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Exploring the Energy Security and Climate Policy Nexus with the POLES Energy Model in the SECURE Project

– preliminary version –

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CONTENT

1. Introduction

It is usually considered that national or regional energy policies should be developed while 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 Transports, 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 a series of trade-offs, aiming at the right balance between these supposedly conflicting goals. The key argument of this paper is to demonstrate that these targets may or may not be conflicting, according to the policy hypotheses retained at the global or regional level. In particular the adoption and implementation of strong climate change policies may be considered as the most effective way to enhance energy security through a lower degree of dependence on hydrocarbons.

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 the European and World level with this model, we propose a set of scenarios based on sets of exogenous hypotheses on economic growth, energy resources, technology performances and climate policies. The POLES model is not a General Equilibrium, but a Partial Equilibrium Model for the energy sector, with a dynamic recursive simulation process. In this paper we propose three scenarios in order to illustrate the consequences of different settings concerning climate policies, whether at global and regional level, on the fundamentals of the energy markets.

These scenarios are currently developed and used in the European SECURE project[1], on top of the model's *Baseline* case. The first one is called *Muddling Through* and illustrates the consequences of low intensity and non-coordinated climate policies in the different world regions. The second one appears as *Europe Alone* and simulates the consequences of a strong European climate policy in a world that is for the rest not engaged in strong and coordinated policies. Finally, the *Global Regime* scenario illustrates the consequences of coordinated and ambitious climate policies at world level. The exercise shows that while energy policies in *Muddling Through* result in emission levels in 2050 that are far in excess of those considered as reasonable in IPCC's AR4, the *Global Regime* 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 sustainability in time of the oil and gas production profile is significantly improved. In between, the *Europe Alone* scenario helps to show that in a world with

[1] **SECURE, Security of Energy Considering its Uncertainty, Risk and Economic implications**, Grant agreement N° 213744 under the Seventh Framework Programme

low policy coordination there might still be strong advantages in pursuing an ambitious regional climate policy as it may considerably limit the vulnerability to events occurring in an otherwise very unstable energy world.

Section 1 of this paper briefly presents the POLES model and the *Baseline* scenario, which, with absolutely no climate policy, is counter-factual and used only for the benchmarking of the model. Section 2 is dedicated to the presentation of the three archetypal scenarios and to the comparative analysis of their results in terms of emission performances, fundamentals of the energy markets and dependence of the European energy system. Section 3 draws insights on the trade-offs or complementarities among the three pillars of energy policy. Section 4 draws conclusions for the future of research in particular in the framework of the SECURE project.

2. The POLES model and the *Baseline* projection to 2050

The *Baseline* projection provides an image of the energy scene to 2050, as resulting from the continuation of on-going trends and structural changes in the world economy, with no climate policy. In that perspective it is a counterfactual scenario, used for benchmarking.

From the identification of the drivers and constraints in the energy system, the model allows to describe the pathways for energy development, fuel supply, greenhouse gas emissions, international and end-user prices, 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 “very low energy” end-use technologies. Therefore, each scenario can be described as the set of economically consistent transformations of the initial *Baseline* case that is induced by the introduction of policy constraints.

2.1. The POLES model

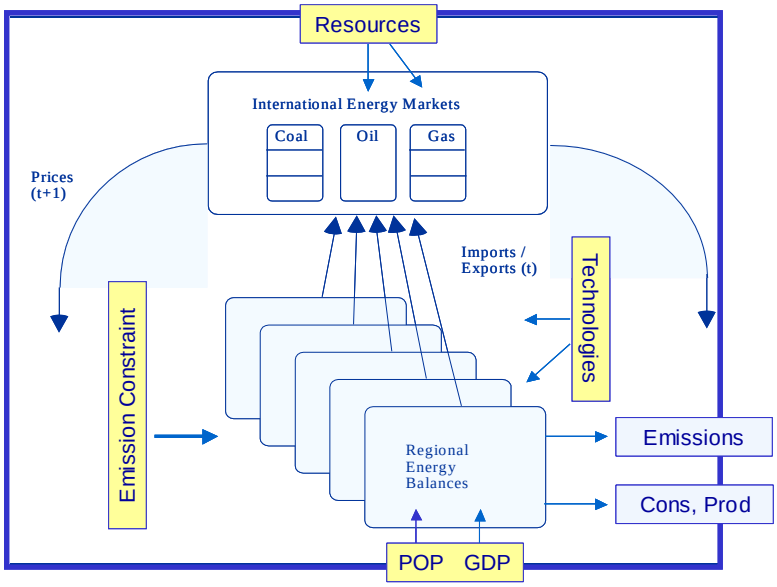
The POLES model is a partial equilibrium model of the world's energy system that provides a detailed year-by-year projection until 2100, for the different regions of the world. The model simulates the energy demand for each economic sector, the supply and prices for the primary energy sources on the international markets, and the impacts of innovation, experience effects and R&D in 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. 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 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 or emission constraint with trading systems. Its main limitation is probably the absence of macro-economic feedbacks, but this allows a robust estimate of the impacts of climate policies on the energy sector only, while the macro impacts are most often taken into account in joint studies with other energy economy model such as GEM-E3 (NTUA, Athens) or IMACLIM (CIRED, Paris).

Figure 1: The POLES model simulation process



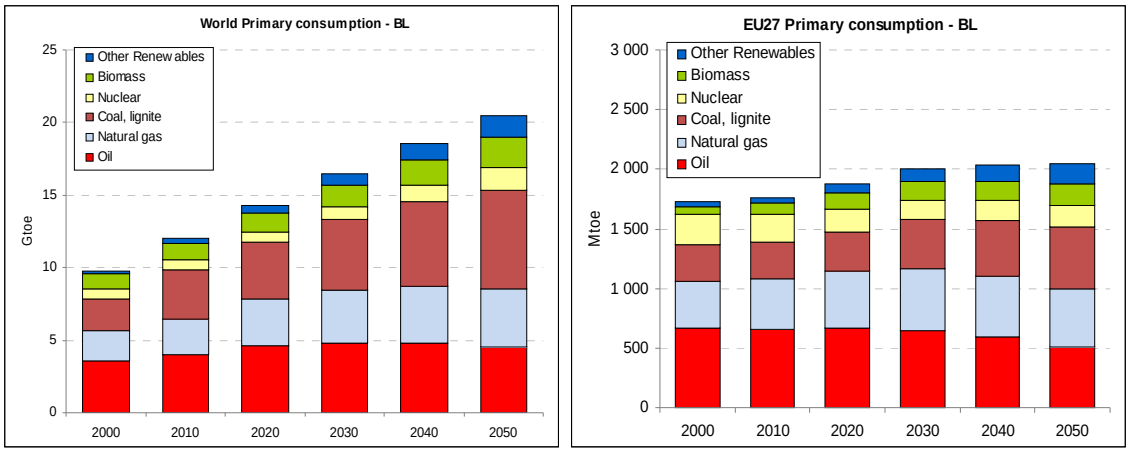
Source: POLES-LEPII

2.2. The baseline projection and the come-back of coal

The *Baseline* 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 SECURE *Baseline* has a GDP growth rate in 2009 that is 50 % lower than in the preceding POLES projections, -40% in 2010, -30% in 2011, -20% in 2012 and -10% in 2013. This corresponds to a world GDP that is in 2015 more than 5.5% lower than considered in preceding POLES energy outlooks. This might however be considered as still an optimistic view on the capability of recovery of the world economy in the short-medium term. Other hypotheses on world economic growth may be explored in future 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 business as usual scenario, a standard discount rate of 8% is used. Figure 2a and 1b describe the dynamics of the world and European energy system, in the initial settings considered in the *Baseline*.

Figure 2 a and b: *Baseline* Case – World and Europe Gross Inland Consumption



Source: POLES model, LEPII, SECURE project

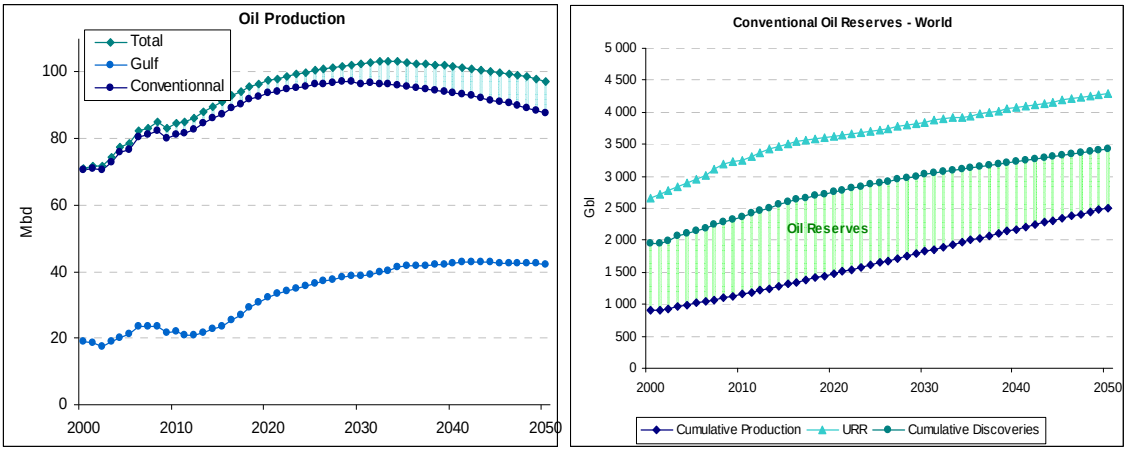
The key outcome of the *Baseline* case is a doubling of world energy consumption from 2000 to 2050, with a levelling-off of world oil and gas production after 2030. In spite of a significant development in nuclear energy, biomass and other renewables, which in 2050 represent more than one fourth of world Gross Inland Consumption (GIC), the primary source that most gains in importance is coal, which passes from 2.2 Gtoe to 6.8 Gtoe between 2000 and 2050. As for Europe, the dynamics in GIC is much less pronounced with an increase from 1.7 Gtoe to 2.04 Gtoe between 2000 and 2050. There again one notes a levelling-off of oil and gas consumption, the progress of renewable and the penetration of coal, although with a more modest magnitude that at world level.

2.3. The probable unsustainability of the baseline: upstream and downstream constraints

To many respects this scenario is probably not 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 a strong increase in cumulative conventional oil production, from 900 Gbl in 2000 to 2 500 Gbl in 2050, i.e. a level that corresponds to the middle of the range of total Ultimate Recoverable Resources estimates for conventional liquids (Figure 4). The consistency of the long run oil projections of the POLES model with the taking into account of available resource limits is indeed based on the possibility of increasing recoverable resources through enhanced recovery rates, which indeed explain the possibility of high cumulative production in 2050. 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 of oil production to 40 Mbd in the Gulf region is extremely questionable, not only for resource and technical reasons, but also for reasons related to the geopolitical and internal political dimensions of the problems encountered in this region of the world. This is why the smooth path for oil price increases that is associated to this scenario can

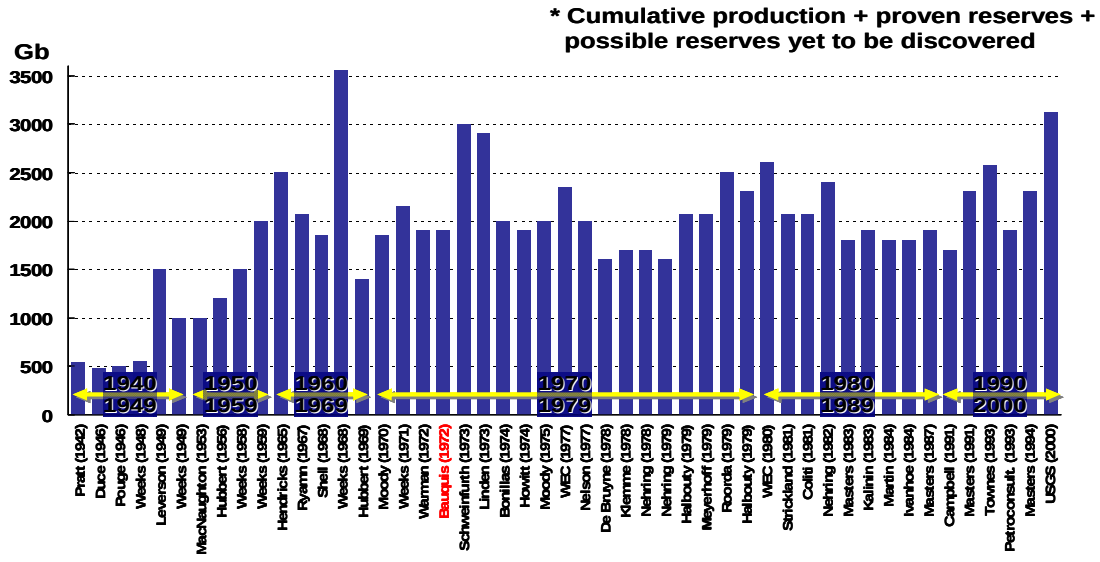
be considered as a relatively optimistic hypothesis, although it ends at more than 110 €/bl in 2050.

