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Abstract
The report provides a synthetic overview of the long term scenario analyses performed for the pan-European system (EU 27++), relevant to the time horizon up to 2030 and the four scenarios selected for REALISEGRID. The report summarizes the lessons learnt from the long term scenario analysis of the European energy system.). In appendix, we present complete tables with the global results for EU27++.

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ACRONYMS AND DEFINITIONS

AEEI	Autonomous energy efficiency improvement
AL	Albania
AT	Austria
BE	Belgium
BG	Bulgaria
BH	Bosnia and Herzegovina
BY	Belarus
CCM	Climate Change Mitigation; it is a key scenario driver.
CCM20	CCM at 20%; it refers to the sensitivity run, where the CCM driver in 2030 is relaxed to -20% with reference to 1990, instead of -30% as in High CCM case.
CCM22.5	CCM at 22.5%; it refers to the sensitivity run, where the CCM driver in 2030 is relaxed to -22.5% with reference to 1990.
CCM25	CCM at 25%; it refers to the sensitivity run, where the CCM driver in 2030 is relaxed to -25% with reference to 1990.
CH	Switzerland
CCS	CO_2 Capture and Storage
Competing	Name of the scenario with High Gross Domestic Product, High Climate Change Mitigation, High Population, Lower Oil and Gas supply, Free Electricity interties.
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EC	European Commission
EE	Estonia
EJ	Exajoules, equivalent to 10^18 J
ELC	Electric cross-country interconnections; it is a key scenario driver.
EPG	Electric Power Generation
ES	Spain
ETSAP	Energy Technology Systems Analysis Program; it is an Implementing Agreement of the International Energy Agency.
EU	European Union
EU27	27 EU Member States. It refers to the EU Member States: Austria, Belgium, Bulgaria, Czech Republic, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, United Kingdom.
EU27+	EU27 plus Iceland, Norway and Switzerland
EU27++	EU27+ plus Western Balkans: Albania, Bosnia Herzegovina, Croatia, Former Yugoslav Republic Of Macedonia (FYROM), Kosovo, Montenegro, Serbia
EU Centric	Name of the scenario with Low Gross Domestic Product, High Climate Change Mitigation, Low Population, Lower Oil and Gas supply, Free Electricity interties.
FI	Finland
FP7	Seventh Framework Program of the EC Research; FP7 covers the years 2007-2013.
FR	France
GAS	Oil and Gas supply; it is a key scenario driver.
GDP	Gross Domestic Product; it is a key scenario driver.
GHG	Greenhouse Gas

GR	Greece
HR	Croatia
HU	Hungary
IE	Ireland
IS	Iceland
IT	Italy
LNG	Liquefied Natural Gas
LT	Lithuania
LU	Luxembourg
LV	Latvia
MARKAL	MARKet ALlocation; it is the model generator developed by IEA-ETSAP.
ME	Montenegro
MK	Former Yugoslav Republic of Macedonia - FYROM
MT	Malta
NI	Northern Ireland
NL	Netherlands
NO	Norway
NTC	Net Transfer Capacity
Optimistic	Name of the scenario with High Gross Domestic Product, High Climate Change Mitigation, High Population, High Oil and Gas supply, Bounded Electricity interties.
Pessimistic	Name of the scenario with Low Gross Domestic Product, Low Climate Change Mitigation, Low Population, Lower Oil and Gas supply, Bounded Electricity interties.
PET	Pan European TIMES; it is a model having several versions, depending on the number of countries modelled separately: PET27 models the EU27, PET30 models the EU27+, PET36 (sometimes referred to as EPET) models EU27++.
PL	Poland
POP	Population; it is a key scenario driver.
PT	Portugal
RO	Romania
ROW	Rest Of the World
RS	Serbia
RU	Russian Federation
SE	Sweden
SI	Slovenia
SK	Slovakia
TECH	Technological learning; it is a key scenario driver.
TFEC	Total Final Energy Consumption
TIMES	The Integrated MARKAL EFOM System; it is a model generator developed by ETSAP.
TPES	Total Primary Energy Supply
TSO	Transmission System Operator
UA	Ukraine
UK	United Kingdom
VEDA	Data base management system for building and using TIMES models
XK	Kosovo

1 EXECUTIVE SUMMARY

This report provides a brief presentation of the results obtained with the Pan European TIMES model of the EU27++[1] for the four REALISEGRID scenarios and some new sensitivity analyses. These results are accompanied with appropriate comments[2]. As illustrated in Table 1, the four scenarios are meant to explore to what extent and how is the European energy system going to react to different future external developments and internal policies.

The total electricity generation (Figure 1) grows by 38% from 2010 to 2030 in the first two scenarios – Optimistic and Competing. In the EU Centric and the Pessimistic scenarios, the growth is 16% and 15% respectively, over the same time span. The much lower electricity growth shown for the last two scenarios is not fully explained by the lower economic growth in these two scenarios: what in fact happens is that, facing a lower economic growth, the strategy to reduce emissions is qualitatively different in the two groups of scenarios. With low growth, there is less need to use the electricity sector as a privileged[3] sector in which to implement reductions of emissions. This is an important finding, since it establishes that electricity production is over sensitive to the growth of GDP whenever a climate target is in effect.

Electricity from renewable sources sees its market share grow from 20% in 2010 to almost 50% in 2030 in all scenarios, spread among Hydro, Wind, Solar, Ocean, and Wood based plants. In comparison, CO_2 Capture and Storage (CCS) remains a modest contributor to emission reductions (between 1 and 4%), and nuclear stays at a moderate level (13-15%). When added together, these non-(or low) emitting plants reach between 68 and 73% of total electricity production, the rest mostly being natural gas, a small amount from coal, and imports. Such a change in the composition of the Electric Power Generation (EPG) sector conforms to results obtained in other projects when considering moderate emission reductions in developed countries in the mid-term (2030). The picture could become different when emissions must be further reduced in the longer term, with CCS and Solar taking a leading role.

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[1] EU27++: 27 Member States of European Union (EU), plus Iceland, Norway, Switzerland and all Western Balkan countries.

[2] The complete set of results consists of 152 Excel files which are available on request, but are not reported nor commented here. All results refer to EU27++.

[3] All studies show that reducing CO_2 emissions in the electric generation sector is easier than in the rest of the system.

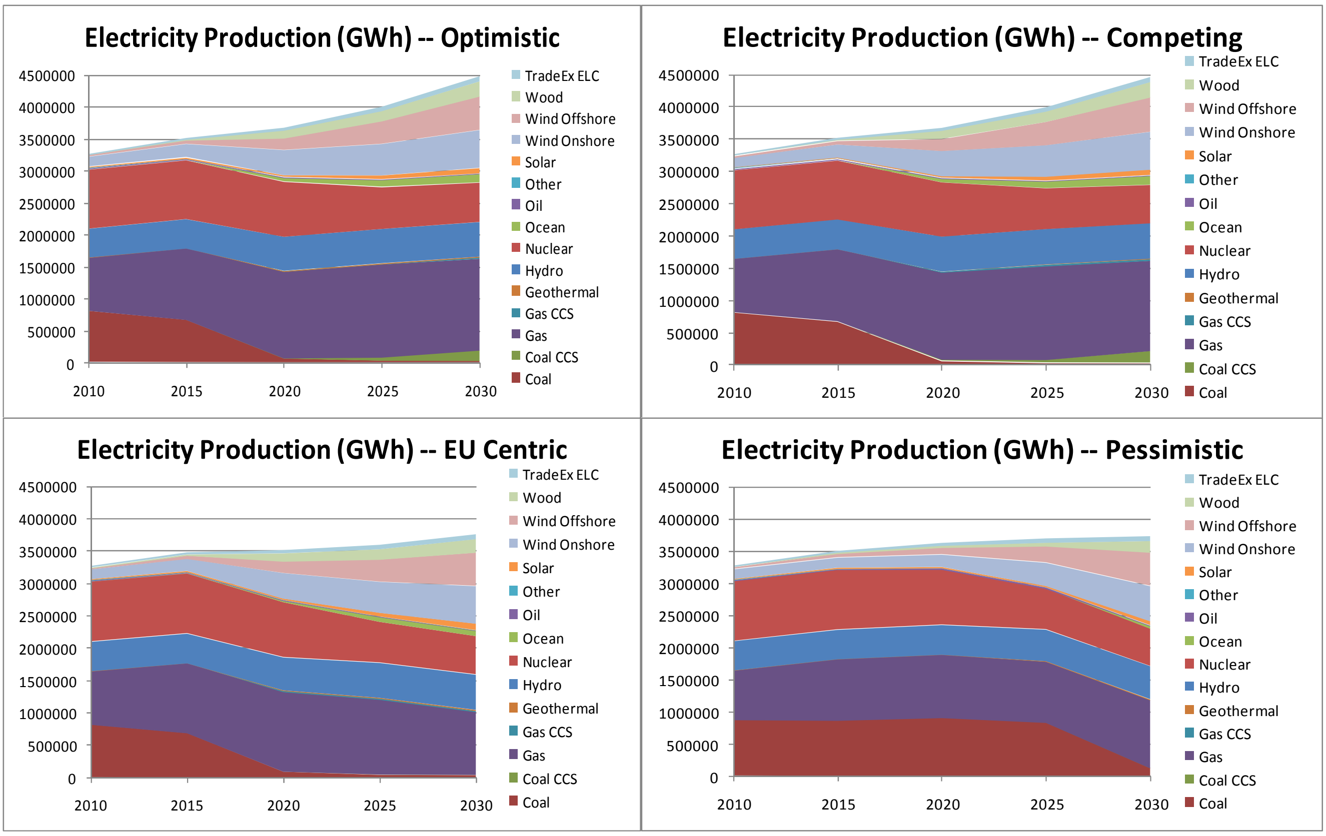

Figure 1: EU27++ electricity generation by type (GWh/year)

