly stable, while the volume diminishes in the *Europe Alone* and *Global Regime* scenarios.

3.4. Consequences for Europe's Energy Dependence and Value of Imports

The scenarios presented above result in very different profiles for energy imports and dependence. The *Muddling Through* corresponds to the scenario with higher consumption, imports, dependence rate and value of energy imports. While Europe's global import dependence rate was of 50 percent in 2005 and the value of energy imports of 236 G€ in 2005, these figures rise respectively to 57 percent and 351 G€ in 2020 and 53 percent and 491 G€ in 2050 (Table 3, upper row).

Table 3: Profiles for Europe Energy Imports and Dependence in Three Contrasted Scenarios

Muddling through

MT Results - EU27		1990	2000	2005	2010	2020	2030	2040	2050
GIC (Mtoe)		1531	1725	1822	1759	1820	1911	1909	1881
Imports (Mtoe)	Coal, lignite	-72	-94	-107	-95	-96	-132	-144	-146
	Oil	-464	-505	-557	-532	-543	-537	-475	-399
	Natural gas	-112	-180	-250	-298	-399	-471	-473	-448
Dependance rate	Coal, lignite	17%	30%	35%	32%	35%	44%	48%	50%
	Oil	79%	76%	82%	81%	83%	86%	86%	85%
	Natural gas	45%	46%	56%	69%	83%	91%	94%	96%
	Total	42%	45%	50%	53%	57%	60%	57%	53%
International prices (€05/boe)	Coal	11.8	7.2	10.9	11.8	12.8	13.6	14.5	15.4
	Oil	24.9	25.9	44.2	51.9	60.5	72.2	85.2	99.6
	Gas	14.0	18.3	25.8	32.2	34.7	38.8	46.1	55.8
Value of imports (G€05)	Coal, lignite	6.2	4.9	8.6	8.2	9.0	13.2	15.3	16.4
	Oil	84.5	96.1	180.4	202.7	240.7	284.4	296.6	291.3
	Natural gas	11.5	24.1	47.3	70.3	101.5	133.8	160.1	183.1
	Total	102.3	125.1	236.3	281.2	351.2	431.5	472.1	490.9

Europe Alone

EA Results - EU27		1990	2000	2005	2010	2020	2030	2040	2050
GIC (Mtoe)		1531	1725	1822	1740	1705	1756	1738	1700
Imports (Mtoe)	Coal, lignite	-72	-94	-107	-86	-46	-55	-59	-60
	Oil	-464	-505	-557	-522	-490	-440	-344	-255
	Natural gas	-112	-180	-250	-295	-366	-373	-324	-295
Dependance rate	Coal, lignite	17%	30%	35%	31%	27%	34%	38%	42%
	Oil	79%	76%	82%	81%	82%	84%	82%	79%
	Natural gas	45%	46%	56%	69%	82%	88%	91%	94%
	Total	42%	45%	50%	52%	53%	49%	42%	36%
International prices (€05/boe)	Coal	11.8	7.2	10.9	11.7	12.7	13.4	14.3	15.2
	Oil	24.9	25.9	44.2	51.0	59.7	70.1	82.1	94.6
	Gas	14.0	18.3	25.8	31.8	35.1	38.1	44.2	53.5
Value of imports (G€05)	Coal, lignite	6.2	4.9	8.6	7.3	4.2	5.4	6.2	6.7
	Oil	84.5	96.1	180.4	195.4	214.5	226.0	206.9	177.1
	Natural gas	11.5	24.1	47.3	68.8	94.2	104.1	105.1	115.7
	Total	102.3	125.1	236.3	271.5	313.0	335.5	318.2	299.6

Global Regime

GR-FT Results - EU27		1990	2000	2005	2010	2020	2030	2040	2050
GIC (Mtoe)		1531	1725	1822	1747	1801	1841	1781	1698
Imports (Mtoe)	Coal, lignite	-72	-94	-107	-91	-73	-73	-73	-68
	Oil	-464	-505	-557	-525	-527	-475	-357	-233
	Natural gas	-112	-180	-250	-293	-397	-407	-341	-271
Dependance rate	Coal, lignite	17%	30%	35%	32%	33%	39%	42%	44%
	Oil	79%	76%	82%	81%	83%	86%	86%	84%
	Natural gas	45%	46%	56%	69%	83%	90%	93%	97%
	Total	42%	45%	50%	52%	55%	52%	43%	34%
International prices (€05/boe)	Coal	11.8	10.9	11.6	12.2	12.9	13.9	14.8	14.8
	Oil	24.9	44.2	51.1	57.9	61.9	59.1	46.4	44.6
	Gas	14.0	25.8	31.9	33.8	33.8	33.0	29.8	30.1
Value of imports (G€05)	Coal, lignite	6.2	7.5	9.2	8.1	7.0	7.5	8.0	7.3
	Oil	84.5	163.5	208.7	222.7	239.1	205.9	121.6	76.3
	Natural gas	11.5	34.0	58.5	72.6	98.5	98.6	74.4	59.9
	Total	102.3	205.0	276.4	303.4	344.6	312.0	203.9	143.5