Figure 3: *Baseline* Case, world oil production, resources and reserves



Source: POLES model, LEPII, SECURE project

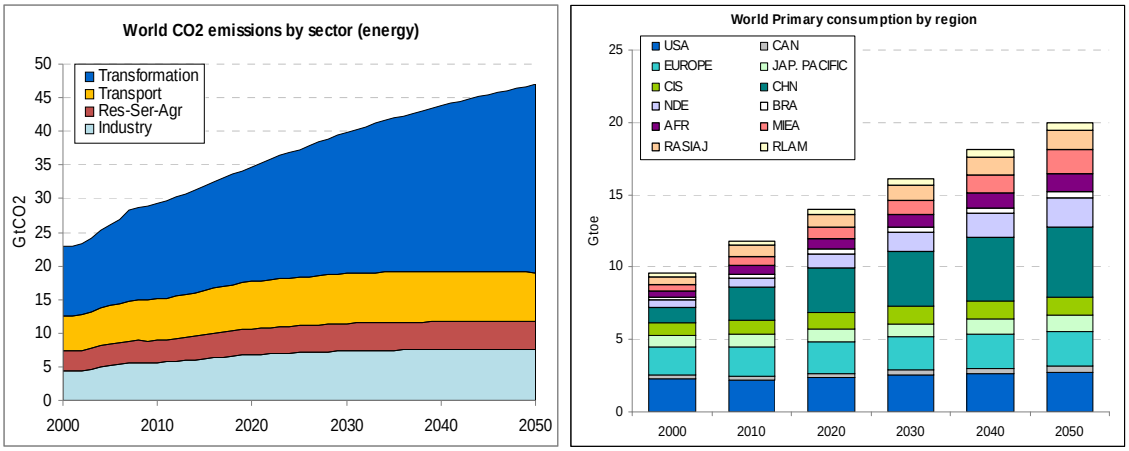
Figure 4: Estimates of conventional oil Ultimate Recoverable Resources (source P.R. Bauquis, 2006)



Source: IFP/DSEP adapted from Martin (1985) and Campbell (1992) - Updated 2000

The second reason for which the *Baseline* is not sustainable is connected to the implied CO2 emission level of the energy sector (Figure 5). 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 from 4.9 to 6.1°C.

Figure 5: World CO2 emissions from energy, by sector and by region



Source: POLES model, LEPII, SECURE project

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

3. Three scenarios for climate policies and their consequences on energy security

Three scenarios (plus a variant) are used in the SECURE study in order to characterize contrasted states of the world from the perspective of the "energy security and climate policy" nexus. They allow illustrating the consequences of contrasted energy policies on the fundamentals of the world energy system.

3.1. Scenario definition

The *Muddling Through* scenario supposes a failure in the efforts to develop a common framework of targets, rules and mechanisms for climate policies. In that case only weak domestic climate policies are implemented without any element of coordination of the different actions. This is simulated through a low level of carbon value, i.e. 10$/tCO2 in 2010, 50 $/tCO2 in 2050. The resulting picture is one of lower emissions than in the *Baseline*, but total emissions are still up of 30% compared to 2000, which corresponds to a Type IV scenario in the AR4 typology (see Table 2).

The second scenario, *Europe Alone* supposes that Europe goes along a stringent climate policy line, while the rest of the world continues on the same line than 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 the same level than in the *Global Regime + Full Trade* scenario described below. In brief, Europe follows domestically the same policy as the one it would adopt in a unified international climate regime.

Table 2: 3+1 Scenarios for exploring the energy security – climate policy nexus

		S1	**S2**	**S3a**	**S3b**
	BL	**MT**	**EA**	**GR-2B**	**GR-FT**
Scenario	**Baseline**	**Muddling Through**	**Europe Alone**	**Global Regime with two bubbles: Annex 1+Non Ann. 1**	**Global Regime with Full Trade**
Carbon Value ($/tCO2)	0	EU: 10 in 2010, 50 in 2050	EU: 10 in 2010, 380 in 2050	Ann 1: 10 in 2010, 680 in 2050	10 in 2010, 380 in 2050
		RoW: 10 years lag / EU	RoW: as in Muddling Through	Non Ann 1: 5 in 2010, 310 in 2050	
World CO2 emissions 2050/2000	+113%	+36%	+30%	World: -50% Annex 1: -80%	-50%
AR4 Scenario Profile	Type VI > 850 CO2e	Type IV > 600 CO2e	Type IV > 600 CO2e	Type II > 500 CO2e	Type II > 500 CO2e

Source: SECURE project

The two *Global Regime* scenarios correspond to a concentration stabilization profile below 450 ppmv CO2 only, 500 ppmv CO2eq. This is simulated through a world emission profile that ends up at 50% of 2000 CO2 emissions in 2050. In compliance to this global profile, two variants have been considered. In the S3a scenario the reductions in Annex I countries are set at 80% and reductions in the non-Annex I countries are determined as a residual. It corresponds to a case in which Annex 1 country adopt a strong target and do not use flexibility mechanisms to comply to this target, leaving room for some emission increases in Non Annex 1 regions. In the S3b scenario, the same world emission profile is obtained while considering a world carbon price obtained either by a world carbon tax or a full trade in emission quotas on a global carbon market. This last scenario indeed corresponds to a least-cost abatement program at world level.

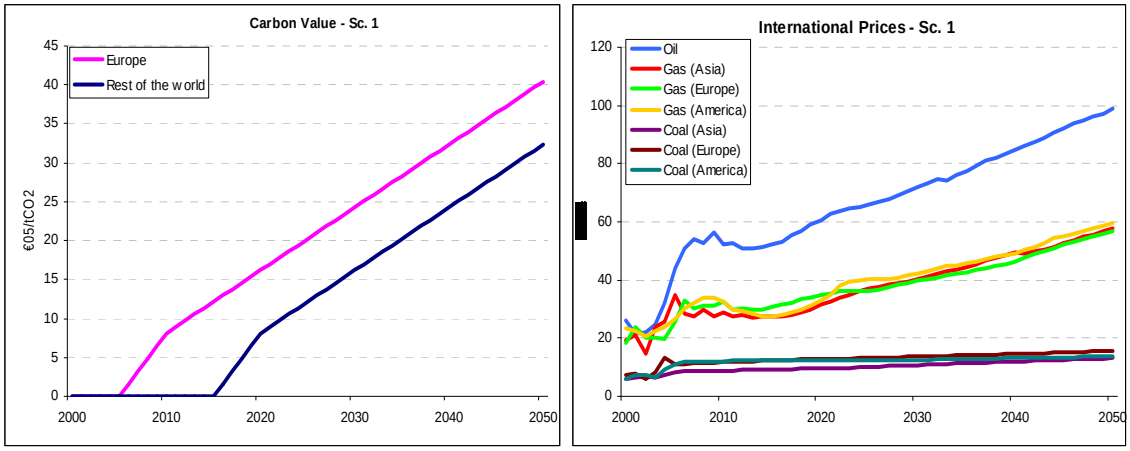
3.2. *Scenario results*

3.2.1. *Muddling Through* (S1)

Even if it doesn't suppose coordinated policies at the international level, the projection of the world energy system in the *Muddling Through* scenario accounts for a minimum level of domestic climate policies, without however any international coordination. GHG abatement policies are included through a carbon penalty or "carbon value", which is differentiated across the main country categories, i.e. higher in the industrialised than in the developing ones, in order to reflect different levels of commitment:

In Europe an average cross-sector carbon value of 8 €/tCO2 is assumed in 2010. This value increases linearly to 16 €/tCO2 in 2020 and 40 €/tCO2 in 2050. In the rest of world countries a still more modest policy is assumed with a carbon value starting with a lag of ten years in comparison with European countries, starting at 2 €/tCO2 in 2015, ending at 32 €/tCO2 in 2050.

Figure 6: Exogenous Carbon Value and endogenous international energy prices in *Muddling Through* (S1)



Source: POLES model, LEPII, SECURE project

The introduction of these domestic policies explains the main results of the scenario, which are characterized by higher energy prices to end-use consumers and consequently lower Gross Inland Consumption and CO_2 emissions at world and EU27 level, as compared to the initial *Baseline* Case. World and Europe Gross Inland Consumption is respectively 10% and 8% lower in *Muddling Through* than in the *Baseline*.

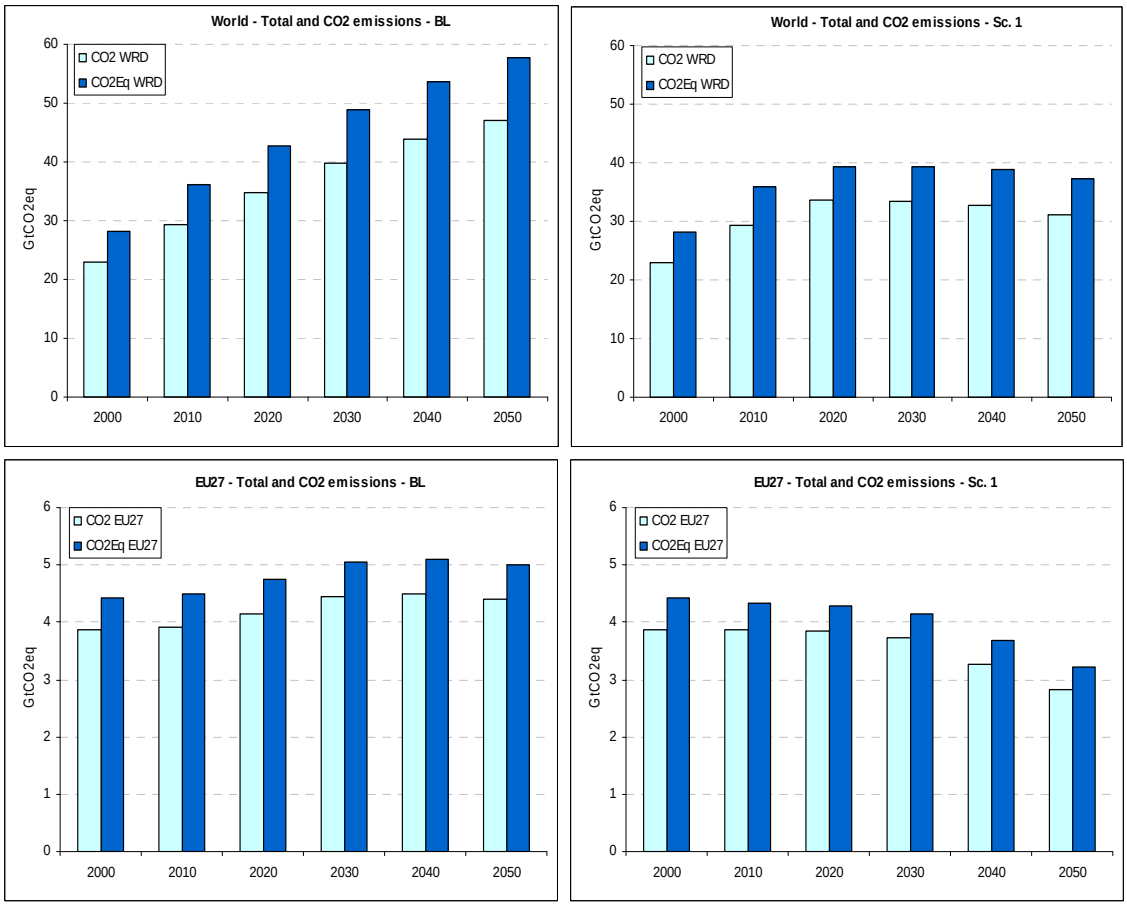
As a consequence the fossil fuel production path is lower than in the *Baseline* inducing similarly lower international energy price. The oil price for example doesn't exceed 100 €/bl by the end of the projection period. Indeed total conventional and non-conventional liquid production peaks at 100 Mbd in 2030, but due to lower prices and lower stimulus to non-OPEC

production, the dependence of world supply towards the Gulf region is still approximately of 50%.

The impact on emissions are already significant, in spite of the relatively low carbon value: world emissions peak in 2030 at a level that is more than one third higher than the 2000 level and then decrease slightly (Figure 7, top). This typically corresponds to a Type IV scenario profile in the AR4 typology (see Table 1). Significant emission reductions can be expected even from relatively low carbon price. This reveals the magnitude of the potentials for low cost mitigation options in the low part of the Marginal Abatement Cost curves. In spite of the significant reductions however, this scenario still corresponds to a strong climate change case, with expected temperature increase at equilibrium of 3.2 to 4°C according to AR4 (Table 1).

As far as Europe is concerned (Figure 7, bottom), emissions are more than 25% lower in 2050 compared to 2000 level. This is a much lower level than world average, but a much higher than the one implied by climate policies in the major European countries, as targets of 60 to 80% reductions compared to 1990 are there commonplace.