In the scenarios where the model is free to add transmission capacity of the interties – Competing and EU Centric scenarios – the increase amounts to a little less than 7 GW (or 10.5% of the 2020 capacity) when expansions in 2025 and 2030 are cumulated. This is a sizable amount. The model

Table 1: Key driver configurations of the four REALISEGRID scenarios

Dimension	Driver	Story lines			
		Optimistic	Competing	EU Centric	Pessimistic
Population	***POP***	HIGH	HIGH	LOW	LOW
Welfare	***GDP***	HIGH	HIGH	LOW	LOW
Oil and gas supply	***GAS***	HIGH	LOW	LOW	LOW
Climate Change Mitigation	***CCM***	STRONG	STRONG	STRONG	WEAK
Technological Improvement	***TECH***	HIGH	HIGH	LOW	LOW
Electric interties	***ELC***	BOUNDED	FREE	FREE	BOUNDED

In red exogenous drivers, policy drivers in blue.

invests in additional intertie capacity in order to increase intra EU27++ electricity trade between certain pairs of countries. In so doing, the countries that have a competitive advantage over some of their neighbours sell more electricity to them, and the buying countries produce less electricity. The net result of this trade is a reduction of the total cost for the entire set of countries.

The annual average prices of electricity vary quite a lot across countries ranging in 2030: from 90 €/MWh to 150 €/MWh in the Optimistic scenario, from 50 €/MWh to 100 €/MWh in the Pessimistic scenario. This is due to the initial fleet of plants in each country, their endowments in resources, and the seasonal characteristics of their demands, all of which influence the future investment and operation pattern. The average prices of electricity depend very strongly on the severity of the CO_2 emission constraint, and to a lesser extent, on the strength of the economic growth.

Achieving the European 2020 environmental targets consisting in a 20% CO2 emission reduction prolonged to a 30% CO2 emission reduction in 2030, which is the target imposed to three scenarios out of four, costs about 250 €/tCO_2 in the high growth scenarios, almost half in the low growth scenario (Figure 2). The cost reduces to about 110 €/tCO_2 if the target is relaxed to 20% in 2030 and the socio-economic growth is low. The growth of the total final energy consumption and the total primary energy supply in Europe is modest between 2010 and 2030, for all four scenarios, ranging between 4% and 18%.

Synthetically the four scenarios can be characterised as follows.

- In the Optimistic scenario – high socio economic development (Population, POP, and Gross Domestic Product, GDP), strong Climate Change Mitigation (CCM), high supply of relatively cheap oil and gas (GAS), and bounded electricity interties (ELC) – energy production and consumption are high, coal declines sharply, renewable energy sources penetrate strongly in electricity and end-use sectors, while a very little contribution is provided by CO_2 Capture and Storage (CCS).

- In the Competing scenario – high POP and GDP, high CCM, lower oil and gas supply (GAS) and free electricity interties (ELC) – there are more intra-European electricity exchanges, but this does not result in significant electricity price reductions. Natural gas prices are a little higher in Competing versus Optimistic scenario, but gas use is almost identical in the two scenarios because more LNG import compensates for the smaller pipeline imports.

- In the EU Centric scenario – low POP and GDP, high CCM, lower oil and gas supply (GAS) and free electricity interties (ELC) – there is less total energy use, but the primary energy mix is little affected, the only notable differences being less biofuels and especially less gas. Final energy is also reduced by about 10% in 2025-2030 with the main reductions occurring in the Industry and Commercial sectors, which consume less electricity and less biomass. CO_2 prices are almost half of the ones in the Competing scenario.

- The Pessimistic scenario – low POP and GDP, low CCM, lower oil and gas supply (GAS) and bounded electricity interties (ELC) – in which all socio-economic drivers have slow growth and the climate policy is more relaxed, is the most contrasted one compared to the other three. On the one hand, the energy needs are lower than in the first two scenarios, but on the other

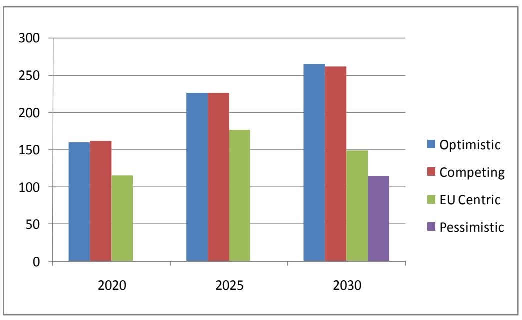

Figure 2: CO_2 price in EU27++ (€/tCO_2)

hand, the lack of a severe emission constraint is a disincentive to implementing energy savings, as well as to using implement alternative (renewable) energy sources. We observe a persistence of the more traditional energy forms, at least until 2025: coal use stays its course until 2025, and the penetration of biofuels is much slowed down.

As a general conclusion, we may therefore state that the development of energy flows and technology mix is strongly influenced by climate change mitigation policies. The socio-economic drivers considerably change the total amount of energy consumed, but comparatively far less the energy mix. The production of electricity is over sensitive to the growth of GDP whenever a climate target is in effect. The cost of imported fossil fuels, mainly crude oil and natural gas, has comparatively less influence than the other scenario variables, if the amount that can be imported is enough to satisfy the demand. In a long term perfect foresight perspective, climate change mitigation policies have a major impact, the GDP a moderate impact, and the ELC driver a very minor impact on electricity prices.

2 INTRODUCTION

2.1 Objectives of this deliverable

The objective of this report is to summarize the lessons learnt from the long term scenario analysis of the European energy system. As far as possible, this report singles out the general trends and conveys the significance of some important factors in non technical terms.

In the more general framework of the REALISEGRID project this synthesis report, together with the detailed result tables, is to be used as input for the assessment of technical-economic and strategic benefits of specific projects.

2.2 Expected outcome

The comments refer only to the aggregated results of the European area under analysis, which includes the 27 EU Member States – Austria, Belgium, Bulgaria, Czech Republic, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, United Kingdom (the model limited to the 27 EU Member States is sometimes called the PET27 model of EU27) – plus Iceland, Norway and Switzerland (the model so extended is sometimes called the PET30 model of EU27+) – plus the Western Balkan countries: Albania, Bosnia Herzegovina, Croatia, Former Yugoslav Republic Of Macedonia (FYROM), Kosovo[4], Montenegro, Serbia (the model so extended is sometimes called the PET36 model of EU27++[5]).

Most comments refer to the entire time period 2010-2030, unless more details are required by the analysis.

The analyses focused on the electricity sectors; however this report highlights also the main aspects of the more general energy system which make the development of the electricity subsystem understandable.

2.3 Approach

The content of this report is based on the scenario results obtained with the use of the Pan European TIMES model (PET36) of the EU27++ states [17, 18]. The comments reported here result from an in depth analysis of the model outputs [20, 21] and their connections with the input assumptions [19].

[4] Due to lack of data it was not possible to build a separate model for Kosovo; some elements of the Kosovar energy system are included in the model of the Serbian energy system.
[5] For the sake of simplicity, instead of using the acronym EU27++, in the text of this report the terms Europe, EU and European are preferred.

3 METHODOLOGY

The REALISEGRID project analysed possible long term future trends of electricity demand and generation with the help of a methodology which is adopted since decades in the field of energy systems [1, 2, 3, 4, 5, 6] and the integrated assessment of climate change mitigation policies [7, 8, 9, 10, 11, 12, 13]

The method envisages three main steps: analysis of the energy system as a whole, representation of the system in a technical economic model and construction of consistent scenarios. Each step has a rationale and follows precise methods.

3.1 Analysis

The analysis phase implied the identification and quantification [14, 15] of the main components of the whole energy system of 36 European states (see above). Compared to the analyses of the electricity markets in a standalone mode, this approach has the advantage of highlighting what parts of the market of other energy commodities can be captured by electricity or vice versa, and why.

Furthermore the analysis is not limited to the supply side. Insight in all end use sectors tend to elucidate what energy service are demanded and to what extent they are presently satisfied by each energy commodity and could be satisfied by others in the future.

Instead of focusing on energy commodities markets, the analysis enters the technological details of supplying and consuming all energy commodities. By gleaning all sort of information on energy production transformation transmission and consumption technologies, the analysis recalculates the present statistical market quantities and prices from base data: the availability of energy resources, cost and efficiencies of supply and demand technologies, levels of the demand for each energy service and other general and particular technical-economic data.

The analysis extends to the characterisation of the interfaces between energy, engineering technological progress, economy and environment.

3.2 Modelling[6]

After the analysis of the present situation and major external and internal trends, the whole system was represented in a technical economic model. In the REALISEGRID project the MARKAL-TIMES model generator of ETSAP was adopted to build the pan European model [16, 17]. This approach combines the technical details of simulation models to the equilibrium properties of neoclassical economic equilibrium models.

[6] The Pan European TIMES model (PET) is described in [17, 18].