Source: POLES model, LEPII, SECURE project

The *Europe Alone* scenario presents interesting characteristics, as it is the one with the lowest level of energy imports in terms of volume and dependence rate. This can be easily explained as this case combines a stringent emission reduction policy in Europe, while the rest of the world continues along a line of modest climate policy. In that case, the global demand and prices for fossil fuels remain high and this not only limits demand in Europe but also stimulates domestic supply. The value of total energy imports is more than halved in the *Europe Alone* scenario in 2050, compared to the *Muddling Through*. One key outcome of the study is thus that a strong European climate policy may create a double dividend in terms of energy security, even in the case of weak global climate coordination.

Finally, the *Global Regime* scenario illustrates a fully different future for the world energy system, with lower global fossil fuel demand and prices. Europe's energy imports are similar in quantities compared to the *Europe Alone* case described above. But oil and gas prices are significantly lower and, as a consequence, the value of imports is at its lowest level: 144 G€ only in 2050, against 491 G€ in the *Muddling Through* scenario.

4. Conclusion

This scenario exercise, allows the illustration of the complex interactions of climate policies and energy security issues. They show in particular that the *Muddling Through* scenario, with low intensity and non-coordinated climate policy does not represent a really sustainable energy future. This is because of the double constraint that impends on the world energy system: upstream through the limitations in oil and gas availability and downstream, by the limited storage capacity of the atmosphere for GHGs. The low carbon price does already change significantly the level of emissions through reduced demand, accelerated development of non-fossil energy sources and some development of Carbon Capture and Storage. But this is not sufficient to meet the emission targets that are considered as desirable in IPCC AR2 in order to limit average temperature increase at level of 2°C compared to the pre-industrial situation. Moreover, this scenario neither significantly alters the balance of demand or supply on the international energy markets, although it alleviates somewhat the potential tensions.

The *Global Regime* scenario clearly allows the improvement of the situation from these two perspectives, of reducing both emissions and the level of tension on international hydrocarbon markets, through lower oil and gas production. This is a potential double dividend situation, probably the most important one to be derived from ambitious climate policies. Finally, the *Europe Alone* scenario does not meet the climate target as the impacts of ambitious policies in Europe are not sufficient to compensate for the massive global emission increases in the rest of the world. However, in this scenario setting, there is still an element that is strongly beneficial for Europe:

1. Imposing strong emission reduction domestically results in a thorough restructuring of the European energy system.
2. While it is supposed in this scenario that other countries adopt a free-riding behaviour and do not trigger such a restructuring, it is probable that tensions on the oil and gas market would remain high, with risks of repeated shocks in the near- and long-term future.
3. In that case, Europe would be protected from these external shocks by lower energy demand, higher contribution of domestic non-fossil fuels (renewable and nuclear), and a much lower level of fossil fuel imports.

Would this reward of ambitious climate policies fully compensate for the extra costs of the energy system restructuring? This question remains open today. Table 4 intends to illustrate the fundamentals of the risks associated for a country (c) to a negative event (e) and develops the risks in the three archetypal scenarios examined in this study.

Table 4: Risk as the Vulnerability to an Adverse Event

$Risk_{c/e}$ =	$Probability_e$	x $Magnitude_e$	x $Vulnerability_{c/e}$
Muddling Through	High	High	High
Europe Alone	High	High	Low
Global Regime	Low	Low	Low

It comes out of this study that an ambitious policy would bring to Europe a double dividend in its capacity to develop a new energy model – adjusted to sound climate policies – and in the resulting lower vulnerability to potential shocks on the international energy markets. Hence, it appears that it would probably be in the interest of Europe to implement the ambitious policy that is part of the Climate and Energy Package of 2008.

Of course, this raises the issue of how to develop cooperative relations with oil- and gas-exporting countries, who on their part may wish to benefit from a certain degree of security of demand. Exchanges and discussions on long-term energy scenarios – however fragile and uncertain these scenarios remain – may help in an improved mutual understanding of the goals that are pursued by both categories of countries in the development of their energy policies. In that way, scenarios can be useful tools to develop a somewhat stabilized framework for the investment decisions that in any case will be necessary to ensure the long-term energy supply of the different world regions.

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