Figure 7: World (top) and Europe (bottom) GHGs emissions in the *Baseline* (left) and in *Muddling Through* (S1) (right)

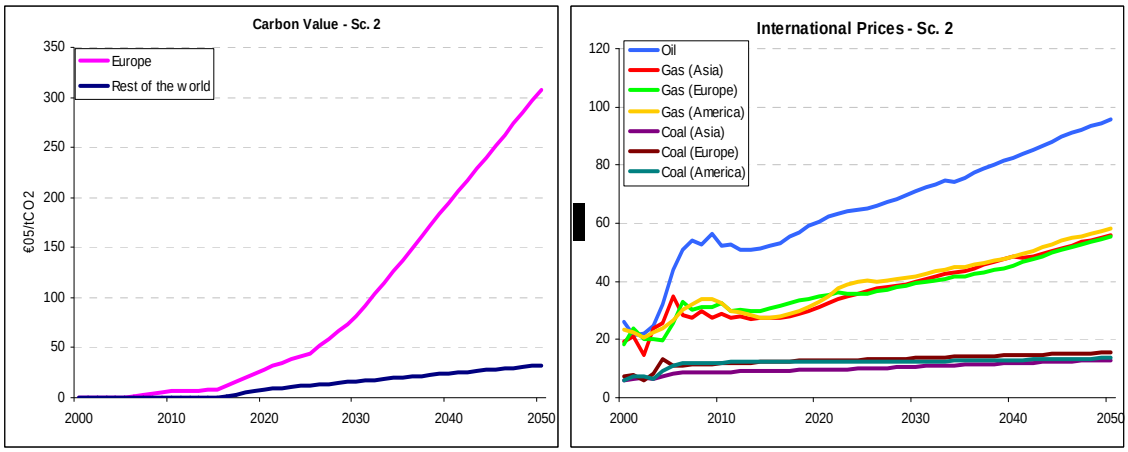


Source: POLES model, LEPII, SECURE project

3.2.2. *Europe Alone* (S2)

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, in which climate policies in the rest of the world have a similar intensity as in *Muddling Through*. In this setting, the carbon value in Europe is about ten times higher than in the rest of the world (Figure 8).

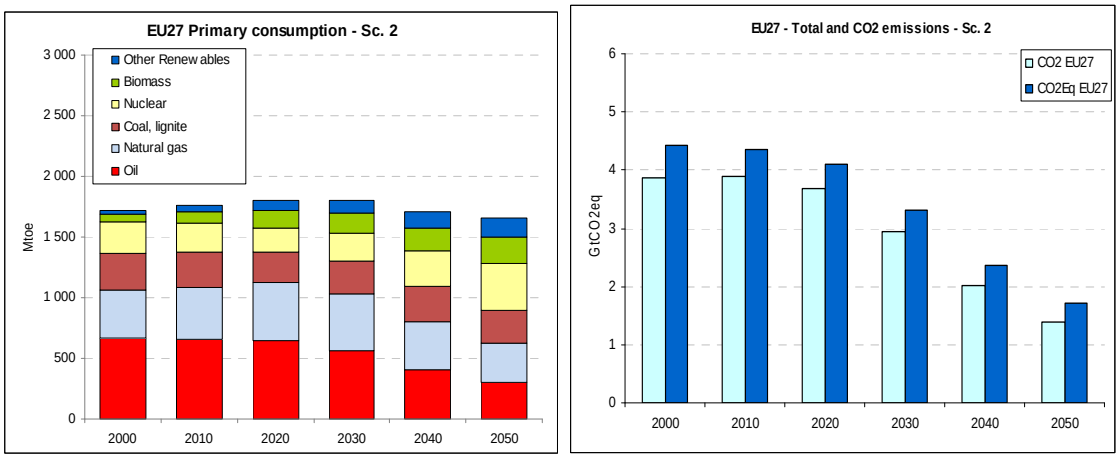
Figure 8: Carbon value and international energy price trajectories



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 Alone* corresponds to a limited and diminishing fraction of the world energy system, i.e. 9% of total GIC in 2050, against 10% in 2050 in *Muddling Through*.

Figure 9: Europe Gross Inland Consumption and CO2 emissions in *Europe Alone*

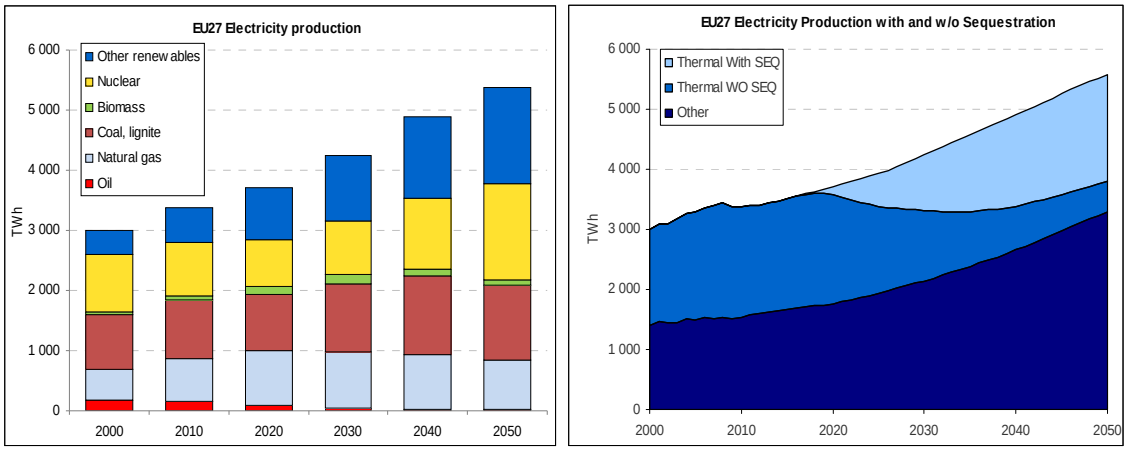


Source: POLES model, LEPII, SECURE project

On the contrary, the European energy system is profoundly altered by the introduction of a high carbon value. Total energy consumption increases only slightly in a first phase, from 1.7 Gtoe in 2000 to 1.8 Gtoe 2020 to 2030 and then again down to 1.7 Gtoe. But the fuel-mix in total supply is quite different: fossil energy sources, which represent in 2000 80% of total GIC

are reduced to 55% in 2050. The electricity system also incurs radical changes and is a major contributor to the reductions of carbon emissions in Europe (Figure 10).

Figure 10: 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 5 400 in 2050. This indicates that the electrification of the energy balance is one important dimension of 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, CCS develops quite rapidly after 2020 and represents almost 80 % 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.

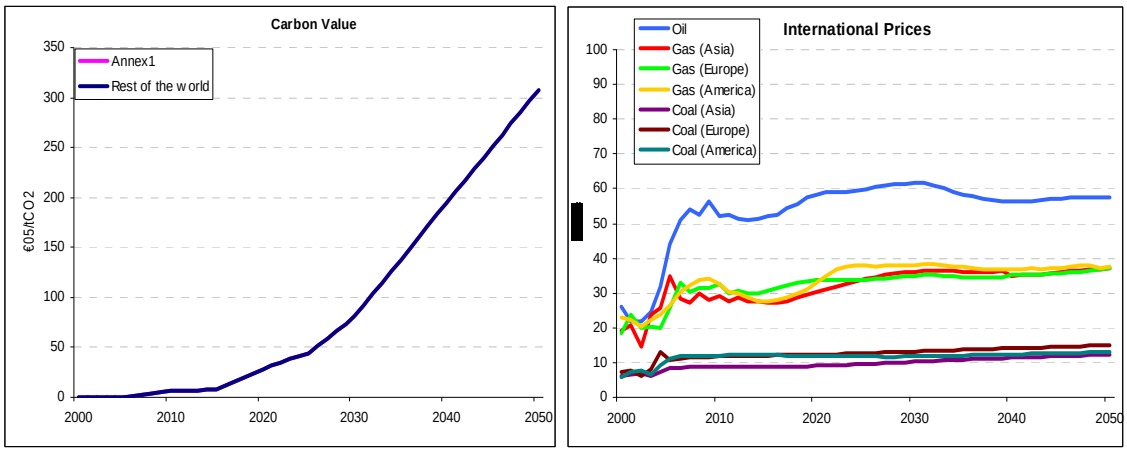
3.2.3. Global climate Regime (S3)

The main feature of this scenario is the introduction of a global cap on emissions. The Carbon Constraint scenario reflects a state of the world with an ambitious climate targets, aiming at an emission profile of Type II in AR4 typology (see Table 1). It allows stabilizing concentrations below 450 CO2 and 500 CO2e and is indeed characterized by a 50% reduction in global emissions.

In the variant of the *Global Regime* consider here, it is supposed that the abatement programs corresponds to a cost-effective program, resulting from a unique carbon value, as introduced either by a global carbon market or by an international carbon tax. In this framework of hypotheses – 50% reduction in global emissions and a world carbon value – the resulting carbon value increases rapidly to 25 €/tCO2 in 2020, 75 in 2030, 200 in 2040 and 300 in 2050. One can note that the carbon Value that is necessary to induce new trajectories in the world

and European energy system is an order of magnitude higher than the value used in *Muddling Through*. This corresponds to the fact that the *Global Regime* scenario reveals the need for radical changes in the energy systems.

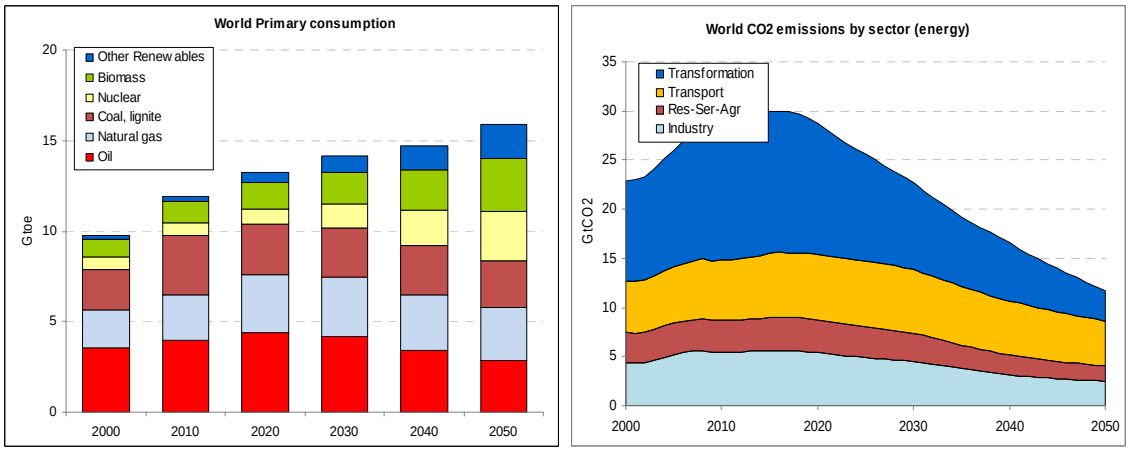
Figure 11: Carbon Value meeting the emission cap and endogenous international energy prices in *Global Regime* (S3-full trade)



Source: POLES model, LEPII, SECURE project

While the European Gross Inland Consumption and fuel-mix is not significantly different from the one simulated in *Europe Alone* (see above Figure 9), major changes occur in the global energy picture. World enegy consumption is about one fourth inferior to the one projected in the *Baseline*. As a result the total amount of coal, oil and gas consumed at world level is not significantly different from the one existing in 2000 (Figure 12): coal consumption is comparable, oil consumption lower and gas consumption higher.

Figure 12: World Gross Inland Consumption and CO2 emissions by sector in *Global Regime* (S3-full trade)



Source: POLES model, LEPII, SECURE project

In order to reduce global emission by 50% this scenario supposes a massive development of Carbon Capture and Storage. By 2050 almost 50% of total gross emissions are

captured, with almost 50% of CCS occurring in the electricity sector and the rest in industry and hydrogen production.

As a consequence of almost unchanged levels of consumption for the different fossil fuels in 2050 compared to 2000, the prices of oil and gas are much lower in this scenario than in the *Baseline* or even *Muddling Through* scenarios. Consequently the endogenous price mechanisms in the model result into a stabilization of international energy price at a level that is only 10 to 20% 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. This new balance of the global energy system will certainly have significant impacts on the international price of coal, oil and gas. A large degree of uncertainty remains on the will and capability of exporting country to maintain some elements of resource rents in front of a reduced world demand. In any case, tensions on the international markets should be expected to be much reduced in a *Global Regime* type of scenario.

4. Impacts of the scenarios on Europe's energy security

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

4.1. Europe's energy dependence and value of imports

The four scenarios presented above result in very different profiles for energy imports and dependence. For all instances, the Baseline correspond to the scenario of higher consumption, imports, dependence rate and value of energy imports. While Europe's import dependence rate was of 50% in 2005 and the value of energy imports of 236 G€ in 2005, these figures rise respectively to 54% and 432 G€ in 2030 and 53% and 554 G€ in 2050. The value of imports thus doubles along the projection period. What is more preoccupying is the fact that Europe depends from the international markets for 86% of its oil supply and 73% of its gas supplies, while these two markets might be subject to tensions, price hikes and shocks in the *Baseline* scenario, which is characterized by a high level of resource mobilization.

The situation already changes in *Muddling Through* as the introduction of the carbon value, though modest it is clearly modifies both the global picture and the degree of external energy dependence of Europe. The global energy dependence rate is reduced to 48% in 2050 through significant reductions in coal imports, while oil and particularly natural gas imports are much less impacted. The value of total energy imports is limited to 445 G€ in 2050.