The time horizon of the model used for this scenario analysis, 2030 and 2050 if necessary, is by far longer than usual forecasting models: it is long enough to see the effects of investments in the energy sector, such as electric power plants and all sorts of energy infrastructures, which have lifetimes of 30, 60 or even hundred years.

The input sets boundaries within which the system can develop: the stock of existing processes and infrastructures – heritage – and the technical-economic frontier. The output shows the actual trajectory of the system inside those boundaries.

The model decides long term energy investments assuming perfect information all along the year to the final time horizon: it is a so-called ‘clairvoyant’ model.

Long term models of the entire energy system, such as PET36, which includes technologies as well as consumer’s preferences, represent system whose development depends on the free choice of millions of individuals. Therefore the results of the PET36 model cannot be interpreted as forecast nor indicate ‘the decision’ to be taken.

Long term models of the entire energy system, such as PET36, are used to build consistent projections which help decision makers to think rationally about future possible decisions and assess the consequences of different choices in a explicit set of assumptions.

3.3 Scenarios building[7]

The first two steps of the method, analyses and modelling, are used to build consistent pictures of future European energy systems and how they could respond to different development assumptions of uncontrollable events and of controllable policies.

This project studies possible reactions of the energy system to three exogenous dirvers:

- population and households (POP),
- development of the Gross Domestic Product (GDP),
- availability of extra European oil and gas supply (GAS),

and three policies

- level of climate change mitigation (CCM),
- degree of improvement of energy technologies (TECH)[8],
- development of electricity cross-border infrastructures (ELC).

[7] The scenarios are fully described in [19].
[8] This TECH variable is partly uncontrollable, because EC research policies cannot totally determine an essentially a global phenomenon such as technology learning.

Possible future variations of drivers and policies are simulated by two diverging developments of a representative variable per driver[9]. These developments are then combined in four scenarios – Optimistic, Competing, EU Centric, and Pessimistic – as illustrated in Table 2.

The analyses show that the population (POP), oil and gas supply (GAS) and technology learning (TECH) drivers only mildly influence the results. Therefore the following text will highlight the role of the other four drivers: economic development (GDP), climate change mitigation (CCM) and electricity interties (ELC) policies.

Table 2: Key driver configurations of the four REALISEGRID scenarios

Dimension	*Driver*	Story lines			
		Optimistic	**Competing**	**EU Centric**	**Pessimistic**
Population	***POP***	HIGH	HIGH	LOW	LOW
Welfare	***GDP***	HIGH	HIGH	LOW	LOW
Oil and gas supply	***GAS***	HIGH	LOW	LOW	LOW
Climate Change Mitigation	***CCM***	STRONG	STRONG	STRONG	WEAK
Technological Improvement	***TECH***	HIGH	HIGH	LOW	LOW
Electric interties after 2020	***ELC***	BOUNDED	FREE	FREE	BOUNDED

In red exogenous drivers, policy drivers in blue.

[9] The actual projected values of the drivers is partly mentioned in next chapter and fully described in [19].

4 LESSONS LEARNT

4.1 Energy efficiency improvement

According to the PET36 model, the consumption of energy grows far less than the economy.

When the GDP is assumed to grow at an annual average rate of 1.5% per annum (GDP low, Figure 3), the Total Final Energy Consumption (TFEC) grows at about 1.1% per annum in the first decade, if the climate change mitigation goal is removed. It means that in the next decade the energy efficiency of end use sectors can increase of about 0.4% per annum. Another 0.3% per annum is gained in the primary sector. It means that according to this analysis the European energy system is expected to show an Autonomous Energy Efficiency Improvement of about 0.7. As an effect of this efficiency improvement, the Total Primary Energy Supply, measured with the substitution principle[10], increases at about 0.8% per annum in the first decade (0.5% if measured with the physical principle).

This expected 'decoupling' of energy market growths from economic growth is the effect of several factors. At the economic development stage of Europe, the structure of the demand expressed by economic consumers and producers shifts towards less energy intensive services: commercial sectors, along with less energy intensive industrial sectors are expected to grow more than the other sectors. A second factor is the availability of more energy efficient end use devices and energy transformation technologies: some of them are already cost competitive and will increasingly enter the market, others are not yet cost competitive but will become competitive in the next two decades because their cost-efficiency performance will grow (technology learning). The efficiency gains extend to the supply sector: more efficient generation plants and energy transformation processes will gradually replace the existing stock.

When the GDP is assumed to grow twice as much, at an annual average rate of 3% per annum, these effects are magnified in the end use sectors, where the energy efficiency improves at a rate of about 1% per annum. Since the efficiency improvement in the generation sector does not improve at a higher rate, the overall AEEI can reach 1.3-1.4% per annum. This value is in line with other studies [22].

The residual efficiency improvement of the Optimistic scenario, which is about 0.7% per annum, is due to the need to comply with CO_2 emission reduction target of -30% in 2030 with reference to 1990. This additional energy efficiency improvements is driven by a price increase mechanism: when emission are bounded, all fossil energy commodities cost more and are phased out to the extent possible by the use of more expensive no / low CO_2 emitting technologies.

[10] The TPES is measured with the substitution principle when all the electricity produced by renewable sources is converted to fossil equivalent using the average efficiency of the fossil power plants. In this evaluation an average efficiency of 40% was adopted. The results tables shown in appendix and in the electronic files use the physical principle, i.e. the fossil equivalent of renewable sources is equal to the electric output. In both cases, the fossil equivalent of nuclear electricity is equal to the output multiplied by three.

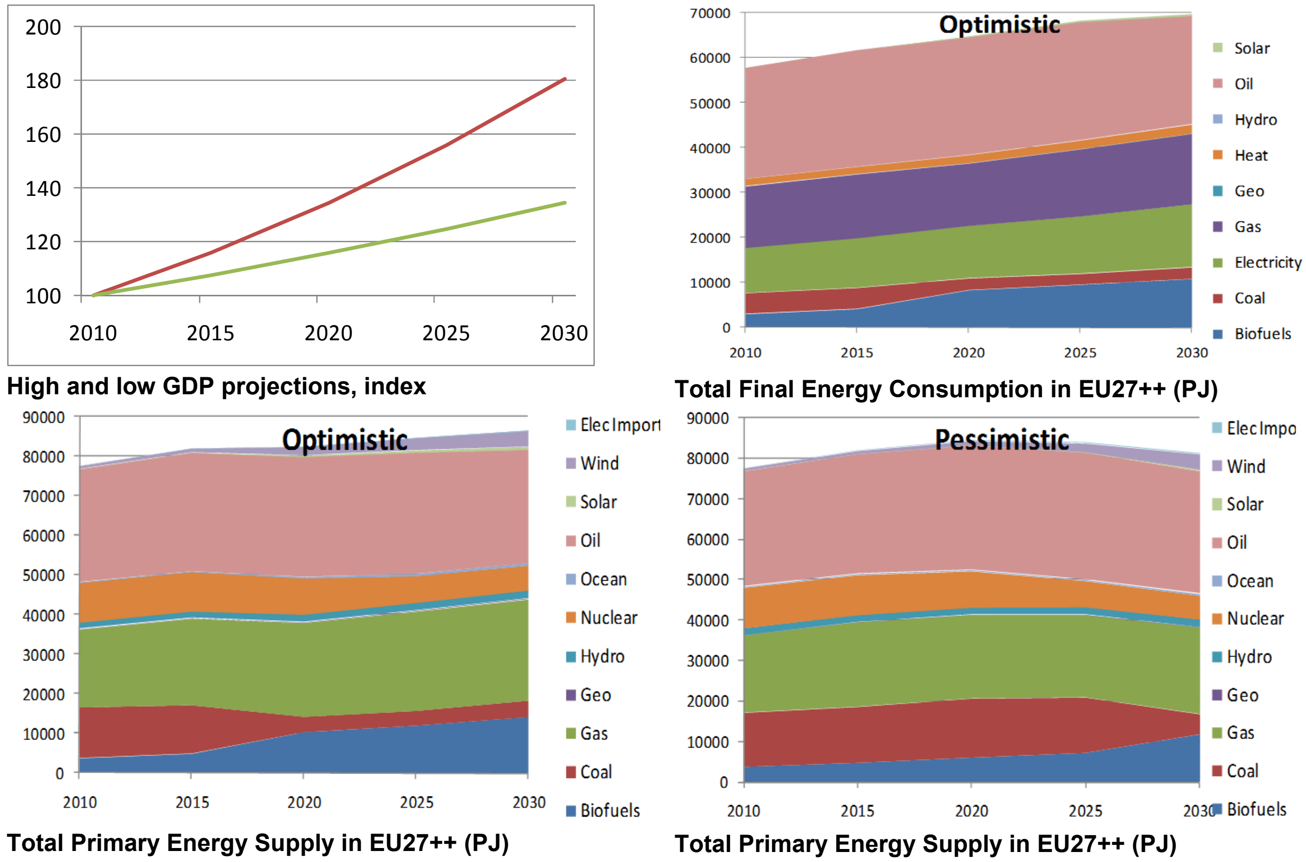

Figure 3: GDP and energy consumption developments

Adding all the effects explains the average annual growth rate of 0.9% per annum (at the substitution principle, equivalent to 0.5% using the physical principle) of the TPES shown by the optimistic scenario of Figure 3.