Table 3: Profiles for Europe energy imports and dependence

Baseline

Baseline Results - EU27		**1990**	**2000**	**2005**	**2010**	**2020**	**2030**	**2040**	**2050**
GIC (Mtoe)		1531	1725	1822	1764	1882	2003	2039	2050
Imports (Mtoe)	Coal, lignite	-72	-94	-107	-102	-130	-192	-247	-286
	Oil	-464	-505	-557	-532	-560	-564	-510	-439
	Natural gas	-112	-180	-250	-217	-271	-335	-362	-355
Dependance rate	Coal, lignite	17%	30%	35%	33%	39%	48%	53%	56%
	Oil	79%	76%	82%	81%	84%	87%	87%	86%
	Natural gas	45%	46%	56%	51%	57%	64%	70%	73%
	Total	42%	45%	50%	48%	51%	54%	55%	53%
International prices (€05/boe)	Coal	11,8	7,2	10,9	11,8	13,0	14,1	15,2	16,4
	Oil	24,9	25,9	44,2	52,0	61,1	75,4	91,2	111,7
	Gas	14,0	18,3	25,8	32,4	34,6	41,2	49,2	61,6
Value of imports (G€05)	Coal, lignite	6,2	4,9	8,6	8,8	12,4	19,9	27,6	34,3
	Oil	84,5	96,1	180,4	203,0	250,8	311,4	341,0	359,6
	Natural gas	11,5	24,1	47,3	51,6	68,8	101,1	130,5	160,1
	Total	102,3	125,1	236,3	263,4	332,0	432,3	499,0	554,0

Muddling through

Sc. 1 Results - EU27		**1990**	**2000**	**2005**	**2010**	**2020**	**2030**	**2040**	**2050**
GIC (Mtoe)		1531	1725	1822	1758	1822	1921	1929	1899
Imports (Mtoe)	Coal, lignite	-72	-94	-107	-95	-98	-149	-182	-190
	Oil	-464	-505	-557	-533	-542	-536	-474	-399
	Natural gas	-112	-180	-250	-221	-276	-328	-336	-323
Dependance rate	Coal, lignite	17%	30%	35%	32%	36%	46%	51%	53%
	Oil	79%	76%	82%	81%	83%	86%	86%	85%
	Natural gas	45%	46%	56%	52%	58%	64%	69%	72%
	Total	42%	45%	50%	48%	50%	53%	51%	48%
International prices (€05/boe)	Coal	11,8	7,2	10,9	11,8	12,8	13,6	14,6	15,5
	Oil	24,9	25,9	44,2	52,0	60,6	72,0	84,6	98,8
	Gas	14,0	18,3	25,8	32,5	34,7	39,7	46,4	56,9
Value of imports (G€05)	Coal, lignite	6,2	4,9	8,6	8,2	9,2	14,9	19,5	21,7
	Oil	84,5	96,1	180,4	203,3	240,8	282,9	293,9	288,8
	Natural gas	11,5	24,1	47,3	52,6	70,1	95,4	114,2	134,7
	Total	102,3	125,1	236,3	264,1	320,1	393,3	427,6	445,2

Europe Alone

Sc. 2 Results - EU27		**1990**	**2000**	**2005**	**2010**	**2020**	**2030**	**2040**	**2050**
GIC (Mtoe)		1531	1725	1822	1760	1803	1806	1708	1663
Imports (Mtoe)	Coal, lignite	-72	-94	-107	-97	-86	-119	-143	-138
	Oil	-464	-505	-557	-533	-533	-474	-338	-239
	Natural gas	-112	-180	-250	-220	-278	-291	-238	-189
Dependance rate	Coal, lignite	17%	30%	35%	33%	34%	44%	49%	51%
	Oil	79%	76%	82%	81%	83%	85%	82%	78%
	Natural gas	45%	46%	56%	52%	58%	62%	61%	59%
	Total	42%	45%	50%	48%	50%	49%	42%	34%
International prices (€05/boe)	Coal	11,8	7,2	10,9	11,8	12,8	13,6	14,5	15,5
	Oil	24,9	25,9	44,2	52,0	60,4	71,0	82,6	95,8
	Gas	14,0	18,3	25,8	32,5	34,8	39,3	45,5	55,5
Value of imports (G€05)	Coal, lignite	6,2	4,9	8,6	8,3	8,1	11,9	15,2	15,6
	Oil	84,5	96,1	180,4	203,2	235,9	246,6	204,5	168,0
	Natural gas	11,5	24,1	47,3	52,4	70,7	83,7	79,2	77,0
	Total	102,3	125,1	236,3	264,0	314,8	342,2	299,0	260,7

Global Regime

Sc. 3b Results - EU27		**1990**	**2000**	**2005**	**2010**	**2020**	**2030**	**2040**	**2050**
GIC (Mtoe)		1531	1725	1822	1759	1798	1804	1710	1667
Imports (Mtoe)	Coal, lignite	-72	-94	-107	-96	-86	-118	-136	-125
	Oil	-464	-505	-557	-533	-533	-486	-369	-281
	Natural gas	-112	-180	-250	-220	-276	-301	-263	-231
Dependance rate	Coal, lignite	17%	30%	35%	33%	34%	44%	49%	50%
	Oil	79%	76%	82%	81%	83%	86%	87%	87%
	Natural gas	45%	46%	56%	51%	58%	63%	67%	69%
	Total	42%	45%	50%	48%	50%	50%	45%	38%
International prices (€05/boe)	Coal	11,8	7,6	11,6	12,5	13,0	13,9	15,0	15,9
	Oil	24,9	32,8	55,8	65,9	72,5	75,3	65,8	64,8
	Gas	14,0	19,5	27,4	34,6	35,5	36,1	35,3	36,7
Value of imports (G€05)	Coal, lignite	6,2	5,3	9,1	8,8	8,2	12,1	14,9	14,5
	Oil	84,5	121,4	228,0	257,2	283,1	268,3	178,2	133,6
	Natural gas	11,5	25,7	50,3	55,8	71,8	79,7	68,1	62,3
	Total	102,3	152,4	287,5	321,8	363,1	360,1	261,1	210,4

Source: POLES model, LEPII, SECURE project

The *Europe Alone* scenario presents interesting characteristics, as it is the scenario with the lowest level of energy imports in volume and of dependence rate. This can be easily explained as in this case Europe follows a stringent emission reduction policy, thus introducing strong constraints on fossil fuel consumption, 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: as a consequence, Europe's imports of oil and gas are lower then in the following scenario, which describes the outcome of a global climate policy, with major consequences on global oil and gas demand but lower international prices. The value of total energy imports is more than halved in the *Europe Alone* scenario in 2050, compared to the *Baseline*. One key outcome of the study is thus that the double dividend of a strong European climate policy in terms of supply security exists even in case of weak global climate coordination; it is even stronger in that case due to this effect of higher prices stimulating domestic production.

Finally, the *Global Regime* scenario illustrates a fully different world energy system, with lower fossil demand and prices. Europe's energy imports are higher in quantities compared to the *Europe Alone* case described above. But oil and gas prices are significantly lower and the consequence is that imports in value are at their lowest level: 210 G€, against 554 G€ in the *Baseline* in 2050.

4.2. European gas imports in the different scenario settings

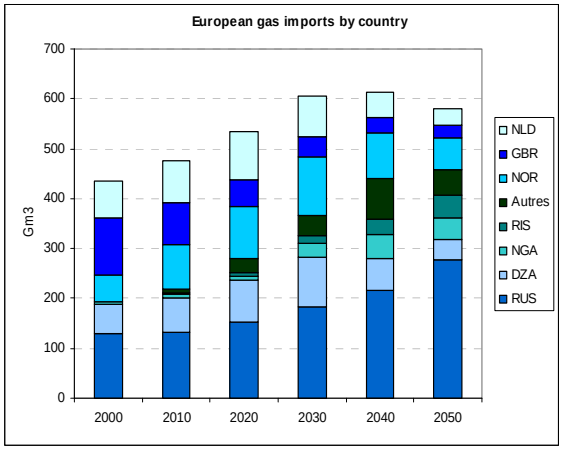
One of the key concerns regarding the long term energy security of Europe is its dependence in terms of gas supply. Natural gas is a key resource with rather favourable environmental characteristics, including in a GHG abatement policy as gas-based electricity has a CO2 content that is on average half 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.

Of course the key issue with natural gas supply is that of the transport infrastructures that are highly investment intensive weather for gas pipeline or for LNG facilities at exporting or importing point. The POLES model allows describe with a relatively level of detail the conditions of supply of the different regions of the world, 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.

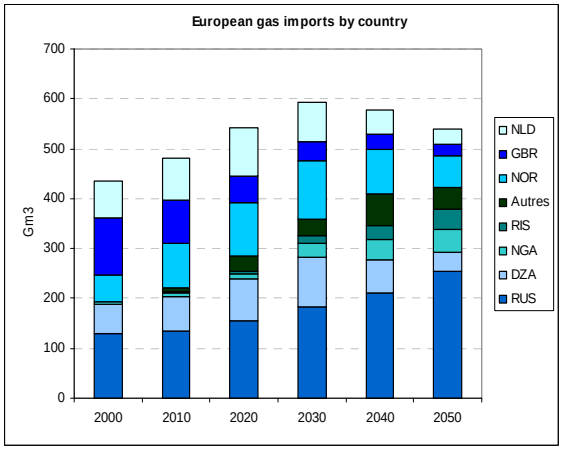
The simulation of very different conditions of international energy markets and European energy system in the four scenarios allows displaying very different profiles for Europe future natural gas supply (Figure 13).

Figure 13: Europe's natural gas supplies in the four scenarios

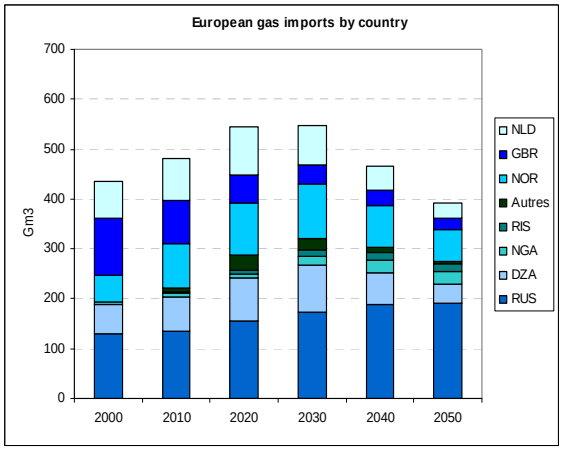
Baseline



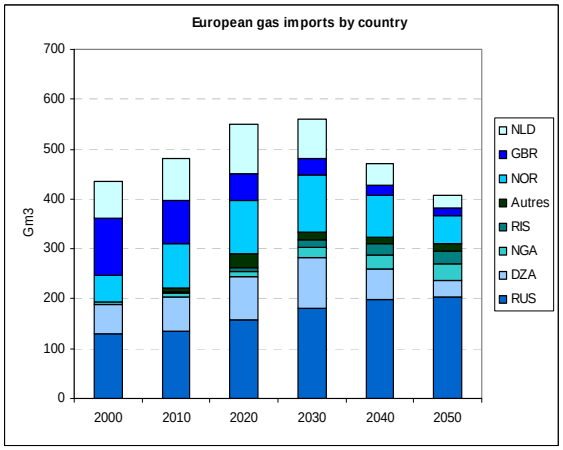
Muddling Through



Europe Alone



Global Regime



Source: POLES model, LEPII, SECURE project

In the *Baseline* as in the *Muddling Through* scenarios, total Western Europe gas imports (i.e. gas consumption minus supplies from UK, Netherland and Norway) are expected to increase significantly over the next decades, from 200 to 450 Gm3 in 2050. This happens, in spite of a total demand that is levelling-off at about 600 Gm3 between 2030 and 2040, but due to the significant reduction in regional domestic production from Norway, UK and Netherland, which decreases by a factor of two between 2000 and 2050, from 240 to 120 Gm3. While supply from Russia increases from 120 Gm3 to 260-280 Gm3 in these two scenarios, as well as supply from Nigeria, Rest of the Community of Independent States (mostly Kazakhstan) and Other regions (mostly Iran).

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 GM3 in both scenarios. To a large extent this reduction of total demand weighs on the new suppliers that played an important role in the *Baseline* as in the *Muddling Through* scenarios, i.e. Nigeria, Rest of the

Community of Independent States and Other. Imports from Russia still represent about 200 GM3 in 2050 in both scenarios.

As a matter of conclusion for this analysis of long term natural gas supply of Europe, one has indeed to emphasise the fact that the volume of Russian exports to Europe appear to be extremely stable in the different scenarios, at least until 2040, when they reach a level of about 200 GM3 in the four cases. Only after that date do the results differ significantly, with exports that are of 30 to 40% higher in *Baseline* and in *Muddling Through* than in *Europe Alone* and *Global Regime.*

5. Conclusions

The scenario exercises developed in the SECURE project of the Commission's FP7 research program allow illustrating the complex interactions of climate policies and energy security issues. They show in particular that the *Baseline* doesn't represent a sustainable energy future, because of the double constraint that is imposed, upstream by the limitations in oil and gas availability and downstream, by the limited storage capacity of the atmosphere for GHGs. The *Muddling Through* scenario illustrate the fact that non-coordinated climate policies, with relatively weak signals in terms of carbon price, already change significantly the level of emissions through reduced demand, accelerated development of non fossil energy and Carbon Capture and Storage. However, this scenario doesn't succeed in meeting 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 pre-industrial situation. This scenario neither significantly alters the balance of demand nor supply on the international energy markets, although it alleviates somehow the potential tensions.

The *Global Regime* scenario clearly allows improving 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 clear double dividend situation, probably the most important one to be derived from Ambitious climate policies. Finally, *Europe Alone* doesn't meet the climate target as the impacts of ambitious policies in Europe are not sufficient to replace massive global emission reductions. However in this scenario setting, ther is still an element that is strongly beneficial for Europe:

- imposing strong emission reduction domestically results in a thorough restructuring of the European energy system
- 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 will remain high, with risk of repeated shocks in the near and long term future;

- in that case, Europe will be largely protected from these external shocks by lower energy demand, higher contribution of domestic non-fossil fuels (renewable and nuclear) and a much lower 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 today open, future developments in the SECURE project may help to better appreciate the magnitude of the risk avoided through virtuous climate policy in a non-cooperative international context.

ANNEX A: World Summary Energy Balances

(*Baseline* + 3 SECURE Scenarios)

World: Baseline

Baseline Results - World

								Annual % change		
	1990	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2000/20**	**20/30**	**30/50**
Key Indicators										
Population (Millions)	5246	6118	6872	7585	8175	8693	9246	1.2%	0.8%	0.6%
GDP (G$95)	29992	49874	72998	104259	138835	178070	223431	3.9%	2.9%	2.4%
Per capita GDP ($95/cap)	5717	8152	10623	13745	16982	20485	24166	2.7%	2.1%	1.8%
Gross Inland Cons/GDP (toe/M$95)	291	200	167	139	120	105	93	-1.7%	-1.5%	-1.3%
Gross Inland Cons/capita (toe/cap)	2	1.6	1.8	1.9	2.0	2.2	2.2	0.9%	0.6%	0.5%
Electricity Cons/capita (kWh/cap)	1830	2053	2538	2959	3547	4210	4856	2.1%	1.8%	1.6%
Transport fuels per capita (toe/cap)	0	0.3	0.3	0.4	0.4	0.4	0.4	0.6%	0.2%	0.2%
CO2 emissions/capita (tCO2/cap)	4	3.8	4.4	4.7	5.0	5.1	5.2	1.3%	0.6%	0.2%
% of renewables in Gross Inland Cons	13	12.3	11.9	12.8	13.5	15.2	17.3	-0.3%	0.5%	1.2%
% of renewables in electricity	20	18.7	18.6	21.6	22.4	24.5	27.0	0.0%	0.4%	0.9%
Primary Production (Mtoe)	**8806**	**9831**	**12198**	**14486**	**16634**	**18682**	**20644**	2.2%	1.4%	1.1%
Coal, lignite	2211	2302	3360	3949	4863	5807	6788	3.9%	2.1%	1.7%
Oil	3234	3507	4170	4807	5054	5015	4798	1.7%	0.5%	-0.3%
Natural gas	1708	2109	2483	3183	3611	3855	3930	1.6%	1.3%	0.4%
Nuclear	525	686	726	692	854	1149	1547	0.6%	2.1%	3.0%
Hydro, geothermal	216	229	294	366	432	496	541	2.5%	1.7%	1.1%
Biomass and wastes	913	994	1121	1352	1527	1789	2066	1.2%	1.2%	1.5%
Wind, solar	0	5	43	137	292	570	974	24.4%	7.9%	6.2%
Gross Inland Consumption (Mtoe)	**8741**	**9955**	**12221**	**14524**	**16685**	**18750**	**20710**	2.1%	1.4%	1.1%
Coal, lignite	2205	2217	3360	3949	4863	5807	6788	4.2%	2.1%	1.7%
Oil	3200	3707	4170	4807	5054	5015	4798	1.2%	0.5%	-0.3%
Natural gas	1678	2118	2505	3220	3663	3924	3996	1.7%	1.3%	0.4%
Biomass and wastes	913	994	1121	1352	1527	1789	2066	1.2%	1.2%	1.5%
Others	745	918	1064	1196	1579	2216	3063	1.5%	2.8%	3.4%
Final Consumption (Mtoe)	**5702**	**7114**	**8556**	**10162**	**11360**	**12273**	**13031**	1.9%	1.1%	0.7%
by source										
Coal, lignite	870	650	941	1077	1148	1143	1137	3.8%	0.6%	0.0%
Oil	2546	3139	3623	4259	4481	4494	4360	1.4%	0.5%	-0.1%
Natural gas	999	1081	1176	1433	1631	1790	1901	0.8%	1.3%	0.8%
Electricity	825	1080	1500	1930	2494	3147	3861	3.3%	2.6%	2.2%
Biomass and wastes	911	911	1023	1122	1209	1243	1253	1.2%	0.8%	0.2%
Heat	179	252	293	323	355	378	387	1.5%	1.0%	0.4%
Hydrogen	0	0	0	3	18	49	94	na	21.1%	8.5%
by sector										
Industry	2411	2600	3252	3994	4501	4805	4971	2.3%	1.2%	0.5%
Transport	1549	1920	2286	2670	2936	3207	3443	1.8%	1.0%	0.8%
Household, Service, Agriculture	1857	2593	3018	3498	3923	4261	4617	1.5%	1.2%	0.8%
Energy inputs in electricity generation (Mtoe)										
Coal		1501	2183	2581	3291	4074	4850	3.8%	2.5%	2.0%
Gas		643	893	1210	1372	1427	1378	3.3%	1.3%	0.0%
Oil		291	264	215	251	244	228	-1.0%	1.6%	-0.5%
Biomass		60	59	159	202	353	554	-0.2%	2.4%	5.2%
Electricity Generation (TWh)	**11846**	**15311**	**21179**	**27564**	**35620**	**44669**	**54389**	3.3%	2.6%	2.1%
Thermal	7600	10026	14648	19515	25078	30618	35839	3.9%	2.5%	1.8%
of which:										
Coal	4427	5987	9213	11804	15831	20122	24398	4.4%	3.0%	2.2%
Gas	1695	2549	3764	5781	6819	7136	6742	4.0%	1.7%	-0.1%
Biomass and wastes	146	167	168	561	781	1520	2576	0.1%	3.4%	6.1%
Nuclear	2013	2591	2759	2656	3350	4613	6362	0.6%	2.3%	3.3%
Hydro+Geoth	2229	2663	3424	4257	5029	5773	6289	2.5%	1.7%	1.1%
Solar	1	1	19	100	343	1040	2343	39.1%	13.2%	10.1%
Wind	4	31	328	1036	1814	2598	3459	26.8%	5.8%	3.3%
Hydrogen	0	0	0	1	6	28	98	na	22.3%	15.3%
Hydrogen Production (Mtoe)	**0**	**0**	**0**	**18**	**42**	**82**	**146**	na	9.1%	6.4%
of which:										
Coal	0	0	0	6	22	51	101	na	14.3%	7.9%
Gas	0	0	0	9	12	14	14	na	3.3%	0.8%
Renewables	0	0	0	1	5	13	21	na	14.3%	7.3%
Nuclear	0	0	0	0	1	3	9	na	13.0%	10.6%
Electricity	0	0	0	0	0	0	0	na	12.0%	1.6%
CO2 Emissions (MtCO2)	**20857**	**23438**	**29940**	**35434**	**40537**	**44550**	**47700**	2.5%	1.4%	0.8%
of which:										
Electricity generation		8314	11514	13667	16978	20208	23152	3.3%	2.2%	1.6%
Industry		4423	5609	6790	7355	7528	7554	2.4%	0.8%	0.1%
Transport		5700	6737	7723	8108	8195	8016	1.7%	0.5%	-0.1%
Household, Service, Agriculture		3026	3307	3834	4087	4147	4127	0.9%	0.6%	0.0%
CO2 Sequestration (Mt CO2)	0	0.0	0.0	0.0	0.0	0.0	0.0	na	na	na

World: Muddling Through

Sc. 1 Results - World

								Annual % change		
	1990	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2000/20**	**20/30**	**30/50**
Key Indicators										
Population (Millions)	5246	6118	6872	7585	8175	8693	9246	1.2%	0.8%	0.6%
GDP (G$95)	29992	49874	72998	104259	138835	178070	223431	3.9%	2.9%	2.4%
Per capita GDP ($95/cap)	5717	8152	10623	13745	16982	20485	24166	2.7%	2.1%	1.8%
Gross Inland Cons/GDP (toe/M$95)	291	200	167	137	113	98	85	-1.7%	-1.9%	-1.4%
Gross Inland Cons/capita (toe/cap)	2	1.6	1.8	1.9	1.9	2.0	2.0	0.9%	0.2%	0.3%
Electricity Cons/capita (kWh/cap)	1830	2053	2538	2931	3372	3937	4459	2.1%	1.4%	1.4%
Transport fuels per capita (toe/cap)	0	0.3	0.3	0.3	0.3	0.3	0.3	0.6%	-0.1%	-0.1%
CO2 emissions/capita (tCO2/cap)	4	3.8	4.4	4.5	4.2	3.8	3.4	1.3%	-0.8%	-1.0%
% of renewables in Gross Inland Cons	13	12.3	11.9	13.2	15.2	17.7	20.5	-0.3%	1.4%	1.5%
% of renewables in electricity	20	18.7	18.6	22.2	25.4	29.0	32.5	0.0%	1.4%	1.2%
Primary Production (Mtoe)	**8806**	**9831**	**12190**	**14251**	**15649**	**17328**	**18796**	2.2%	0.9%	0.9%
Coal, lignite	2211	2302	3349	3653	3800	4224	4525	3.8%	0.4%	0.9%
Oil	3234	3507	4169	4779	4904	4799	4528	1.7%	0.3%	-0.4%
Natural gas	1708	2109	2486	3217	3489	3668	3735	1.7%	0.8%	0.3%
Nuclear	525	686	727	721	1072	1556	2140	0.6%	4.0%	3.5%
Hydro, geothermal	216	229	295	368	443	510	555	2.5%	1.9%	1.1%
Biomass and wastes	913	994	1122	1370	1595	1885	2172	1.2%	1.5%	1.6%
Wind, solar	0	5	43	143	345	687	1141	24.4%	9.2%	6.2%
Gross Inland Consumption (Mtoe)	**8741**	**9955**	**12213**	**14294**	**15707**	**17407**	**18884**	2.1%	0.9%	0.9%
Coal, lignite	2205	2217	3349	3653	3800	4224	4525	4.2%	0.4%	0.9%
Oil	3200	3707	4169	4779	4904	4799	4528	1.2%	0.3%	-0.4%
Natural gas	1678	2118	2509	3260	3548	3747	3823	1.7%	0.9%	0.4%
Biomass and wastes	913	994	1122	1370	1595	1885	2172	1.2%	1.5%	1.6%
Others	745	918	1064	1233	1860	2753	3837	1.5%	4.2%	3.7%
Final Consumption (Mtoe)	**5702**	**7114**	**8550**	**9989**	**10693**	**11371**	**11890**	1.9%	0.7%	0.5%
by source										
Coal, lignite	870	650	939	1011	857	767	687	3.7%	-1.6%	-1.1%
Oil	2546	3139	3620	4193	4294	4234	4028	1.4%	0.2%	-0.3%
Natural gas	999	1081	1175	1404	1532	1693	1818	0.8%	0.9%	0.9%
Electricity	825	1080	1500	1912	2371	2943	3545	3.3%	2.2%	2.0%
Biomass and wastes	911	911	1023	1130	1244	1289	1321	1.2%	1.0%	0.3%
Heat	179	252	293	323	355	378	387	1.5%	1.0%	0.4%
Hydrogen	0	0	0	3	15	37	66	na	19.2%	7.7%
by sector										
Industry	2411	2600	3250	3901	4116	4338	4451	2.3%	0.5%	0.4%
Transport	1549	1920	2283	2628	2816	2997	3121	1.7%	0.7%	0.5%
Household, Service, Agriculture	1857	2593	3017	3460	3761	4036	4318	1.5%	0.8%	0.7%
Energy inputs in electricity generation (Mtoe)										
Coal		1501	2174	2381	2621	3038	3338	3.8%	1.0%	1.2%
Gas		643	898	1273	1380	1379	1316	3.4%	0.8%	-0.2%
Oil		291	266	246	275	268	250	-0.9%	1.1%	-0.5%
Biomass		60	59	167	227	396	590	-0.2%	3.1%	4.9%
Electricity Generation (TWh)	**11846**	**15311**	**21177**	**27334**	**33862**	**41780**	**49961**	3.3%	2.2%	2.0%
Thermal	7600	10026	14645	19098	21905	25064	27486	3.9%	1.4%	1.1%
of which:										
Coal	4427	5987	9174	10918	12463	14591	16188	4.4%	1.3%	1.3%
Gas	1695	2549	3787	6091	6811	6812	6312	4.0%	1.1%	-0.4%
Biomass and wastes	146	167	169	592	886	1716	2735	0.1%	4.1%	5.8%
Nuclear	2013	2591	2760	2769	4234	6282	8864	0.6%	4.3%	3.8%
Hydro+Geoth	2229	2663	3425	4282	5149	5927	6457	2.5%	1.9%	1.1%
Solar	1	1	19	104	425	1345	2909	39.1%	15.1%	10.1%
Wind	4	31	328	1081	2143	3133	4151	26.8%	7.1%	3.4%
Hydrogen	0	0	0	1	6	28	94	na	22.9%	14.7%
Hydrogen Production (Mtoe)	**0**	**0**	**0**	**18**	**40**	**72**	**117**	na	8.6%	5.4%
of which:										
Coal	0	0	0	5	16	30	44	na	11.8%	5.1%
Gas	0	0	0	9	13	16	19	na	3.5%	2.2%
Renewables	0	0	0	2	9	18	30	na	16.9%	6.5%
Nuclear	0	0	0	0	2	6	22	na	14.1%	13.8%
Electricity	0	0	0	0	0	0	0	na	10.6%	2.2%
CO2 Emissions (MtCO2)	**20857**	**23438**	**29902**	**34246**	**34093**	**33461**	**31854**	2.5%	0.0%	-0.3%
of which:										
Electricity generation		8314	11496	13067	12812	12173	11141	3.3%	-0.2%	-0.7%
Industry		4423	5603	6513	6200	6147	6001	2.4%	-0.5%	-0.2%
Transport		5700	6730	7594	7765	7671	7334	1.7%	0.2%	-0.3%
Household, Service, Agriculture		3026	3303	3737	3708	3594	3393	0.9%	-0.1%	-0.4%
CO2 Sequestration (Mt CO2)	0	0.0	0.0	112.1	1996.5	4550.5	6843.7	na	33.4%	6.4%