4.2 The market for electricity

In the frame of the energy system as a whole, the market for electricity is more dynamic. In the high growth scenario, when the GDP grows of about 80% from 2010 to 2030, at an annual average growth of about 3% per annum, the market for electricity grows of about 40 %, at an annual average growth of about 1.7% per annum. The growth of electricity consumption is closer to the GDP in industry, which is the largest consuming sector. The growth is contrasted in the other two large consuming sectors: it is just below 50% in the commercial sector and negligible in the residential sector.

This expected 'decoupling' of energy market growths from economic growth is the effect of several factors. At the economic development stage of Europe, the structure of the demand expressed by economic consumers and producers shifts towards less energy intensive services: commercial sectors, along with less energy intensive energy sectors are expected to grow more than the most energy intensive sectors. A second factor is the availability of more energy efficient end use technologies: some of them are already cost competitive and will increasingly enter the market, others are not yet cost competitive but will become competitive in the next two decades because their cost-efficiency performance will grow (technology learning) and the price of final energy commodities is going to increase. The efficiency gains extend to the supply sector: more efficient generation plants and energy transformation processes will gradually replace the existing stock. An additional factor is the gradual shift away from fossil fuels plants to renewable plants.

In the low growth scenarios, when the GDP grows by about 40% from 2010 to 2030, at an annual average growth of about 1.5% per annum, the market for electricity grows of about 17% - 19%, at an annual average growth of about 0.8% - 0.9% per annum. The growth of electricity consumption is three fourth of the GDP in the industry, which is the largest consuming sector. The development is contrasted in the other two large consuming sectors: it increases of just above 25% in the commercial sector and it decreases of about 6% in the residential sector.

As an effect of these differential growths, the consumption of electricity in the commercial sector overtakes residential consumption around the year 2020 in all scenarios. When the high economic growth is associated with strong climate change mitigation policies, the use of electricity in the transport sector becomes significant after 2025.

The share of electricity in the market for final energy consumption grows slightly from 18% to 20% in 2030 in the high GDP growth scenarios, but remains almost constant at 18% in the low GDP growth scenarios.

4.3 Electric generation plants

The mix of Electricity Generation Plant (EGP) types partly depends on the assumed development of drivers and policies (Figure 4).

- Coal fired plants quasi disappear as early as 2020 in the first three scenarios – Optimistic, Competing, EU Centric – but only in 2030 for the Pessimistic scenario.
- Coal+CCS makes a weak appearance in the first two scenarios (4% in 2030), but not in the last two ones. It thus appears that CCS is only needed when there is a combination of early emission reductions and strong economic growth.
- Gas fired plants see their market share increase in the first three scenarios until 2020, but then decline somewhat in 2030. This is due to the increasing severity of the emission constraint. In the Pessimistic scenario, the natural gas market share increases more modestly, but continues to progress until 2030, at a low pace.
- Wind (onshore and offshore) takes a large market share in all scenarios, between 25 and 28% of total electricity production (wind share is higher in the Pessimistic scenario at 29%, but only because total electricity generation is lower. In absolute terms, it is smaller than in Optimistic or Competing scenarios).
- Solar and Ocean based power both achieve a small penetration each around 2% of total market, even in 2030. It is surmised that their market shares would increase later in the century.
- Wood fired plants take around 5% of the market by 2030, faster in the first three scenarios than in Pessimistic.

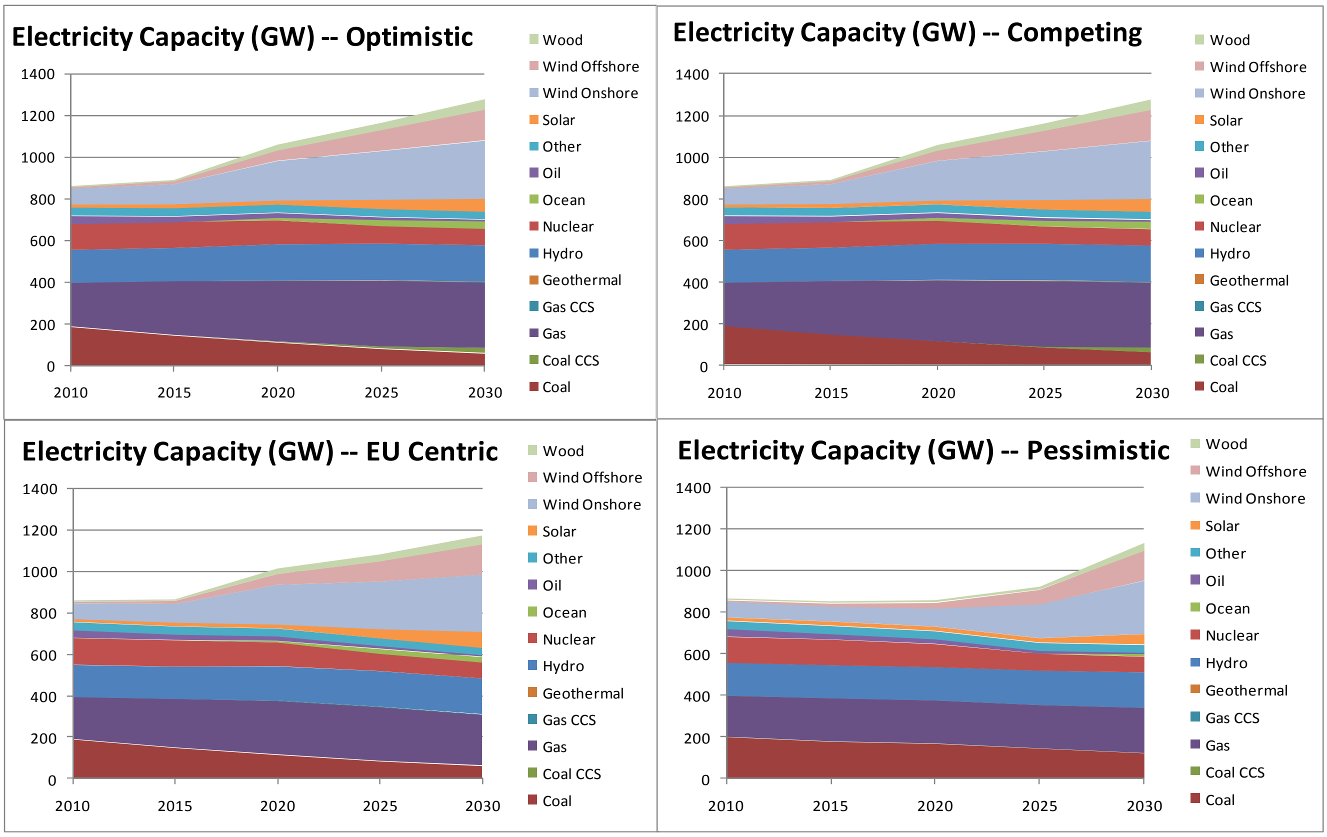

Figure 4: Installed capacities of electric plants by type in EU27++ (GW)

- Nuclear and Hydro plants do not exhibit large variations across scenarios, because their penetration is strongly guided by their potential (hydro) or by the national policies (Nuclear).
- All other plant types (oil, biogas, bio-waste, geothermal, and Gas + CCS) have markets shares less than 1% each.

It has to be remarked that electricity from renewable sources sees its market share grow from 20% in 2010 to almost 50% in 2030, spread among Hydro, Wind, Solar, Ocean, and Wood based plants[11]. In comparison, CCS remains a modest contributor to emission reductions (between 1 and 4%), and nuclear stays at a moderate level (13-15%). When added together, these non-(or low) emitting plants reach between 68 and 73% of total electricity production, the rest mostly based on gas and a small amount from coal and electricity imports. Such a change in the composition of the EPG sector conforms to results obtained in other projects when considering moderate emission reductions in developed countries in the mid-term (2030). The picture could become different when emissions must be further reduced in the longer term, with CCS and Solar taking a leading role.

[11] In view of the large role played by intermittent renewable plants in most of the scenarios, it is worth repeating here that the modelling paradigm used in this research does to some extent take intermittency into account, not only by attributing low availability factors to the intermittent sources, but also by taking this into account during the peak demand periods. However, when the share of intermittent renewable electricity becomes very large, it is necessary to supplement the evaluations resulting from this model with the results of models that represent intermittent renewable electricity generation on an hourly basis.

The values of the capacities of intra-EU27++ electricity interties are fixed and grow to 67.7 GW in 2020. After 2020 the model chooses to increase the total interties of little less than 7GW, about 10.5% . The model invests in additional intertie capacity in order to increase intra-EU27++ electricity trade by about 17% in the same time span, from about 620 TWh in 2020 to about 730 TWh in 2030.

With lower trade the long term marginal prices of electricity vary quite a lot across countries, due to their initial fleet of plants, their endowments in resources, and the seasonal characteristics of their demands, all of which influence the future investment and operation pattern. When more electricity trade is permitted, the net result is a reduction of the total cost for the entire set of countries. Prices reflect this advantage not directly on the average values but rather to somewhat equalize them across the EU27++ countries.