World: Europe Alone

Sc. 2 Results - World

	1990	2000	2010	2020	2030	2040	2050	Annual % change 2000/20	20/30	30/50
Key Indicators										
Population (Millions)	5246	6118	6872	7585	8175	8693	9246	1.2%	0.8%	0.6%
GDP (G$95)	29992	49874	72998	104259	138835	178070	223431	3.9%	2.9%	2.4%
Per capita GDP ($95/cap)	5717	8152	10623	13745	16982	20485	24166	2.7%	2.1%	1.8%
Gross Inland Cons/GDP (toe/M$95)	291	200	167	137	112	97	84	-1.7%	-1.9%	-1.5%
Gross Inland Cons/capita (toe/cap)	2	1.6	1.8	1.9	1.9	2.0	2.0	0.9%	0.1%	0.3%
Electricity Cons/capita (kWh/cap)	1830	2053	2538	2930	3364	3941	4477	2.1%	1.4%	1.4%
Transport fuels per capita (toe/cap)	0	0.3	0.3	0.3	0.3	0.3	0.3	0.6%	-0.1%	-0.1%
CO2 emissions/capita (tCO2/cap)	4	3.8	4.4	4.5	4.1	3.7	3.3	1.3%	-1.0%	-1.0%
% of renewables in Gross Inland Cons	13	12.3	11.9	13.2	15.3	17.9	20.7	-0.3%	1.5%	1.5%
% of renewables in electricity	20	18.7	18.6	22.2	25.4	28.8	32.3	0.0%	1.4%	1.2%
Primary Production (Mtoe)	**8806**	**9831**	**12192**	**14233**	**15561**	**17160**	**18628**	2.2%	0.9%	0.9%
Coal, lignite	2211	2302	3351	3633	3749	4142	4408	3.8%	0.3%	0.8%
Oil	3234	3507	4169	4771	4860	4712	4433	1.7%	0.2%	-0.5%
Natural gas	1708	2109	2486	3219	3462	3607	3667	1.7%	0.7%	0.3%
Nuclear	525	686	727	725	1097	1615	2244	0.6%	4.2%	3.6%
Hydro, geothermal	216	229	295	368	443	510	555	2.5%	1.9%	1.1%
Biomass and wastes	913	994	1122	1374	1603	1889	2187	1.2%	1.6%	1.6%
Wind, solar	0	5	43	143	346	686	1133	24.4%	9.2%	6.1%
Gross Inland Consumption (Mtoe)	**8741**	**9955**	**12215**	**14276**	**15617**	**17236**	**18713**	2.1%	0.9%	0.9%
Coal, lignite	2205	2217	3351	3633	3749	4142	4408	4.2%	0.3%	0.8%
Oil	3200	3707	4169	4771	4860	4712	4433	1.2%	0.2%	-0.5%
Natural gas	1678	2118	2508	3262	3518	3682	3752	1.7%	0.8%	0.3%
Biomass and wastes	913	994	1122	1374	1603	1889	2187	1.2%	1.6%	1.6%
Others	745	918	1064	1237	1886	2811	3932	1.5%	4.3%	3.7%
Final Consumption (Mtoe)	**5702**	**7114**	**8551**	**9972**	**10604**	**11197**	**11697**	1.9%	0.6%	0.5%
by source										
Coal, lignite	870	650	939	1008	845	752	672	3.7%	-1.8%	-1.1%
Oil	2546	3139	3620	4182	4253	4144	3928	1.4%	0.2%	-0.4%
Natural gas	999	1081	1175	1398	1496	1610	1719	0.8%	0.7%	0.7%
Electricity	825	1080	1500	1911	2365	2946	3560	3.3%	2.2%	2.1%
Biomass and wastes	911	911	1023	1132	1248	1300	1327	1.2%	1.0%	0.3%
Heat	179	252	293	323	355	378	387	1.5%	1.0%	0.4%
Hydrogen	0	0	0	3	15	38	68	na	19.1%	7.9%
by sector										
Industry	2411	2600	3251	3896	4081	4274	4384	2.3%	0.5%	0.4%
Transport	1549	1920	2283	2622	2798	2960	3078	1.7%	0.7%	0.5%
Household, Service, Agriculture	1857	2593	3017	3454	3725	3963	4234	1.5%	0.8%	0.6%
Energy inputs in electricity generation (Mtoe)										
Coal		1501	2176	2365	2588	2988	3258	3.8%	0.9%	1.2%
Gas		643	897	1281	1386	1398	1341	3.4%	0.8%	-0.2%
Oil		291	266	250	276	270	254	-0.9%	1.0%	-0.4%
Biomass		60	59	168	229	387	602	-0.2%	3.1%	4.9%
Electricity Generation (TWh)	**11846**	**15311**	**21178**	**27327**	**33797**	**41784**	**50122**	3.3%	2.1%	2.0%
Thermal	7600	10026	14646	19075	21757	24875	27315	3.9%	1.3%	1.1%
of which:										
Coal	4427	5987	9182	10841	12259	14310	15777	4.4%	1.2%	1.3%
Gas	1695	2549	3782	6129	6868	6970	6535	4.0%	1.1%	-0.2%
Biomass and wastes	146	167	169	595	896	1676	2800	0.1%	4.2%	5.9%
Nuclear	2013	2591	2760	2783	4334	6522	9296	0.6%	4.5%	3.9%
Hydro+Geoth	2229	2663	3425	4284	5151	5929	6458	2.5%	1.9%	1.1%
Solar	1	1	19	104	423	1329	2861	39.1%	15.0%	10.0%
Wind	4	31	329	1079	2126	3100	4093	26.8%	7.0%	3.3%
Hydrogen	0	0	0	1	6	29	100	na	23.1%	14.9%
Hydrogen Production (Mtoe)	**0**	**0**	**0**	**18**	**43**	**72**	**117**	na	8.7%	5.2%
of which:										
Coal	0	0	0	5	14	26	40	na	10.5%	5.2%
Gas	0	0	0	9	14	16	19	na	4.0%	1.8%
Renewables	0	0	0	2	10	19	30	na	16.5%	5.7%
Nuclear	0	0	0	0	3	10	27	na	20.1%	11.3%
Electricity	0	0	0	0	0	0	0	na	10.1%	2.3%
CO2 Emissions (MtCO2)	**20857**	**23438**	**29909**	**34098**	**33257**	**32308**	**30617**	2.5%	-0.2%	-0.4%
of which:										
Electricity generation		8314	11500	12976	12232	11554	10530	3.3%	-0.6%	-0.7%
Industry		4423	5604	6497	6119	5992	5816	2.4%	-0.6%	-0.3%
Transport		5700	6731	7574	7708	7535	7177	1.7%	0.2%	-0.4%
Household, Service, Agriculture		3026	3304	3720	3611	3395	3156	0.9%	-0.3%	-0.7%
CO2 Sequestration (Mt CO2)	0	0.0	0.0	166.7	2462.8	4998.4	7180.5	na	30.9%	5.5%

World: Global Regime (Full Trade)

Sc. 3b Results - World

								Annual % change		
	1990	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2000/20**	**20/30**	**30/50**
Key Indicators										
Population (Millions)	5246	6118	6872	7585	8175	8693	9246	1.2%	0.8%	0.6%
GDP (G$05)	29992	49874	72998	104259	138835	178070	223431	3.9%	2.9%	2.4%
Per capita GDP ($05/cap)	5717	8152	10623	13745	16982	20485	24166	2.7%	2.1%	1.8%
Gross Inland Cons/GDP (toe/M$05)	291	200	166	128	102	82	71	-1.8%	-2.3%	-1.8%
Gross Inland Cons/capita (toe/cap)	2	1.6	1.8	1.8	1.7	1.7	1.7	0.8%	-0.2%	-0.1%
Electricity Cons/capita (kWh/cap)	1830	2053	2533	2827	3231	3863	4637	2.1%	1.3%	1.8%
Transport fuels per capita (toe/cap)	0	0.3	0.3	0.3	0.3	0.3	0.3	0.5%	-0.5%	-0.9%
CO2 emissions/capita (tCO2/cap)	4	3.8	4.3	3.8	2.7	1.8	1.2	1.2%	-3.2%	-4.1%
% of renewables in Gross Inland Cons	13	12.3	12.1	15.2	18.9	24.9	30.7	-0.2%	2.2%	2.5%
% of renewables in electricity	20	18.7	18.8	25.7	29.2	33.6	40.0	0.1%	1.3%	1.6%
Primary Production (Mtoe)	**8806**	**9831**	**12112**	**13301**	**14040**	**14557**	**15669**	2.1%	0.5%	0.6%
Coal, lignite	2211	2302	3236	2657	2575	2618	2488	3.5%	-0.3%	-0.2%
Oil	3234	3507	4172	4605	4283	3416	2858	1.8%	-0.7%	-2.0%
Natural gas	1708	2109	2507	3128	3157	2832	2630	1.7%	0.1%	-0.9%
Nuclear	525	686	731	884	1362	2032	2845	0.6%	4.4%	3.8%
Hydro, geothermal	216	229	296	382	460	526	557	2.6%	1.9%	1.0%
Biomass and wastes	913	994	1126	1454	1775	2285	2982	1.3%	2.0%	2.6%
Wind, solar	0	5	45	190	429	848	1308	24.9%	8.5%	5.7%
Gross Inland Consumption (Mtoe)	**8741**	**9955**	**12137**	**13357**	**14126**	**14670**	**15806**	2.0%	0.6%	0.6%
Coal, lignite	2205	2217	3236	2657	2575	2618	2488	3.9%	-0.3%	-0.2%
Oil	3200	3707	4172	4605	4283	3416	2858	1.2%	-0.7%	-2.0%
Natural gas	1678	2118	2532	3185	3243	2945	2767	1.8%	0.2%	-0.8%
Biomass and wastes	913	994	1126	1454	1775	2285	2982	1.2%	2.0%	2.6%
Others	745	918	1072	1456	2250	3406	4711	1.6%	4.4%	3.8%
Final Consumption (Mtoe)	**5702**	**7114**	**8494**	**9305**	**9482**	**9211**	**9398**	1.8%	0.2%	0.0%
by source										
Coal, lignite	870	650	909	720	445	244	223	3.4%	-4.7%	-3.4%
Oil	2546	3139	3604	3964	3768	3095	2628	1.4%	-0.5%	-1.8%
Natural gas	999	1081	1166	1272	1249	1021	915	0.8%	-0.2%	-1.5%
Electricity	825	1080	1497	1844	2272	2888	3687	3.3%	2.1%	2.5%
Biomass and wastes	911	911	1025	1161	1350	1519	1446	1.2%	1.5%	0.3%
Heat	179	252	293	323	355	375	383	1.5%	1.0%	0.4%
Hydrogen	0	0	0	2	15	48	98	na	20.0%	10.0%
by sector										
Industry	2411	2600	3215	3489	3483	3350	3423	2.1%	0.0%	-0.1%
Transport	1549	1920	2276	2531	2588	2481	2433	1.7%	0.2%	-0.3%
Household, Service, Agriculture	1857	2593	3004	3285	3410	3381	3542	1.5%	0.4%	0.2%
Energy inputs in electricity generation (Mtoe)										
Coal		1501	2106	1749	1915	2098	2018	3.4%	0.9%	0.3%
Gas		643	927	1351	1426	1426	1402	3.7%	0.5%	-0.1%
Oil		291	279	301	215	127	69	-0.4%	-3.3%	-5.5%
Biomass		60	61	211	266	508	1216	0.0%	2.3%	7.9%
Electricity Generation (TWh)	**11846**	**15311**	**21135**	**26373**	**32367**	**40551**	**50854**	3.3%	2.1%	2.3%
Thermal	7600	10026	14552	16945	18556	20982	24594	3.8%	0.9%	1.4%
of which:										
Coal	4427	5987	8885	7974	8782	9847	9763	4.0%	1.0%	0.5%
Gas	1695	2549	3926	6504	7297	7706	7861	4.4%	1.2%	0.4%
Biomass and wastes	146	167	173	753	1040	2286	5977	0.4%	3.3%	9.1%
Nuclear	2013	2591	2778	3413	5399	8208	11777	0.7%	4.7%	4.0%
Hydro+Geoth	2229	2663	3442	4445	5344	6115	6476	2.6%	1.9%	1.0%
Solar	1	1	20	135	540	1692	3442	39.3%	14.8%	9.7%
Wind	4	31	344	1433	2521	3516	4436	27.4%	5.8%	2.9%
Hydrogen	0	0	0	1	8	39	129	na	23.3%	15.2%
Hydrogen Production (Mtoe)	**0**	**0**	**0**	**21**	**44**	**77**	**135**	na	7.4%	5.8%
of which:										
Coal	0	0	0	5	4	3	2	na	-1.2%	-4.6%
Gas	0	0	0	10	15	13	9	na	3.6%	-2.5%
Renewables	0	0	0	4	18	32	54	na	16.2%	5.8%
Nuclear	0	0	0	1	6	28	68	na	23.8%	12.8%
Electricity	0	0	0	0	0	0	1	na	5.4%	6.7%
CO2 Emissions (MtCO2)	**20857**	**23438**	**29518**	**28554**	**22150**	**15703**	**10880**	2.3%	-2.5%	-3.5%
of which:										
Electricity generation		8314	11328	9748	5187	2401	-61	3.1%	-6.1%	na
Industry		4423	5486	5273	4286	2800	2171	2.2%	-2.1%	-3.3%
Transport		5700	6707	7284	6986	5768	4727	1.6%	-0.4%	-1.9%
Household, Service, Agriculture		3026	3265	3259	2718	1873	1404	0.8%	-1.8%	-3.2%
CO2 Sequestration (Mt CO2)	0	0.0	34.0	1355.9	6695.3	10498.2	12708.7	na	17.3%	3.3%