4.4 The crucial factor: climate change mitigation

All results are strongly influenced by the Clime Change Mitigation policies (CCM).Two emission reduction profiles have been analysed. In the strong mitigation case the European effort to reduce emissions over the 1990 values continues; after reaching 10% in 2010, it arrives to 20% in 2020 and 30% in 2030. This mitigation effort is applied in the first three scenarios – Optimistic, Competing and EU Centric (Figure 5).In the weak mitigation case, emissions are free in 2020 and in 2030 should be 20% lower than in 1990. Additional sensitivity runs have explored intermediate

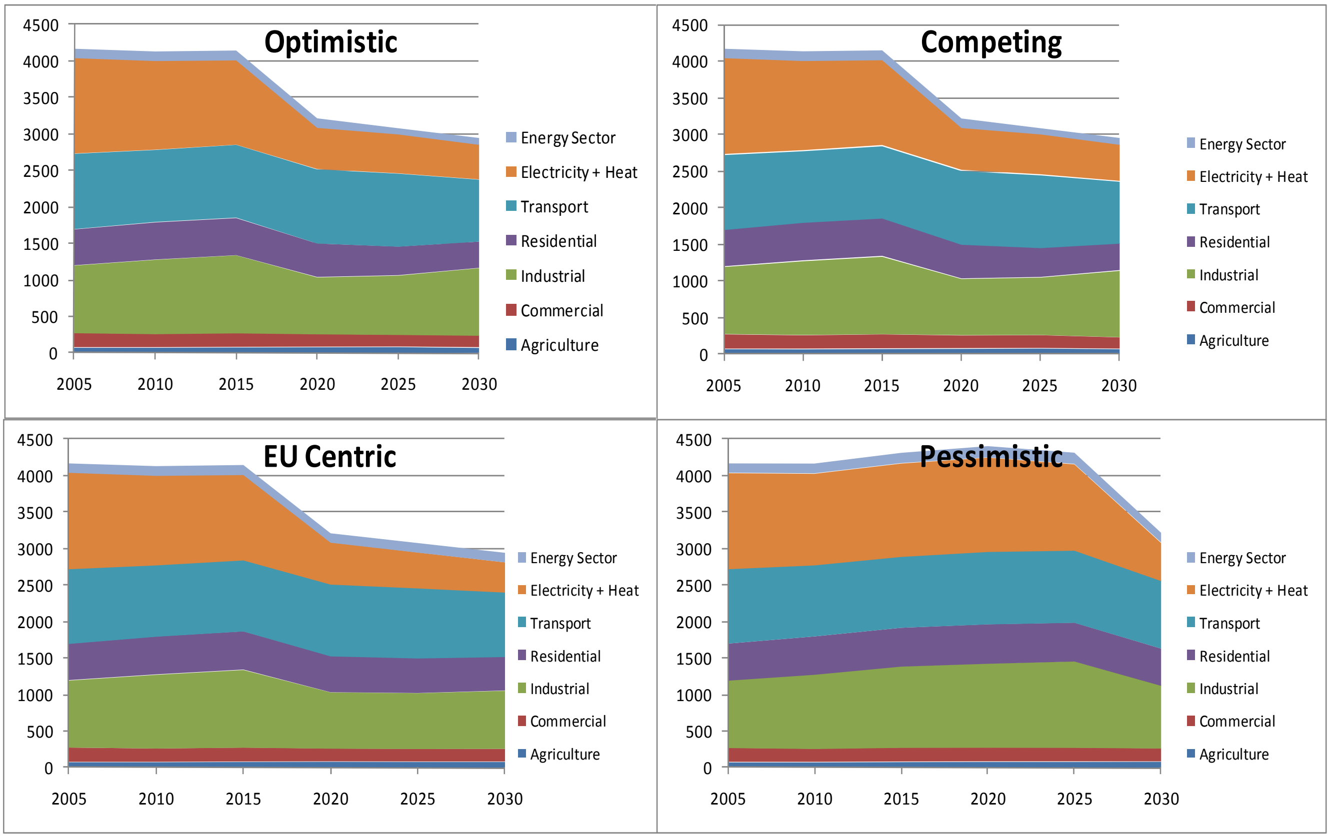

Figure 5: EU27++ Emissions of CO_2 by sector (Mt/yr)

mitigation efforts, where the strong CCM case in 2030 is relaxed from -30% to -25%, -22.5% and -20%[12].

The largest variations in emissions occur in two sectors: electric power generation and industry. All other sectors also experience emission reductions, but to a lesser extent[13].

The substitution of lower emitting and more expensive technologies is triggered by the marginal price of CO_2, which is calculated by the model for each emission reduction target: the more stringent is the target, the higher the price of CO_2 (Figure 6).

With reference to 1990, reducing emissions in 2030 by 20% obliges to implement the technical options with an equivalent cost of about 100 €/tCO_2. If emissions are to be reduced by 30%, it is necessary to accept the technical option with an equivalent mitigation cost of about 250 €/tCO_2.

Climate change mitigation policies have a major impact on electricity prices. When the emission constraint is severe, electricity prices are more than double those ones of the scenario without emission constraints.

Climate change mitigation policies have an impact also on the consumption of electricity. This stems from the fact that the electricity sector is somehow a privileged sector with respect to climate change mitigation policies: it is the sector with more technical mitigation options, which in principle can reduce emissions to zero, if all the generation comes from renewable, nuclear and fossil power plants with CCS. When CCM is weak, there is less need to use the electricity sector.

[12] It has to be remarked however that this objective falls short of meeting the reductions demanded by the climate change scientists: global temperature increase can remain below 3^C only if emissions in developed countries reduced by 80% in 2050.

[13] Electric vehicles can be used in 2010, but enter the market in important share not before 2030, and are able to capture a share capable of contributing significantly to emission reductions only after 2030.

4.5 Energy dependence

In recent years the area analysed in this project, EU27++, imports almost half of its energy consumption. Without specific policies this dependence is not expected to change much in the next twenty years: it can become slightly lower in the next decade but then it is expected to grow again to about 50%. This result takes into account the expected profile of oil and gas domestic findings, the development of the demand for energy services and the expected development of supply and demand technologies. The dependence could become higher if a strong economic growth would be accompanied by a relaxation of mitigation policies; although this seems unlikely.

The present analysis assumes that all kind of energy can be imported from the rest of the world without restrictions. The import price of natural gas is assumed to grow from recent values of 4.5 €/GJ to 8.3 €/GJ in 2030, with an 82% growth. When the pipelines cannot bring the amount of natural gas demanded, additional quantities can be imported via LNG terminals, at a slightly higher price. The price of imported crude oil grows from about 70$/bbl to about 100 in the same years.

About one fourth of the Total Primary Energy Supply (TPES) in EU27++ was supplied by natural gas in recent years. This share is expected to increase to 30% in 2030 in the optimistic case, with slight variations through the years and the scenarios. Taking into account the different development of the demand for energy services, similar shares means rather different amounts, with imports to EU27++ ranging from 10 to 14 EJ in 2030.

Since about 30% of the electricity is generated in gas fired power plants, the dependence on natural gas imports makes the electric generation partly dependent on imports. Also in this sector strong

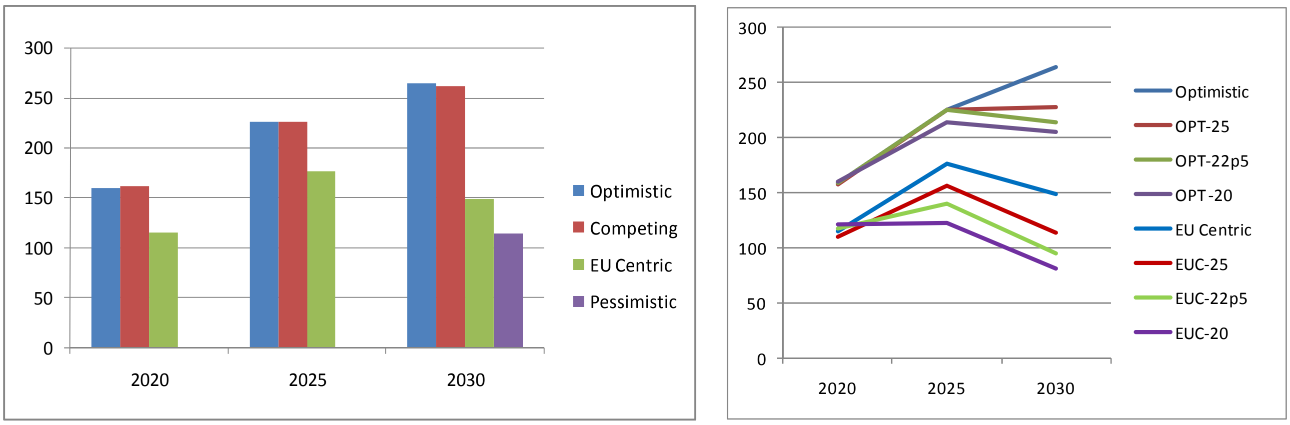

Figure 6: EU27++, CO_2 price for the four scenarios (a) and sensitivity runs (b) (€/tCO_2)

climate change mitigation policies have the indirect effect of reducing the European energy dependence.

5 CONCLUSION AND RECOMMENDATIONS

The development of energy flows and technology mix is strongly influenced by climate change mitigation policies. The socio-economic drivers considerably change the total amount of energy consumed, but comparatively far less the energy mix. The production of electricity is over sensitive to the growth of GDP whenever a climate target is in effect.

The cost of imported fossil fuels, mainly crude oil and natural gas, has comparatively less influence than the other scenario variables, if the amount that can be imported is enough to satisfy the demand. The technological learning driver, in the range assumed [19] has minor impacts on the scenarios.

Energy efficiency improvements, particularly in the end use sectors are expected to continue the decoupling the development of energy market from the economic development at large. The improvement of energy efficiency is enhanced by climate change mitigation policies. Electricity markets are expected to increase far less than GDP, but more than the total primary energy supply. Electricity increases its share in the total final consumption market if climate change mitigation policies are enforced to an intermediate level, because it is the simplest market to decarbonise.

Electricity from renewable sources could see its market share grow from 20% in 2010 to almost 50% in 2030. In view of the large role played by intermittent renewable plants in most of the scenarios it is recommended to supplement the evaluations resulting from this analysis with the results of models that represent intermittent renewable electricity generation, both central and distributed, on an hourly basis.

After 2020 it seems cost effective to increase by about 10% the capacity of cross border electric interties. This could increase by up to 20% the economic effective intra EU electricity trade and reduce price divergence across Europe. Average European electricity prices are strongly impacted by climate change mitigation policies, moderately by GDP growth rates and negligibly by the development of cross boarder interties.

Without specific policies, the European energy system remains strongly dependent on extra EU imports; this dependence is partly extended to the electric generation system. Climate change mitigation policies indirectly reduce the European energy dependence.

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7 APPENDIX: EU27++ RESULT TABLES

List of tables:

1. Notes to the tables

Code	Note
A	Electricity is converted at the Joule equivalence: 1 MWh = 3.6 GJ = 0.086 toe
B	The primary energy supply of nuclear energy sources is equal to the output multiplied by 3, which is equivalent to assume a 33% thermal conversion efficiency of thermo-nuclear reactors.
C	The primary energy supply of renewable energy sources is equal to their output, ('physical equivalent'). In order to apply the substitution principle, which is more significant from the economic point of view, multiply the values reported here by approximately 3 (i.e. using a theoretical conversion efficiency of 33%, as for nuclear).
D	Electricity capacities are net of internal consumption, taken at the plant gate
E	The total electricity production represents here the total energy requested to the grid.
nr	Not reported, refers to results not significant for this project

2a. EU27++: Electricity consumption by Sector (TWh)

	1 - Optimistic Scenario					2 – Competitive Scenario				
Sector	**2010**	**2015**	**2020**	**2025**	**2030**	**2010**	**2015**	**2020**	**2025**	**2030**
Agriculture	51	54	58	61	63	51	54	58	61	63
Commercial	748	821	916	1014	1105	748	821	917	1014	1105
Energy Sector	2	2	3	4	5	2	2	3	4	5
Industrial-Energy	1129	1296	1383	1572	1804	1128	1296	1383	1573	1801
Residential	880	902	883	892	910	879	903	882	887	901
Transport	78	77	76	85	177	78	77	76	85	176
TOTAL	**2888**	**3153**	**3319**	**3628**	**4064**	**2886**	**3154**	**3318**	**3623**	**4050**

2b. EU27++: Electricity consumption by Sector (TWh)

3 - EU-centric Scenario					4 - Pessimistic Scenario					
2010	**2015**	**2020**	**2025**	**2030**	**2010**	**2015**	**2020**	**2025**	**2030**	**Sector**
51	54	56	57	57	51	54	56	57	57	**Agriculture**
748	821	869	907	945	749	821	870	906	944	**Commercial**
2	2	2	2	2	2	2	2	1	1	**Energy Sector**
1123	1271	1298	1373	1478	1120	1273	1359	1423	1470	**Industrial-Energy**
880	890	865	843	831	881	883	887	860	822	**Residential**
78	76	74	77	113	78	74	70	65	88	**Transport**
2882	**3114**	**3164**	**3259**	**3425**	**2881**	**3107**	**3243**	**3313**	**3383**	**TOTAL**

3a. EU27++: Final Energy Consumption by sector and fuel group (PJ)

		1 - Optimistic Scenario					2 – Competitive Scenario				
Sector	Fuel/Period	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Agriculture	Biofuels	70	77	103	119	217	70	77	94	111	183
	Coal	47	49	52	55	56	47	49	52	55	57
	Electricity	183	195	208	219	226	183	195	208	219	226
	Gas	181	187	201	198	200	181	187	193	215	200
	Geo	4	4	4	5	9	4	4	4	5	9
	Heat	9	10	18	41	110	9	10	18	31	92
	Oil	816	868	889	920	707	816	868	911	920	794
	Solar	1	2	10	12	95	1	2	4	12	61
	Total	1311	1392	1485	1568	1621	1311	1392	1485	1568	1621
Commercial	Biofuels	882	1227	1688	1700	1816	882	1230	1690	1695	1861
	Coal	47	31	1	0	1	47	31	1	0	1
	Electricity	2600	2861	3205	3557	3886	2600	2861	3205	3556	3883
	Gas	1938	2065	2028	2095	2055	1938	2062	2028	2105	2038
	Geo	3	1	3	21	25	3	1	3	19	23
	Heat	74	77	87	107	115	74	77	87	107	115
	Oil	413	384	195	181	177	413	384	193	179	177
	Solar	2	1	89	123	149	2	1	89	123	129
	Total	5959	6647	7295	7785	8223	5959	6649	7296	7785	8226
Industry-Energy	Biofuels	406	804	4054	5116	6074	406	812	4107	5136	6065
	Coal	4201	4371	2421	2280	2456	4207	4377	2384	2280	2464
	Electricity	4065	4666	4978	5659	6494	4061	4667	4979	5662	6485
	Gas	5759	6312	6293	7266	8221	5755	6311	6290	7265	8224
	Heat	287	265	322	342	323	287	257	322	333	326
	Hydro	26	25	25	24	2	26	25	25	24	2
	Oil	1120	1209	1116	1174	1269	1118	1207	1115	1174	1268
	Wind	0	0	0	0	0	0	0	0	0	0
	Total	15864	17654	19210	21862	24838	15860	17656	19223	21874	24835
Industry-Non En	Coal	13	14	16	17	19	13	14	16	17	19
	Gas	660	703	743	788	834	660	703	743	788	834
	Oil	4029	4305	4574	4879	5196	4029	4305	4574	4879	5196
	Total	4701	5022	5333	5684	6049	4701	5022	5333	5684	6049
Residential	Biofuels	1104	1225	1351	1361	1448	1109	1219	1356	1355	1438
	Coal	283	169	66	0	0	283	169	66	0	0
	Electricity	3077	3158	3088	3121	3185	3074	3162	3086	3104	3152
	Gas	5073	4885	4567	4513	4273	5062	4880	4536	4469	4215
	Geo	32	28	36	40	43	32	28	37	42	45
	Heat	1148	1228	1346	1414	1477	1147	1230	1345	1422	1504
	Oil	2874	3222	2916	2560	1935	2884	3209	2923	2596	2004
	Solar	17	13	185	236	274	17	13	184	237	273
	Total	13609	13928	13555	13246	12635	13609	13909	13534	13225	12631
Transport	Biofuels	503	750	1110	1290	1422	495	765	1125	1292	1368
	Electricity	281	279	273	272	269	281	279	273	271	267
	Gas	19	17	13	13	17	19	17	13	13	13
	Oil	15407	15914	16526	16608	14710	15415	15899	16547	16638	14797
	Synthetic	0	1	62	133	196	0	1	44	115	178
	Total	16210	16961	17984	18316	16614	16210	16961	18002	18329	16624
GRAND	TOTAL	57654	61604	64863	68461	69981	57651	61589	64874	68465	69986

3b. EU27++: Final Energy Consumption by sector and fuel group (PJ)

3 - EU-centric Scenario					4 - Pessimistic Scenario						
2010	2015	2020	2025	2030	2010	2015	2020	2025	2030	Fuel/Period	Sector
70	77	82	102	104	70	77	82	85	89	Biofuels	Agriculture
47	49	50	51	52	47	49	50	51	52	Coal	
183	195	200	204	207	183	195	200	204	207	Electricity	
181	187	186	184	181	181	187	186	184	181	Gas	
4	4	5	4	4	4	4	5	5	5	Geo	
9	10	11	24	26	9	10	10	11	12	Heat	
816	868	892	876	886	816	868	894	912	920	Oil	
1	2	4	11	12	1	2	3	4	5	Solar	
1311	1392	1431	1456	1472	1311	1392	1431	1456	1472	Total	
888	1253	1716	1813	1897	947	1324	1649	1854	1938	Biofuels	Commercial
47	31	3	0	0	47	31	15	0	0	Coal	
2600	2860	3035	3173	3307	2601	2862	3040	3168	3303	Electricity	
1929	2049	1965	1993	2013	1934	2052	2039	2009	2014	Gas	
3	1	1	5	6	3	1	1	0	1	Geo	
74	77	78	96	96	74	80	85	92	93	Heat	
417	376	228	168	163	350	299	241	216	202	Oil	
2	1	43	64	67	2	1	0	0	35	Solar	
5959	6650	7068	7313	7549	5957	6652	7070	7339	7586	Total	
425	799	3267	4140	4723	418	698	1138	1589	4174	Biofuels	Industry-Energy
4204	4404	2689	2361	2368	4139	4554	4836	4928	3078	Coal	
4044	4576	4673	4943	5320	4032	4583	4891	5124	5293	Electricity	
5769	6416	5960	6310	6554	5718	6260	6157	6084	6430	Gas	
297	253	292	299	293	311	306	259	278	294	Heat	
28	25	25	24	16	28	25	25	24	16	Hydro	
1120	1169	1073	1062	1071	1114	1167	1209	1411	1095	Oil	
0	0	0	0	0	0	0	0	0	0	Wind	
15886	17643	17979	19140	20346	15759	17594	18517	19440	20380	Total	
13	14	15	16	17	13	14	15	16	17	Coal	Ind-Non.En.
660	703	716	731	746	660	703	716	731	746	Gas	
4029	4305	4408	4530	4649	4029	4305	4408	4530	4649	Oil	
4701	5022	5139	5278	5412	4701	5022	5139	5278	5412	Total	
1114	1220	1412	1489	1548	1098	1162	1224	1330	1618	Biofuels	Residential
283	169	71	0	0	283	169	72	0	0	Coal	
3077	3112	3025	2944	2900	3082	3088	3102	3006	2871	Electricity	
5079	5052	4807	4749	4739	5078	5123	4998	4961	4859	Gas	
32	28	36	45	47	32	28	27	27	34	Geo	
1149	1215	1360	1398	1446	1150	1234	1371	1417	1468	Heat	
2856	3198	3166	3057	2863	2866	3201	3538	3566	3331	Oil	
17	12	137	183	196	17	10	41	60	134	Solar	
13608	14007	14014	13865	13739	13607	14015	14373	14368	14314	Total	
488	735	1025	1225	1340	496	705	958	1101	1268	Biofuels	Transport
281	274	267	263	263	281	266	251	234	219	Electricity	
19	13	14	13	13	19	18	17	0	12	Gas	
15427	15687	16101	16026	15129	15423	15744	16306	16498	15732	Oil	
0	0	3	14	23	0	0	0	0	3	Synthetic	
16214	16708	17409	17540	16767	16219	16733	17532	17833	17234	Total	
57681	61422	63040	64593	65285	57555	61407	64062	65713	66398	GRAND	TOTAL