ANNEX B: EU27 Summary Energy Balances

(*Baseline* + 3 SECURE Scenarios)

Europe: Baseline

Baseline Results - EU27

								Annual % change		
	1990	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2000/20**	**20/30**	**30/50**
Key Indicators										
Population (Millions)	440	483	496	500	499	494	487	0.3%	0.0%	-0.1%
GDP (G$95)	7570	11870	13836	16299	18846	21643	24382	1.5%	1.5%	1.3%
Per capita GDP ($95/cap)	17218	24582	27883	32610	37790	43798	50079	1.3%	1.5%	1.4%
Gross Inland Cons/GDP (toe/M$95)	202	145	128	115	106	94	84	-1.3%	-0.8%	-1.2%
Gross Inland Cons/capita (toe/cap)	3	3.6	3.6	3.8	4.0	4.1	4.2	0.0%	0.6%	0.2%
Electricity Cons/capita (kWh/cap)	4601	5212	5759	6391	7604	8916	10313	1.0%	1.8%	1.5%
Transport fuels per capita (toe/cap)	1	0.7	0.8	0.8	0.8	0.7	0.7	0.6%	-0.2%	-0.4%
CO2 emissions/capita (tCO2/cap)	9	8.0	7.9	8.3	8.9	9.1	9.0	-0.2%	0.7%	0.1%
% of renewables in Gross Inland Cons	4	6.0	8.0	11.4	13.1	14.7	17.1	3.0%	1.3%	1.4%
% of renewables in electricity	13	15.1	19.0	26.3	29.0	30.5	33.1	2.4%	1.0%	0.7%
Primary Production (Mtoe)	**879**	**945**	**912**	**920**	**911**	**919**	**968**	-0.4%	-0.1%	0.3%
Coal, lignite	349	215	204	205	211	218	225	-0.5%	0.3%	0.3%
Oil	124	164	125	109	87	79	73	-2.7%	-2.3%	-0.8%
Natural gas	140	212	206	201	186	154	132	-0.3%	-0.8%	-1.7%
Nuclear	198	250	236	189	165	167	188	-0.6%	-1.3%	0.6%
Hydro, geothermal	26	33	32	36	39	41	42	-0.2%	0.9%	0.4%
Biomass and wastes	43	68	91	136	155	165	182	2.9%	1.3%	0.8%
Wind, solar	0	2	19	44	68	95	126	23.5%	4.4%	3.2%
Gross Inland Consumption (Mtoe)	**1531**	**1725**	**1764**	**1882**	**2003**	**2039**	**2050**	0.2%	0.6%	0.1%
Coal, lignite	421	309	305	335	404	465	511	-0.1%	1.9%	1.2%
Oil	588	669	657	669	651	589	513	-0.2%	-0.3%	-1.2%
Natural gas	252	392	423	473	521	517	487	0.8%	1.0%	-0.3%
Biomass and wastes	43	68	91	136	155	165	182	2.9%	1.3%	0.8%
Others	228	287	288	269	273	304	357	0.0%	0.2%	1.3%
Final Consumption (Mtoe)	**1088**	**1236**	**1278**	**1387**	**1464**	**1460**	**1431**	0.3%	0.5%	-0.1%
by source										
Coal, lignite	137	73	62	55	45	34	31	-1.5%	-2.0%	-1.8%
Oil	506	583	581	608	595	539	470	0.0%	-0.2%	-1.2%
Natural gas	201	270	268	301	336	329	311	-0.1%	1.1%	-0.4%
Electricity	174	216	246	275	326	379	432	1.3%	1.7%	1.4%
Biomass and wastes	35	50	60	85	96	101	102	1.7%	1.2%	0.3%
Heat	36	44	61	59	58	64	67	3.3%	-0.2%	0.7%
Hydrogen	0	0	0	1	3	7	12	na	18.8%	6.2%
by sector										
Industry	416	440	412	448	475	465	447	-0.7%	0.6%	-0.3%
Transport	275	346	377	396	386	368	348	0.9%	-0.2%	-0.5%
Household, Service, Agriculture	396	450	488	543	603	627	637	0.8%	1.1%	0.3%
Energy inputs in electricity generation (Mtoe)										
Coal		225	230	265	339	404	448	0.2%	2.5%	1.4%
Gas		94	130	142	151	154	144	3.3%	0.6%	-0.2%
Oil		41	32	16	12	10	8	-2.5%	-3.1%	-1.9%
Biomass		17	25	34	39	37	46	3.8%	1.4%	0.8%
Electricity Generation (TWh)	**2413**	**3001**	**3379**	**3784**	**4473**	**5176**	**5868**	1.2%	1.7%	1.4%
Thermal	1367	1651	1911	2190	2692	3095	3375	1.5%	2.1%	1.1%
of which:										
Coal	964	963	1006	1208	1647	2034	2307	0.4%	3.1%	1.7%
Gas	185	418	579	646	653	642	573	3.3%	0.1%	-0.6%
Biomass and wastes	15	47	71	121	154	155	215	4.2%	2.4%	1.7%
Nuclear	759	945	896	721	637	653	753	-0.5%	-1.2%	0.8%
Hydro+Geoth	287	383	376	413	452	477	487	-0.2%	0.9%	0.4%
Solar	0	0	12	52	96	175	291	59.3%	6.4%	5.7%
Wind	1	22	184	409	597	774	952	23.5%	3.9%	2.4%
Hydrogen	0	0	0	0	1	3	10	na	20.5%	14.9%
Hydrogen Production (Mtoe)	**0**	**0**	**0**	**4**	**8**	**15**	**21**	na	6.6%	4.9%
of which:										
Coal	0	0	0	2	4	7	10	na	8.9%	4.8%
Gas	0	0	0	1	2	2	2	na	4.1%	-0.4%
Renewables	0	0	0	1	1	4	6	na	9.1%	8.3%
Nuclear	0	0	0	0	0	1	2	na	10.0%	9.1%
Electricity	0	0	0	0	0	0	0	na	5.7%	3.9%
CO2 Emissions (MtCO2)	**3740**	**3876**	**3912**	**4147**	**4444**	**4492**	**4398**	0.1%	0.7%	-0.1%
of which:										
Electricity generation		1235	1305	1426	1726	1989	2136	0.6%	1.9%	1.1%
Industry		688	583	607	607	558	523	-1.6%	0.0%	-0.7%
Transport		1020	1100	1115	1031	900	755	0.8%	-0.8%	-1.5%
Household, Service, Agriculture		691	682	745	817	786	737	-0.1%	0.9%	-0.5%
CO2 Sequestration (Mt CO2)	0	0.0	0.0	0.0	0.0	0.0	0.0	na	na	na

Europe: Muddling Through

Sc. 1 Results - EU27

								Annual % change		
	1990	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2000/20**	**20/30**	**30/50**
Key Indicators										
Population (Millions)	440	483	496	500	499	494	487	0.3%	0.0%	-0.1%
GDP (G$95)	7570	11870	13836	16299	18846	21643	24382	1.5%	1.5%	1.3%
Per capita GDP ($95/cap)	17218	24582	27883	32610	37790	43798	50079	1.3%	1.5%	1.4%
Gross Inland Cons/GDP (toe/M$95)	202	145	127	112	102	89	78	-1.3%	-0.9%	-1.3%
Gross Inland Cons/capita (toe/cap)	3	3.6	3.5	3.6	3.9	3.9	3.9	-0.1%	0.6%	0.1%
Electricity Cons/capita (kWh/cap)	4601	5212	5755	6264	7362	8491	9559	1.0%	1.6%	1.3%
Transport fuels per capita (toe/cap)	1	0.7	0.8	0.8	0.7	0.7	0.6	0.6%	-0.4%	-0.7%
CO2 emissions/capita (tCO2/cap)	9	8.0	7.8	7.7	7.5	6.6	5.8	-0.3%	-0.3%	-1.3%
% of renewables in Gross Inland Cons	4	6.0	8.1	12.1	13.7	15.7	18.2	3.0%	1.3%	1.4%
% of renewables in electricity	13	15.1	19.1	26.9	29.1	31.3	33.7	2.4%	0.8%	0.7%
Primary Production (Mtoe)	**879**	**945**	**908**	**905**	**906**	**936**	**986**	-0.4%	0.0%	0.4%
Coal, lignite	349	215	198	177	179	177	171	-0.8%	0.1%	-0.2%
Oil	124	164	125	109	85	75	68	-2.7%	-2.5%	-1.1%
Natural gas	140	212	207	202	182	151	129	-0.2%	-1.1%	-1.7%
Nuclear	198	250	236	195	198	230	273	-0.6%	0.1%	1.6%
Hydro, geothermal	26	33	32	36	39	41	42	-0.2%	0.9%	0.4%
Biomass and wastes	43	68	91	141	159	171	184	2.9%	1.2%	0.7%
Wind, solar	0	2	19	43	65	91	119	23.5%	4.1%	3.1%
Gross Inland Consumption (Mtoe)	**1531**	**1725**	**1758**	**1822**	**1921**	**1929**	**1899**	0.2%	0.5%	-0.1%
Coal, lignite	421	309	293	275	328	360	361	-0.5%	1.8%	0.5%
Oil	588	669	658	651	621	548	467	-0.2%	-0.5%	-1.4%
Natural gas	252	392	428	478	510	487	452	0.9%	0.7%	-0.6%
Biomass and wastes	43	68	91	141	159	171	184	2.9%	1.2%	0.7%
Others	228	287	288	276	303	363	436	0.0%	0.9%	1.8%
Final Consumption (Mtoe)	**1088**	**1236**	**1273**	**1339**	**1392**	**1362**	**1309**	0.3%	0.4%	-0.3%
by source										
Coal, lignite	137	73	60	42	30	20	16	-1.8%	-3.3%	-3.0%
Oil	506	583	579	587	565	501	427	-0.1%	-0.4%	-1.4%
Natural gas	201	270	268	290	316	300	276	-0.1%	0.9%	-0.7%
Electricity	174	216	246	269	316	361	400	1.3%	1.6%	1.2%
Biomass and wastes	35	50	60	87	99	104	106	1.8%	1.2%	0.3%
Heat	36	44	61	59	58	64	67	3.3%	-0.2%	0.7%
Hydrogen	0	0	0	1	3	6	9	na	18.1%	5.9%
by sector										
Industry	416	440	410	424	446	435	417	-0.7%	0.5%	-0.3%
Transport	275	346	376	386	370	344	314	0.8%	-0.4%	-0.8%
Household, Service, Agriculture	396	450	487	529	576	583	578	0.8%	0.8%	0.0%
Energy inputs in electricity generation (Mtoe)										
Coal		225	220	221	282	322	328	-0.2%	2.5%	0.8%
Gas		94	135	158	161	155	146	3.7%	0.2%	-0.5%
Oil		41	35	20	14	10	8	-1.7%	-3.8%	-2.5%
Biomass		17	25	36	39	39	41	3.9%	0.6%	0.3%
Electricity Generation (TWh)	**2413**	**3001**	**3377**	**3710**	**4317**	**4908**	**5408**	1.2%	1.5%	1.1%
Thermal	1367	1651	1908	2097	2445	2628	2650	1.5%	1.5%	0.4%
of which:										
Coal	964	963	965	1010	1341	1550	1599	0.0%	2.9%	0.9%
Gas	185	418	605	726	711	655	595	3.8%	-0.2%	-0.9%
Biomass and wastes	15	47	72	132	153	168	190	4.3%	1.5%	1.1%
Nuclear	759	945	896	748	766	909	1115	-0.5%	0.2%	1.9%
Hydro+Geoth	287	383	376	417	456	481	490	-0.2%	0.9%	0.4%
Solar	0	0	12	52	96	174	284	59.3%	6.3%	5.6%
Wind	1	22	185	396	553	714	860	23.5%	3.4%	2.2%
Hydrogen	0	0	0	0	1	3	10	na	19.8%	14.6%
Hydrogen Production (Mtoe)	**0**	**0**	**0**	**5**	**9**	**14**	**18**	na	6.4%	3.8%
of which:										
Coal	0	0	0	2	3	3	3	na	6.5%	0.5%
Gas	0	0	0	1	2	3	2	na	4.7%	0.0%
Renewables	0	0	0	1	2	5	8	na	10.1%	6.5%
Nuclear	0	0	0	0	1	2	4	na	12.1%	9.5%
Electricity	0	0	0	0	0	0	0	na	4.0%	3.1%
CO2 Emissions (MtCO2)	**3740**	**3876**	**3877**	**3838**	**3730**	**3276**	**2831**	0.0%	-0.3%	-1.4%
of which:										
Electricity generation		1235	1285	1257	1217	1030	872	0.4%	-0.3%	-1.7%
Industry		688	577	546	539	495	462	-1.7%	-0.1%	-0.8%
Transport		1020	1096	1086	986	841	687	0.7%	-1.0%	-1.8%
Household, Service, Agriculture		691	679	707	745	681	605	-0.2%	0.5%	-1.0%
CO2 Sequestration (Mt CO2)	0	0.0	0.0	43.3	323.5	650.9	807.1	na	22.3%	4.7%