4a. EU27++, Primary Energy Supply by source and fuel group (PJ)

Notes A, B, C		1 - Optimistic Scenario					2 – Competitive Scenario				
Sector	Fuel/Period	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Export	Electricity	22	23	27	49	49	22	23	27	49	49
	Oil	16227	19624	23991	21091	15852	16222	19637	23954	21043	15684
Import	Biofuels	40	198	631	673	697	40	204	645	672	695
	Coal	6735	5509	1937	2180	2459	6753	5515	1930	2151	2867
	Electricity	77	112	173	251	286	77	112	173	251	286
	Gas	8245	10703	11009	12851	14351	8314	10833	11279	12408	13620
	Nuclear	9886	9419	8193	5545	4894	9886	9419	8193	5545	4894
	Oil	29042	30865	31611	31862	36696	29053	30848	31619	31879	36768
Domestic Mining	Biofuels	3571	4530	9516	11173	13458	3567	4545	9544	11193	13414
	Coal	7036	6847	2019	1607	1707	7052	6872	2024	1593	1925
	Gas	11262	11002	12736	12400	11953	11141	10836	12519	12938	11964
	Geo	83	74	98	138	157	83	74	100	138	157
	Hydro	1682	1705	1947	1971	1982	1682	1705	1922	1970	1982
	Nuclear	679	1020	1318	1430	1421	679	1020	1192	1304	1295
	OCEAN	227	227	371	605	689	227	227	373	600	720
	Oil	15567	18609	22643	19757	7584	15567	18609	22643	19757	7585
	Solar	68	92	362	576	818	68	92	356	578	763
	Wind	624	921	2089	3047	4014	624	923	2086	3049	4029
TOTAL	PRIMARY	78575	82186	82637	84924	87265	78568	82175	82617	84934	87230

5a. EU27++: Electricity capacity by fuel group and plant type (GW)

	1 - Optimistic Scenario					2 – Competitive Scenario				
Fuel/Period	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Biogas & Waste	5	3	3	2	2	5	3	3	2	2
Coal	186	149	111	80	59	186	149	111	81	59
Coal CCS	0	0	2	12	14	0	0	3	10	35
Gas	244	318	352	364	337	241	317	351	359	312
Gas CCS	0	0	4	2	14	0	0	7	4	6
Geothermal	1	1	3	3	3	1	1	3	3	3
Hydro	158	159	185	174	176	158	160	182	175	176
Nuclear	134	149	140	101	91	134	149	137	100	89
Ocean	0	0	23	49	44	0	0	23	48	49
Oil	40	28	24	14	8	40	28	24	14	8
Other	39	40	38	38	37	39	40	38	38	37
Solar	30	24	20	68	81	30	24	20	68	80
Wind Onshore	124	130	297	279	373	124	132	296	280	373
Wind Offshore	13	23	87	149	202	13	23	87	149	205
Wood	7	9	49	43	65	7	9	49	43	68
TOTAL	981	1034	1337	1377	1505	978	1034	1334	1372	1502

4b. EU27++, Primary Energy Supply by source and fuel group (PJ)

3 - EU-centric Scenario					4 - Pessimistic Scenario						Notes A, B, C
2010	2015	2020	2025	2030	2010	2015	2020	2025	2030	Fuel/Period	Sector
22	23	27	49	49	22	23	27	49	49	Electricity	Export
16170	19741	24018	21117	14968	16233	19791	24030	20855	14415	Oil	
43	139	576	649	657	43	76	235	343	631	Biofuels	Import
6740	5595	1979	1759	1787	6875	6381	6530	6070	2602	Coal	
77	112	173	251	286	77	112	173	251	286	Electricity	
8257	10874	10270	9077	9653	8103	9444	9012	7651	10071	Gas	
9886	9419	8193	5545	4894	9886	9408	8193	5545	4894	Nuclear	
29006	30666	31231	31183	36427	28991	30745	32123	32601	37040	Oil	
3579	4624	8735	10374	11839	3611	4611	5735	6783	11014	Biofuels	Domestic Mining
7049	6917	2544	1936	1777	7300	7517	7986	7407	2345	Coal	
11237	10876	12284	13298	11731	10999	11520	11800	13048	11810	Gas	
83	74	102	126	137	83	74	64	100	120	Geo	
1682	1697	1843	1964	1971	1682	1689	1698	1794	1872	Hydro	
679	1020	1192	1178	1168	679	1020	1192	1178	1042	Nuclear	
227	227	284	501	543	227	227	227	227	391	OCEAN	
15567	18609	22645	19755	7585	15567	18609	22658	19755	7584	Oil	
68	91	265	462	634	68	89	123	142	354	Solar	
618	869	2077	2965	3960	612	738	996	2145	3742	Wind	
78605	82044	80349	79856	80033	78548	82446	84687	84137	81335	TOTAL	PRIMARY

5b. EU27++: Electricity capacity by fuel group and plant type (GW)

3 - EU-centric Scenario					4 - Pessimistic Scenario					
2010	2015	2020	2025	2030	2010	2015	2020	2025	2030	Fuel/Period
4	3	2	2	2	4	3	2	2	1	Biogas & Waste
187	150	112	81	59	203	184	191	137	112	Coal
0	0	0	1	0	0	0	0	0	2	Coal CCS
233	282	306	276	243	222	230	232	232	258	Gas
0	0	6	3	3	0	0	0	0	0	Gas CCS
1	1	3	2	3	1	1	1	3	3	Geothermal
158	159	174	179	173	158	158	159	168	172	Hydro
134	149	137	96	88	134	149	137	96	84	Nuclear
0	0	9	39	29	0	0	0	0	26	Ocean
40	28	24	14	8	40	30	28	17	10	Oil
39	40	38	38	37	39	40	38	38	37	Other
30	24	21	67	110	30	24	20	20	60	Solar
124	119	297	269	366	124	85	108	233	389	Wind Onshore
12	22	89	143	203	12	22	36	112	223	Wind Offshore
7	9	48	42	53	7	9	13	18	65	Wood
969	986	1268	1253	1376	973	936	964	1076	1442	TOTAL

6a. EU27++: Electricity Production by fuel group & plant type (TWh)

Notes B, C, E	1 - Optimistic Scenario					2 – Competitive Scenario				
Fuel/Period	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Biogas & Waste	10	7	4	3	4	10	7	4	4	5
Coal	794	664	61	27	22	796	666	60	27	22
Coal CCS	0	0	3	35	60	0	0	9	32	138
Gas	787	1066	1328	1451	1494	784	1068	1336	1451	1426
Gas CCS	0	0	16	16	61	0	0	26	27	35
Geothermal	6	5	11	14	16	6	5	11	14	16
Hydro	460	467	534	541	550	460	467	527	541	550
Nuclear	971	967	895	671	617	971	967	883	659	604
Ocean	1	1	41	106	129	1	1	41	104	138
Oil	16	15	13	10	11	16	15	13	10	11
Other	13	6	3	1	1	13	6	4	1	1
Solar	13	21	21	57	83	13	21	21	57	83
Wind Onshore	149	203	399	491	590	149	204	398	492	590
Wind Offshore	24	53	181	355	525	24	52	181	355	529
Wood	10	21	129	165	242	334	273	15	-203	-429
Trade IntraEU27++ ELC	0	0	0	0	0	0	0	0	0	0
Trade ExtraEU27++ ELC	22	31	48	70	79	22	31	48	70	79
TOTAL	3275	3526	3689	4011	4484	3598	3782	3576	3639	3798

6c. EU27++: Electricity fuel input by fuel group and plant type (PJ)

Notes B, C	1 - Optimistic Scenario					2 – Competitive Scenario				
Fuel/Period	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Biogas & Waste	113	90	47	31	36	113	88	47	42	48
Coal	8058	6690	551	212	163	8077	6706	530	212	163
Coal CCS	0	0	36	313	513	0	0	77	278	1126
Gas	5419	7028	8491	9041	9123	5391	7013	8543	9037	8732
Gas CCS	0	0	120	120	460	0	0	196	203	266
Geothermal	32	28	43	60	68	32	28	43	60	68
Hydro	1682	1705	1947	1971	1982	1682	1705	1922	1970	1982
Nuclear	10565	10439	9511	6976	6315	10565	10439	9385	6850	6189
Ocean	227	227	371	605	689	227	227	373	600	720
Oil	150	143	113	83	90	150	143	113	84	90
Other	104	67	17	4	5	104	67	20	5	5
Solar	46	74	77	204	299	46	74	77	205	299
Wind Onshore	537	729	1437	1768	2123	537	734	1433	1770	2123
Wind Offshore	87	191	652	1278	1891	87	189	652	1278	1906
Wood	123	251	1524	1917	2732	123	249	1508	1922	2752
TOTAL	27143	27663	24938	24584	26487	27134	27663	24921	24515	26468

7a. EU27++: Gas Consumption by sector (PJ)

	1 - Optimistic Scenario					2 – Competitive Scenario				
Sector / Period	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Agriculture	181	187	201	198	200	181	187	193	215	200
Commercial	2156	2286	2254	2329	2292	2156	2284	2255	2339	2272
Elc & Heat	5501	7078	8958	9545	9982	5467	7056	9062	9611	9380
Energy Sector	784	792	879	828	745	782	788	874	849	735
Industrial-Energy	5759	6312	6293	7266	8221	5755	6311	6290	7265	8224
Industrial-NonEnergy	660	703	743	788	834	660	703	743	788	834
Residential	5073	4885	4567	4513	4273	5062	4880	4536	4469	4215
Transport	19	17	13	13	17	19	17	13	13	13
TOTAL	20133	22261	23908	25481	26565	20081	22226	23968	25550	25872

6b. EU27++: Electricity Production by fuel group & plant type (TWh)

3 - EU-centric Scenario					4 - Pessimistic Scenario					Notes A, B, C
2010	2015	2020	2025	2030	2010	2015	2020	2025	2030	Fuel/Period
10	6	4	3	5	10	7	6	5	4	Biogas & Waste
795	676	73	39	33	845	811	882	776	93	Coal
0	0	0	2	2	0	0	0	0	6	Coal CCS
782	1031	1220	1142	974	737	922	966	987	1115	Gas
0	0	24	24	24	0	0	0	0	0	Gas CCS
6	5	12	14	16	6	5	5	13	16	Geothermal
460	464	505	539	543	460	462	465	492	515	Hydro
971	967	883	646	592	971	966	883	646	579	Nuclear
1	1	16	77	89	1	1	1	1	46	Ocean
18	16	11	8	9	16	25	34	35	8	Oil
13	8	7	1	1	13	7	4	4	5	Other
13	21	22	56	99	13	21	21	21	50	Solar
149	190	392	477	576	148	154	186	347	530	Wind Onshore
23	52	184	347	524	22	50	91	249	510	Wind Offshore
10	20	126	162	207	10	24	39	61	188	Wood
0	0	0	0	0	0	0	0	0	0	Trade IntraEU27++ ELC
22	31	48	70	79	22	31	48	70	79	Trade ExtraEU27++ ELC
3271	3487	3528	3605	3772	3273	3486	3630	3707	3744	TOTAL

6d. EU27++: Electricity fuel input by fuel group and plant type (PJ)

3 - EU-centric Scenario					4 - Pessimistic Scenario					Notes B, C
2010	2015	2020	2025	2030	2010	2015	2020	2025	2030	Fuel/Period
111	81	47	39	54	111	83	71	65	46	Biogas & Waste
8067	6804	686	338	271	8497	7986	8357	7250	822	Coal
0	0	0	15	15	0	0	0	0	46	Coal CCS
5404	6831	7798	7152	6002	5071	6118	6175	6135	6829	Gas
0	0	178	178	178	0	0	0	0	0	Gas CCS
32	28	49	60	68	32	28	19	56	68	Geothermal
1682	1697	1843	1964	1971	1682	1689	1698	1794	1872	Hydro
10565	10439	9385	6724	6063	10565	10428	9385	6724	5937	Nuclear
227	227	284	501	543	227	227	227	227	391	Ocean
166	155	101	69	74	156	226	299	302	66	Oil
104	80	39	4	5	104	76	46	39	23	Other
46	74	80	202	357	46	74	77	77	179	Solar
535	683	1412	1717	2075	534	556	669	1249	1907	Wind Onshore
83	185	664	1248	1885	78	181	326	896	1835	Wind Offshore
123	245	1496	1913	2437	122	293	458	721	2178	Wood
27145	27530	24062	22124	21998	27224	27968	27807	25536	22200	TOTAL

7b. EU27++: Gas Consumption by sector (PJ)

3 - EU-centric Scenario					4 - Pessimistic Scenario					
2010	2015	2020	2025	2030	2010	2015	2020	2025	2030	Sector / Period
181	187	186	184	181	181	187	186	184	181	Agriculture
2147	2270	2192	2233	2261	2152	2274	2261	2233	2263	Commercial
5479	6876	8047	7524	6398	5123	6135	6215	6202	6890	Electricity & Heat
783	781	848	883	734	769	821	830	897	738	Energy Sector
5769	6416	5960	6310	6554	5718	6260	6157	6084	6430	Industrial-Energy
660	703	716	731	746	660	703	716	731	746	Industrial-Non Energy
5079	5052	4807	4749	4739	5078	5123	4998	4961	4859	Residential
19	13	14	13	13	19	18	17	0	12	Transport
20118	22298	22770	22626	21627	19700	21520	21382	21294	22120	TOTAL

8. EU27++: Extra-European assumed electricity trade (TWh) [22]

Import from	2010	2015	2020	2025	2030	Export to	2010	2015	2020	2025	2030
Algeria				6.6	6.6	Morocco	4.2	5.5	5.5	8.6	8.6
Belarus	3.5	2.7	1.9	3.9	8.1	Belarus			1.0	2.0	2.0
Moldova	1.2	3.5	4.0	7.5	7.5						
Russia	13.0	14.4	17.1	18.9	20.1	Russia	1.0				
Tunisia			6.6	6.6	6.6						
Turkey		4.4	9.8	11.7	11.7						
Ukraine	3.8	6.0	8.7	14.6	18.9	Ukraine	1.0	1.0	1.0	3.2	3.2
TOTAL	**21.5**	**31.1**	**48.1**	**69.7**	**79.4**	**TOTAL**	**6.2**	**6.5**	**7.5**	**13.7**	**13.7**

9. EU27++: Extra-European natural gas import, results (PJ)

Scenario		1 - Optimistic		2 – Competitive		3 - EU-centric		4 - Pessimistic	
Import from	2010	2020	2030	2020	2030	2020	2030	2020	2030
Extra-EU LNG total	2051	2361	2186	2804	4556	1967	2340	1716	2636
North Africa	2257	2490	4460	2490	2490	2490	2490	2490	2490
Russia-Belarus	1533	1437	1610	1216	1240	1230	856	1576	774
Russia Ukraine	2197	2750	3553	2798	3400	2468	2933	2208	2875
Russia North Sea	205	1903	2535	1902	1927	2057	1030	1019	1292
TOTAL	**8242**	**10941**	**14345**	**11210**	**13614**	**10213**	**9649**	**9009**	**10067**

10a. EU27++: CO_2 Emissions by sector (Mt CO_2) and CO_2 price

		1 - Optimistic Scenario					2 – Competitive Scenario				
Sector	2005	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Agriculture	75.2	75	79	82	84	69	75	79	83	85	75
Commercial	192.6	180	188	171	158	157	180	188	171	160	148
Industrial	786.1	840	870	582	596	643	841	871	578	582	646
Residential	499.9	518	517	465	400	363	518	516	464	411	363
Transport	1027.9	981	992	1011	995	839	982	991	1013	997	845
Elec + Heat	1318.1	1203	1154	575	552	522	1204	1155	578	536	525
Energy Sector	128.7	129	130	130	64	85	129	130	130	80	77
TOTAL	**4011.8**	**3926**	**3931**	**3017**	**2850**	**2679**	**3928**	**3930**	**3017**	**2850**	**2679**
CO2 price (euro/tCO2)		nr	nr	157	226	269	nr	nr	159	226	264

10b. EU27++: CO_2 Emissions by sector (Mt CO_2) and CO_2 price

3 - EU-centric Scenario					4 - Pessimistic Scenario					
2010	2015	2020	2025	2030	2010	2015	2020	2025	2030	Sector
75	79	81	80	80	75	79	81	83	83	Agriculture
180	188	173	170	170	181	191	190	188	179	Commercial
840	875	594	570	580	839	914	939	958	648	Industrial
517	524	496	479	465	518	528	532	524	502	Residential
983	978	989	967	890	983	983	1003	999	933	Transport
1205	1156	562	484	412	1228	1240	1281	1168	518	Electricity + Heat
129	130	130	131	131	129	130	140	151	131	Energy Sector
3928	**3931**	**3025**	**2880**	**2728**	**3952**	**4066**	**4167**	**4071**	**2994**	**TOTAL**
Nr	Nr	106	174	150	nr	0	0	0	110	CO2 price (€/tCO2)