Europe: Europe Alone

Sc. 2 Results - EU27

								Annual % change		
	1990	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2000/20**	**20/30**	**30/50**
Key Indicators										
Population (Millions)	440	483	496	500	499	494	487	0.3%	0.0%	-0.1%
GDP (G$95)	7570	11870	13836	16299	18846	21643	24382	1.5%	1.5%	1.3%
Per capita GDP ($95/cap)	17218	24582	27883	32610	37790	43798	50079	1.3%	1.5%	1.4%
Gross Inland Cons/GDP (toe/M$95)	202	145	127	111	96	79	68	-1.3%	-1.4%	-1.7%
Gross Inland Cons/capita (toe/cap)	3	3.6	3.5	3.6	3.6	3.5	3.4	-0.1%	0.0%	-0.3%
Electricity Cons/capita (kWh/cap)	4601	5212	5756	6250	7229	8564	9965	1.0%	1.5%	1.6%
Transport fuels per capita (toe/cap)	1	0.7	0.8	0.8	0.7	0.6	0.5	0.6%	-0.9%	-1.4%
CO2 emissions/capita (tCO2/cap)	9	8.0	7.8	7.4	5.9	4.1	2.9	-0.2%	-2.2%	-3.5%
% of renewables in Gross Inland Cons	4	6.0	8.1	12.5	15.3	18.6	22.5	3.0%	2.0%	2.0%
% of renewables in electricity	13	15.1	19.1	27.0	29.7	30.3	33.4	2.4%	1.0%	0.6%
Primary Production (Mtoe)	**879**	**945**	**909**	**906**	**921**	**988**	**1095**	-0.4%	0.2%	0.9%
Coal, lignite	349	215	199	169	155	149	134	-0.8%	-0.9%	-0.7%
Oil	124	164	125	109	84	73	67	-2.7%	-2.6%	-1.1%
Natural gas	140	212	207	203	182	151	129	-0.2%	-1.1%	-1.7%
Nuclear	198	250	236	199	226	296	391	-0.6%	1.3%	2.8%
Hydro, geothermal	26	33	32	36	40	42	43	-0.2%	0.9%	0.4%
Biomass and wastes	43	68	91	145	169	181	209	2.9%	1.5%	1.1%
Wind, solar	0	2	19	43	67	95	122	23.5%	4.4%	3.1%
Gross Inland Consumption (Mtoe)	**1531**	**1725**	**1760**	**1803**	**1806**	**1708**	**1663**	0.2%	0.0%	-0.4%
Coal, lignite	421	309	296	256	274	292	272	-0.4%	0.7%	0.0%
Oil	588	669	657	642	557	411	306	-0.2%	-1.4%	-3.0%
Natural gas	252	392	427	481	473	388	319	0.9%	-0.2%	-2.0%
Biomass and wastes	43	68	91	145	169	181	209	2.9%	1.5%	1.1%
Others	228	287	288	280	333	435	557	0.0%	1.8%	2.6%
Final Consumption (Mtoe)	**1088**	**1236**	**1274**	**1321**	**1283**	**1144**	**1058**	0.3%	-0.3%	-1.0%
by source										
Coal, lignite	137	73	61	39	17	6	5	-1.8%	-7.7%	-6.1%
Oil	506	583	579	576	509	376	280	-0.1%	-1.2%	-2.9%
Natural gas	201	270	268	284	275	204	156	-0.1%	-0.3%	-2.8%
Electricity	174	216	246	269	310	364	417	1.3%	1.4%	1.5%
Biomass and wastes	35	50	60	89	103	117	116	1.7%	1.5%	0.6%
Heat	36	44	61	59	58	64	67	3.3%	-0.2%	0.7%
Hydrogen	0	0	0	1	3	7	13	na	18.0%	7.5%
by sector										
Industry	416	440	410	418	402	353	328	-0.7%	-0.4%	-1.0%
Transport	275	346	376	380	347	294	253	0.8%	-0.9%	-1.6%
Household, Service, Agriculture	396	450	488	523	534	497	477	0.8%	0.2%	-0.6%
Energy inputs in electricity generation (Mtoe)										
Coal		225	222	205	246	276	259	-0.2%	1.8%	0.3%
Gas		94	134	166	166	159	143	3.6%	0.0%	-0.7%
Oil		41	34	23	11	7	5	-1.9%	-6.6%	-3.6%
Biomass		17	25	37	42	32	56	3.9%	1.0%	1.5%
Electricity Generation (TWh)	**2413**	**3001**	**3377**	**3703**	**4249**	**4909**	**5580**	1.2%	1.4%	1.4%
Thermal	1367	1651	1908	2075	2273	2375	2371	1.5%	0.9%	0.2%
of which:										
Coal	964	963	974	933	1131	1298	1249	0.1%	1.9%	0.5%
Gas	185	418	600	767	757	741	671	3.7%	-0.1%	-0.6%
Biomass and wastes	15	47	72	135	167	138	271	4.3%	2.1%	2.4%
Nuclear	759	945	896	763	879	1181	1605	-0.5%	1.4%	3.1%
Hydro+Geoth	287	383	376	419	461	487	495	-0.2%	0.9%	0.4%
Solar	0	0	12	52	96	175	282	59.3%	6.4%	5.5%
Wind	1	22	185	394	540	688	814	23.5%	3.2%	2.1%
Hydrogen	0	0	0	0	1	4	14	na	21.2%	15.7%
Hydrogen Production (Mtoe)	**0**	**0**	**0**	**5**	**11**	**14**	**19**	na	7.1%	3.0%
of which:										
Coal	0	0	0	1	1	1	0	na	-1.3%	-4.8%
Gas	0	0	0	2	3	2	1	na	7.0%	-4.2%
Renewables	0	0	0	1	4	6	8	na	10.7%	4.1%
Nuclear	0	0	0	0	2	6	9	na	22.1%	7.7%
Electricity	0	0	0	0	0	0	0	na	3.5%	3.3%
CO2 Emissions (MtCO2)	**3740**	**3876**	**3885**	**3689**	**2932**	**2024**	**1398**	0.0%	-2.3%	-3.6%
of which:										
Electricity generation		1235	1289	1166	733	437	237	0.4%	-4.5%	-5.5%
Industry		688	579	529	442	307	240	-1.7%	-1.8%	-3.0%
Transport		1020	1097	1066	911	656	454	0.7%	-1.6%	-3.4%
Household, Service, Agriculture		691	680	689	634	452	328	-0.2%	-0.8%	-3.2%
CO2 Sequestration (Mt CO2)	0	0.0	0.0	98.1	667.2	1064.5	1165.9	na	21.1%	2.8%

Europe: Global Regime (full trade)

Sc. 3b Results - EU27

								Annual % change		
	1990	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2000/20**	**20/30**	**30/50**
Key Indicators										
Population (Millions)	440	483	496	500	499	494	487	0.3%	0.0%	-0.1%
GDP (G$05)	7570	11870	13836	16299	18846	21643	24382	1.5%	1.5%	1.3%
Per capita GDP ($05/cap)	17218	24582	27883	32610	37790	43798	50079	1.3%	1.5%	1.4%
Gross Inland Cons/GDP (toe/M$05)	202	145	127	110	96	79	68	-1.3%	-1.4%	-1.7%
Gross Inland Cons/capita (toe/cap)	3	3.6	3.5	3.6	3.6	3.5	3.4	-0.1%	0.1%	-0.3%
Electricity Cons/capita (kWh/cap)	4601	5212	5756	6237	7218	8562	10003	1.0%	1.5%	1.6%
Transport fuels per capita (toe/cap)	1	0.7	0.8	0.8	0.7	0.6	0.5	0.6%	-0.8%	-1.4%
CO2 emissions/capita (tCO2/cap)	9	8.0	7.8	7.3	5.7	4.0	2.9	-0.3%	-2.3%	-3.4%
% of renewables in Gross Inland Cons	4	6.0	8.1	12.6	15.2	18.7	22.6	3.0%	2.0%	2.0%
% of renewables in electricity	13	15.1	19.1	27.1	29.7	30.6	33.9	2.4%	0.9%	0.6%
Primary Production (Mtoe)	**879**	**945**	**909**	**902**	**897**	**942**	**1029**	-0.4%	-0.1%	0.7%
Coal, lignite	349	215	199	164	149	141	124	-0.8%	-1.0%	-0.9%
Oil	124	164	125	108	76	56	43	-2.7%	-3.4%	-2.8%
Natural gas	140	212	207	204	174	132	106	-0.2%	-1.6%	-2.4%
Nuclear	198	250	236	201	224	292	380	-0.6%	1.1%	2.7%
Hydro, geothermal	26	33	32	36	40	42	42	-0.2%	0.9%	0.3%
Biomass and wastes	43	68	91	146	169	184	212	2.9%	1.5%	1.1%
Wind, solar	0	2	19	44	67	95	122	23.5%	4.3%	3.1%
Gross Inland Consumption (Mtoe)	**1531**	**1725**	**1759**	**1798**	**1804**	**1710**	**1667**	0.2%	0.0%	-0.4%
Coal, lignite	421	309	295	250	267	276	248	-0.5%	0.7%	-0.4%
Oil	588	669	657	641	562	425	324	-0.2%	-1.3%	-2.7%
Natural gas	252	392	427	480	475	395	337	0.9%	-0.1%	-1.7%
Biomass and wastes	43	68	91	146	169	184	212	2.9%	1.5%	1.1%
Others	228	287	288	281	331	430	545	0.0%	1.6%	2.5%
Final Consumption (Mtoe)	**1088**	**1236**	**1274**	**1317**	**1283**	**1150**	**1068**	0.3%	-0.3%	-0.9%
by source										
Coal, lignite	137	73	61	38	16	6	4	-1.8%	-8.1%	-6.3%
Oil	506	583	579	574	513	389	297	-0.1%	-1.1%	-2.7%
Natural gas	201	270	268	282	271	198	151	-0.1%	-0.4%	-2.9%
Electricity	174	216	246	268	310	364	419	1.3%	1.4%	1.5%
Biomass and wastes	35	50	60	90	104	116	113	1.7%	1.4%	0.5%
Heat	36	44	61	59	58	64	67	3.3%	-0.2%	0.7%
Hydrogen	0	0	0	1	3	7	12	na	18.0%	7.5%
by sector										
Industry	416	440	410	416	402	355	331	-0.7%	-0.3%	-1.0%
Transport	275	346	376	380	349	298	258	0.8%	-0.8%	-1.5%
Household, Service, Agriculture	396	450	488	521	532	497	478	0.8%	0.2%	-0.5%
Energy inputs in electricity generation (Mtoe)										
Coal		225	221	200	241	261	236	-0.2%	1.8%	-0.1%
Gas		94	134	167	171	171	166	3.6%	0.2%	-0.1%
Oil		41	34	23	12	8	6	-1.8%	-6.6%	-3.5%
Biomass		17	25	38	41	36	64	3.9%	0.9%	2.2%
Electricity Generation (TWh)	**2413**	**3001**	**3377**	**3696**	**4242**	**4909**	**5607**	1.2%	1.4%	1.4%
Thermal	1367	1651	1908	2061	2276	2396	2441	1.5%	1.0%	0.4%
of which:										
Coal	964	963	970	911	1102	1223	1134	0.1%	1.9%	0.1%
Gas	185	418	602	774	791	820	825	3.7%	0.2%	0.2%
Biomass and wastes	15	47	72	136	166	155	305	4.3%	2.0%	3.1%
Nuclear	759	945	896	768	870	1164	1559	-0.5%	1.3%	3.0%
Hydro+Geoth	287	383	376	420	461	486	493	-0.2%	0.9%	0.3%
Solar	0	0	12	52	96	175	282	59.3%	6.3%	5.5%
Wind	1	22	185	395	539	685	819	23.6%	3.1%	2.1%
Hydrogen	0	0	0	0	1	4	14	na	21.2%	15.7%
Hydrogen Production (Mtoe)	**0**	**0**	**0**	**5**	**11**	**14**	**19**	na	7.0%	2.9%
of which:										
Coal	0	0	0	1	1	1	0	na	-2.9%	-5.0%
Gas	0	0	0	2	3	2	1	na	6.6%	-4.3%
Renewables	0	0	0	1	4	5	7	na	10.3%	3.7%
Nuclear	0	0	0	0	2	6	9	na	22.6%	7.2%
Electricity	0	0	0	0	0	0	0	na	2.7%	3.3%
CO2 Emissions (MtCO2)	**3740**	**3876**	**3882**	**3628**	**2867**	**1993**	**1389**	0.0%	-2.3%	-3.6%
of which:										
Electricity generation		1235	1287	1118	669	390	200	0.4%	-5.0%	-5.9%
Industry		688	578	526	439	300	236	-1.7%	-1.8%	-3.0%
Transport		1020	1096	1065	917	673	475	0.7%	-1.5%	-3.2%
Household, Service, Agriculture		691	679	683	629	453	335	-0.2%	-0.8%	-3.1%
CO2 Sequestration (Mt CO2)	0	0.0	0.0	132.8	724.7	1086.9	1168.0	na	18.5%	2.4%